Electrical installation handbook
Volume 1

2nd edition

Protection and control devices

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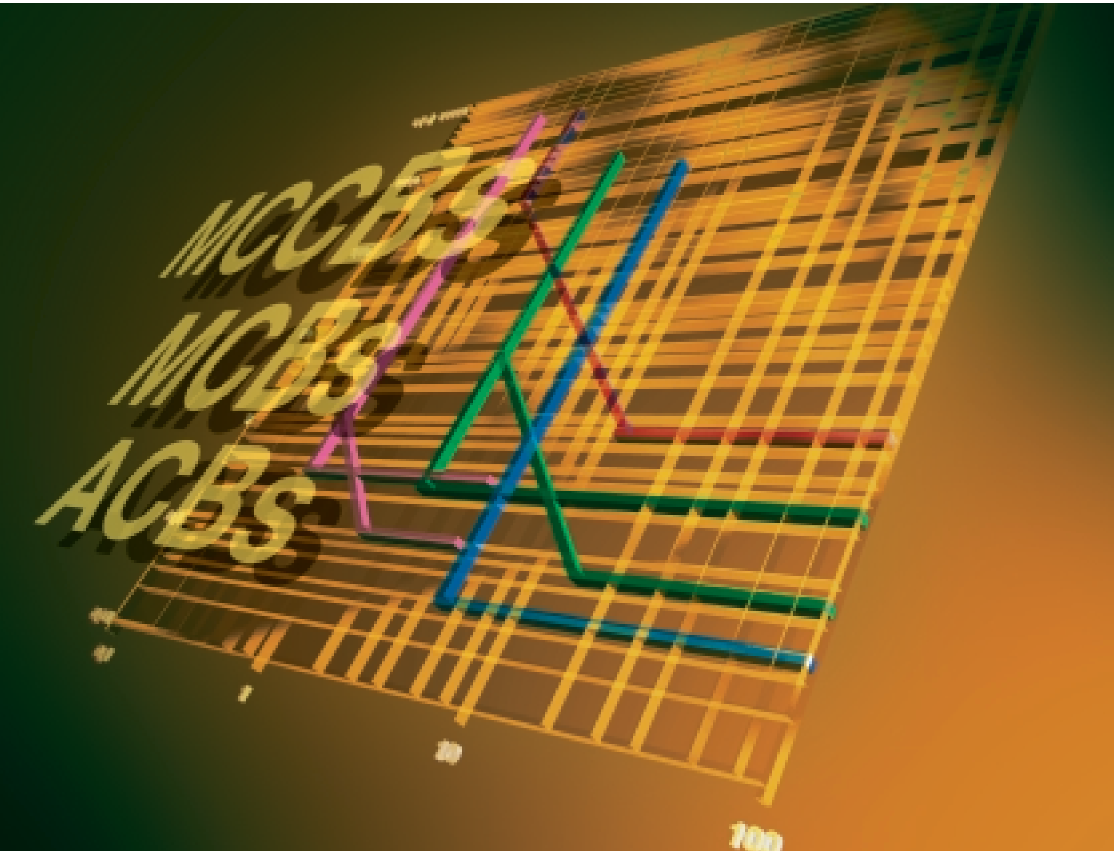
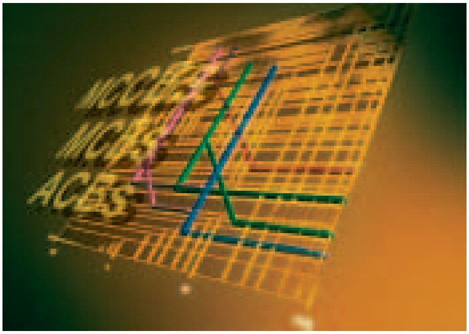


ABB SACE

Electrical installation handbook

Volume 1

Protection and control devices



2nd edition
February 2004

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Index

Introduction 2

1 Standards
- 1.1 General aspects 3
- 1.2 IEC Standards for electrical installation 15

2 Protection and control devices
- 2.1 Circuit-breaker nameplates 22
- 2.2 Main definitions 25
- 2.3 Types of releases 28

3 General characteristics
- 3.1 Electrical characteristics of circuit breakers 38
- 3.2 Trip curves 49
- 3.3 Limitation curves 107
- 3.4 Specific let-through energy curves 134
- 3.5 Temperature derating 160
- 3.6 Altitude derating 175
- 3.7 Electrical characteristics of switch disconnectors 176

4 Protection coordination
- 4.1 Protection coordination 182
- 4.2 Discrimination tables 189
- 4.3 Back-up tables 214
- 4.4 Coordination tables between circuit breakers and switch disconnectors 218

5 Special applications
- 5.1 Direct current networks 222
- 5.2 Networks at particular frequencies; 400 Hz and 16 2/3 Hz 233
- 5.3 1000 Vdc and 1000 Vac networks 250
- 5.4 Automatic Transfer Switches 262

6 Switchboards
- 6.1 Electrical switchboards 271
- 6.2 MNS switchboards 279
- 6.3 ArTu distribution switchboards 280

Annex A: Protection against short-circuit effects inside low-voltage switchboards 283

Annex B: Temperature rise evaluation according to IEC 60890 292

Introduction

Scope and objectives

The scope of this electrical installation handbook is to provide the designer and user of electrical plants with a quick reference, immediate-use working tool. This is not intended to be a theoretical document, nor a technical catalogue, but, in addition to the latter, aims to be of help in the correct definition of equipment, in numerous practical installation situations.

The dimensioning of an electrical plant requires knowledge of different factors relating to, for example, installation utilities, the electrical conductors and other components; this knowledge leads the design engineer to consult numerous documents and technical catalogues. This electrical installation handbook, however, aims to supply, in a single document, tables for the quick definition of the main parameters of the components of an electrical plant and for the selection of the protection devices for a wide range of installations. Some application examples are included to aid comprehension of the selection tables.

Electrical installation handbook users

The electrical installation handbook is a tool which is suitable for all those who are interested in electrical plants: useful for installers and maintenance technicians through brief yet important electrotechnical references, and for sales engineers through quick reference selection tables.

Validity of the electrical installation handbook

Some tables show approximate values due to the generalization of the selection process, for example those regarding the constructional characteristics of electrical machinery. In every case, where possible, correction factors are given for actual conditions which may differ from the assumed ones. The tables are always drawn up conservatively, in favour of safety; for more accurate calculations, the use of DOCWin software is recommended for the dimensioning of electrical installations.

1 Standards

1.1 General aspects

In each technical field, and in particular in the electrical sector, a condition sufficient (even if not necessary) for the realization of plants according to the **"status of the art"** and a requirement essential to properly meet the demands of customers and of the community, is the respect of all the relevant laws and technical standards.
Therefore, a precise knowledge of the standards is the fundamental premise for a correct approach to the problems of the electrical plants which shall be designed in order to guarantee that **"acceptable safety level"** which is never absolute.

Juridical Standards
These are all the standards from which derive rules of behavior for the juridical persons who are under the sovereignty of that State.

Technical Standards
These standards are the whole of the prescriptions on the basis of which machines, apparatus, materials and the installations should be designed, manufactured and tested so that efficiency and function safety are ensured.
The technical standards, published by national and international bodies, are circumstantially drawn up and can have legal force when this is attributed by a legislative measure.

Application fields

	Electrotechnics and Electronics	Telecommunications	Mechanics, Ergonomics and Safety
International Body	IEC	ITU	ISO
European Body	CENELEC	ETSI	CEN

This technical collection takes into consideration only the bodies dealing with electrical and electronic technologies.

IEC International Electrotechnical Commission

The *International Electrotechnical Commission* (IEC) was officially founded in 1906, with the aim of securing the international co-operation as regards standardization and certification in electrical and electronic technologies. This association is formed by the International Committees of over 40 countries all over the world.
The IEC publishes international standards, technical guides and reports which are the bases or, in any case, a reference of utmost importance for any national and European standardization activity.
IEC Standards are generally issued in two languages: English and French.
In 1991 the IEC has ratified co-operation agreements with CENELEC (European standardization body), for a common planning of new standardization activities and for parallel voting on standard drafts.

1 Standards

CENELEC European Committee for Electrotechnical Standardization

The *European Committee for Electrotechnical Standardization* (CENELEC) was set up in 1973. Presently it comprises 27 countries (Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Portugal, Poland, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom) and cooperates with 8 affiliates (Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Romania, Turkey, Ukraine) which have first maintained the national documents side by side with the CENELEC ones and then replaced them with the Harmonized Documents (HD). CENELEC hopes and expects Cyprus to become the 28th members before May 2004.
There is a difference between EN Standards and Harmonization Documents (HD): while the first ones have to be accepted at any level and without additions or modifications in the different countries, the second ones can be amended to meet particular national requirements.
EN Standards are generally issued in three languages: English, French and German.
From 1991 CENELEC cooperates with the IEC to accelerate the standards preparation process of International Standards.
CENELEC deals with specific subjects, for which standardization is urgently required.
When the study of a specific subject has already been started by the IEC, the European standardization body (CENELEC) can decide to accept or, whenever necessary, to amend the works already approved by the International standardization body.

EC DIRECTIVES FOR ELECTRICAL EQUIPMENT

Among its institutional roles, the European Community has the task of promulgating directives which must be adopted by the different member states and then transposed into national law.
Once adopted, these directives come into juridical force and become a reference for manufacturers, installers, and dealers who must fulfill the duties prescribed by law.
Directives are based on the following principles:
- harmonization is limited to essential requirements;
- only the products which comply with the essential requirements specified by the directives can be marketed and put into service;
- the harmonized standards, whose reference numbers are published in the Official Journal of the European Communities and which are transposed into the national standards, are considered in compliance with the essential requirements;
- the applicability of the harmonized standards or of other technical specifications is facultative and manufacturers are free to choose other technical solutions which ensure compliance with the essential requirements;
- a manufacturer can choose among the different conformity evaluation procedure provided by the applicable directive.

The scope of each directive is to make manufacturers take all the necessary steps and measures so that the product does not affect the safety and health

1 Standards

of persons, animals and property.

“Low Voltage” Directive 73/23/CEE – 93/68/CEE

The Low Voltage Directive refers to any electrical equipment designed for use at a rated voltage from 50 to 1000 V for alternating current and from 75 to 1500 V for direct current.
In particular, it is applicable to any apparatus used for production, conversion, transmission, distribution and use of electrical power, such as machines, transformers, devices, measuring instruments, protection devices and wiring materials.
The following categories are outside the scope of this Directive:
- electrical equipment for use in an explosive atmosphere;
- electrical equipment for radiology and medical purposes;
- electrical parts for goods and passenger lifts;
- electrical energy meters;
- plugs and socket outlets for domestic use;
- electric fence controllers;
- radio-electrical interference;
- specialized electrical equipment, for use on ships, aircraft or railways, which complies with the safety provisions drawn up by international bodies in which the Member States participate.

Directive EMC 89/336/EEC (“Electromagnetic Compatibility”)

The Directive on electromagnetic compatibility regards all the electrical and electronic apparatus as well as systems and installations containing electrical and/or electronic components. In particular, the apparatus covered by this Directive are divided into the following categories according to their characteristics:
- domestic radio and TV receivers;
- industrial manufacturing equipment;
- mobile radio equipment;
- mobile radio and commercial radio telephone equipment;
- medical and scientific apparatus;
- information technology equipment (ITE);
- domestic appliances and household electronic equipment;
- aeronautical and marine radio apparatus;
- educational electronic equipment;
- telecommunications networks and apparatus;
- radio and television broadcast transmitters;
- lights and fluorescent lamps.

The apparatus shall be so constructed that:
a) the electromagnetic disturbance it generates does not exceed a level allowing radio and telecommunications equipment and other apparatus to operate as intended;
b) the apparatus has an adequate level of intrinsic immunity to electromagnetic disturbance to enable it to operate as intended.

An apparatus is declared in conformity to the provisions at points a) and b) when the apparatus complies with the harmonized standards relevant to its product family or, in case there aren’t any, with the general standards.

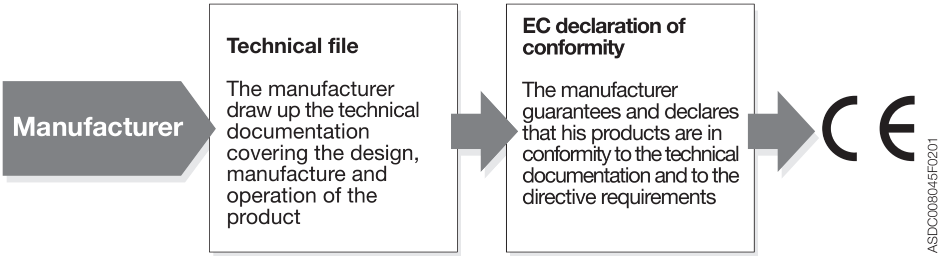
1 Standards

CE conformity marking

The CE conformity marking shall indicate conformity to all the obligations imposed on the manufacturer, as regards his products, by virtue of the European Community directives providing for the affixing of the CE marking.

When the CE marking is affixed on a product, it represents a declaration of the manufacturer or of his authorized representative that the product in question conforms to all the applicable provisions including the conformity assessment procedures. This prevents the Member States from limiting the marketing and putting into service of products bearing the CE marking, unless this measure is justified by the proved non-conformity of the product.

Flow diagram for the conformity assessment procedures established by the Directive 73/23/EEC on electrical equipment designed for use within particular voltage range:



Naval type approval

The environmental conditions which characterize the use of circuit breakers for on-board installations can be different from the service conditions in standard industrial environments; as a matter of fact, marine applications can require installation under particular conditions, such as:
- environments characterized by high temperature and humidity, including salt-mist atmosphere (damp-heat, salt-mist environment);
- on board environments (engine room) where the apparatus operate in the presence of vibrations characterized by considerable amplitude and duration.

In order to ensure the proper function in such environments, the shipping registers require that the apparatus has to be tested according to specific type approval tests, the most significant of which are vibration, dynamic inclination, humidity and dry-heat tests.

1 Standards

ABB SACE circuit-breakers (Isomax-Tmax-Emax) are approved by the following shipping registers:

• **RINA**	Registro Italiano Navale	Italian shipping register
• **DNV**	Det Norske Veritas	Norwegian shipping register
• **BV**	Bureau Veritas	French shipping register
• **GL**	Germanischer Lloyd	German shipping register
• **LRs**	Lloyd's Register of Shipping	British shipping register
• **ABS**	American Bureau of Shipping	American shipping register

It is always advisable to ask ABB SACE as regards the typologies and the performances of the certified circuit-breakers or to consult the section certificates in the website **http://bol.it.abb.com.**

Marks of conformity to the relevant national and international Standards

The international and national marks of conformity are reported in the following table, for information only:

COUNTRY	**Symbol**	**Mark designation**	**Applicability/Organization**
EUROPE		–	Mark of compliance with the harmonized European standards listed in the ENEC Agreement.
AUSTRALIA		AS Mark	Electrical and non-electrical products. It guarantees compliance with SAA (Standard Association of Australia).
AUSTRALIA		S.A.A. Mark	Standards Association of Australia (S.A.A.). The Electricity Authority of New South Wales Sydney Australia
AUSTRIA		Austrian Test Mark	Installation equipment and materials

1 Standards

COUNTRY	Symbol	Mark designation	Applicability/Organization
AUSTRIA		ÖVE Identification Thread	Cables
BELGIUM	CEBEC	CEBEC Mark	Installation materials and electrical appliances
BELGIUM	△ CEBEC	CEBEC Mark	Conduits and ducts, conductors and flexible cords
BELGIUM	CEBEC *	Certification of Conformity	Installation material and electrical appliances (in case there are no equivalent national standards or criteria)
CANADA		CSA Mark	Electrical and non-electrical products. This mark guarantees compliance with CSA (Canadian Standard Association)
CHINA		CCEE Mark	Great Wall Mark Commission for Certification of Electrical Equipment
Czech Republic		EZU' Mark	Electrotechnical Testing Institute
Slovakia Republic		EVPU' Mark	Electrotechnical Research and Design Institute

1 Standards

COUNTRY	Symbol	Mark designation	Applicability/Organization
CROATIA	KONČAR	KONKAR	Electrical Engineering Institute
DENMARK	D	DEMKO Approval Mark	Low voltage materials. This mark guarantees the compliance of the product with the requirements (safety) of the “Heavy Current Regulations”
FINLAND	SÄHKÖTARKASTUSLAITOKSEN HYVÄKSYMÄ GODKÄND AV ELEKTRISKA INSPEKTORATET *	Safety Mark of the Elektriska Inspektoratet	Low voltage material. This mark guarantees the compliance of the product with the requirements (safety) of the “Heavy Current Regulations”
FRANCE	CONTRÔLE NF LIMITÈ À LA SÈCURITÈ	ESC Mark	Household appliances
FRANCE	NF USE	NF Mark	Conductors and cables – Conduits and ducting – Installation materials
FRANCE		NF Identification Thread	Cables
FRANCE	OUTILLAGE NF ÉLECTRICITÉ	NF Mark	Portable motor-operated tools
FRANCE	NF ÉLECTRICITÉ	NF Mark	Household appliances

1 Standards

COUNTRY	Symbol	Mark designation	Applicability/Organization
GERMANY	VDE	VDE Mark	For appliances and technical equipment, installation accessories such as plugs, sockets, fuses, wires and cables, as well as other components (capacitors, earthing systems, lamp holders and electronic devices)
GERMANY		VDE Identification Thread	Cables and cords
GERMANY	VDE	VDE Cable Mark	For cables, insulated cords, installation conduits and ducts
GERMANY	VDE GS geprüfte Sicherheit	VDE-GS Mark for technical equipment	Safety mark for technical equipment to be affixed after the product has been tested and certified by the VDE Test Laboratory in Offenbach; the conformity mark is the mark VDE, which is granted both to be used alone as well as in combination with the mark GS
HUNGARY	MEEI	MEEI	Hungarian Institute for Testing and Certification of Electrical Equipment
JAPAN	JIS GIAPPONE	JIS Mark	Mark which guarantees compliance with the relevant Japanese Industrial Standard(s).
IRELAND	IIRS IRLANDA	IIRS Mark	Electrical equipment
IRELAND	MARK OF CONFORMITY I.I.R.S.	IIRS Mark	Electrical equipment

1 Standards

COUNTRY	Symbol	Mark designation	Applicability/Organization
ITALY		IMQ Mark	Mark to be affixed on electrical material for non-skilled users; it certifies compliance with the European Standard(s).
NORWAY		Norwegian Approval Mark	Mandatory safety approval for low voltage material and equipment
NETHERLANDS	KEMA-KEUR	KEMA-KEUR	General for all equipment
POLAND		KWE	Electrical products
RUSSIA		Certification of Conformity	Electrical and non-electrical products. It guarantees complance with national standard (Gosstandard of Russia)
SINGAPORE		SISIR	Electrical and non-electrical products
SLOVENIA	SIQ - Slovenia	SIQ	Slovenian Institute of Quality and Metrology
SPAIN		AEE	Electrical products. The mark is under the control of the Asociación Electrotécnica Española (Spanish Electrotechnical Association)

1 Standards

COUNTRY	Symbol	Mark designation	Applicability/Organization
SPAIN		AENOR	Asociación Española de Normalización y Certificación. (Spanish Standarization and Certification Association)
SWEDEN		SEMKO Mark	Mandatory safety approval for low voltage material and equipment.
SWITZERLAND	* PZ 1	Safety Mark	Swiss low voltage material subject to mandatory approval (safety).
SWITZERLAND		–	Cables subject to mandatory approval
SWITZERLAND		SEV Safety Mark	Low voltage material subject to mandatory approval
UNITED KINGDOM		ASTA Mark	Mark which guarantees compliance with the relevant “British Standards”
UNITED KINGDOM		BASEC Mark	Mark which guarantees compliance with the “British Standards” for conductors, cables and ancillary products.
UNITED KINGDOM		BASEC Identification Thread	Cables

1 Standards

COUNTRY	Symbol	Mark designation	Applicability/Organization
UNITED KINGDOM		BEAB Safety Mark	Compliance with the “British Standards” for household appliances
UNITED KINGDOM		BSI Safety Mark	Compliance with the “British Standards”
UNITED KINGDOM		BEAB Kitemark	Compliance with the relevant “British Standards” regarding safety and performances
U.S.A.	LISTED (Product Name) (Control Number)	UNDERWRITERS LABORATORIES Mark	Electrical and non-electrical products
U.S.A.	UL U.S.A.	UNDERWRITERS LABORATORIES Mark	Electrical and non-electrical products
U.S.A.	UL U.S.A.	UL Recognition	Electrical and non-electrical products
CEN		CEN Mark	Mark issued by the European Committee for Standardization (CEN): it guarantees compliance with the European Standards.
CENELEC	HAR	Mark	Cables

1 Standards

COUNTRY	Symbol	Mark designation	Applicability/Organization
CENELEC		Harmonization Mark	Certification mark providing assurance that the harmonized cable complies with the relevant harmonized CENELEC Standards – identification thread
EC		Ex EUROPEA Mark	Mark assuring the compliance with the relevant European Standards of the products to be used in environments with explosion hazards
CEEel		CEEel Mark	Mark which is applicable to some household appliances (shavers, electric clocks, etc).

EC - Declaration of Conformity

The EC Declaration of Conformity is the statement of the manufacturer, who declares under his own responsibility that all the equipment, procedures or services refer and comply with specific standards (directives) or other normative documents.
The EC Declaration of Conformity should contain the following information:
- name and address of the manufacturer or by its European representative;
- description of the product;
- reference to the harmonized standards and directives involved;
- any reference to the technical specifications of conformity;
- the two last digits of the year of affixing of the CE marking;
- identification of the signer.

A copy of the EC Declaration of Conformity shall be kept by the manufacturer or by his representative together with the technical documentation.

1.2 IEC Standards for electrical installation

STANDARD	YEAR	TITLE
IEC 60027-1	1992	Letter symbols to be used in electrical technology - Part 1: General
IEC 60034-1	1999	Rotating electrical machines - Part 1: Rating and performance
IEC 60617-DB-12M	2001	Graphical symbols for diagrams - 12-month subscription to online database comprising parts 2 to 11 of IEC 60617
IEC 61082-1	1991	Preparation of documents used in electrotechnology - Part 1: General requirements
IEC 61082-2	1993	Preparation of documents used in electrotechnology - Part 2: Function-oriented diagrams
IEC 61082-3	1993	Preparation of documents used in electrotechnology - Part 3: Connection diagrams, tables and lists
IEC 61082-4	1996	Preparation of documents used in electrotechnology - Part 4: Location and installation documents
IEC 60038	1983	IEC standard voltages
IEC 60664-1	2000	Insulation coordination for equipment within low-voltage systems - Part 1: Principles, requirements and tests
IEC 60909-0	2001	Short-circuit currents in three-phase a.c. systems - Part 0: Calculation of currents
IEC 60865-1	1993	Short-circuit currents - Calculation of effects - Part 1: Definitions and calculation methods
IEC 60781	1989	Application guide for calculation of short-circuit currents in low-voltage radial systems
IEC 60076-1	2000	Power transformers - Part 1: General
IEC 60076-2	1993	Power transformers - Part 2: Temperature rise
IEC 60076-3	2000	Power transformers - Part 3: Insulation levels, dielectric tests and external clearances in air
IEC 60076-5	2000	Power transformers - Part 5: Ability to withstand short circuit
IEC/TR 60616	1978	Terminal and tapping markings for power transformers
IEC 60726	1982	Dry-type power transformers
IEC 60445	1999	Basic and safety principles for man-machine interface, marking and identification - Identification of equipment terminals and of terminations of certain designated conductors, including general rules for an alphanumeric system

1 Standards

STANDARD	YEAR	TITLE
IEC 60073	1996	Basic and safety principles for man-machine interface, marking and identification – Coding for indication devices and actuators
IEC 60446	1999	Basic and safety principles for man-machine interface, marking and identification - Identification of conductors by colours or numerals
IEC 60447	1993	Man-machine-interface (MMI) - Actuating principles
IEC 60947-1	2001	Low-voltage switchgear and controlgear - Part 1: General rules
IEC 60947-2	2001	Low-voltage switchgear and controlgear - Part 2: Circuit-breakers
IEC 60947-3	2001	Low-voltage switchgear and controlgear - Part 3: Switches, disconnectors, switch-disconnectors and fuse-combination units
IEC 60947-4-1	2000	Low-voltage switchgear and controlgear - Part 4-1: Contactors and motor-starters – Electromechanical contactors and motor-starters
IEC 60947-4-2	2002	Low-voltage switchgear and controlgear - Part 4-2: Contactors and motor-starters – AC semiconductor motor controllers and starters
IEC 60947-4-3	1999	Low-voltage switchgear and controlgear - Part 4-3: Contactors and motor-starters – AC semiconductor controllers and contactors for non-motor loads
IEC 60947-5-1	2000	Low-voltage switchgear and controlgear - Part 5-1: Control circuit devices and switching elements - Electromechanical control circuit devices
IEC 60947-5-2	1999	Low-voltage switchgear and controlgear - Part 5-2: Control circuit devices and switching elements – Proximity switches
IEC 60947-5-3	1999	Low-voltage switchgear and controlgear - Part 5-3: Control circuit devices and switching elements – Requirements for proximity devices with defined behaviour under fault conditions
IEC 60947-5-4	1996	Low-voltage switchgear and controlgear - Part 5: Control circuit devices and switching elements – Section 4: Method of assessing the performance of low energy contacts. Special tests
IEC 60947-5-5	1997	Low-voltage switchgear and controlgear - Part 5-5: Control circuit devices and switching elements - Electrical emergency stop device with mechanical latching function

1 Standards

STANDARD	YEAR	TITLE
IEC 60947-5-6	1999	Low-voltage switchgear and controlgear - Part 5-6: Control circuit devices and switching elements – DC interface for proximity sensors and switching amplifiers (NAMUR)
IEC 60947-6-1	1998	Low-voltage switchgear and controlgear - Part 6-1: Multiple function equipment – Automatic transfer switching equipment
IEC 60947-6-2	1999	Low-voltage switchgear and controlgear - Part 6-2: Multiple function equipment - Control and protective switching devices (or equipment) (CPS)
IEC 60947-7-1	1999	Low-voltage switchgear and controlgear - Part 7: Ancillary equipment - Section 1: Terminal blocks
IEC 60947-7-2	1995	Low-voltage switchgear and controlgear - Part 7: Ancillary equipment - Section 2: Protective conductor terminal blocks for copper conductors
IEC 60439-1	1999	Low-voltage switchgear and controlgear assemblies - Part 1: Type-tested and partially type-tested assemblies
IEC 60439-2	2000	Low-voltage switchgear and controlgear assemblies - Part 2: Particular requirements for busbar trunking systems (busways)
IEC 60439-3	2001	Low-voltage switchgear and controlgear assemblies - Part 3: Particular requirements for low-voltage switchgear and controlgear assemblies intended to be installed in places where unskilled persons have access for their use - Distribution boards
IEC 60439-4	1999	Low-voltage switchgear and controlgear assemblies - Part 3: Particular requirements for low-voltage switchgear and controlgear assemblies intended to be installed in places where unskilled persons have access for their use - Distribution boards
IEC 60439-5	1999	Low-voltage switchgear and controlgear assemblies - Part 3: Particular requirements for low-voltage switchgear and controlgear assemblies intended to be installed in places where unskilled persons have access for their use - Distribution boards
IEC 61095	2000	Low-voltage switchgear and controlgear assemblies - Part 3: Particular requirements for low-voltage switchgear and controlgear assemblies intended to be installed in places where unskilled persons have access for their use - Distribution boards

1 Standards

STANDARD	YEAR	TITLE
IEC 60890	1987	A method of temperature-rise assessment by extrapolation for partially type-tested assemblies (PTTA) of low-voltage switchgear and controlgear
IEC 61117	1992	A method for assessing the short-circuit withstand strength of partially type-tested assemblies (PTTA)
IEC 60092-303	1980	Electrical installations in ships. Part 303: Equipment - Transformers for power and lighting
IEC 60092-301	1980	Electrical installations in ships. Part 301: Equipment - Generators and motors
IEC 60092-101	1994	Electrical installations in ships - Part 101: Definitions and general requirements
IEC 60092-401	1980	Electrical installations in ships. Part 401: Installation and test of completed installation
IEC 60092-201	1994	Electrical installations in ships - Part 201: System design - General
IEC 60092-202	1994	Electrical installations in ships - Part 202: System design - Protection
IEC 60092-302	1997	Electrical installations in ships - Part 302: Low-voltage switchgear and controlgear assemblies
IEC 60092-350	2001	Electrical installations in ships - Part 350: Shipboard power cables - General construction and test requirements
IEC 60092-352	1997	Electrical installations in ships - Part 352: Choice and installation of cables for low-voltage power systems
IEC 60364-5-52	2001	Electrical installations of buildings - Part 5-52: Selection and erection of electrical equipment – Wiring systems
IEC 60227		Polyvinyl chloride insulated cables of rated voltages up to and including 450/750 V
	1998	Part 1: General requirements
	1997	Part 2: Test methods
	1997	Part 3: Non-sheathed cables for fixed wiring
	1997	Part 4: Sheathed cables for fixed wiring
	1998	Part 5: Flexible cables (cords)
	2001	Part 6: Lift cables and cables for flexible connections
	1995	Part 7: Flexible cables screened and unscreened with two or more conductors
IEC 60228	1978	Conductors of insulated cables
IEC 60245		Rubber insulated cables - Rated voltages up to and including 450/750 V
	1998	Part 1: General requirements
	1998	Part 2: Test methods
	1994	Part 3: Heat resistant silicone insulated cables

1 Standards

STANDARD	YEAR	TITLE
	1994	Part 5: Lift cables
	1994	Part 6: Arc welding electrode cables
	1994	Part 7: Heat resistant ethylene-vinyl acetate rubber insulated cables
	1998	Part 8: Cords for applications requiring high flexibility
IEC 60309-2	1999	Plugs, socket-outlets and couplers for industrial purposes - Part 2: Dimensional interchangeability requirements for pin and contact-tube accessories
IEC 61008-1	1996	Residual current operated circuit-breakers without integral overcurrent protection for household and similar uses (RCCBs) - Part 1: General rules
IEC 61008-2-1	1990	Residual current operated circuit-breakers without integral overcurrent protection for household and similar uses (RCCB's). Part 2-1: Applicability of the general rules to RCCB's functionally independent of line voltage
IEC 61008-2-2	1990	Residual current operated circuit-breakers without integral overcurrent protection for household and similar uses (RCCB's). Part 2-2: Applicability of the general rules to RCCB's functionally dependent on line voltage
IEC 61009-1	1996	Residual current operated circuit-breakers with integral overcurrent protection for household and similar uses (RCBOs) - Part 1: General rules
IEC 61009-2-1	1991	Residual current operated circuit-breakers with integral overcurrent protection for household and similar uses (RCBO's) Part 2-1: Applicability of the general rules to RCBO's functionally independent of line voltage
IEC 61009-2-2	1991	Residual current operated circuit-breakers with integral overcurrent protection for household and similar uses (RCBO's) - Part 2-2: Applicability of the general rules to RCBO's functionally dependent on line voltage
IEC 60670	1989	General requirements for enclosures for accessories for household and similar fixed electrical installations
IEC 60669-2-1	2000	Switches for household and similar fixed electrical installations - Part 2-1: Particular requirements – Electronic switches
IEC 60669-2-2	2000	Switches for household and similar fixed electrical installations - Part 2: Particular requirements – Section 2: Remote-control switches (RCS)
IEC 606692-3	1997	Switches for household and similar fixed electrical installations - Part 2-3: Particular requirements – Time-delay switches (TDS)

1 Standards

STANDARD	YEAR	TITLE
IEC 60079-10	1995	Electrical apparatus for explosive gas atmospheres - Part 10: Classification of hazardous areas
IEC 60079-14	1996	Electrical apparatus for explosive gas atmospheres - Part 14: Electrical installations in hazardous areas (other than mines)
IEC 60079-17	1996	Electrical apparatus for explosive gas atmospheres - Part 17: Inspection and maintenance of electrical installations in hazardous areas (other than mines)
IEC 60269-1	1998	Low-voltage fuses - Part 1: General requirements
IEC 60269-2	1986	Low-voltage fuses. Part 2: Supplementary requirements for fuses for use by authorized persons (fuses mainly for industrial application)
IEC 60269-3-1	2000	Low-voltage fuses - Part 3-1: Supplementary requirements for fuses for use by unskilled persons (fuses mainly for household and similar applications) - Sections I to IV
IEC 60127-1/10		Miniature fuses -
	1999	Part 1: Definitions for miniature fuses and general requirements for miniature fuse-links
	1989	Part 2: Cartridge fuse-links
	1988	Part 3: Sub-miniature fuse-links
	1996	Part 4: Universal Modular Fuse-Links (UMF)
	1988	Part 5: Guidelines for quality assessment of miniature fuse-links
	1994	Part 6: Fuse-holders for miniature cartridge fuse-links
	2001	Part 10: User guide for miniature fuses
IEC 60730-2-7	1990	Automatic electrical controls for household and similar use. Part 2: Particular requirements for timers and time switches
IEC 60364-1	2001	Electrical installations of buildings - Part 1: Fundamental principles, assessment of general characteristics, definitions
IEC 60364-4	2001	Electrical installations of buildings - Part 4: Protection for safety
IEC 60364-5	2001…2002	Electrical installations of buildings - Part 5: Selection and erection of electrical equipment
IEC 60364-6	2001	Electrical installations of buildings - Part 6: Verification
IEC 60364-7	1983…2002	Electrical installations of buildings. Part 7: Requirements for special installations or locations
IEC 60529	2001	Degrees of protection provided by enclosures (IP Code)

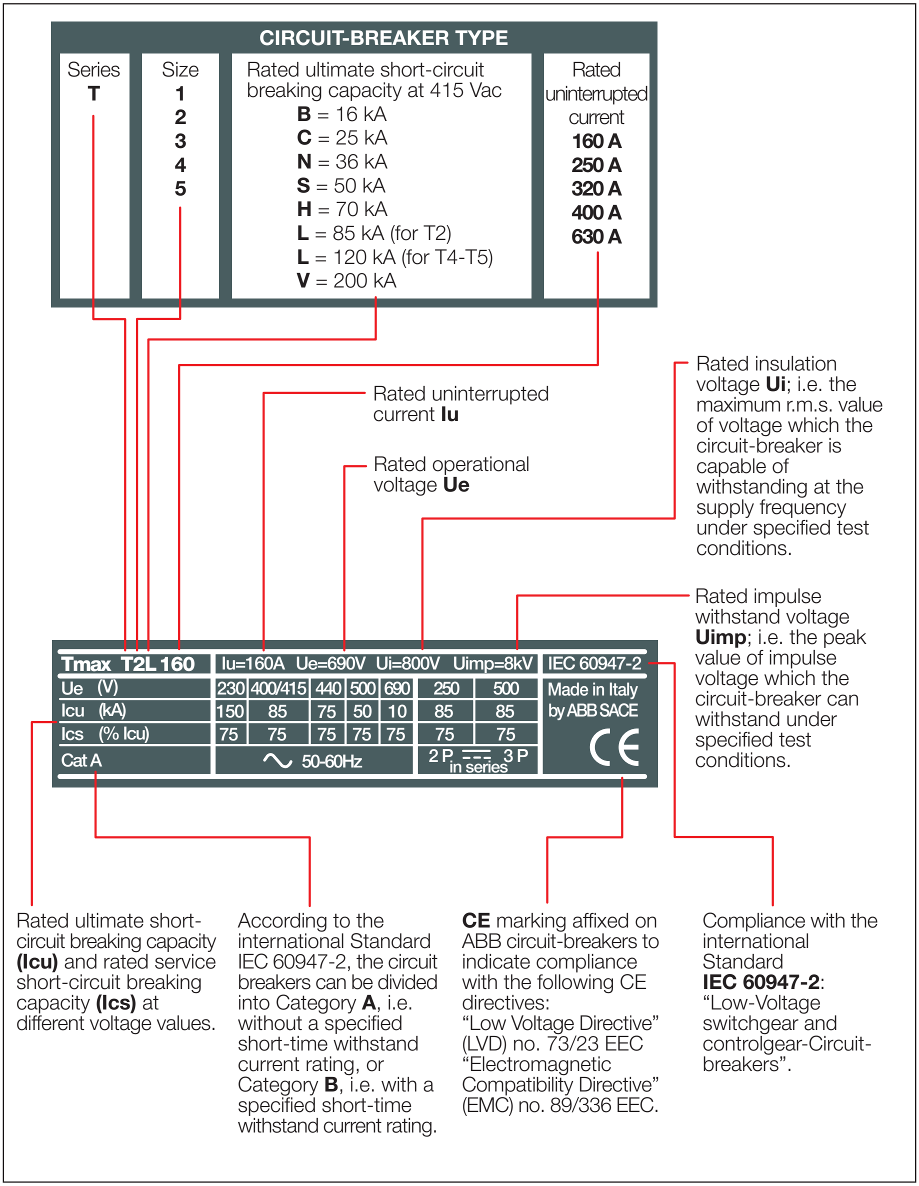
1 Standards

STANDARD	YEAR	TITLE
IEC 61032	1997	Protection of persons and equipment by enclosures - Probes for verification
IEC 61000-1-1	1992	Electromagnetic compatibility (EMC) - Part 1: General - Section 1: Application and interpretation of fundamental definitions and terms
IEC 61000-1-2	2001	Electromagnetic compatibility (EMC) - Part 1-2: General - Methodology for the achievement of the functional safety of electrical and electronic equipment with regard to electromagnetic phenomena
IEC 61000-1-3	2002	Electromagnetic compatibility (EMC) - Part 1-3: General - The effects of high-altitude EMP (HEMP) on civil equipment and systems

2 Protection and control devices

2.1 Circuit-breaker nameplates

Moulded-case circuit-breaker: Tmax



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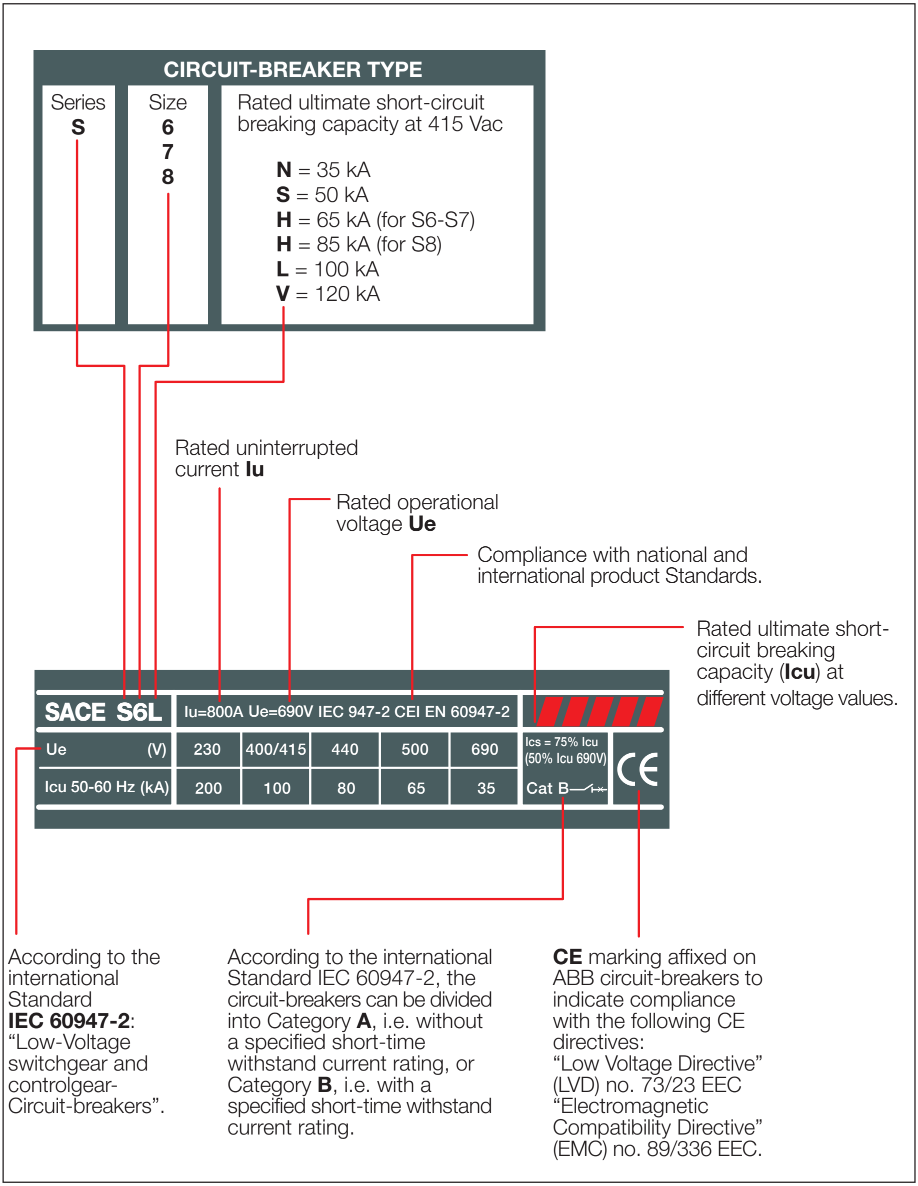
2 Protection and control devices

Moulded-case circuit-breaker: Isomax



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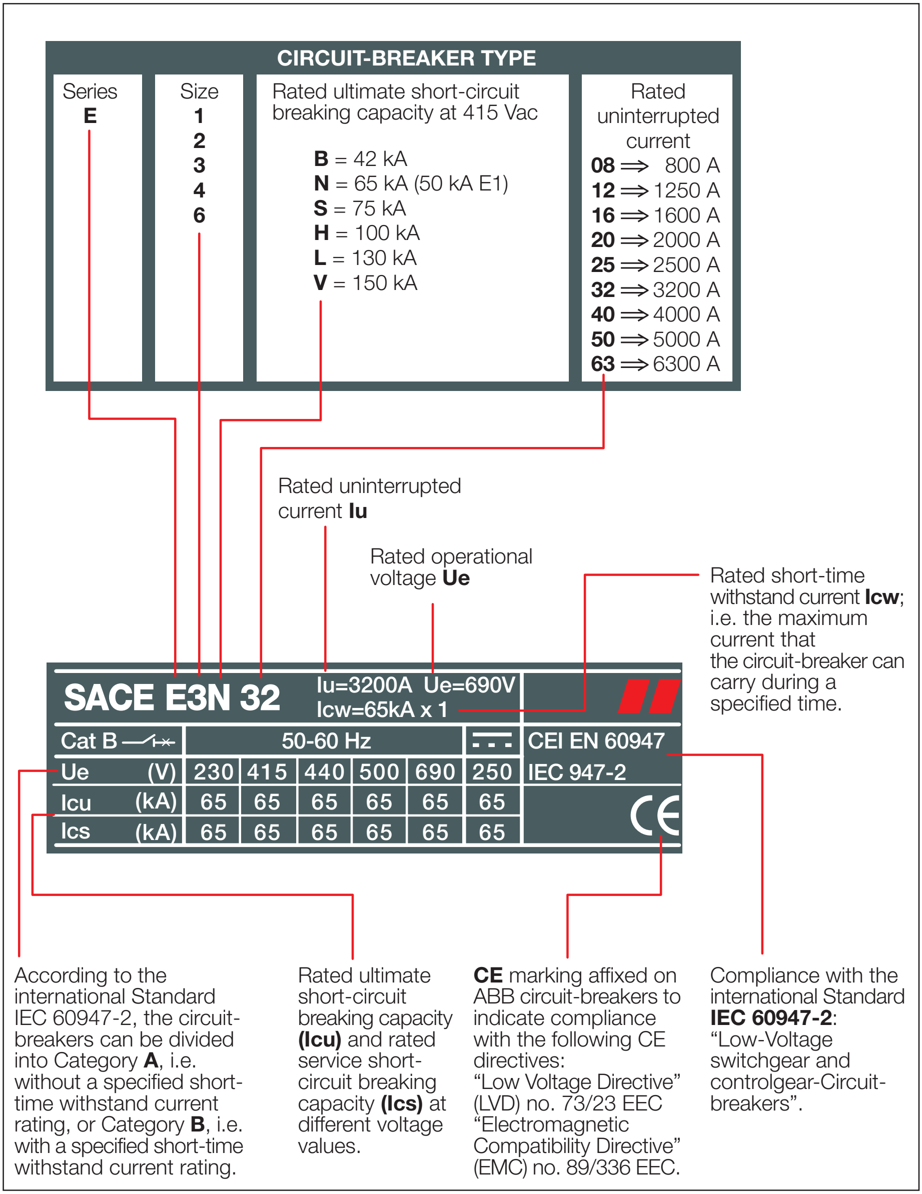
2 Protection and control devices

Air circuit-breaker: Emax



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2.2 Main definitions

The main definitions regarding LV switchgear and controlgear are included in the international Standards IEC 60947-1, IEC 60947-2 and IEC 60947-3.

Main characteristics

Circuit-breaker
A mechanical switching device, capable of making, carrying and breaking currents under normal circuit conditions and also making, carrying for a specified time and breaking currents under specified abnormal circuit conditions such as those of short-circuit.

Current-limiting circuit-breaker
A circuit-breaker with a break-time short enough to prevent the short-circuit current reaching its otherwise attainable peak value.

Plug-in circuit-breaker
A circuit-breaker which, in addition to its interrupting contacts, has a set of contacts which enable the circuit-breaker to be removed.

Withdrawable circuit-breaker
A circuit-breaker which, in addition to its interrupting contacts, has a set of isolating contacts which enable the circuit-breaker to be disconnected from the main circuit, in the withdrawn position, to achieve an isolating distance in accordance with specified requirements.

Moulded-case circuit-breaker
A circuit-breaker having a supporting housing of moulded insulating material forming an integral part of the circuit-breaker.

Disconnector
A mechanical switching device which, in the open position, complies with the requirements specified for the isolating function.

Release
A device, mechanically connected to a mechanical switching device, which releases the holding means and permits the opening or the closing of the switching device.

Fault types and currents

Overload
Operating conditions in an electrically undamaged circuit which cause an over-current.

Short-circuit
The accidental or intentional connection, by a relatively low resistance or impedance, of two or more points in a circuit which are normally at different voltages.

Residual current (I_Δ)
It is the vectorial sum of the currents flowing in the main circuit of the circuit-breaker.

2 Protection and control devices

Rated performances

Voltages and frequencies

Rated operational voltage (U_e)
A rated operational voltage of an equipment is a value of voltage which, combined with a rated operational current, determines the application of the equipment and to which the relevant tests and the utilization categories are referred to.

Rated insulation voltage (U_i)
The rated insulation voltage of an equipment is the value of voltage to which dielectric tests voltage and creepage distances are referred. In no case the maximum value of the rated operational voltage shall exceed that of the rated insulation voltage.

Rated impulse withstand voltage (U_{imp})
The peak value of an impulse voltage of prescribed form and polarity which the equipment is capable of withstanding without failure under specified conditions of test and to which the values of the clearances are referred.

Rated frequency
The supply frequency for which an equipment is designed and to which the other characteristic values correspond.

Currents

Rated uninterrupted current (I_u)
The rated uninterrupted current of an equipment is a value of current, stated by the manufacturer, which the equipment can carry in uninterrupted duty.

Rated residual operating current ($I_{\Delta n}$)
It is the r.m.s. value of a sinusoidal residual operating current assigned to the CBR by the manufacturer, at which the CBR shall operate under specified conditions.

Performances under short-circuit conditions

Rated making capacity
The rated making capacity of an equipment is a value of current, stated by the manufacturer, which the equipment can satisfactorily make under specified making conditions.

Rated breaking capacity
The rated breaking of an equipment is a value of current, stated by the manufacturer, which the equipment can satisfactorily break, under specified breaking conditions.

2 Protection and control devices

Rated ultimate short-circuit breaking capacity (I_{cu})

The rated ultimate short-circuit breaking capacity of a circuit-breaker is the maximum short-circuit current value which the circuit-breaker can break twice (in accordance with the sequence O – t – CO), at the corresponding rated operational voltage. After the opening and closing sequence the circuit-breaker is not required to carry its rated current.

Rated service short-circuit breaking capacity (I_{cs})

The rated service short-circuit breaking capacity of a circuit-breaker is the maximum short-circuit current value which the circuit-breaker can break three times in accordance with a sequence of opening and closing operations (O - t - CO - t – CO) at a defined rated operational voltage (U_e) and at a defined power factor. After this sequence the circuit-breaker is required to carry its rated current.

Rated short-time withstand current (I_{cw})

The rated short-time withstand current is the current that the circuit-breaker in the closed position can carry during a specified short time under prescribed conditions of use and behaviour; the circuit-breaker shall be able to carry this current during the associated short-time delay in order to ensure discrimination between the circuit-breakers in series.

Rated short-circuit making capacity (I_{cm})

The rated short-circuit making capacity of an equipment is the value of short-circuit making capacity assigned to that equipment by the manufacturer for the rated operational voltage, at rated frequency, and at a specified power-factor for ac.

Utilization categories

The utilization category of a circuit-breaker shall be stated with reference to whether or not it is specifically intended for selectivity by means of an intentional time delay with respect to other circuit-breakers in series on the load side, under short-circuit conditions (Table 4 IEC 60947-2).

Category A - Circuit-breakers not specifically intended for selectivity under short-circuit conditions with respect to other short-circuit protective devices in series on the load side, i.e. without a short-time withstand current rating.

Category B - Circuit-breakers specifically intended for selectivity under short-circuit conditions with respect to other short-circuit protective devices in series on the load side, i.e. with and intentional short-time delay provided for selectivity under short-circuit conditions. Such circuit-breakers have a short-time withstand current rating.

2 Protection and control devices

A circuit-breaker is classified in category B if its I_{cw} is higher than (Table 3 IEC 60947-2):

12·In or 5 kA, whichever is the greater	for	In ≤ 2500A
30 kA	for	In > 2500A

Electrical and mechanical durability

Mechanical durability

The mechanical durability of an apparatus is expressed by the number of no-load operating cycles (each operating cycle consists of one closing and opening operation) which can be effected before it becomes necessary to service or replace any of its mechanical parts (however, normal maintenance may be permitted).

Electrical durability

The electrical durability of an apparatus is expressed by the number of on-load operating cycles and gives the contact resistance to electrical wear under the service conditions stated in the relevant product Standard.

2.3 Types of releases

A circuit-breaker must control and protect, in case of faults or malfunctioning, the connected elements of a plant. In order to perform this function, after detection of an anomalous condition, the release intervenes in a definite time by opening the interrupting part.
The protection releases fitted with ABB SACE moulded-case and air circuit-breakers can control and protect any plant, from the simplest ones to those

Circuit-breaker		In [A] →	1	1.6	2	2.5	3.2	4	5	6.3	8	8.5	10	11	12.5	16	20	25	32	40
	Magnetic type	Thermal [A]→	MO	1.1-1.6	1.4-2	1.8-2.5	2.2-3.2	2.8-4	3.5-5	4.4-6.3	5.6-8	MO	7-10	MO	8.8-12.5	11-16	14-20	18-25	22-32	28-40
T1	10xIn															500	500	500	500	500
T2	10xIn			16	20	25	32	40	50	63	80		100		125	500	500	500	500	500
	(MO*)13xIn		13	21	26	33	42	52	65	84		110		145	163					
	(MO*)6-12xIn																120-240		192-384	
T3	10xIn																			
	3xIn																			
	(MO*)6-12xIn																			
T4	10xIn	I3 [A]															320		320	
	5-10xIn																			
	(MO*)6-14xIn												60-140					150-350		
T5	5-10xIn																			
	2.5-5xIn																			
S6	5-10xIn																			

*Note: MO Magnetic only

2 Protection and control devices

with particular requirements, thanks to their wide setting possibilities of both thresholds and tripping times.
Among the devices sensitive to overcurrents, the following can be considered:

- thermomagnetic releases and magnetic only releases;
- microprocessor-based releases;
- residual current devices.

The choice and adjusting of protection releases are based both on the requirements of the part of plant to be protected, as well as on the coordination with other devices; in general, discriminating factors for the selection are the required threshold, time and curve characteristic.

2.3.1 THERMOMAGNETIC RELEASES AND MAGNETIC ONLY RELEASES

The thermomagnetic releases use a bimetal and an electromagnet to detect overloads and short-circuits; they are suitable to protect both alternating and direct current networks.

The following table shows the available rated currents and the relevant magnetic settings.

50	**52**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**320**	**400**	**500**	**630**	**800**
35-50	MO	44-63	56-80	70-100	88-125	112-160	140-200	175-250	224-320	280-400	350-500	441-630	560-800
500		630	800	1000	1250	1600							
500		630	800	1000	1250	1600							
	314-624		480-960	600-1200									
		630	800	1000	1250	1600	2000	2500					
		400	400	400	400	480	600	750					
				600-1200	750-1500	960-1920	1200-2400						
500													
			400-800	500-1000	625-1250	800-1600	1000-2000	1250-2500	1600-3200				
	314-728		480-1120	600-1400	750-1750	960-2240	1200-2800						
									1600-3200	2000-4000	2500-5000	3150-6300	
									800-1600	1000-2000	1250-2500	1600-3200	
													4000-8000

2 Protection and control devices

For example, a circuit-breaker type T2, with rated current In equal to 2.5 A, is available in two versions:
- thermomagnetic with adjustable thermal current I_1 from 1.8 up to 2.5 A and fixed magnetic current I_3 equal to 25 A;
- magnetic only (MO) with fixed magnetic current I_3 equal to 33 A.

2.3.2 ELECTRONIC RELEASES

These releases are connected with current transformers (three or four according to the number of conductors to be protected), which are positioned inside the circuit-breaker and have the double functions of supplying the power necessary to the proper functioning of the release (self-supply) and of detecting the value of the current flowing inside the live conductors; therefore they are compatible with alternating current networks only.
The signal coming from the transformers and from the Rogowsky coils is processed by the electronic component (microprocessor) which compares it with the set thresholds. When the signal exceeds the thresholds, the trip of the circuit-breaker is operated through an opening solenoid which directly acts on the circuit-breaker operating mechanism.
In case of auxiliary power supply in addition to self-supply from the current transformers, the voltage shall be 24 Vdc ± 20%.

Rated Current In [A] →		10	25	63	100	160	200	250	320
L Function	PR221	4-10	10-25	25-63	40-100	64-160		100-250	128-320
	PR222				40-100	64-160		100-250	128-320
	PR211/PR212								
	PR222/MP				40-100	64-160	80-200		128-320
	PR212/MP								
S Function	PR221(1)	10-100	25-250	63-630	100-1000	160-1600		250-2500	320-3200
	PR222				60-1000	96-1600		150-2500	192-3200
	PR211/PR212								
I Function	PR221(1)	10-100	25-250	63-630	100-1000	160-1600		250-2500	320-3200
	PR222				150-1200	240-1920		375-3000	480-3200*
	PR211/PR212								
	PR222/MP				600-1300	960-2080	1200-2600		1920-4160
	PR212/MP								

(1) For T2 only: S function is in alternative to I function
* For T5 480-3840

2 Protection and control devices

Besides the standard protection functions, releases provide:
- measurements of the main characteristics of the plant: voltage, frequency, power, energy and harmonics (PR112-PR113);
- serial communication with remote control for a complete management of the plant (PR212-PR222-PR112-PR113, equipped with dialogue unit).

CURRENT TRANSFORMER SIZE

Rated Current In [A] →		**10**	**25**	**63**	**100**	**160**	**250**	**320**	**400**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3200**
Circuit- breaker	Iu[A]																
T2	160	■	■	■	■	■											
T4	250				■	■	■										
	320							■									
T5	400							■	■								
	630									■							
S6	800										■						
S7	1250											■	■				
	1600													■			
S8	2000													■	■		
	2500															■	
	3200																■

400	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3200**
160-400	252-630							
160-400	252-630							
	320-800	400-1000	500-1250	640-1600	800-2000	1000-2500	1280-3200	
160-400								
	252-630		400-1000					
400-4000	630-6300							
240-4000	378-6300							
		800-8000	1000-10000	1250-12500	1600-1600	2000-20000	2500-25000	3200-32000
400-4000	630-6300							
600-4800	945-6300							
		1200-9600	1500-12000	2875-15000	2400-19200	3000-24000	3750-30000	4800-38400
2400-5200								
	3780-8190		6000-13000					

2 Protection and control devices

CURRENT TRANSFORMER SIZE

Rated Current In [A] →		250	400	800	1000	1250	1600	2000	2500	3200	4000	5000	6300
Circuit- breaker	Iu[A]												
E1B	800	■	■	■									
E1N	1250	■	■	■	■	■							
E2B	1600	■	■	■	■	■	■						
	2000	■	■	■	■	■	■	■					
E2N	1250	■	■	■	■	■							
	1600	■	■	■	■	■	■						
	2000	■	■	■	■	■	■	■					
E2L	1250	■	■	■	■	■	■						
	1600	■	■	■	■	■	■	■					
E3N	2500	■	■	■	■	■	■	■	■				
	3200	■	■	■	■	■	■	■	■	■			
E3S	1250	■	■	■	■	■							
E3H	1600	■	■	■	■	■	■						
	2000	■	■	■	■	■	■	■					
	2500	■	■	■	■	■	■	■	■				
	3200	■	■	■	■	■	■	■	■	■			
E3L	2000	■	■	■	■	■	■	■					
	2500	■	■	■	■	■	■	■	■				
E4S	4000							■		■	■		
E4H	3200							■		■			
	4000							■		■	■		
E4S/f	4000							■		■	■		
E6H	5000									■	■	■	
	6300									■	■	■	■
E6H/f	5000									■	■	■	
	6300									■	■	■	■
E6V	3200									■			
	4000									■	■		
	5000									■	■	■	
	6300									■	■	■	■

Rated Current In [A] →		250	400	800	1000	1250
L Function	PR111 PR112/PR113	100÷250	160÷400	320÷800	400÷1000	500÷1250
S	PR111	250÷2500	400÷4000	800÷8000	1000÷10000	1250÷12500
Function	PR112/PR113	150÷2500	240÷4000	480÷8000	600÷10000	750÷12500
I	PR111	375÷3000	600÷4800	1200÷9600	1500÷12000	1875÷15000
Function	PR112/PR113	375÷3750	600÷6000	1200÷12000	1500÷15000	1875÷18750

2 Protection and control devices

2.3.2.1 PROTECTION FUNCTIONS OF ELECTRONIC RELEASES

The protection functions available for the electronic releases are:

L - Overload protection with inverse long time delay
Function of protection against overloads with inverse long time delay and constant specific let-through energy; it cannot be excluded.

L - Overload protection in compliance with Std. IEC 60255-3
Function of protection against overloads with inverse long time delay and trip curves complying with IEC 60255-3; applicable in the coordination with fuses and with medium voltage protections.

S - Short-circuit protection with adjustable delay
Function of protection against short-circuit currents with adjustable delay; thanks to the adjustable delay, this protection is particularly useful when it is necessary to obtain selective coordination between different devices.

D - Directional short-circuit protection with adjustable delay
The directional protection, which is similar to function S, can intervene in a different way according to the direction of the short-circuit current; particularly suitable in meshed networks or with multiple supply lines in parallel.

I - Short-circuit protection with instantaneous trip
Function for the instantaneous protection against short-circuit.

G - Earth fault protection with adjustable delay
Function protecting the plant against earth faults.

U - Phase unbalance protection
Protection function which intervenes when an excessive unbalance between the currents of the single phases protected by the circuit-breaker is detected.

OT - Self-protection against overtemperature
Protection function controlling the opening of the circuit-breaker when the temperature inside the release can jeopardize its functioning.

UV - Undervoltage protection
Protection function which intervenes when the phase voltage drops below the preset threshold.

1600	2000	2500	3200	4000	5000	6300
640÷1600	800÷2000	1000÷2500	1280÷3200	1600÷4000	2000÷5000	2520÷6300
1600÷16000	2000÷20000	2500÷25000	3200÷32000	4000÷40000	5000÷50000	6300÷63000
960÷16000	1200÷20000	1500÷25000	1920÷32000	2400÷40000	3000÷50000	3780÷63000
2400÷19200	3000÷24000	3750÷30000	4800÷38400	6000÷48000	7500÷60000	9450÷75600
2400÷24000	3000÷30000	3750÷37500	4800÷48000	6000÷60000	7500÷75000	9450÷94500

2 Protection and control devices

OV - Overvoltage protection
Protection function which intervenes when the phase voltage exceeds the preset threshold.
RV - Residual voltage protection
Protection which identifies anomalous voltages on the neutral conductor.
RP - Reverse power protection
Protection which intervenes when the direction of the active power is opposite to normal operation.
R - Protection against rotor blockage
Function intervening as soon as conditions are detected, which could lead to the block of the rotor of the protected motor during operation.
Iinst - Very fast instantaneous protection against short-circuit
This particular protection function has the aim of maintaining the integrity of the circuit-breaker and of the plant in case of high currents requiring delays lower than those guaranteed by the protection against instantaneous short-circuit. This protection must be set exclusively by ABB SACE and cannot be excluded.

The following table summarizes the types of electronic release and the functions they implement:

SERIES	SIZE	RELEASE	PROTECTION FUNCTION
Tmax	T2	PR221DS LS	L-S or L-I
		PR221DS I	I
	T4-T5	PR221DS LS/I	L-S-I
		PR222DS/P LSI	L-S-I
		PR222DS/P LSIG	L-S-I-G
		PR222MP LRIU	L-R-I-U
Isomax	S6-S7	PR211/P LI	L-I
		PR211/P I	I
	S6-S7-S8	PR212/P LSI	L-S-I
		PR212/P LSIG	L-S-I-G
	S6-S7	PR212/MP LRIU	L-R-I-U
Emax	E1-E2-E3-E4-E6	PR111/P LI	L-I
		PR111/P LSI	L-S-I
		PR111/P LSIG	L-S-I-G
		PR112/P LSI	L-S-I-OT
		PR112/P LSIG	L-S-I-G-OT
		PR113/P LSIG	L-S-I-G-D-UV-OV-RV-U-RP-OT

The settings and curves of the single protection functions are reported in the chapter 3.2.2

2.3.3 RESIDUAL CURRENT DEVICES

The residual current releases are associated with the circuit-breaker in order to obtain two main functions in a single device:
- protection against overloads and short-circuits;
- protection against indirect contacts (presence of voltage on exposed conductive parts due to loss of insulation).

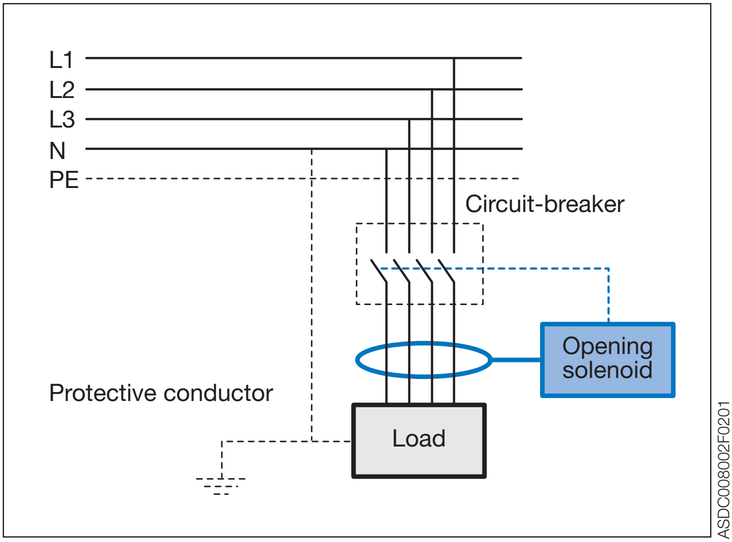
Besides, they can guarantee an additional protection against the risk of fire deriving from the evolution of small fault or leakage currents which are not detected by the standard protections against overload.
Residual current devices having a rated residual current not exceeding 30 mA are also used as a means for additional protection against direct contact in case of failure of the relevant protective means.
Their logic is based on the detection of the vectorial sum of the line currents through an internal or external toroid.
This sum is zero under service conditions or equal to the earth fault current (I_Δ) in case of earth fault.

2 Protection and control devices

When the release detects a residual current different from zero, it opens the circuit-breaker through an opening solenoid.

As we can see in the picture the protection conductor or the equipotential conductor have to be installed outside the eventual external toroid.

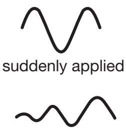
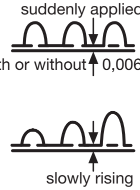
Generic distribution system (IT, TT, TN)



The operating principle of the residual current release makes it suitable for the distribution systems TT, IT (even if paying particular attention to the latter) and TN-S, but not in the systems TN-C. In fact, in these systems, the neutral is used also as protective conductor and therefore the detection of the residual current would not be possible if the neutral passes through the toroid, since the vectorial sum of the currents would always be equal to zero.

2 Protection and control devices

One of the main characteristics of a residual current release is its minimum rated residual current $I_{\Delta n}$. This represents the sensitivity of the release.
According to their sensitivity to the fault current, the residual current circuit-breakers are classified as:
- type AC: a residual current device for which tripping is ensured in case of residual sinusoidal alternating current, in the absence of a dc component whether suddenly applied or slowly rising;
- type A: a residual current device for which tripping is ensured for residual sinusoidal alternating currents in the presence of specified residual pulsating direct currents, whether suddenly applied or slowly rising.
- type B residual current device for which tripping is ensured for residual sinusoidal alternating currents in presence of specified residual pulsanting direct currents whether suddenly applied or slowy rising, for residual directs may result from rectifying circuits.

	Form of residual current	Correct functioning of residual current devices Type		
		AC	A	B
Sinusoidal ac	 suddenly applied / slowly rising	+	+	+
Pulsating dc	 suddenly applied / with or without 0,006A / slowly rising		+	+
Smooth dc				+

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In presence of electrical apparatuses with electronic components (computers, photocopiers, fax etc.) the earth fault current might assume a non sinusoidal shape but a type of a pulsating unidirectional dc shape. In these cases it is necessary to use a residual current release classified as type A.
In presence of rectifying circuits (i.e. single phase connection with capacitive load causing smooth direct current, three pulse star connection or six pulse bridge connection, two pulse connection line-to-line) the earth fault current might assume a unidirectional dc shape.

2 Protection and control devices

In these case it is necessary to use a residual current release classified as type B. The following table shows the main characteristics of ABB SACE residual current devices; they can be mounted both on circuit-breakers as well as on switch disconnectors (in case of fault currents to earth lower than the apparatus breaking capacity), are type A devices and they do not need auxiliary supply since they are self-supplied.

		RC221		**RC222**	
Suitable for circuit-breaker type		T1-T2-T3 T1D-T3D	T1-T2-T3 T1D-T3D	T4 T4D	T5 T5D
Primary service voltage	[V]	85-500	85-500	85-500	85-500
Rated service current	[A]	250	250	250	400
Rated residual current trip $I\Delta_n$	[A]	0.03-0.1-0.3-0.5-1-3	0.03-0.05-0.1-0.3-0.5-1 3-5-10	0.03-0.05-0.1-0.3-0.5-1 3-5-10	0.03-0.05-0.1-0.3-0.5-1 3-5-10
Time limit for non-trip (at 2x $I\Delta_{n)}$	[s]	Instantaneous	Inst.-0.1-0.2-0.3-0.5-1-2-3	Inst.-0.1-0.2-0.3-0.5-1-2-3	Inst.-0.1-0.2-0.3-0.5-1-2-3
Tolerance over Trip times	[%]		± 20	± 20	± 20

Note: for detailed information, please consult the relevant technical catalogues.

Along with the family of residual current releases illustrated previously, ABB SACE is developing the RC223 (B type) residual current release, which can only be combined with the Tmax T4 four-pole circuit-breaker in the fixed or plug-in version. It is characterized by the same types of reference as the RC222 (S and AE type) release, but can also boast conformity with type B operation, which guarantees sensitivity to residual fault currents with alternating, alternating pulsating and direct current components.
Apart from the signals and settings typical of the RC222 residual current release, the RC223 also allows selection of the maximum threshold of sensitivity to the residual fault frequency (3 steps: 400 – 700 –1000 Hz). It is therefore possible to adapt the residual current device to the different requirements of the industrial plant according to the prospective fault frequencies generated on the load side of the release.

ABB SACE moulded-case circuit-breakers series Isomax[1] and Tmax and air circuit-breakers series Emax[1] can be combined with the switchboard residual current relay type RCQ, type A, with separate toroid (to be installed externally on the line conductors).

[1] up to 2000 A rated currents

			RCQ
Power supply voltage	ac	[V]	80 ÷ 500
	dc	[V]	48÷125
Trip threshold adjustements $I_{\Delta n}$			
1st range of adjustements		[A]	0.03 – 0.05 - 0.1 - 0.3 – 0.5
2nd range of adjustements		[A]	1 – 3 – 5 – 10 - 30
Trip time adjustement		[s]	0 - 0.1 - 0.2 - 0.3 - 0.5 - 0.7 - 1 - 2 - 3 - 5
Tolerance over Trip times		[%]	± 20

Note: for detailed information, please consult the relevant technical catalogues.

The versions with adjustable trip times allow to obtain a residual current protection system coordinated from a discrimination point of view, from the main switchboard up to the ultimate load.

3 General characteristics

3.1 Electrical characteristics of circuit-breakers

Tmax moulded-case

			Tmax T1 1P	Tmax T1		
Rated uninterrupted current, **Iu [A]**		[A]	160	160		
Poles		[No.]	1	3/4		
Rated operational voltage, **Ue**	(ac) 50-60 Hz	[V]	240	690		
	(dc)	[V]	125	500		
Rated impulse withstand voltage, **Uimp**		[kV]	8	8		
Rated insulation voltage, **Ui**		[V]	500	800		
Test voltage at industrial frequency for 1 min.		[V]	3000	3000		
Rated ultimate short-circuit breaking capacity, **Icu**			**B**	**B**	**C**	**N**
(ac) 50-60 Hz 220/230 V		[kA]	25 (*)	25	40	50
(ac) 50-60 Hz 380/415 V		[kA]	–	16	25	36
(ac) 50-60 Hz 440 V		[kA]	–	10	15	22
(ac) 50-60 Hz 500 V		[kA]	–	8	10	15
(ac) 50-60 Hz 690 V		[kA]	–	3	4	6
(dc) 250 V - 2 poles in series		[kA]	25 (at 125 V)	16	25	36
(dc) 250 V - 3 poles in series		[kA]	–	20	30	40
(dc) 500 V - 2 poles in series		[kA]	–	–	–	–
(dc) 500 V - 3 poles in series		[kA]	–	16	25	36
(dc) 750 V - 3 poles in series		[kA]	–	–	–	–
Rated service short-circuit breaking capacity, **Ics**						
(ac) 50-60 Hz 220/230 V		[%Icu]	75%	100%	75%	75%
(ac) 50-60 Hz 380/415 V		[%Icu]	–	100%	100%	50% (25 kA)
(ac) 50-60 Hz 440 V		[%Icu]	–	100%	75%	50%
(ac) 50-60 Hz 500 V		[%Icu]	–	100%	75%	50%
(ac) 50-60 Hz 690 V		[%Icu]	–	100%	75%	50%
Rated short-circuit making capacity, **Icm**						
(ac) 50-60 Hz 220/230 V		[kA]	52.5	52.5	84	105
(ac) 50-60 Hz 380/415 V		[kA]	–	32	52.5	75.6
(ac) 50-60 Hz 440 V		[kA]	–	17	30	46.2
(ac) 50-60 Hz 500 V		[kA]	–	13.6	17	30
(ac) 50-60 Hz 690 V		[kA]	–	4.3	5.9	9.2
Opening time (415 V)		[ms]	7	7	6	5
Utilization category (EN 60947-2)			A	A		
Isolation behaviour			■	■		
Reference standard			IEC 60947-2	IEC 60947-2		
Releases: thermomagnetic						
T fixed, M fixed	TMF		■	–		
T adjustable, M fixed	TMD		–	■		
T adjustable, M adjustable (5…10 x In)	TMA		–	–		
T adjustable, M fixed (3 x In)	TMG		–	–		
T adjustable, M adjustable (2.5…5 x In)	TMG		–	–		
magnetic only	MA		–	–		
electronic	PR221DS-LS/I		–	–		
	PR221DS-I		–	–		
	PR222DS/P-LSI		–	–		
	PR222DS/P-LSIG		–	–		
	PR222DS/PD-LSI		–	–		
	PR222DS/PD-LSIG		–	–		
	PR222MP		–	–		
Interchangeability			–	–		
Versions			F	F		
Terminals fixed			FC Cu	FC Cu-EF-FC CuAl -HR		
plug-in			–	–		
withdrawable			–	–		
Fixing on DIN rail			–	DIN EN 50022		
Mechanical life		[No. operations]	25000	25000		
		[No. hourly operations]	240	240		
Electrical life @ 415 V ac		[No. operations]	8000	8000		
		[No. hourly operations]	120	120		
Basic dimensions - fixed version		L [mm]	25.4 (1 pole)	76		
	4 poles	L [mm]	–	102		
		D [mm]	70	70		
		H [mm]	130	130		
Weight fixed	3/4 poles	[kg]	0.4 (1 pole)	0.9/1.2		
plug-in	3/4 poles	[kg]	–	–		
withdrawable	3/4 poles	[kg]	–	–		

TERMINAL CAPTION
F = Front
EF = Front extended
ES = Front extended spread
FC Cu = Front for copper cables
FC CuAl = Front for CuAl cables
R = Rear orientated
HR = Rear in horizontal flat bar
VR = Rear in vertical flat bar
MC = Multicable

3 General characteristics

Tmax T2				Tmax T3		Tmax T4					Tmax T5				
160				250		250/320					400/630				
3/4				3/4		3/4					3/4				
690				690		690					690				
500				500		750					750				
8				8		8					8				
800				800		1000					1000				
3000				3000		3500					3500				
N	**S**	**H**	**L**	**N**	**S**	**N**	**S**	**H**	**L**	**V**	**N**	**S**	**H**	**L**	**V**
65	85	100	120	50	85	70	85	100	200	200	70	85	100	200	200
36	50	70	85	36	50	36	50	70	120	200	36	50	70	120	200
30	45	55	75	25	40	30	40	65	100	180	30	40	65	100	180
25	30	36	50	20	30	25	30	50	85	150	25	30	50	85	150
6	7	8	10	5	8	20	25	40	70	80	20	25	40	70	80
36	50	70	85	36	50	36	50	70	100	100	36	50	70	100	100
40	55	85	100	40	55	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	25	36	50	70	100	25	36	50	70	100
36	50	70	85	36	50	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	16	25	36	50	70	16	25	36	50	70
100%	100%	100%	100%	75%	50%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
100%	100%	100%	75% (70 kA)	75%	50% (27 kA)	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
100%	100%	100%	75%	75%	50%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
100%	100%	100%	75%	75%	50%	100%	100%	100%	100%	100%	100%	100%	100%	100%[1]	100%[2]
100%	100%	100%	75%	75%	50%	100%	100%	100%	100%	100%	100%	100%	100%[1]	100%[2]	100%[2]
143	187	220	264	105	187	154	187	220	440	660	154	187	220	440	660
75.6	105	154	187	75.6	105	75.6	105	154	264	440	75.6	105	154	264	440
63	94.5	121	165	52.5	84	63	84	143	220	396	63	84	143	220	396
52.5	63	75.6	105	40	63	52.5	63	105	187	330	52.5	63	105	187	330
9.2	11.9	13.6	17	7.7	13.6	40	52.5	84	154	176	40	52.5	84	154	176
3	3	3	3	7	6	5	5	5	5	5	6	6	6	6	6
A				A		A					A (630 A) - B (400 A)[3]				
■				■		■					■				
IEC 60947-2				IEC 60947-2		IEC 60947-2					IEC 60947-2				
–				–		–					–				
■				■		■ (up to 50 A)					–				
–				–		■					■				
–				■		–					–				
–				–		–					■				
■ (MF up to In 12.5 A)				■		■					–				
■				–		■					■				
■				–		■					■				
–				–		■					■				
–				–		■					■				
–				–		■					■				
–				–		■					■				
–				–		■					■				
–				–		■					■				
F-P				F-P		F-P-W					F-P-W				
F-FC Cu-FC CuAl-EF-ES-R				F-FC Cu-FC Cu Al-EF-ES-R		F-FC Cu-FC CuAl-EF-ES-R-MC					F-FC Cu-FC CuAl-EF-ES-R				
F-FC Cu-FC CuAl-EF-ES-R				F-FC Cu-FC Cu Al-EF-ES-R		EF-ES-HR-VR-FC Cu-FC CuAl					EF-ES-HR-VR-FC Cu-FC CuAl				
–				–		EF-ES-HR-VR-FC Cu-FC CuAl					EF-ES-HR-VR-FC Cu-FC CuAl				
DIN EN 50022				DIN EN 50022		–					–				
25000				25000		20000					20000				
240				240		240					120				
8000				8000		8000 (250 A) - 6000 (320 A)					7000 (400 A) - 5000 (630 A)				
120				120		120					60				
90				105		105					140				
120				140		140					184				
70				70		103.5					103.5				
130				150		205					205				
1.1/1.5				2.1/3		2.35/3.05					3.25/4.15				
1.5/1.9				2.7/3.7		3.6/4.65					5.15/6.65				
–				–		3.85/4.9					5.4/6.9				

F = Fixed circuit-breakers
P = Plug-in circuit-breakers
W = Withdrawable circuit-breakers

(*) The breaking capacity for settings In=16 A and In= 20 A is 16 kA

[1] 75% for T5 630
[2] 50% for T5 630
[3] Icw = 5 kA

Notes: in the plug-in version of T2 and T3 the maximum setting is derated by 10% at 40 °C

3 General characteristics

SACE Isomax moulded-case circuit-breakers

Rated uninterrupted current, **Iu**		[A]
Poles		No.
Rated operational voltage, **Ue**	(ac) 50-60Hz	[V]
	(dc)	[V]
Rated impulse withstand voltage, **Uimp**		[kV]
Rated insulation voltage, **Ui**		[V]
Test voltage at industrial frequency for 1 min.		[V]
Rated ultimate short-circuit breaking capacity, **Icu**		
(ac) 50-60 Hz 220/230 V	[kA]	
(ac) 50-60 Hz 380/415 V	**[kA]**	
(ac) 50-60 Hz 440 V		[kA]
(ac) 50-60 Hz 500 V		[kA]
(ac) 50-60 Hz 690 V		[kA]
(dc) 250 V - 2 poles in series	[kA]	
(dc) 500 V - 2 poles in series	[kA]	
(dc) 500 V - 3 poles in series	[kA]	
(dc) 750 V - 3 poles in series	[kA]	
Rated short-circuit service breaking capacity, **Ics** (2)		[%Icu]
Rated short-circuit making capacity (415 V) **Icm**		[kA]
Opening time (415V at Icu)		[ms]
Rated short-time withstand current for 1 s, **Icw**		[kA]
Utilization category (EN 60947-2)		
Isolation behaviour		
IEC 60947-2, EN 60947-2		
Releases: thermomagnetic	T adjustable, M adjustable TMA	
	T adjustable, M fixed 2,5 In TMG	
with microprocessor	PR211/P (I-LI)	
	PR212/P (LSI-LSIG)	
Interchangeability		
Versions		
Terminals	fixed	
	plug-in	
	withdrawable (3)	
Mechanical life	[No. operations / operations per hours]	
Electrical life (at 415 V)	[No. operations / operations per hours]	
Basic dimensions, fixed	3/4 poles	L [mm]
		D [mm]
		H [mm]
Weights fixed	3/4 poles	[kg]
plug-in	3/4 poles	[kg]
withdrawable	3/4 poles	[kg]

(1) All the versions with Icu=35kA are certified at 36kA
(2) For S6 N/S/H circuit-breakers the performance percentage of Ics at 690V is reduced by 25%.
(3) The withdrawable version circuit-breakers must be fitted with the front flange for the lever operating mechanism or with its alternative accessories, such as the rotary handle or the motor operator

3 General characteristics

S6				S7			S8	
800				**1250 - 1600**			**2000 - 2500 - 3200**	
3-4				3-4			3-4	
690				690			690	
750				-			-	
8				8			8	
800				800			690	
3000				3000			2500	
N	**S**	**H**	**L**	**S**	**H**	**L**	**H**	**V**
65	85	100	200	85	100	200	85	120
35 (1)	**50**	**65**	**100**	**50**	**65**	**100**	85	120
30	45	50	80	40	55	80	70	100
25	35	40	65	35	45	70	50	70
20	22	25	30	20	25	35	40	50
35	50	65	100	-	-	-	-	-
20	35	50	65	-	-	-	-	-
-	-	-	-	-	-	-	-	-
16	20	35	50	-	-	-	-	-
100%	100%	100%	75%	100%	75%	50%	50%	50%
74	105	143	220	105	143	220	187	264
10	9	8	7	22	22	22	20	20
10				15 (1250A) - 20 (1600A)			35	
B				B			B	
■				■			■	
■				■			■	
■	■	■	■	-			-	
■	-	-	-	-			-	
■	■	■	■	■	■	■	-	
■	■	■	■	■	■	■	■	■
■				■			-	
F - W				F - W			F	
F - EF - ES - FC CuAl RC - R				F - EF - ES - FC CuAl (1250A) HR - VR			F (2000-2500A) - VR	
-				-			-	
EF - HR - VR				EF - HR - VR			-	
20000/120				10000/120			10000/20	
5000/60				7000(1250A)-5000(1600A)/20			2500(2500A)/20-1500(3200A)/10	
210/280				210/280			406/556	
103.5				138.5			242	
268				406			400	
9.5 / 12				17 / 22			57/76	
-				-			-	
12.1 / 15.1				21.8 / 29.2			-	

KEY TO VERSIONS
F = Fixed
P = Plug-in
W = Withdrawable

KEY TO TERMINALS
F = Front
EF = Extended front
ES = Extended spreaded front
FC CuAl = Front for copper or aluminium cables
R = Rear threaded
RC = Rear for copper or aluminium cables
HR = Rear horizontal flat bar
VR = Rear vertical flat bar

3 General characteristics

Tmax moulded-case circuit-breakers for motor protection

				Tmax T2			
Rated uninterrupted current, **Iu**		[A]	160				
Rated current, **In**		[A]	1…100				
Poles		[No.]	3				
Rated operational voltage, **Ue**	(ac) 50-60 Hz	[V]	690				
	(dc)	[V]	500				
Rated impulse withstand voltage, **Uimp**		[kV]	8				
Rated insulation voltage, **Ui**		[V]	800				
Test voltage at industrial frequency for 1 min.		[V]	3000				
Rated ultimate short-circuit breaking capacity, **Icu**				N	S	H	L
	(ac) 50-60 Hz 220/230 V	[kA]		65	85	100	120
	(ac) 50-60 Hz 380/415 V	[kA]		36	50	70	85
	(ac) 50-60 Hz 440 V	[kA]		30	45	55	75
	(ac) 50-60 Hz 500 V	[kA]		25	30	36	50
	(ac) 50-60 Hz 690 V	[kA]		6	7	8	10
Rated short-circuit service breaking capacity, **Ics**		[%Icu]					
	(ac) 50-60 Hz 220/230 V	[%Icu]		100%	100%	100%	100%
	(ac) 50-60 Hz 380/415 V	[%Icu]		100%	100%	100%	75% (70 kA)
	(ac) 50-60 Hz 440 V	[%Icu]		100%	100%	100%	75%
	(ac) 50-60 Hz 500 V	[%Icu]		100%	100%	100%	75%
	(ac) 50-60 Hz 690 V	[%Icu]		100%	100%	100%	75%
Rated short-circuit making capacity, **Icm**		[kA]					
	(ac) 50-60 Hz 220/230 V	[kA]		143	187	220	264
	(ac) 50-60 Hz 380/415 V	[kA]		75.6	105	154	187
	(ac) 50-60 Hz 440 V	[kA]		63	94.5	121	165
	(ac) 50-60 Hz 500 V	[kA]		52.5	63	75.6	105
	(ac) 50-60 Hz 690 V	[kA]		9.2	11.9	13.6	17
Opening time (415 V)		[ms]		3	3	3	3
Utilization category (EN 60947-2)			A				
Isolation behaviour			■				
Reference Standard			IEC 60947-2				
Protection against short-circuit							
Magnetic only release	MA		■ (MF up to In 12.5 A)				
Electronic release	PR221DS-I		■				
Integrated protection (IEC 60947-4-1)							
Electronic release	PR222MP		–				
Interchangeability			–				
Versions			F-P				
Terminals	fixed		F - FC Cu - FC CuAl - EF - ES - R - FC CuAl				
	plug-in		F - FC Cu - FC CuAl - EF - ES - R - FC CuAl				
	withdrawable		–				
Fixing on DIN rail			DIN EN 50022				
Mechanical life		[No. operations]	25000				
		[No.hourly operations]	240				
Electrical life @ 415 V ac		[No. operations]	8000				
		[No.hourly operations]	120				
Basic fixed version dimensions		L [mm]	90				
		D [mm]	70				
		H [mm]	130				
Weight	fixed	[kg]	1.1				
	plug-in	[kg]	1.5				
	withdrawable	[kg]	–				

TERMINAL CAPTION
F = Front
EF = Front extended
ES = Front extended spread
FC Cu = Front for copper cables
R = Rear orientated

FC CuAl = Front for CuAl cables
MC = Multicable
HR = Rear in horizontal flat bar
VR = Rear in vertical flat bar
(*) Icw = 5 kA

(1) 75% for T5 630
(2) 50% for T5 630

3 General characteristics

Tmax T3 250		**Tmax T4** 250, 320					**Tmax T5** 400, 630				
100…200		10…320					320, 400, 630				
3		3					3				
690		690					690				
500		750					750				
8		8					8				
800		1000					1000				
3000		3500					3500				
N	**S**	**N**	**S**	**H**	**L**	**V**	**N**	**S**	**H**	**L**	**V**
50	85	70	85	100	200	300	70	85	100	200	300
36	50	36	50	70	120	200	36	50	70	120	200
25	40	30	40	65	100	180	30	40	65	100	180
20	30	25	30	50	85	150	25	30	50	85	150
5	8	20	25	40	70	80	20	25	40	70	80
75%	50%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
75%	50% (27 kA)	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
75%	50%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
75%	50%	100%	100%	100%	100%	100%	100%	100%	100%	100%[1]	100%[2]
75%	50%	100%	100%	100%	100%	100%	100%	100%	100%[1]	100%[2]	100%[2]
105	187	154	187	220	440	660	154	187	220	440	660
75.6	105	75.6	105	154	264	440	75.6	105	154	264	440
52.5	84	63	84	143	220	396	63	84	143	220	396
40	63	52.5	63	105	187	330	52.5	63	105	187	330
7.7	13.6	40	52.5	84	154	176	40	52.5	84	154	176
7	6	5	5	5	5	5	6	6	6	6	6
A		A					B (400 A)[*] - A (630 A)				
IEC 60947-2		IEC 60947-2					IEC 60947-2				
■		■					–				
–		■					■				
–		■					■				
–		■					■				
F-P		F-P-W					F-P-W				
F - FC Cu - FC CuAl - EF - ES - R - FC CuAl		F - FC Cu - FC CuAl - EF - ES - R - MC					F - FC Cu - FC CuAl - EF - ES - R				
F - FC Cu - FC CuAl - EF - ES - R - FC CuAl		EF - ES - FC Cu - FC CuAl - HR - VR					EF - ES - FC Cu - FC CuAl - HR - VR				
–		EF - ES - FC Cu - FC CuAl - HR - VR					EF - ES - FC Cu - FC CuAl - HR - VR				
DIN EN 50022		–					–				
25000		20000					20000				
240		240					120				
8000		8000					7000				
120		120					60				
105		105					140				
70		103.5					103.5				
150		205					205				
2.1		2.35					3.25				
2.7		3.6					5.15				
–		3.85					5.4				

3 General characteristics

SACE Isomax moulded-case circuit-breakers for motor protection

		S6			
Rated uninterrupted current, Iu	[A]	**630 / 800**			
Rated current, In	[A]	630 / 800			
Poles	No	3			
Rated operational voltage (ac) 50-60 Hz, Ue	[V]	690			
Rated impulse withstand voltage, Uimp	[kV]	8			
Rated insulation voltage, Ui	[V]	800			
Test voltage at industrial frequency for 1 minute	[V]	3000			
Rated ultimate short-circuit braking capacity, Icu		N	S	H	L
(ac) 50-60Hz 220/230V	[kA]	65	85	100	200
(ac) 50-60Hz 380/415V	[kA]	35 (1)	50	65	100
(ac) 50-60Hz 440V	[kA]	30	45	50	80
(ac) 50-60Hz 500V	[kA]	25	35	40	65
(ac) 50-60Hz 690V	[kA]	20	22	25	30
Rated service short-circuit braking capacity, Ics	[%Icu]	100% (2)	1	100% (2)	0,75
Rated short-circuit making capacity (415Vac), Icm	[kA]	74	105	143	220
Opening time (415Vac at Icu)	[ms]	10	9	8	7
Utilization category (EN 60947-2)		B			
Insulation behaviour		■			
Reference standard					
IEC 60947-2, EN60947-2		■			
IEC 60947-4-1, EN60947-4-1		-			
Microprocessor-base release					
PR212/MP (L-R-I-U)		-			
PR211/P (I)		■			
Interhambiability		■			
Versions		F - W			
Terminals					
Terminals – Fixed		F - EF - ES - FCCuAl - R - RC			
Terminals – Plug-in		-			
Terminals – Withdrawable		EF - HR - VR			
Mechanical life	[No. of operations]	20000			
Mechanical life	[Operation per hour]	120			
Basic dimensions, fixed 3 poles	L [mm]	210			
Basic dimensions, fixed 3 poles	D [mm]	103.5			
Basic dimensions, fixed 3 poles	H [mm]	268			
Weight	3 poles fixed [kg]	9.5			
Weight	3 poles plug-in [kg]	-			
Weight	3 poles withdrawable [kg]	12.1			

(1) All the versions with Icu=35kA are certified at 36kA
(2) (3) For S6N/H circuit-breakers the percentage performance of Ics at 500V and 690V is reduced by 25%

KEY TO VERSIONS
F = Fixed
P = Plug-in
W= Withdrawable

KEY TO TERMINALS
F = Front
EF = Extended front
ES = Extended spreaded front

3 General characteristics

	S7			**S6**		**S7**	
	1250 / 1600			**800**		**12150**	
	1000,1250 / 1600			630		1000	
	3			3		3	
	690			690		690	
	8			8		8	
	8000			8000		800	
	3000			3000		3000	
S	H	L	N	H	L	S	H
85	100	200	65	100	200	85	100
50	65	100	35(1)	65	100	50	65
40	55	80	30	50	80	40	55
35	45	70	25	40	65	35	45
20	25	35	20	25	35	20	25
1	0,75	0,5	100% (2) (3)	100% (2) (3)	0,75	1	0,75
105	143	220	74	143	220	105	143
22	22	22	9	8	7	22	22
	B			B		B	
	■			■		■	
	■			■		■	
	-			■		■	
	-			■		■	
	■			-		-	
	■			■		■	
	F - W			F - W		F - W	
	F - EF -ES -FCCuAl (1250A) - HR - VR			F - EF - ES - FCCuAl - R - RC		F - EF -ES -FCCuAl - HR - VR	
	-			-		-	
	EF - HR - VR			EF - HR - VR		EF - HR - VR	
	10000			20000		10000	
	120			120		120	
	210			210		210	
	138.5			103.5		138.5	
	406			268		406	
	17			9.5		17	
	-			-		-	
	21.8			12.1		21.8	

FC CuAl = Front for copper or aluminium cables
R = Rear threaded
RC = Rear for copper or aluminium cables
HR = Rear horizontal flat bar
VR = Rear vertical flat bar

3 General characteristics

SACE Emax air circuit-breakers

Common data

Voltages		
Rated operational voltage Ue	[V]	690 ~
Rated insulation voltage Ui	[V]	1000
Rated impulse withstand voltage Uimp	[kV]	12
Test voltage at industrial frequency for 1 min.	[V]	3500 ~
Service temperature	[°C]	-25....+70
Storage temperature	[°C]	-40....+70
Frequency f	[Hz]	50 - 60
Number of poles		3 - 4
Version		Fixed -Withdrawable

(1) Without intentional delays
(2) Performance at 600 V is 100 kA
(3) Performance at 500 V is 100 kA

Performance levels		
Currents		
Rated uninterrupted current (at 40 °C) Iu		[A]
		[A]
		[A]
		[A]
		[A]
Neutral pole capacity for four-pole circuit-breakers		[%Iu]
Rated ultimate short-circuit breaking capacity **Icu**		
220/230/380/400/415 V ~		[kA]
440 V ~		[kA]
500/660/690 V ~		[kA]
Rated service short-circuit breaking capacity **Ics**		
220/230/380/400/415 V ~		[kA]
440 V ~		[kA]
500/660/690 V ~		[kA]
Rated short-time withstand current **Icw**	(1s)	[kA]
	(3s)	
Rated short-circuit making capacity **Icm**		
220/230/380/400/415 V ~		[kA]
440 V ~		[kA]
500/660/690 V ~		[kA]
Utilization category (in accordance with IEC 60947-2)		
Isolation behavior (in accordance with IEC 60947-2)		
Overcurrent protection		
Microprocessor-based releases for ac applications		
Operating times		
Closing time (max)		[ms]
Breaking time for I<Icw (max) (1)		[ms]
Breaking time for I>Icw (max)		[ms]
Overall dimensions		
Fixed: H = 418 mm - D = 302 mm L (3/4 poles)		[mm]
Withdrawable: H = 461 mm - D = 396.5 mm L (3/4 poles)		[mm]
Weight (circuit-breaker complete with releases and CT, not including accessories)		
Fixed 3/4 poles		[kg]
Withdrawable 3/4 poles (including fixed part)		[kg]

SACE Emax air circuit-breakers			**E1 B-N**		**E2 B-N**			**E2 L**	
Rated uninterrupted current (@ 40 °C) **Iu**		[A]	800	1250	1250	1600	2000	1250	1600
Mechanical life									
with regular routine maintenance		[Operations x 1000]	25	25	25	25	25	20	20
Frequency		[Operations per hour]	60	60	60	60	60	60	60
Electrical life	(440 V ~)	[Operations x 1000]	10	10	15	12	10	4	3
	(690 V ~)	[Operations x 1000]	10	8	15	10	8	3	2
Frequency		[Operations per hour]	30	30	30	30	30	20	20

3 General characteristics

E1		E2			E3				E4		E6	
B	N	B	N	L	N	S	H	L	S	H	H	V
800	**800**	**1600**	**1250**	**1250**	**2500**	**1250**	**1250**	**2000**	**4000**	**3200**	**5000**	**3200**
1250	**1250**	**2000**	**1600**	**1600**	**3200**	**1600**	**1600**	**2500**		**4000**	**6300**	**4000**
			2000			**2000**	**2000**					**5000**
						2500	**2500**					**6300**
						3200	**3200**					
100	100	100	100	100	100	100	100	100	50	50	50	50
42	50	42	65	130	65	75	100	130	75	100	100	150
42	50	42	65	110	65	75	100	110	75	100	100	150
36	36	42	55	85	65	75	85 (2)	85	75	85 (2)(3)	100	100
42	50	42	65	130	65	75	85	130	75	100	100	125
42	50	42	65	110	65	75	85	110	75	100	100	125
36	36	42	55	65	65	75	85	65	75	85 (3)	100	100
36	50	42	55	10	65	75	75	15	75	100	100	100
36	36	42	42	–	65	65	65	–	75	75	85	85
88.2	105	88.2	143	286	143	165	220	286	165	220	220	330
88.2	105	88.2	143	242	143	165	220	242	165	220	220	330
75.6	75.6	88.2	121	187	143	165	187	187	165	187	220	220
B	B	B	B	A	B	B	B	A	B	B	B	B
■	■	■	■	■	■	■	■	■	■	■	■	■
■	■	■	■	■	■	■	■	■	■	■	■	■
80	80	80	80	80	80	80	80	80	80	80	80	80
70	70	70	70	70	70	70	70	70	70	70	70	70
30	30	30	30	12	30	30	30	12	30	30	30	30
296/386		296/386			404/530				566/656		782/908	
324/414		324/414			432/558				594/684		810/936	
45/54	45/54	50/61	50/61	52/63	66/80	66/80	66/80	72/83	97/117	97/117	140/160	140/160
70/82	70/82	78/93	78/93	80/95	104/125	104/125	104/125	110/127	147/165	147/165	210/240	210/240

E3 N-S-H					E3 L		E4 S-H		E6 H-V			
1250	1600	2000	2500	3200	2000	2500	3200	4000	3200	4000	5000	6300
20	20	20	20	20	15	15	15	15	12	12	12	12
60	60	60	60	60	60	60	60	60	60	60	60	60
12	10	9	8	6	2	1.8	7	5	5	4	3	2
12	10	9	7	5	1.5	1.3	7	4	5	4	2	1.5
20	20	20	20	20	20	20	10	10	10	10	10	10

3 General characteristics

SACE Emax air circuit-breakers with full-size neutral conductor

			E4S/f	E6H/f
Rated uninterrupted current (at 40 °C) Iu		[A]	**4000**	**5000**
		[A]		**6300**
Number of poles			4	4
Rated operational voltage **Ue**		[V ~]	690	690
Rated ultimate short-circuit breaking capacity **Icu**				
	220/230/380/400/415 V ~	[kA]	80	100
	440 V ~	[kA]	80	100
	500/660/690 V ~	[kA]	75	100
Rated service short-circuit breaking capacity **Ics**				
	220/230/380/400/415 V ~	[kA]	80	100
	440 V ~	[kA]	80	100
	500/660/690 V ~	[kA]	75	100
Rated short-time withstand current **Icw**				
	(1s)	[kA]	80	100
	(3s)	[kA]	75	85
Rated short-circuit making capacity **Icm**		[kA]	176	220
Utilization category (in accordance with IEC 60947-2)			B	B
Isolation behavior (in accordance with IEC 60947-2)			■	■
Overall dimensions				
	Fixed: H = 418 mm - D = 302 mm L	[mm]	746	1034
	Withdrawable: H = 461 - D = 396.5 mm L	[mm]	774	1062
Weight (circuit-breaker complete with releases and CT, not including accessories)				
	Fixed	[kg]	120	165
	Withdrawable (including fixed part)	[kg]	170	250

3 General characteristics

3.2 Trip curves

3.2.1 Trip curves of thermomagnetic and magnetic only releases

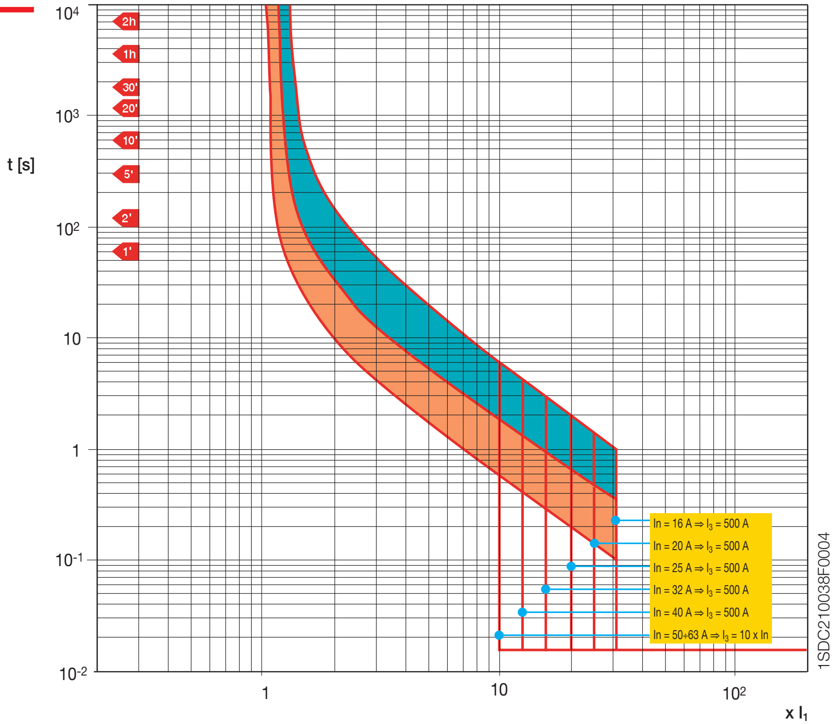
The overload protection function must not trip the breaker in 2 hours for current values which are lower than 1.05 times the set current, and must trip within 1.3 times the set current. By "cold trip conditions", it is meant that the overload occurs when the circuit-breaker has not reached normal working temperature (no current flows through the circuit-breaker before the anomalous condition occurs); on the contrary by "hot trip conditions" refers to the circuit-breaker having reached the normal working temperature with the rated current flowing through, before the overload current occurs. For this reason "cold trip conditions" times are always greater than "hot trip conditions" times.
The protection function against short-circuit is represented in the time-current curve by a vertical line, corresponding to the rated value of the trip threshold I3. In accordance with the Standard IEC 60947-2, the real value of this threshold is within the range 0.8·I3 and 1.2·I3. The trip time of this protection varies according to the electrical characteristics of the fault and the presence of other devices: it is not possible to represent the envelope of all the possible situations in a sufficiently clear way in this curve; therefore it is better to use a single straight line, parallel to the current axis. All the information relevant to this trip area and useful for the sizing and coordination of the plant are represented in the limitation curve and in the curves for the specific let-through energy of the circuit-breaker under short-circuit conditions.

Trip curve thermomagnetic release

T1 160

TMD

In = 16÷63 A



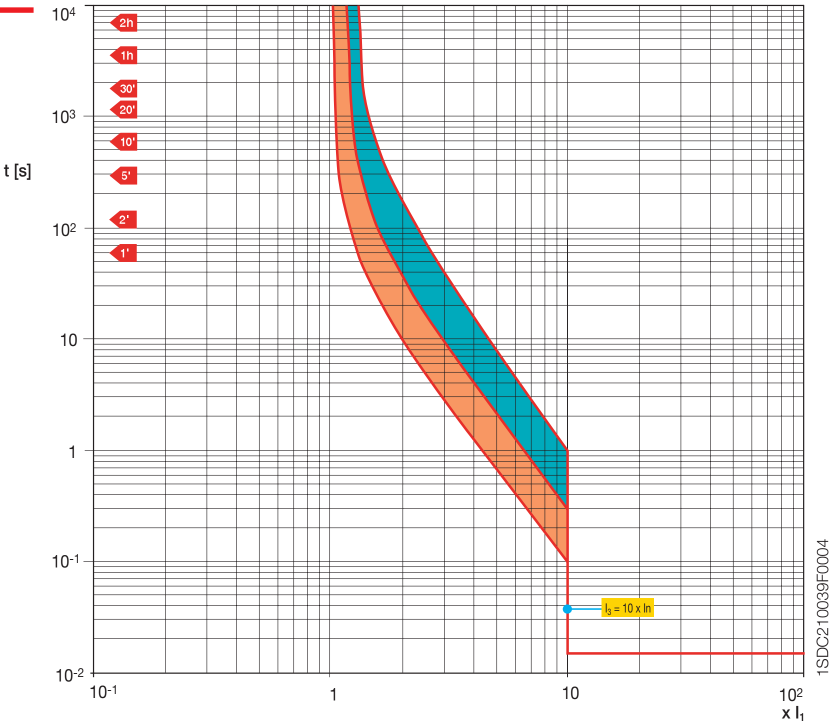
3 General characteristics

Trip curve thermomagnetic release

T1 160

TMD

In = 80÷160 A



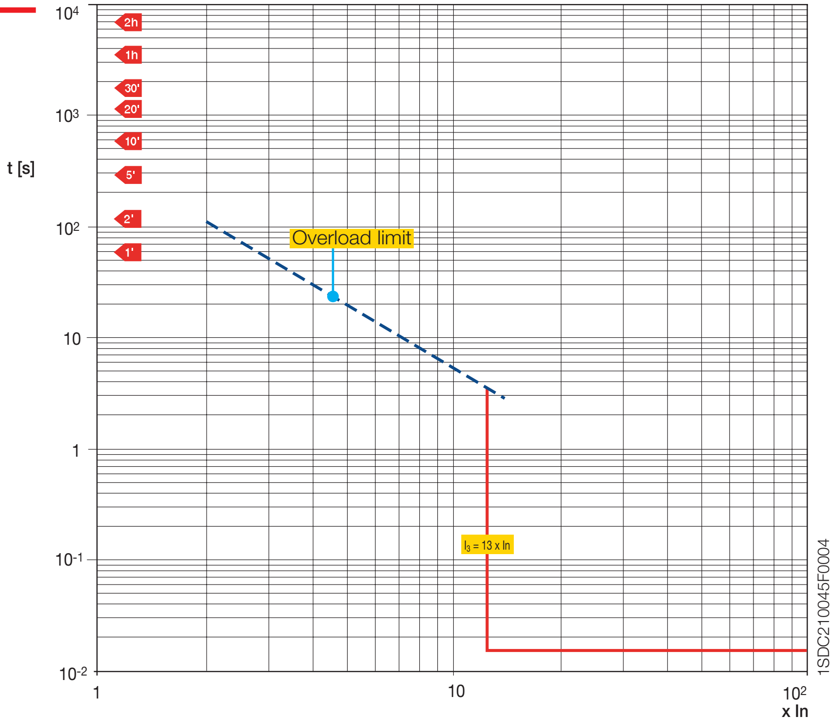
3 General characteristics

Trip curve
thermomagnetic
release

T2 160

MF

I_3 = 13 x In



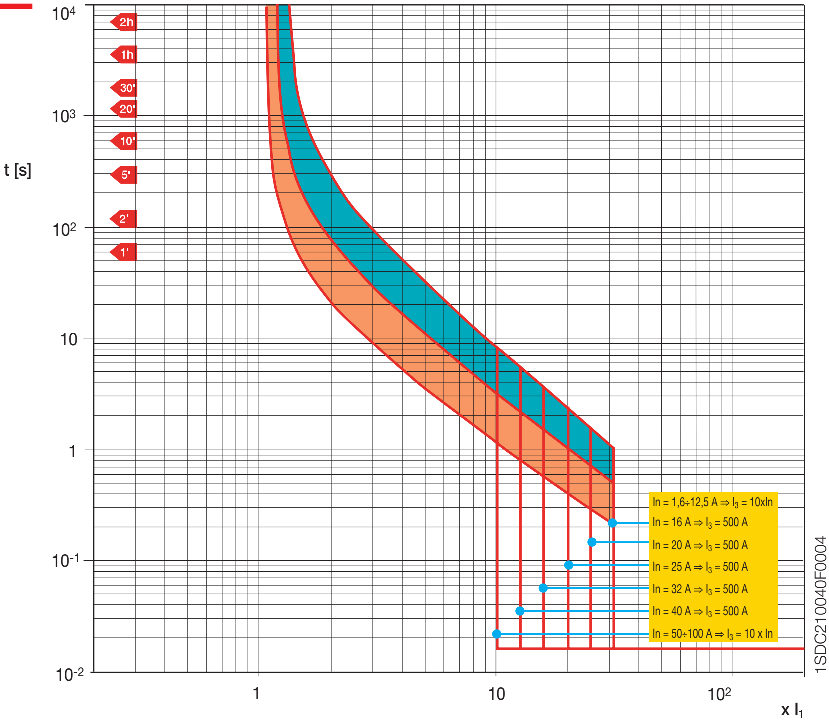
3 General characteristics

Trip curve
thermomagnetic
release

T2 160

TMD

In = 1.6÷100 A



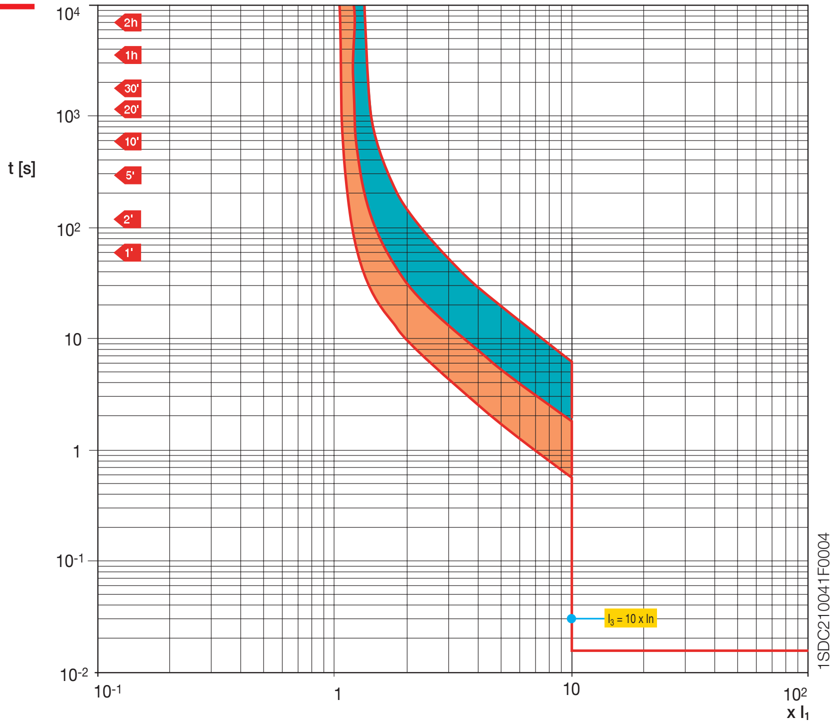
3 General characteristics

Trip curve thermomagnetic release

T2 160

TMD

In = 125÷160 A

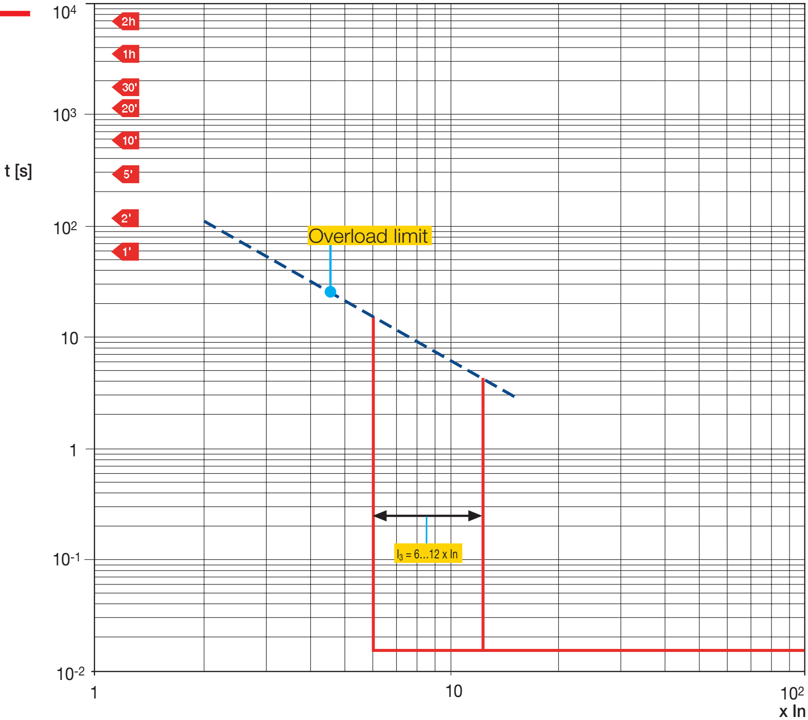


3 General characteristics

Trip curve
thermomagnetic
release

T2 160/T3 250
MA

I_3 = 6…12 x In



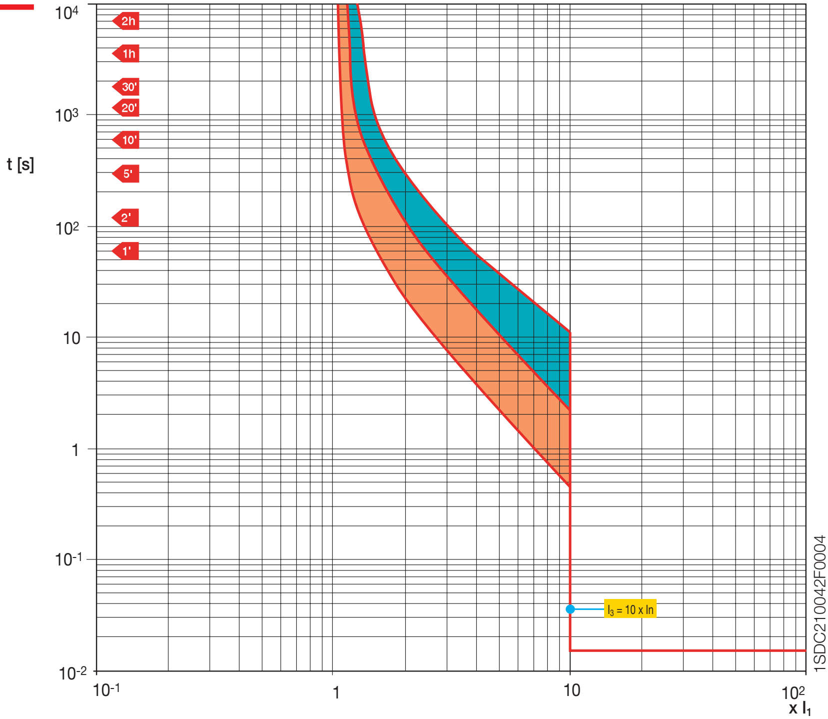
3 General characteristics

Trip curve thermomagnetic release

T3 250

TMD

In = 63÷250 A



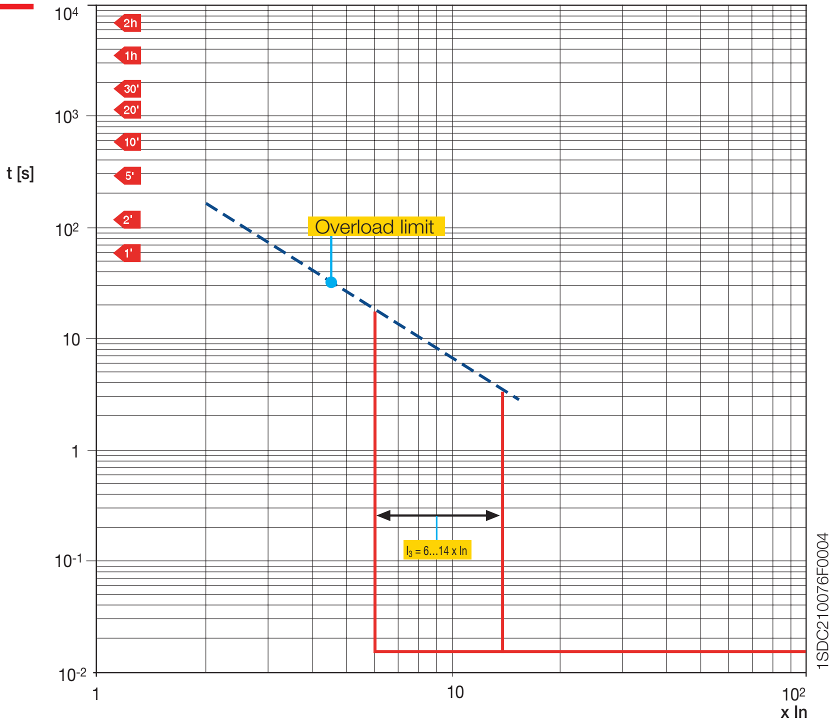
3 General characteristics

Trip curve
thermomagnetic
release

T4 250

MA

I_3 = 6…14 x In



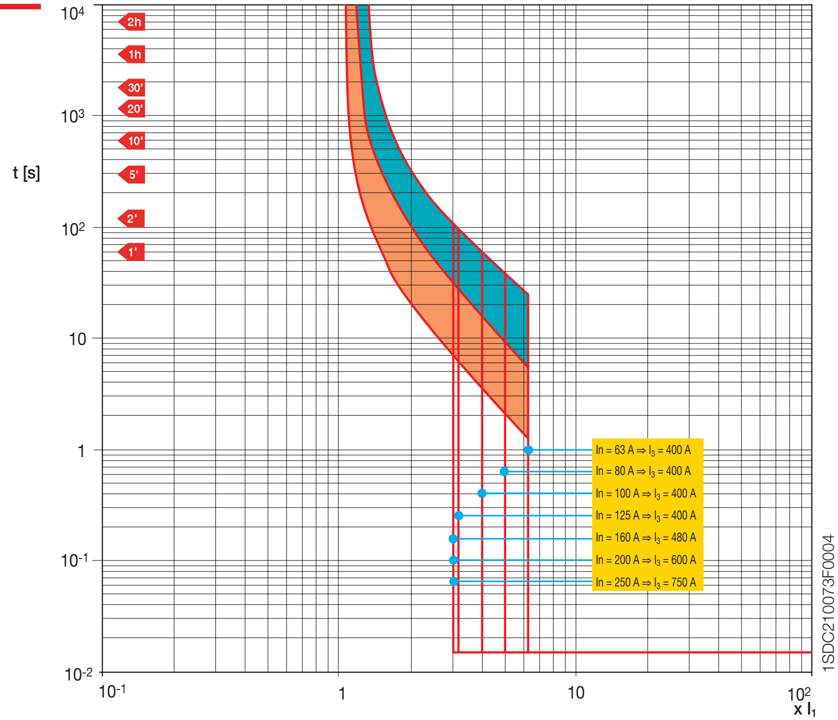
3 General characteristics

Trip curve thermomagnetic release

T3 250

TMG

In = 63÷250 A



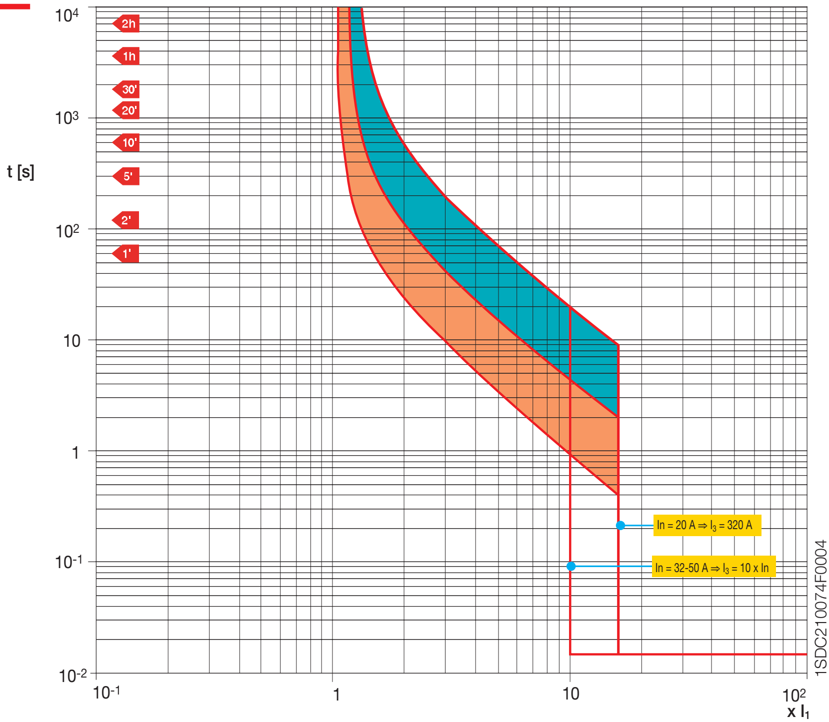
3 General characteristics

Trip curve
thermomagnetic
release

T4 250

TMD

In = 20÷50 A



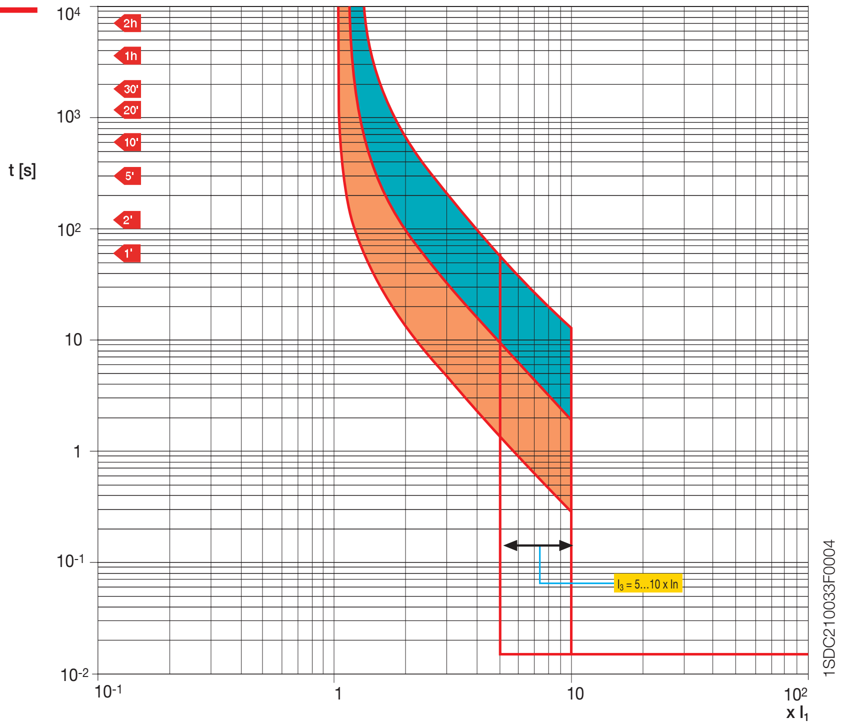
3 General characteristics

Trip curve
thermomagnetic
release

T4 250/320

TMA

In = 80÷320 A

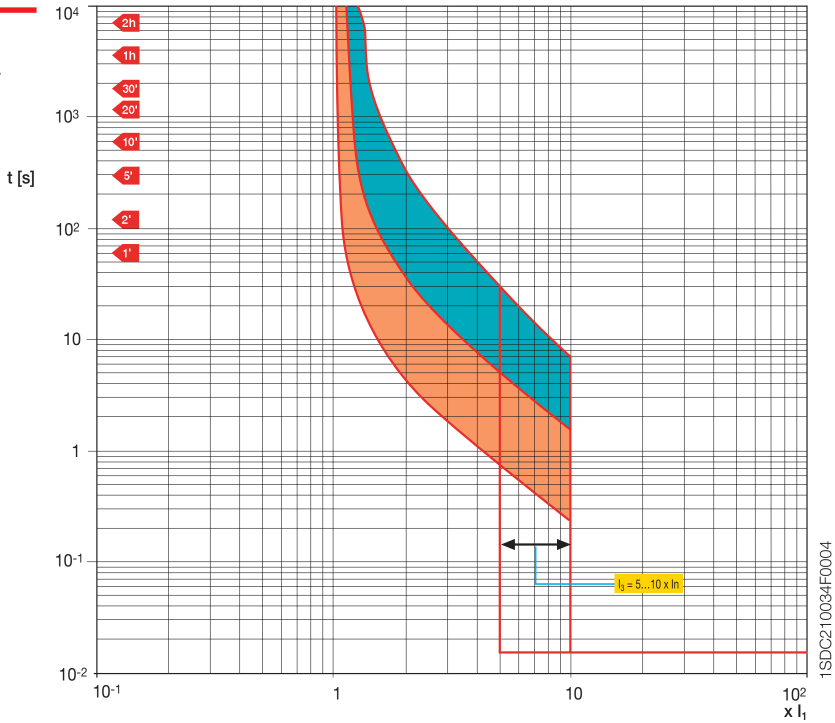


3 General characteristics

Trip curve
thermomagnetic
release

T5 400/630
TMA

In = 320÷630 A



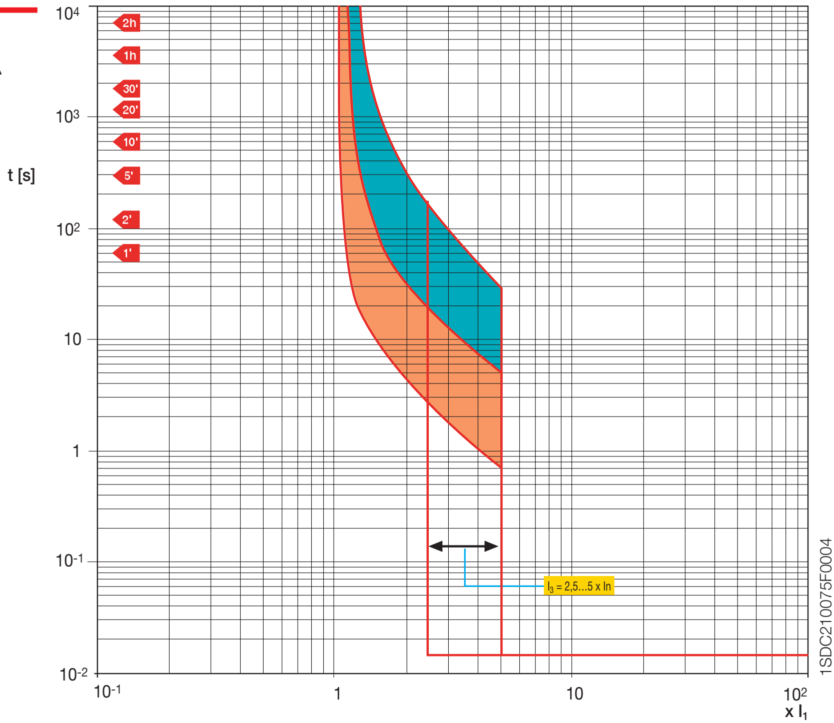
3 General characteristics

Trip curve
thermomagnetic
release

T5 400/630

TMG

In = 320÷630 A



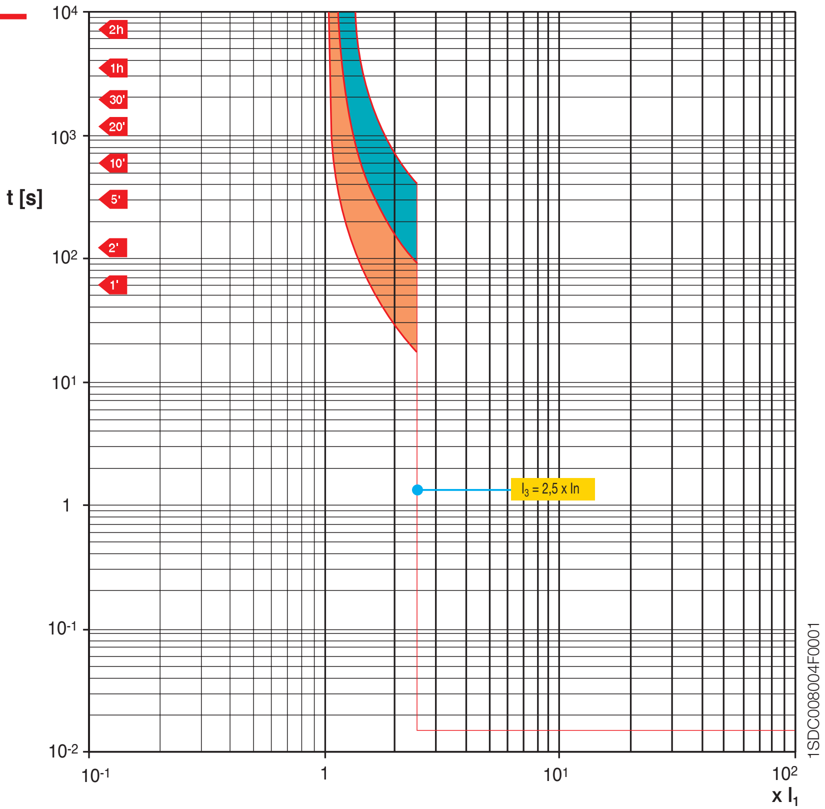
3 General characteristics

Trip curve
thermomagnetic
release

S6 800

TMG

In = 800 A



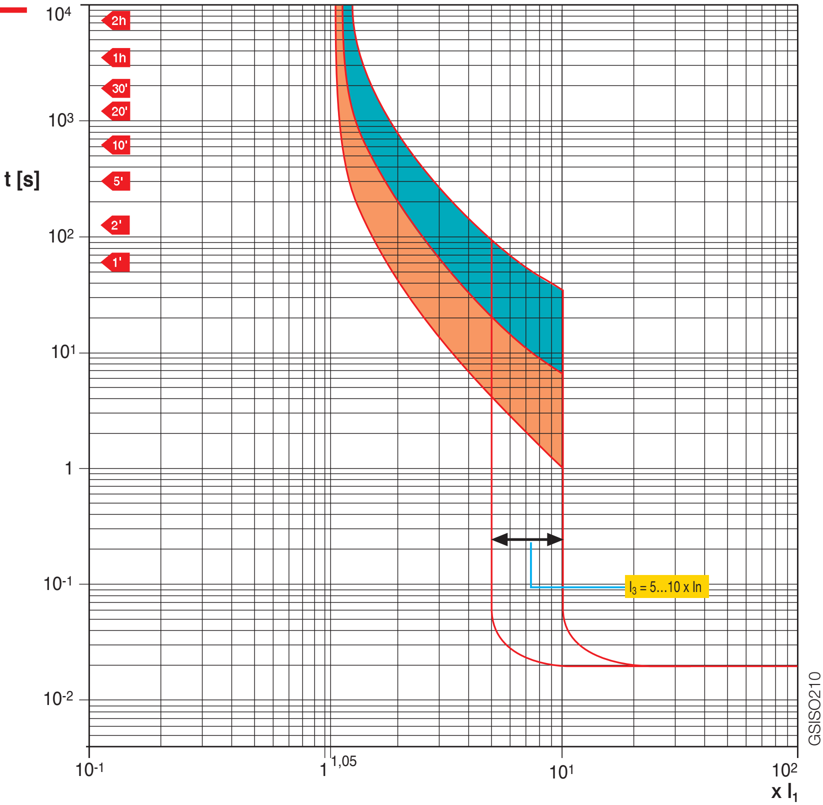
3 General characteristics

Trip curve
thermomagnetic
release

S6 800

TMA

In = 800 A

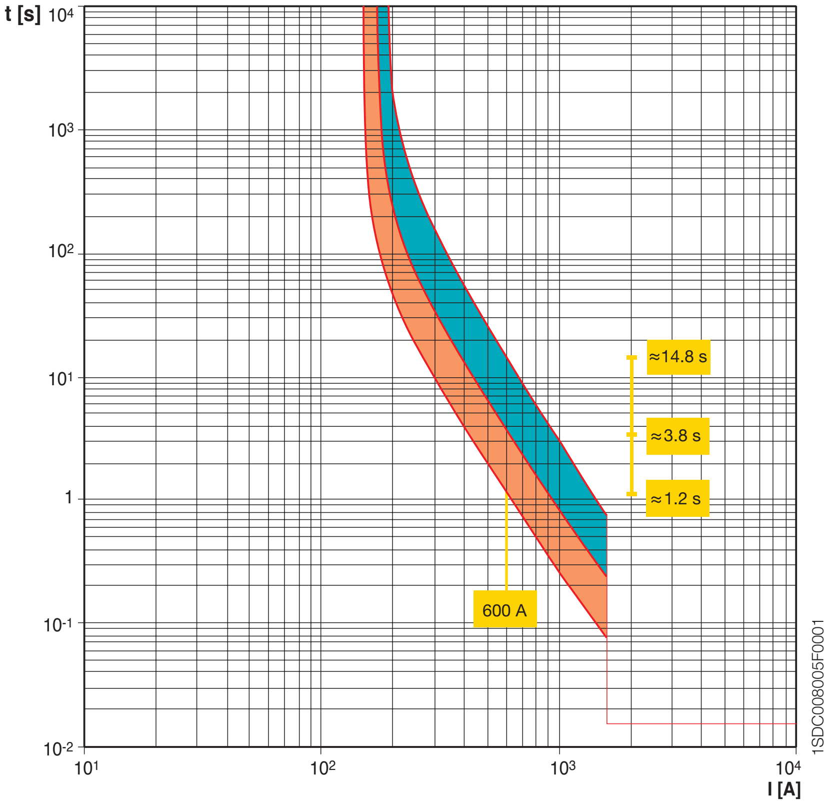


3 General characteristics

Example of thermomagnetic release setting

Consider a circuit-breaker type T1 160 In 160 and select, using the trimmer for thermal regulation, the current threshold, for example at 144 A; the magnetic trip threshold, fixed at 10·In, is equal to 1600 A.
Note that, according to the conditions under which the overload occurs, that is either with the circuit-breaker at full working temperature or not, the trip of the thermal release varies considerably. For example, for an overload current of 600 A, the trip time is between 1.2 and 3.8 s for hot trip, and between 3.8 and 14.8 s for cold trip.
For fault current values higher than 1600 A, the circuit-breaker trips instantaneously through magnetic protection.

T1 160 - In 160 Time-Current curves



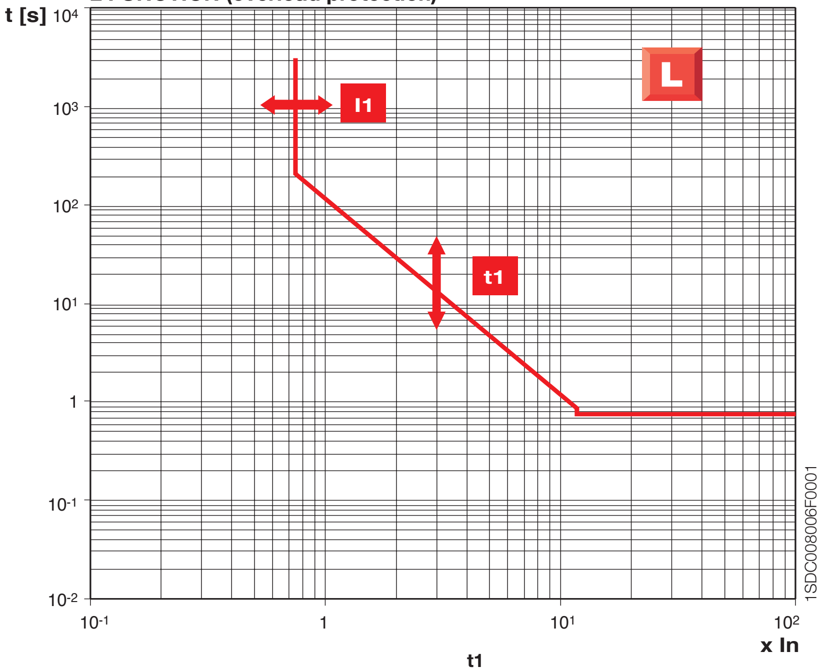
3 General characteristics

3.2.2 Trip curves of electronic releases

Introduction

The following figures show the curves of the single protection functions available in the electronic releases. The setting ranges and resolution are referred to setting operations to be carried out locally.

L FUNCTION (overload protection)



	I1	t1
PR221	(0.4 – 0.44 – 0.48 – 0.52 – 0.56 – 0.6 – 0.64 – 0.68 – 0.72 – 0.76 – 0.8 – 0.84 – 0.88 - 0.92 – 0.96 – 1) x In	3s - 6s (@ 6 x I1) for T2 3s - 12s (@ 6 x I1) for T4, T5
PR222	(0.4…1) x In with step 0.02 x In	3s - 6s - 9s - 18[1]s (@ 6xI1)
PR211	(0.4 – 0.5 – 0.6 – 0.7 – 0.8 – 0.9 – 0.95 – 1) x In	A= 3s; B= 6s; C= 12s; D= 18s (@ 6 x I1)
PR212	(0.4 – 0.5 – 0.55 – 0.6 – 0.65 – 0.7 – 0.75 – 0.8 – 0.85 – 0.875 – 0.9 – 0.925 – 0.95 - 0.975 – 1) x In	A= 3s; B= 6s; C= 12s; D= 18s (@ 6 x I1)
PR111	(0.4 – 0.5 – 0.6 – 0.7 – 0.8 – 0.9 – 0.95 – 1) x In	A= 3s; B= 6s; C= 12s; D= 18s (@ 6 x I1)
PR112 PR113	(0.4 … 1) x In with step 0.01 x In	3 … 144s with step 3s (@ 3 x I1)

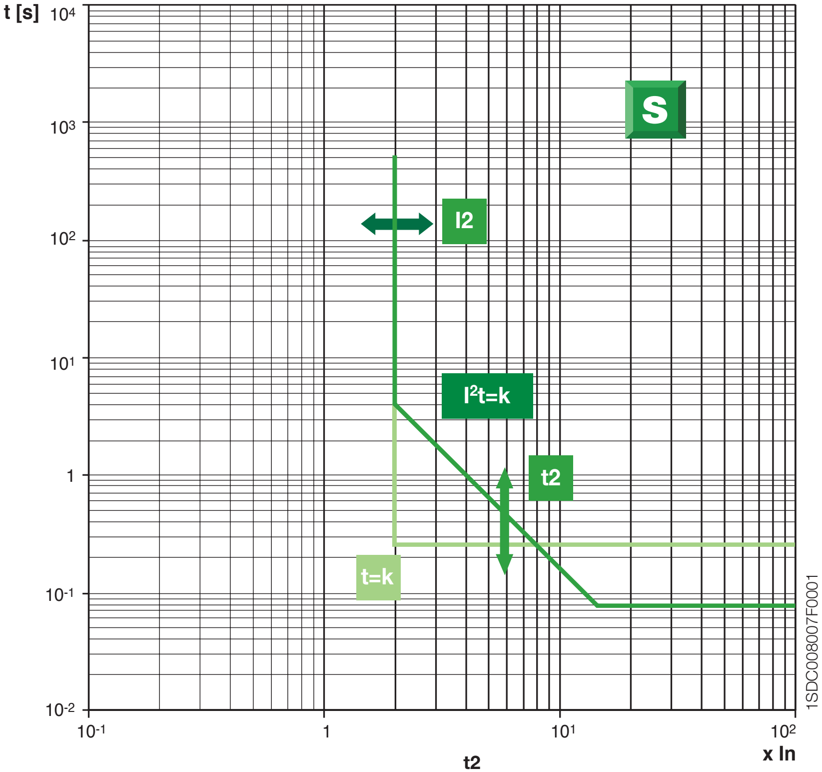
[1] *for T4 In = 320 A and T5 In = 630 A → t1 = 12s.*

Here below the tolerances:

	I1	t1
PR221	1.1÷1.3 x I1	± 10 % (up to 6 x In) ± 20 % (over 6 x In)
PR222	1.1÷1.3 x I1	± 10 %
PR221 PR211	1.05÷1.3 x I1	± 10 % (up to 2 x In) ± 20 % (over 2 x In)
PR111	1.1÷1.2 x I1	± 10 % (up to 3 x In) ± 20 % (over 3 x In)
PR112 PR113	1.1÷1.2 x I1	± 10 % (up to 4 x In) ± 20 % (over 4 x In)

3 General characteristics

S FUNCTION (short-circuit protection with time delay) (I^2t=k, t=k)



	I2	t2
PR221	(1 – 1.5 – 2 – 2.5 – 3 – 3.5 – 4.5 – 5.5 – 6.5 – 7 – 7.5 – 8 – 8.5 – 9 – 10 – OFF) x In	0.1s - 0.25s (@ 8 x I2)
PR222	0.6…10 x In with step 0.6 x In	0.05s - 0.1s - 0.25s - 0.5s (@ 8 x In)
PR211 PR212 PR111	(1 – 2 – 3 – 4 – 6 – 8 – 10 – OFF) x In	A= 0.05s; B= 0.1s; C= 0.25s; D= 0.5s (@ 8 x I2)
PR112 PR113	(0.6 … 10 – OFF) x In with step 0.1 x In	0.05 … 0.75s with step 0.01s (@ 10 x I2)

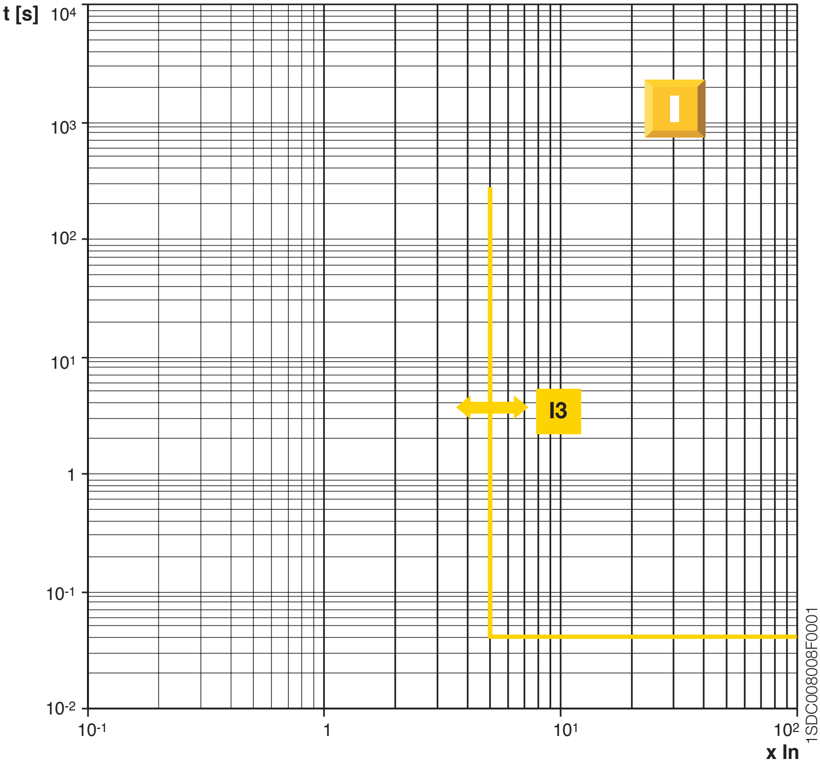
Here below the tolerances:

	I2	t2
PR221	± 10 % (T4-T5) ± 10 % (up to 2 x In) ± 20 % (over 2 x In)	± 10 % up to 6 x In (T4-T5) ± 20 % over to 6 x In (T4-T5) ± 20 % (T2)
PR222	± 10 %	± 10 %(1)
PR211 PR212	± 10 %	± 20 %
PR111	± 10 %	± 20 % (I^2t=k) the best between ± 20 % and ± 50 ms (t=k)
PR112 PR113	± 7 % (up to 4 x In) ± 10 % (over 4 x In)	the best between ± 10 % and ± 50 ms (up to 4 x In, with t=k) the best between ± 15 % and ± 50 ms (over 4 x In, with t=k) ± 15 % (up to 4 x In, with I^2t=k) ± 20 % (over 4 x In, with I^2t=k)

(1) *Tollerance ± 10ms up to t2 = 0.1s.*

3 General characteristics

I FUNCTION (short-circuit istantaneous protection)



	I3
PR221	(1 – 1.5 – 2 – 2.5 – 3 – 3.5 – 4.5 – 5.5 – 6.5 – 7 – 7.5 – 8 – 8.5 – 9 – 10 – OFF) x In
PR222	(1.5 – 2.5 – 3 – 4 – 3.5 – 4.5 – 5 – 5.5 – 6.5 – 7 – 7.5 – 8 – 9 – 9.5 – 10.5 – 12 – OFF) x In(1)
PR211 PR212 PR111	(1.5 – 2 – 4 – 6 – 8 – 10 – 12 – OFF) x In
PR112 PR113	(1.5 … 15 – OFF) x In with step 0.1 x In

(1) for T4 In = 320 A and T5 In = 630 A → I3 max = 10 x In

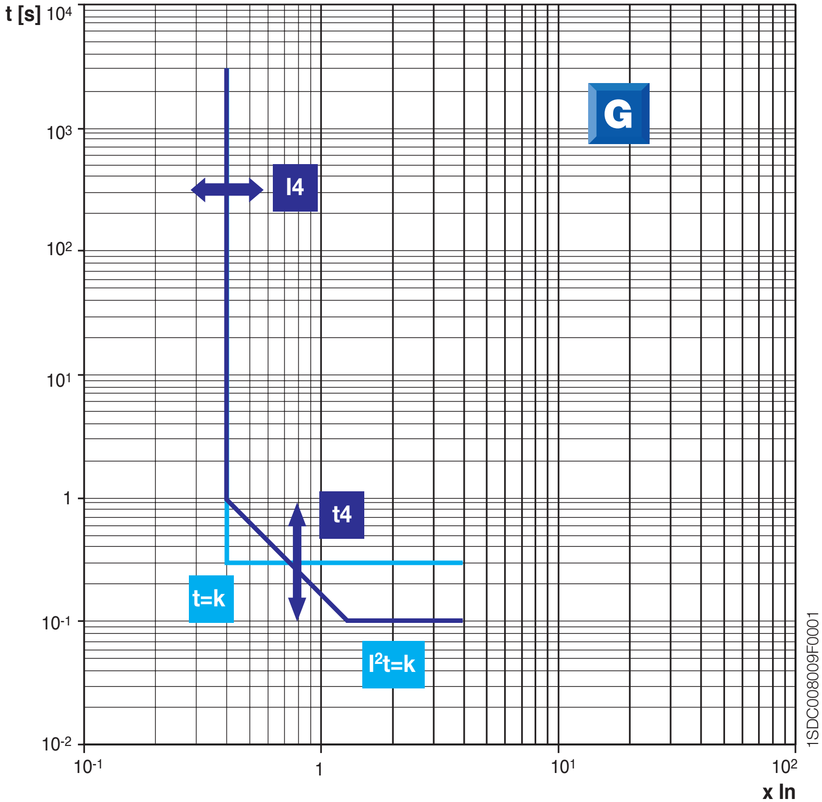
Here below the tolerances:

	I3	Tripping time:
PR221	± 10 % (T4-T5) ± 20 % (T2)	≤ 25 ms
PR222	± 10 %	≤ 25 ms
PR211 PR212	± 20 %	≤ 25 ms
PR111	± 20 %	35 ms up to 3 x In 30 ms over 3 x In
PR112 PR113	± 10 % up to 4 x In ± 15 % over 4 x In	≤ 25 ms

The given tolerances are valid only if the release is self-supplied in steady state condition with two-phase or three-phase power supply.

3 General characteristics

G FUNCTION (earth fault protection) ($I^2t=k$, $t=k$)



	I4	t4
PR111 (1)	(0.2 – 0.25 – 0.45 – 0.55 – 0.75 – 0.8 – 1 – OFF) x In	0.1s up to 3.15x14; 0.2s up to 2.25x14 0.4s up to 1.6x14; 0.8s up to 1.10x14
PR212 PR111 (1)	(0.2 – 0.3 – 0.4 – 0.6 – 0.8 – 0.9 – 1 – OFF) x In	A= 0.1s; B= 0.2s; C= 0.4s; D= 0.8s (@ 4 x I4)
PR112 PR113	(0.2 … 1 – OFF) x In with step 0.02 x In	0.1 … 1s with step 0.05s (@ 4 x I4)

(1) only with $I^2t=k$ characteristic only.

Here below the tolerances:

	I4	t4
PR222	± 10 %	± 20 %
PR212	± 20 %	± 20 %
PR111 (1)	± 10 %	± 20 %
PR112	± 10 %	± 20 % ($I^2t=k$) the best between ± 10 % and ± 50 ms (t=k) up to 4 x In
PR113	± 7 % up to 4 x In	± 15 % ($I^2t=k$) the best between ± 10 % and ± 50 ms (t=k) up to 4 x In

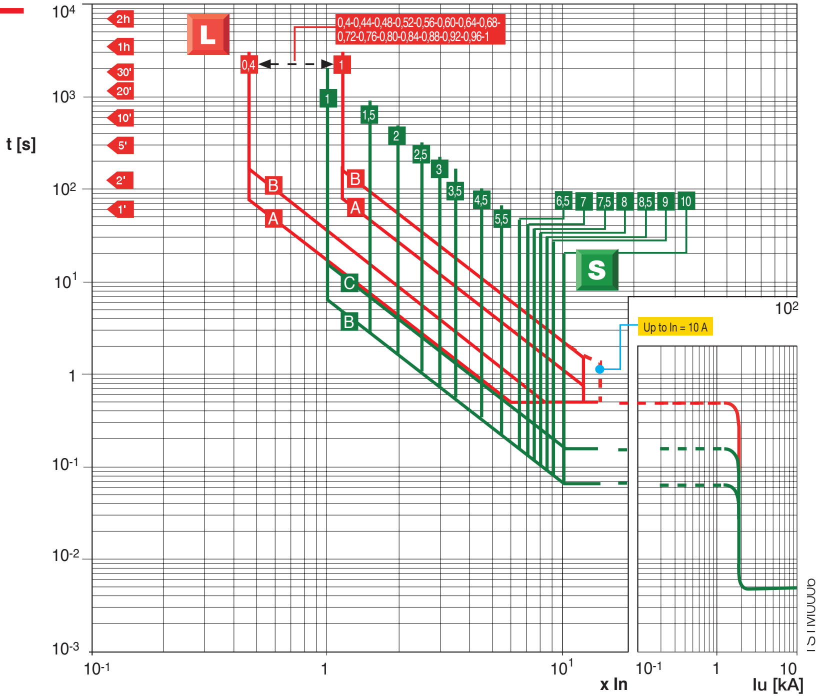
3 General characteristics

Trip curve
electronic releases

T2 160

PR221DS

L-S Functions

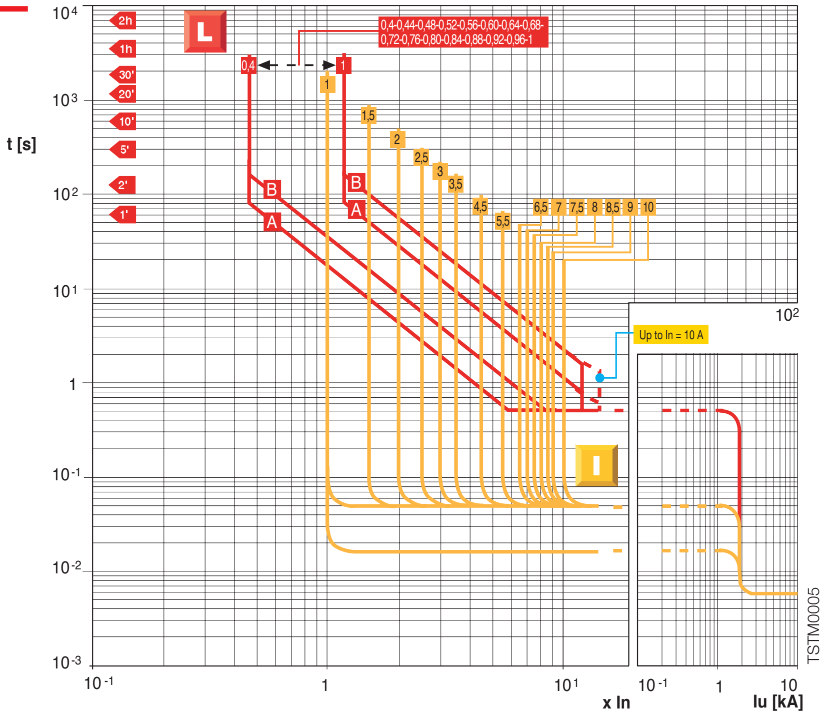


3 General characteristics

Trip curve
electronic releases

T2 160
PR221DS

L-I Functions

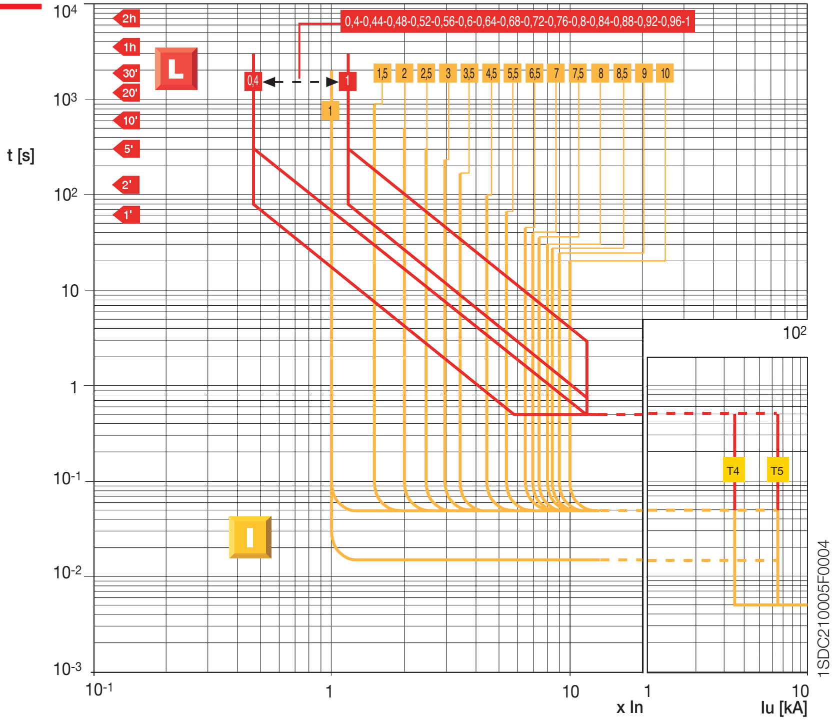


3 General characteristics

Trip curve
electronic releases

T4 250/320
T5 400/630
PR221DS

L-I Functions



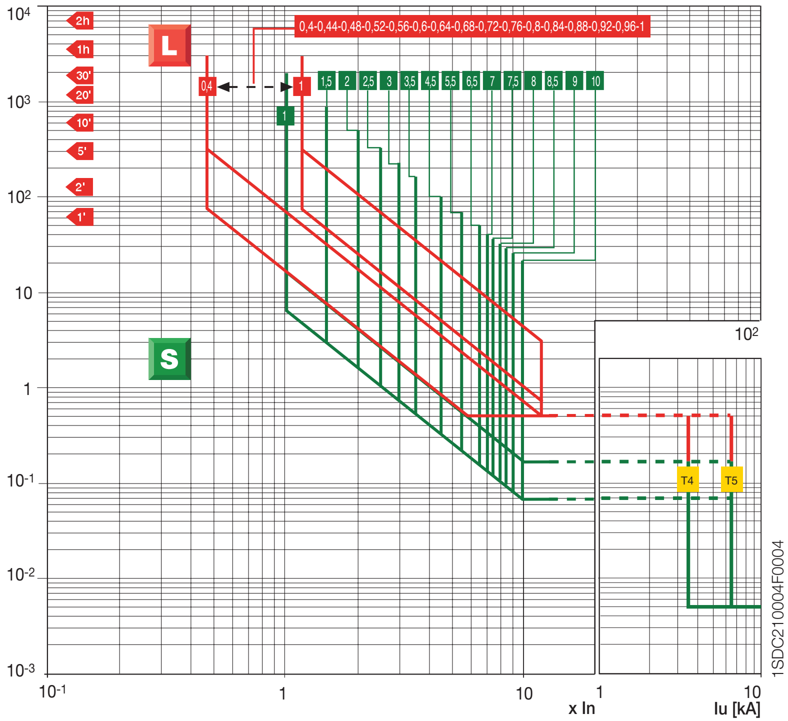
3 General characteristics

Trip curve
electronic releases

T4 250/320
T5 400/630

PR221DS

L-S Functions



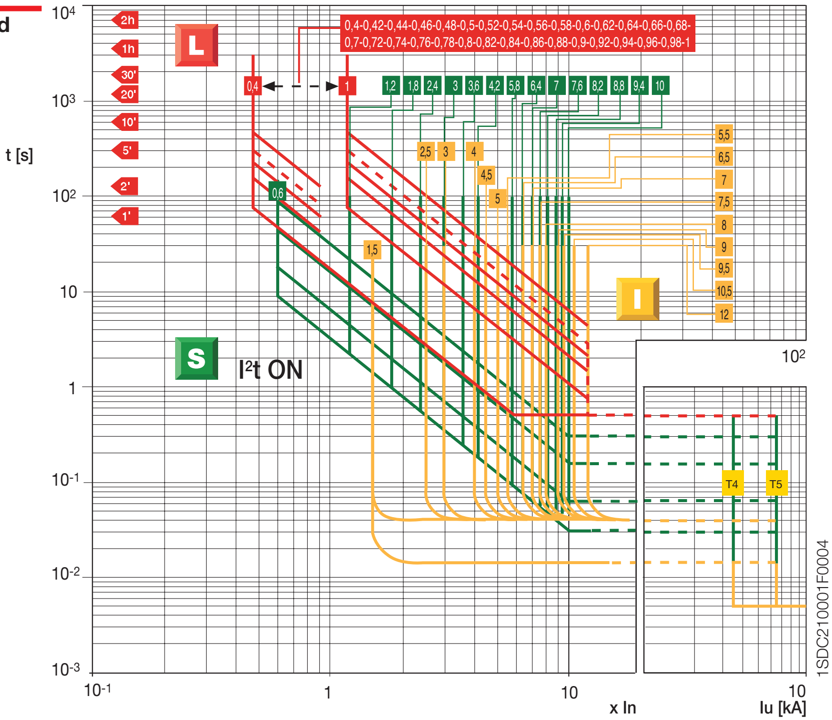
3 General characteristics

Trip curve
electronic releases

T4 250/320
T5 400/630

PR222DS/P and PR222DS/PD

L-S-I Functions
(I^2t const = ON)



Note:
The dotted curve of function L corresponds to the maximum delay (t_1) which can be set at $6xI_1$, in the case where 320 A CTs are used for T4 and 630 A for T5. For all the CT sizes t_1=18s, except with 320 A CT (T4) and 630 A (T5) where t_1=12s.
For T4 In = 320 A and T5 In = 630 A ⇒ I_3 max = 10 x In

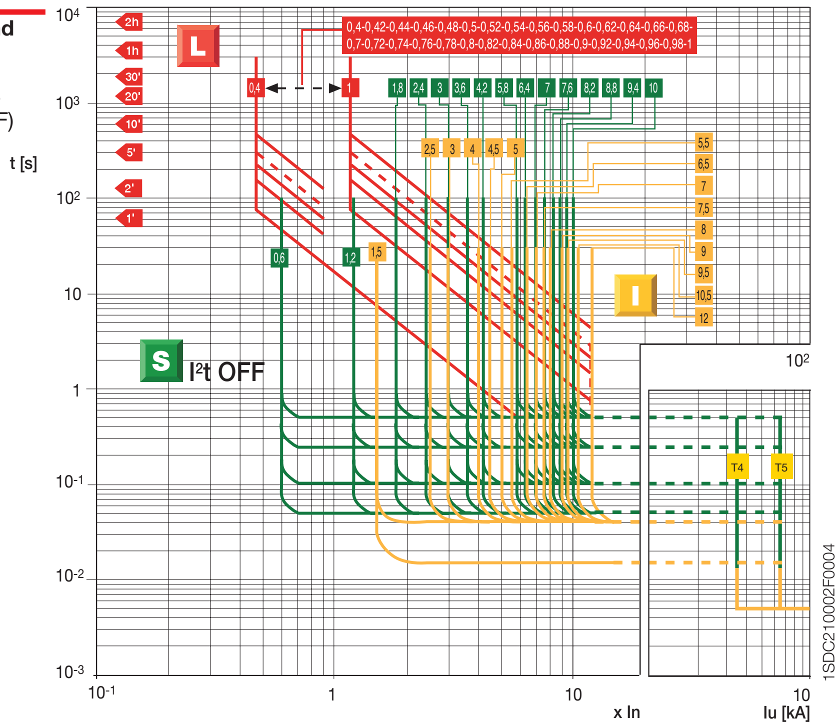
3 General characteristics

Trip curve
electronic releases

T4 250/320
T5 400/630

PR222DS/P and PR222DS/PD

L-S-I Functions
(I^2t const = OFF)



Note:
The dotted curve of function L corresponds to the maximum delay (t_1) which can be set at $6xI_1$, in the case where 320 A CTs are used for T4 and 630 A for T5. For all the CT sizes t_1=18s, except with 320 A CT (T4) and 630 A (T5) where t_1=12s.
For T4 In = 320 A and T5 In = 630 A ⇒ I_3 max = 10 x In

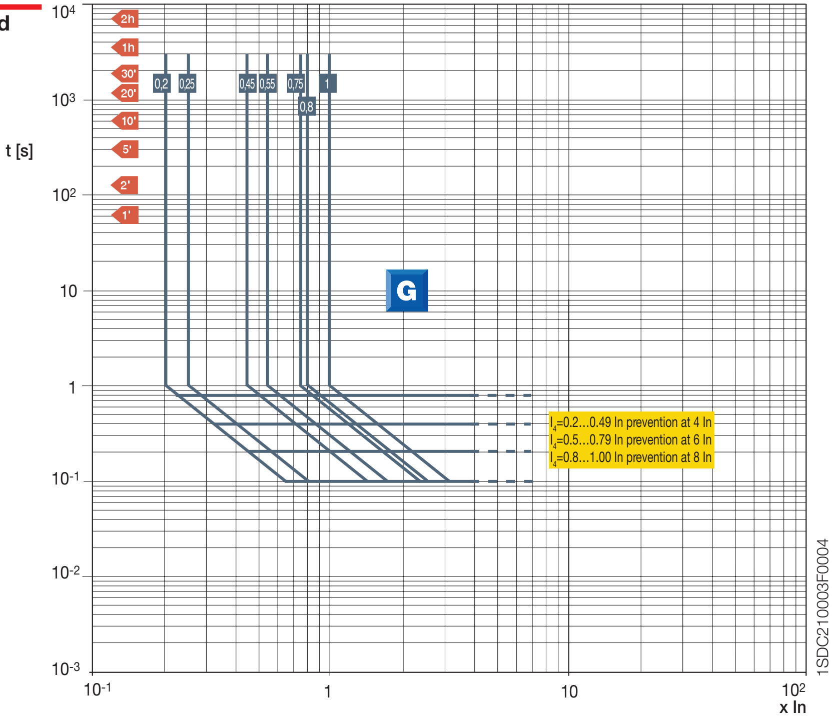
3 General characteristics

Trip curve
electronic releases

T4 250/320
T5 400/630

PR222DS/P and
PR222DS/PD

G Function

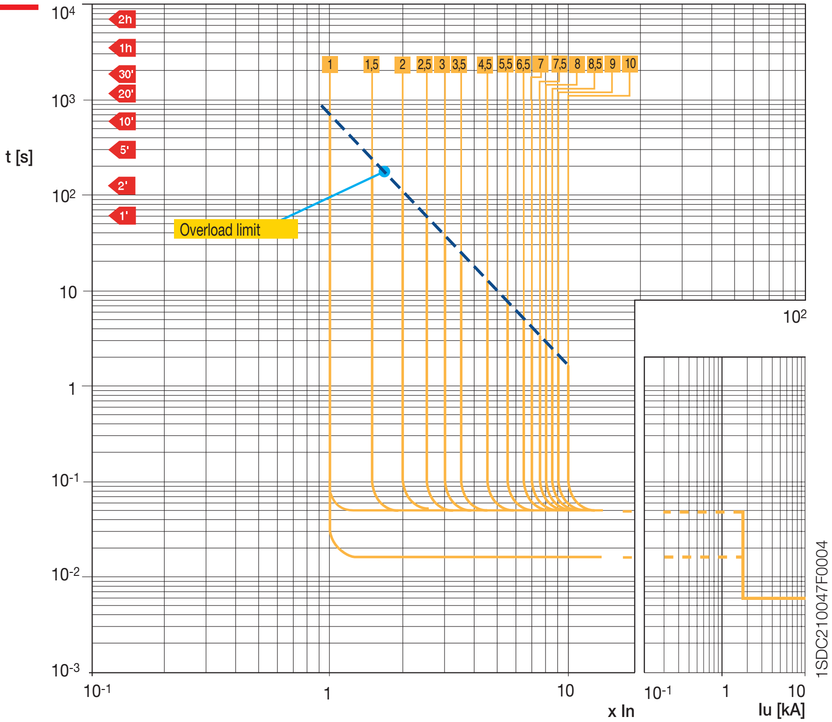


3 General characteristics

Trip curve
electronic releases

T2 160
PR221DS-I

I Function



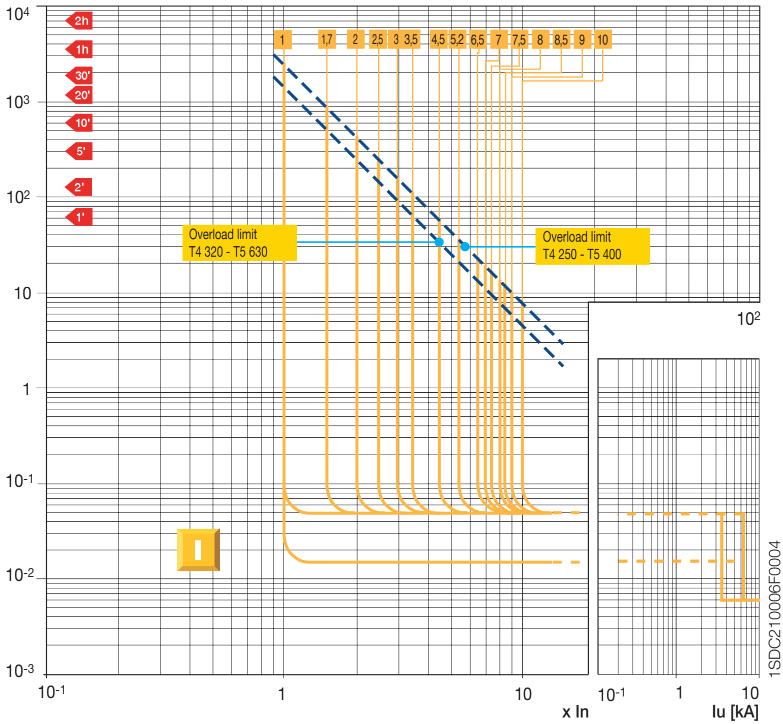
3 General characteristics

Trip curve
electronic releases

T4 250/320
T5 400/630

PR221DS-I

I Function



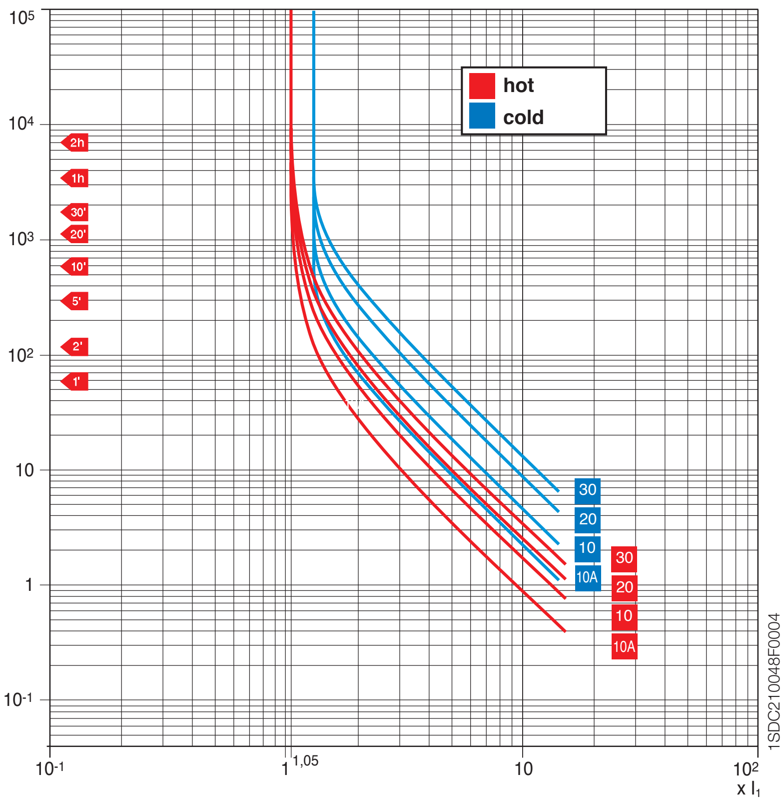
3 General characteristics

Trip curve
electronic releases

T4 250 - T5 400

PR222MP

L Function
(hot and cold trip)



	I1	t1
PR212/MP	(0.4 ÷ 1) x In with step 0.01 x In	4 – 8 – 16 – 24 s

Here the tolerances

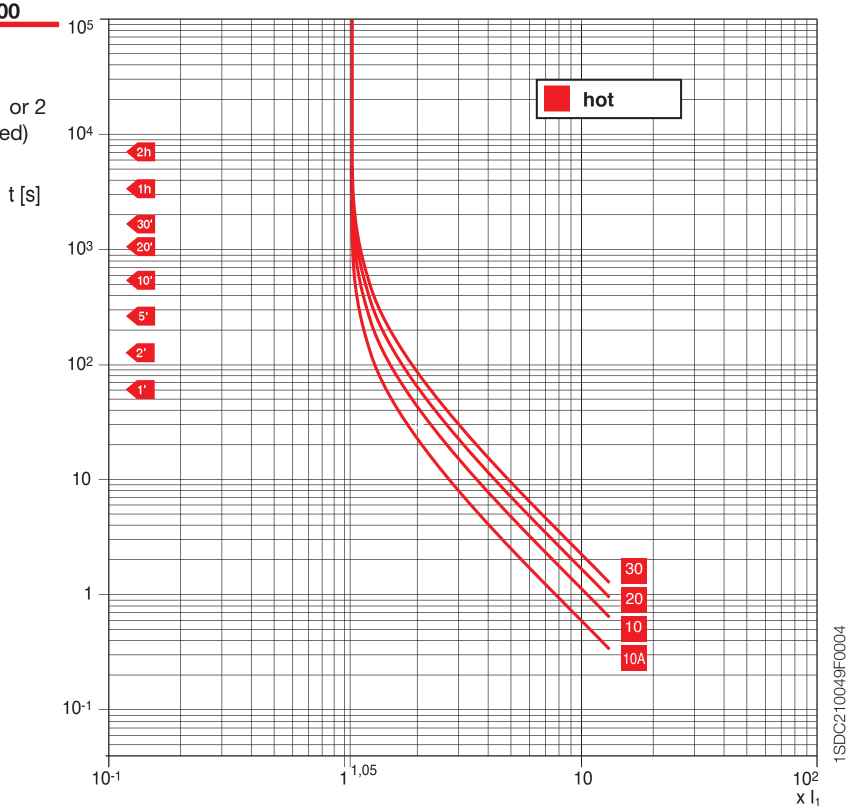
	I1	t1
PR212/MP	According to IEC 60947-4-1	According to IEC 60947-4-1

3 General characteristics

Trip curve
electronic releases

T4 250 - T5 400
PR222MP

L Function
(hot trip with 1 or 2 phases supplied)



	I1	t1
PR222/MP	(0.4 ÷ 1) x In with step 0.01 x In	4 – 8 – 16 – 24 s

Here the tolerances

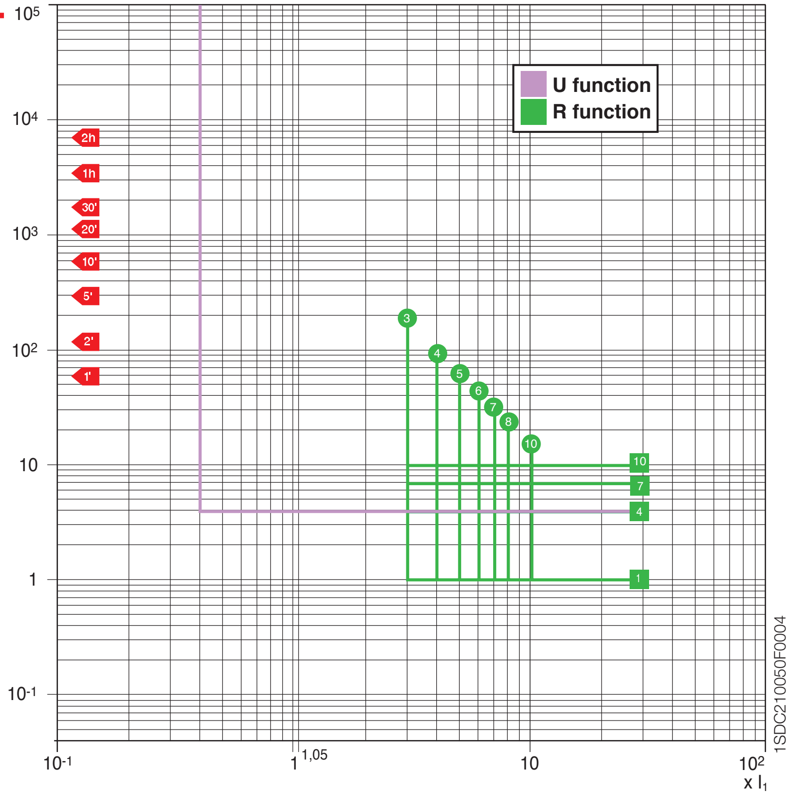
	I1	t1
PR222/MP	±15%	±15%

3 General characteristics

Trip curve
electronic releases

T4 250 - T5 400
PR222MP

R-U Functions



R	I5	t5
PR222/MP	(3 - 4- 5 - 6 - 7 - 8 - 10 - OFF) x I1	1 – 4 – 7 – 10 s
U	**I6**	**t6**
PR222/MP	ON (0.4 x I1) - OFF	4 s

Here the tolerances

R	I5	t5
PR222/MP	± 15 %	± 10 %
U	**I6**	**t6**
PR222/MP	± 15 %	± 10 %

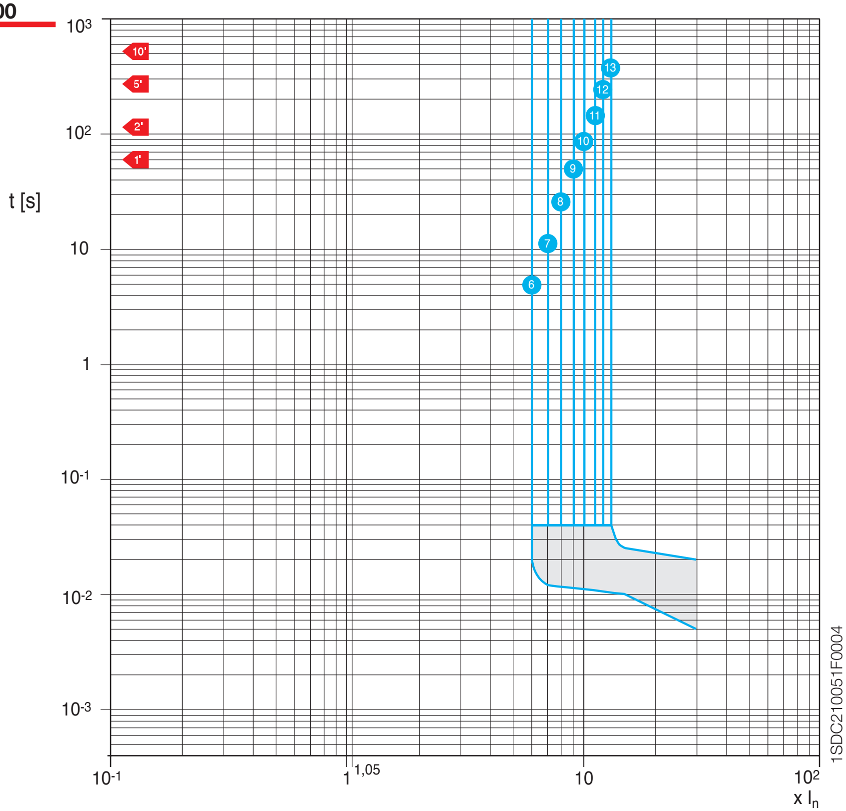
3 General characteristics

Trip curve
electronic releases

T4 250 - T5 400

PR222MP

I Function



	I3
PR222/MP	(6 - 7- 8 - 9 - 10 - 11 - 12 - 13) x In

Here the tolerances

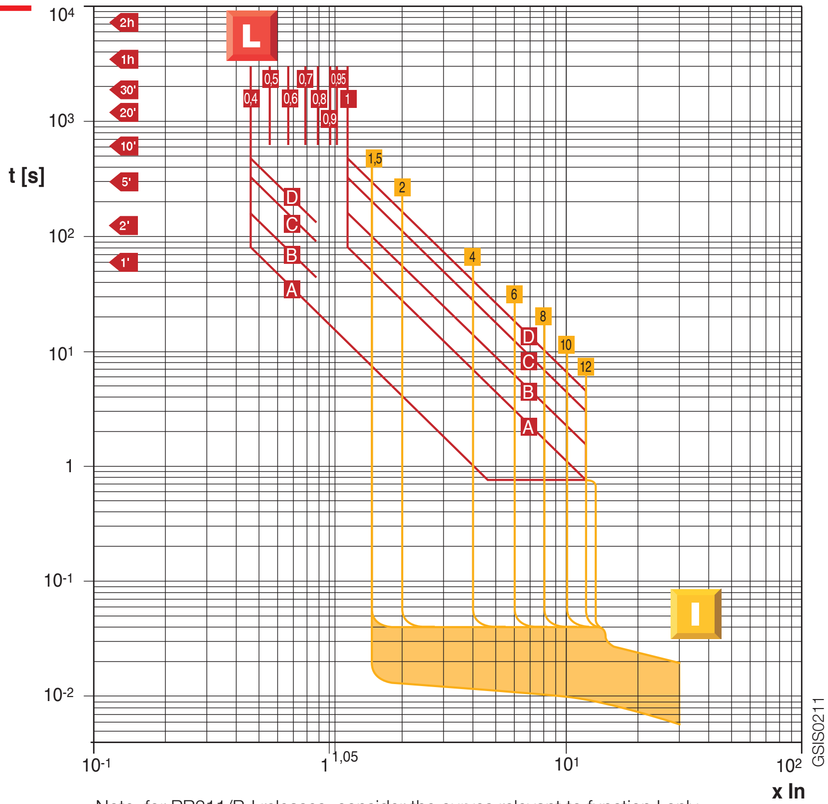
	I3
PR222/MP	± 15 %

3 General characteristics

Trip curve
electronic releases

S6 - S7
PR211/P

L-I Functions



Note: for PR211/P-I releases, consider the curves relevant to function I only.

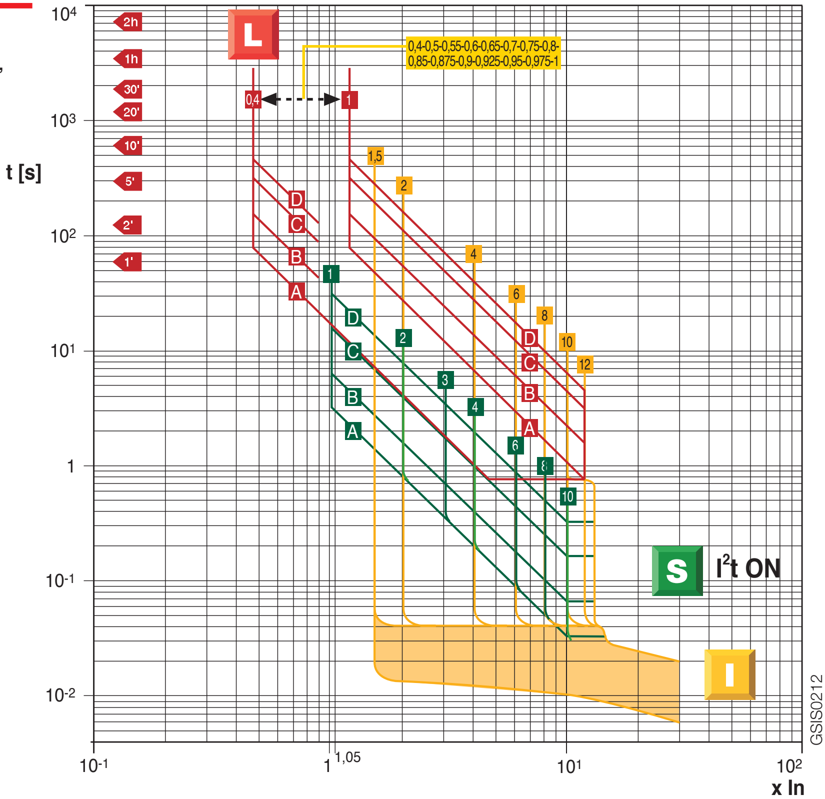
3 General characteristics

Trip curve
electronic releases

S6 - S7 - S8

PR212/P

L-S-I Functions,
S inverse short
delay
(I^2t = constant)



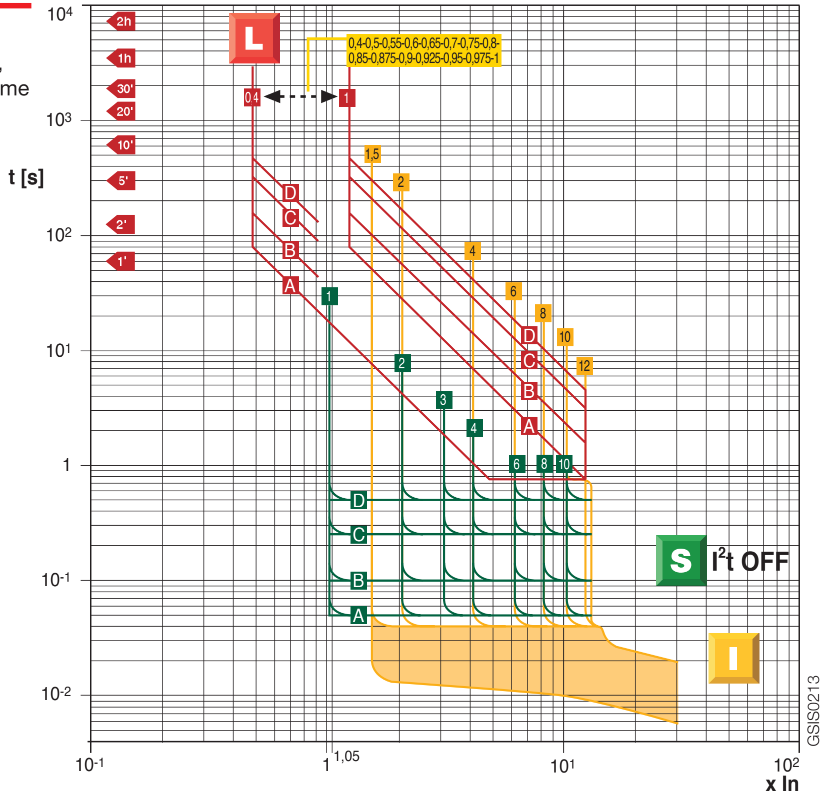
3 General characteristics

Trip curve
electronic releases

S6 - S7 - S8

PR212/P

L-S-I Functions,
S indipendent time delay
(t = constant)

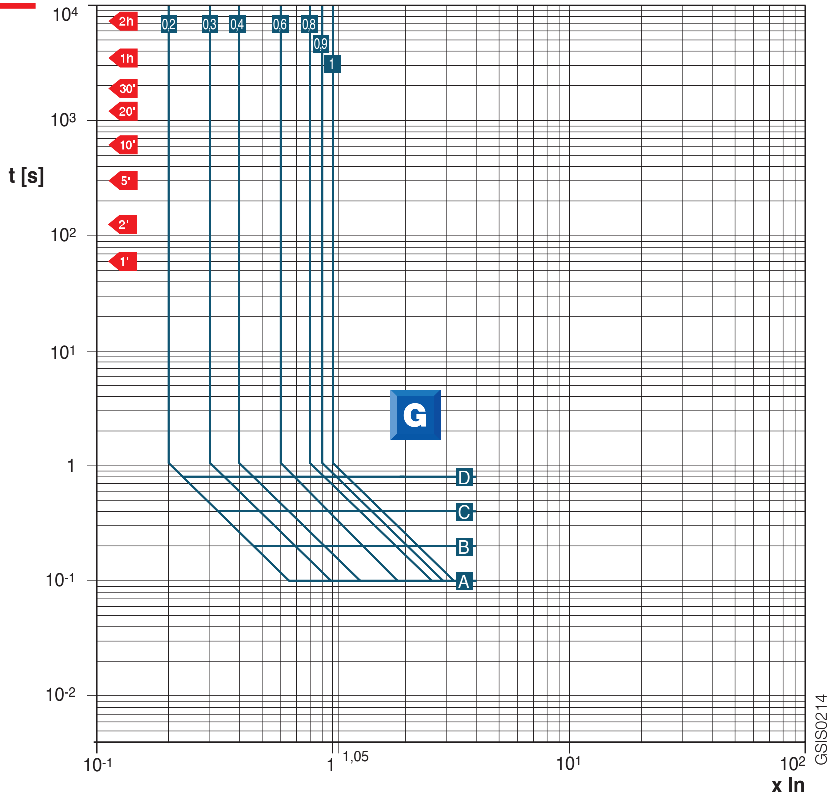


3 General characteristics

Trip curve
electronic releases

S6 - S7 - S8
PR212/P

G Function



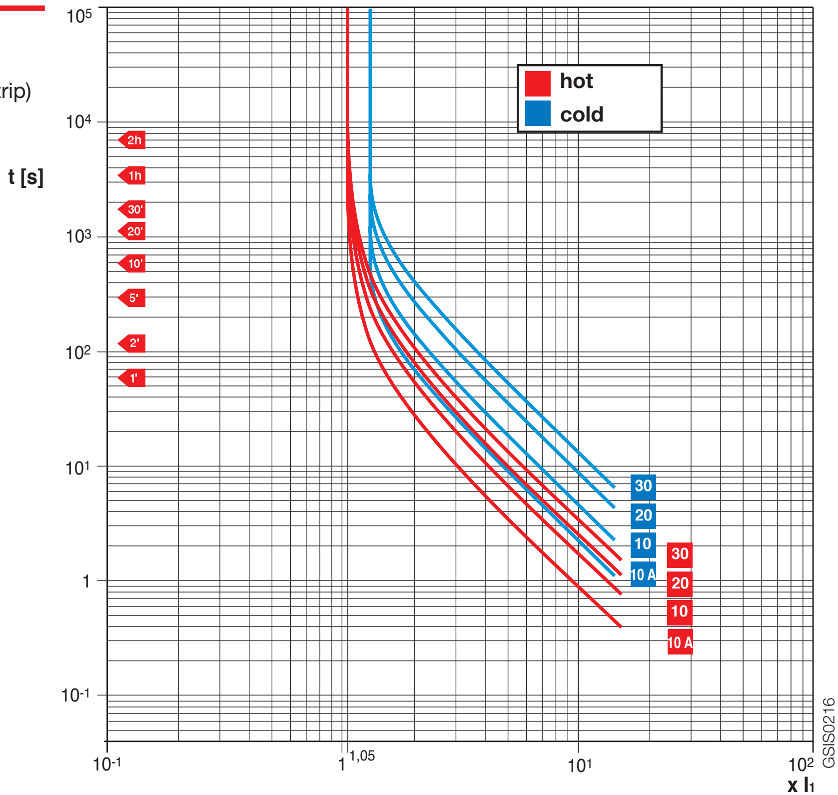
3 General characteristics

Trip curve
electronic releases

S6 - S7

PR212/MP

L Function
(hot and cold trip)



	I1	t1
PR212/MP	(0.4 ÷ 1) x In with step 0.01 x In	4 – 8 – 16 – 24 s

Here the tolerances

	I1	t1
PR212/MP	According to IEC 60947-4-1	According to IEC 60947-4-1

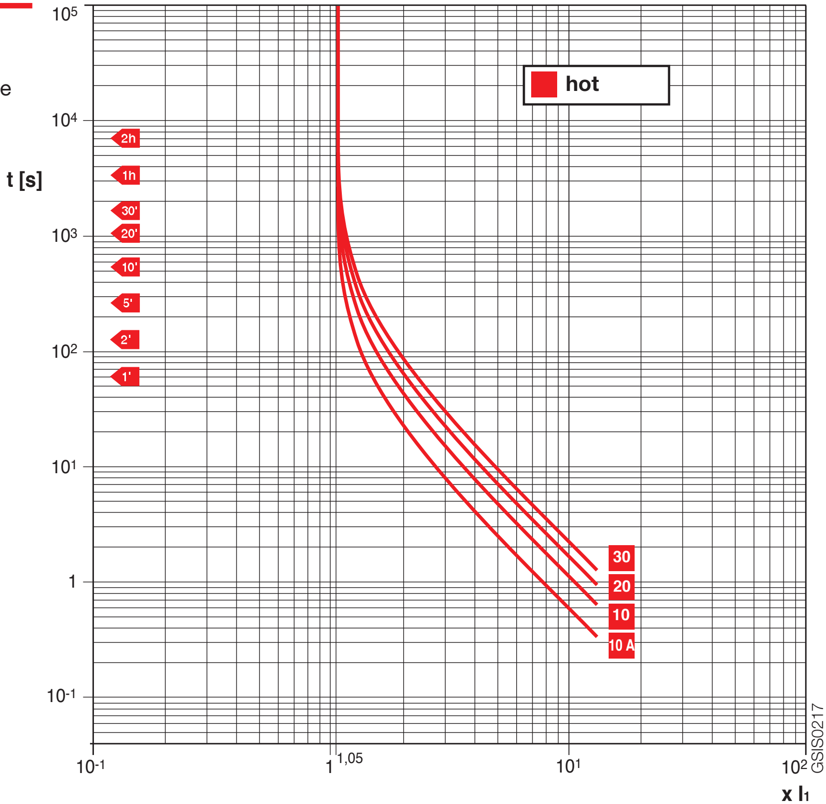
3 General characteristics

Trip curve
electronic releases

S6 - S7

PR212/MP

L Function
(hot trip with one or two phases supplied)

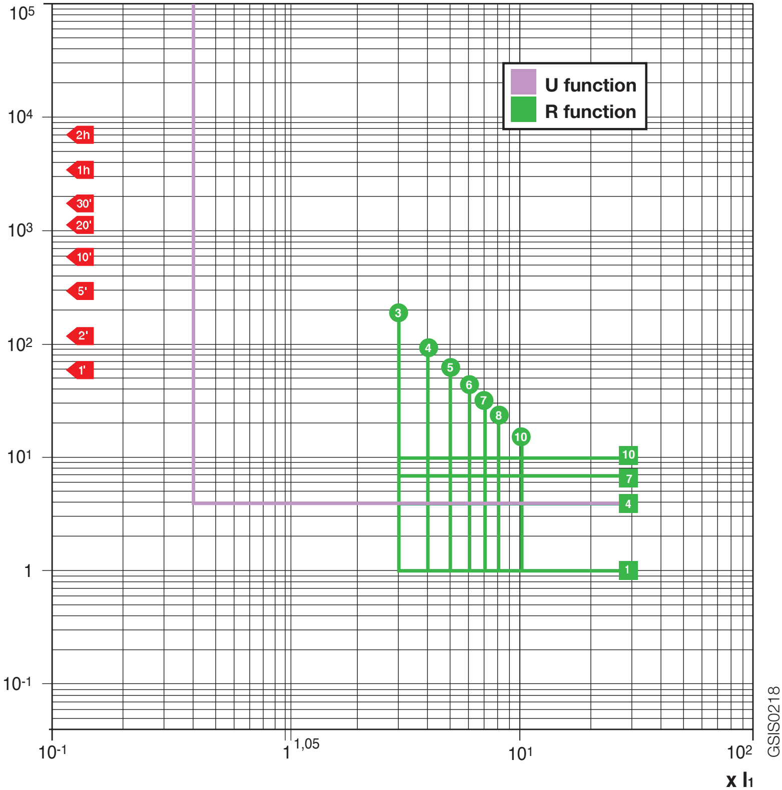


3 General characteristics

Trip curve
electronic releases

S6 - S7
PR212/MP

R-U Functions



R	I5	t5
PR212/MP	(3 - 4- 5 - 6 - 7 - 8 - 10 - OFF) x I1	1 – 4 – 7 – 10 s
U	I6	t6
PR212/MP	0.4 x I1	4 s

Here the tolerances

R	I5	t5
PR212/MP	± 10 %	± 20 %
U	I6	t6
PR212/MP	± 20 %	± 20 %

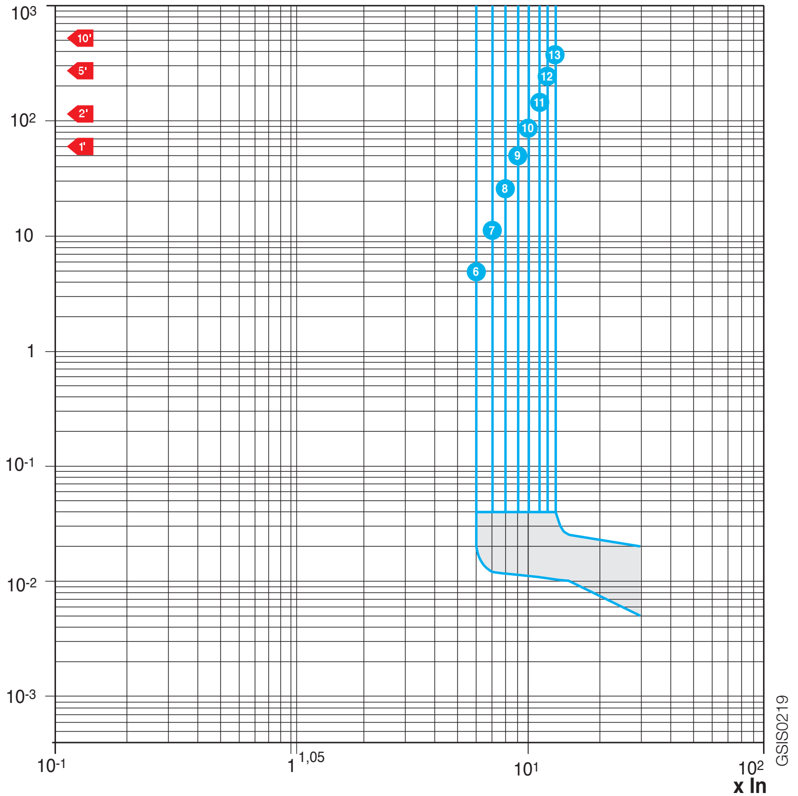
3 General characteristics

Trip curve
electronic releases

S6 - S7

PR212/MP

I Function



	I3
PR212/MP	(6 - 7- 8 - 9 - 10 - 11 - 12 - 13 - OFF) x In

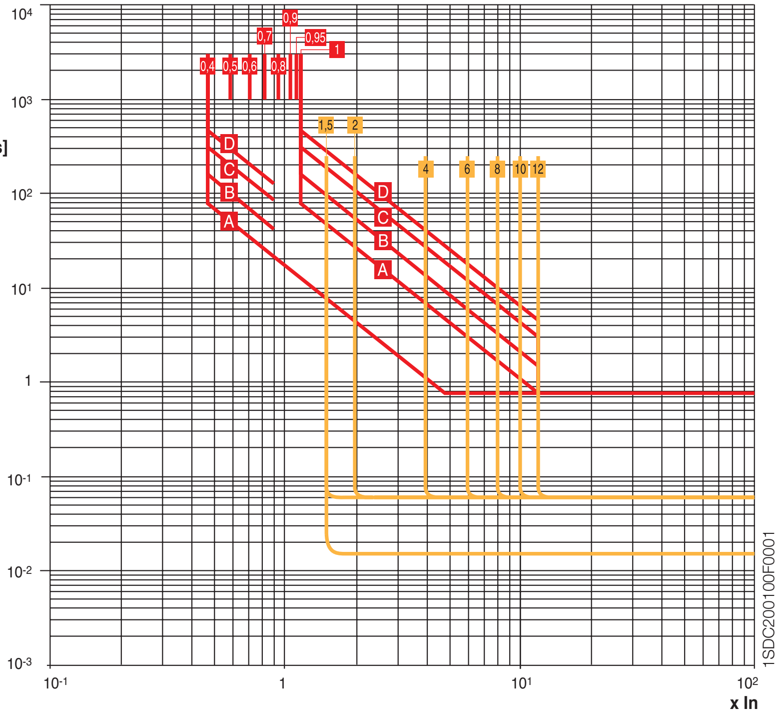
The tolerances are according to IEC 60947-4-1.

3 General characteristics

Trip curve
electronic releases

Emax
PR111/P

L- I Functions

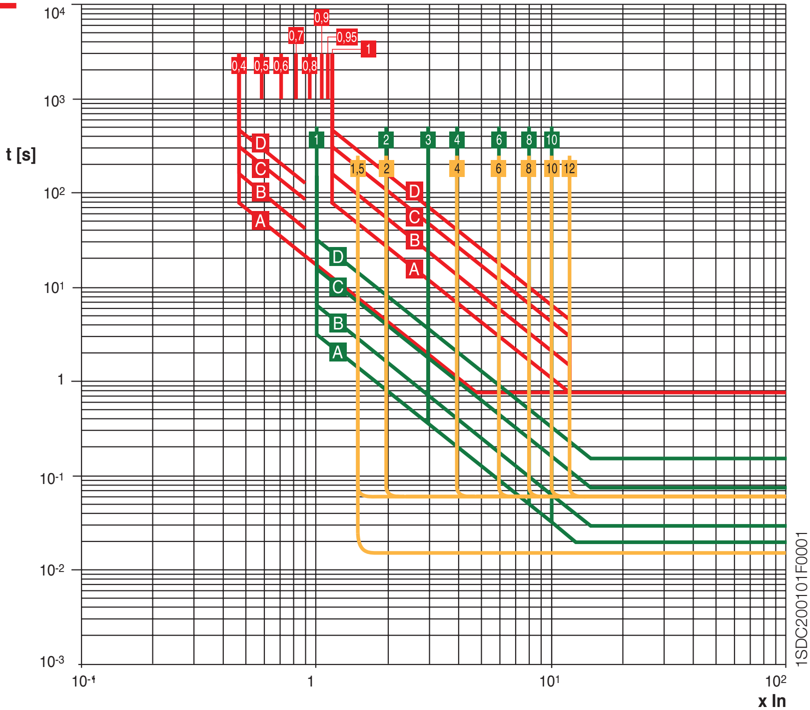


3 General characteristics

Trip curve
electronic releases

Emax
PR111/P

L-S-I Functions,
S inverse short
time delay
(I^2t = const.)

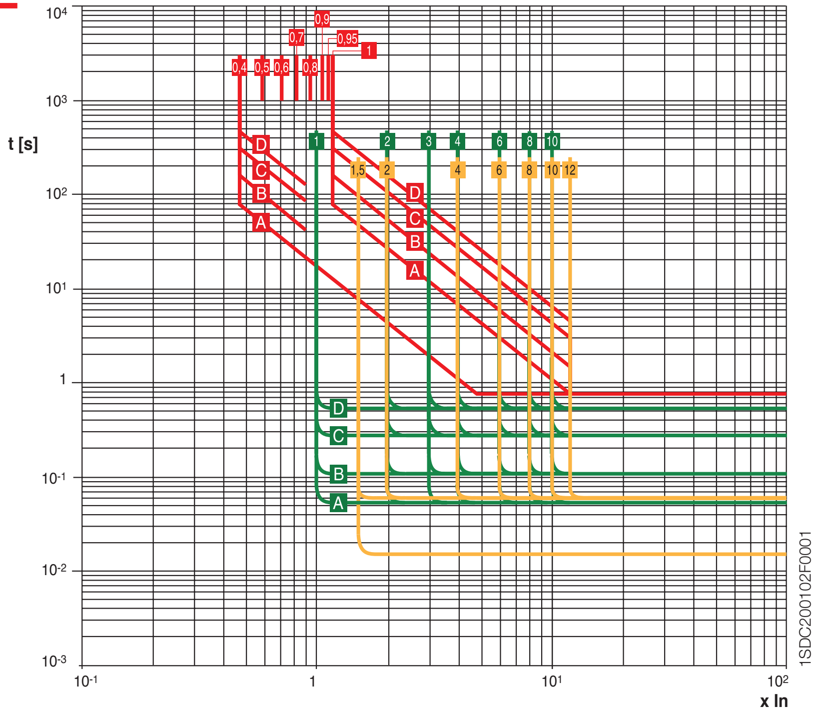


3 General characteristics

Trip curve
electronic releases

Emax
PR111/P

L-S-I Functions,
S indipendent
time delay
(t = constant)

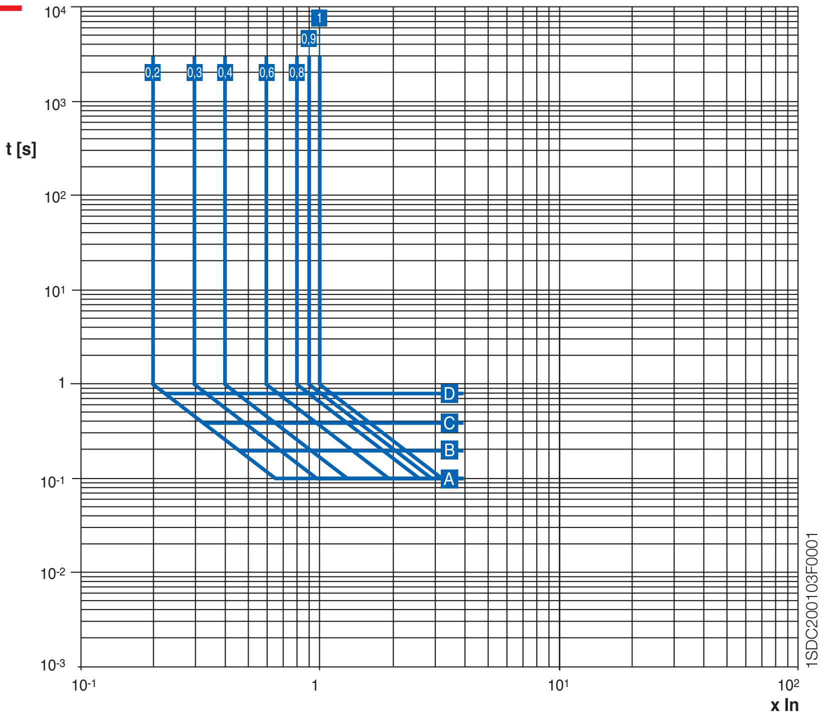


3 General characteristics

Trip curve
electronic releases

Emax
PR111/P

G Function

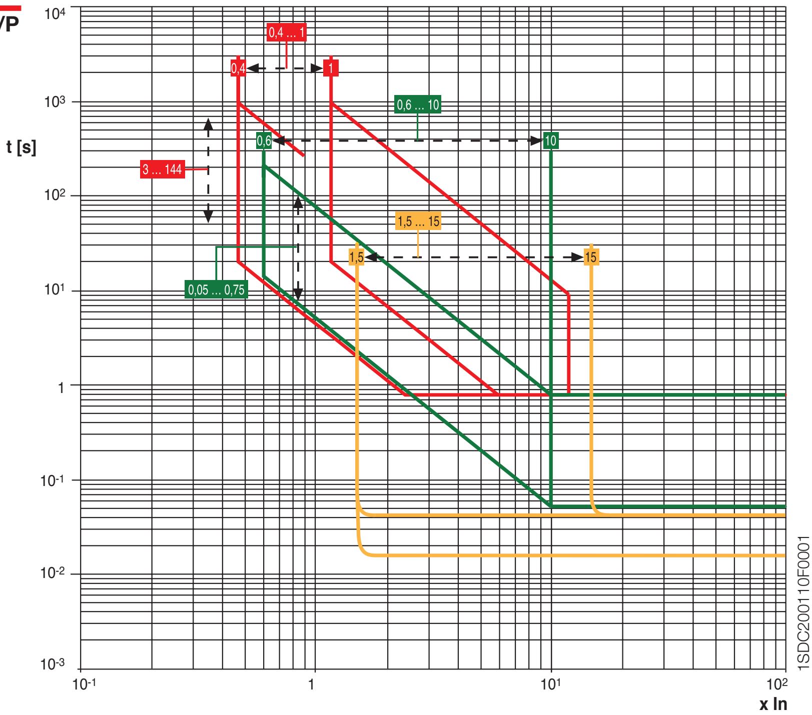


3 General characteristics

Trip curve
electronic releases

Emax
PR112/P-PR113/P

L-S-I Functions,
S inverse short
time delay
(I^2t = const.)

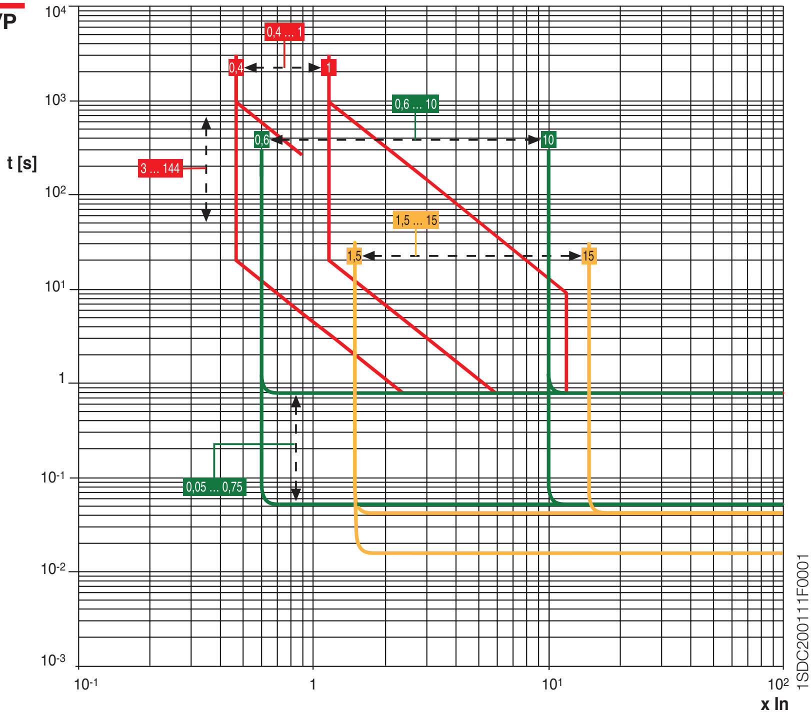


3 General characteristics

Trip curve
electronic releases

Emax
PR112/P-PR113/P

L-S-I Functions,
S indipendent
time delay
(t = constant)

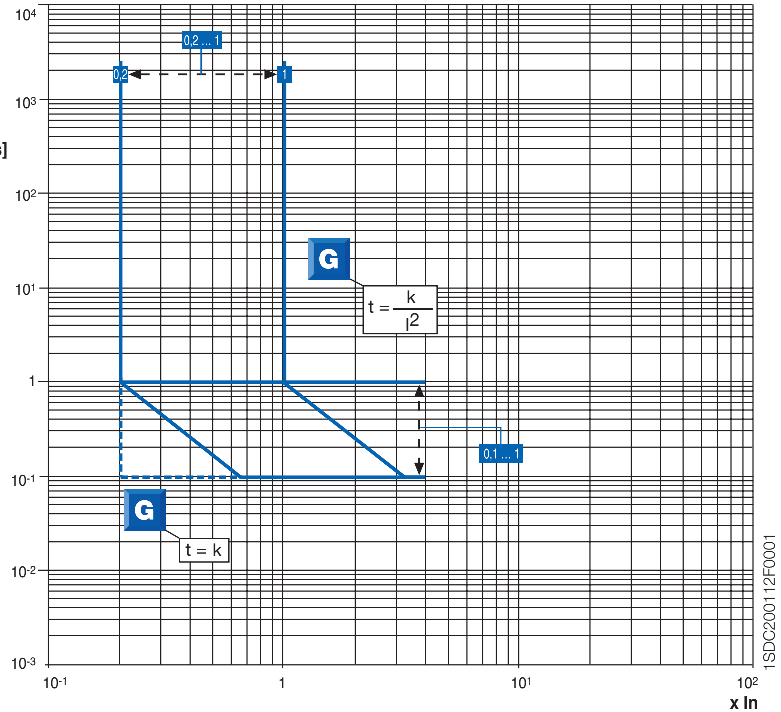


3 General characteristics

Trip curve
electronic releases

Emax
PR112/P-PR113/P

G Function



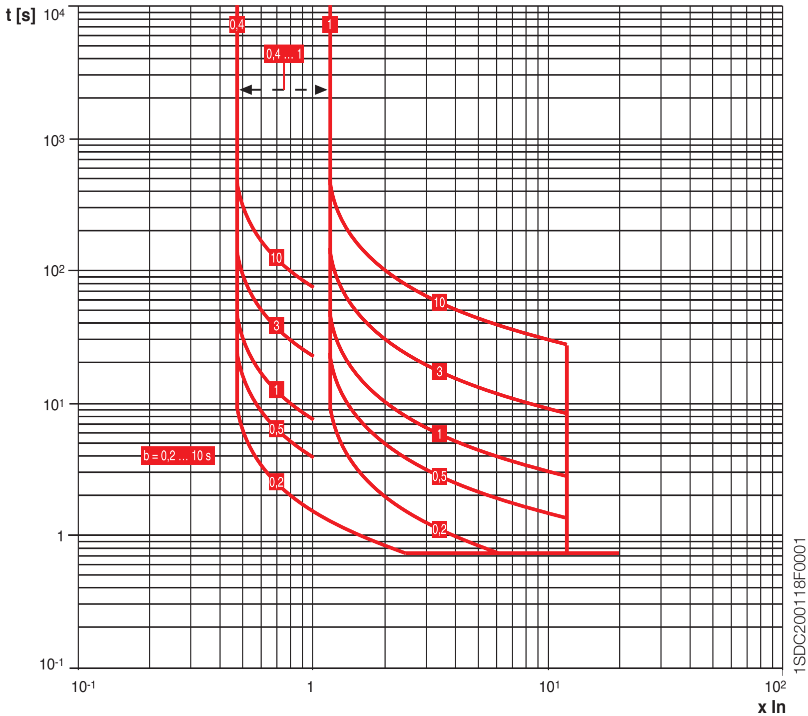
3 General characteristics

PR113/P release – Function L in compliance with Std. IEC 60255-3

The following three curves refer to the protection function L complying with Std. IEC 60255-3 and integrate the standard one; they are applicable in coordination with fuses and MV circuit-breakers.

Trip curve
electronic releases

L Function, Normal Inverse Curve



	I1	t1
PR113	(0.4 ÷ 1) x In with step 0.01 x In	b = 0.2 ÷ 10 with step 0.1 s

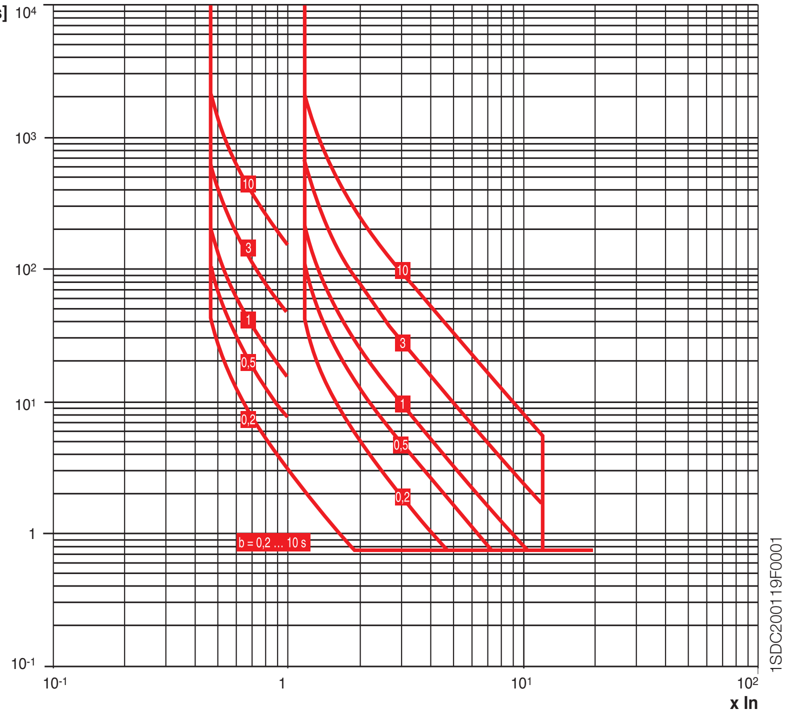
Here below the tolerances:

PR113	1.1÷1.25 x I1	± 30 % (2 ÷ 5) x In ± 20 % over 5 x In

3 General characteristics

Trip curve
electronic releases

L Function, Very Inverse Curve



	I1	t1
PR113	(0.4 ÷ 1) x In with step 0.01 x In	b = 0.2 ÷ 10 with step 0.1 s

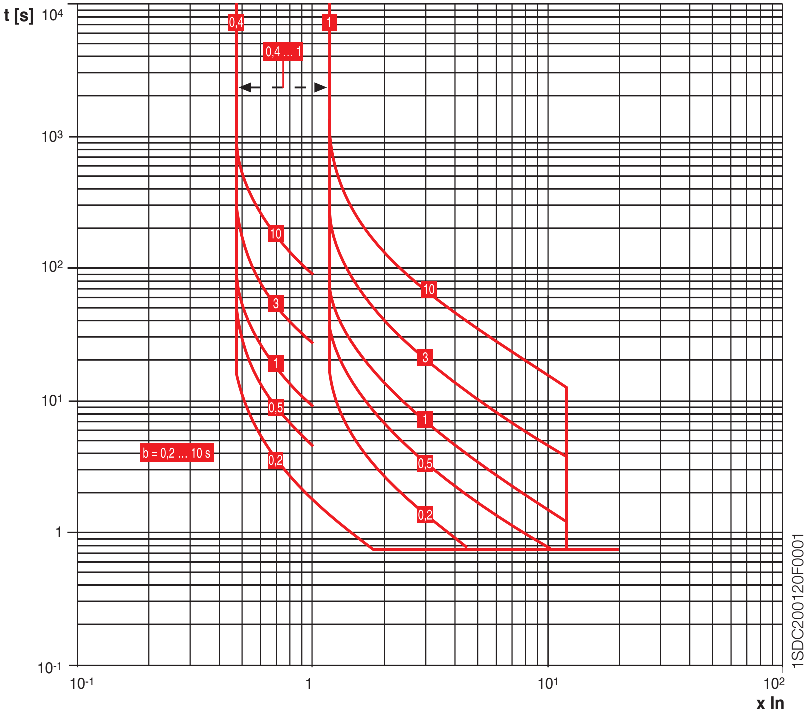
Here below the tolerances:

PR113	1.1÷1.25 x I1	± 30 % (2 ÷ 5) x In ± 20 % over 5 x In

3 General characteristics

Trip curve
electronic releases

L Function, Extremely Inverse Curve



	I1	t1
PR113	(0.4 ÷ 1) x In with step 0.01 x In	b = 0.2 ÷ 10 with step 0.1 s

Here below the tolerances:

PR113	1.1÷1.25 x I1	± 30 % (2 ÷ 5) x In ± 20 % over 5 x In

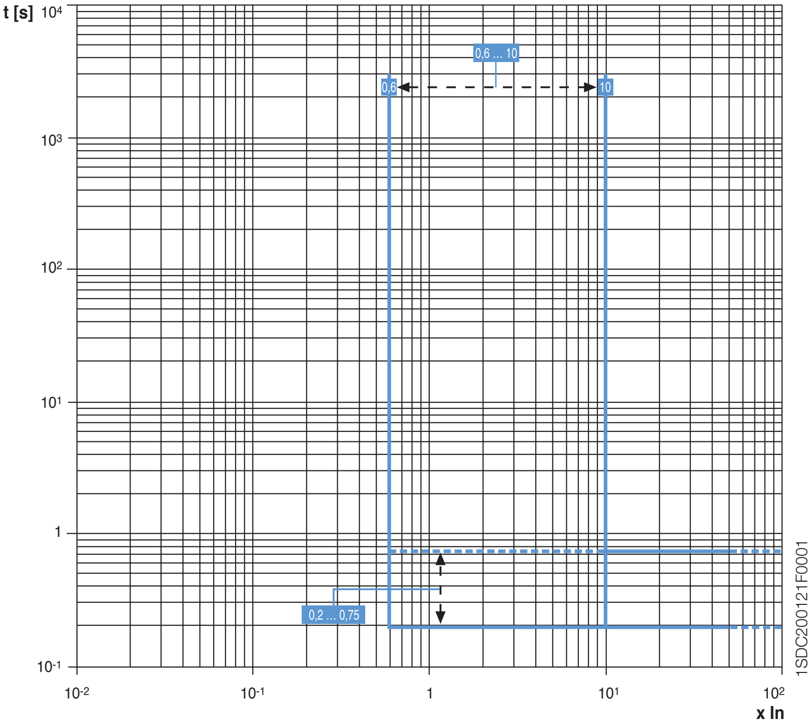
3 General characteristics

PR113/P release – Other protection functions

Trip curve
electronic releases

The following curves refer to the particular protection functions provided for PR113/P.

D Function, Directional Short Circuit Protection



	I7	t7
PR113	(0.6 … 10 – OFF) x In with step 0.1 x In	0.2 … 0.75s with step 0.01s

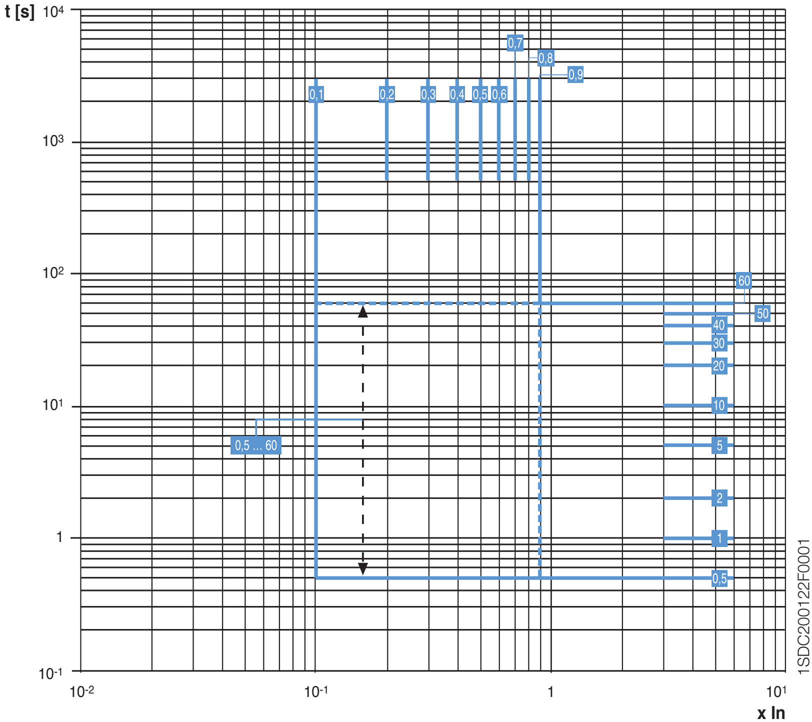
Here below the tolerances:

	I7	t7
PR113	± 10 %	± 20 %

3 General characteristics

Trip curve
electronic releases

U Function, Phase Unbalance Protection



	I6	t6
PR113	(10% … 90% – OFF) with step 10%	0.5 … 60s with step 0.5s

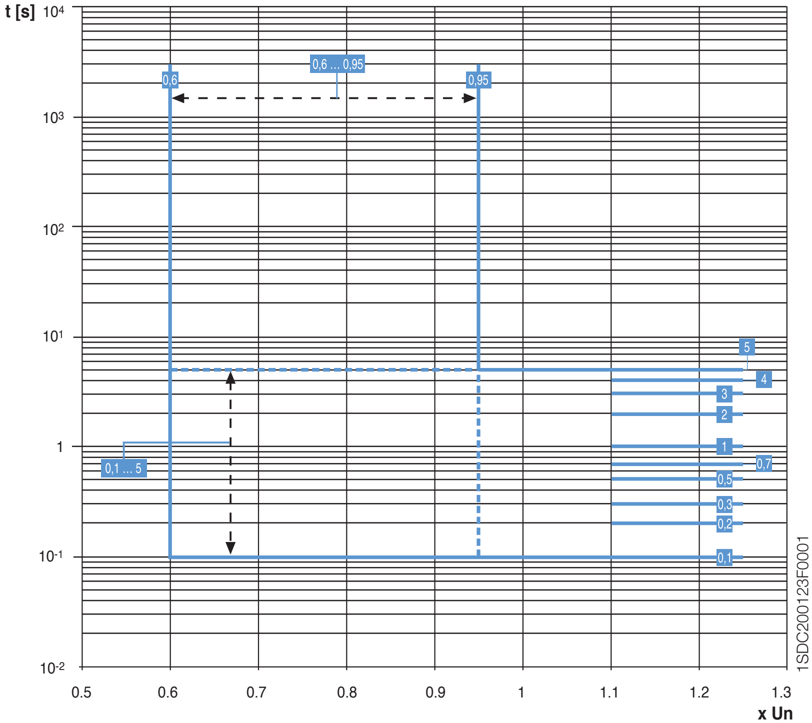
Here below the tolerances:

	I6	t6
PR113	± 10 %	± 20 %

3 General characteristics

Trip curve
electronic releases

UV Function, Undervoltage Protection



	I8	t8
PR113	(0.6 … 0.95 – OFF) x Un with step 0.01 x Un	0.1 … 5s with step 0.1s

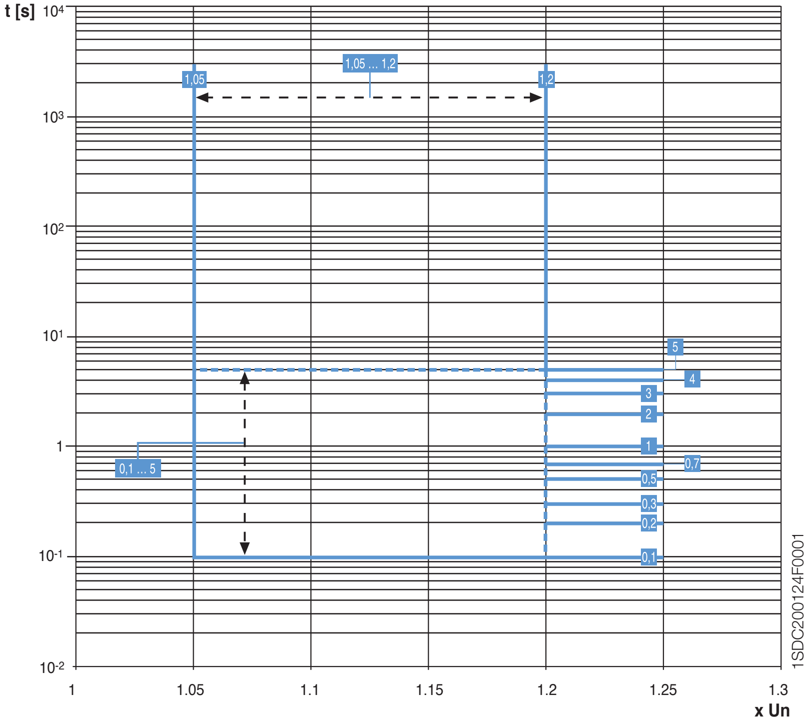
Here below the tolerances:

	I8	t8
PR113	± 5 %	± 20 %

3 General characteristics

Trip curve
electronic releases

OV Function, Overvoltage Protection



	I9	t9
PR113	(1.05 … 1.2 – OFF) x Un with step 0.01 x Un	0.1 … 5s with step 0.1s

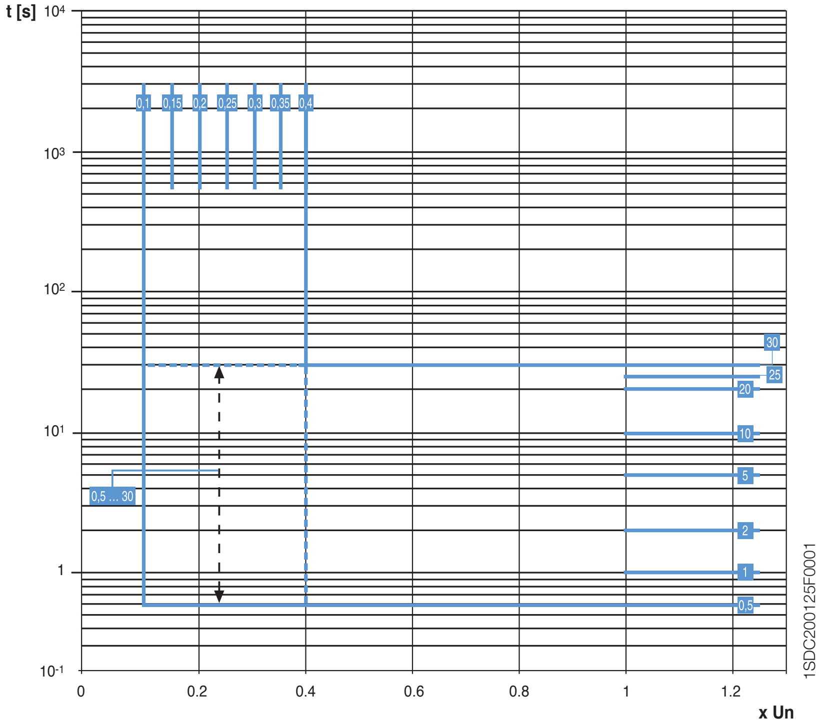
Here below the tolerances:

	I9	t9
PR113	± 5 %	± 20 %

3 General characteristics

Trip curve
electronic releases

RV Function, Residual Voltage Protection



	I10	t10
PR113	(0.1 … 0.4 – OFF) x Un with step 0.05 x Un	0.5 … 30s with step 0.5s

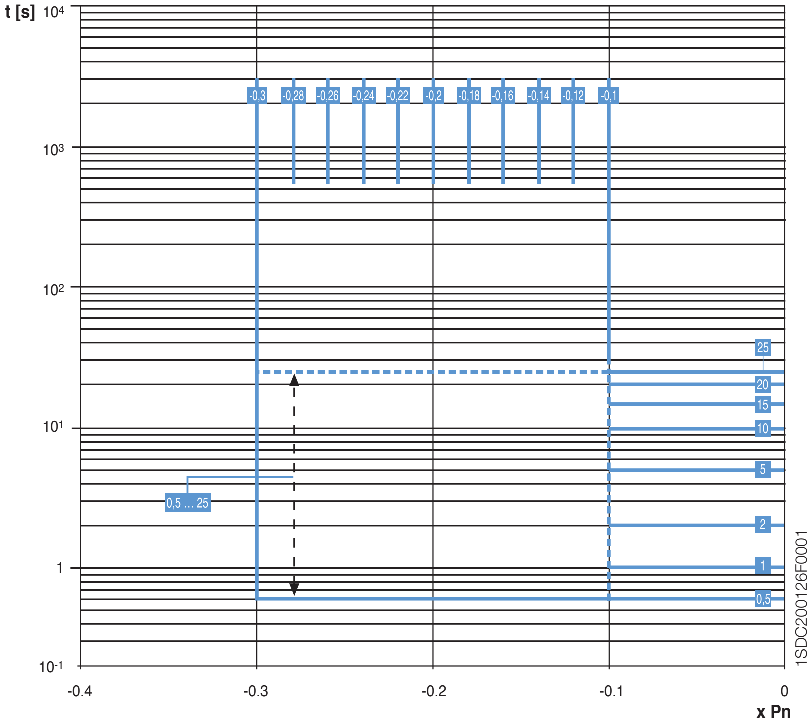
Here below the tolerances:

	I10	t10
PR113	± 5 %	± 20 %

3 General characteristics

Trip curve
electronic releases

RP Function, Reverse Power Protection



	P11	t11
PR113	(-0.3 … -0.1 – OFF) x Pn with step 0.02 x Pn	0.1 … 25s with step 0.1s

Here below the tolerances:

	P11	t11
PR113	± 10 %	± 20 %

3 General characteristics

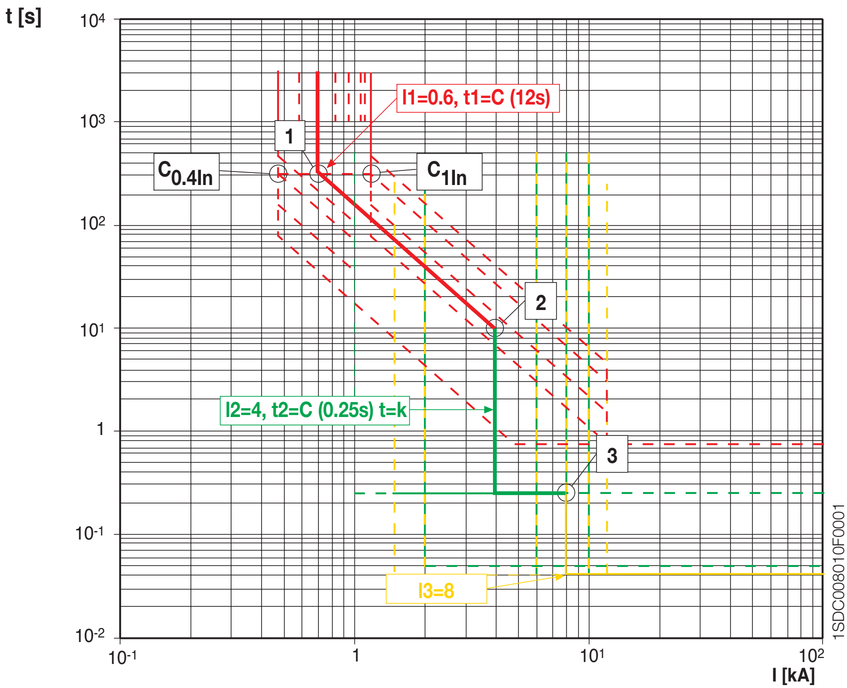
Example of electronic release setting

Considering a circuit-breaker type E1B1250 fitted with a PR111/P LSI release and with TA of 1000 A, it is supposed that for the system requirements, the protection functions are regulated according to the following settings:

L	I1=0.6	t1=C
S	I2=4	t2=C (t=k)
I	I3=8	

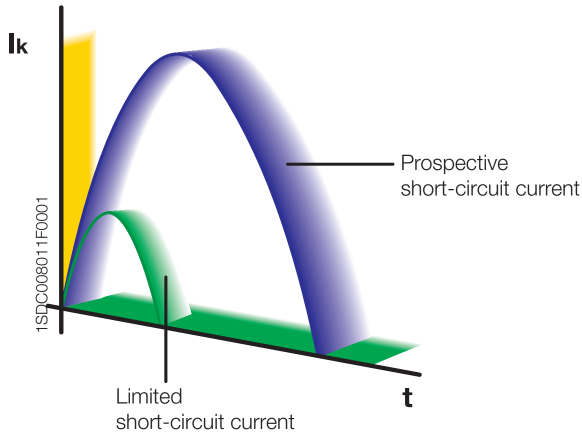
The trip curve of the release is represented in the following figure (continuous lines): it can be seen that:

- for function L, the curve is represented by the mean value between the tolerances given by the Standard (the overload protection function must not trip for current values lower than 1.05·In, and must trip within 1.3·In), therefore corresponding to 1.175·In (around 700 A);
- graphically, point **1** is obtained at the intersection of the vertical part of function L and the horizontal segment ($C_{0.4In}$-C_{1In}) which connects the points relevant to the same t1, taken from the curves with setting 0.4·In and 1·In;
- corresponding to point **2** (4000 A), the function S takes the place of function L, as the trip time of function S is lower than the trip time of function L;
- in the same way as for point **2**, for point **3** (8000 A) and beyond, function S is substituted by function I.



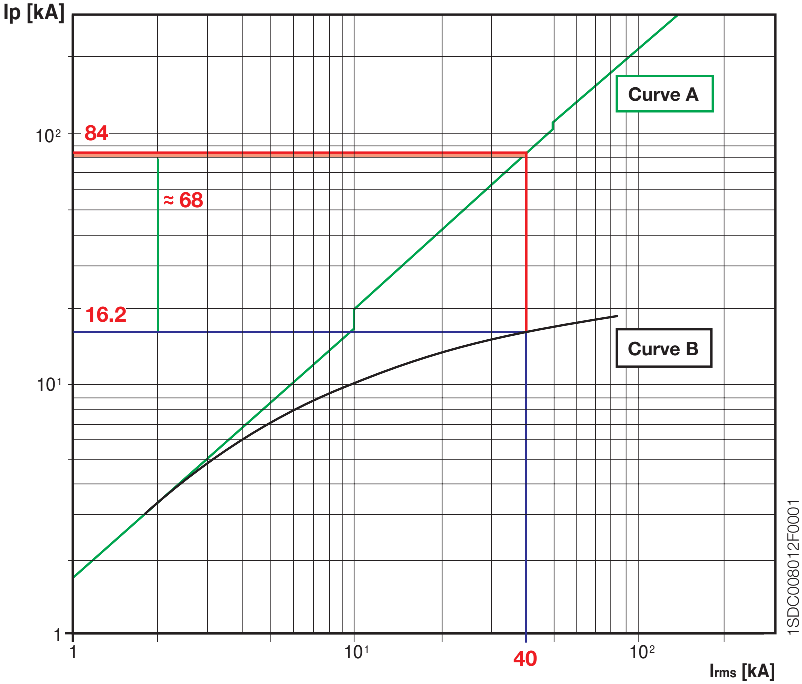
3.3 Limitation curves

A circuit-breaker in which the opening of the contacts occurs after the passage of the peak of the short-circuit current, or in which the trip occurs with the natural passage to zero, allows the system components to be subjected to high stresses, of both thermal and dynamic type. To reduce these stresses, current-limiting circuit-breakers have been designed (see Chapter 2.2 "Main definitions"), which are able to start the opening operation before the short-circuit current has reached its first peak, and to quickly extinguish the arc between the contacts; the following diagram shows the shape of the waves of both the prospective short-circuit current as well as of the limited short-circuit current.



The following diagram shows the limit curve for Tmax T2L160, In160 circuit-breaker. The x-axis shows the effective values of the symmetrical prospective short-circuit current, while the y-axis shows the relative peak value. The limiting effect can be evaluated by comparing, at equal values of symmetrical fault current, the peak value corresponding to the prospective short-circuit current (curve A) with the limited peak value (curve B).
Circuit-breaker T2L160 with thermomagnetic release In160 at 400 V, for a fault current of 40 kA, limits the short-circuit peak to 16.2 kA only, with a reduction of about 68 kA compared with the peak value in the absence of limitation (84 kA).

3 General characteristics



Considering that the electro-dynamic stresses and the consequent mechanical stresses are closely connected to the current peak, the use of current limiting circuit-breakers allows optimum dimensioning of the components in an electrical plant. Besides, current limitation may also be used to obtain back-up protection between two circuit-breakers in series.
In addition to the advantages in terms of design, the use of current-limiting circuit-breakers allows, for the cases detailed by Standard IEC 60439-1, the avoidance of short-circuit withstand verifications for switchboards. Clause 8.2.3.1 of the Standard "Circuits of ASSEMBLIES which are exempted from the verification of the short-circuit withstand strength" states that:

"A verification of the short-circuit withstand strength is not required in the following cases.
…
For ASSEMBLIES protected by current-limiting devices having a cut-off current not exceeding 17 kA at the maximum allowable prospective short-circuit current at the terminals of the incoming circuit of the ASSEMBLY.
…"

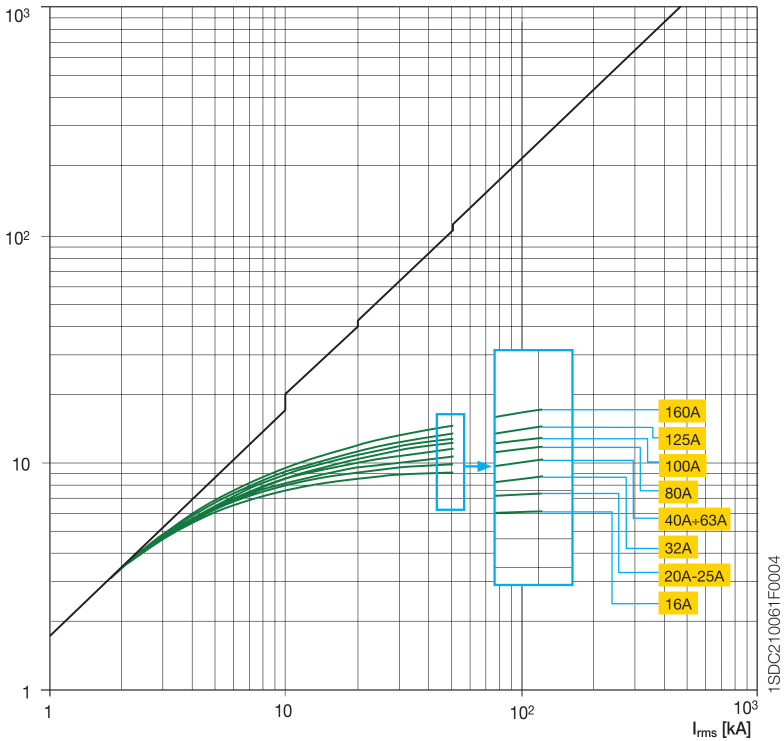
The example above is included among those considered by the Standard: if the circuit-breaker was used as a main breaker in a switchboard to be installed in a point of the plant where the prospective short-circuit current is 40 kA, it would not be necessary to carry out the verification of short-circuit withstand.

3 General characteristics

Limitation curves

T1 160

230 V

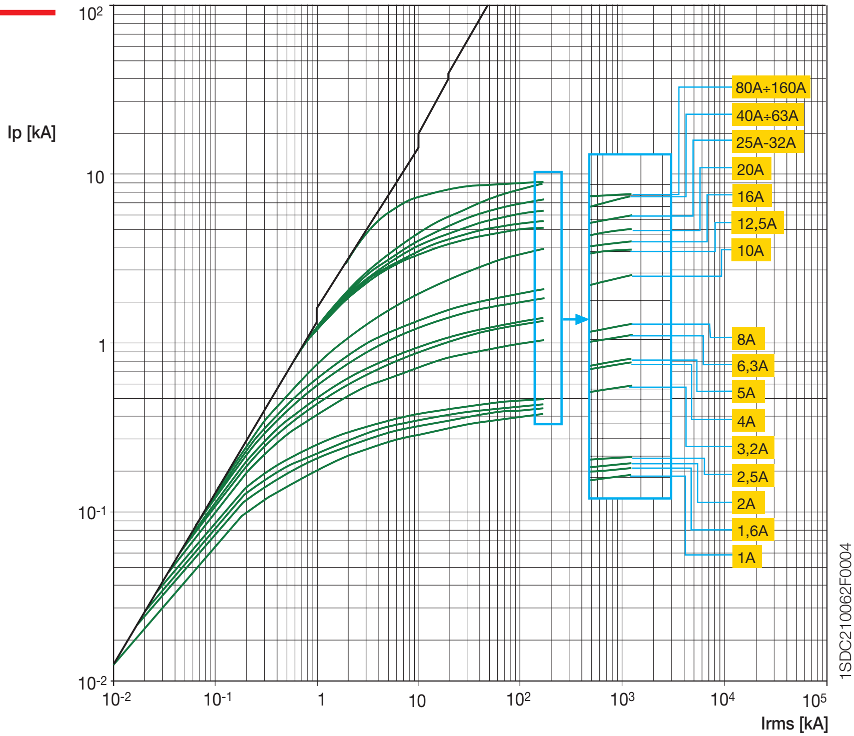


3 General characteristics

Limitation curves

T2 160

230 V

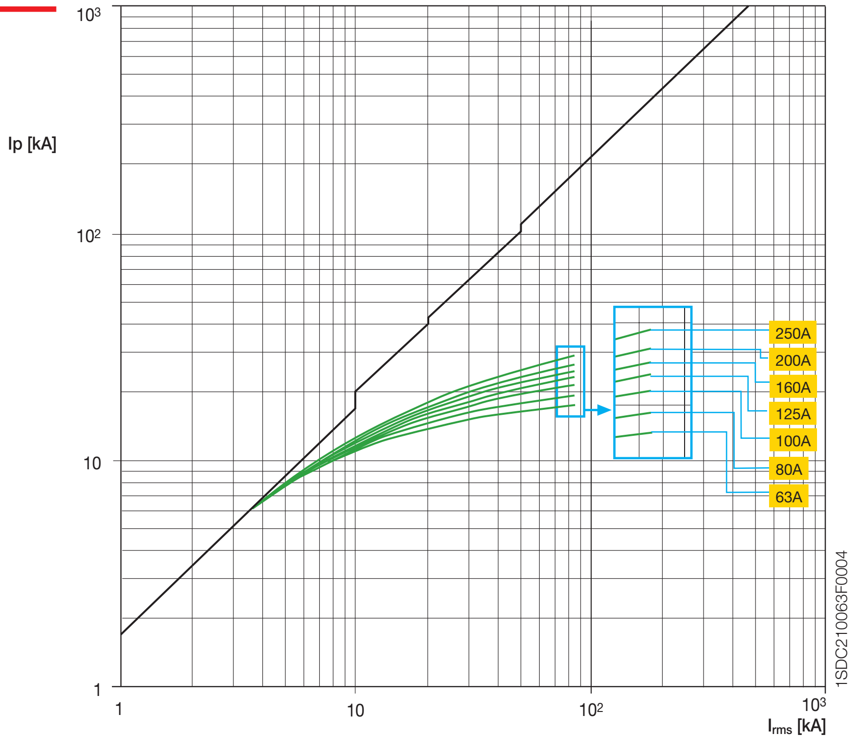


3 General characteristics

Limitation curves

T3 250

230 V

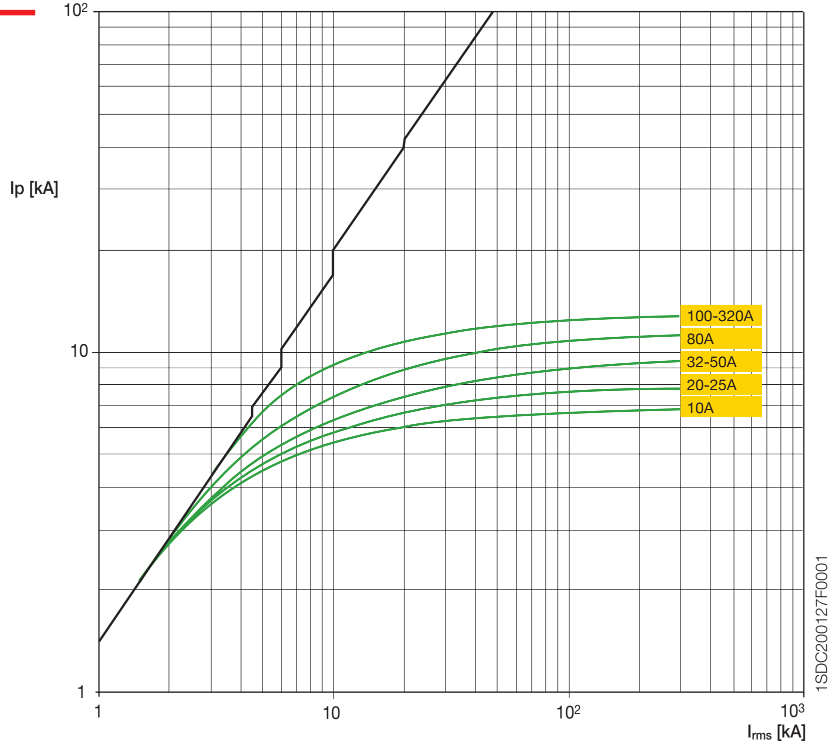


3 General characteristics

Limitation curves

T4 250/320

230 V

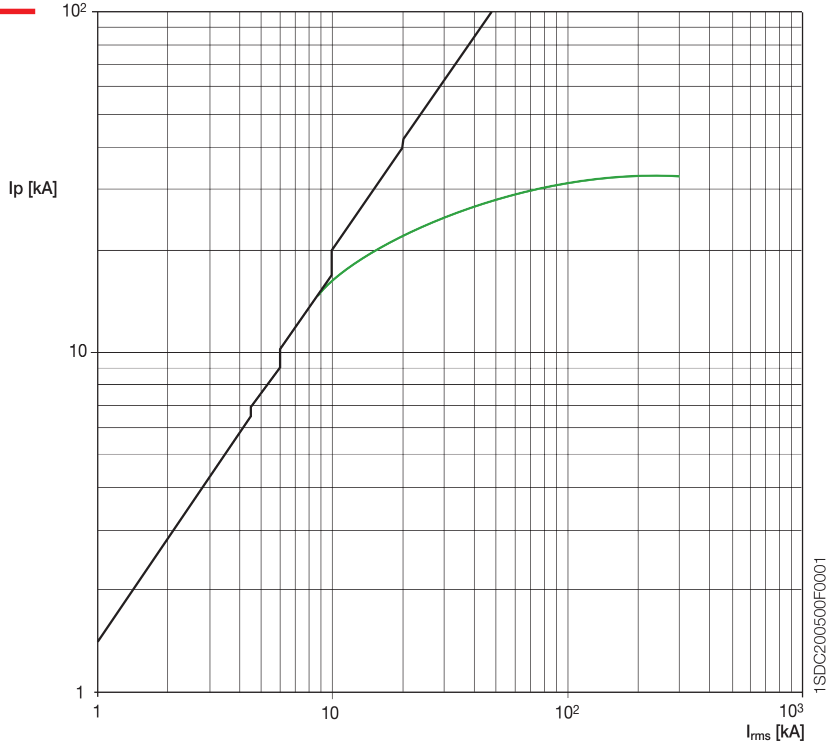


3 General characteristics

Limitation curves

T5 400/630

230 V

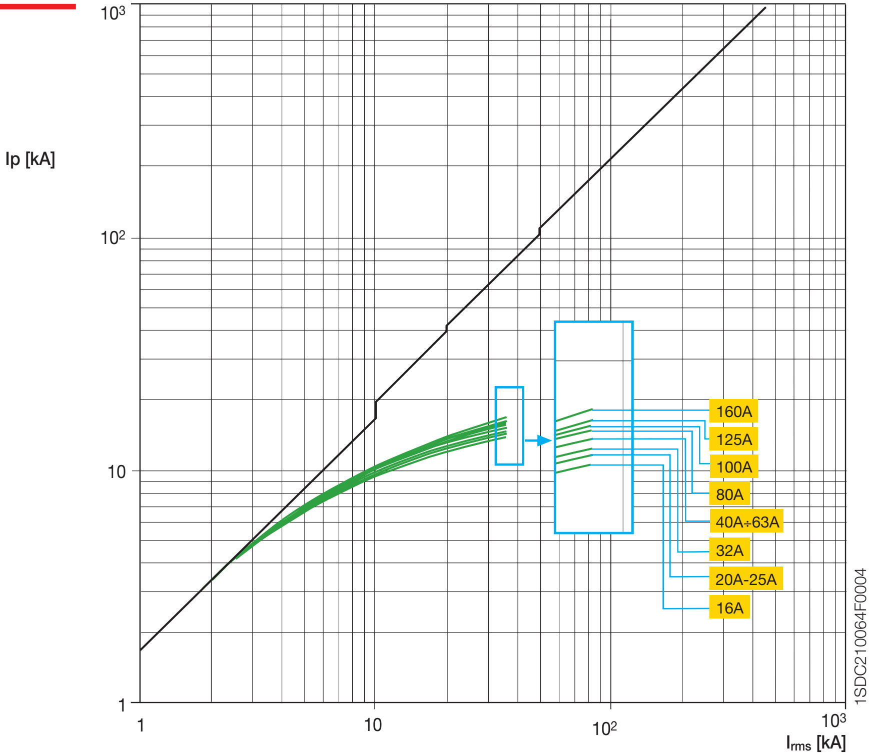


3 General characteristics

Limitation curves

T1 160

400-440 V

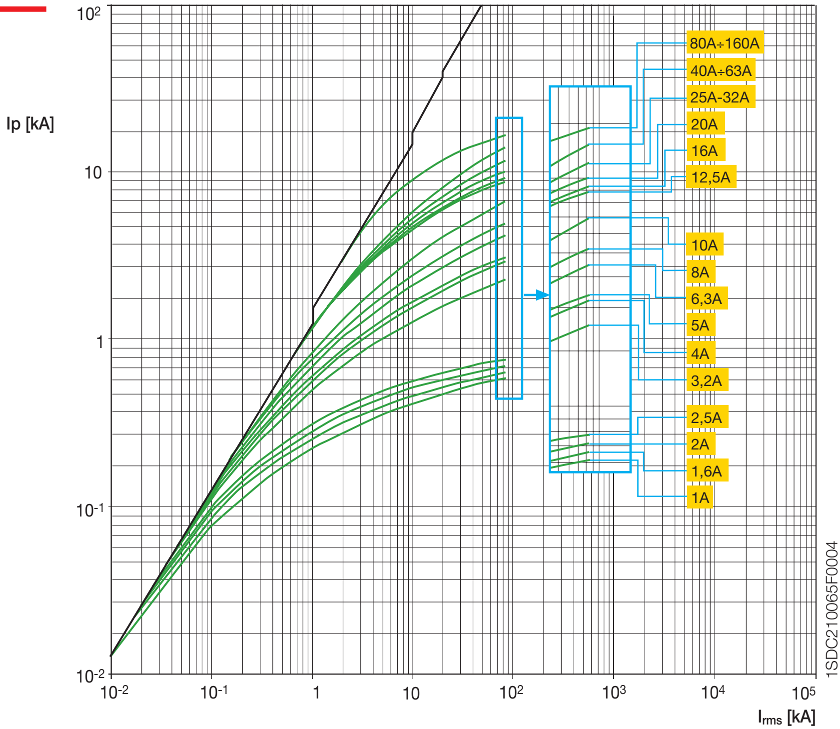


3 General characteristics

Limitation curves

T2 160

400-440 V

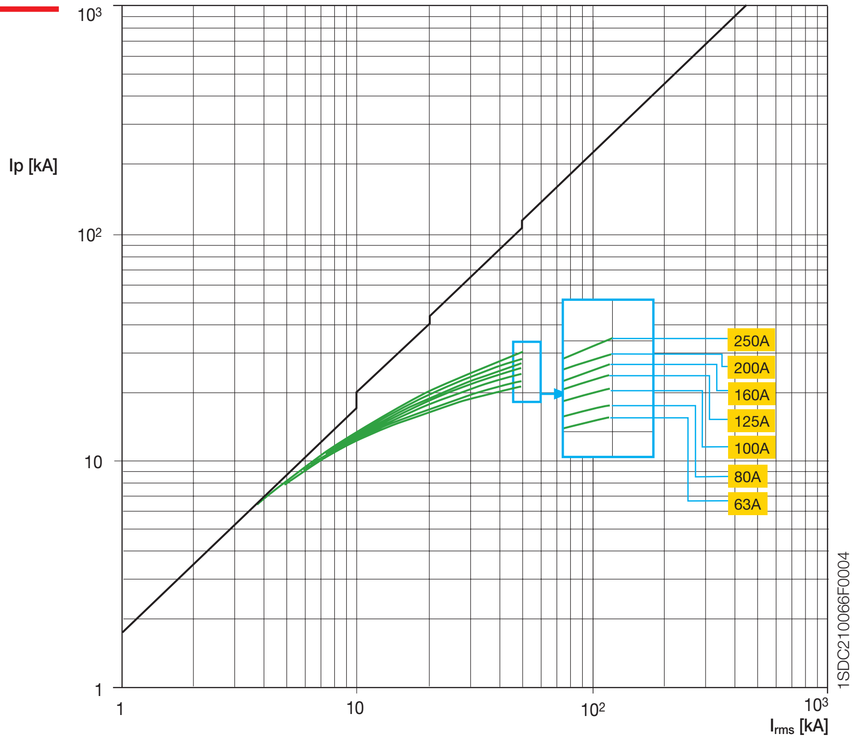


3 General characteristics

Limitation curves

T3 250

400-440 V

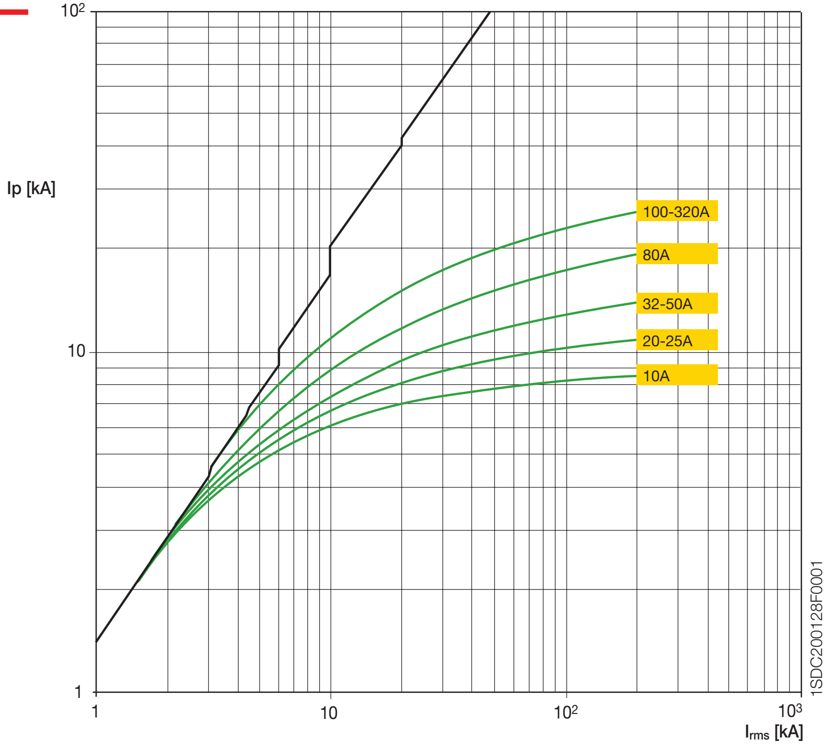


3 General characteristics

Limitation curves

T4 250/320

400-440 V

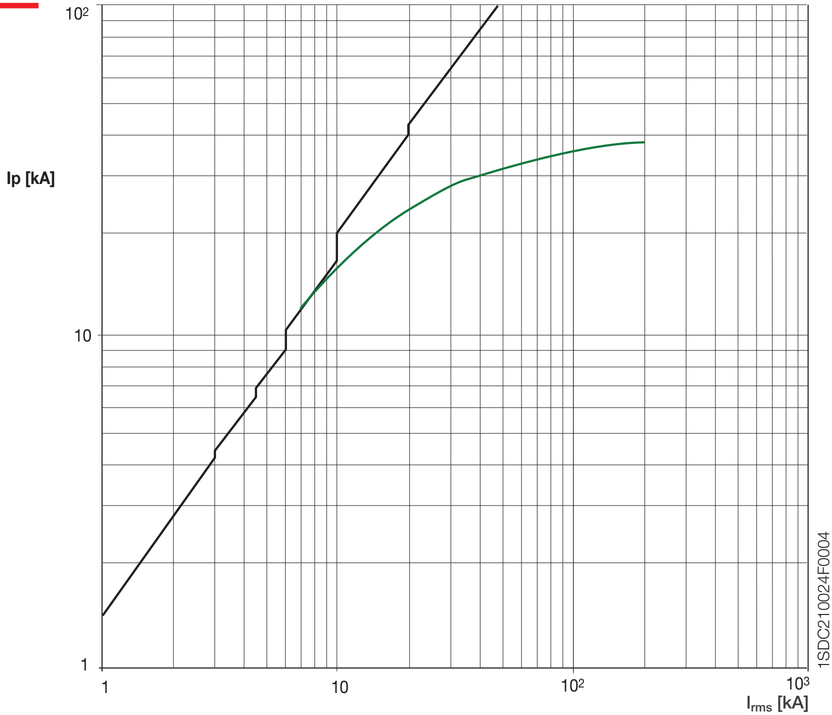


3 General characteristics

Limitation curves

T5 400/620

400-440 V

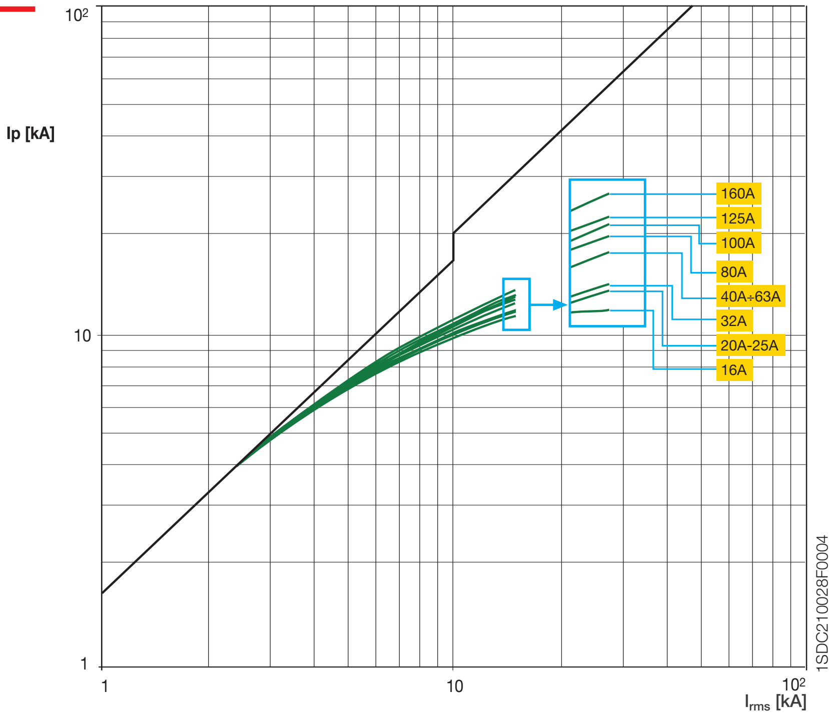


3 General characteristics

Limitation curves

T1 160

500 V

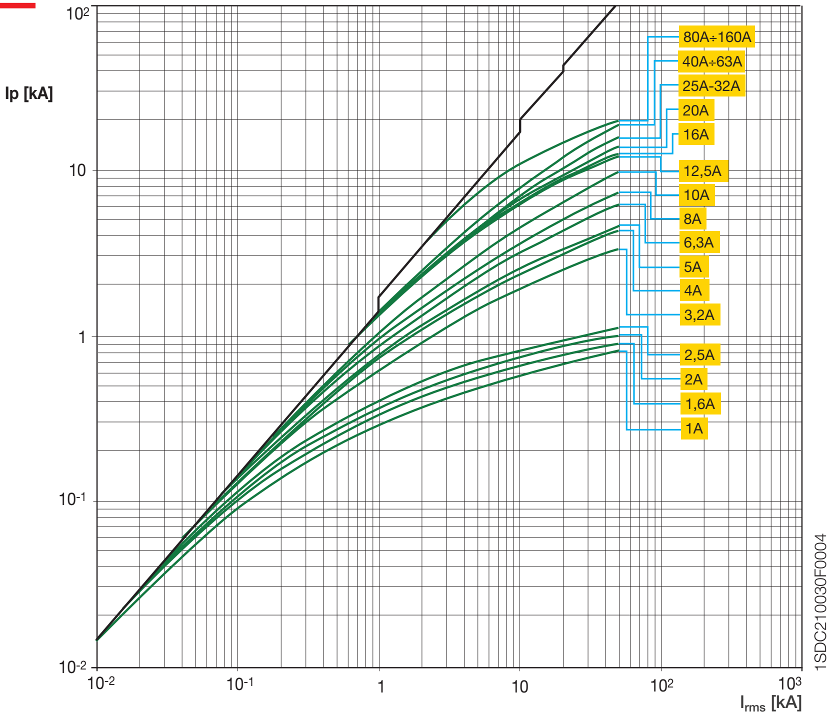


3 General characteristics

Limitation curves

T2 160

500 V

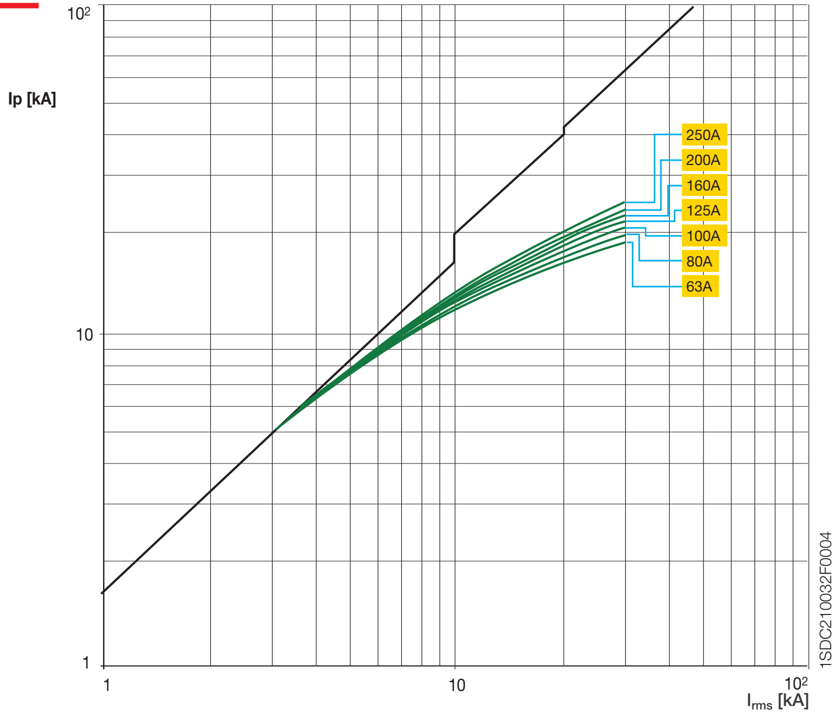


3 General characteristics

Limitation curves

T3 250

500 V

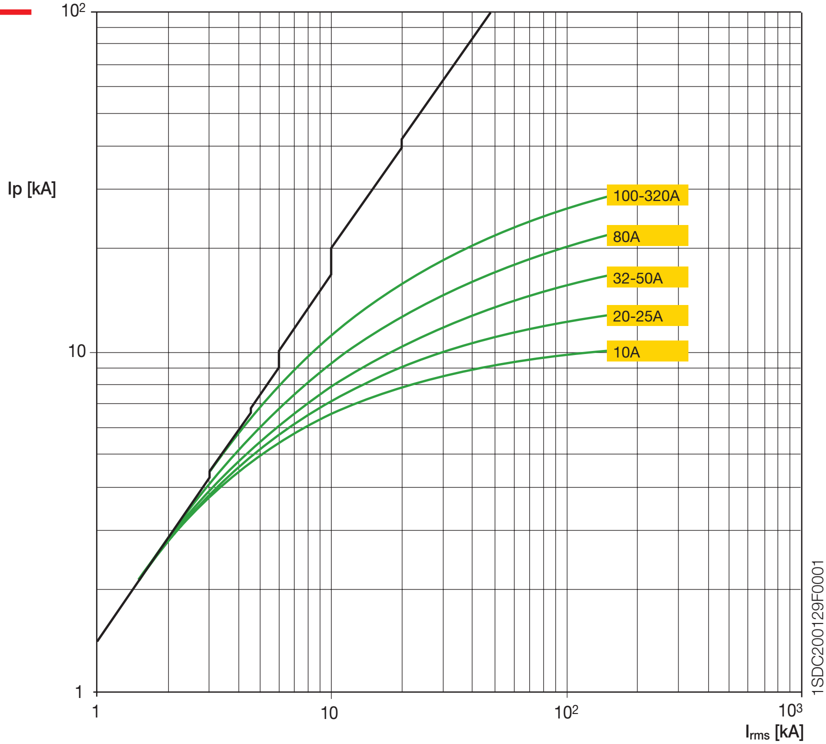


3 General characteristics

Limitation curves

T4 250/320

500 V

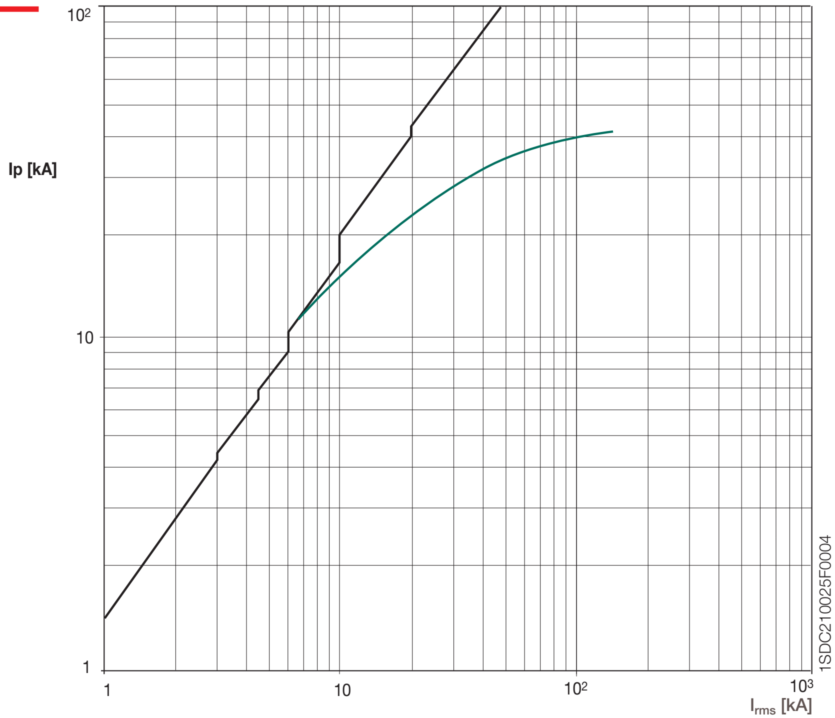


3 General characteristics

Limitation curves

T5 400/630

500 V

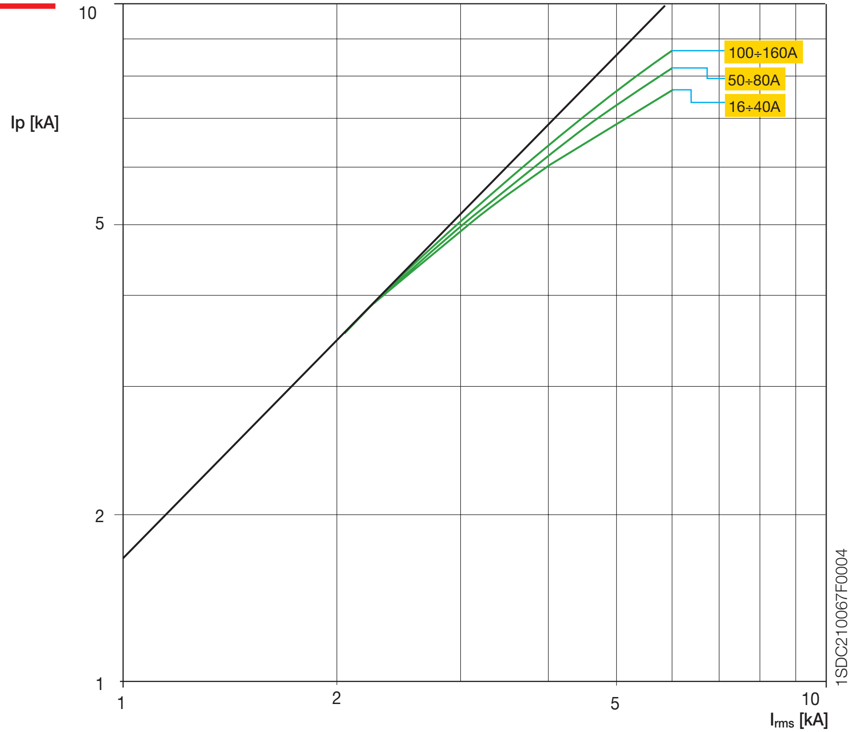


3 General characteristics

Limitation curves

T1 160

690 V

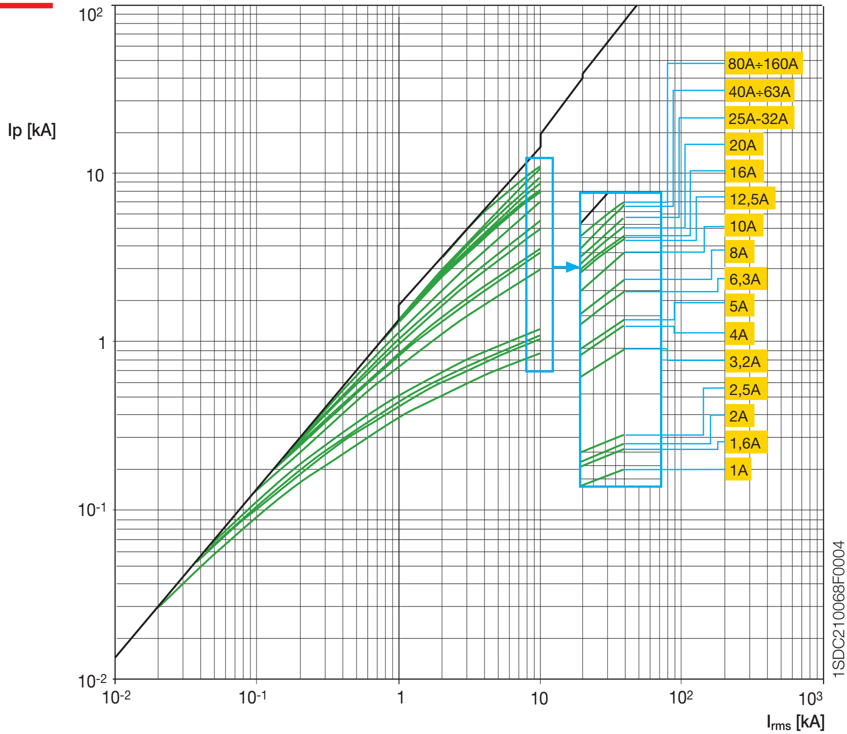


3 General characteristics

Limitation curves

T2 160

690 V

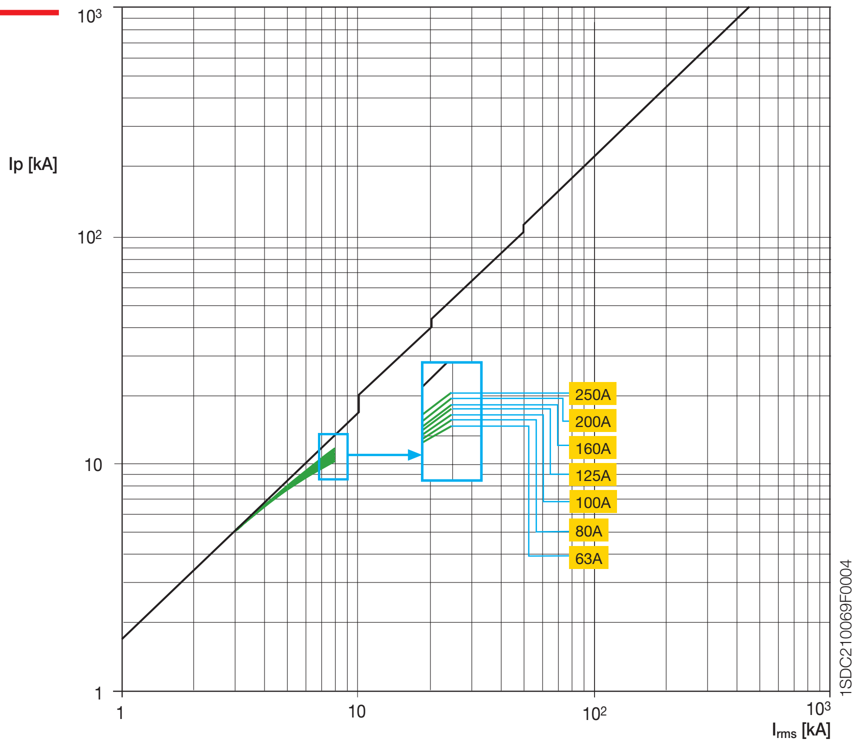


3 General characteristics

Limitation curves

T3 250

690 V

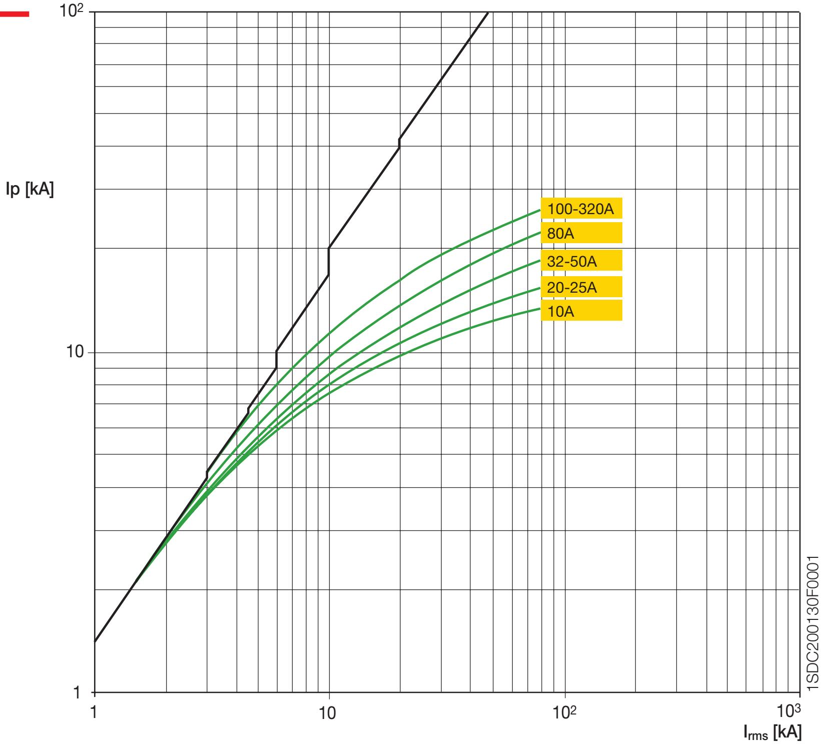


3 General characteristics

Limitation curves

T4 250/320

690 V

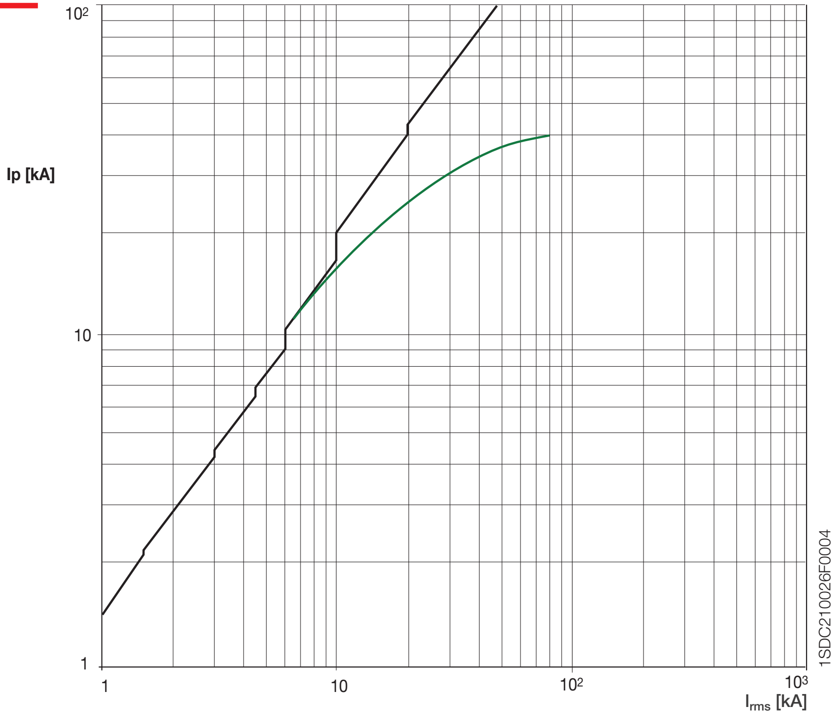


3 General characteristics

Limitation curves

T5 400/630

690 V

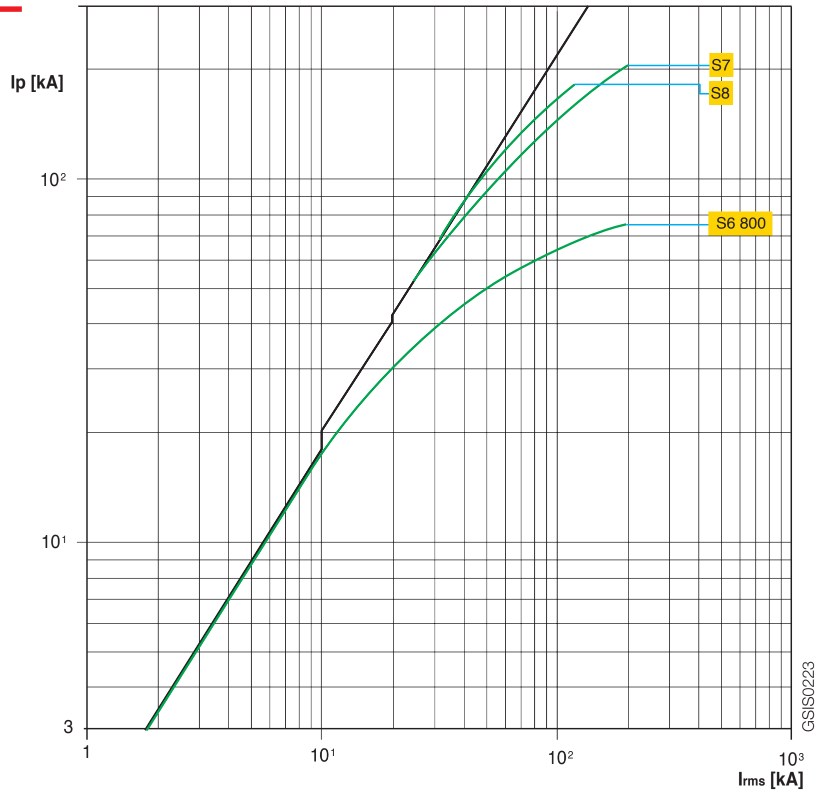


3 General characteristics

Limitation curves

S6 800 - S7 - S8

230 V

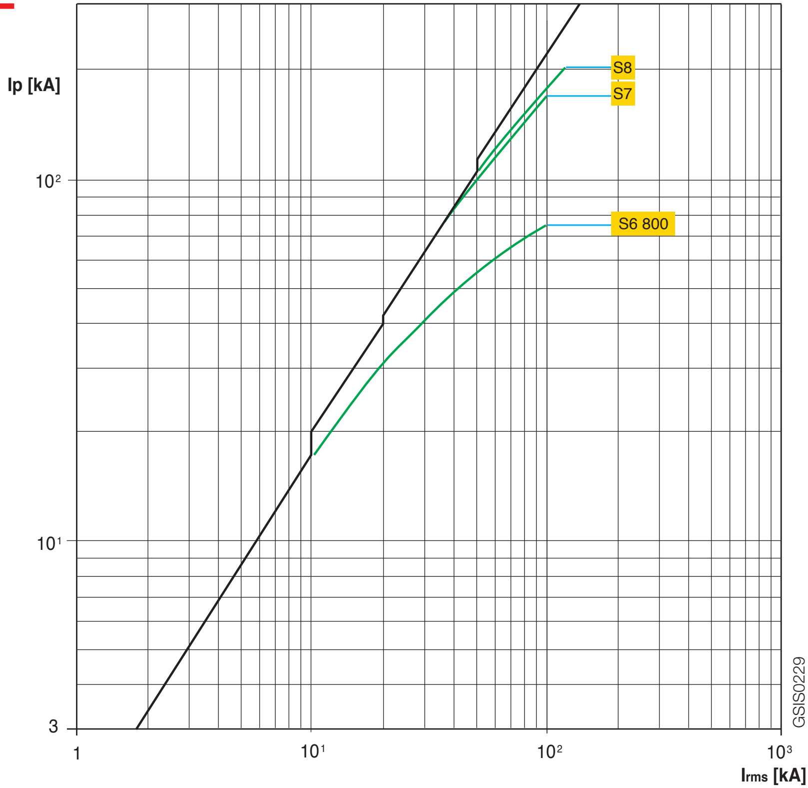


3 General characteristics

Limitation curves

S6 800 - S7 - S8

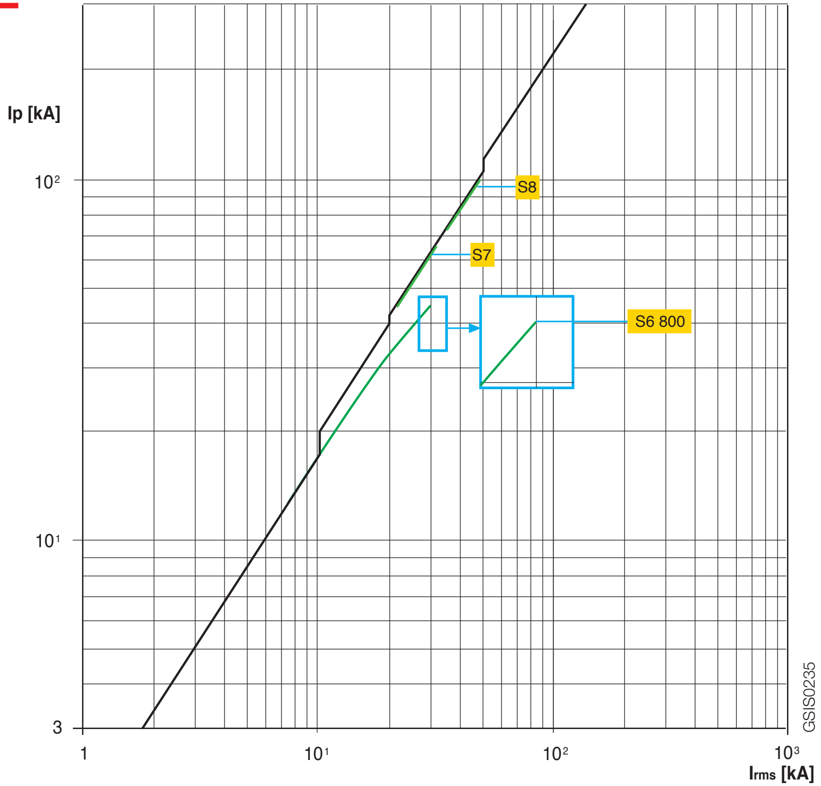
400-440 V



3 General characteristics

S6 800 - S7 - S8

690 V

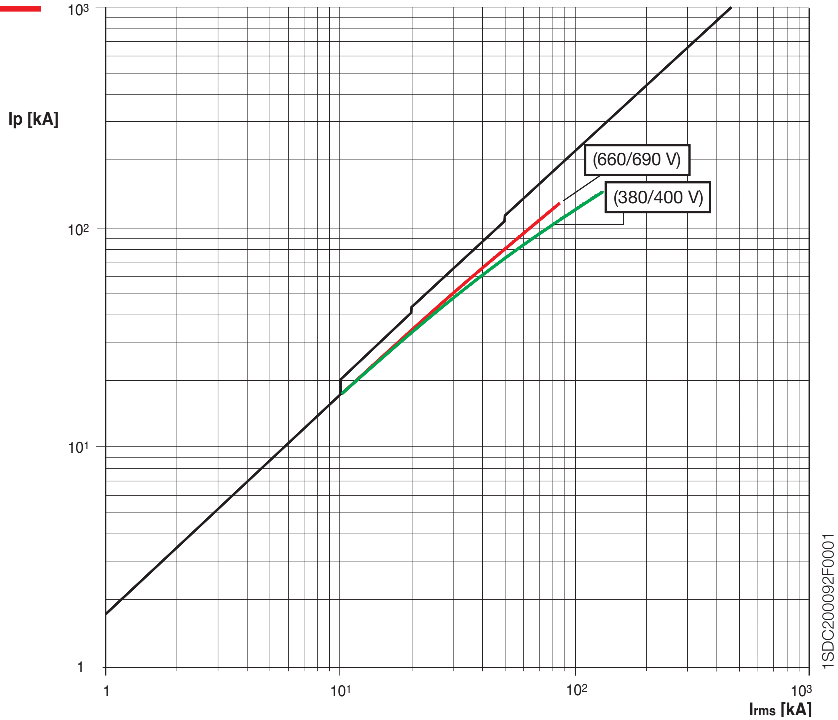


3 General characteristics

Limitation curves

E2L

660/690 V
380/400 V

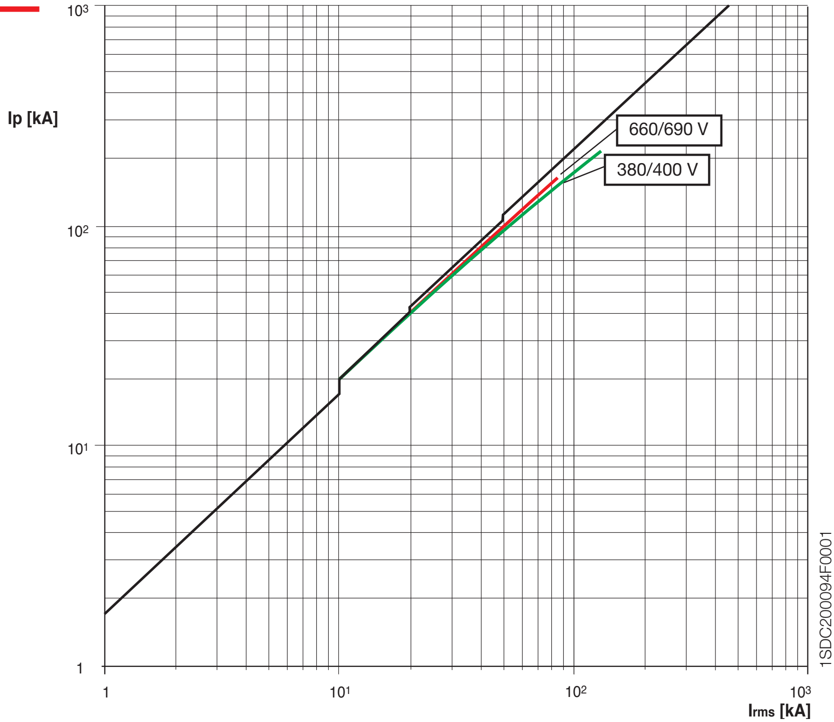


3 General characteristics

Limitation curves

E3L

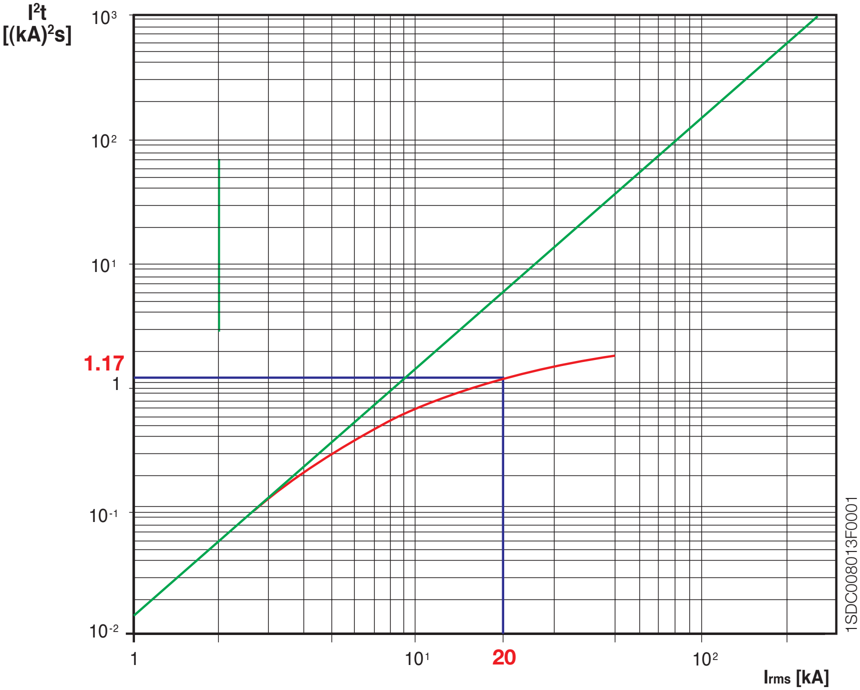
660/690 V
380/400 V



3.4 Specific let-through energy curves

In case of short-circuit, the parts of a plant affected by a fault are subjected to thermal stresses which are proportional both to the square of the fault current as well as to the time required by the protection device to break the current. The energy let through by the protection device during the trip is termed "specific let-through energy" (I^2t), measured in A^2s. The knowledge of the value of the specific let-through energy in various fault conditions is fundamental for the dimensioning and the protection of the various parts of the installation.
The effect of limitation and the reduced trip times influence the value of the specific let-through energy. For those current values for which the tripping of the circuit-breaker is regulated by the timing of the release, the value of the specific let-through energy is obtained by multiplying the square of the effective fault current by the time required for the protection device to trip; in other cases the value of the specific let-through energy may be obtained from the following diagrams.

The following is an example of the reading from a diagram of the specific let-through energy curve for a circuit-breaker type T3S 250 In160 at 400 V.
The x-axis shows the symmetrical prospective short-circuit current, while the y-axis shows the specific let-through energy values, expressed in $(kA)^2s$.
Corresponding to a short-circuit current equal to 20 kA, the circuit-breaker lets through a value of I^2t equal to 1.17 $(kA)^2s$ (1170000 A^2s).

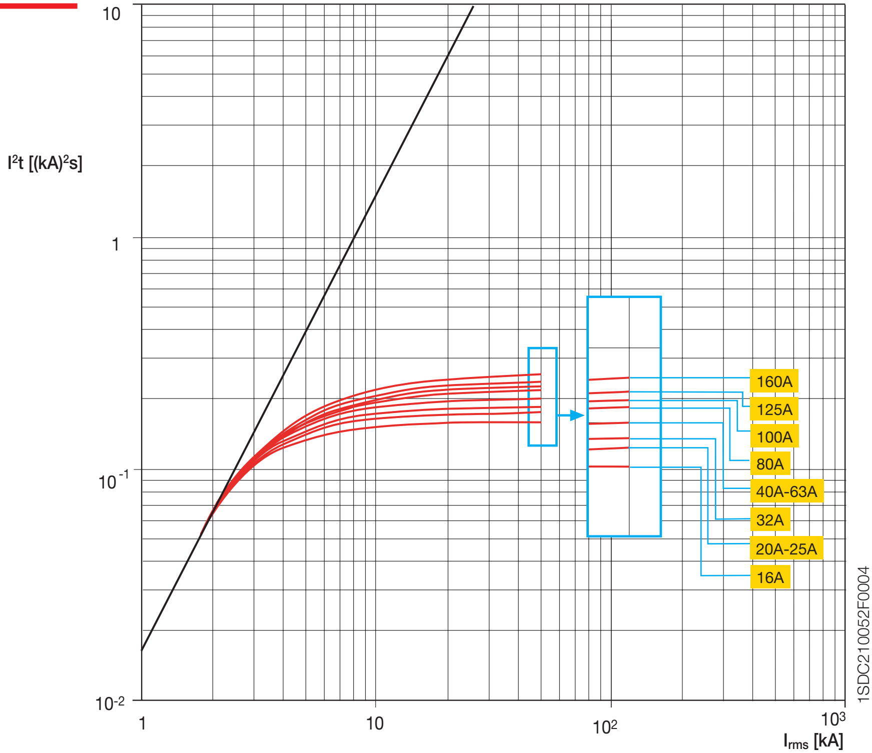


3 General characteristics

Specific let-through energy curves

T1 160

230 V

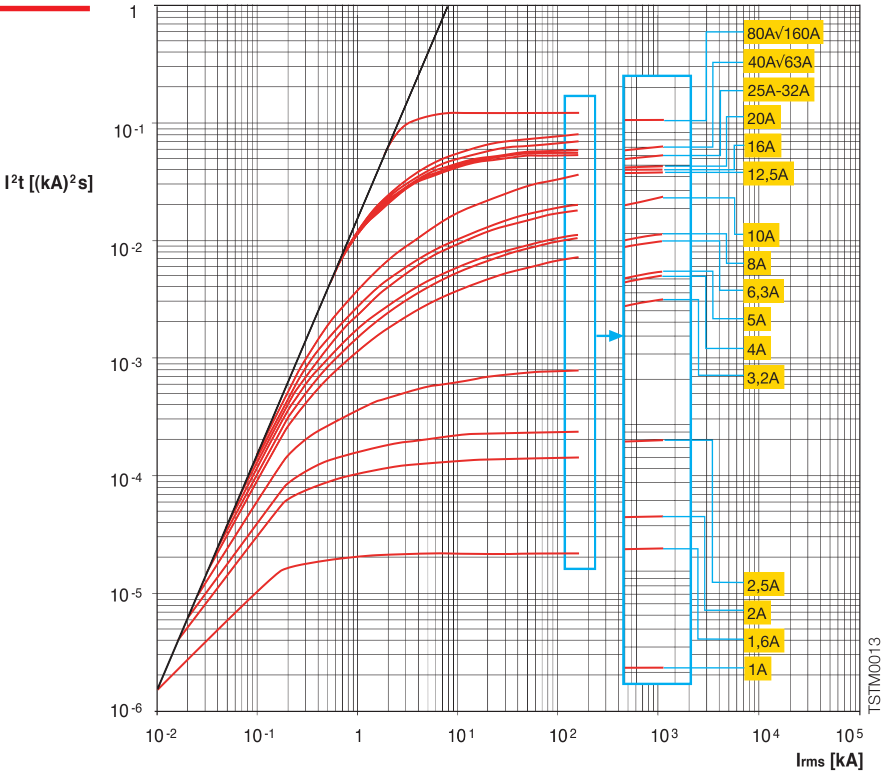


3 General characteristics

Specific let-through energy curves

T2 160

230 V

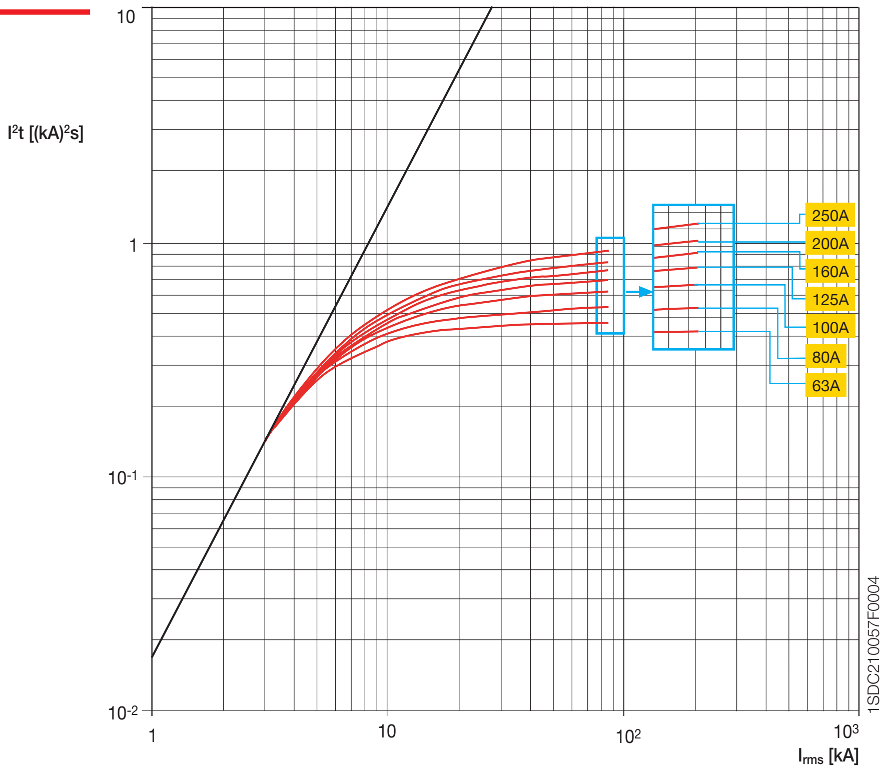


3 General characteristics

Specific let-through energy curves

T3 250

230 V

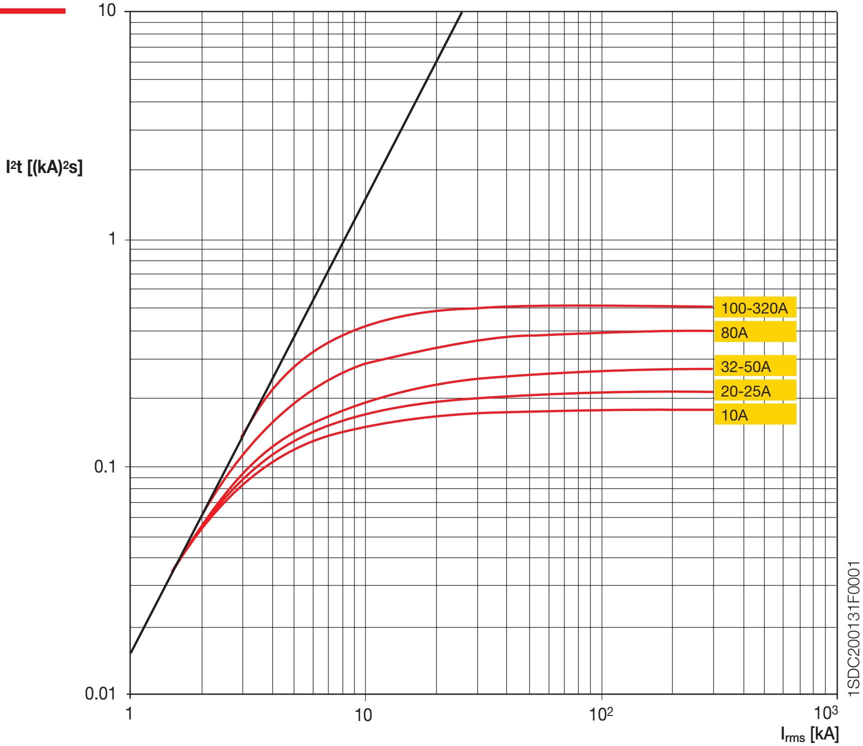


3 General characteristics

Specific let-through energy curves

T4 250/320

230 V

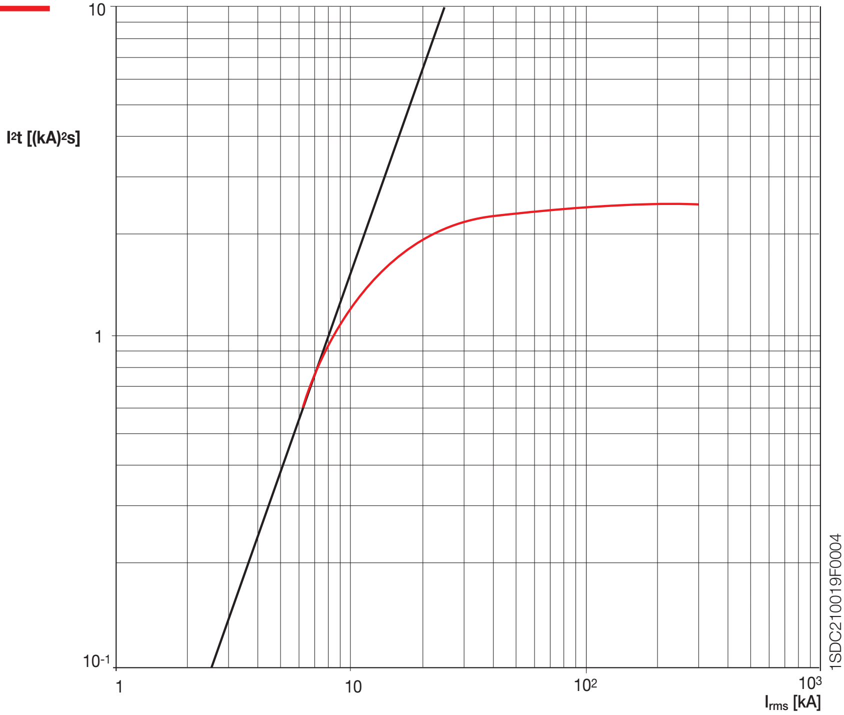


3 General characteristics

Specific let-through energy curves

T5 400/630

230 V

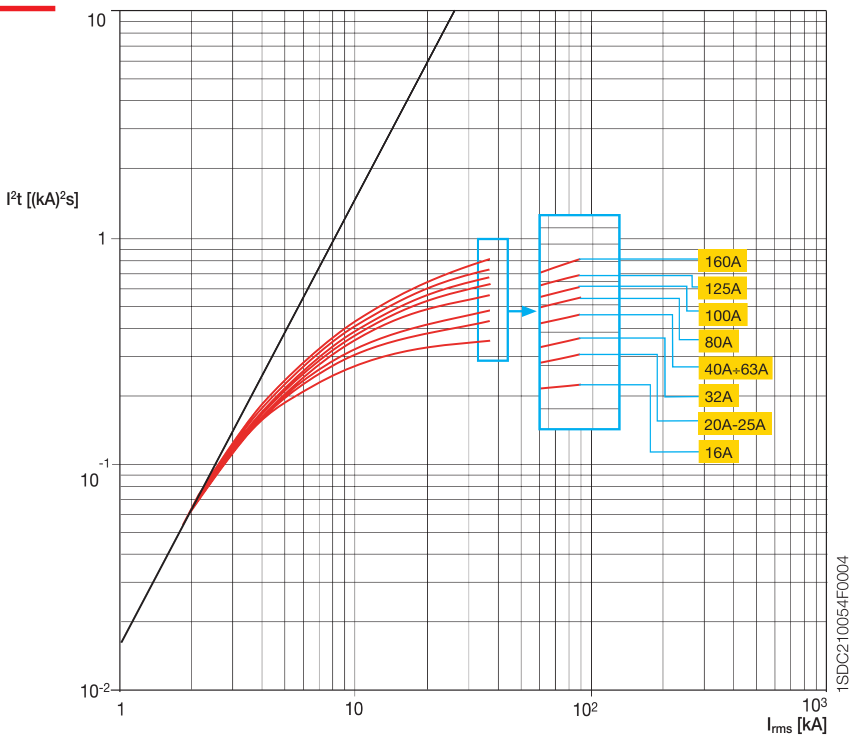


3 General characteristics

Specific let-through energy curves

T1 160

400-440 V

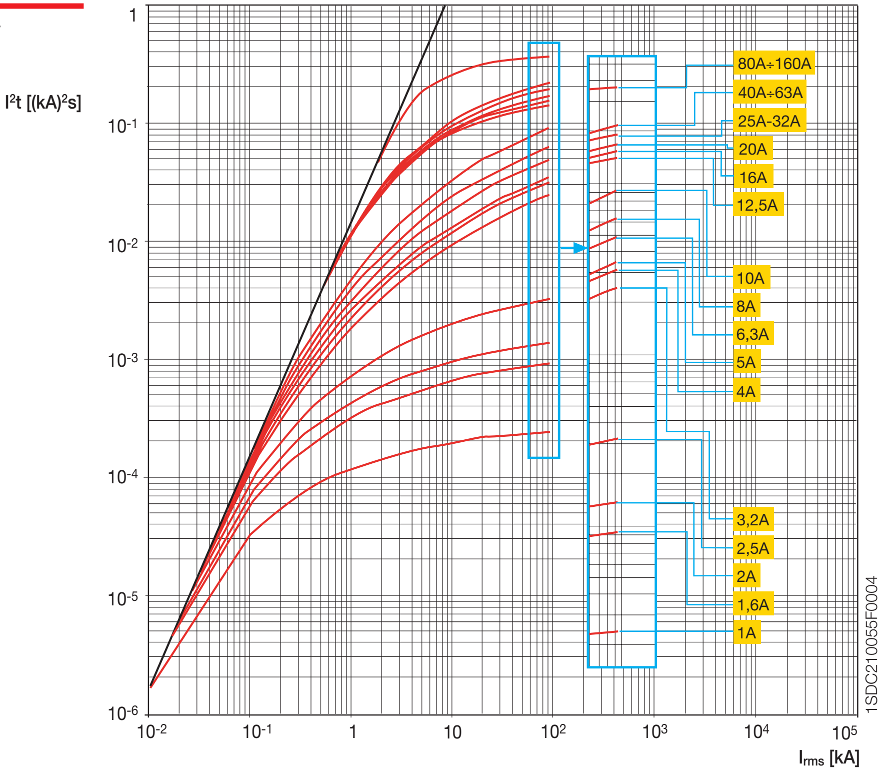


3 General characteristics

Specific let-through energy curves

T2 160

400-440 V

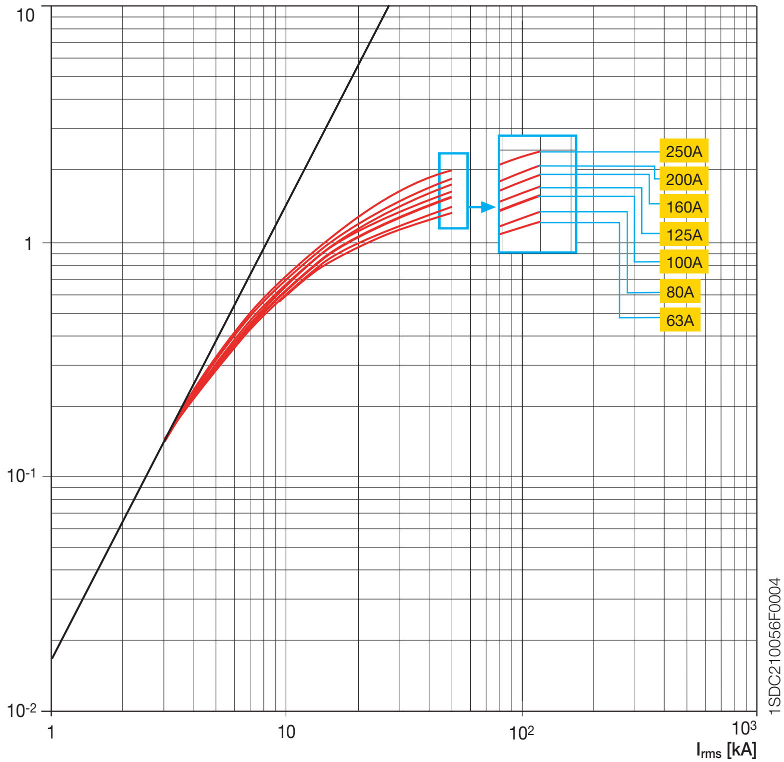


3 General characteristics

Specific let-through energy curves

T3 250

400-440 V

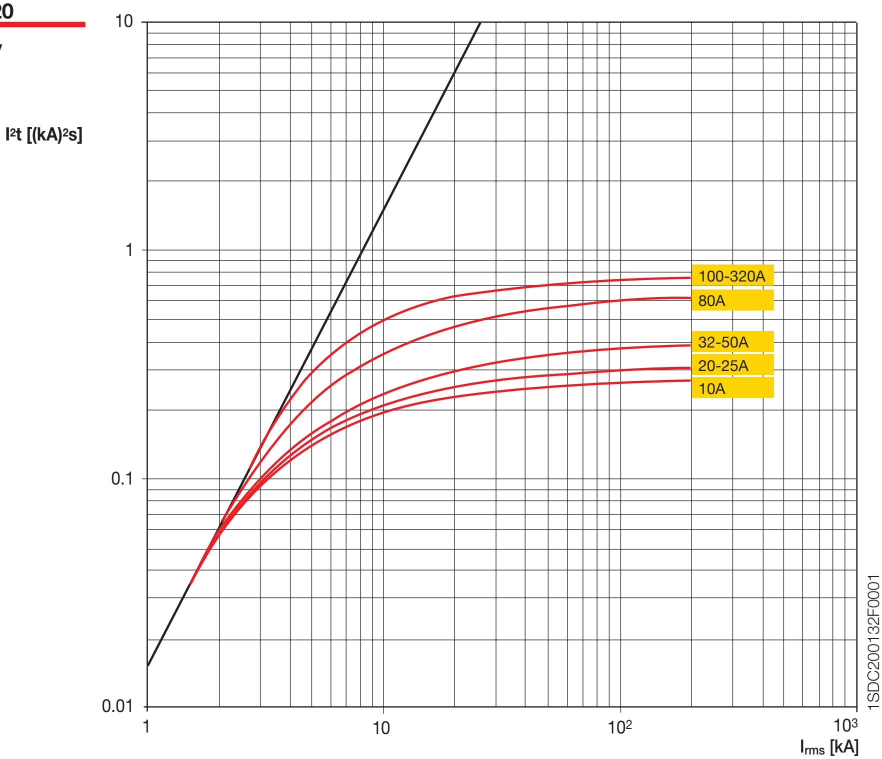


3 General characteristics

Specific let-through energy curves

T4 250/320

400-440 V

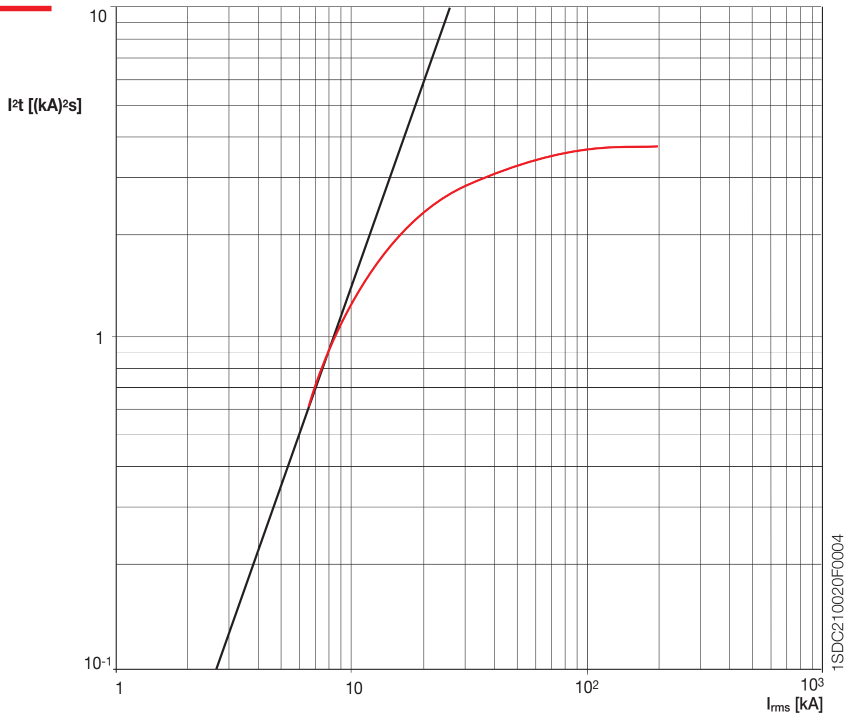


3 General characteristics

Specific let-through energy curves

T5 400/630

400-440 V

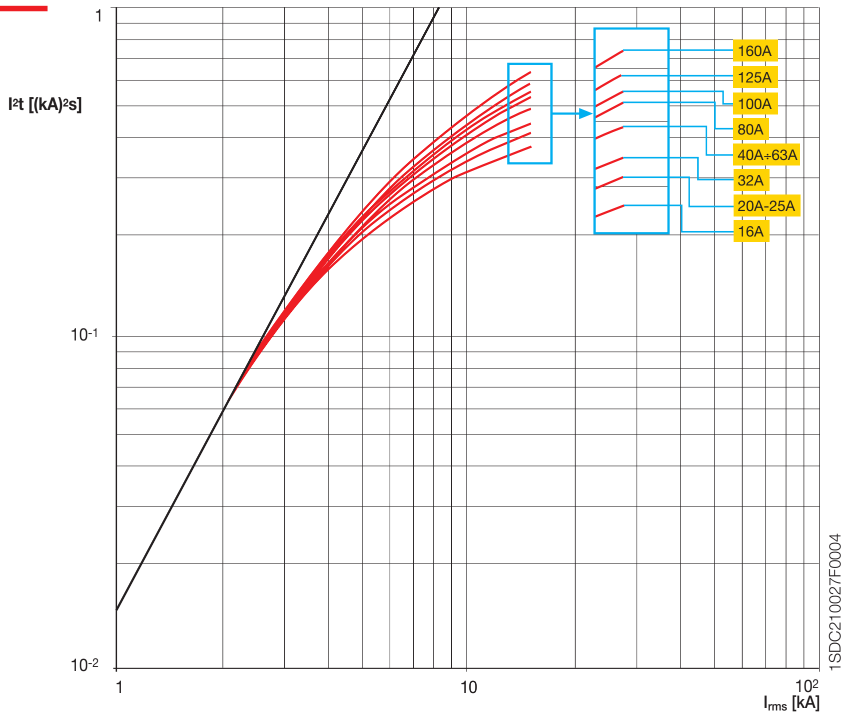


3 General characteristics

Specific let-through energy curves

T1 160

500 V

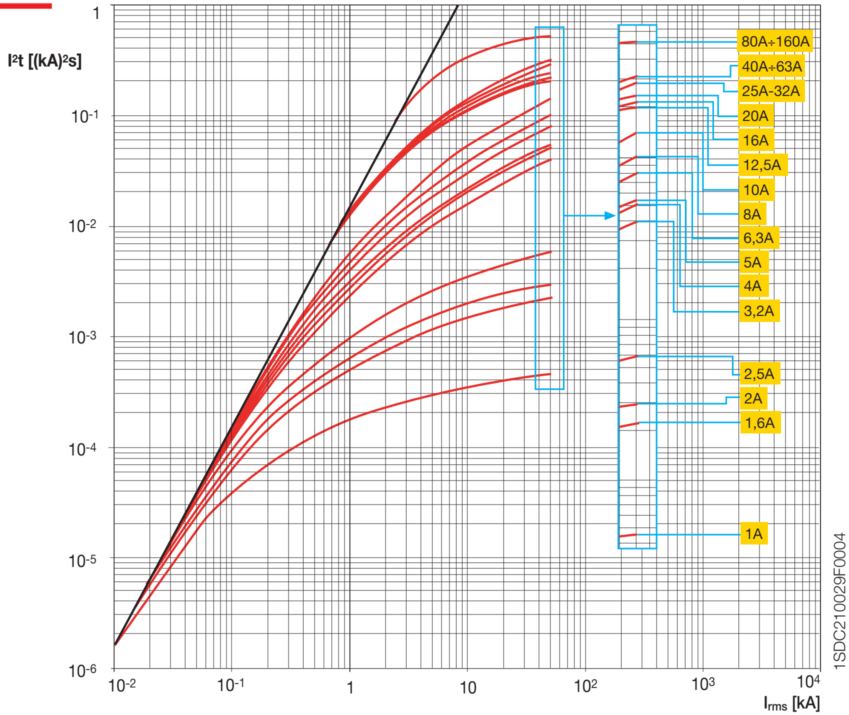


3 General characteristics

Specific let-through energy curves

T2 160

500 V

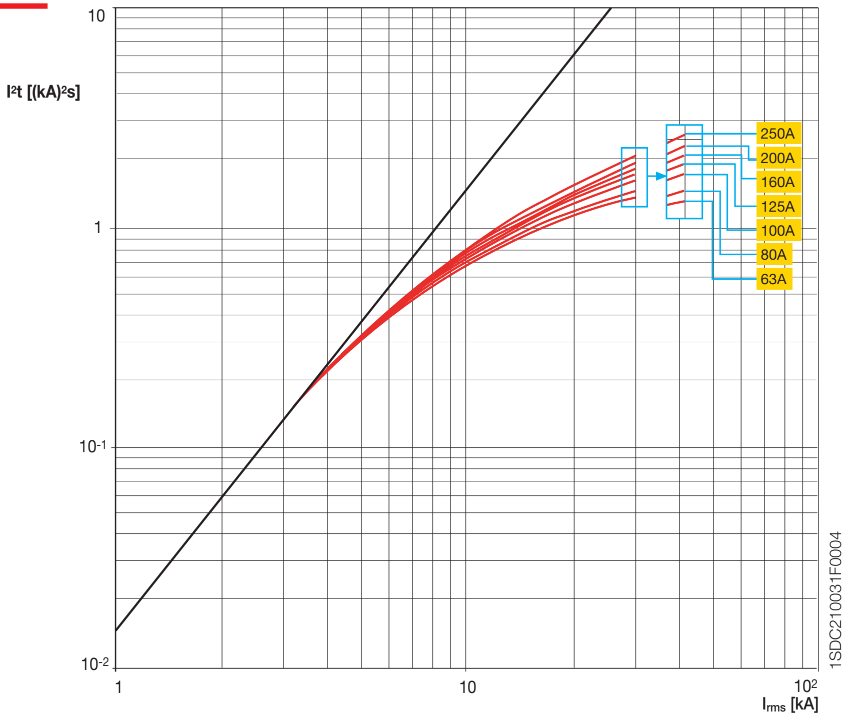


3 General characteristics

Specific let-through energy curves

T3 250

500 V

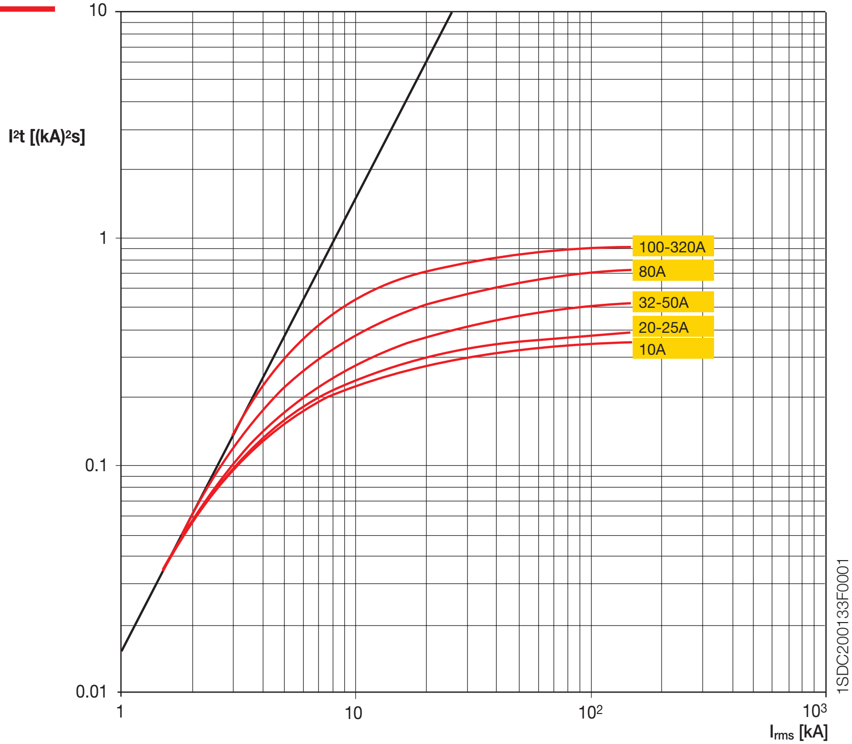


3 General characteristics

Specific let-through energy curves

T4 250/320

500 V

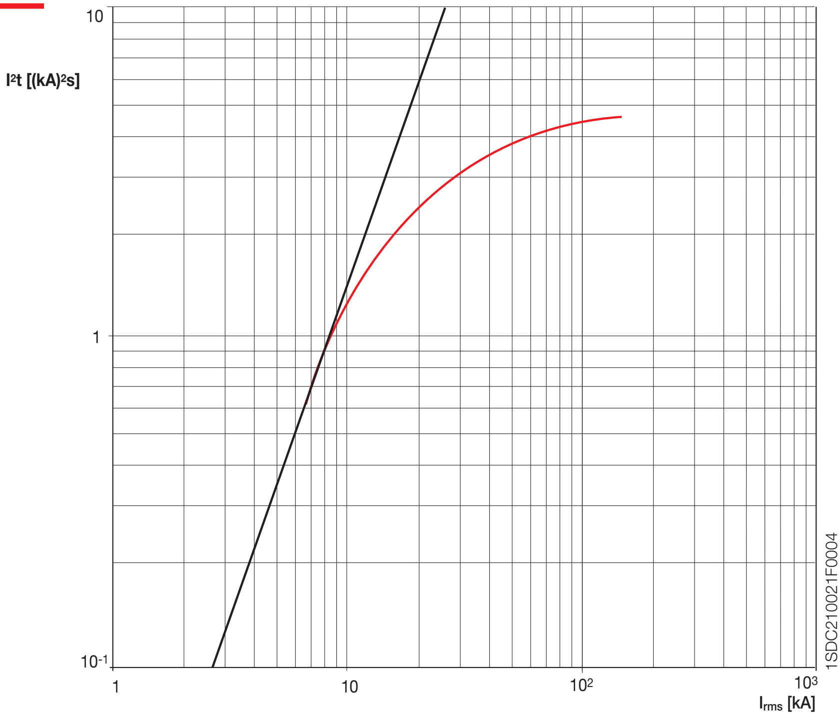


3 General characteristics

Specific let-through energy curves

T5 400/630

500 V

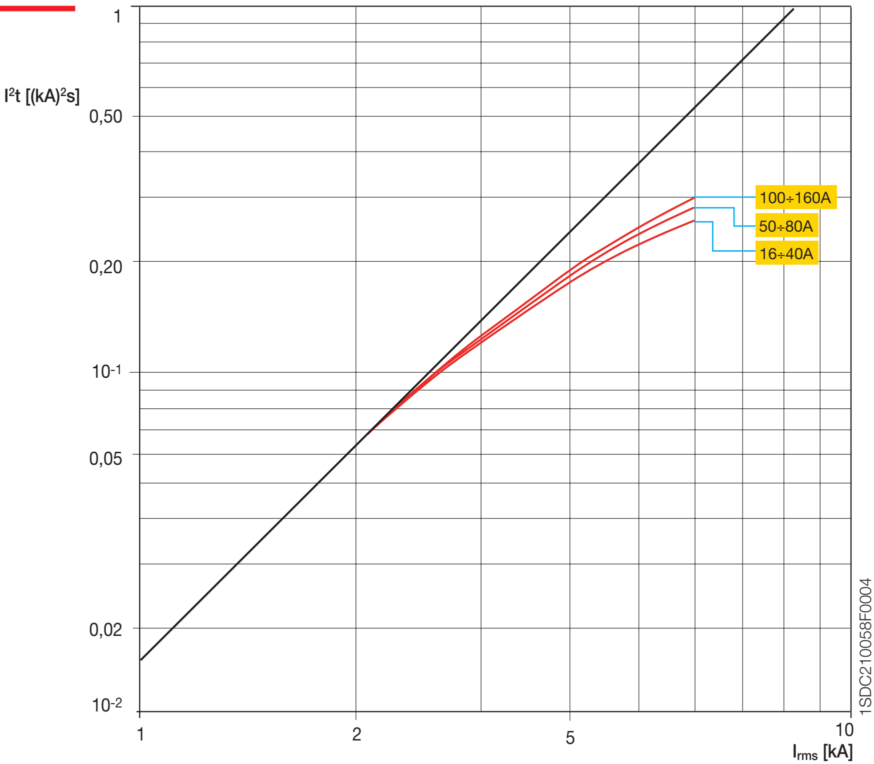


3 General characteristics

Specific let-through energy curves

T1 160

690 V

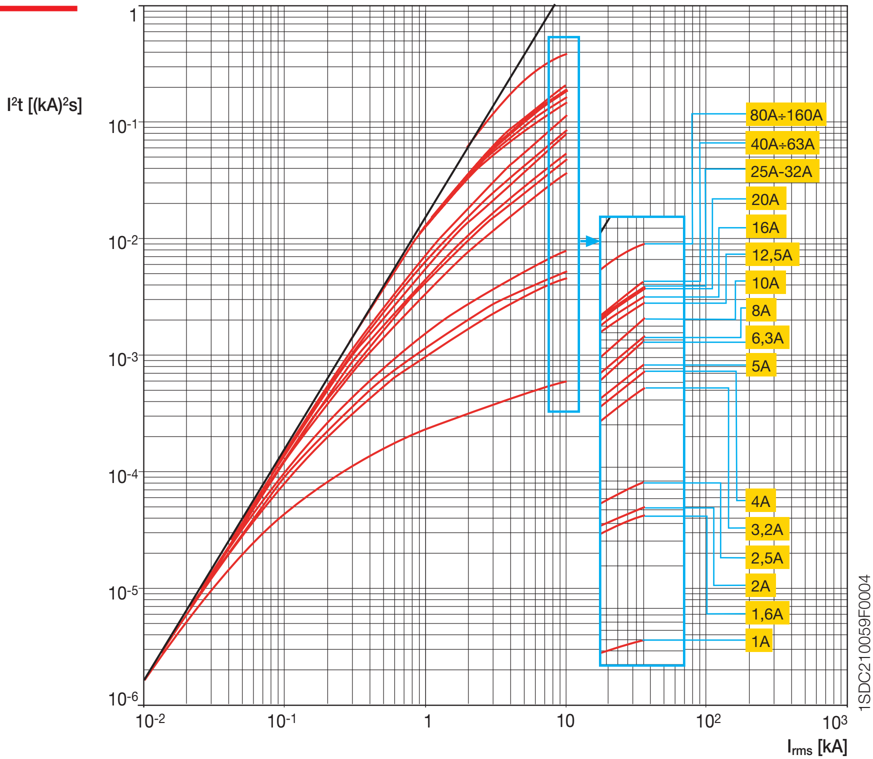


3 General characteristics

Specific let-through energy curves

T2 160

690 V

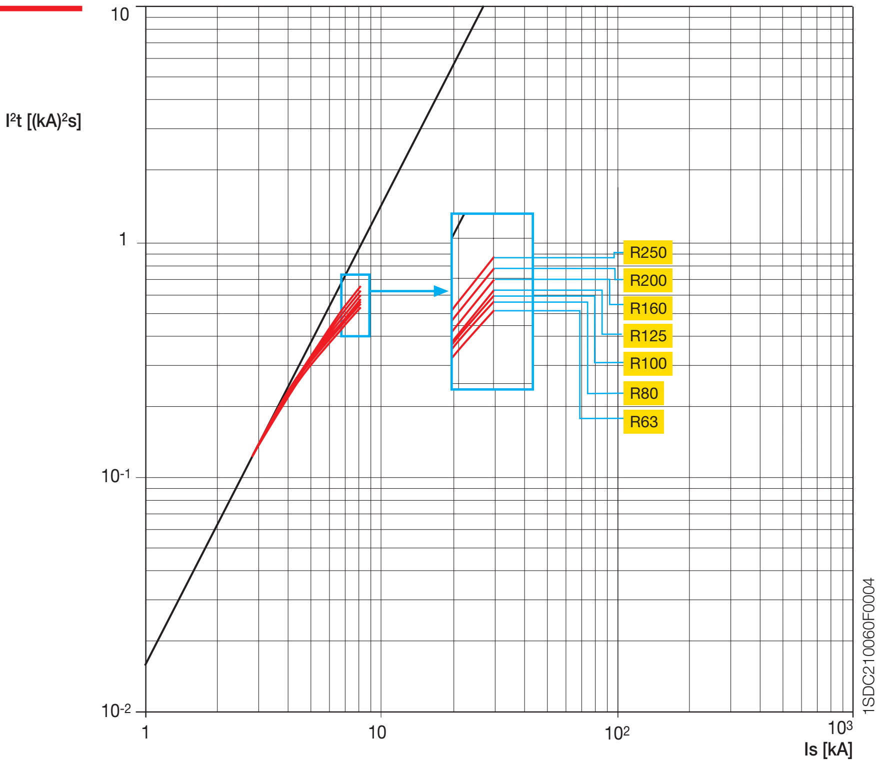


3 General characteristics

Specific let-through energy curves

T3 250

690 V

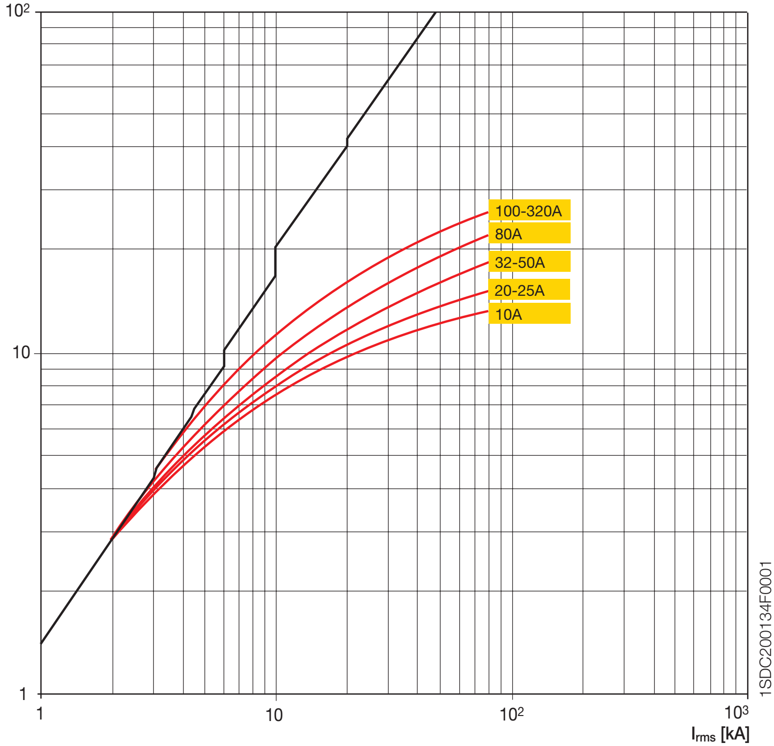


3 General characteristics

Specific let-through energy curves

T4 250/320

690 V

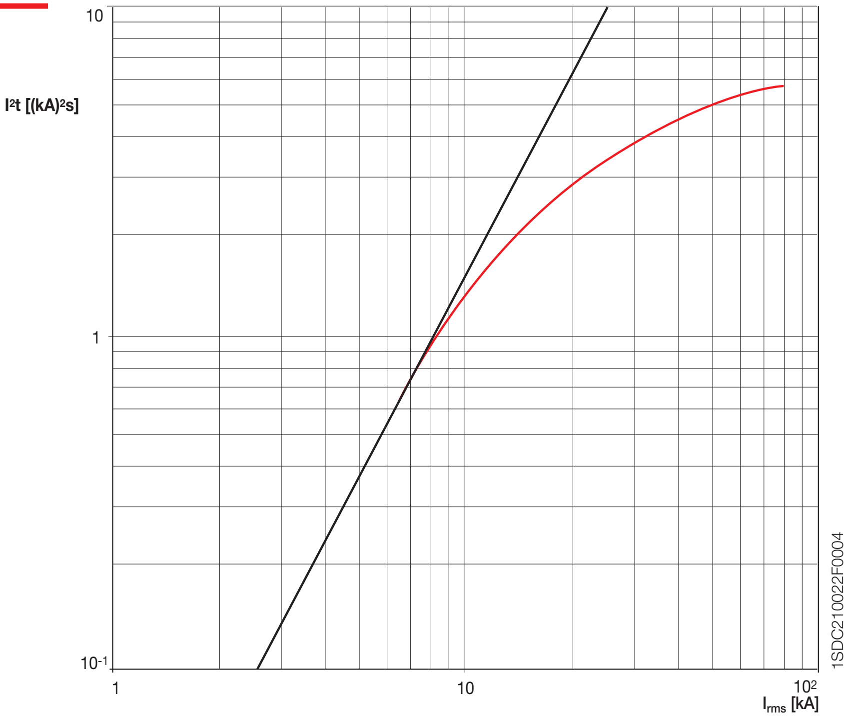


3 General characteristics

Specific let-through energy curves

T5 400/630

690 V

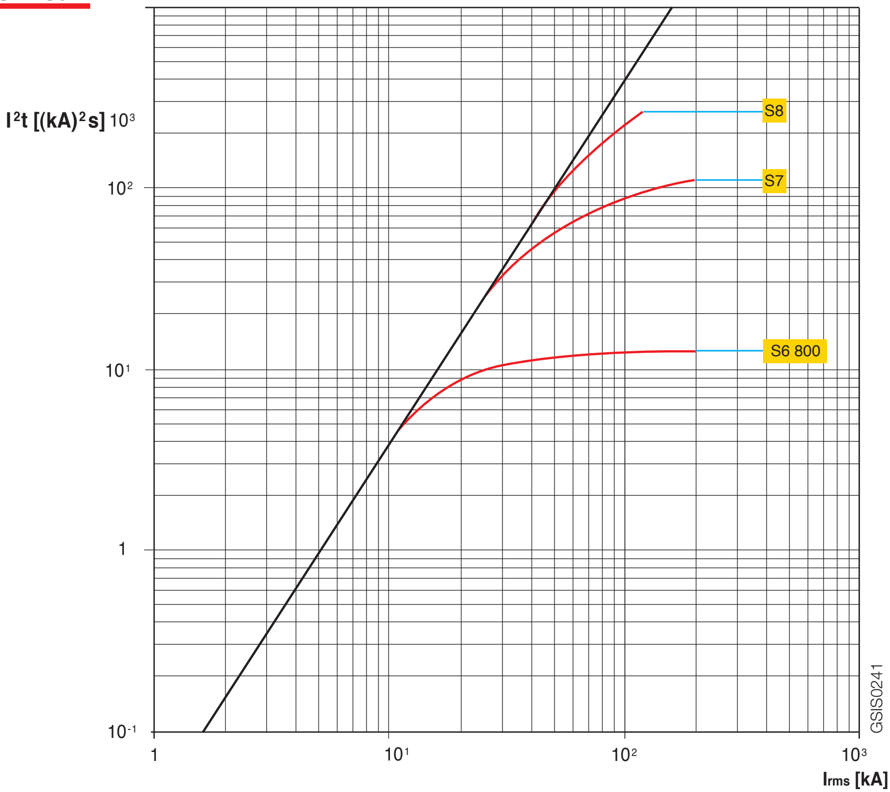


3 General characteristics

Specific let-through energy curves

S6 800 - S7 - S8

230 V

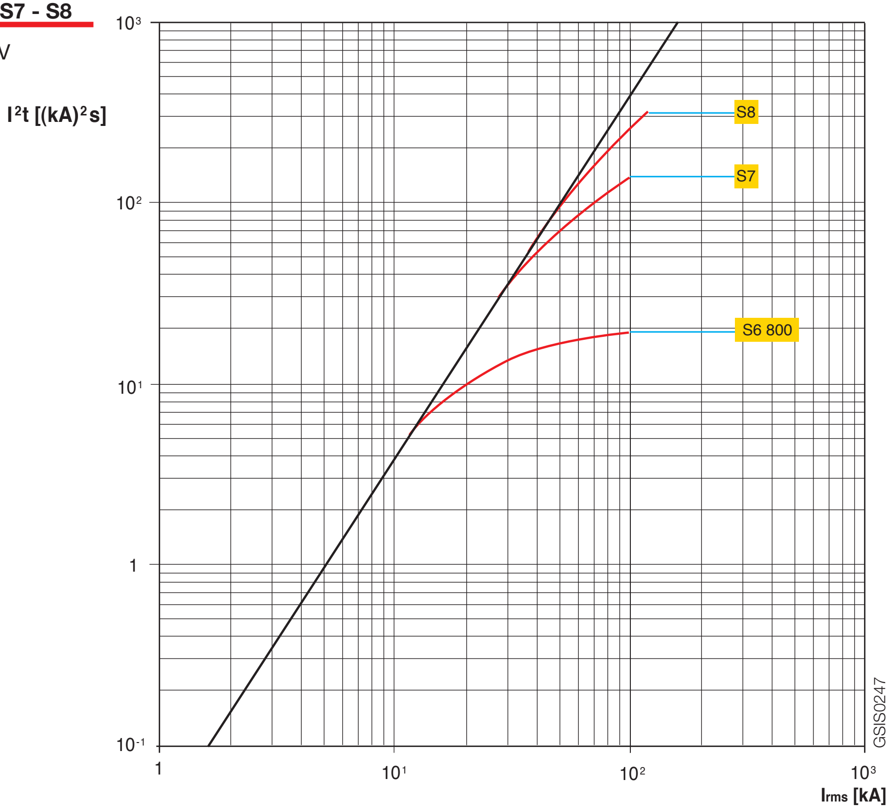


3 General characteristics

Specific let-through energy curves

S6 800 - S7 - S8

400-440 V

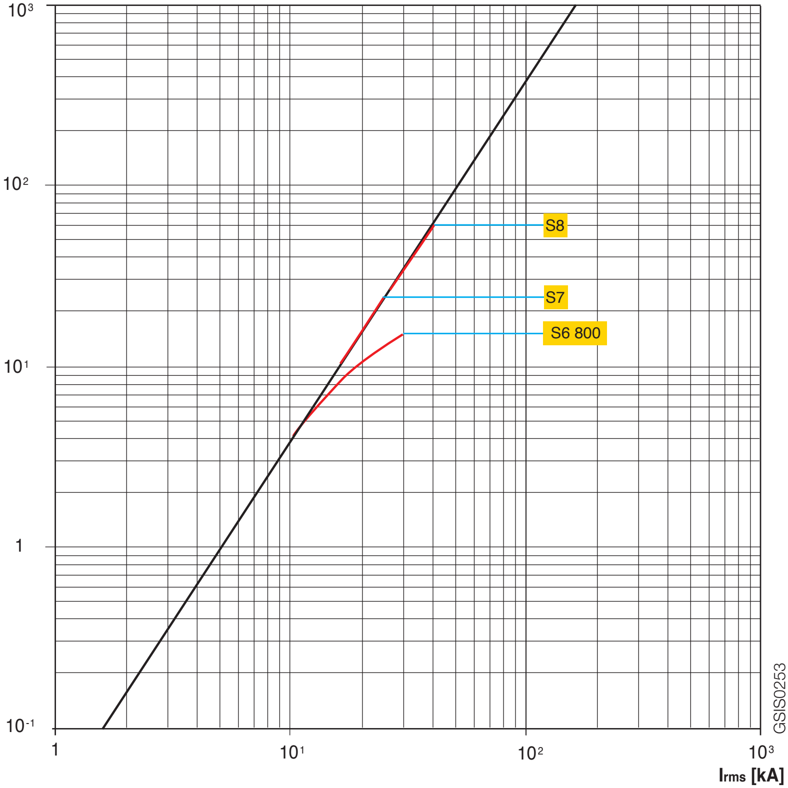


3 General characteristics

Specific let-through energy curves

S6 800 - S7 - S8

690 V

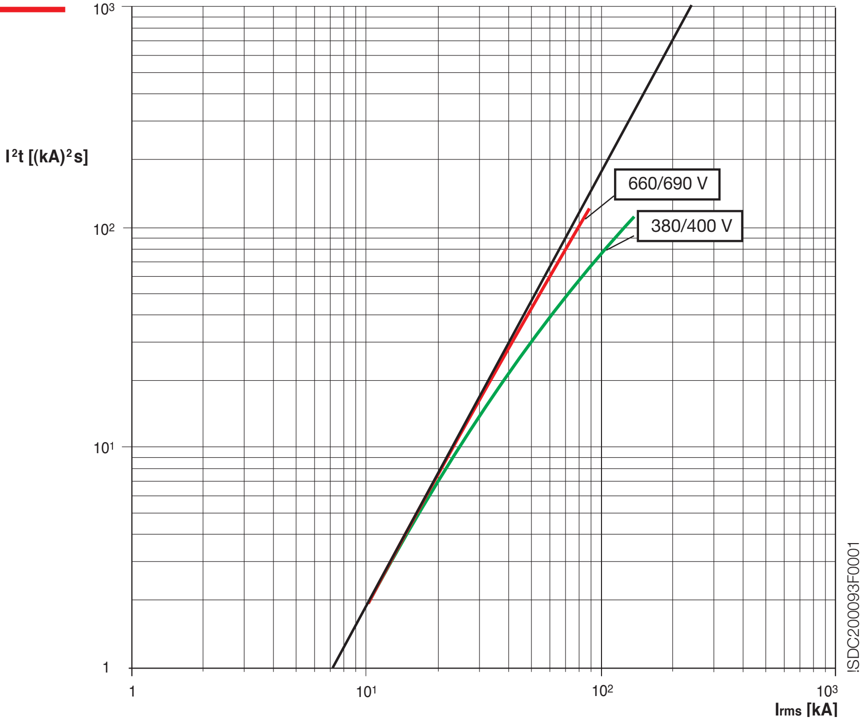


3 General characteristics

Specific let-through energy curves

E2L

660/690 V~
380/400 V~

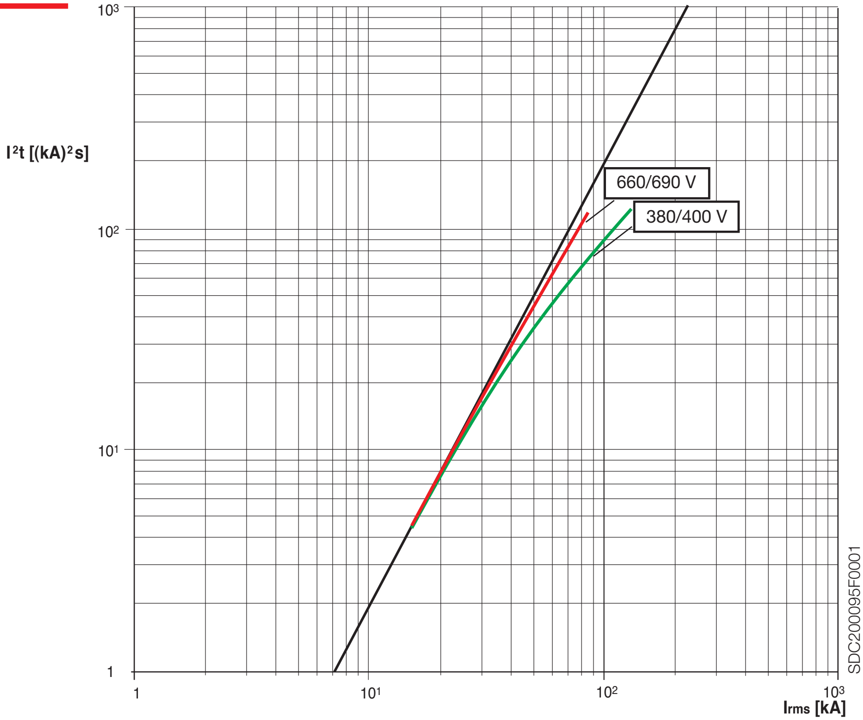


3 General characteristics

Specific let-through energy curves

E3L

660/690 V~
380/400 V~



3.5 Temperature derating

Standard IEC 60947-2 states that the temperature rise limits for circuit-breakers working at rated current must be within the limits given in the following table:

Table 1 - Temperature rise limits for terminals and accessible parts

Description of part*		Temperature rise limits K
- Terminal for external connections		80
- Manual operating means:	metallic	25
	non metallic	35
- Parts intended to be touched but not hand-held:	metallic	40
	non metallic	50
- Parts which need not be touched for normal operation:	metallic	50
	non metallic	60

* No value is specified for parts other than those listed but no damage should be caused to adjacent parts of insulating materials.

These values are valid for a maximum reference ambient temperature of 40°C, as stated in Standard IEC 60947-1, clause 6.1.1.
Whenever the ambient temperature is other than 40°C, the value of the current which can be carried continuously by the circuit-breaker is given in the following tables:

Circuit-breakers with thermomagnetic release

Tmax T1 and T1 1P (*)

	10 °C		20 °C		30 °C		40 °C		50 °C		60 °C		70 °C	
In [A]	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
16	13	18	12	18	12	17	11	16	11	15	10	14	9	13
20	16	23	15	22	15	21	14	20	13	19	12	18	11	16
25	20	29	19	28	18	26	18	25	16	23	15	22	14	20
32	26	37	25	35	24	34	22	32	21	30	20	28	18	26
40	32	46	31	44	29	42	28	40	26	38	25	35	23	33
50	40	58	39	55	37	53	35	50	33	47	31	44	28	41
63	51	72	49	69	46	66	44	63	41	59	39	55	36	51
80	64	92	62	88	59	84	56	80	53	75	49	70	46	65
100	81	115	77	110	74	105	70	100	66	94	61	88	57	81
125	101	144	96	138	92	131	88	125	82	117	77	109	71	102
160	129	184	123	176	118	168	112	160	105	150	98	140	91	130

(*) For the T1 1P circuit-breaker (fitted with TMF fixed thermomagnetic release), consider only the column corresponding to the maximum adjustment of the TMD releases.

3 General characteristics

Tmax T2

	10 °C		20 °C		30 °C		40 °C		50 °C		60 °C		70 °C	
In [A]	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
1	0.8	1.1	0.8	1.1	0.7	1.1	0.7	1.0	0.7	0.9	0.6	0.9	0.6	0.8
1.6	1.3	1.8	1.2	1.8	1.2	1.7	1.1	1.6	1.0	1.5	1.0	1.4	0.9	1.3
2	1.6	2.3	1.5	2.2	1.5	2.1	1.4	2.0	1.3	1.9	1.2	1.7	1.1	1.6
2.5	2.0	2.9	1.9	2.8	1.8	2.6	1.8	2.5	1.6	2.3	1.5	2.2	1.4	2.0
3.2	2.6	3.7	2.5	3.5	2.4	3.4	2.2	3.2	2.1	3.0	1.9	2.8	1.8	2.6
4	3.2	4.6	3.1	4.4	2.9	4.2	2.8	4.0	2.6	3.7	2.4	3.5	2.3	3.2
5	4.0	5.7	3.9	5.5	3.7	5.3	3.5	5.0	3.3	4.7	3.0	4.3	2.8	4.0
6.3	5.1	7.2	4.9	6.9	4.6	6.6	4.4	6.3	4.1	5.9	3.8	5.5	3.6	5.1
8	6.4	9.2	6.2	8.8	5.9	8.4	5.6	8.0	5.2	7.5	4.9	7.0	4.5	6.5
10	8.0	11.5	7.7	11.0	7.4	10.5	7.0	10.0	6.5	9.3	6.1	8.7	5.6	8.1
12.5	10.1	14.4	9.6	13.8	9.2	13.2	8.8	12.5	8.2	11.7	7.6	10.9	7.1	10.1
16	13	18	12	18	12	17	11	16	10	15	10	14	9	13
20	16	23	15	22	15	21	14	20	13	19	12	17	11	16
25	20	29	19	28	18	26	18	25	16	23	15	22	14	20
32	26	37	25	35	24	34	22	32	21	30	19	28	18	26
40	32	46	31	44	29	42	28	40	26	37	24	35	23	32
50	40	57	39	55	37	53	35	50	33	47	30	43	28	40
63	51	72	49	69	46	66	44	63	41	59	38	55	36	51
80	64	92	62	88	59	84	56	80	52	75	49	70	45	65
100	80	115	77	110	74	105	70	100	65	93	61	87	56	81
125	101	144	96	138	92	132	88	125	82	117	76	109	71	101
160	129	184	123	178	118	168	112	160	105	150	97	139	90	129

Tmax T3

In [A]	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
63	51	72	49	69	46	66	44	63	41	59	38	55	35	51
80	64	92	62	88	59	84	56	80	52	75	48	69	45	64
100	80	115	77	110	74	105	70	100	65	93	61	87	56	80
125	101	144	96	138	92	132	88	125	82	116	76	108	70	100
160	129	184	123	176	118	168	112	160	104	149	97	139	90	129
200	161	230	154	220	147	211	140	200	130	186	121	173	112	161
250	201	287	193	278	184	263	175	250	163	233	152	216	141	201

3 General characteristics

Tmax T4

	10 °C		20 °C		30 °C		40 °C		50 °C		60 °C		70 °C	
In [A]	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
20	19	27	18	24	16	23	14	20	12	17	10	15	8	13
32	26	43	24	39	22	36	19	32	16	27	14	24	11	21
50	37	62	35	58	33	54	30	50	27	46	25	42	22	39
80	59	98	55	92	52	86	48	80	44	74	40	66	32	58
100	83	118	80	113	74	106	70	100	66	95	59	85	49	75
125	103	145	100	140	94	134	88	125	80	115	73	105	63	95
160	130	185	124	176	118	168	112	160	106	150	100	104	90	130
200	162	230	155	220	147	210	140	200	133	190	122	175	107	160
250	200	285	193	275	183	262	175	250	168	240	160	230	150	220
320	260	368	245	350	234	335	224	320	212	305	200	285	182	263

Tmax T4

In [A]	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
320	260	368	245	350	234	335	224	320	212	305	200	285	182	263
400	325	465	310	442	295	420	280	400	265	380	250	355	230	325
500	435	620	405	580	380	540	350	500	315	450	280	400	240	345
630	520	740	493	705	462	660	441	630	405	580	380	540	350	500

SACE Isomax S6 800

In [A]	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
630	520	740	493	705	462	660	441	630	405	580	380	540	350	500
800	685	965	640	905	605	855	560	800	520	740	470	670	420	610

3 General characteristics

Circuit-breakers with electronic release

Tmax T2 160

	up to 40 °C		50 °C		60 °C		70 °C	
Fixed	I_{max} [A]	I_1	I_{max} [A]	I_1	I_{max} [A]	I_1	I_{max} [A]	I_1
F	**160**	1	153.6	0.96	140.8	0.88	128	0.8
EF	**160**	1	153.6	0.96	140.8	0.88	128	0.8
ES	**160**	1	153.6	0.96	140.8	0.88	128	0.8
FC Cu	**160**	1	153.6	0.96	140.8	0.88	128	0.8
FC Cu	**160**	1	153.6	0.96	140.8	0.88	128	0.8
R	**160**	1	153.6	0.96	140.8	0.88	128	0.8

F = Front flat terminals; EF = Front extended terminals; ES = Front extended spread terminals;
FC Cu = Front terminals for copper cables; FC CuAl = Front terminals for CuAl cables; R = Rear terminals

Tmax T4 250

	up to 40 °C		50 °C		60 °C		70 °C	
Fixed	I_{max} [A]	I_1	I_{max} [A]	I_1	I_{max} [A]	I_1	I_{max} [A]	I_1
FC	**250**	1	250	1	250	1	230	0.92
F	**250**	1	250	1	250	1	230	0.92
HR	**250**	1	250	1	250	1	220	0.88
VR	**250**	1	250	1	250	1	220	0.88
Plug-in - Withdrawable								
FC	**250**	1	250	1	240	0.96	220	0.88
F	**250**	1	250	1	240	0.96	220	0.88
HR	**250**	1	250	1	230	0.92	210	0.84
VR	**250**	1	250	1	230	0.92	210	0.84

FC = Front terminal for cables; F = Front flat terminals; HR = Rear flat horizontal terminals; VR = Rear flat vertical terminals.

Tmax T4 320

	up to 40 °C		50 °C		60 °C		70 °C	
Fixed	I_{max} [A]	I_1	I_{max} [A]	I_1	I_{max} [A]	I_1	I_{max} [A]	I_1
FC	**320**	1	307	0.96	281	0.88	256	0.80
F	**320**	1	307	0.96	281	0.88	256	0.80
HR	**320**	1	294	0.92	269	0.84	243	0.76
VR	**320**	1	294	0.92	269	0.84	243	0.76
Plug-in - Withdrawable								
FC	**320**	1	294	0.92	268	0.84	242	0.76
F	**320**	1	307	0.96	282	0.88	256	0.80
HR	**320**	1	294	0.92	268	0.84	242	0.76
VR	**320**	1	294	0.92	268	0.84	242	0.76

FC = Front terminal for cables; F = Front flat terminals; HR = Rear flat horizontal terminals; VR = Rear flat vertical terminals.

3 General characteristics

Tmax T5 400

	up to 40 °C		50 °C		60 °C		70 °C	
Fixed	I_{max} [A]	I_1	I_{max} [A]	I_1	I_{max} [A]	I_1	I_{max} [A]	I_1
FC	**400**	1	400	1	400	1	368	0.92
F	**400**	1	400	1	400	1	368	0.92
HR	**400**	1	400	1	400	1	352	0.88
VR	**400**	1	400	1	400	1	352	0.88
Plug-in - Withdrawable								
FC	**400**	1	400	1	382	0.96	350	0.88
F	**400**	1	400	1	382	0.96	350	0.88
HR	**400**	1	400	1	368	0.92	336	0.84
VR	**400**	1	400	1	368	0.92	336	0.84

FC = Front terminal for cables; F = Front flat terminals; HR = Rear flat horizontal terminals; VR = Rear flat vertical terminals.

Tmax T5 630

	up to 40 °C		50 °C		60 °C		70 °C	
Fixed	I_{max} [A]	I_1	I_{max} [A]	I_1	I_{max} [A]	I_1	I_{max} [A]	I_1
FC	**630**	1	605	0.96	554	0.88	504	0.80
F	**630**	1	605	0.96	554	0.88	504	0.80
HR	**630**	1	580	0.92	529	0.84	479	0.76
VR	**630**	1	580	0.92	529	0.84	479	0.76
Plug-in - Withdrawable								
F	**630**	1	607	0.96	552	0.88	476	0.76
HR	**630**	1	580	0.92	517	0.82	454	0.72
VR	**630<**	1	580	0.92	517	0.82	454	0.72

FC = Front terminal for cables F = Front flat terminals HR = Rear flat horizontal terminals VR = Rear flat vertical terminals

SACE Isomax S6 800

	up to 40 °C		50 °C		60 °C		70 °C	
Fixed	I_{max} [A]	I_1	I_{max} [A]	I_1	I_{max} [A]	I_1	I_{max} [A]	I_1
Front flat bar	**800**	1	800	1	800	1	760	0.95
Front for cables	**800**	1	800	1	760	0.95	720	0.9
Rear for cables	**800**	1	800	1	760	0.95	720	0.9
Rear threaded	**800**	1	800	1	720	0.9	640	0.8
Plug-in - Withdrawable								
Front flat bar	**800**	1	800	1	760	0.95	720	0.9
Rear vertical flat bar	**800**	1	800	1	760	0.95	720	0.9
Rear horizontal flat bar	**800**	1	760	0.95	720	0.9	640	0.8

SACE Isomax S7 1250

	up to 40 °C		50 °C		60 °C		70 °C	
Fixed	I_{max} [A]	I_1	I_{max} [A]	I_1	I_{max} [A]	I_1	I_{max} [A]	I_1
Front flat bar	**1250**	1	1250	1	1250	1	1187.5	0.95
Rear vertical flat bar	**1250**	1	1250	1	1250	1	1187.5	0.95
Front for cables	**1250**	1	1250	1	1187.5	0.95	1125	0.9
Rear horizontal flat bar	**1250**	1	1250	1	1250	1	1125	0.9
Plug-in - Withdrawable								
Front flat bar	**1250**	1	1250	1	1187.5	0.95	1125	0.9
Rear vertical flat bar	**1250**	1	1250	1	1187.5	0.95	1125	0.9
Rear horizontal flat bar	**1250**	1	1250	1	1125	0.9	1000	0.8

3 General characteristics

SACE Isomax S7 1600

	up to 40 °C		50 °C		60 °C		70 °C	
Fixed	I_{max} [A]	I_1	I_{max} [A]	I_1	I_{max} [A]	I_1	I_{max} [A]	I_1
Front flat bar	**1600**	1	1520	0.95	1440	0.9	1280	0.8
Rear vertical flat bar	**1600**	1	1520	0.95	1440	0.9	1280	0.8
Rear horizontal flat bar	**1600**	1	1440	0.9	1280	0.8	1120	0.7
Plug-in - Withdrawable								
Front flat bar	**1600**	1	1440	0.9	1280	0.8	1120	0.7
Rear vertical flat bar	**1600**	1	1440	0.9	1280	0.8	1120	0.7
Rear horizontal flat bar	**1600**	1	1280	0.8	1120	0.7	906	0.6

SACE Isomax S8 2000

	up to 40 °C		50 °C		60 °C		70 °C	
Fixed	I_{max} [A]	I_1	I_{max} [A]	I_1	I_{max} [A]	I_1	I_{max} [A]	I_1
Front flat bar	**2000**	1	2000	1	1900	0,95	1715	0,85
Rear vertical flat bar	**2000**	1	2000	1	2000	1	1785	0,9

SACE Isomax S8 2500

	up to 40 °C		50 °C		60 °C		70 °C	
Fixed	I_{max} [A]	I_1	I_{max} [A]	I_1	I_{max} [A]	I_1	I_{max} [A]	I_1
Front flat bar	**2500**	1	2500	1	2270	0,9	2040	0,8
Rear vertical flat bar	**2500**	1	2500	1	2375	0,95	2130	0,85

SACE Isomax S8 3200

	up to 40 °C		50 °C		60 °C		70 °C	
Fixed	I_{max} [A]	I_1	I_{max} [A]	I_1	I_{max} [A]	I_1	I_{max} [A]	I_1
Rear vertical flat bar	**3200**	1	3060	0,95	2780	0,85	2510	0,8

3 General characteristics

Emax E1

Temperature	E1 800		E1 1250	
[°C]	%	[A]	%	[A]
10	100	800	100	1250
20	100	800	100	1250
30	100	800	100	1250
40	100	800	100	1250
45	100	800	100	1250
50	100	800	100	1250
55	100	800	100	1250
60	100	800	100	1250
65	100	800	99	1240
70	100	800	98	1230

Emax E2

Temperature	E2 1250		E2 1600		E2 2000	
[°C]	%	[A]	%	[A]	%	[A]
10	100	1250	100	1600	100	2000
20	100	1250	100	1600	100	2000
30	100	1250	100	1600	100	2000
40	100	1250	100	1600	100	2000
45	100	1250	100	1600	100	2000
50	100	1250	100	1600	97	1945
55	100	1250	100	1600	94	1885
60	100	1250	98	1570	91	1825
65	100	1250	96	1538	88	1765
70	100	1250	94	1510	85	1705

Emax E3

Temperature	E3 1250		E3 1600		E3 2000		E3 2500		E3 3200	
[C°]	%	[A]	%	[A]	%	[A]	%	[A]	%	[A]
10	100	1250	100	1600	100	2000	100	2500	100	3200
20	100	1250	100	1600	100	2000	100	2500	100	3200
30	100	1250	100	1600	100	2000	100	2500	100	3200
40	100	1250	100	1600	100	2000	100	2500	100	3200
45	100	1250	100	1600	100	2000	100	2500	100	3200
50	100	1250	100	1600	100	2000	100	2500	97	3090
55	100	1250	100	1600	100	2000	100	2500	93	2975
60	100	1250	100	1600	100	2000	100	2500	89	2860
65	100	1250	100	1600	100	2000	97	2425	86	2745
70	100	1250	100	1600	100	2000	94	2350	82	2630

3 General characteristics

Emax E4

Temperature	E4 3200		E4 4000	
[°C]	%	[A]	%	[A]
10	100	3200	100	4000
20	100	3200	100	4000
30	100	3200	100	4000
40	100	3200	100	4000
45	100	3200	100	4000
50	100	3200	98	3900
55	100	3200	95	3790
60	100	3200	92	3680
65	98	3120	89	3570
70	95	3040	87	3460

Emax E6

Temperature	E6 3200		E6 4000		E6 5000		E6 6300	
[°C]	%	[A]	%	[A]	%	[A]	%	[A]
10	100	3200	100	4000	100	5000	100	6300
20	100	3200	100	4000	100	5000	100	6300
30	100	3200	100	4000	100	5000	100	6300
40	100	3200	100	4000	100	5000	100	6300
45	100	3200	100	4000	100	5000	100	6300
50	100	3200	100	4000	100	5000	100	6300
55	100	3200	100	4000	100	5000	98	6190
60	100	3200	100	4000	98	4910	96	6070
65	100	3200	100	4000	96	4815	94	5850
70	100	3200	100	4000	94	4720	92	5600

3 General characteristics

The following table lists examples of the continuous current carrying capacity for circuit breakers installed in a switchboards with the dimensions indicated below. These values refer to withdrawable switchgear installed in non segregated switchboards with a protection rating of up to IP31, and following dimensions:
2300x800x900 (HxLxD) for E1 - E2 - E3;
2300x1400x1500 (HxLxD) for E4 - E6.
The values refer to a maximum temperature at the terminals of 120 °C.
For withdrawable circuit-breakers with a rated current of 6300 A, the use of vertical rear terminals is recommended.

		Vertical terminals				**Horizontal and front terminals**			
Type	Iu [A]	Continuous capacity [A] 35°C	45°C	55°C	Busbars section [mm²]	Continuous capacity [A] 35°C	45°C	55°C	Busbars section [mm²]
E1B/N 08	800	800	800	800	1x(60x10)	800	800	800	1x(60x10)
E1B/N 12	1250	1250	1250	1250	1x(80x10)	1250	1250	1200	2x(60x8)
E2N 12	1250	1250	1250	1250	1x(60x10)	1250	1250	1250	1x(60x10)
E2B/N 16	1600	1600	1600	1600	2x(60x10)	1600	1600	1530	2x(60x10)
E2B/N 20	2000	2000	2000	1800	3x(60x10)	2000	2000	1750	3x(60x10)
E2L 12	1250	1250	1250	1250	1x(60x10)	1250	1250	1250	1x(60x10)
E2L 16	1600	1600	1600	1500	2x(60x10)	1600	1490	1400	2x(60x10)
E3S/H 12	1250	1250	1250	1250	1x(60x10)	1250	1250	1250	1x(60x10)
E3S/H 16	1600	1600	1600	1600	1x(100x10)	1600	1600	1600	1x(100x10)
E3S/H 20	2000	2000	2000	2000	2x(100x10)	2000	2000	2000	2x(100x10)
E3N/S/H 25	2500	2500	2500	2500	2x(100x10)	2500	2490	2410	2x(100x10)
E3N/S/H 32	3200	3200	3100	2800	3x(100x10)	3000	2880	2650	3x(100x10)
E3L 20	2000	2000	2000	2000	2x(100x10)	2000	2000	1970	2x(100x10)
E3L 25	2500	2500	2390	2250	2x(100x10)	2375	2270	2100	2x(100x10)
E4H 32	3200	3200	3200	3200	3x(100x10)	3200	3200	3020	3x(100x10)
E4S/H 40	4000	4000	3980	3500	4x(100x10)	3600	3510	3150	6x(60x10)
E6V 32	3200	3200	3200	3200	3x(100x10)	3200	3200	3200	3x(100x10)
E6V 40	4000	4000	4000	4000	4x(100x10)	4000	4000	4000	4x(100x10)
E6H/V 50	5000	5000	4850	4600	6x(100x10)	4850	4510	4250	6x(100x10)
E6H/V 63	6300	6000	5700	5250	7x(100x10)	-	-	-	-

Note: the reference temperature is the ambient temperature

Examples:

Selection of a moulded-case circuit-breaker, with thermomagnetic release, for a load current of 180 A, at an ambient temperature of 60°C.
From the table referring to Tmax circuit-breakers (page 160-161), it can be seen that the most suitable breaker is the T3 In 250, which can be set from 152 A to 216 A.

Selection of a moulded-case circuit-breaker, with electronic release, in withdrawable version with rear flat horizontal bar terminals, for a load current equal to 720 A, with an ambient temperature of 50 °C.
From the table referring to SACE Isomax circuit-breakers (page 164), it can be seen that the most suitable breaker is the S6 800, which can be set from 320 A to 760 A.

Selection of an air circuit-breaker, with electronic release, in withdrawable version with vertical terminals, for a load current of 2700 A, with a temperature outside of the IP31 switchboard of 55 °C.
From the tables referring to the current carrying capacity inside the switchboard for Emax circuit-breakers (see above), it can be seen that the most suitable breaker is the E3 3200, with busbar section 3x(100x10)mm², which can be set from 1280 A to 2800 A.

3 General characteristics

The following tables show the maximum settings for L protection (against overload) for electronic releases, according to temperature, version and terminals.

Tmax T2 In ≤ 125A	All terminals	
	F	P
≤40	1	1
45		
50		
55		
60		
65		
70		

Tmax T2 In = 160A	All terminals	
	F	P
≤40	1	0.88
45	0.96	0.88
50	0.96	0.88
55	0.92	0.88
60	0.88	0.88
65	0.84	0.84
70	0.8	0.8

Tmax T2 In ≤ 100A	Fixed - Plug-in
	PR221
	All terminals
≤40	1
45	
50	
55	
60	
65	
70	

Tmax T2 In 160A	Fixed - Plug-in
	PR221
	All terminals
≤40	1
45	0.96
50	0.96
55	0.92
60	0.88
65	0.84
70	0.8

Tmax T2 In ≤ 160A	Fixed - Plug-in Withdrawable
	PR221 - PR222
	FC – F – HR – VR
≤40	1
45	
50	
55	
60	
65	
70	

Tmax T4 In = 250A	Fixed				Plug-in - Withdrawable			
	PR221		PR222		PR221		PR222	
	FC – F	HR – VR	FC – F	HR – VR	FC – F	HR – VR	FC – F	HR – VR
≤40	1	1	1	1	1	1	1	1
45								
50								
55								
60					0.96	0.92	0.96	0.92
65	0.96	0.92	0.96	0.94	0.92	0.88	0.92	0.88
70	0.92	0.88	0.92	0.88	0.88	0.84	0.88	0.84

FC = Front terminal for cables; F = Front flat terminals; HR = Rear flat horizontal terminals; VR = Rear flat vertical terminals.

3 General characteristics

Tmax T4 In = 320A	Fixed				Plug-in - Withdrawable			
	PR221		PR222		PR221		PR222	
	FC – F	HR – VR	FC – F	HR – VR	F	FC–HR–VR	F	FC–HR–VR
≤40	1	1	1	1	1	1	1	1
45						0.96		0.96
50	0.96	0.92	0.96	0.92	0.96	0.92	0.96	0.92
55	0.92	0.88	0.92	0.88	0.92	0.88	0.92	0.88
60	0.88	0.84	0.88	0.84	0.88	0.84	0.88	0.84
65	0.84	0.8	0.84	0.8	0.84	0.80	0.84	0.80
70	0.8	0.76	0.8	0.76	0.8	0.76	0.8	0.76

Tmax T5 In ≤ 320A	Fixed - Plug-in Withdrawable
	PR221 - PR222
	FC – F – HR – VR
≤40	1
45	
50	
55	
60	
65	
70	

Tmax T5 In = 400A	Fixed				Plug-in - Withdrawable			
	PR221		PR222		PR221		PR222	
	FC – F	HR – VR	FC – F	HR – VR	FC – F	HR – VR	FC – F	HR – VR
≤40	1	1	1	1	1	1	1	1
45								
50								
55					0.96	0.96	0.98	0.96
60						0.92	0.96	0.92
65	0.96	0.92	0.96	0.94	0.92	0.88	0.92	0.88
70	0.92	0.88	0.92	0.88	0.88	0.84	0.88	0.84

Tmax T5 In = 630A	Fixed				Plug-in - Withdrawable			
	PR221		PR222		PR221		PR222	
	FC – F	HR – VR	FC – F	HR – VR	F	HR–VR	F	HR–VR
≤40	1	1	1	1	1	1	1	1
45								
50	0.96	0.92	0.96	0.92	0.96	0.92	0.96	0.92
55	0.92	0.88	0.92	0.88	0.92	0.84	0.92	0.86
60	0.88	0.84	0.88	0.84	0.88	0.8	0.88	0.82
65	0.84	0.8	0.84	0.8	0.8	0.76	0.8	0.76
70	0.8	0.76	0.8	0.76	0.76	0.72	0.76	0.72

FC = Front terminal for cables; F = Front flat terminals; HR = Rear flat horizontal terminals; VR = Rear flat vertical terminals.

3 General characteristics

<table>
<tr><th rowspan="3">Isomax S6
In = 800A</th><th colspan="2">Front flat bar</th><th colspan="2">Front for cables
Rear for cables</th><th colspan="2">Rear threaded</th><th colspan="2">Front flat bar
Rear vertical flat bar</th><th colspan="2">Rear horizontal
flat bar</th></tr>
<tr><th>PR211</th><th>PR212</th><th>PR211</th><th>PR212</th><th>PR211</th><th>PR212</th><th>PR211</th><th>PR212</th><th>PR211</th><th>PR212</th></tr>
<tr><th>F</th><th>F</th><th>F</th><th>F</th><th>F</th><th>F</th><th>W</th><th>W</th><th>W</th><th>W</th></tr>
<tr><td>≤40</td><td rowspan="5">1</td><td rowspan="5">1</td><td rowspan="3">1</td><td rowspan="3">1</td><td rowspan="3">1</td><td rowspan="3">1</td><td rowspan="3">1</td><td rowspan="3">1</td><td>1</td><td>1</td></tr>
<tr><td>45</td><td rowspan="2">0.95</td><td>0.975</td></tr>
<tr><td>50</td><td>0.95</td></tr>
<tr><td>55</td><td rowspan="2">0.95</td><td>0.975</td><td>0.95</td><td>0.95</td><td rowspan="2">0.95</td><td>0.975</td><td rowspan="2">0.9</td><td>0.925</td></tr>
<tr><td>60</td><td>0.95</td><td>0.9</td><td>0.9</td><td>0.95</td><td>0.9</td></tr>
<tr><td>65</td><td rowspan="2">0.95</td><td>0.975</td><td rowspan="2">0.9</td><td>0.925</td><td rowspan="2">0.8</td><td>0.85</td><td rowspan="2">0.9</td><td>0.925</td><td rowspan="2">0.8</td><td>0.85</td></tr>
<tr><td>70</td><td>0.95</td><td>0.9</td><td>0.8</td><td>0.9</td><td>0.8</td></tr>
</table>

<table>
<tr><th rowspan="3">Isomax S7
In ≤ 1250A</th><th colspan="2">Front flat bar
Rear vertical flat bar</th><th colspan="2">Front flat bar
Rear vertical flat bar</th><th colspan="2">Front for cables</th><th colspan="2">Rear horizontal
flat bar</th><th colspan="2">Rear horizontal
flat bar</th></tr>
<tr><th colspan="2">PR211</th><th colspan="2">PR212</th><th>PR211</th><th>PR212</th><th colspan="2">PR211</th><th colspan="2">PR212</th></tr>
<tr><th>F</th><th>W</th><th>F</th><th>W</th><th>F</th><th>F</th><th>F</th><th>W</th><th>F</th><th>W</th></tr>
<tr><td>≤40</td><td rowspan="5">1</td><td rowspan="3">1</td><td rowspan="5">1</td><td rowspan="3">1</td><td rowspan="3">1</td><td rowspan="3">1</td><td rowspan="5">1</td><td rowspan="3">1</td><td rowspan="5">1</td><td rowspan="3">1</td></tr>
<tr><td>45</td></tr>
<tr><td>50</td></tr>
<tr><td>55</td><td rowspan="2">0.95</td><td>0.975</td><td rowspan="2">0.95</td><td>0.975</td><td>0.95</td><td>0.95</td></tr>
<tr><td>60</td><td>0.95</td><td>0.95</td><td>0.9</td><td>0.9</td></tr>
<tr><td>65</td><td rowspan="2">0.95</td><td rowspan="2">0.9</td><td>0.975</td><td>0.975</td><td rowspan="2">0.9</td><td>0.925</td><td>0.95</td><td rowspan="2">0.8</td><td>0.95</td><td>0.85</td></tr>
<tr><td>70</td><td>0.95</td><td>0.9</td><td>0.9</td><td>0.9</td><td>0.9</td><td>0.8</td></tr>
</table>

<table>
<tr><th rowspan="3">Isomax S7
In = 1600A</th><th colspan="2">Front flat bar
Rear vertical flat bar</th><th colspan="2">Front flat bar
Rear vertical flat bar</th><th colspan="2">Rear horizontal
flat bar</th><th colspan="2">Rear horizontal
flat bar</th></tr>
<tr><th colspan="2">PR211</th><th colspan="2">PR212</th><th colspan="2">PR211</th><th colspan="2">PR212</th></tr>
<tr><th>F</th><th>W</th><th>F</th><th>W</th><th>F</th><th>W</th><th>F</th><th>W</th></tr>
<tr><td>≤40</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>45</td><td rowspan="2">0.95</td><td>0.95</td><td>0.975</td><td>0.95</td><td>0.95</td><td>0.9</td><td>0.95</td><td>0.9</td></tr>
<tr><td>50</td><td>0.9</td><td>0.95</td><td>0.9</td><td>0.9</td><td>0.8</td><td>0.9</td><td>0.8</td></tr>
<tr><td>55</td><td rowspan="2">0.9</td><td rowspan="2">0.8</td><td>0.925</td><td>0.85</td><td rowspan="2">0.8</td><td rowspan="2">0.7</td><td>0.85</td><td>0.75</td></tr>
<tr><td>60</td><td>0.9</td><td>0.8</td><td>0,8</td><td>0.7</td></tr>
<tr><td>65</td><td rowspan="2">0.95</td><td rowspan="2">0.7</td><td>0.85</td><td>0.75</td><td rowspan="2">0.7</td><td rowspan="2">0.6</td><td>0.75</td><td>0.65</td></tr>
<tr><td>70</td><td>0.8</td><td>0.7</td><td>0.7</td><td>0.6</td></tr>
</table>

<table>
<tr><th rowspan="3">Isomax S8
In ≤ 2000A</th><th>Front
flat bar</th><th>Rear vertical
flat bar</th></tr>
<tr><th colspan="2">PR212</th></tr>
<tr><th>F</th><th>F</th></tr>
<tr><td>≤40</td><td rowspan="4">1</td><td rowspan="5">1</td></tr>
<tr><td>45</td></tr>
<tr><td>50</td></tr>
<tr><td>55</td></tr>
<tr><td>60</td><td>0.95</td></tr>
<tr><td>65</td><td>0.9</td><td>0.925</td></tr>
<tr><td>70</td><td>0.85</td><td>0.875</td></tr>
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<table>
<tr><th rowspan="3">Isomax S8
In = 2500A</th><th>Front
flat bar</th><th>Rear vertical
flat bar</th></tr>
<tr><th colspan="2">PR212</th></tr>
<tr><th>F</th><th>F</th></tr>
<tr><td>≤40</td><td rowspan="3">1</td><td rowspan="4">1</td></tr>
<tr><td>45</td></tr>
<tr><td>50</td></tr>
<tr><td>55</td><td>0.95</td></tr>
<tr><td>60</td><td>0.9</td><td>0.95</td></tr>
<tr><td>65</td><td>0.85</td><td>0.9</td></tr>
<tr><td>70</td><td>0.8</td><td>0.85</td></tr>
</table>

<table>
<tr><th rowspan="3">Isomax S8
In = 3200A</th><th>Rear vertical
flat bar</th></tr>
<tr><th>PR212</th></tr>
<tr><th>F</th></tr>
<tr><td>≤40</td><td rowspan="2">1</td></tr>
<tr><td>45</td></tr>
<tr><td>50</td><td>0.95</td></tr>
<tr><td>55</td><td>0.9</td></tr>
<tr><td>60</td><td>0.85</td></tr>
<tr><td>65</td><td>0.8</td></tr>
<tr><td>70</td><td>0.75</td></tr>
</table>

3 General characteristics

Emax E1	800 A	
	PR111	PR112/PR113
≤40		
45		
50		
55	1	1
60		
65		
70		

Emax E1	1250 A	
	PR111	PR112/PR113
≤40		
45		
50	1	1
55		
60		
65	0.95	0.99
70		0.98

Emax E2	1250 A	
	PR111	PR112/PR113
≤40		
45		
50		
55	1	1
60		
65		
70		

Emax E2	1600 A	
	PR111	PR112/PR113
≤40		
45	1	1
50		
55		
60	0.95	0.98
65		0.96
70	0.9	0.94

Emax E2	2000 A	
	PR111	PR112/PR113
≤40	1	1
45		
50	0.95	0.97
55	0.9	0.94
60		0.91
65	0.85	0.88
70		0.85

Emax E3	1250/1600/2000 A	
	PR111	PR112/PR113
≤40		
45		
50		
55	1	1
60		
65		
70		

Emax E3	2500 A	
	PR111	PR112/PR113
≤40		
45		
50	1	1
55		
60		
65	0.95	0.97
70	0.9	0.94

Emax E3	3200 A	
	PR111	PR112/PR113
≤40	1	1
45		
50	0.95	0.97
55	0.9	0.93
60	0.85	0.89
65		0.86
70	0.8	0.82

Emax E4	3200 A	
	PR111	PR112/PR113
≤40		
45		
50	1	1
55		
60		
65	0.95	0.98
70		0.95

Emax E4	4000 A	
	PR111	PR112/PR113
≤40	1	1
45		
50	0.95	0.98
55		0.95
60	0.9	0.92
65	0.85	0.89
70		0.87

3 General characteristics

Emax E6	3200/4000 A	
	PR111	PR112/PR113
≤40	1	1
45		
50		
55		
60		
65		
70		

Emax E6	5000 A	
	PR111	PR112/PR113
≤40	1	1
45		
50		
55		
60	0.95	0.98
65		0.96
70	0.9	0.94

Emax E6	6000 A	
	PR111	PR112/PR113
≤40	1	1
45		
50		
55	0.95	0.98
60		0.96
65	0.9	0.94
70		0.92

	Vertical Terminals					
	35 °C		45 °C		55 °C	
	PR111	PR112/PR113	PR111	PR112/PR113	PR111	PR112/PR113
E1B/N 08	1	1	1	1	1	1
E1B/N 12	1	1	1	1	1	1
E2N 12	1	1	1	1	1	1
E2B/N 16	1	1	1	1	1	1
E2B/N 20	1	1	1	1	0.9	0.9
E2L 12	1	1	1	1	1	1
E2L 16	1	1	1	1	0.9	0.93
E3S/H 12	1	1	1	1	1	1
E3S/H 16	1	1	1	1	1	1
E3S/H 20	1	1	1	1	1	1
E3N/S/H 25	1	1	1	1	1	1
E3N/S/H 32	1	1	0.95	0.96	0.8	0.87
E3L 20	1	1	1	1	1	1
E3L 25	1	1	0.95	0.95	0.9	0.9
E4H 32	1	1	1	1	1	1
E4S/H 40	1	1	0.95	0.99	0.8	0.87
E6V 32	1	1	1	1	1	1
E6V 40	1	1	1	1	1	1
E6H/V 50	1	1	0.95	0.97	0.9	0.92
E6H/V 63	0.95	0.95	0.9	0.9	0.8	0.83

3 General characteristics

	Horizontal and front terminals					
	35 °C		45 °C		55 °C	
	PR111	PR112/PR113	PR111	PR112/PR113	PR111	PR112/PR113
E1B/N 08	1	1	1	1	1	1
E1B/N 12	1	1	1	1	0.95	0.96
E2N 12	1	1	1	1	1	1
E2B/N 16	1	1	1	1	0.95	0.95
E2B/N 20	1	1	1	1	0.8	0.87
E2L 12	1	1	1	1	1	1
E2L 16	1	1	0.9	0.93	0.8	0.87
E3S/H 12	1	1	1	1	1	1
E3S/H 16	1	1	1	1	1	1
E3S/H 20	1	1	1	1	1	1
E3N/S/H 25	1	1	0.95	0.99	0.95	0.94
E3N/S/H 32	0.9	0.93	0.9	0.9	0.8	0.82
E3L 20	1	1	1	1	0.95	0.98
E3L 25	0.95	0.95	0.9	0.9	0.8	0.84
E4H 32	1	1	1	1	0.9	0.94
E4S/H 40	0.9	0.9	0.8	0.87	0.7	0.78
E6V 32	1	1	1	1	1	1
E6V 40	1	1	1	1	1	1
E6H/V 50	0.95	0.97	0.9	0.9	0.8	0.85
E6H/V 63	---	---	---	---	---	---

3.6 Altitude derating

For installations carried out at altitudes of more than 2000 m above sea level, the performance of low voltage circuit-breakers is subject to a decline.
Basically there are two main phenomena:

- the reduction of air density causes a lower efficiency in heat transfer. The allowable heating conditions for the various parts of the circuit-breaker can only be followed if the value of the rated uninterrupted current is decreased;
- the rarefaction of the air causes a decrease in dielectric rigidity, so the usual isolation distances become insufficient. This leads to a decrease in the maximum rated voltage at which the device can be used.

The correction factors for the different types of circuit-breakers, both moulded- case and air circuit-breakers, are given in the following table:

		Rated operational voltage Ue [V]		
Altitude	2000[m]	3000[m]	4000[m]	5000[m]
Tmax*	690	600	500	440
Isomax	690	600	500	440
Emax	690	600	500	440

		Rated uninterrupted current Iu [A]		
Altitude	2000[m]	3000[m]	4000[m]	5000[m]
Tmax	100%	98%	93%	90%
Isomax	100%	95%	90%	85%
Emax	100%	98%	93%	90%

*Excluding Tmax T1P

3.7 Electrical characteristics of switch disconnectors

A switch disconnector as defined by the standard IEC 60947-3 is a mechanical switching device which, when in the open position, carries out a disconnecting function and ensures an isolating distance (distance between contacts) sufficient to guarantee safety. This safety of disconnection must be guaranteed and verified by the positive operation: the operating lever must always indicate the actual position of the mobile contacts of the device.
The mechanical switching device must be able to make, carry and break currents in normal circuit conditions, including any overload currents in normal service, and to carry, for a specified duration, currents in abnormal circuit conditions, such as, for example, short-circuit conditions.

Switch disconnectors are often used as:
- main sub-switchboard devices;
- switching and disconnecting devices for lines, busbars or load units;
- bus-tie.

The switch disconnector shall ensure that the whole plant or part of it is not live, safely disconnecting from any electrical supply. The use of such a switch disconnector allows, for example, personnel to carry out work on the plant without risks of electrical nature.
Even if the use of a single pole devices side by side is not forbidden, the standards recommend the use of multi-pole devices so as to guarantee the simultaneous isolation of all poles in the circuit.
The specific rated characteristics of switch disconnectors are defined by the standard IEC 60947-3, as detailed below:
- **Icw [kA]**: rated short-time withstand current:
  is the current that a switch is capable of carrying, without damage, in the closed position for a specific duration
- **Icm [kA]**: rated short-circuit making capacity:
  is the maximum peak value of a short-circuit current which the switch disconnector can close without damages. When this value is not given by the manufacturer it must be taken to be at least equal to the peak current corresponding to Icw. It is not possible to define a breaking capacity Icu [kA] since switch disconnectors are not required to break short-circuit currents
- **utilization categories with alternating current AC and with direct current DC:**
  define the kind of the conditions of using which are represented by two letters to indicate the type of circuit in which the device may be installed (AC for alternating current and DC for direct current), with a two digit number for the type of load which must be operated, and an additional letter (A or B) which represents the frequency in the using.
  With reference to the utilization categories, the product standard defines the current values which the switch disconnector must be able to break and make under abnormal conditions.

3 General characteristics

The characteristics of the utilization categories are detailed in Table 1 below. The most demanding category in alternating current is AC23A, for which the device must be capable of connecting a current equal to 10 times the rated current of the device, and of disconnecting a current equal to 8 times the rated current of the device.

From the point of view of construction, the switch disconnector is a very simple device. It is not fitted with devices for overcurrent detection and the consequent automatic interruption of the current. Therefore the switch disconnector cannot be used for automatic protection against overcurrent which may occur in the case of failure, protection must be provided by a coordinated circuit-breaker. The combination of the two devices allows the use of switch disconnectors in systems in which the short-circuit current value is greater than the electrical parameters which define the performance of the disconnector (back-up protection see Chapter 4.4. This is valid only for Isomax and Tmax switch-disconnectors. For the Emax/MS air disconnectors, it must be verified that the values for Icw and Icm are higher to the values for short-circuit in the plant and correspondent peak, respectively.

Table1: Utilization categories

Nature of current	Utilization categories		
	Utilization category		Typical applications
	Frequent operation	Non-frequent operation	
Alternating Current	AC-20A	AC-20B	Connecting and disconnecting under no-load conditions
	AC-21A	AC-21B	Switching of resistive loads including moderate overloads
	AC-22A	AC-22B	Switching of mixed resistive and inductive loads, including moderate overload
	AC-23A	AC-23B	Switching of motor loads or other highly inductive loads
Direct Current	DC-20A	DC-20B	Connecting and disconnecting under no-load conditions
	DC-21A	DC-21B	Switching of resistive loads including moderate overloads
	DC-22A	DC-22B	Switching of mixed resistive and inductive loads, including moderate overload (e.g. shunt motors)
	DC-23A	DC-23B	Switching of highly inductive loads

3 General characteristics

Tables 2, 3 and 4 detail the main characteristics of the disconnectors.

Table 2: Tmax switch disconnectors

Conventional thermal current, Ith	[A]
Rated current in AC-22A utilization category, Ie	[A]
Rated current in AC-23A utilization category, Ie	[A]
Poles	[Nr]
Rated operational voltage, Ue	50-60 Hz [Vac]
	dc [Vdc]
Rated impulse withstand voltage, Uimp	[kV]
Rated insulation voltage, Ui	[V]
Test voltage at industrial frequency for 1 minute	[V]
Rated short-circuit making capacity (415Vac), Icm	(min) switch disconnector only [kA]
	(max) with circuit-breaker on supply side [kA]
Rated short time withstand current for 1s, Icw	[kA]
Insulation behaviour	■
Reference standard	
Versions	
Terminals	
Mechanical life	[No. Of operations]
	[Operation per hour]
	3 poles L [mm]
Basic dimensions, fixed	4 poles L [mm]
	D [mm]
	H [mm]
Weight	3/4 poles fixed [kg]
	3/4 poles plug-in [kg]
	3/4 poles withdrawable [kg]

3 General characteristics

T1D	T3D	T4D	T5D
160	250	250/320	400/630
160	250	250/320	400/630
125	200	250	400
3/4	3/4	3/4	3/4
690	690	690	690
500	500	750	750
8	8	8	8
800	800	800	800
3000	3000	3000	3000
2.8	5.3	5,3	11
187	105	440	440
2	3.6	3.6	6
■	■	■	■
IEC 60947-3	IEC 60947-3	IEC 60947-3	IEC 60947-3
F	F - P	F - P - W	F - P - W
FC Cu - EF FC CuAl	F - FC Cu - FC CuAl EF-ES - R - FC CuAl	F - FCCu - FCCuAl - EF-ES R- MC -HR - VR	F - FCCu - FCCuAl -EF ES- R - HR - VR
25000	25000	20000	20000
120	120	120	120
76	105	105	140
102	140	140	184
130	150	205	205
70	70	103,5	103,5
0.9/1.2	2.1/3	2.35/3.05	3.25/4.15
-	2.1/3.7	3.6/4.65	5.15/6.65
-	-	3.85/4.9	5.4/6.9

KEY TO VERSIONS
F = Fixed
P = Plug-in
W = Withdrawable

K Y TO TERMINALS
F = Front
EF = Extended front
ES = Extended spreaded front

FC C Al = Front for copper or aluminium cat es
R = Rear threaded
RC = Rear for copper or aluminium cables
HR = Rear horizontal flat bar

VR = Rear vertical flat bar

3 General characteristics

Table 3: SACE Isomax switch disconnectors

Conventional thermal current at 40 °C, **Ith**		[A]
Number of poles		Nr.
Rated operational voltage, **Ue**	(ac) 50-60Hz	[V~]
	(dc)	[V–]
Rated current, **Ie**	[A]	
Rated impulse withstand voltage, **Uimp**		[kV]
Rated insulation voltage, **Ui**		[V]
Test voltage at industrial frequency for 1 min.		[V]
Rated short-circuit making capacity (415 V~), **Icm**		[kA]
Rated short-time withstand current for 1 s, **Icw**		[kA]
Isolation behaviour		
IEC 60947-3		
Versions		
Terminals	fixed	
	plug-in	
	withdrawable	
Mechanical life	[No. of operations / operation per hour]	
Basic dimensions, fixed	L (3/4 poles)	[mm]
	D	[mm]
	H	[mm]
Weight, fixed	3/4 poles	[kg]

Table 4: Emax switch disconnectors

			E1B/MS	E1N/MS	E2B/MS
Rated uninterrupted current		[A]	**800**	**800**	**1600**
(a 40 °C) Ith		[A]	**1250**	**1250**	**2000**
		[A]			
		[A]			
		[A]			
Rated operational voltage **Ue**		[V ~]	690	690	690
		[V –]	250	250	250
Rated insulation voltage **Ui**		[V ~]	1000	1000	1000
Rated impulse withstand voltage **Uimp**		[kV]	12	12	12
Rated short-time withstand current **Icw**	(1s)	[kA]	36	50	42
	(3s)	[kA]	36	36	42
Rated short-circuit making capacity (peak value) **Icm**					
220/230/380/400/415/440 V ~		[kA]	75.6	105	88.2
500/660/690 V ~		[kA]	75.6	75.6	88.2

3 General characteristics

S6D	S7D	S8D
630-800	1000 / 1250 / 1600	2000 / 2500 / 3200
3/4	3/4	3/4
690	690	690
750	750	750
630-800	1000-1250-1600	2000-2500-3200
8	8	8
800	800	800
3000	3000	3000
30	52,5	85
15	25	40
■	■	■
■	■	■
F - W	F - W	F
F - EF - FC CuAl R - RC	F - EF - FC CuAl (1250A) HR - VR	EF (2500A)-R
-	-	-
F - HR - VR	F - HR - VR	-
20000/120	10000/120	10000/20
210/280	210/280	406/556
103,5	138,5	242
268	406	400
9.5/12	17/22	57/76

E2N/MS	E3N/MS	E3S/MS	E4S/MS	E4S/fMS	E4H/MS	E6H/MS	E6H/f MS
1250	**2500**	**1250**	**4000**	**4000**	**3200**	**5000**	**5000**
1600	**3200**	**1600**			**4000**	**6300**	**6300**
2000		**2000**					
		2500					
		3200					
690	690	690	690	690	690	690	690
250	250	250	250	250	250	250	250
1000	1000	1000	1000	1000	1000	1000	1000
12	12	12	12	12	12	12	12
55	65	75	75	80	100	100	100
42	65	65	75	75	75	85	85
121	143	165	165	176	220	220	220
121	143	165	165	165	187	220	220

4 Protection coordination

4.1 Protection coordination

The design of a system for protecting an electric network is of fundamental importance both to ensure the correct economic and functional operation of the installation as a whole and to reduce to a minimum any problem caused by anomalous operating conditions and/or malfunctions.
The present analysis discusses the coordination between the different devices dedicated to the protection of zones and specific components with a view to:

- guaranteeing safety for people and installation at all times;
- identifying and rapidly excluding only the zone affected by a problem, instead of taking indiscriminate actions and thus reducing the energy available to the rest of the network;
- containing the effects of a malfunction on other intact parts of the network (voltage dips, loss of stability in the rotating machines);
- reducing the stress on components and damage in the affected zone;
- ensuring the continuity of the service with a good quality feeding voltage;
- guaranteeing an adequate back-up in the event of any malfunction of the protective device responsible for opening the circuit;
- providing staff and management systems with the information they need to restore the service as rapidly as possible and with a minimal disturbance to the rest of the network;
- achieving a valid compromise between reliability, simplicity and cost effectiveness.

To be more precise, a valid protection system must be able to:

- understand what has happened and where it has happened, discriminating between situations that are anomalous but tolerable and faults within a given zone of influence, avoiding unnecessary tripping and the consequent unjustified disconnection of a sound part of the system;
- take action as rapidly as possible to contain damage (destruction, accelerated ageing, ...), safeguarding the continuity and stability of the power supply.

The most suitable solution derives from a compromise between these two opposing needs - to identify precisely the fault and to act rapidly - and is defined in function of which of these two requirements takes priority.

Over-current coordination

Influence of the network's electrical parameters (rated current and short-circuit current)

The strategy adopted to coordinate the protective devices depends mainly on the rated current (I_n) and short-circuit current (I_k) values in the considered point of network.
Generally speaking, we can classify the following types of coordination:

- current discrimination;
- time (or time-current) discrimination;
- zone (or logical) discrimination;
- energy discrimination;
- back-up.

4 Protection coordination

Definition of discrimination

The **over-current discrimination** is defined in the Standards as *"coordination of the operating characteristics of two or more over-current protective devices such that, on the incidence of over-currents within stated limits, the device intended to operate within these limits does so, while the others do not operate"* (IEC 60947-1, def. 2.5.23);
It is possible to distinguish between:
- **total discrimination**, which means *"over-current discrimination such that, in the case of two over-current protective devices in series, the protective device on the load side provides protection without tripping the other protective device"* (IEC 60947-2, def. 2.17.2);
- **partial discrimination**, which means *"over-current discrimination such that, in the case of two over-current protective devices in series, the protective device on the load side provides protection up to a given over-current limit without tripping the other"* (IEC 60947-2, def. 2.17.3); this over-current threshold is called *"discrimination limit current I_S"* (IEC 60947-2, def. 2.17.4).

Current discrimination

This type of discrimination is based on the observation that the closer the fault comes to the network's feeder, the greater the short-circuit current will be. We can therefore pinpoint the zone where the fault has occurred simply by calibrating the instantaneous protection of the device upstream to a limit value higher than the fault current which causes the tripping of the device downstream.
We can normally achieve total discrimination only in specific cases where the fault current is not very high (and comparable with the device's rated current) or where a component with high impedance is between the two protective devices (e.g. a transformer, a very long or small cable...) giving rise to a large difference between the short-circuit current values.

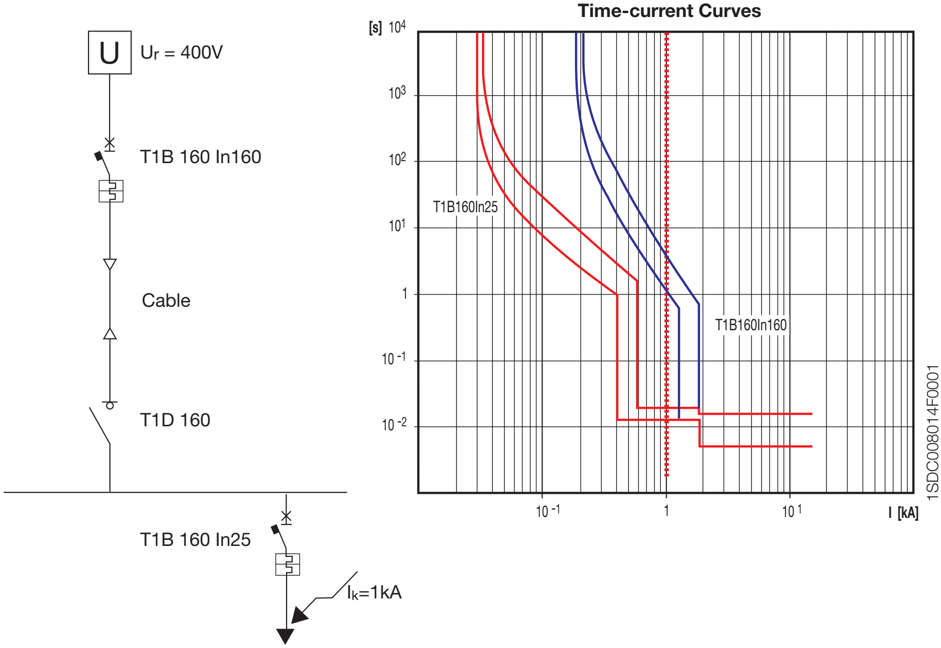
This type of coordination is consequently feasible mainly in final distribution networks (with low rated current and short-circuit current values and a high impedance of the connection cables).
The devices' time-current tripping curves are generally used for the study.
This solution is:
- rapid;
- easy to implement;
- and inexpensive.

On the other hand:
- the discrimination limits are normally low;
- increasing the discrimination levels causes a rapid growing of the device sizes.

The following example shows a typical application of current discrimination based on the different instantaneous tripping threshold values of the circuit-breakers considered.

4 Protection coordination

With a fault current value at the defined point equal to 1000 A, an adequate coordination is obtained by using the considered circuit-breakers as verified in the tripping curves of the protection devices.
The discrimination limit is given by the minimum magnetic threshold of the circuit-breaker upstream, T1B160 In160.



Time discrimination

This type of discrimination is an evolution from the previous one. The setting strategy is therefore based on progressively increasing the current thresholds and the time delays for tripping the protective devices as we come closer to the power supply source. As in the case of current discrimination, the study is based on a comparison of the time-current tripping curves of the protective devices.

This type of coordination:

- is easy to study and implement;
- is relatively inexpensive;
- enables to achieve even high discrimination levels, depending on the I_{cw} of the upstream device;
- allows a redundancy of the protective functions and can send valid information to the control system,

but has the following disadvantages:

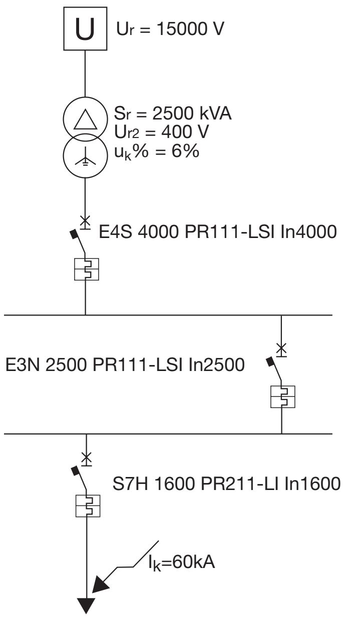
- the tripping times and the energy levels that the protective devices (especially those closer to the sources) let through are high, with obvious problems concerning safety and damage to the components even in zones unaffected by the fault;

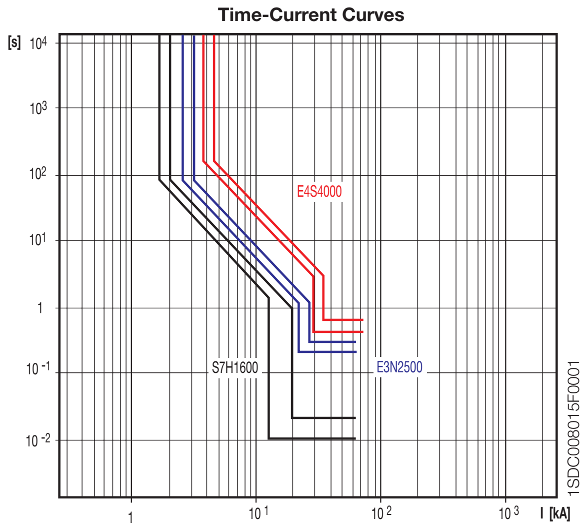
4 Protection coordination

- it enables the use of current-limiting circuit-breakers only at levels hierarchically lower down the chain; the other circuit-breakers have to be capable of withstanding the thermal and electro-dynamic stresses related to the passage of the fault current for the intentional time delay. Selective circuit-breakers, often air type, have to be used for the various levels to guarantee a sufficiently high short-time withstand current;
- the duration of the disturbance induced by the short-circuit current on the power supply voltages in the zones unaffected by the fault can cause problems with electronic and electro-mechanical devices (voltage below the electromagnetic releasing value);
- the number of discrimination levels is limited by the maximum time that the network can stand without loss of stability.

The following example shows a typical application of time discrimination obtained by setting differently the tripping times of the different protection devices.

Electronic release:	L (Long delay)	S (Short delay)	I (IST)
E4S 4000 PR111-LSI In4000	Setting: 0.9 Curve: B	Setting: 8 Curve: D	Off
E3N 2500 PR111-LSI In2500	Setting: 1 Curve: A	Setting: 10 Curve: C	Off
S7H 1600 PR211-LI In1600	Setting: 1 Curve: A		Setting: 10





4 Protection coordination

Zone (or logical) discrimination

This type of coordination is implemented by means of a dialogue between current measuring devices that, when they ascertain that a setting threshold has been exceeded, give the correct identification and disconnection only of the zone affected by the fault.
It is available with the circuit-breakers of Emax series only.
In practice, it can be implemented in two ways:
- the releases send information on the preset current threshold that has been exceeded to the supervisor system and the latter decides which protective device has to trip;
- in the event of current values exceeding its setting threshold, each protective device sends a blocking signal via a direct connection or bus to the protective device higher in the hierarchy (i.e. upstream with respect to the direction of the power flow) and, before it trips, it makes sure that a similar blocking signal has not arrived from the protective device downstream; in this way, only the protective device immediately upstream of the fault trips.

The first mode foresees tripping times of about one second and is used mainly in the case of not particularly high short-circuit currents where a power flow is not uniquely defined.
The second mode enables distinctly shorter tripping times: with respect to a time discrimination coordination, there is no longer any need to increase the intentional time delay progressively as we move closer to the source of the power supply. The maximum delay is in relation to the time necessary to detect any presence of a blocking signal sent from the protective device downstream.
Advantages:
- reduction of the tripping times and increase of the safety level; the tripping times will be around 100 milliseconds;
- reduction of both the damages caused by the fault as well of the disturbances in the power supply network;
- reduction of the thermal and dynamic stresses on the circuit-breakers and on the components of the system;
- large number of discrimination levels;
- redundancy of protections: in case of malfunction of zone discrimination, the tripping is ensured by the settings of the other protection functions of the circuit-breakers. In particular, it is possible to adjust the time-delay protection functions against short-circuit at increasing time values, the closer they are to the network's feeder.

Disadvantages:
- higher costs;
- greater complexity of the system (special components, additional wiring, auxiliary power sources, ...).

This solution is therefore used mainly in systems with high rated current and high short-circuit current values, with precise needs in terms of both safety and continuity of service: in particular, examples of logical discrimination can be often found in primary distribution switchboards, immediately downstream of transformers and generators and in meshed networks.

4 Protection coordination

Energy discrimination

Energy coordination is a particular type of discrimination that exploits the current-limiting characteristics of moulded-case circuit-breakers. It is important to remember that a current-limiting circuit-breaker is *"a circuit-breaker with a break time short enough to prevent the short-circuit current reaching its otherwise attainable peak value"* (IEC 60947-2, def. 2.3).
In practice, ABB SACE moulded-case circuit-breakers of Isomax and Tmax series, under short-circuit conditions, are extremely rapid (tripping times of about some milliseconds) and therefore it is impossible to use the time-current curves for the coordination studies.
The phenomena are mainly dynamic (and therefore proportional to the square of the instantaneous current value) and can be described by using the specific let-through energy curves.
In general, it is necessary to verify that the let-through energy of the circuit-breaker downstream is lower than the energy value needed to complete the opening of the circuit-breaker upstream.
This type of discrimination is certainly more difficult to consider than the previous ones because it depends largely on the interaction between the two devices placed in series and demands access to data often unavailable to the end user. Manufacturers provide tables, rules and calculation programs in which the minimum discrimination limits are given between different combinations of circuit-breakers.
Advantages:
- fast breaking, with tripping times which reduce as the short-circuit current increases;
- reduction of the damages caused by the fault (thermal and dynamic stresses), of the disturbances to the power supply system, of the costs...;
- the discrimination level is no longer limited by the value of the short-time withstand current I_{cw} which the devices can withstand;
- large number of discrimination levels;
- possibility of coordination of different current-limiting devices (fuses, circuit-breakers,..) even if they are positioned in intermediate positions along the chain.

Disadvantage:
- difficulty of coordination between circuit-breakers of similar sizes.

This type of coordination is used above all for secondary and final distribution networks, with rated currents below 1600A.

Back-up protection

The back-up protection is an *"over-current coordination of two over-current protective devices in series where the protective device, generally but not necessarily on the supply side, effects the over-current protection with or without the assistance of the other protective device and prevents any excessive stress on the latter"* (IEC 60947-1, def. 2.5.24).
Besides, IEC 60364-4-43, § 434.5.1 states: *"… A lower breaking capacity is admitted if another protective device having the necessary breaking capacity is installed on the supply side. In that case, characteristics of the devices, must be co-ordinated so that the energy let through by these two devices does not exceed that which can be withstood without damage by the device on the load side and the conductors protected by these devices."*

4 Protection coordination

Advantages:
• cost-saving solution;
• extremely rapid tripping.
Disadvantages:
• extremely low discrimination values;
• low service quality, since at least two circuit-breakers in series have to trip.

Coordination between circuit-breaker and switch disconnector

The switch disconnector

The switch disconnectors derive from the corresponding circuit-breakers, of which they keep the overall dimensions, the fixing systems and the possibility of mounting all the accessories provided for the basic versions. They are devices which can make, carry and break currents under normal service conditions of the circuit.
They can also be used as general circuit-breakers in sub-switchboards, as bus-ties, or to isolate installation parts, such as lines, busbars or groups of loads.
Once the contacts have opened, these switches guarantee isolation thanks to their contacts, which are at the suitable distance to prevent an arc from striking in compliance with the prescriptions of the standards regarding aptitude to isolation.

Protection of switch disconnectors

Each switch disconnector shall be protected by a coordinated device which safeguards it against overcurrents, usually a circuit-breaker able to limit the short-circuit current and the let-through energy values at levels acceptable for the switch-disconnector.
As regards overload protection, the rated current of the circuit-breaker shall be lower than or equal to the size of the disconnector to be protected.
Regarding Isomax and Tmax series switch disconnectors the coordination tables show the circuit-breakers which can protect them against the indicated prospective short-circuit currents values.
Regarding Emax series switch disconnectors it is necessary to verify that the short-circuit current value at the installation point is lower than the short-time withstand current I_{cw} of the disconnector, and that the peak value is lower than the making current value (I_{cm}).

4.2 Discrimination tables

The tables below give the selectivity values of short-circuit currents (in kA) between pre-selected combinations of circuit-breakers, for voltages from 380 to 415 V. The tables cover the possible combinations of ABB SACE Emax air circuit-breakers series, ABB SACE Isomax and Tmax moulded-case circuit-breakers series and the series of ABB modular circuit-breakers.
The values are obtained following particular rules which, if not respected, may give selectivity values which in some cases may be much lower than those given. Some of these guidelines are generally valid and are indicated below; others refer exclusively to particular types of circuit-breakers and will be subject to notes below the relevant table.

General rules:

- the function I of electronic releases (PR111-PR112-PR113, PR211/P-PR212/P, PR221DS-PR222DS/P) of upstream breakers must be excluded (I3 in OFF);
- the magnetic trip of thermomagnetic (TM) or magnetic only (MO) breakers positioned upstream must be ≥ $10 \cdot I_n$ and set to the maximum threshold;
- it is fundamentally important to verify that the setting adopted by the user for the electronic and thermomagnetic releases of breakers positioned either upstream or downstream do not cause intersections in the time-current curves.

Notes for the correct reading of the coordination tables:

The limit value of selectivity is obtained considering the lower among the given value, the breaking capacity of the CB on the supply side and the breaking capacity of the CB on the load side.
The letter T indicates total selectivity for the given combination, the corresponding value in kA is obtained considering the lower of the downstream and upstream circuit-breakers' breaking capacities (Icu).

The following tables show the breaking capacities at 415Vac for SACE Emax, Isomax and Tmax circuit-breakers.

Tmax @ 415V ac	
Version	Icu [kA]
B	16
C	25
N	36
S	50
H	70
L (for T2)	85
L (for T4-T5)	120
V	200

Isomax @ 415V ac	
Version	Icu [kA]
N	35*
S	50
H	65
L	100

Emax @ 415V ac	
Version	Icu [kA]
B	42
N	65**
S	75
H	100
L	130
V	150

* Versions certified at 36 kA
** For Emax E1 version N Icu=50 kA

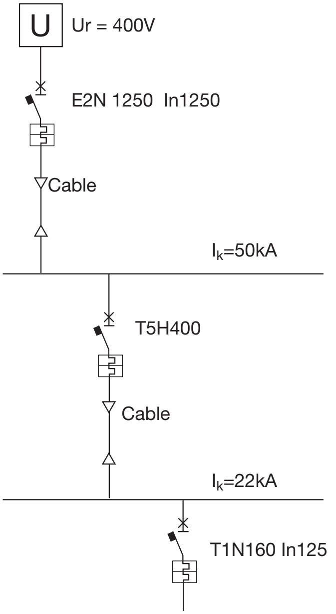
Keys

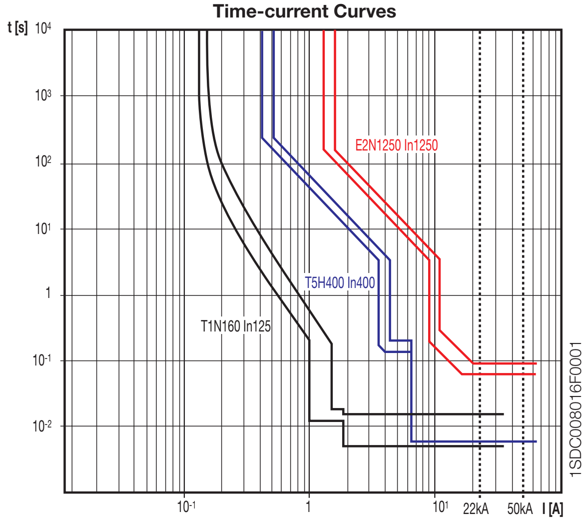
For MCCB (Moulded-case circuit-breaker)	For MCB (Modular circuit-breaker):
ACB (Air circuit-breaker)	B = charatteristic trip (I3=3...5In)
TM = thermomagnetic release	C = charatteristic trip (I3=5...10In)
– TMD (Tmax)	D = charatteristic trip (I3=10...20In)
– TMA (Tmax)	K = charatteristic trip (I3=8...14In)
– T adjustable M adjustable (Isomax)	Z = charatteristic trip (I3=2...3In)
M = magnetic only release	
– MF (Tmax)	
– MA (Tmax)	
EL = elettronic release	
– PR111/P - PR112/P - PR113/P (Emax)	
– PR211/P - PR212/P (Isomax)	
– PR221DS - PR222DS (Tmax)	

4 Protection coordination

Example:

From the selectivity table on page 213 it can be seen that breakers E2N1250 and T5H400,correctly set, are selective up to 55kA (higer than the short-circuit current at the busbar).
From the selectivity table on page 206 it can be seen that, between T5H400 and T1N160 In125, the total sectivity is granted; as aleady specified on age 189 this means selectivity up to the breaking capacity of T1N and therefore up to 36 kA (higher than the short-circuit current at the busbar).





From the curves it is evident that between breakers E2N1250 and T5H400 time discrimination exists, while between breakers T5H400 and T1N160 there is energy discrimination.

4 Protection coordination

Discrimination tables MCB-MCB

MCB - S2.. B @ 415V

						Supply s.					
						S290		S500			
Char.						D		D			
Icu [kA]						15		50			
7.5	10	15	20	25	In [A]	80	100	32	40	50	63
-	-	-	-	-	**≤2**						
-	-	-	-	-	**3**						
-	-	-	-	-	**4**						
-	S250-S260	S270-S280	-	-	**6**	10.5	T	1.5	2	3	5.5
-	S250-S260	S270-S280	-	-	**8**	10.5	T	1.5	2	3	5.5
-	S250-S260	S270	-	S280	**10**	5	8	1	1.5	2	3
-	S250-S260	S270	-	S280	**13**	4.5	7		1.5	2	3
-	S250-S260	S270	-	S280	**16**	4,5	7			2	3
-	S250-S260	S270	-	S280	**20**	3.5	5				2.5
-	S250-S260	S270	-	S280	**25**	3.5	5				
-	S250-S260	S270	S280	-	**32**		4.5				
-	S250-S260	S270	S280	-	**40**						
-	S250-S260	S270-S280	-	-	**50**						
-	S250-S260	S270-S280	-	-	**63**						

Load s. **B**

MCB - S2.. C @ 415V

						Supply s.					
						S290		S500			
Char.						D		D			
Icu [kA]						15		50			
7.5	10	15	20	25	In [A]	80	100	32	40	50	63
-	S250-S260	S270	-	S280	**≤2**	T	T	T	T	T	T
-	S250-S260	S270-S280	-	-	**3**	T	T	3	6	T	T
-	S250-S260	S270-S280	-	-	**4**	T	T	2	3	6	T
S240	S250-S260	S270-S280	-	-	**6**	10.5	T	1.5	2	3	5.5
S240	S250-S260	S270-S280	-	-	**8**	10.5	T	1.5	2	3	5.5
S240	S250-S260	S270	-	S280	**10**	5	8	1	1.5	2	3
S240	S250-S260	S270	-	S280	**13**	4.5	7		1.5	2	3
S240	S250-S260	S270	-	S280	**16**	4,5	7			2	3
S240	S250-S260	S270	-	S280	**20**	3.5	5				2.5
S240	S250-S260	S270	-	S280	**25**	3.5	5				
S240	S250-S260	S270	S280	-	**32**		4.5				
S240	S250-S260	S270	S280	-	**40**						
-	S250-S260	S270-S280	-	-	**50**						
-	S250-S260	S270-S280	-	-	**63**						

Load s. **C**

1SDC008004F0201

4 Protection coordination

Discrimination tables MCB-MCB

MCB - S2.. D @ 415V

							Supply s.					
							S290		S500			
	Char.						D		D			
	Icu [kA]						15		50			
	7.5	10	15	20	25	In [A]	80	100	32	40	50	63
Load s. D	-	-	S270	-	S280	**≤2**	T	T	T	T	T	T
	-	-	S270-S280	-	-	**3**	T	T	3	6	T	T
	-	-	S270-S280	-	-	**4**	T	T	2	3	6	T
	-	-	S270-S280	-	-	**6**	10.5	T	1.5	2	3	5.5
	-	-	S270-S280	-	-	**8**	10.5	T	1.5	2	3	5.5
	-	-	S270	-	S280	**10**	5	8	1	1.5	2	3
	-	-	S270	-	S280	**13**	3	5			1.5	2
	-	-	S270	-	S280	**16**	3	5				2
	-	-	S270	-	S280	**20**	3	5				
	-	-	S270	-	S280	**25**	2.5	4				
	-	-	S270	S280	-	**32**		4				
	-	-	S270	S280	-	**40**						
	-	-	S270-S280	-	-	**50**						
	-	-	S270-S280	-	-	**63**						

MCB - S2.. K @ 415V

							Supply s.					
							S290		S500			
	Char.						D		D			
	Icu [kA]						15		50			
	7.5	10	15	20	25	In [A]	80	100	32	40	50	63
Load s. K	-	S250	-	-	S280	**≤2**	T	T	T	T	T	T
	-	S250	S280	-	-	**3**	T	T	3	6	T	T
	-	S250	S280	-	-	**4**	T	T	2	3	6	T
	-	S250	S280	-	-	**6**	10.5	T	1.5	2	3	5.5
	-	S250	S280	-	-	**8**	10.5	T	1.5	2	3	5.5
	-	S250	-	-	S280	**10**	5	8		1.5	2	3
	-	-	-	-	S280	**13**	3	5			1.5	2
	-	S250	-	-	S280	**16**	3	5				2
	-	S250	-	-	S280	**20**	3	5				
	-	S250	-	-	S280	**25**		4				
	-	S250	-	S280	-	**32**						
	-	S250	-	S280	-	**40**						
	-	S250	S280	-	-	**50**						
	-	S250	S280	-	-	**63**						

4 Protection coordination

MCB - S2.. Z @ 415V

							Supply s.					
							S290		S500			
Char.							D		D			
Icu [kA]							15		50			
	7.5	10	15	20	25	In [A]	80	100	32	40	50	63
Load s. Z	-	S270	-	-	S280	**≤2**	T	T	T	T	T	T
	-	S270	S280	-	-	**3**	T	T	3	6	T	T
	-	S270	S280	-	-	**4**	T	T	2	3	6	T
	-	S270	S280	-	-	**6**	10.5	T	1.5	2	3	5.5
	-	S270	S280	-	-	**8**	10.5	T	1.5	2	3	5.5
	-	S270	-	-	S280	**10**	5	8	1	1.5	2	3
	-	-	-	-	S280	**13**	4.5	7	1	1.5	2	3
	-	S270	-	-	S280	**16**	4.5	7	1	1.5	2	3
	-	S270	-	-	S280	**20**	3.5	5		1.5	2	2.5
	-	S270	-	-	S280	**25**	3.5	5			2	2.5
	-	S270	-	S280	-	**32**	3	4.5				2
	-	S270	-	S280	-	**40**	3	4.5				
	-	S270	S280	-	-	**50**		3				
	-	S270	S280	-	-	**63**						

1SDC008005F0201

4 Protection coordination

Discrimination tables MCB/MCCB - S500

MCB/MCCB - S500 @ 415V

			Version			B, C, N, S, H, L, V									
			Release			TM									
			Supply s.	S290 D		T2	T1-T2						T1-T2-T3		
Load s.	Char.	Icu [kA]	In [A]	80	100	12.5	16	20	25	32	40	50	63	80	100
S500	B, C	50	6	6	10	4.5	5.5	5.5	5.5	5.5	5.5	5.5	10.5	15	20
			10	6	10			4.5(1)	4.5	4.5	4.5	4.5	8	10	20
			13	6	10			4.5(1)		4.5	4.5	4.5	7.5	10	15
			16	6	10					4.5(1)	4.5	4.5	7.5	10	15
			20	6	7.5					4.5(1)		4.5	7.5	10	15
			25	4.5	6							4.5(1)	6	10	15
			32		6							4.5(1)		7.5	10
			40											5(1)	10
			50											5(1)	7.5(2)
			63												5(2)
	D	50	6	6	10	4.5	5.5	5.5	5.5	5.5	5.5	5.5	10.5	15	20
			10	6	10			4.5(1)	4.5	4.5	4.5	4.5	8	10	20
			13	6	10			4.5(1)		4.5	4.5	4.5	7.5	10	15
			16	6	10					4.5(1)	4.5	4.5	7.5	10	15
			20	6	7.5					4.5(1)		4.5	7.5	10	15
			25	4.5	6							4.5(1)	6	10	15
			32		6							4.5(1)		7.5	10
			40											5(1)	10
			50											5(1)	7.5(2)
			63												5(2)
	K	50	≤5.8	T	T	36	36	36	36	36	36	36	36	36	36
			5.3...8	10	T	4.5(1)	5.5	5.5	5.5	5.5	5.5	5.5	10.5	36	36
			7.3...11	7.5	T			4.5(1)	4.5	4.5	4.5	4.5	8	36	36
		30	10...15	4.5	10			4.5(1)		4.5	4.5	4.5	7.5	10	15
			14...20	4.5	6					4.5(1)	4.5	4.5	7.5	10	15
			18...26		4.5					4.5(1)		4.5	7.5	10	15
			23...32									4.5(1)	6	10	15
			29...37									4.5(1)		7.5	10
			34...41											5(1)	10
			38...45											5(1)	7.5(2)

(1) Value for the supply side magnetic only T2 circuit-breaker.
(2) Value for the supply side magnetic only T2-T3 circuit-breaker.
(3) Value for the supply side magnetic only T3 circuit-breaker.
(4) Value for the supply side magnetic only T4 circuit-breaker.

4 Protection coordination

B, C, N, S, H, L, V																		
TM													EL					
		T3		T4									T2					T4-T5
125	160	200	250	20	25	32	50	80	100	125	160	200÷320	10	25	63	100	160	100÷630
25	36	36	36	7.5	7.5(4)	7.5	7.5	16	T	T	T	T		36	36	36	36	T
25	36	36	36	6.5	6.5(4)	6.5	6.5	11	T	T	T	T		36	36	36	36	T
25	36	36	36	6.5	5(4)	6.5	6.5	11	T	T	T	T		36	36	36	36	T
25	36	36	36		5(4)	6.5	6.5	11	T	T	T	T			36	36	36	T
25	36	36	36		4(4)	6.5	6.5	11	T	T	T	T			36	36	36	T
20	36	36	36				6.5	11	T	T	T	T			36	36	36	T
20	36	36	36				6.5	8	T	T	T	T			36	36	36	T
20	36	36	36				5(4)	6.5	T	T	T	T				36	36	T
15	36	36	36					5(4)	7.5	T	T	T				36	36	T
6(3)	36	36	36						5(4)	7	T	T					36	T
25	36	36	36	7.5	7.5(4)	7.5	7.5	16	T	T	T	T		36	36	36	36	T
25	36	36	36	6.5	6.5(4)	6.5	6.5	11	T	T	T	T		36	36	36	36	T
25	36	36	36		5(4)		6.5	11	T	T	T	T		36	36	36	36	T
25	36	36	36				6.5	11	T	T	T	T			36	36	36	T
25	36	36	36				6.5(4)	11	T	T	T	T			36	36	36	T
20	36	36	36				6.5(4)	11	T	T	T	T			36	36	36	T
20	36	36	36					8	T	T	T	T			36	36	36	T
20	36	36	36					6.5(4)	T(4)	T	T	T				36	36	T
15	36	36	36						7.5(4)	T(4)	T	T				36	36	T
6(3)	36	36	36							7(4)	T(4)	T					36	T
36	50	T	T	40	40(4)	40	40	40	T	T	T	T	50	50	50	50	50	T
36	50	T	T	6	6(4)	6	6	40	T	T	T	T		50	50	50	50	T
36	50	T	T		5(4)	5	5	40	T	T	T	T		50	50	50	50	T
T	T	T	T		5(4)		5	12	T	T	T	T		T	T	T	T	T
T	T	T	T				5	12	T	T	T	T			T	T	T	T
T	T	T	T				5(4)	12(4)	T	T	T	T			T	T	T	T
20	T	T	T				5(4)	12(4)	T(4)	T	T	T			T	T	T	T
20	T	T	T				5(4)	8(4)	T(4)	T(4)	T	T				T	T	T
20	T	T	T					6(4)	T(4)	T(4)	T	T				T	T	T
15	T	T	T					6(4)	8(4)	T(4)	T(4)	T				T	T	T

1SDC008006F0201

4 Protection coordination

Discrimination tables MCCB - S2..

MCCB - S2.. B @ 415V

							Version	B, C, N, S, H, L							
							Release	TM							
	Char.	Icu [kA]					Supply s.	T2	T1-T2						
		7.5	10	15	20	25	In [A]	12.5	16	20	25	32	40	50	63
Load s.	B	-	-	-	-	-	≤2								
		-	-	-	-	-	3								
		-	-	-	-	-	4								
		-	S250-S260	S270-S280	-	-	6	5.5(1)	5.5	5.5	5.5	5.5	5.5	5.5	10.5
		-	S250-S260	S270	-	-	8			5.5	5.5	5.5	5.5	5.5	10.5
		-	S250-S260	S270	-	S280	10			3(1)	3	3	3	4.5	7.5
		-	S250-S260	S270	-	S280	13			3(1)		3	3	4.5	7.5
		-	S250-S260	S270	-	S280	16					3(1)	3	4.5	5
		-	S250-S260	S270	-	S280	20					3(1)		3	5
		-	S250-S260	S270	-	S280	25							3(1)	5
		-	S250-S260	S270	S280	-	32							3(1)	
		-	S250-S260	S270	S280	-	40								
		-	S250-S260	S270-S280	-	-	50								
		-	S250-S260	S270-S280	-	-	63								
		-	-	-	-	-	80								
		-	-	-	-	-	100								
		-	-	-	-	-	125								

(1) Value for the supply side magnetic only T2 circuit-breaker.
(2) Value for the supply side magnetic only T2-T3 circuit-breaker.
(3) Value for the supply side magnetic only T3 circuit-breaker.
(4) Value for the supply side magnetic only T4 circuit-breaker.

4 Protection coordination

	B, C, N, S, H, L,V																							
	TM																	EL						TM/ EL
	T1-T2-T3				T3		T4											T2					T4		T5
	80	100	125	160	200	250	20	25	32	50	80	100	125	160	200	250	320	10	25	63	100	160	100 160	250 320	320÷ 630
	T	T	T	T	T	T	7.5	7.5[4]	7.5	7.5	T	T	T	T	T	T	T		T	T	T	T	T	T	T
	T	T	T	T	T	T	7.5	7.5[4]	7.5	7.5	T	T	T	T	T	T	T		T	T	T	T	T	T	T
	8.5	17	T	T	T	T	5	5[4]	5	6.5	9	T	T	T	T	T	T		T	T	T	T	T	T	T
	7.5	12	20	T	T	T		5[4]	5	6.5	8	T	T	T	T	T	T		T	T	T	T	T	T	T
	7.5	12	20	T	T	T		3[4]	5	6.5	8	T	T	T	T	T	T			T	T	T	T	T	T
	6	10	15	T	T	T				5	7.5	T	T	T	T	T	T			T	T	T	T	T	T
	6	10	15	T	T	T				5	7.5	T	T	T	T	T	T			T	T	T	T	T	T
	6	7.5	12	T	T	T				5[4]	7.5	T	T	T	T	T	T			T	T	T	T	T	T
	5.5[1]	7.5	12	T	T	T					6.5	T	T	T	T	T	T				T	T	T	T	T
	3[1]	5[2]	7.5	10.5	T	T					5[4]	T	T	T	T	T	T				10.5	10.5	T	T	T
		5[2]	6[3]	10.5	T	T						T[4]	T[4]	T	T	T	T					10.5	T	T	T

1SDC008007F0201

4 Protection coordination

Discrimination tables MCCB - S2..

MCCB - S2.. C @ 415V

							Version	B, C, N, S, H, L							
							Release	TM							
	Char.	Icu [kA]					Supply s.	T2	T1-T2						
		7.5	10	15	20	25	In [A]	12.5	16	20	25	32	40	50	63
Load s.	C	-	S250-S260	S270	-	S280	≤2	T	T	T	T	T	T	T	T
		-	S250-S260	S270-S280	-	-	3	T	T	T	T	T	T	T	T
		-	S250-S260	S270-S280	-	-	4	T	T	T	T	T	T	T	T
		S240	S250-S260	S270-S280	-	-	6	5.5[1]	5.5	5.5	5.5	5.5	5.5	5.5	10.5
		S240	S250-S260	S270-S280	-	-	8			5.5	5.5	5.5	5.5	5.5	10.5
		S240	S250-S260	S270	-	S280	10			3[1]	3	3	3	4.5	7.5
		S240	S250-S260	S270	-	S280	13			3[1]		3	3	4.5	7.5
		S240	S250-S260	S270	-	S280	16					3[1]	3	4.5	5
		S240	S250-S260	S270	-	S280	20					3[1]		3	5
		S240	S250-S260	S270	-	S280	25							3[1]	5
		S240	S250-S260	S270	S280	-	32							3[1]	
		S240	S250-S260	S270	S280	-	40								
		-	S250-S260	S270-S280	-	-	50								
		-	S250-S260	S270-S280	-	-	63								
		-	-	S290	-	-	80								
		-	-	S290	-	-	100								
		-	-	S290	-	-	125								

[1] Value for the supply side magnetic only T2 circuit-breaker.
[2] Value for the supply side magnetic only T2-T3 circuit-breaker.
[3] Value for the supply side magnetic only T3 circuit-breaker.
[4] Value for the supply side magnetic only T4 circuit-breaker.
[5] Value for the supply side T4 In160 circuit-breaker.

4 Protection coordination

	B, C, N, S, H, L,V																								
	TM																	EL							TM/EL
	T1-T2-T3				T3		T4											T2					T4		T5
	80	100	125	160	200	250	20	25	32	50	80	100	125	160	200	250	320	10	25	63	100	160	100 160	250 320	320÷ 630
	T	T	T	T	T	T	T	T[4]	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
	T	T	T	T	T	T	T	T[4]	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
	T	T	T	T	T	T	T	T[4]	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
	T	T	T	T	T	T	7.5	7.5[4]	7.5	7.5	T	T	T	T	T	T	T		T	T	T	T	T	T	T
	T	T	T	T	T	T	7.5	7.5[4]	7.5	7.5	T	T	T	T	T	T	T		T	T	T	T	T	T	T
	8.5	17	T	T	T	T	5	5[4]	5	6.5	9	T	T	T	T	T	T		T	T	T	T	T	T	T
	7.5	12	20	T	T	T		5[4]	5	6.5	8	T	T	T	T	T	T		T	T	T	T	T	T	T
	7.5	12	20	T	T	T		3[4]	5	6.5	8	T	T	T	T	T	T			T	T	T	T	T	T
	6	10	15	T	T	T				5	7.5	T	T	T	T	T	T			T	T	T	T	T	T
	6	10	15	T	T	T				5	7.5	T	T	T	T	T	T			T	T	T	T	T	T
	6	7.5	12	T	T	T				5[4]	7.5	T	T	T	T	T	T			T	T	T	T	T	T
	5.5[1]	7.5	12	T	T	T					6.5	T	T	T	T	T	T				T	T	T	T	T
	3[1]	5[2]	7.5	10.5	T	T					5[4]	T	T	T	T	T	T				10.5	10.5	T	T	T
		5[2]	6[3]	10.5	T	T						T[4]	T[4]	T	T	T	T					10.5	T	T	T
				4[3]	10	15								5	11	T	T					4	T[5]	T	T
				4[3]	7.5[3]	15								5[4]	8	T	T					4	12[4	T	T
					7.5[3]										8[4]	12	T					4		T	T

1SDC008008F0201

4 Protection coordination

Discrimination tables MCCB - S2..

MCCB - S2.. D @ 415V

							Version	B, C, N, S, H, L							
							Release	TM							
	Char.	Icu [kA]					Supply s.	T2	T1-T2						
		7.5	10	15	20	25	In [A]	12.5	16	20	25	32	40	50	63
Load s.	D	-	-	S270	-	S280	≤2	T	T	T	T	T	T	T	T
		-	-	S270-S280	-	-	3	T	T	T	T	T	T	T	T
		-	-	S270-S280	-	-	4	T	T	T	T	T	T	T	T
		-	-	S270-S280	-	-	6	5.5[1]	5.5	5.5	5.5	5.5	5.5	5.5	10.5
		-	-	S270-S280	-	-	8			5.5	5.5	5.5	5.5	5.5	10.5
		-	-	S270	-	S280	10			3[1]	3	3	3	3	5
		-	-	-	-	S280	13					2[1]	2	2	3
		-	-	S270	-	S280	16					2[1]	2	2	3
		-	-	S270	-	S280	20					2[1]		2	3
		-	-	S270	-	S280	25							2[1]	2.5
		-	-	S270	S280	-	32								
		-	-	S270	S280	-	40								
		-	-	S270-S280	-	-	50								
		-	-	S270-S280	-	-	63								
		-	-	S290	-	-	80								
		-	-	S290	-	-	100								
		-	-	-	-	-	125								

(1) Value for the supply side magnetic only T2 circuit-breaker.
(2) Value for the supply side magnetic only T2-T3 circuit-breaker.
(3) Value for the supply side magnetic only T3 circuit-breaker.
(4) Value for the supply side magnetic only T4 circuit-breaker.
(5) Value for the supply side T4 In160 circuit-breaker.

4 Protection coordination

	B, C, N, S, H, L,V																							
	TM																	EL						TM/EL
	T1-T2-T3				T3		T4											T2					T4		T5
	80	100	125	160	200	250	20	25	32	50	80	100	125	160	200	250	320	10	25	63	100	160	100 160	250 320	320÷ 630
	T	T	T	T	T	T	T	T[4]	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
	T	T	T	T	T	T	T	T[4]	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
	T	T	T	T	T	T	T	T[4]	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
	T	T	T	T	T	T	7.5	7.5[4]	7.5	7.5	T	T	T	T	T	T	T		T	T	T	T	T	T	T
	12	T	T	T	T	T	7.5	7.5[4]	7.5	7.5	T	T	T	T	T	T	T		T	T	T	T	T	T	T
	8.5	17	T	T	T	T	5	5[4]	5	5	9	T	T	T	T	T	T		T	T	T	T	T	T	T
	5	8	13.5	T	T	T		5[4]		4	5.5	T	T	T	T	T	T			T	T	T	T	T	T
	5	8	13.5	T	T	T				4	5.5	T	T	T	T	T	T			T	T	T	T	T	T
	4.5	6.5	11	T	T	T				4[4]	5	T	T	T	T	T	T			T	T	T	T	T	T
	4	6	9.5	T	T	T				4[4]	4.5	T	T	T	T	T	T			T	T	T	T	T	T
	4	6	9.5	T	T	T					4.5[4]	T	T	T	T	T	T			T	T	T	T	T	T
	3[1]	5	8	T	T	T					4.5[4]	T[4]	T	T	T	T	T				T	T	T	T	T
	2[1]	3[2]	5	9.5	T	T						T[4]	T[4]	T	T	T	T				9.5	9.5	T	T	T
		3[2]	5[3]	9.5	T	T							T[4]	T[4]	T	T	T					9.5	T	T	T
				4[3]	10	15								5	11	T	T					4	T[5]	T	T
				4[3]	7.5[3]	15									8	T	T					4	12[5]	T	T

1SDC008009F0201

4 Protection coordination

Discrimination tables MCCB - S2..

MCCB - S2.. K @ 415V

							Version	B, C, N, S, H, L							
							Release	TM							
	Char.	Icu [kA]					Supply s.	T2	T1-T2						
		7.5	10	15	20	25	In [A]	12.5	16	20	25	32	40	50	63
Load s.	K	-	S250	-	-	S280	≤2	T	T	T	T	T	T	T	T
		-	S250	S280	-	-	3	T	T	T	T	T	T	T	T
		-	S250	S280	-	-	4	T	T	T	T	T	T	T	T
		-	S250	S280	-	-	6	5.5(1)	5.5	5.5	5.5	5.5	5.5	5.5	10.5
		-	S250	S280	-	-	8			5.5	5.5	5.5	5.5	5.5	10.5
		-	S250	-	-	S280	10			3(1)	3	3	3	3	6
		-	-	-	-	S280	13					2(1)	3	3	5
		-	S250	-	-	S280	16					2(1)	3	3	4.5
		-	S250	-	-	S280	20					2(1)		3	3.5
		-	S250	-	-	S280	25							2(1)	3.5
		-	S250	-	S280	-	32								
		-	S250	-	S280	-	40								
		-	S250	S280	-	-	50								
		-	S250	S280	-	-	63								
		-	-	S290	-	-	80								
		-	-	S290	-	-	100								
		-	-	-	-	-	125								

(1) Value for the supply side magnetic only T2 circuit-breaker.
(2) Value for the supply side magnetic only T2-T3 circuit-breaker.
(3) Value for the supply side magnetic only T3 circuit-breaker.
(4) Value for the supply side magnetic only T4 circuit-breaker.
(5) Value for the supply side T4 In160 circuit-breaker.

4 Protection coordination

	B, C, N, S, H, L,V																							
	TM																	EL						TM/ EL
	T1-T2-T3				T3		T4											T2					T4		T5
	80	100	125	160	200	250	20	25	32	50	80	100	125	160	200	250	320	10	25	63	100	160	100 160	250 320	320÷ 630
	T	T	T	T	T	T	T	T(4)	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
	T	T	T	T	T	T	T	T(4)	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
	T	T	T	T	T	T	T	T(4)	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
	T	T	T	T	T	T	7.5	7.5(4)	7.5	7.5	T	T	T	T	T	T	T		T	T	T	T	T	T	T
	12	T	T	T	T	T	7.5	7.5(4)	7.5	7.5	T	T	T	T	T	T	T		T	T	T	T	T	T	T
	8.5	17	T	T	T	T		5(4)	5	5	9	T	T	T	T	T	T		T	T	T	T	T	T	T
	7.5	10	13.5	T	T	T		5(4)	5	5	8	T	T	T	T	T	T		T	T	T	T	T	T	T
	7.5	10	13.5	T	T	T		5(4)		5	8	T	T	T	T	T	T			T	T	T	T	T	T
	5.5	6.5	11	T	T	T				5	6	T	T	T	T	T	T			T	T	T	T	T	T
	5.5	6	9.5	T	T	T				5(4)	6(4)	T	T	T	T	T	T			T	T	T	T	T	T
	4.5	6	9,5	T	T	T				5(4)	6(4)	T(4)	T	T	T	T	T			T	T	T	T	T	T
	3(1)	5	8	T	T	T					5.5(4)	T(4)	T(4)	T	T	T	T				T	T	T	T	T
	2(1)	3(2)	6	9.5	T	T					5(4)	T(4)	T(4)	T(4)	T	T	T				9.5	9.5	T	T	T
		3(2)	5.5(3)	9.5	T	T						T(4)	T(4)	T(4)	T(4)	T	T					9.5	T	T	T
				4(3)	10	15								5	11	T	T					4	T(5)	T	T
				4(3)	7.5(3)	15								5(4)	8	T	T					4	12(5)	T	T

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4 Protection coordination

Discrimination tables MCCB - S2..

MCCB - S2.. Z @ 400V

							Version	B, C, N, S, H, L							
							Release	TM							
	Char.	Icu [kA]					Supply s.	T2	T1-T2						
		7.5	10	15	20	25	In [A]	12.5	16	20	25	32	40	50	63
Load s.	Z	-	S270	-	-	S280	≤2	T	T	T	T	T	T	T	T
		-	S270	S280	-	-	3	T	T	T	T	T	T	T	T
		-	S270	S280	-	-	4	T	T	T	T	T	T	T	T
		-	S270	S280	-	-	6	5.5[1]	5.5	5.5	5.5	5.5	5.5	5.5	10.5
		-	S270	S280	-	-	8			5.5	5.5	5.5	5.5	5.5	10.5
		-	S270	-	-	S280	10			3[1]	3	3	3	4.5	8
		-	-	-	-	S280	13			3[1]		3	3	4.5	7.5
		-	S270	-	-	S280	16					3[1]	3	4.5	5
		-	S270	-	-	S280	20					3[1]		3	5
		-	S270	-	-	S280	25							3[1]	5
		-	S270	-	S280	-	32							3[1]	
		-	S270	-	S280	-	40								
		-	S270	S280	-	-	50								
		-	S270	S280	-	-	63								
		-	-	-	-	-	80								
		-	-	-	-	-	100								
		-	-	-	-	-	125								

(1) Value for the supply side magnetic only T2 circuit-breaker.
(2) Value for the supply side magnetic only T2-T3 circuit-breaker.
(3) Value for the supply side magnetic only T3 circuit-breaker.
(4) Value for the supply side magnetic only T4 circuit-breaker.

4 Protection coordination

	B, C, N, S, H, L,V																								
	TM																	EL							TM/ EL
	T1-T2-T3				T3		T4											T2					T4		T5
	80	100	125	160	200	250	20	25	32	50	80	100	125	160	200	250	320	10	25	63	100	160	100 160	250 320	320÷ 630
	T	T	T	T	T	T	T	T(4)	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
	T	T	T	T	T	T	T	T(4)	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
	T	T	T	T	T	T	T	T(4)	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
	T	T	T	T	T	T	7.5	7.5(4)	7.5	7.5	T	T	T	T	T	T	T		T	T	T	T	T	T	T
	T	T	T	T	T	T	7.5	7.5(4)	7.5	7.5	T	T	T	T	T	T	T		T	T	T	T	T	T	T
	8.5	17	T	T	T	T	5	5(4)	5	6.5	9	T	T	T	T	T	T		T	T	T	T	T	T	T
	7.5	12	20	T	T	T		5(4)	5	6.5	8	T	T	T	T	T	T		T	T	T	T	T	T	T
	7.5	12	20	T	T	T		5(4)	4.5	6.5	8	T	T	T	T	T	T			T	T	T	T	T	T
	6	10	15	T	T	T				5	6.5	T	T	T	T	T	T			T	T	T	T	T	T
	6	10	15	T	T	T				5	6.5	T	T	T	T	T	T			T	T	T	T	T	T
	6	7.5	12	T	T	T				5(4)	6.5	T	T	T	T	T	T			T	T	T	T	T	T
	5.5(1)	7.5	12	T	T	T					5	T	T	T	T	T	T				T	T	T	T	T
	4(1)	5(2)	7.5	10.5	T	T					3.5(4)	T	T	T	T	T	T				10.5	10.5	T	T	T
		5(2)	6(3)	10.5	T	T						T(4)	T	T	T	T	T					10.5	T	T	T

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4 Protection coordination

Discrimination tables MCCB - MCCB

MCCB - T1 @ 415V

				Supply s.	T1	T2					T3			T4										
	Version				B, C, N	N,S,H,L					N,S			N,S,H,L,V										
		Release			TM	TM,M	EL				TM,M			TM,M										
			I_u [A]		160	160					250			250										320
Load s.				I_n [A]	160	160	25	63	100	160	160	200	250	20	25	32	50	80	100	125	160	200	250	320
T1	B, C, N	TM	160	16	3	3		3	3	3	3	4	5				10*	10	10	10	10	10	10	10
				20	3	3		3	3	3	3	4	5				10*	10	10	10	10	10	10	10
				25	3	3		3	3	3	3	4	5				10*	10	10	10	10	10	10	10
				32	3	3			3	3	3	4	5					10*	10	10	10	10	10	10
				40	3	3			3	3	3	4	5					10*	10	10	10	10	10	10
				50	3	3			3	3	3	4	5						10*	10	10	10	10	10
				63	3	3				3	3	4	5							10*	10	10	10	10
				80						3		4	5								10	10	10	10
				100									5								10*	10	10	10
				125																		10*	10	10
				160																				10

* Value for the supply side magnetic only circuit-breaker.

4 Protection coordination

T4				T5							S6		S7		
N,S,H,L,V				N,S,H,L,V							N,S,H,L		S,H,L		
EL				TM				EL			TM	EL	EL		
250			320	400		630		400		630	800		1250		1600
100	160	250	320	320	400	500	630	320	400	630	800	800	1000	1250	1600
10	10	10	10	T	T	T	T	T	T	T	T	T	T	T	T
10	10	10	10	T	T	T	T	T	T	T	T	T	T	T	T
10	10	10	10	T	T	T	T	T	T	T	T	T	T	T	T
10	10	10	10	T	T	T	T	T	T	T	T	T	T	T	T
10	10	10	10	T	T	T	T	T	T	T	T	T	T	T	T
10	10	10	10	T	T	T	T	T	T	T	T	T	T	T	T
10	10	10	10	T	T	T	T	T	T	T	T	T	T	T	T
	10	10	10	T	T	T	T	T	T	T	T	T	T	T	T
	10	10	10	T	T	T	T	T	T	T	T	T	T	T	T
		10	10	T	T	T	T	T	T	T	T	T	T	T	T
		10	10	T	T	T	T	T	T	T	T	T	T	T	T

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4 Protection coordination

Discrimination tables MCCB - MCCB

MCCB T2 @ 415V

Load s.	Version	Release	I_u [A]	Supply s.	T1	T2					T3			T4										
				Version	B,C,N	N,S,H,L					N,S			N,S,H,L,V										
				Release	TM	TM,M	EL				TM,M			TM,M										
				I_u [A]	160	160					250			250										320
				I_n [A]	160	160	25	63	100	160	160	200	250	20	25	32	50	80	100	125	160	200	250	320
T2	N, S, H, L	TM	160	1.6-2.5	T	T	T	T	T	T	T	T	T	T	T*	T	T	T	T	T	T	T	T	T
				3.2	T	T	T	T	T	T	T	T	T	T	T*	T	T	T	T	T	T	T	T	T
				4-5	T	T	T	T	T	T	T	T	T	T	T*	T	T	T	T	T	T	T	T	T
				6.3	10	10	10	10	10	10	10	15	40	T	T*	T	T	T	T	T	T	T	T	T
				8	10	10	10	10	10	10	10	15	40		T*	T	T	T	T	T	T	T	T	T
				10	10	10	10	10	10	10	10	15	40		T*	T	T	T	T	T	T	T	T	T
				12.5	3	3		3	3	3	3	4	5			T	T	T	T	T	T	T	T	T
				16	3	3		3	3	3	3	4	5					70	70	70	70	70	70	70
				20	3	3		3	3	3	3	4	5					55*	55	55	55	55	55	55
				25	3	3		3	3	3	3	4	5					40*	40	40	40	40	40	40
				32	3	3			3	3	3	4	5					40*	40	40	40	40	40	40
				40	3	3			3	3	3	4	5					30*	30*	30	30	30	30	30
				50	3	3			3	3	3	4	5					30*	30*	30	30	30	30	30
				63	3	3				3	3	4	5					30*	30*	30*	30	30	30	30
				80						3	3*	4	5						25*	25*	25*	25	25	25
				100								4	5							25*	25*	25*	25	25
				125																	25*	25*		25
				160																		25*		
		EL	160	10								3	4				25	25	25	25	25	25	25	25
				25								3	4					25	25	25	25	25	25	25
				63								3	4								25	25	25	25
				100								3	4										25	25
				160								3	4											25

* Value for the supply side magnetic only circuit-breaker.

4 Protection coordination

T4				T5							S6		S7		
N,S,H,L,V				N,S,H,L,V							N,S,H,L		S,H,L		
EL				TM				EL			TM	EL	EL		
250			320	400		630		400		630	800		1250		1600
100	160	250	320	320	400	500	630	320	400	630	800	800	1000	1250	1600
T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
70	70	70	70	T	T	T	T	T	T	T	T	T	T	T	T
55	55	55	55	T	T	T	T	T	T	T	T	T	T	T	T
40	40	40	40	T	T	T	T	T	T	T	T	T	T	T	T
40	40	40	40	T	T	T	T	T	T	T	T	T	T	T	T
30	30	30	30	T	T	T	T	T	T	T	T	T	T	T	T
30	30	30	30	T	T	T	T	T	T	T	T	T	T	T	T
30	30	30	30	T	T	T	T	T	T	T	T	T	T	T	T
	25	25	25	T	T	T	T	T	T	T	T	T	T	T	T
	25	25	25	T	T	T	T	T	T	T	T	T	T	T	T
		25	25	T	T	T	T	T	T	T	T	T	T	T	T
		25	25	T	T	T	T	T	T	T	T	T	T	T	T
25	25	25	25	T	T	T	T	T	T	T	T	T	T	T	T
25	25	25	25	T	T	T	T	T	T	T	T	T	T	T	T
25	25	25	25	T	T	T	T	T	T	T	T	T	T	T	T
	25	25	25	T	T	T	T	T	T	T	T	T	T	T	T
		25	25	T	T	T	T	T	T	T	T	T	T	T	T

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4 Protection coordination

Discrimination tables MCCB - MCCB

MCCB - T3 @ 415V

Load s.	Version	Release	Iu [A]	In [A]	T1 B,C,N TM 160	T2 N,S,H,L TM.M 160	T2 N,S,H,L EL 160				T3 N,S TM.M 250			T4 N,S,H,L,V TM.M 250										T4 N,S,H,L,V TM.M 320
				In [A]	160	160	25	63	100	160	160	200	250	20	25	32	50	80	100	125	160	200	250	320
T3	N, S	TM	160	63							3	4	5							7*	7	7	7	7
				80							3*	4	5								7*	7	7	7
				100								4*	5								7*	7*	7	7
				125																		7*		7
				160																				
				200																				
				250																				

* Value for the supply side magnetic only circuit-breaker.

MCCB - T4 @ 415V

Load s.	Version	Release	Iu [A]	In [A]	T5 N,S,H,L TM 400		T5 N,S,H,L TM 630		T5 N,S,H,L EL 400		T5 N,S,H,L EL 630	S6 N,S,H,L TM 800	S6 N,S,H,L EL 800	S7 S,H,L EL 1250		S7 S,H,L EL 1600
				In [A]	320	400	500	630	320	400	630	800	800	1000	1250	1600
T4	N. S. H. L. V	TM	250	20	T	T	T	T	T	T	T	T	T	T	T	T
				25	T	T	T	T	T	T	T	T	T	T	T	T
				32	T	T	T	T	T	T	T	T	T	T	T	T
				50	T	T	T	T	T	T	T	T	T	T	T	T
				80	T	T	T	T	T	T	T	T	T	T	T	T
				100		50	50	50	50	50	50	T	T	T	T	T
				125			50	50	50	50	50	T	T	T	T	T
				160				50	50	50	50	T	T	T	T	T
				200					50	50	50	T	T	T	T	T
				250						50	50	T	T	T	T	T
			320	320							50	T	T	T	T	T
		EL	250	100	50	50	50	50	50	50	50	T	T	T	T	T
				160	50	50	50	50	50	50	50	T	T	T	T	T
				250			50	50		50	50	T	T	T	T	T
			320	320							50	T	T	T	T	T

* Value for the supply side magnetic only circuit-breaker.

4 Protection coordination

T4				T5							S6		S7		
N,S,H,L,V				N,S,H,L,V							N,S,H,L		S,H,L		
EL				TM				EL			TM	EL	EL		
250			320	400		630		400		630	800		1250		1600
100	160	250	320	320	400	500	630	320	400	630	800	800	1000	1250	1600
7	7	7	7	25	25	25	25	25	25	25	T	T	T	T	T
	7	7	7	25	25	25	25	25	25	25	T	T	T	T	T
	7	7	7	25	25	25	25	25	25	25	T	T	T	T	T
		7	7	20	20	20	20	20	20	20	T	T	T	T	T
		7	7			20	20	20	20	20	T	T	T	T	T
			7				20	20	20	20	T	T	T	T	T
							20	20	20	20	40	40	T	T	T

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4 Protection coordination

Discrimination tables MCCB - MCCB

MCCB - T5 @ 415V

Load s.	Version	Release	I_u [A]	I_n [A]	S6	S6	S7	S7	S7
	Version				N,S,H,L		S,H,L		
		Release			TM	EL	EL		
			I_u [A]		800		1250		1600
				I_n [A]	800	800	1000	1250	1600
T5	N, S, H, L, V	TM	400	320	30	30	T	T	T
				400	30	30	T	T	T
			630	500		30	T	T	T
				630			T	T	T
		EL	400	320	30	30	T	T	T
				400	30	30	T	T	T
			630	630			T	T	T

MCCB - S6 @ 415V

Load s.	Version	Release	I_u [A]	I_n [A]	S7	S7	S7
	Version				S,H,L		
		Release			EL		
			I_u [A]		1250		1600
				I_n [A]	1000	1250	1600
S6	N	TM	800	800		T	T
		EL	800	800	T	T	T
	S	TM	800	800		40	40
		EL	800	800	40	40	40
	H	TM	800	800		40	40
		EL	800	800	40	40	40
	L	TM	800	800		40	40
		EL	800	800	40	40	40

4 Protection coordination

Discrimination tables ACB - MCCB

ACB - MCCB @ 415V

			Supply s.	E1		E2			E3				E4		E6	
	Version			B	N	B	N	L*	N	S	H	L*	S	H	H	V
		Release		EL		EL			EL				EL		EL	
Load s.			I_u [A]	800 1250	800 1250	1600 2000	1250 1600 2000	1250 1600	2500 3200	1250 1600 2000 2500 3200	1250 1600 2000 2500 3200	2000 2500	4000	3200 4000	5000 6300	3200 4000 5000 6300
T1	B	TM	160	T	T	T	T	T	T	T	T	T	T	T	T	T
	C			T	T	T	T	T	T	T	T	T	T	T	T	T
	N			T	T	T	T	T	T	T	T	T	T	T	T	T
T2	N	TM.EL	160	T	T	T	T	T	T	T	T	T	T	T	T	T
	S			36	T	T	T	T	T	T	T	T	T	T	T	T
	H			36	T	T	55	T	T	T	T	T	T	T	T	T
	L			36	T	T	55	T	T	T	75	T	T	T	T	T
T3	N	TM	250	T	T	T	T	T	T	T	T	T	T	T	T	T
	S			36	T	T	T	T	T	T	T	T	T	T	T	T
T4	N	TM.EL	250 320	T	T	T	T	T	T	T	T	T	T	T	T	T
	S			36	T	T	T	T	T	T	T	T	T	T	T	T
	H			36	T	T	55	T	T	T	T	T	T	T	T	T
	L			36	T	T	55	100	T	T	75	100	T	T	T	100
	V			36	T	T	55	100	T	T	75	100	T	T	T	100
T5	N	TM.EL	400 630	T	T	T	T	T	T	T	T	T	T	T	T	T
	S			36	T	T	T	T	T	T	T	T	T	T	T	T
	H			36	T	T	55	T	T	T	T	T	T	T	T	T
	L			36	T	T	55	100	T	T	75	100	T	T	T	100
	V			36	T	T	55	100	T	T	75	100	T	T	T	100
S6	N	TM.EL	800	T	T	T	T	T	T	T	T	T	T	T	T	T
	S			36	T	T	T	T	T	T	T	T	T	T	T	T
	H			36	T	T	55	T	T	T	T	T	T	T	T	T
	L			36	T	T	55	T	T	T	75	T	T	T	T	T
S7	S	EL	1250 1600			T	T		T	T	75	100	T	T	T	T
	H					T	55		T	T	75	100	T	T	T	T
	L					T	55		T	T	75	100	T	T	T	T

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* Circuit-breaker Emax L with release PR112/P or PR113/P only .

4.3 Back-up tables

The tables shown give the short-circuit current value (in kA) for which the back-up protection is verified for the chosen circuit-breaker combination, at voltages from 380 up to 415 V. These tables cover all the possible combinations between ABB SACE moulded-case circuit-breakers Isomax and Tmax and those between the above mentioned circuit-breakers and ABB MCBs.

Notes for a correct interpretation of the coordination tables:

Tmax @ 415V ac	
Version	Icu [kA]
B	16
C	25
N	36
S	50
H	70
L (for T2)	85
L (for T4-T5)	120
V	200

Isomax @ 415V ac	
Version	Icu [kA]
N	35*
S	50
H	65
L	100

Emax @ 415V ac	
Version	Icu [kA]
B	42
N	65**
S	75
H	100
L	130
V	150

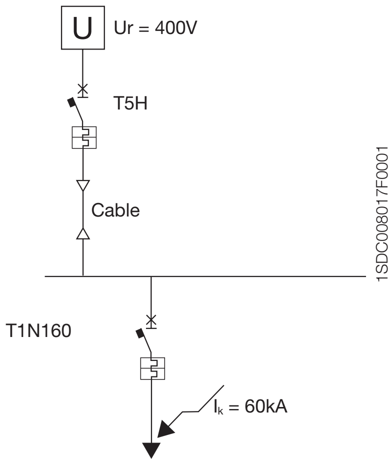
* Versions certified at 36 kA
** For Emax E1 version N Icu=50 kA

Keys

For MCCB (Moulded-case circuit-breaker)	For MCB (Modular circuit-breaker):
ACB (Air circuit-breaker) TM = thermomagnetic release – TMD (Tmax) – TMA (Tmax) – T adjustable M adjustable (Isomax) M = magnetic only release – MF (Tmax) – MA (Tmax) EL = elettronic release – PR111/P - PR112/P - PR113/P (Emax) – PR211/P - PR212/P (Isomax) – PR221DS - PR222DS (Tmax)	B = charateristic trip (I3=3...5In) C = charateristic trip (I3=5...10In) D = charateristic trip (I3=10...20In) K = charateristic trip (I3=8...14In) Z = charateristic trip (I3=2...3In)

4 Protection coordination

Example:
From the coordination table on page 217 the following conclusion is derived: the circuit-breakers type T5H and T1N are coordinated in back-up protection up to a value of 65 kA (higher than the short-circuit current measured at the installation point), although the maximum breaking capacity of T1N, at 415 V, is 36 kA.



MCB - MCB @ 240V

			Supply s.	S 240	S 250	S 260	S 270	S 280	S 280	S 280	S 280	S 290	S 500
	Chart.			C	B-C	B-C	B-C	B-C	B-C	B-C	B-C	C	B-C
Load side		I_{cu} [kA]		10	20	20	25	40	30	25	20	25	100
			I_n [A]	6..40	0,5..63	0,5..63	0,5..63	10..25	32..40	50, 63	80, 100	80..125	6..63
S 931 N	C	3	2..40	10	20	20	25	40	30	25	15	15	100
S 941 N	B,C	6	2..40	10	20	20	25	40	30	25	15	15	100
S 951 N	B,C	10	2..40	10	20	20	25	40	30	25	15	15	100
S 971 N	B,C	10	2..40	10	20	20	25	40	30	25	15	15	100
S 240	C	10	6..40		20	20	25	40	30	25	15	15	100
S 250	B,C,K	20	0,5..63				25	40	30	25			100
S 260	B,C	20	0,5..63				25	40	30	25			100
S 270	B,C,D	25	0,5..63					40	30				100
	Z	20					25	40	30	25			100
S 280	B, C, D, K, Z	25	3..8					40	30				100
		40	10..25										100
		30	32..40										100
		25	50, 63										
	B,C	20	80, 100										
S 290	C,D	25	80..125										
S 500	B,C,D	100	6..63										

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4 Protection coordination

MCB - MCB @ 415V

			Supply s.	S 240	S 250	S 260	S 270	S 280	S 280	S 280	S 280	S 290	S 500
	Chart.			C	B-C	B-C	B-C	B-C	B-C	B-C	B-C	C	B-C
Load side		Icu [kA]		7,5	10	10	15	25	20	15	6	15	50
			In [A]	6..40	0,5..63	0,5..63	0,5..63	10..25	32..40	50, 63	80, 100	80..125	6..63
S 240	C	7,5	6..40		10	10	15	25	20	15		15	50
S 250	B,C,K	10	0,5..63				15	25	20	15		15	50
S 260	B,C	10	0,5..63				15	25	20	15		15	50
S 270	B,C,D	15	0,5..63					25	20				50
S 270	Z	10	0,5..63				15	25	20	15		15	50
S 280	B, C, D, K, Z	15	3..8					25	20				50
S 280	B, C, D, K, Z	25	10..25										50
S 280	B, C, D, K, Z	20	32..40										50
S 280	B, C, D, K, Z	15	50, 63										
S 280	B,C	6	80, 100										
S 290	C,D	15	80..125										
S 500	B,C,D	50	6..63										

MCCB - MCB @ 415V

			Supply s.	T1	T1	T1	T2	T3	T4	T2	T3	T4	T2	T4	T2	T4	T4
			Version	B	C	N				S			H		L	L	V
Load side	Chart.	In [A]	Icu [kA]	16	25	36				50			70		85	120	200
S240	C	6..10	7,5	16	25	30	36	36	36	36	40	40	40	40	40	40	40
S240	C	13..40	7,5	16	25	30	36	16	36	36	16	40	40	40	40	40	40
S250	B,C,K	3..10	10	16	25	30	36	36	36	36	40	40	40	40	40	40	40
S250	B,C,K	13..63	10	16	25	30	36	16	36	36	16	40	40	40	40	40	40
S260	B,C	3..10	10	16	25	30	36	36	36	36	40	40	40	40	40	40	40
S260	B,C	13..63	10	16	25	30	36	16	36	36	16	40	40	40	40	40	40
S270	B,C,D	3..10	15	16	25	30	36	36	36	50	40	40	70	40	85	40	40
S270	B,C,D	13..63	15	16	25	30	36	25	36	50	25	40	60	40	60	40	40
S270	Z	3..10	10	16	25	30	36	36	36	36	40	40	40	40	40	40	40
S270	Z	13..63	10	16	25	30	36	16	36	36	16	40	40	40	40	40	40
S280	B, C, D, K, Z	3..8	15	16	25	30	36	36	36	50	40	40	70	40	85	40	40
S280	B, C, D, K, Z	10..25	25			30	36	30	36	50	30	40	60	40	60	40	40
S280	B, C, D, K, Z	32..40	20		25	30	36	25	36	50	25	40	60	40	60	40	40
S280	B, C, D, K, Z	50, 63	15	16	25	30	36	25	36	50	25	40	60	40	60	40	40
S280	B, C, D, K, Z	80, 100	6	16	16	16	36	16	30	36	16	30	36	30	36	30	30
S290	C,D,K	80..125	15	16	25	30	36	30	30	50	30	30	70	30	85	30	30
S500	B,C,D	6..63	50										70	70	85	120	200

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4 Protection coordination

MCCB - MCCB @ 415V

		Supply s.	T1	T1	T2	T3	T4	T5	S6	T2	T3	T4	T5	S6	S7	T2	T4	T5	S6	S7	T2	T4	T5	S6	S7	T4	T5
		Version	C	N						S						H					L	L		L		V	
Load side	Version	I_{cu} [kA]	25	36						50						70			65	65	85	120		100		200	
T1	B	16	25	36	36	36	30	30	30	50	50	36	36	36		70	40	40	40		85	50	50	50		85	65
T1	C	25		36	36	36	36	36	36	50	50	40	40	50	50	70	65	65	65	50	85	85	85	70	50	130	100
T1	N	36								50	50	50	50	50	50	70	65	65	65	50	85	100	100	70	50	200	120
T2	N	36								50	50	50	50	50	50	70	65	65	65	65	85	100	100	85	85	200	120
T3	N	36									50	50	50	50	50		65	65	65	50		100	100	100	50	200	120
T4	N	36										50	50	50	50		65	65	65	50		100	100	65	65	200	120
T5	N	36											50	50	50			65	65	50			100	85	65		120
S6	N	36													40					40					50		
T2	S	50															70	70	65	65	85	100	100	85	85	200	130
T3	S	50															70	70	65			100	100	100		200	150
T4	S	50															70	70	65	65		100	100	85	85	200	150
T5	S	50																70	65	65			100	85	85		150
S6	S	50																							85		
T2	H	70																			85	120	120	85	85	200	150
T4	H	70																				120	120	100	100	200	180
T5	H	70																					120	100	100		180
S6	H	65																							85		
T2	L	85																				120	120			200	180
T4	L	120																								200	200
T5	L	120																									200

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4 Protection coordination

4.4 Coordination tables between circuit-breakers and switch disconnectors

The tables shown give the values of the short-circuit current (in kA) for which back-up protection is verified by the pre-selected combination of circuit-breaker and switch disconnector, for voltages between 380 and 415 V. The tables cover the possible combinations of moulded-case circuit-breakers in the ABB SACE Isomax and Tmax series, with the switch disconnectors detailed above.

415 V	T1D 160	T3D 250	T4D 320	T5D 400	T5D 630
T1B					
T1C					
T1N					
T2N					
T2S					
T2H					
T2L					
T3N					
T3S					
T4N		36*			
T4S		50*			
T4H		70*			
T4L		120*			
T4V		200*			
T5N					
T5S					
T5H					
T5L					
T5V					
S6N					
S6S					
S6H					
S6L					
S7S					
S7H					
S7L					
S8H					
S8V					

* for T4 250 or T4 320 only with I1 setting at 250 A.

4 Protection coordination

Notes for the correct reading of the coordination tables:

Tmax @ 415V ac	
Version	Icu [kA]
B	16
C	25
N	36
S	50
H	70
L (T2)	85
L (T4, T5)	120
V	200

Isomax @ 415V ac	
Version	Icu [kA]
N	35*
S	50
H	65 (S8 = 85)
L	100
V	120

* Versions certified at 36 kA

SWITCH DISCONNECTOR							
S6D 630	S6D 800	S7D 1000	S7D 1250	S7D 1600	S8D 2000	S8D 2500	S8D 3200
16							
25							
36							
36							
50							
70							
85							
36							
50							
	36						
	50						
	70						
	120						
	200						
		36					
		50					
		70					
		120					
		200					
				35			
				50			
				65			
				100			
				50			
				65			
				100			
						85	
						120	

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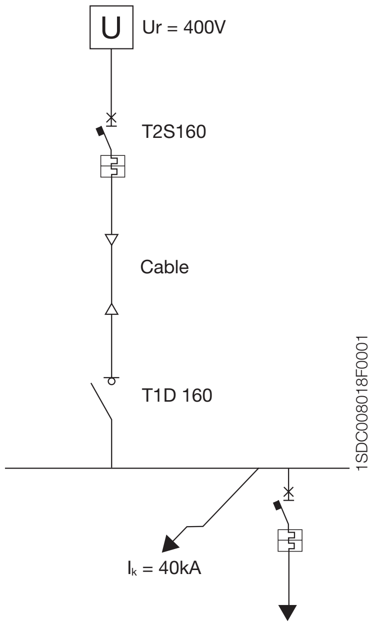
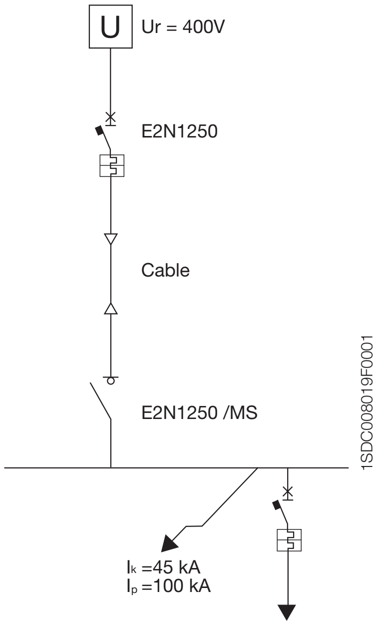
4 Protection coordination

Example:
From the coordination table on page 218-219 it can be seen that circuit-breaker T2S160 is able to protect the switch disconnector T1D160 up to a short-circuit current of 50 kA (higher than the short-circuit current at the installation point). Overload protection is also verified, as the rated current of the breaker is not higher than the size of the disconnector.



4 Protection coordination

Example:
For the correct selection of the components, the disconnector must be protected from overloads by a device with a rated current not greater than the size of the disconnector, while in short-circuit conditions it must be verified that:
$I_{cw} \geq I_k$
$I_{cm} \geq I_p$.
Therefore, with regard to the electrical parameters of the single devices, Emax E2N1250/MS disconnector is selected, and a E2N1250 breaker.
That is:
I_{cw}(E2N /MS) = 55 kA > 45 kA
I_{cm} (E2N /MS) = 121 kA > 100 kA.



5 Special applications

5.1 Direct current networks

Main applications of direct current:

- Emergency supply or auxiliary services:
  the use of direct current is due to the need to employ a back-up energy source which allows the supply of essential services such as protection services, emergency lighting, alarm systems, hospital and industrial services, data-processing centres etc., using accumulator batteries, for example.
- Electrical traction:
  the advantages offered by the use of dc motors in terms of regulation and of single supply lines lead to the widespread use of direct current for railways, underground railways, trams, lifts and public transport in general.
- Particular industrial installations:
  there are some electrolytic process plants and applications which have a particular need for the use of electrical machinery.

Typical uses of circuit-breakers include the protection of cables, devices and the operation of motors.

Considerations for the interruption of direct current

Direct current presents larger problems than alternating current does in terms of the phenomena associated with the interruption of high currents. Alternating currents have a natural passage to zero of the current every half-cycle, which corresponds to a spontaneous extinguishing of the arc which is formed when the circuit is opened.
This characteristic does not exist in direct currents, and furthermore, in order to extinguish the arc, it is necessary that the current lowers to zero.
The extinguishing time of a direct current, all other conditions being equal, is proportional to the time constant of the circuit $T = L/R$.
It is necessary that the interruption takes place gradually, without a sudden switching off of the current which could cause large over-voltages. This can be carried out by extending and cooling the arc so as to insert an ever higher resistance into the circuit.
The energetic characteristics which develop in the circuit depend upon the voltage level of the plant and result in the installation of breakers according to connection diagrams in which the poles of the breaker are positioned in series to increase their performance under short-circuit conditions. The breaking capacity of the switching device becomes higher as the number of contacts which open the circuit increases and, therefore, when the arc voltage applied is larger.
This also means that when the supply voltage of the installation rises, so must the number of current switches and therefore the poles in series.

5 Special applications

Calculation of the short-circuit current of an accumulator battery

The short-circuit current at the terminals of an accumulator battery may be supplied by the battery manufacturer, or may be calculated using the following formula:

$$I_k = \frac{U_{Max}}{R_i}$$

where:

- U_{Max} is the maximum flashover voltage (no-load voltage);
- R_i is the internal resistance of the elements forming the battery.

The internal resistance is usually supplied by the manufacturer, but may be calculated from the discharge characteristics obtained through a test such as detailed by IEC 60896 – 1 or IEC 60896 – 2.

For example, a battery of 12.84 V and internal resistance of 0.005 Ω gives a short-circuit current at the terminals of 2568 A.

Under short-circuit conditions the current increases very rapidly in the initial moments, reaches a peak and then decreases with the discharge voltage of the battery. Naturally, this high value of the fault current causes intense heating inside the battery, due to the internal resistance, and may lead to explosion. Therefore it is very important to prevent and / or minimize short-circuit currents in direct currents systems supplied by accumulator batteries.

Criteria for the selection of circuit-breakers

For the correct selection of a circuit-breaker for the protection of a direct current network, the following factors must be considered:

1. the load current, according to which the size of the breaker and the setting for the thermo-magnetic over-current release can be determined;
2. the rated plant voltage, according to which the number of poles to be connected in series is determined, thus the breaking capacity of the device can also be increased;
3. the prospective short-circuit current at the point of installation of the breaker influencing the choice of the breaker;
4. the type of network, more specifically the type of earthing connection.

Note: in case of using of four pole circuit-breakers, the neutral must be at 100%

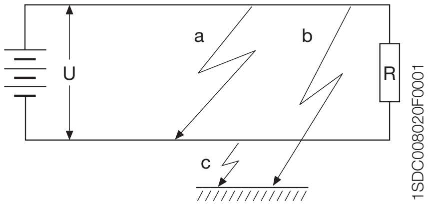
Direct current network types

Direct current networks may be carried out:

- with both polarities insulated from earth;
- with one polarity connected to earth;
- with median point connected to earth.

5 Special applications

Network with both polarities insulated from earth



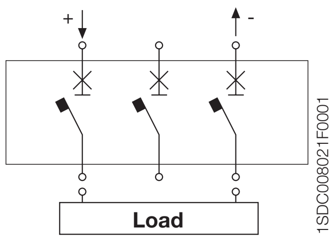
- Fault a: the fault, without negligible impedance, between the two polarities sets up a short-circuit current to which both polarities contribute to the full voltage, according to which the breaking capacity of the breaker must be selected.
- Fault b: the fault between the polarity and earth has no consequences from the point of view of the function of the installation.
- Fault c: again, this fault between the polarity and earth has no consequences from the point of view of the function of the installation.

In insulated networks it is necessary to install a device capable of signalling the presence of the first earth fault in order to eliminate it. In the worst conditions, when a second earth fault is verified, the breaker may have to interrupt the short-circuit current with the full voltage applied to a single polarity and therefore with a breaking capacity which may not be sufficient.
In networks with both polarities insulated from earth it is appropriate to divide the number of poles of the breaker necessary for interruption on each polarity (positive and negative) in such a way as to obtain separation of the circuit.

The diagrams to be used are as follows:

Diagram A

Three-pole breaker with one pole per polarity



5 Special applications

Diagram B

Three-pole breaker with two poles in series for one polarity and one pole for the other polarity (1)

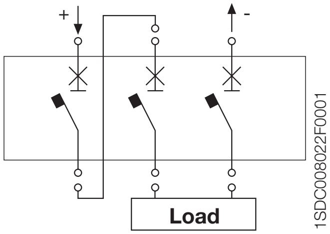


Diagram D

Four-pole breaker with two poles in parallel per polarity

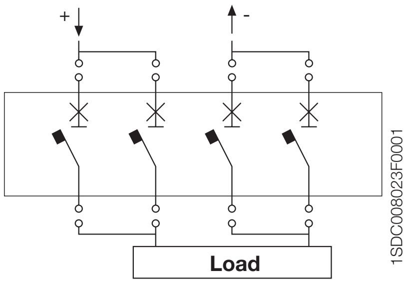
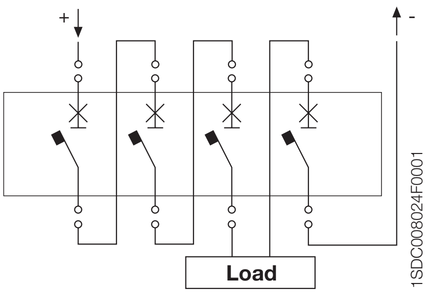


Diagram G

Four-pole breaker with three poles in series on one polarity and one pole on the remaining polarity (1)

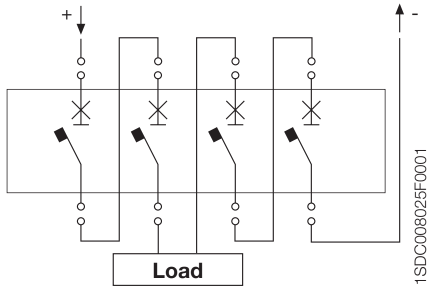


(1) It is not advisable to divide the poles of the breaker unequally as, in this type of network, a second earth fault may lead to the single pole working under fault conditions at full voltage. In these circumstances, it is essential to install a device capable of signalling the earth fault or the loss of insulation of one polarity.

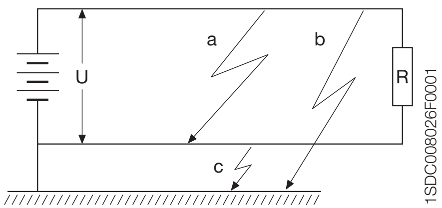
5 Special applications

Diagram H

Four-pole breaker with two poles in series per polarity



Network with one polarity connected to earth



- Fault a: the fault between the two polarities sets up a short-circuit current to which both polarities contribute to the full voltage U, according to which the breaking capacity of the breaker is selected.
- Fault b: the fault on the polarity not connected to earth sets up a current which involves the over-current protection according to the resistance of the ground.
- Fault c: the fault between the polarity connected to earth and earth has no consequences from the point of view of the function of the installation.

In a network with one polarity connected to earth, all the poles of the breaker necessary for protection must be connected in series on the non-earthed polarity. If isolation is required, it is necessary to provide another breaker pole on the earthed polarity.

5 Special applications

Diagrams to be used with circuit isolation are as follows:

Diagram A

Three-pole breaker with one pole per polarity

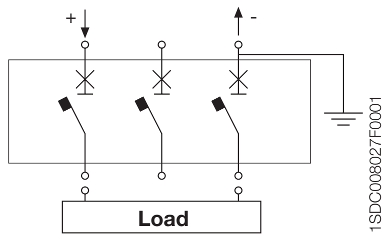


Diagram B

Three-pole breaker with two poles in series on the polarity not connected to earth, and one pole on the remaining polarity

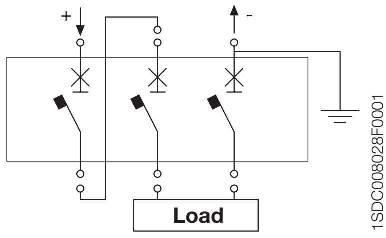
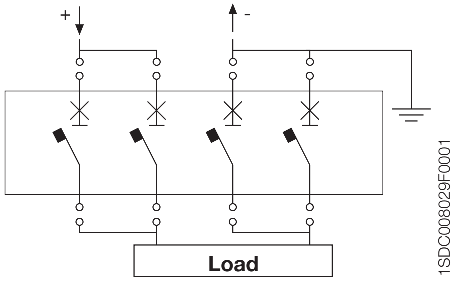


Diagram D

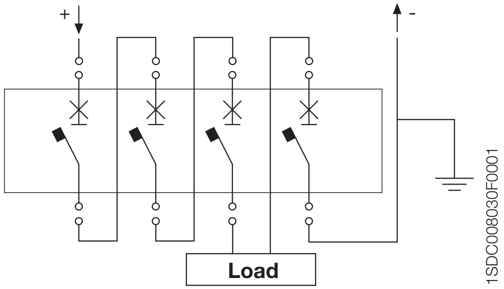
Four-pole breaker with two poles in parallel per polarity



5 Special applications

Diagram G

Four-pole breaker with three poles in series on the polarity not connected to earth, and one pole on the remaining polarity



Diagrams to be used without circuit isolation are as follows:

Diagram C

Three-pole breaker with three poles in series

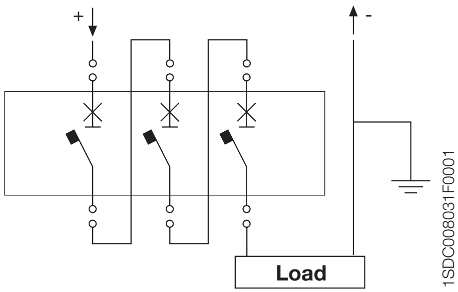
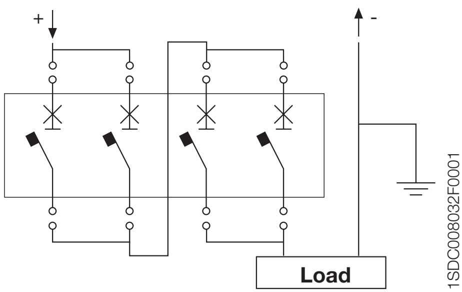


Diagram E

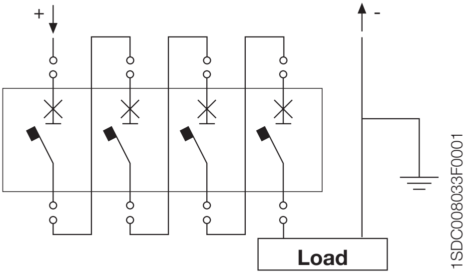
Four-pole breaker with series of two poles in parallel



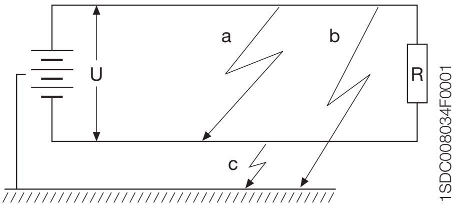
5 Special applications

Diagram F

Four-pole breaker with four poles in series on the polarity not connected to earth



Network with the median point connected to earth



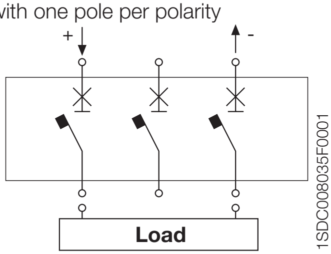
- Fault a: the fault between the two polarities sets up a short-circuit current to which both polarities contribute to the full voltage U, according to which the breaking capacity of the breaker is selected.
- Fault b: the fault between the polarity and earth sets up a short-circuit current less than that of a fault between the two polarities, as it is supplied by a voltage equal to 0.5 U.
- Fault c: the fault in this case is analogous to the previous case, but concerns the negative polarity.

With network with the median point connected to earth the breaker must be inserted on both polarities.

Diagrams to be used are as follows:

Diagram A

Three-pole breaker with one pole per polarity



5 Special applications

Diagram D

Four-pole breaker with two poles in parallel per polarity

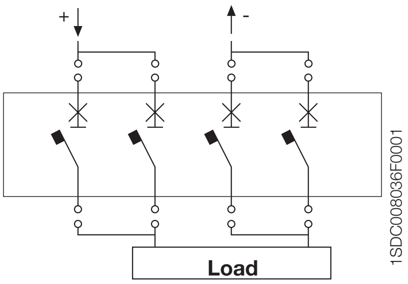
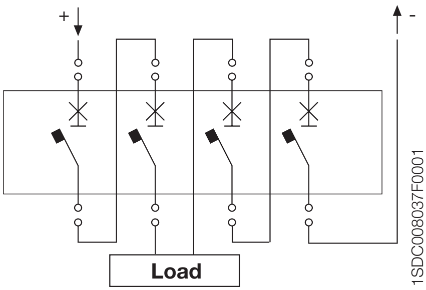


Diagram H

Four-pole breaker with two poles in series per polarity



Use of switching devices in direct current

Parallel connection of breaker poles

According to the number of poles connected in parallel, the coefficients detailed in the following table must be applied:

Table 1: Correction factor for poles connected in parallel

number of poles in parallel	2	3	4 (neutral 100%)
reduction factor of dc carrying capacity	0.9	0.8	0.7
breaker current carrying capacity	1.8xIn	2.4xIn	2.8xIn

The connections which are external from the breaker terminals must be carried out by the user in such a way as to ensure that the connection is perfectly balanced.

5 Special applications

Example:

Using a SACE Isomax S6N800 In800 circuit-breaker with three poles in parallel, a coefficient equal to 0.8 must be applied, therefore the maximum carrying current will be 0.8·3·800 = 1920 A.

Behaviour of thermal releases

As the functioning of these releases is based on thermal phenomena arising from the flowing of current, they can therefore be used with direct current, their trip characteristics remaining unaltered.

Behaviour of magnetic releases

The values of the trip thresholds of ac magnetic releases, used for direct current, must be multiplied by the following coefficient (k_m), according to the breaker and the connection diagram:

Table 2: k_m coefficient

Circuit-breaker	diagram A	diagram B	diagram C	diagram D	diagram E	diagram F	diagram G	diagram H
S6	1.1	1	0.9	1	0.8	0.8	0.8	0.8
T1	1.3	1	1	-	-	-	-	-
T2	1.3	1.15	1.15	-	-	-	-	-
T3	1.3	1.15	1.15	-	-	-	-	-
T4	1.3	1.15	1.15	1	1	1	-	-
T5	1.1	1	1	0.9	0.9	0.9	-	-

Example

Data:
- Direct current network connected to earth;
- Rated voltage Ur = 250 V;
- Short-circuit current Ik = 32 kA
- Load current Ib = 230 A

Using Table 3, it is possible to select the Tmax T3N250 In = 250 A three pole breaker, using the connection shown in diagram B (two poles in series for the polarity not connected to earth and one poles in series for the polarity connected to earth). In this way an adequate breaking capacity is ensured, even in the case of a second earth fault which would involve only two poles at full network voltage.
From Table 2 corresponding to diagram B, and with breaker Tmax T3, it risults k_m=1.15; therefore the nominal magnetic trip will occur at 2875 A (taking into account the tolerance, the trip will occur between 2300 A and 3450 A).

5 Special applications

The following table summarizes the breaking capacity of the various circuit-breakers available for direct current. The number of poles to be connected in series to guarantee the breaking capacity is given in brackets.

Table 3: Breaking capacity in direct current according to the voltage

Circuit-breaker	Rated current [A]	Breaking capacity [kA] ≤ 125 [V][1]	250 [V]	500 [V]	750 [V]
T1B160	16 ÷ 160	16 (1P)	20 (3P) - 16 (2P)	16 (3P)	
T1C160	25 ÷ 160	25 (1P)	30 (3P) - 25 (2P)	25 (3P)	
T1N160	32 ÷ 160	36 (1P)	40 (3P) - 36 (2P)	36 (3P)	
T2N160	1.6 ÷ 160	36 (1P)	40 (3P) - 36 (2P)	36 (3P)	
T2S160	1.6 ÷ 160	50 (1P)	55 (3P) - 50 (2P)	50 (3P)	
T2H160	1.6 ÷ 160	70 (1P)	85 (3P) - 70 (2P)	70 (3P)	
T2L160	1.6 ÷ 160	85 (1P)	100 (3P) - 85 (2P)	85 (3P)	
T3N250	63 ÷ 250	36 (1P)	40 (3P) - 36 (2P)	36 (3P)	
T3S250	63 ÷ 250	50 (1P)	55 (3P) - 50 (2P)	50 (3P)	
T4N250/320	20 ÷ 320	36 (1P)	36 (2P)	25 (2P)	16 (3P)
T4S250/320	20 ÷ 320	50 (1P)	50 (2P)	36 (2P)	25 (3P)
T4H250/320	20 ÷ 320	70 (1P)	70 (2P)	50 (2P)	36 (3P)
T4L250/320	20 ÷ 320	100 (1P)	100 (2P)	70 (2P)	50 (3P)
T4V250/320	20 ÷ 320	100 (1P)	100 (2P)	100 (2P)	70 (3P)
T5N400/630	320 ÷ 630	36 (1P)	36 (2P)	25 (2P)	16 (3P)
T5S400/630	320 ÷ 630	50 (1P)	50 (2P)	36 (2P)	25 (3P)
T5H400/630	320 ÷ 630	70 (1P)	70 (2P)	50 (2P)	36 (3P)
T5L400/630	320 ÷ 630	100 (1P)	100 (2P)	70 (2P)	50 (3P)
T5V400/630	320 ÷ 630	100 (1P)	100 (2P)	100 (2P)	70 (3P)
S6N800	800	35 (1P)	35 (2P)	20 (2P)	16 (3P)
S6S800	800	50 (1P)	50 (2P)	35 (2P)	20 (3P)
S6H800	800	65 (1P)	65 (2P)	50 (2P)	35 (3P)
S6L800	800	100 (1P)	100 (2P)	65 (2P)	50 (3P)

[1] Minimum allowed voltage 24 Vdc.

5 Special applications

5.2 Networks at particular frequencies: 400 Hz and 16 2/3 Hz

Standard production breakers can be used with alternating currents with frequencies other than 50/60 Hz (the frequencies to which the rated performance of the device refer, with alternating current) as appropriate derating coefficients are applied.

5.2.1 400 Hz networks

At high frequencies, performance is reclassified to take into account phenomena such as:

- the increase in the skin effect and the increase in the inductive reactance directly proportional to the frequency causes overheating of the conductors or the copper components in the breaker which normally carry current;
- the lengthening of the hysteresis loop and the reduction of the magnetic saturation value with the consequent variation of the forces associated with the magnetic field at a given current value.

In general these phenomena have consequences on the behaviour of both thermo-magnetic releases and the current interrupting parts of the circuit-breaker.

The following tables refer to circuit-breakers with thermomagnetic releases, with a breaking capacity lower than 36 kA. This value is usually more than sufficient for the protection of installations where such a frequency is used, normally characterized by rather low short-circuit currents.
As can be seen from the data shown, the tripping threshold of the thermal element (I_n) decreases as the frequency increases because of the reduced conductivity of the materials and the increase of the associated thermal phenomena; in general, the derating of this performance is generally equal to 10%.
Vice versa, the magnetic threshold (I_3) increases with the increase in frequency: for this reason it is recommended practice to use a $5 \cdot I_n$ version.

5 Special applications

Table 1: Tmax performance T1 16-63 A TMD

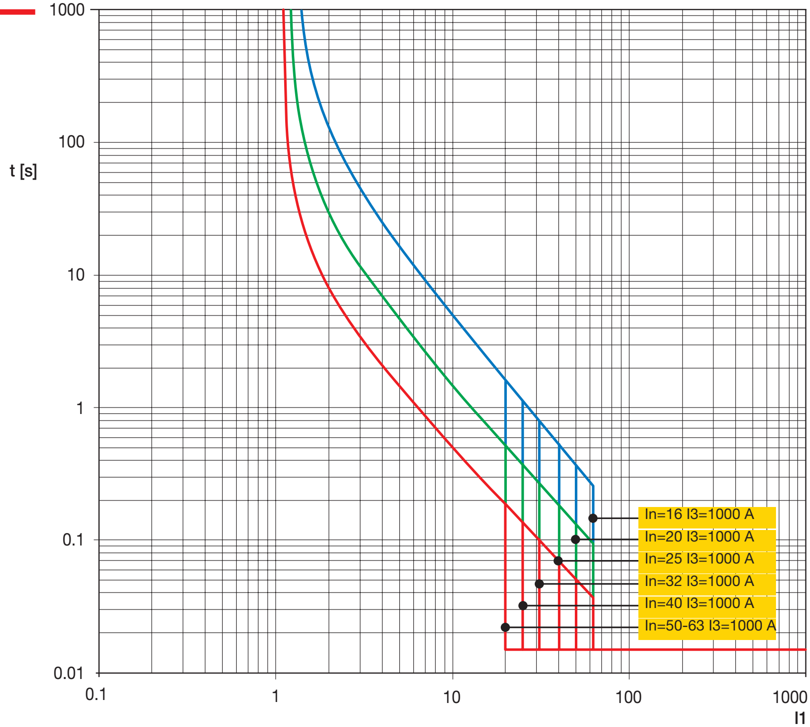
		I1 (400Hz)			I3		
		MIN	MED	MAX	I3 (50Hz)	K_m	I3 (400Hz)
T1B 160 T1C 160 T1N 160	In16	10	12	14	500	2	1000
	In20	12	15	18	500	2	1000
	In25	16	19	22	500	2	1000
	In32	20	24.5	29	500	2	1000
	In40	25	30.5	36	500	2	1000
	In50	31	38	45	500	2	1000
	In63	39	48	57	630	2	1260

K_m = Multiplier factor of I3 due to the induced magnetic fields

Trip curves
thermomagnetic release

T1 B/C/N 160

In 16 to 63 A
TMD



5 Special applications

Table 2: Tmax performance T1 80 A TMD

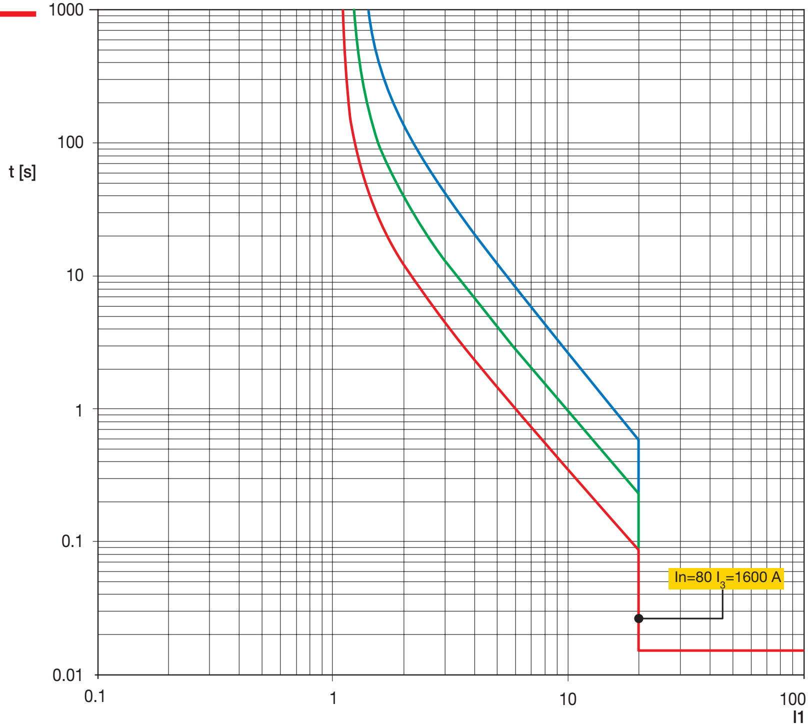
		I1 (400Hz)			I3		
		MIN	MED	MAX	I3 (50Hz)	K_m	I3 (400Hz)
T1B 160 T1C 160 T1N 160	In80	50	61	72	800	2	1600

K_m = Multiplier factor of I3 due to the induced magnetic fields

Trip curves
thermomagnetic release

T1 B/C/N 160

In 80 A
TMD



5 Special applications

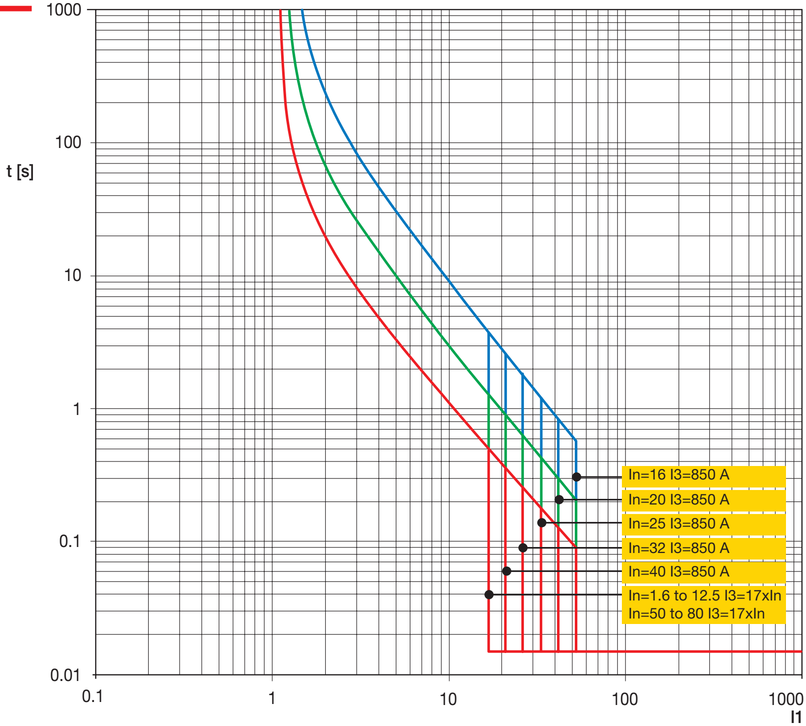
Table 3: Tmax performance T2 1.6-80 A TMD

T2N 160		I1 (400Hz)			I3		
		MIN	MED	MAX	I3 (50Hz)	K_m	I3 (400Hz)
	In1.6	1	1.2	1.4	16	1.7	27.2
	In2	1.2	1.5	1.8	20	1.7	34
	In2.5	1.5	1.9	2.2	25	1.7	42.5
	In3.2	2	2.5	2.9	32	1.7	54.4
	In4	2.5	3	3.6	40	1.7	68
	In5	3	3.8	4.5	50	1.7	85
	In6.3	4	4.8	5.7	63	1.7	107.1
	In8	5	6.1	7.2	80	1.7	136
	In10	6.3	7.6	9	100	1.7	170
	In12.5	7.8	9.5	11.2	125	1.7	212.5
	In16	10	12	14	500	1.7	850
	In20	12	15	18	500	1.7	850
	In25	16	19	22	500	1.7	850
	In32	20	24.5	29	500	1.7	850
	In40	25	30.5	36	500	1.7	850
	In50	31	38	45	500	1.7	850
	In63	39	48	57	630	1.7	1071
	In80	50	61	72	800	1.7	1360

K_m = Multiplier factor of I3 due to the induced magnetic fields

Trip curves
thermomagnetic release
T2 N 160

In 1.6 to 80 A
TMD



5 Special applications

Table 4: Tmax performance T3 63-250 A TMG

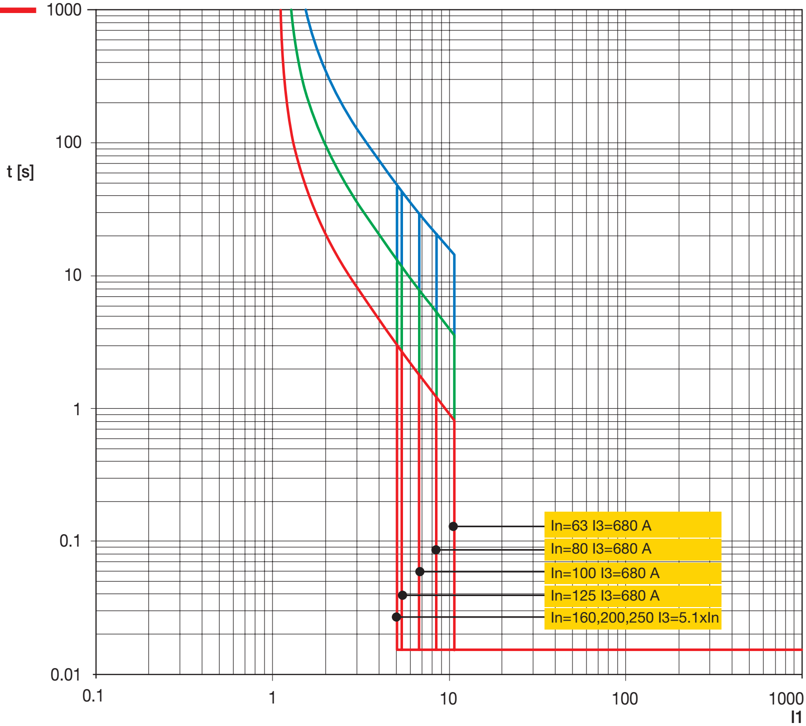
T3N 250	I1 (400Hz)			I3 (Low magnetic setting)		
	MIN	MED	MAX	I3 (50Hz)	K_m	I3 (400Hz)
In63	39	48	57	400	1.7	680
In80	50	61	72	400	1.7	680
In100	63	76.5	90	400	1.7	680
In125	79	96	113	400	1.7	680
In160	100	122	144	480	1.7	816
In200	126	153	180	600	1.7	1020
In250	157	191	225	750	1.7	1275

K_m = Multiplier factor of I3 due to the induced magnetic fields

Trip curves
thermomagnetic release

T3N 250

In 63 to 250 A
TMG



5 Special applications

Table 5: Tmax performance T3 63-125 A TMD

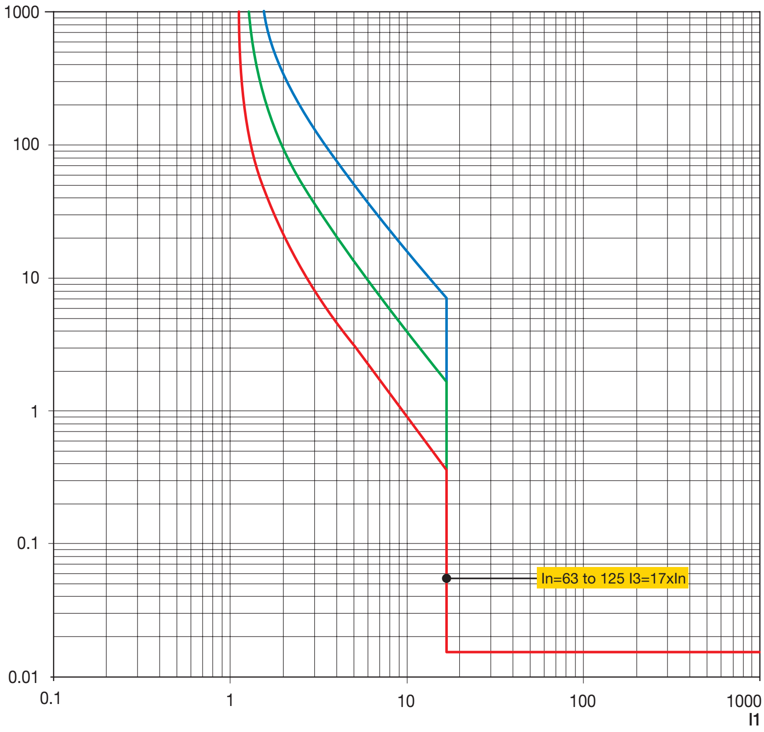
T3N 250		I1 (400Hz)			I3		
		MIN	MED	MAX	I3 (50Hz)	K_m	I3 (400Hz)
	In63	39	48	57	630	1.7	1071
	In80	50	61	72	800	1.7	1360
	In100	63	76.5	90	1000	1.7	1700
	In125	79	96	113	1250	1.7	2125

K_m = Multiplier factor of I3 due to the induced magnetic fields

Trip curves
thermomagnetic release

T3N 250

In 63 to 125 A
TMD



5 Special applications

Table 6: Tmax performance T4 20-50 A TMD

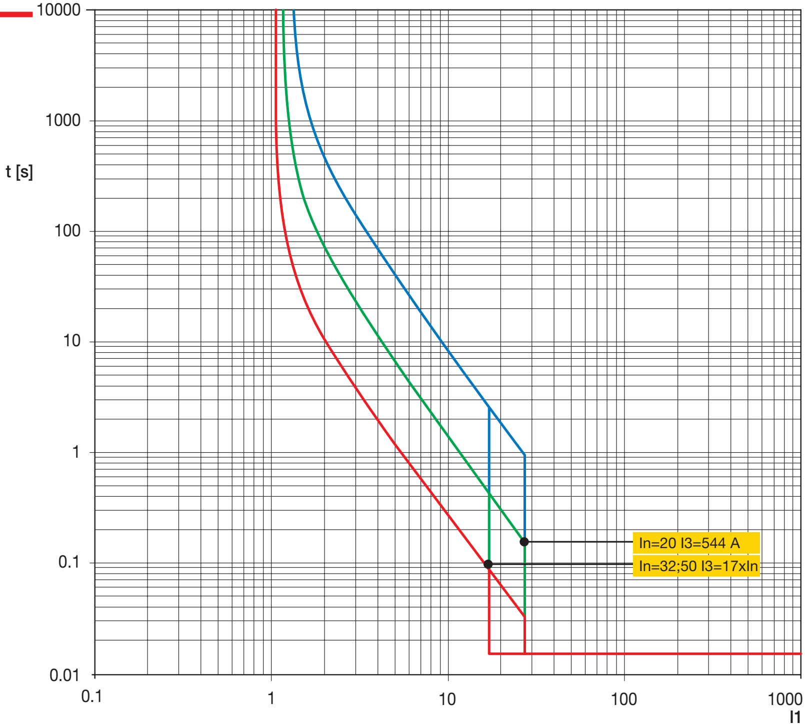
T4N 250		I1 (400Hz)			I3		
		MIN	MED	MAX	I3 (50Hz)	K_m	I3 (400Hz)
	In20	12	15	18	320	1.7	544
	In32	20	24.5	29	320	1.7	544
	In50	31	38	45	500	1.7	850

K_m = Multiplier factor of I3 due to the induced magnetic fields

Trip curves
thermomagnetic release

T4 N 250

In 20 to 50 A
TMD



5 Special applications

Table 7: Tmax performance T4N 80-320 A TMA

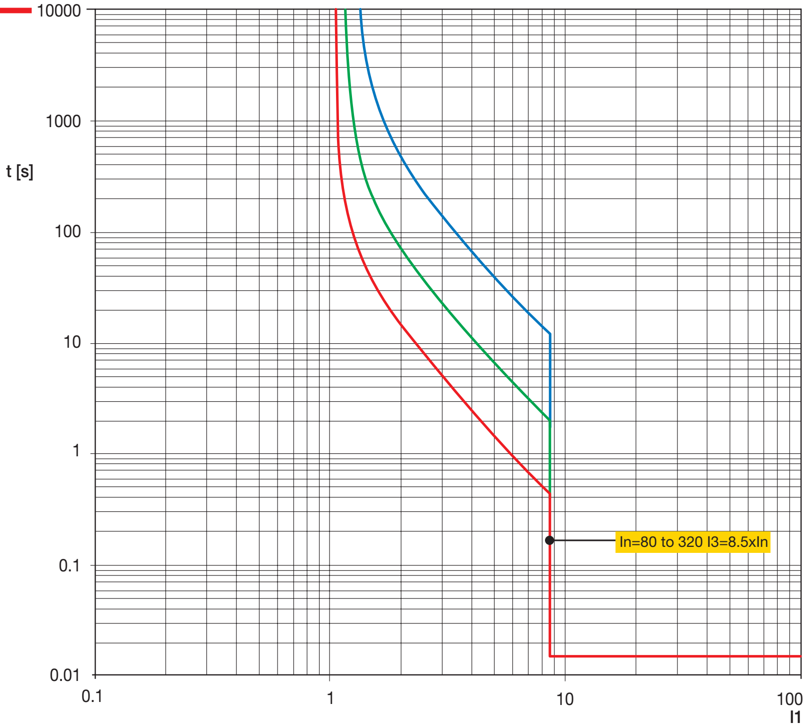
T4N 250/320	I1 (400Hz) MIN	I1 (400Hz) MED	I1 (400Hz) MAX	I3 setting (MIN=5xIn) I3 @ 5xIn (50Hz)	K_m	I3 @ 5xIn (400Hz)
In80	50	61	72	400	1.7	680
In100	63	76.5	90	500	1.7	850
In125	79	96	113	625	1.7	1060
In160	100	122	144	800	1.7	1360
In200	126	153	180	1000	1.7	1700
In250	157	191	225	1250	1.7	2125
In320	201	244	288	1600	1.7	2720

K_m = Multiplier factor of I3 due to the induced magnetic fields

Trip curves
thermomagnetic release

T4N 250/320

In 80 to 320 A
TMA



5 Special applications

Table 8: Tmax performance T5N 320-630 A TMA

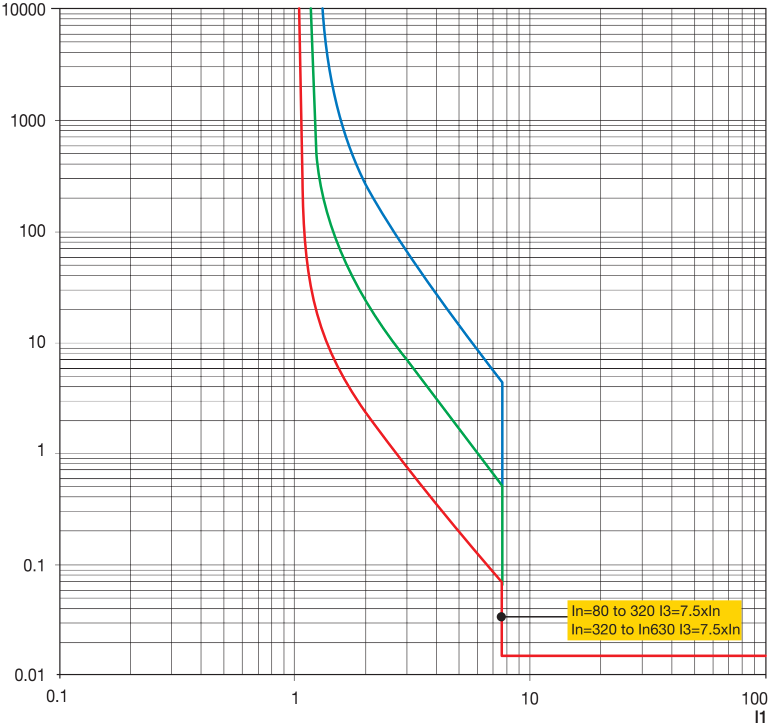
	I1 (400Hz)			I3 setting (MIN=5xIn)		
T5N400/630	MIN	MED	MAX	I3 @ 5xIn(50Hz)	K_m	I3 @ 5xIn (400)Hz
In320	201	244	288	1600	1.5	2400
In400	252	306	360	2000	1.5	3000
In500	315	382	450	2500	1.5	3750
In630	397	482	567	3150	1.5	4725

K_m = Multiplier factor of I3 due to the induced magnetic fields

Trip curves
thermomagnetic release

T5 N 400/630

In 320 to 630 A
TMA



5 Special applications

Table 9: Tmax performance T5N 320-630 A TMG

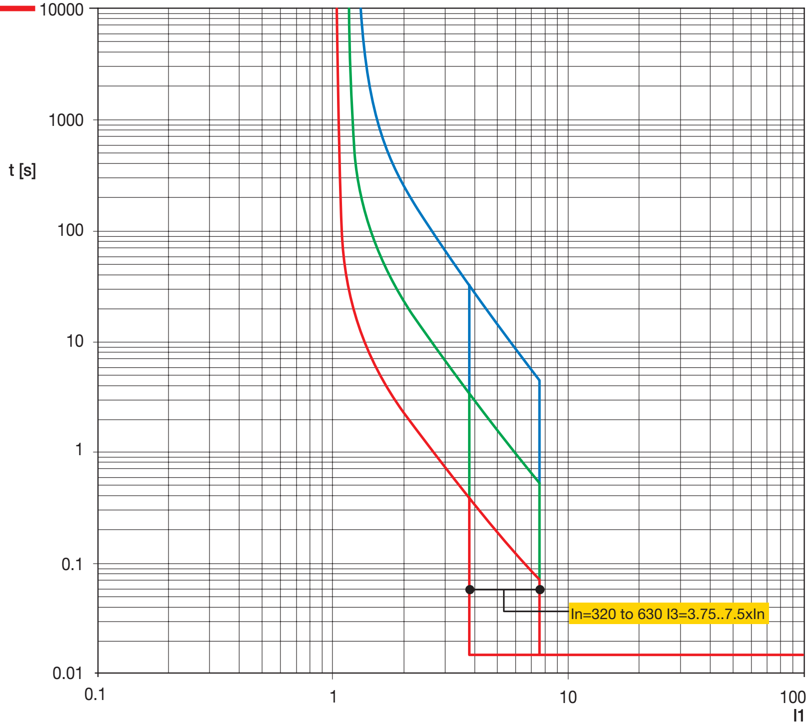
T5N400/630	I1 (400Hz)			I3 setting (2.5…5xIn)		
	MIN	MED	MAX	I3 @ 2.5..5xIn (50Hz)	K_m	I3 @ 2.5..5xIn (400Hz)
In320	201	244	288	800...1600	1.5	1200...2400
In400	252	306	360	1000...2000	1.5	1500...3000
In500	315	382	450	1250...2500	1.5	1875...3750
In630	397	482	567	1600...3150	1.5	2400...4725

K_m = Multiplier factor of I3 due to the induced magnetic fields

Trip curves
thermomagnetic release

T5N 400/630

In 320 to 630 A
TMG



5 Special applications

Table 10: SACE Isomax performance S6N 800 A TMA

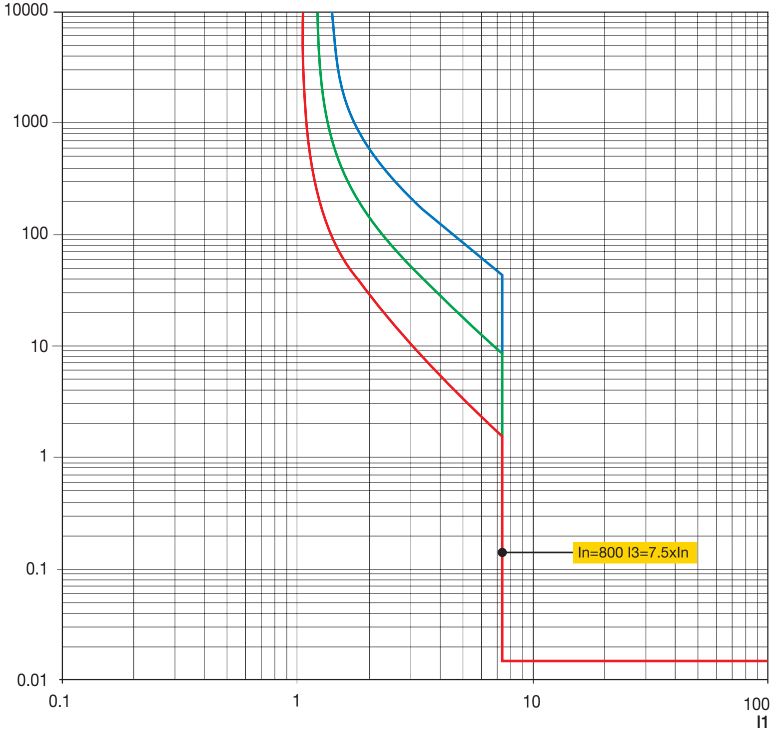
		I1 (400Hz)			I3 = 5-10In (set I3=5In)		
S6N 800	In800	MIN	MED	MAX	I3 (50Hz)	K_m	I3 (400Hz)
		504	602	720	4000	1.5	6000

K_m = Multiplier factor of I3 due to the induced magnetic fields

Trip curves
thermomagnetic release

S6N 800

In 800 A
TMA



5 Special applications

5.2.2 16 2/3 Hz networks

Single phase distribution with a frequency of 16 2/3 Hz was developed for electrical traction systems as an alternative to three phase 50 Hz systems, and to direct current systems.
At low frequencies the thermal tripping threshold is not subject to any derating, while the magnetic threshold requires a correction coefficient k_m, as detailed in table 2.
The Isomax and Tmax series thermomagnetic moulded-case circuit-breakers are suitable for use with frequencies of 16 2/3 Hz; the electrical performance and the relevant connection diagrams are shown below.

5 Special applications

Table 1: Breaking capacity [kA]

	In [A]	250 V	500 V	750 V	1000 V (1)
T1B160	16 ÷160	16 (2P) 20 (3P)	16 (3P)	-	-
T1C160	25 ÷ 160	25 (2P) 30 (3P)	25 (3P)	-	-
T1N160	32 ÷ 160	36 (2P) 40 (3P)	36 (3P)	-	-
T2N160	1.6 ÷ 160	36 (2P) 40 (3P)	36 (3P)	-	-
T2S160	1.6 ÷ 160	50 (2P) 55 (3P)	50 (3P)	-	-
T2H160	1.6 ÷ 160	70 (2P) 85 (3P)	70 (3P)	-	-
T2L160	1.6 ÷ 160	85 (2P) 100 (3P)	85 (3P)	50 (4P) (2)	-
T3N250	63 ÷ 250	36 (2P) 40 (3P)	36 (3P)	-	-
T3S250	63 ÷ 250	50 (2P) 55 (3P)	50 (3P)	-	-
T4N250/320	20 ÷ 320	36 (2P)	25 (2P)	16 (3P)	-
T4S250/320	20 ÷ 320	50 (2P)	36 (2P)	25 (3P)	-
T4H250/320	20 ÷ 320	70 (2P)	50 (2P)	36 (3P)	-
T4L250/320	20 ÷ 320	100 (2P)	70 (2P)	50 (3P)	-
T4V250/320	20 ÷ 320	150 (2P)	100 (2P)	70 (3P)	-
T4V250	32 ÷ 250				40 (4P)
T5N400/630	320 ÷ 630	36 (2P)	25 (2P)	16 (3P)	-
T5S400/630	320 ÷ 630	50 (2P)	36 (2P)	25 (3P)	-
T5H400/630	320 ÷ 630	70 (2P)	50 (2P)	36 (3P)	-
T5L400/630	320 ÷ 630	100 (2P)	70 (2P)	50 (3P)	-
T5V400/630	320 ÷ 630	150 (2P)	100 (2P)	70 (3P)	-
T5V400/630	400 ÷ 630				40 (4P)
S6N800	800	35 (2P)	20 (2P)	16 (3P)	-
S6S800	800	50 (2P)	35 (2P)	20 (3P)	-
S6H800	800	65 (2P)	50 (2P)	35 (3P)	-
S6L800	800	100 (2P)	65 (2P)	50 (3P)	50 (4P)

(1) 1000V version circuit-breakers in dc, with neutral at 100%.
(2) Circuit-breakers with neutral at 100%.

5 Special applications

Table 2: k_m factor

	Diagram A	Diagram B	Diagram C
T1	1	1	-
T2	0.9	0.9	0.9
T3	0.9	0.9	-
T4	0.9	0.9	0.9
T5	0.9	0.9	0.9
S6	0.9	0.9	0.9

Table 3: Possible connections according to the voltage, the type of distribution and the type of fault

	Neutral not grounded	Neutral grounded*	
		L-N fault	L-E fault
250 V 2 poles in series	A1	A2	B2
250 V 3 poles in series**	B1	B2, B3	B3
500 V 2 poles in series	A1	A2, B2	B2, B3
500 V 3 poles in series**	B1	B2, B3	B3
750 V 3 poles in series	B1	B2, B3	B3
750 V 4 poles in series***	C1	C2, C3	C2
1000 V 4 poles in series	C1	C2, C3	C2

* In the case of the only possible faults being L-N or L-E (E=Earth) with non-significant impedance, use the diagrams shown. If both faults are possible, use the diagrams valid for L-E fault.

** T1, T2, T3 only

*** T2 only

5 Special applications

Connection diagrams

Diagram A1

Configuration with two poles in series (without neutral connected to earth)
• Interruption for phase to neutral fault: 2 poles in series
• Interruption for phase to earth fault: not considered
(The installation method must be such as to make the probability of a second earth fault negligible)

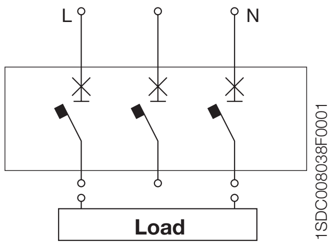
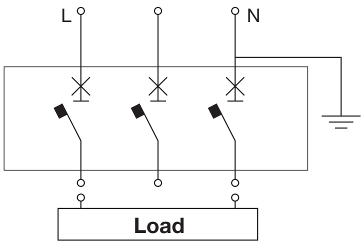


Diagram A2

Configuration with two poles in series (with neutral connected to earth)
• Interruption for phase to neutral fault: 2 poles in series
• Interruption for phase to earth fault: single pole (same capacity as two poles in series, but limited to 125V)



5 Special applications

Diagram B1

Configuration with three poles in series (without neutral connected to earth)
• Interruption for phase to neutral fault: 3 poles in series
• Interruption for phase to earth fault: not considered
(The installation method must be such as to make the probability of a second earth fault negligible)

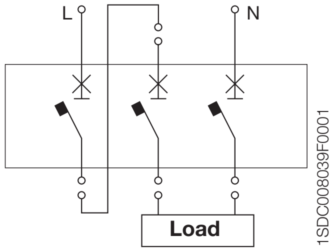


Diagram B2

Configuration with three poles in series (with neutral connected to earth and interrupted)
• Interruption for phase to neutral fault: 3 poles in series
• Interruption for phase to earth fault: 2 poles in series

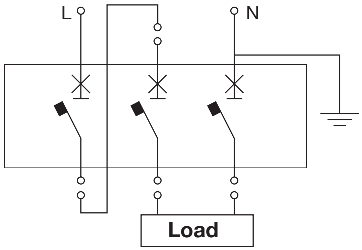
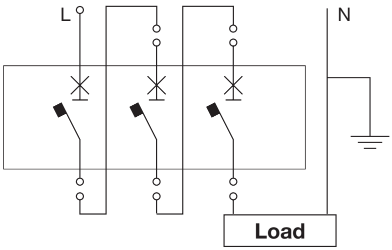


Diagram B3

Configuration with three poles in series (with neutral connected to earth but not interrupted)
• Interruption for phase to neutral fault: 3 poles in series
• Interruption for phase to earth fault: 3 poles in series



5 Special applications

Diagram C1

Configuration with four poles in series (without neutral connected to earth)
• Interruption for phase to neutral fault: 4 poles in series
• Interruption for phase to earth fault: not considered
(The installation method must be such as to make the probability of a second earth fault negligible)

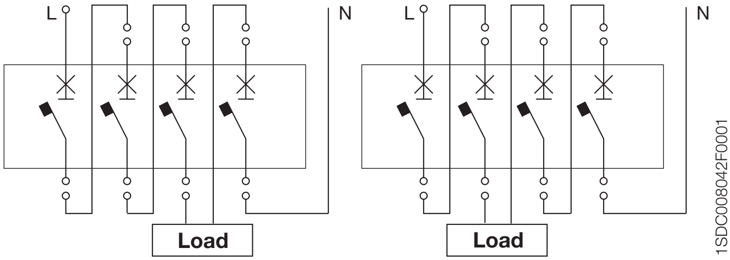


Diagram C2

Configuration with four poles in series, on one polarity (with neutral connected to earth and not interrupted)
• Interruption for phase to neutral fault: 4 poles in series
• Interruption for phase to earth fault: 4 poles in series

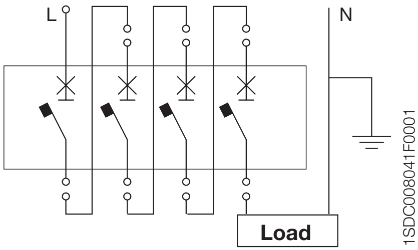
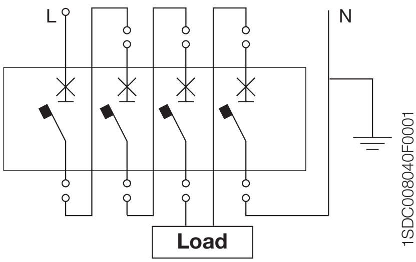


Diagram C3

Interruption with four poles in series (with neutral connected to earth and interrupted)
• Interruption for phase to neutral fault: 4 poles in series
• Interruption for phase to earth fault: 3 poles in series



5 Special applications

Example:

Network data:
Rated voltage 250 V
Rated frequency 16 2/3 Hz
Load current 120 A
Phase to neutral short-circuit current 45 kA
Neutral connected to earth

Assuming that the probability of a phase to earth fault is negligible, Table 3 shows that connections A2, B2 or B3 may be used.
Therefore it is possible to choose a Tmax T2S160 In125 circuit-breaker, which with the connection according to diagram A2 (two poles in series) has a breaking capacity of 50 kA, while according to diagrams B2 or B3 (three poles in series) the breaking capacity is 55 kA (Table 1). To determine the magnetic trip, see factor k_m in Table 2. The magnetic threshold will be:
I_3= 1250·0.9 = 1125 A
whichever diagram is used.
If it is possible to have an earth fault with non significant impedance, the diagrams to be considered (Table 3) are only B2 or B3. In particular, in diagram B2 it can be seen that only 2 poles are working in series, the breaking capacity will be 50 kA (Table 1), while with diagram B3, with 3 poles working in series, the breaking capacity is 55 kA.

5.3 1000 Vdc and 1000 Vac networks

The Tmax, SACE Isomax and Emax /E 1000 V circuit-breakers are particularly suitable for use in installations in mines, petrochemical plants and services connected to electrical traction (tunnel lighting).

5.3.1 1000 V dc networks

1000 Vdc Moulded case circuit-breakers

General Characteristics

The range of Tmax and SACE Isomax S moulded-case circuit-breakers for use in installations with rated voltage up to 1000 V direct current comply with international standard IEC 60947-2. The range is fitted with adjustable thermo-magnetic releases and is suitable for all installation requirements and has a range of available settings from 32 A to 800 A. The four-pole version circuit breakers allow high performance levels to be reached thanks to the series connection of the poles.
The circuit breakers in the Tmax and SACE Isomax S 1000 V range maintain the same dimensions and fixing points as standard circuit breakers.
These circuit-breakers can also be fitted with the relevant range of standard accessories, with the exception of residual current releases for Tmax and mechanical interlocks for SACE Isomax.
In particular it is possible to use conversion kits for removable and withdrawable moving parts and various terminal kits.

5 Special applications

1000 V dc Moulded-case circuit-breakers		**T4**	**T5**	**S6**
Rated uninterrupted current, **Iu**	[A]	**250**	**400/630**	**800**
Poles	Nr.	4	4	4
Rated operational voltage, **Ue**	[V –]	1000	1000	1000
Rated impulse withstand voltage, **Uimp**	[kV]	8	8	8
Rated insulation voltage, **Ui**	[V]	1000	1000	1000
Test voltage at industrial frequency for 1 min.	[V]	3500	3500	3000
Rated ultimate short-circuit breaking capacity, **Icu**		**V**	**V**	**L**
(4 poles in series)	[kA]	40	40	50
Rated short-time withstand current for 1 s, Icw	[kA]	–	5 (400A)	10
Utilisation category (EN 60947-2)		A	B (400A)-A (630A)	B
Isolation behaviour		■	■	■
IEC 60947-2, EN 60947-2		■	■	■
Thermomagnetic releases	TMD	■	–	–
Thermomagnetic releases	TMA	■	■	
Thermomagnetic releases, T adjustable - M adjustable		–	–	■
Versions		F-P-W	F-P-W	F
Terminals	Fixed	F-FC Cu/CuAl-EF-ES-MC-R	F-FC Cu/CuAl-EF-ES -R	F
	Plug-in	FC Cu/CuAl-EF-ES-HR-VR-R	FC Cu/CuAl-EF-ES-HR-VR-R	–
	Withdrawable	FC Cu/CuAl-EF-ES-HR-VR-R	FC Cu/CuAl-EF-ES-HR-VR-R	–
Mechanical life [No. operations / operations per hours]		20000/240	20000/120	20000/120
Basic dimensions, fixed	L [mm]	140	184	280
	D [mm]	103.5	103.5	103.5
	H [mm]	205	205	268

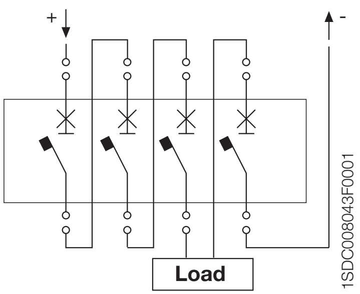
TERMINAL CAPTION
F = Front
EF = Front extended
ES = Front extended spread
FC Cu = Front for copper cables
FC CuAl = Front for CuAl cables
R = Rear orientated
HR = Rear in horizontal flat bar
VR = Rear in vertical flat bar
MC = Multicable

Connection diagrams

Possible connection diagrams with reference to the type of distribution system in which they can be used follow.

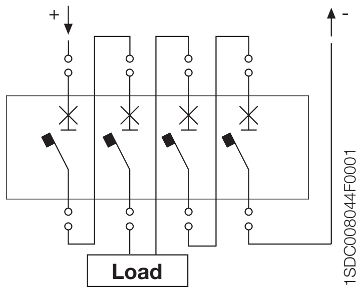
Networks insulated from earth

The following diagrams can be used (the polarity may be inverted).



A) 3+1 poles in series (1000 Vdc)

5 Special applications

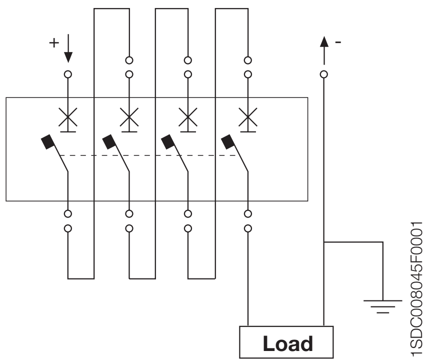


B) 2+2 poles in series (1000 Vdc)

It is assumed that the risk of a double earth fault in which the first fault is downstream of the breaker on one polarity and the second is upstream of the same switching device on the opposite polarity is null.
In this condition the fault current, which can reach high values, effects only some of the 4 poles necessary to ensure the breaking capacity.
It is possible to prevent the possibility of a double earth fault by installing a device which signals the loss of insulation and identifies the position of the first earth fault, allowing it to be eliminated quickly.

Networks with one polarity connected to earth

As the polarity connected to earth does not have to be interrupted (in the example it is assumed that the polarity connected to earth is negative, although the following is also valid with the polarity inverted), the diagram which shows the connection of 4 poles in series on the polarity not connected to earth may be used.

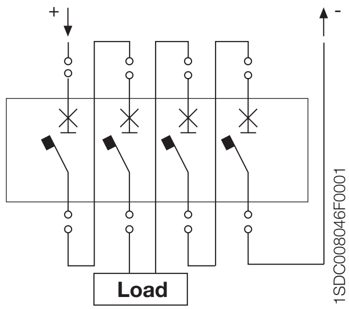


C) 4 poles in series (1000 Vdc)

5 Special applications

Networks with median point of the supply source connected to earth

In the presence of an earth fault of positive or negative polarity, the poles involved in the fault work at U/2 (500 V); the following diagram must be used:



D) 2+2 poles in series (1000 Vdc)

Correction factors for tripping thresholds

With regard to overload protection, no correction factors need to be applied. However, for the magnetic threshold values in use with 1000 Vdc with the previously described applicable diagrams, refer to the corresponding values for alternating current, multiplied by the correction factors given in the following table:

Circuit-breaker	k_m
T4V	1
T5V	0.9
S6L	0.9

Circuit-breakers with thermomagnetic release for direct current

In [A]	32 (1)	50 (1)	80 (2)	100 (2)	125 (2)	160 (2)	200 (2)	250 (2)	400 (2)	630 (2)	800 (2)
T4V 250	■	■	■	■	■	■	■	■	–	–	–
T5V 400	–	–	–	–	–	–	–	–	■	–	–
T5V 630	–	–	–	–	–	–	–	–	–	■	–
S6L 800	–	–	–	–	–	–	–	–	–	–	■
I3 = (10xI_n) [A]	320	500	–	–	–	–	–	–	–	–	–
I3 = (5 -10xI_n) [A]	–	–	400÷800	500÷1000	625÷1250	800÷1600	1000÷2000	1250÷2500	2000÷4000	3150÷6300	4000÷8000

(1) Thermal threshold adjustable from 0.7 and 1 x In; fixed magnetic threshold
(2) Thermal threshold adjustable from 0.7 and 1 x In; magnetic threshold adjustable between 5 and 10 x In.

5 Special applications

Example

To ensure the protection of a user supplied with a network having the following characteristics:

Rated voltage	U_r = 1000 Vdc
Short-circuit current	I_k = 18 kA
Load current	I_b = 520 A

Network with both polarities insulated from earth.

From the table of available settings, the circuit-breaker to be used is:
T5V 630 I_n=630 four-pole I_{cu}@1000 Vdc = 40 kA
Thermal trip threshold adjustable from (0.7-1) x I_n therefore from 441 A to 630 A to be set at 0.85.
Magnetic trip threshold adjustable from (5-10) x I_n which with correction factor k_m = 0.9 gives the following adjustment range: 2835 A to 5670 A. The magnetic threshold will be adjusted according to any conductors to be protected.
The connection of the poles must be as described in diagrams A or B.
A device which signals any first earth fault must be present.
With the same system data, if the network is carried out with a polarity connected to earth, the circuit-breaker must be connected as described in diagram C.

5 Special applications

1000 Vdc air switch disconnectors

The air switch disconnectors derived from the Emax air breakers are identified by the standard range code together with the code "/E MS".
These comply with the international Standard IEC 60947-3 and are especially suitable for use as bus-ties or principle isolators in direct current installations, for example in electrical traction applications.
The overall dimensions and the fixing points remain unaltered from those of standard breakers, and they can be fitted with various terminal kits and all the accessories for the Emax range; they are available in both withdrawable and fixed versions, and in three-pole version (up to 750 Vdc) and four-pole (up to 1000 Vdc).
The withdrawable breakers are assembled with special version fixed parts for applications of 750/1000 Vdc.
The range covers all installation requirements up to 1000 Vdc / 3200 A or up to 750 Vdc / 4000 A.
A breaking capacity equal to the rated short-time withstand current is attributed to these breakers when they are associated with a suitable external relay.

The following table shows the available versions and their relative electrical performance:

			E1B/E MS		E2N/E MS		E3H/E MS		E4H/E MS
Rated uninterrupted current (at 40 °C) Iu		[A]	**800**		**1250**		**1250**		**3200**
		[A]	**1250**		**1600**		**1600**		**4000**
		[A]			**2000**		**2000**		
		[A]					**2500**		
		[A]					**3200**		
Number of poles			3	4	3	4	3	4	3
Rated operational voltage **Ue**		[V]	750	1000	750	1000	750	1000	750
Rated insulation voltage **Ui**		[V]	1000	1000	1000	1000	1000	1000	1000
Rated impulse withstand voltage **Uimp**		[kV]	12	12	12	12	12	12	12
Rated short-time withstand current **Icw** (1s)		[kA]	20	20	25	25	40	40	65
Rated making capacity **Icm**	750 V dc	[kA]	20	20	25	25	105	105	143
	1000 V dc		–	20	–	25	–	105	–

5 Special applications

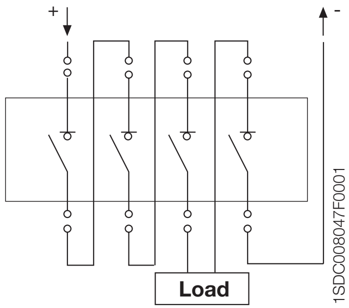
Connection diagrams

Connection diagrams to be used according to the type of distribution system follow.

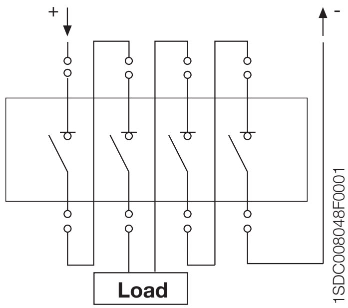
The risk of a double earth fault on different poles is assumed to be zero, that is, the fault current involves only one part of the breaker poles.

Networks insulated from earth

The following diagrams may be used (the polarity may be inverted).

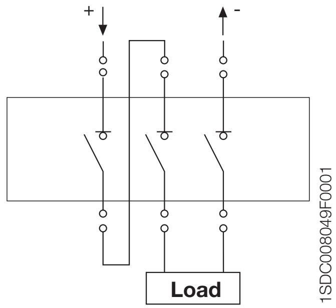


E) 3+1 poles in series (1000 Vdc)



F) 2+2 poles in series (1000 Vdc)

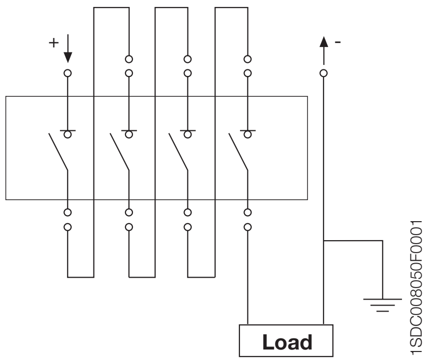
5 Special applications



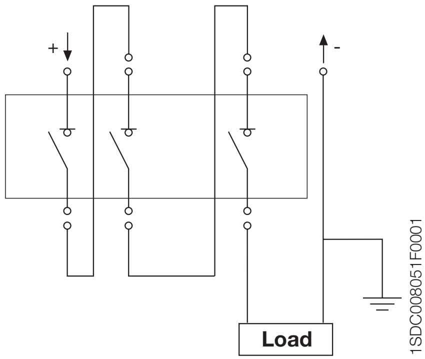
G) 2+1 poles in series (750 Vdc)

Networks with one polarity connected to earth

The polarity connected to earth does not have to be interrupted (in the examples it is assumed that the polarity connected to earth is negative):



H) 4 poles in series (1000 Vdc)



I) 3 poles in series (750 Vdc)

Networks with median point of the supply source connected to earth

Only four-pole breakers may be used as in the configuration shown in diagram F).

5 Special applications

5.3.2 1000 Vac networks

1000 Vac moulded-case circuit-breakers

General Characteristics

The circuit breakers in the Tmax and SACE Isomax S 1000 V range comply with the international standard IEC 60947-2.
These circuit breakers can be fitted with thermo-magnetic releases (for the smaller sizes) and with electronic releases. All installation requirements can be met with a range of available settings from 32 A to 800 A and with breaking capacity up to 20 kA at 1000 Vac.

1000 Vac moulded-case circuit-breakers

Rated uninterrupted current, **Iu**	[A]
Poles	Nr.
Rated operational voltage, **Ue** (ac) 50-60Hz	[V]
Rated impulse withstand voltage, **Uimp**	[kV]
Rated insulation voltage, **Ui**	[V]
Test voltage at industrial frequency for 1 min.	[V]
Rated ultimate short-circuit breaking capacity, **Icu** (ac) 50-60 Hz 1000 V	[kA]
Rated service short-circuit breaking capacity, **Ics** (ac) 50-60 Hz 1000 V	[%Icu]
Rated short-circuit making capacity **Icm** (ac) 50-60 Hz 1000 V	[kA]
Rated short-time withstand current for 1 s, **Icw**	[kA]
Utilisation category (EN 60947-2)	
Isolation behaviour	
IEC 60947-2, EN 60947-2	
Thermomagnetic releases	TMD
	TMA
Electronic releases	PR221DS-LS
	PR221DS-I
	PR222DS-LSI
	PR222DS-LSIG
	PR211/P (LI only)
	PR212/P (LSI-LSIG)
Interchangeability	
Versions	
Terminals	Fixed
	Plug-in
	Withadrawable
Mechanical life	[No. operations / operations per hours]
Dimensions	L [mm]
	D [mm]
	H [mm]

5 Special applications

The circuit-breakers in the 1000 V range maintain the same dimensions as standard circuit breakers.
These circuit-breakers can also be fitted with the relevant range of standard accessories, with the exception of residual current releases for Tmax and mechanical interlocks for SACE Isomax.
In particular it is possible to use conversion kits for removable and withdrawable moving parts and various terminal kits.
The circuit-breakers in the SACE Isomax S 1000 V range can be supplied via the upper terminals only.

The following tables show the electrical characteristics of the range:

	T4			T5		S6
	250			**400/630**		800
3	3	4	3	3	4	3
	1000			1000		1000
	8			8		8
	1000			1000		1000
	3500			3500		3000
L	**V**	**V**	**L**	**V**	**V**	**L**
12	20	20	12	20	20	12
100%	100%	75%	75%	75%	75%	75%
24	40	40	24	40	40	24
	–			5 (400A)		10
	A			B (400A) A (630A)		B
	■			■		■
	■			■		■
–	–	■	–	–	–	–
–	–	■	–	–	■	–
■	■	–	■	■	–	–
■	■	–	■	■	–	–
■	■	–	■	■	–	–
■	■	–	■	■	–	–
	–			–		■
	–			–		■
	■			–		–
	F-P-W			F-P-W		F
	F-FC Cu/CuAl-EF-ES-R-MC			F-FC Cu/CuAl-EF-R-ES		F
	FC Cu/CuAl-EF-ES-HR-VR-R			FC Cu/CuAl-EF-ES-HR-VR-R		–
	FC Cu/CuAl-EF-ES-HR-VR-R			FC Cu/CuAl-EF-ES-HR-VR-R		–
	20000/240			20000/120		20000/120
105	105	140	140	140	184	210
103.5	103.5	103.5	103.5	103.5	103.5	103.5
205	205	205	205	205	205	268

TERMINAL CAPTION
F = Front
EF = Front extended
ES = Front extended spread
FC Cu = Front for copper cables
FC CuAl = Front for CuAl cables
R = Rear orientated
HR = Rear in horizontal flat bar
VR = Rear in vertical flat bar
MC = Multicable

5 Special applications

The following tables show the available releases.

Circuit-breakers with electronic release for alternating currents

	In100	In250	In400	In630	In800
T4 250	■	■	–	–	–
T5 400	–	–	■	–	–
T5 630	–	–	–	■	–
S6L 800	–	–	–	–	■
I_3 (1÷10x In) [A] (1)	100÷1000	250÷2500	400÷4000	630÷6300	–
I_3 (1.5÷12 x In) [A] (2)	150÷1200	375÷3000	600÷4800	945÷7560	1200÷9600

(1) PR221
(2) PR222 - PR211 - PR212

Circuit-breakers with thermomagnetic release for alternating currents

(thermal threshold adjustable from 0.7 to 1 x In; fixed magnetic threshold)

In [A]	32 (1)	50 (1)	80 (2)	100 (2)	125 (2)	160 (2)	200 (2)	250 (2)	400 (2)	630 (2)
T4V 250	■	■	■	■	■	■	■	■	–	–
T5V 400	–	–	–	–	–	–	–	–	■	–
T5V 630	–	–	–	–	–	–	–	–	–	■
I_3 = (10xI_n) [A]	320	500	–	–	–	–	–	–	–	–
I_3 = (5 -10xI_n) [A]	–	–	400÷800	500÷1000	625÷1250	800÷1600	1000÷2000	1250÷2500	2000÷4000	3150÷6300

(1) Thermal threshold adjustable from 0.7 and 1 x In; fixed magnetic threshold
(2) Thermal threshold adjustable from 0.7 and 1 x In; magnetic threshold adjustable between 5 and 10 x In.

1000 Vac Air circuit-breakers and switch disconnectors

For 1000 V alternating current installations, the following devices are available:

- **Circuit-breakers** in compliance with Standard IEC 60947-2.
  The special version breakers up to 1000 Vac are identified by the standard range code together with the suffix "/E", and are derived from the correspondent Emax standard breakers and retain the same versions, accessories and overall dimensions.
  The Emax range of breakers is available in both withdrawable and fixed versions with three and four poles, and can be fitted with accessories and equipped with the full range of electronic releases and microprocessors (PR111-PR112-PR113).
- **Switch disconnectors** in compliance with Standard IEC 60947-3.
  These breakers are identified by the code of the standard range, from which they are derived, together with the suffix "/E MS". Three-pole and four-pole versions are available in both withdrawable and fixed versions with the same dimensions, accessory characteristics and installation as the standard switch disconnectors.

5 Special applications

The following tables show the electrical characteristics of the devices:

Air circuit-breakers

		E2B/E		E2N/E			E3H/E					E4H/E	
Rated uninterrupted current (at 40 °C) Iu	[A]	**1600**	**2000**	**1250**	**1600**	**2000**	**1250**	**1600**	**2000**	**2500**	**3200**	**3200**	**4000**
Rated operational voltage **Ue**	[V~]	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Rated ultimate short-circuit breaking capacity **Icu**	[kA]	20	20	30	30	30	50	50	50	50	50	65	65
Rated duty short-circuit breaking capacity **Ics**	[kA]	20	20	30	30	30	50	50	50	50	50	65	65
Rated short-time withstand current **Icw** (1s)	[kA]	20	20	30	30	30	50	50	50	50	50	65	65

Air switch disconnectors

		E2B/E MS	E2N/E MS	E3H/E MS	E4H/E MS
Rated uninterrupted current (at 40 °C) Iu	[A]	**1600**	**1250**	**1250**	**3200**
	[A]	**2000**	**1600**	**1600**	**4000**
	[A]		**2000**	**2000**	
	[A]			**2500**	
	[A]			**3200**	
Number of poles		3/4	3/4	3/4	3/4
Rated operational voltage **Ue**	[V]	1000	1000	1000	1000
Rated insulation voltage **Ui**	[V]	1000	1000	1000	1000
Rated impulse withstand voltage **Uimp**	[kV]	12	12	12	12
Rated short-time withstand current **Icw** (1s)	[kA]	20	30	50	65
Rated making capacity **Icm** 1000 Vac (peak value)	[kA]	40	63	105	143

5.4 Automatic Transfer Switches

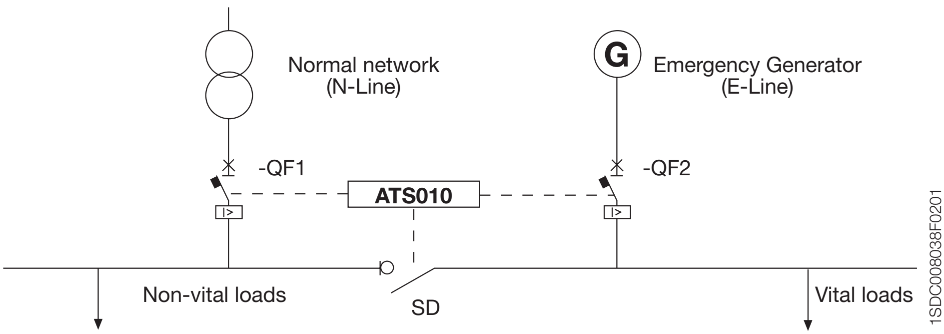
In the electrical plants, where a high reliability is required from the power supply source because the operation cycle cannot be interrupted and the risk of a lack of power supply is unacceptable, an emergency line supply is indispensable to avoid the loss of large quantities of data, damages to working processes, plant stops etc.
For these reasons, transfer switch devices are used mainly for:
- power supply of hotels and airports;
- surgical rooms and primary services in hospitals;
- power supply of UPS groups;
- databanks, telecommunication systems, PC rooms;
- power supply of industrial lines for continuous processes.

ATS010 is the solution offered by ABB: it is an automatic transfer switch system with micro-processor based technology which allows switching of the supply from the normal line (N-Line) to the emergency line (E-Line) in case any of the following anomalies occurs on the main network:
- overvoltages and voltage dips;
- lack of one of the phases;
- asymmetries in the phase cycle;
- frequency values out of the setting range.

Then, when the network standard parameters are recovered, the system switches again the power supply to the main network (N-Line).

ATS010 is used in systems with two distinct supply lines connected to the same busbar system and functioning independently ("island condition"): the first one is used as normal supply line, the second is used for emergency power supply from a generator system. It is also possible to provide the system with a device to disconnect the non-priority loads when the network is supplied from the E-Line.

The following scheme shows a plant having a safety auxiliary power supply:



5 Special applications

ATS010 device is interfaced by means of appropriate terminals:
- with the protection circuit-breakers of the N-Line and of the E-Line, motorized and mechanically interlocked, to detect their status and send opening and closing commands according to the set time delays;
- with the control card of the Gen set to control its status and send start and stop commands;
- with any further signals coming from the plant in order to block the switching logic;
- with the N-Line to detect any possible anomaly and with the E-Line to verify the voltage presence;
- with an additional device to disconnect non-priority loads;
- with an auxiliary power supply at 24 Vdc ± 20% (or 48 Vdc ± 10%). This supply source shall be present also in case of lack of voltage on both lines (N-Line and E-Line).

The circuit-breakers used to switch from the N-line to the E-line shall have all the necessary accessories and shall be properly interlocked in order to guarantee the correct working of the plant. The following accessories are required:

Moulded-case circuit-breakers Tmax (T4-T5) and SACE Isomax (S6-S7):

- motor operator from 48 V to 110 V dc or up to 250V ac;
- trip signaling contact;
- open/closed signaling contact;
- racked-in signaling contact in case of plug-in or withdrawable circuit-breakers;
- mechanical interlock between two circuit-breakers.

Air circuit-breakers Emax:

- charging spring motor;
- shunt opening release;
- shunt closing release;
- trip signaling contact;
- open/closed signaling contacts;
- racked-in signaling contact in case of withdrawable circuit-breakers;
- mechanical interlock between two circuit-breakers.

Switching strategies

According to the application where ATS010 device is used, two different switching strategies can be chosen.
Strategy 1: this strategy is used when an auxiliary supply source is available for the supply of the motor operators of the circuit-breakers; the switching sequence is as follows:
- normal line anomaly detection;
- normal line circuit-breaker opening and Gen Set starting;
- waiting for presence of Gen Set voltage and emergency circuit-breaker closing.

5 Special applications

For example, strategy 1 is used for systems in which a redundant 110 V auxiliary power supply is available (MV/LV substations); the plant is designed so that the auxiliary voltage is always present even when neither the normal line nor the Gen Set are active. In this case, the auxiliary power supply can be used to feed the motor operators and/or the shunt opening and closing releases of the circuit-breakers. ATS010 operates the circuit-breakers regardless of the presence of the network and of the Gen Set.

Strategy 2: this strategy is absolutely necessary when the power supply for the auxiliary accessories of the circuit-breakers is directly derived from the network and the Gen Set, since a safety auxiliary power supply is not available; in this case, before operating the circuit-breakers, ATS010 waits for availability of normal line or emergency line voltage: normal line or Gen Set. The switching sequence is as follows:
- normal line anomaly detection;
- Gen Set starting;
- waiting for presence of Gen Set voltage and normal line circuit-breaker opening;
- Gen Set circuit-breaker closing.

Note: in both strategies, it is necessary to provide an auxiliary power supply for ATS010.

Operating modes

By using the front selector it is possible to choose one of the following six operating modes:

TEST:
This operating mode is useful to test the Gen Set start and therefore to test the emergency line power supply status without disconnecting normal line power supply.

AUTOMATIC:
The transfer switch logic is ON and checks both the circuit-breakers as well as the generator. In case of normal line anomalies, the transfer switch procedure begins from normal to emergency line and viceversa when normal line voltage become available again.

5 Special applications

MANUAL:
The MANUAL mode offers a choice between the following possibilities:

1. Normal ON

The emergency line circuit-breaker is forced to open and the normal line circuit-breaker is forced to close; the Gen Set is stopped and the transfer switch logic is disabled.
This selector position guarantees that the emergency line is not closed and that the Gen Set is not running; this position is useful when the user wants to carry out maintenance on the emergency line or on the Gen Set (in these cases it is advisable to install mechanical lock in open position for the emergency line circuit-breaker).

2. Normal – Emergency OFF (maintenance)

Both circuit-breakers (N-Line and E-Line) are forced in open position. It is useful when all loads are to be disconnected from the power supply sources, for example to carry out maintenance on the plant (in these cases, it is advisable to mechanically lock both circuit-breakers in the open position).

3. Gen Set START

The START command of the Gen Set has been activated through the proper output. The circuit-breakers are not operated and the transfer switch logic is disabled.
When emergency line voltage is present and switching is enabled, it is possible to switch the selector to ‘Emergency ON’ position in order to force supply from the emergency line.

4. Emergency ON

Power supply is forced from the emergency line. Before switching to this position, ‘Gen-Set START’ operating mode is activated and shall be present until switching is enabled as previously described.

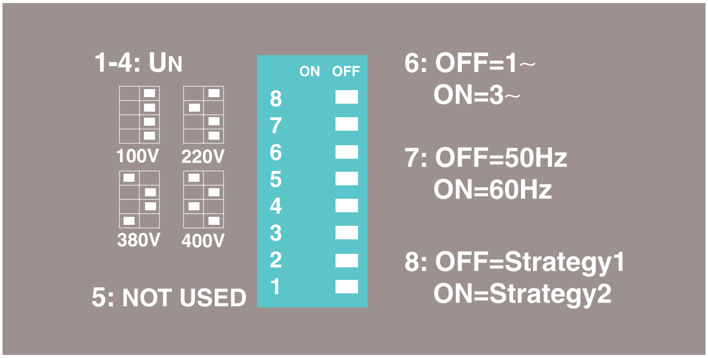
5 Special applications

Setting of parameters

All the parameters for the functioning of ATS010 can be simply adjusted through dip-switches or trimmers.

Rated voltage for three-phase or single-phase plant
The following parameters of the N-Line can be set through dip-switches:
- network rated voltage value (from 100 V up to 500 V);
- power supply type (three-phase or single-phase);
- frequency value (50 Hz or 60 Hz);
- type of strategy.

Note: Voltages higher than 500 V can be reached by using VTs (voltage transformers); in this case the setting of the voltage value shall consider the transformation ratio.



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The figure below shows all the possible voltage values which can be set by the dip-switches from 1 to 4.

		ON	OFF
100V	4		■
	3		■
	2		■
	1		■

		ON	OFF
115V	4		■
	3		■
	2		■
	1	■	

		ON	OFF
120V	4		■
	3		■
	2	■	
	1		■

		ON	OFF
208V	4		■
	3		■
	2	■	
	1	■	

5 Special applications

220V		ON	OFF
	4		■
	3	■	
	2		■
	1		■

230V		ON	OFF
	4		■
	3	■	
	2		■
	1	■	

240V		ON	OFF
	4		■
	3	■	
	2	■	
	1		■

277V		ON	OFF
	4		■
	3	■	
	2	■	
	1	■	

347V		ON	OFF
	4	■	
	3		■
	2		■
	1		■

380V		ON	OFF
	4	■	
	3		■
	2		■
	1	■	

400V		ON	OFF
	4	■	
	3		■
	2	■	
	1		■

415V		ON	OFF
	4	■	
	3		■
	2	■	
	1	■	

440V		ON	OFF
	4	■	
	3	■	
	2		■
	1		■

480V		ON	OFF
	4	■	
	3	■	
	2		■
	1	■	

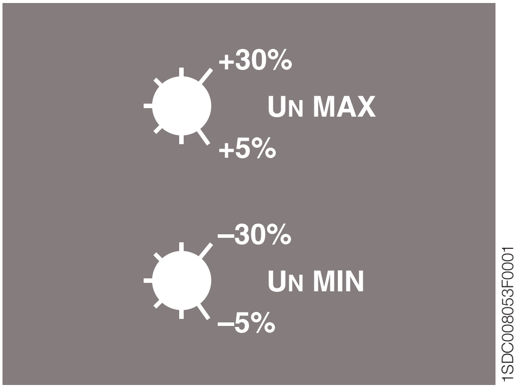
500V		ON	OFF
	4	■	
	3	■	
	2	■	
	1		■

Note: the black square shows the dip-switch position.

5 Special applications

Overvoltage threshold

According to the load characteristics, it is possible to set the voltage range outside which the N-Line supply cannot be accepted and switching to the E-Line is necessary.

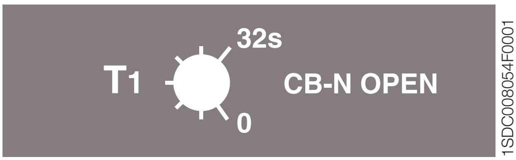


Transfer switch delay configuration

Transfer switch delays can be set through special trimmers. Setting times and relevant purposes are reported below:

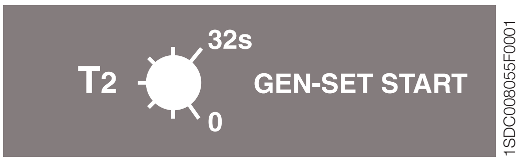
T1 = 0 ÷ 32 s CB-N open

Delay time from net anomaly detection to N-Line CB opening. It is used to avoid transfer switching in case of short voltage dips.



T2 = 0 ÷ 32 s GEN-SET START

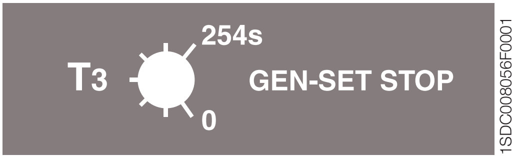
Delay time from net anomaly detection to Gen set start command. It is used to prevent from transfer switching in case of short voltage dips.



5 Special applications

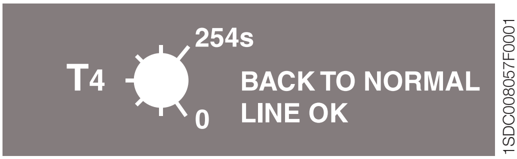
T3= 0 ÷ 254 s GEN-SET STOP

Delay time from N-Line return to Gen set stop command. It is used when the Generator needs a cooling time after the disconnection of the load (opening of the E-Line circuit-breaker).



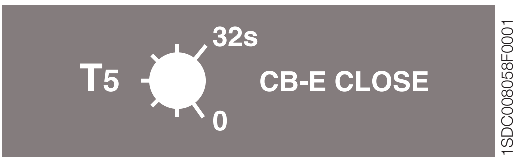
T4= 0 ÷ 254 s BACK TO NORMAL LINE OK

Delay time necessary for N-Line voltage to establish, before inverse switching procedure is started.



T5 = 0 ÷ 32 s CB-E CLOSE

Delay time to allow the gen-set voltage to stabilize: after starting the generator and detecting a voltage on the emergency line, the ATS010 unit waits for a time T5 before considering this voltage stable.
In Strategy 1, after detecting the gen-set voltage, the ATS010 unit waits for time T5 before closing CB-E.
In strategy 2, the ATS010 unit cannot open or close the breakers unless there is a stable voltage source. Therefore, the unit waits for a time T5 before opening CB-N. If, however, a time delay T1 since voltage loss has not elapsed, the ATS010 unit waits until T1 has elapsed, and only then opens CB-N.



5 Special applications

Check on the plant and on the circuit-breakers

ATS010 can be used in plants with the following characteristics:
- the Gen set shall function independently (“island” condition);
- rated voltage and frequency of the plants are included within the given ranges;
- ATS010 supply is guaranteed even if N-Line and E-Line voltages are missing.

The two circuit-breakers controlled by ATS are to be:
- mechanically interlocked;
- of the prescribed type and size;
- equipped with the prescribed accessories.

References Standards

EN 50178 (1997): ”Electronic equipment for use in power installations”
Compliance with “Low Voltage Directive” (LVD) no. 73/23/EEC and “Electromagnetic Compatibility Directive” (EMC) no. 89/336/EEC.
Electromagnetic compatibility: EN 50081-2, EN 50082-2
Environmental conditions: IEC 60068-2-1, IEC 60068-2-2, IEC 60068-2-3.

ATS010 - main technical characteristics

Rated power supply voltage (galvanically isolated from the ground)	24 Vdc ± 20% 48 Vdc ± 10% (maximum ripple ± 5%)
Maximum power consumption	5 W @ 24 Vdc 10 W @ 48 Vdc
Rated power (N-Line voltage present and CBs not operated)	1,8 W @ 24 Vdc 4,5 W @ 48 Vdc
Operating temperature	-25 °C…+70 °C
Maximum humidity	90 % without condensation
Storing temperature	-20 °C…..+80 °C
Degree of protection	IP54 (front panel)
Dimensions (H x W x D)	144 x 144 x 85
Weight [kg]	0,8

Normal line voltage sensor

Normal line rated voltage	100…500 Vac with direct connection Over 500 Vac with external voltage transformers
Rated frequency	50 Hz / 60 Hz
Impulse withstand voltage on L1, L2, L3 inputs	6 kV

Motor operators - shunt opening/closing releases

Tmax T4-T5 Isomax S6-S7	Up to 250 Vac From 48 Vdc to 110 Vdc
Emax	Up to 250 Vac From 24 Vdc to 110 Vdc

6 Switchboards

6.1 Electrical switchboards

The switchboard is a combination of one or more low voltage switching, protection and other devices assembled in one or more enclosure so as to satisfy the requirements regarding safety and to allow the functions for which it was designed to be carried out.
A switchboard consists of a container, termed enclosure by the relevant Standards (which has the function of support and mechanical protection of the components contained within), and the electrical equipment, which consists of devices, internal connections and input and output terminals for connection with the system.

The reference Standard is IEC 60439-1 published in 1999, titled "Low-voltage switchgear and controlgear assemblies - Part 1: Type-tested and partially type-tested assemblies", approved by CENELEC code number EN 60439-1.

Supplementary calculation guides are:

IEC 60890 "A method of temperature-rise assessment by extrapolation for partially type-tested assemblies (PTTA) of low-voltage switchgear and controlgear".

IEC 61117 "A method for assessing the short-circuit withstand strength of partially type-tested assemblies (PTTA)".

IEC 60865-1 "Short-circuit currents - Calculation of effects - Part 1: Definitions and calculation methods".

Standard IEC 60439-1 sets out the requirements relating to the construction, safety and maintainability of electrical switchboards, and identifies the nominal characteristics, the operational environmental conditions, the mechanical and electrical requirements and the performance regulations.
The type-tests and individual tests are defined, as well as the method of their execution and the criteria necessary for the evaluation of the results.

Standard IEC 60439-1 distinguishes between the two types of switchboard: TTA (type-tested assemblies) and PTTA (partially type-tested assemblies).
By "type-tested assemblies" (TTA), it is meant a low voltage switchgear and controlgear assemblies conforming to an established type or system without deviations likely to significantly influence the performance from the typical assembly verified to be in accordance with the Standard prescriptions.
TTA switchboards are assemblies derived directly from a prototype designed in all details and subjected to type-tests; as the type-tests are very complex, switchboards designed by a manufacturer with a sound technical and financial basis are referred to. Nevertheless, TTA assemblies can be mounted by a panel builder or installer who follows the manufacturer's instructions; deviations from the prototype are only allowed if they do not significantly change the performance compared with the type-tested equipment.

6 Switchboards

By “partially type-tested assemblies” (PTTA), it is meant a low voltage and controlgear assembly, tested only with a part of the type-tests; some tests may be substituted by extrapolation which are calculations based on experimental results obtained from assemblies which have passed the type-tests. Verifications through simplified measurements or calculations, allowed as an alternative to type tests, concern heating, short circuit withstand and insulation.

Standard IEC 60439-1 states that some steps of assembly may take place outside the factory of the manufacturer, provided the assembly is performed in accordance with the manufacturer’s instructions.
The installer may use commercial assembly kits to realize a suitable switchboard configuration.
The same Standard specifies a division of responsibility between the manufacturer and the assembler in Table 7: “List of verifications and tests to be performed on TTA and PTTA” in which the type-tests and individual tests to be carried out on the assembly are detailed.
The type-tests verify the compliance of the prototype with the requirements of the Standard, and are generally under the responsibility of the manufacturer, who must also supply instructions for the production and assembly of the switchboard. The assembler has responsibility for the selection and assembly of components in accordance with the instructions supplied and must confirm compliance with the Standards through the previously stated checks in the case of switchboards that deviate from a tested prototype. Routine tests must also be carried out on every example produced.

The distinction between TTA and PTTA switchgear and controlgear assemblies has no relevance to the declaration of conformity with Standard IEC 60439-1, in so far as the switchboard must comply with this Standard.

6 Switchboards

List of verifications and tests to be performed on TTA and PTTA

No.	Characteristics to be checked	Sub-clauses	TTA	PTTA
1	Temperature-rise limits	8.2.1	Verification of temperature-rise limits by test (type test)	Verification of temperature-rise limits by test or extrapolation
2	Dielectric properties	8.2.2	Verification of dielectric properties by test (type test)	Verification of dielectric properties by test according to 8.2.2 or 8.3.2, or verification of insulation resistance according to 8.3.4 (see No. 9 and 11)
3	Short-circuit withstand strength	8.2.3	Verification of the short-circuit withstand strength by test (type test)	Verification of the short-circuit withstand strength by test or by extrapolation from similar type-tested arrangements
4	Effectiveness of the protective circuit	8.2.4		
	Effective connection between the exposed conductive parts of the ASSEMBLY and the protective circuit	8.2.4.1	Verification of the effective connection between the exposed conductive parts of the ASSEMBLY and the protective circuit by inspection or by resistance measurement (type test)	Verification of the effective connection between the exposed conductive parts of the ASSEMBLY and the protective circuit by inspection or by resistance measurement
	Short-circuit withstand strength of the protective circuit	8.2.4.2	Verification of the short-circuit withstand strength of the protective circuit by test (type test)	Verification of the short-circuit withstand strength of the protective circuit by test or appropriate design and arrangement of the protective conductor (see 7.4.3.1.1, last paragraph)
5	Clearances and creepage distances	8.2.5	Verification of the clearances and creepage distances (type test)	Verification of clearances and creepage distances
6	Mechanical operation	8.2.6	Verification of mechanical operation (type test)	Verification of mechanical operation
7	Degree of protection	8.2.7	Verification of the degree of protection (type test)	Verification of the degree of protection
8	Wiring, electrical operation	8.3.1	Inspection of the ASSEMBLY including inspection of wiring and, if necessary, electrical operation test (routine test)	Inspection of the ASSEMBLY including inspection of wiring and, if necessary, electrical operation test
9	Insulation	8.3.2	Dielectric test (routine test)	Dielectric test or verification of insulation resistance according to 8.3.4 (see No. 2 and 11)
10	Protective measures	8.3.3	Checking of protective measures and of the electrical continuity of the protective circuits (routine test)	Checking of protective measures
10	Insulation resistance	8.3.4		Verification of insulation resistance unless test according to 8.2.2 or 8.3.2 has been made (see No. 2 and 9)

6 Switchboards

Degrees of protection

The degree of protection IP indicates a level of protection provided by the assembly against access to or contact with live parts, against ingress of solid foreign bodies and against the ingress of liquid. The IP code is the system used for the identification of the degree of protection, in compliance with the requirements of Standard IEC 60529. Unless otherwise specified by the manufacturer, the degree of protection applies to the complete switchboard, assembled and installed for normal use (with door closed).
The manufacturer shall also state the degree of protection applicable to particular configurations which may arise in service, such as the degree of protection with the door open or with devices removed or withdrawn.

Elements ofthe IP Code and their meanings

Element	Numerials or letters	Meaning for the protection of equipment	Meaning for the protection of persons	Ref.
Code letters	**IP**			
First characteristic numeral		Against ingress of the solid foreign objects	Against access to hazardous parts with	Cl.5
	0	(non-protected)	(non-protected)	
	1	≥ 50 mm diameter	back of hand	
	2	≥ 12.5 mm diameter	finger	
	3	≥ 2.5 mm diameter	tool	
	4	≥ 1.0 mm diameter	wire	
	5	dust-protected	wire	
	6	dust-tight	wire	
Second characteristic numeral		Against ingress of water with harmful effects		Cl.6
	0	(non-protected)		
	1	vertically dripping		
	2	dripping (15° tilted)		
	3	spraying		
	4	splashing		
	5	jetting		
	6	powerful jetting		
	7	temporary immersion		
	8	continuous immersion		
Additional letter (optional)			Against access to hazardous parts with	Cl.7
	A		back of hand	
	B		finger	
	C		tool	
	D		wire	
Supplementary letter (optional		Supplemetary information specific to:		Cl.8
	A	Hight voltage apparatus		
	B	Motion during water test		
	C	Stationary during water test		
	D	Weather conditions		

6 Switchboards

Form of separation and classification of switchboards

Forms of internal separation

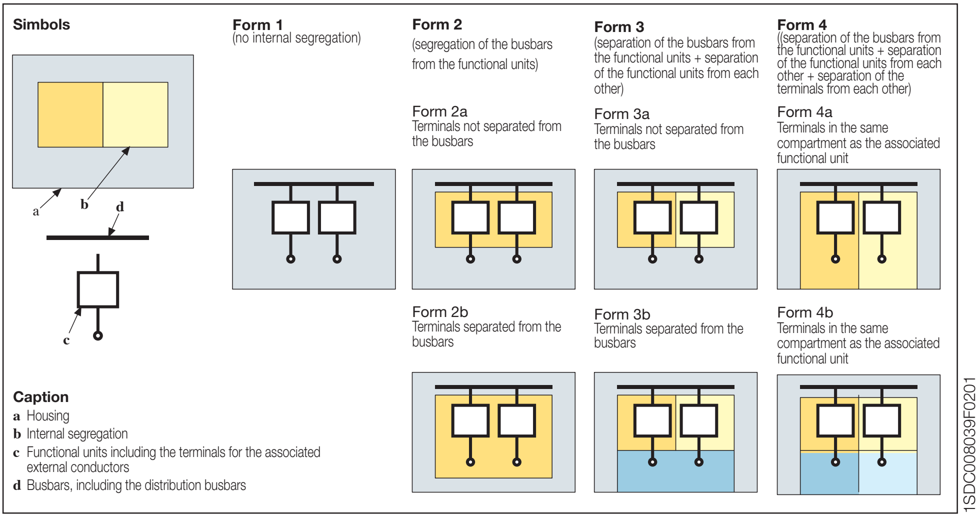
By form of separation it is meant the type of subdivision provided within the switchboard. Separation by means of barriers or partitions (metallic or insulating) may have the function to:

- provide protection against direct contact (at least IPXXB) in the case of access to a part of the switchboard which is not live, with respect to the rest of the switchboard which remains live;
- reduce the risk of starting or propagating an internal arc;
- impede the passage of solid bodies between different parts of the switchboard (degree of protection of at least IP2X).

A partition is a separation element between two parts, while a barrier protects the operator from direct contact and from arcing effects from any interruption devices in the normal access direction.
The following table from Standard IEC 60439-1 highlights typical forms of separation which can be obtained using barriers or partitions:

Main criteria	Subcriteria	Form
No separation		Form 1
Separation of busbars from the functional units	Terminals for external conductors not separated from busbars	Form 2a
	Terminals for external conductors separated from busbars	Form 2b
Separation of busbars from the functional units and separation of all functional units from one another. Separation of the terminals for external conductors from the functional units, but not from each other	Terminals for external conductors not separated from busbars	Form 3a
	Terminals for external conductors separated from busbars	Form 3b
Separation of busbars from the functional units and separation of all functional units from one another, including the terminals for external conductors which are an integral part of the functional unit	Terminals for external conductors in the same compartment as the associated functional unit	Form 4a
	Terminals for external conductors not in the same compartment as the associated functional unit, but in individual, separate, enclosed protected spaces or compartments	Form 4b

6 Switchboards



Classification

Different classifications of electrical switchboard exist, depending on a range of factors.

Based on construction type, Standard IEC 60439-1 firstly distinguishes between open and enclosed assemblies.
A switchboard is enclosed when it comprises protective panels on all sides, providing a degree of protection against direct contact of at least IPXXB. Switchboards used in normal environments must be enclosed.

Open switchboards, with or without front covering, which have the live parts accessible. These switchboards may only be used in electrical plants.

With regard to external design, switchboards are divided into the following categories:

- **Cubicle-type assembly**
  Used for large scale control and distribution equipment; multi-cubicle-type assembly can be obtained by placing cubicles side by side.

6 Switchboards

- **Desk-type assembly**
  Used for the control of machinery or complex systems in the mechanical, iron and steel, and chemical industries.

- **Box-type assembly**
  Characterized by wall mounting, either mounted on a wall or flush-fitting; these switchboards are generally used for distribution at department or zone level in industrial environments and in the tertiary sector.

- **Multi-box-type assembly**
  Each box, generally protected and flanged, contains a functional unit which may be an automatic circuit-breaker, a starter, a socket complete with locking switch or circuit-breaker.

With regard to the intended function, switchboards may be divided into the following types:

- **Main distribution boards**
  Main distribution boards are generally installed immediately downstream of MV/LV transformers, or of generators; they are also termed power centres. Main distribution boards comprise one or more incoming units, busbar connectors, and a relatively smaller number of output units.

- **Secondary distribution boards**
  Secondary distribution boards include a wide range of switchboards for the distribution of power, and are equipped with a single input unit and numerous output units.

- **Motor operation boards**
  Motor control boards are designed for the control and centralised protection of motors: therefore they comprise the relative coordinated devices for operation and protection, and auxiliary control and signalling devices.

- **Control, measurement and protection boards**
  Control, measurement and protection boards generally consist of desks containing mainly equipment for the control, monitoring and measurement of industrial processes and systems.

- **Machine-side boards**
  Machine-side boards are functionally similar to the above; their role is to provide an interface between the machine with the power supply and the operator.

- **Assemblies for construction sites (ASC)**
  Assemblies for construction sites may be of different sizes, from a simple plug and socket assembly to true distribution boards with enclosures of metal or insulating material. They are generally mobile or, in any case, transportable.

6 Switchboards

Method of temperature rise assessment by extrapolation for partially tested assemblies (PTTA)

For PTTA assemblies, the temperature rise can be determined by laboratory tests or calculations, which can be carried out in accordance with Standard IEC 60890. The formulae and coefficients given in this Standard are deduced from measurements taken from numerous switchboards, and the validity of the method has been checked by comparison with the test results.
This method does not cover the whole range of low voltage switchgear and controlgear assemblies since it has been developed under precise hypotheses which limit the applications; this can however be correct, suited and integrated with other calculation procedures which can be demonstrated to have a technical basis.
Standard IEC 60890 serves to determine the temperature rise of the air inside the switchboard caused by the energy dissipated by the devices and conductors installed within the switchboard.
To calculate the temperature rise of the air inside an enclosure, once the requirements of the Standard have been met, the following must be considered:

- Dimensions of the enclosure.
- Type of installation:
  - enclosure open to air on all sides;
  - wall-mounted enclosure;
  - enclosure designed for mounting in extremities;
  - enclosure in an internal position in a multi-compartment switchboard;
- Any ventilation openings, and their dimensions.
- Number of horizontal internal separators;
- Power losses from the effective current flowing through any device and conductor installed within the switchboard or compartment.

The Standard allows the calculation of temperature rise of the air at mid-height and at the highest point of the switchboard. Once the values are calculated, it must be evaluated if the switchboard can comply with the requirements relating to the set limits at certain points within the same switchboard.
The Annex B explains the calculation method described in the Standard.
ABB supplies the client with calculation software which allows the temperature rise inside the switchboard to be calculated quickly.

6 Switchboards

6.2 MNS switchboards

MNS systems are suitable for applications in all fields concerning the generation, distribution and use of electrical energy; e. g., they can be used as:
- main and sub-distribution boards;
- motor power supply of MCCs (Motor Control Centres);
- automation switchboards.

The MNS system is a framework construction with maintenance-free bolted connections which can be equipped as required with standardized components and can be adapted to any application. The consistent application of the modular principle both in electrical and mechanical design permits optional selection of the structural design, interior arrangement and degree of protection according to the operating and environmental conditions.

The design and material used for the MNS system largely prevent the occurrence of electric arcs, or provide for arc extinguishing within a short time. The MNS System complies with the requirements laid down in VDE0660 Part 500 as well as IEC 61641 and has furthermore been subjected to extensive accidental arc tests by an independent institute.

The MNS system offers the user many alternative solutions and notable advantages in comparison with conventional-type installations:
- compact, space-saving design;
- back-to-back arrangement;
- optimized energy distribution in the cubicles;
- easy project and detail engineering through standardized components;
- comprehensive range of standardized modules;
- various design levels depending on operating and environmental conditions;
- easy combination of the different equipment systems, such as fixed and withdrawable modules in a single cubicle;
- possibility of arc-proof design (standard design with fixed module design);
- possibility of earthquake-, vibration- and shock-proof design;
- easy assembly without special tools;
- easy conversion and retrofit;
- largely maintenance-free;
- high operational reliability;
- high safety for human beings.

The basic elements of the frame are C-sections with holes at 25 mm intervals in compliance with Standard DIN 43660. All frame parts are secured maintenance-free with tapping screws or ESLOK screws. Based on the basic grid size of 25 mm, frames can be constructed for the various cubicle types without any special tools. Single or multi-cubicle switchgear assemblies for front or front and rear operations are possible.
Different designs are available, depending on the enclosure required:
- single equipment compartment door;
- double equipment compartment door;
- equipment and cable compartment door;
- module doors and/or withdrawable module covers and cable compartment door.

The bottom side of the cubicle can be provided with floor plates. With the aid of flanged plates, cable ducts can be provided to suit all requirements. Doors and cladding can be provided with one or more ventilation opening, roof plates can be provided with metallic grid (IP 30 – IP40) or with ventilation chimney (IP 40, 41, 42).

6 Switchboards

Depending on the requirements, a frame structure can be subdivided into the following compartments (functional areas):
- equipment compartment;
- busbar compartment;
- cable compartment.

The equipment compartment holds the equipment modules, the busbar compartment contains the busbars and distribution bars, the cable compartment houses the incoming and outgoing cables (optionally from above and from below) with the wiring required for connecting the modules as well as the supporting devices (cable mounting rails, cable connection parts, parallel connections, wiring ducts, etc.). The functional compartments of a cubicle as well as the cubicles themselves can be separated by partitions. Horizontal partitions with or without ventilation openings can also be inserted between the compartments.
All incoming/outgoing feeder and bus coupler cubicles include one switching device. These devices can be fixed-mounted switch disconnectors, fixed-mounted or withdrawable air or moulded-case circuit-breakers.
This type of cubicles is subdivided into equipment and busbar compartments; their size (H x W) is 2200 mm x 400 mm / 1200 mm x 600 mm, and the depth depends on the dimensions of the switchgear used.
Cubicles with air circuit-breakers up to 2000 A can be built in the reduced dimensioned version (W = 400 mm).
It is possible to interconnect cubicles to form optimal delivery units with a maximum width of 3000 mm.

6.3 ArTu distribution switchboards

The range of ABB SACE ArTu distribution switchboards provides a complete and integrated offer of switchboards and kit systems for constructing primary and secondary low voltage distribution switchboards.
With a single range of accessories and starting from simple assembly kits, the ArTu switchboards make it possible to assembly a wide range of configurations mounting modular, moulded-case and air circuit-breakers, with any internal separation up to Form 4.
ABB SACE offers a series of standardized kits, consisting of pre-drilled plates and panels for the installation of the whole range of circuit-breakers type System pro M, Isomax, Tmax and Emax E1, E2, E3, E4 without the need of additional drilling operations or adaptations.
Special consideration has been given to cabling requirements, providing special seats to fix the plastic cabling duct horizontally and vertically.
Standardization of the components is extended to internal separation of the switchboard: in ArTu switchboards, separation is easily carried out and it does not require either construction of “made-to-measure” switchboards or any additional sheet cutting, bending or drilling work.

ArTu switchboards are characterized by the following features:
- integrated range of modular metalwork structures up to 4000 A with common accessories;
- possibility of fulfilling all application requirements in terms of installation (wall-mounting, floor-mounting, monoblock and cabinet kits) and degree of protection (IP31, IP41, IP43, IP65);
- structure made of hot-galvanized sheet;

6 Switchboards

- maximum integration with modular devices and ABB SACE moulded-case and air circuit-breakers;
- minimum switchboard assembly times thanks to the simplicity of the kits, the standardization of the small assembly items, the self-supporting elements and the presence of clear reference points for assembly of the plates and panels;
- separations in kits up to Form 4.

The range of ArTu switchboards includes four versions, which can be equipped with the same accessories.

ArTu L series

ArTu L series consists of a range of modular switchboard kits, with a capacity of 24 modules per row and degree of protection IP31 (without door) or IP43 (basic version with door). These switchboards can be wall- or floor-mounted:
- wall-mounted ArTu L series, with heights of 600, 800, 1000 and 1200 mm, depth 200 mm, width 700 mm. Both System pro M modular devices and moulded-case circuit-breakers Tmax T1-T2-T3 are housed inside this switchboard series;
- floor-mounted ArTu L series, with heights of 1400, 1600, 1800 and 2000 mm, depth 240 mm, width 700 mm. System pro M modular devices, moulded-case circuit-breakers type Tmax T1-T2-T3-T4-T5 and Isomax S6 800A (fixed version with front terminals) are housed inside this switchboard series.

ArTu M series

ArTu M series consists of a modular range of monoblock switchboards for wall-mounted (with depths of 150 and 200 mm with IP65 degree of protection) or floor-mounted (with depth of 250 mm and IP31 or IP65 degrees of protection) installations, in which it is possible to mount System pro M modular devices and Tmax T1-T2-T3 moulded-case circuit-breakers on a DIN rail ArTu M series of floor-mounted switchboards can be equipped with Tmax series and Isomax S6 800A circuit-breakers.

ArTu K series

ArTu K series consists of a range of modular switchboard kits for floor-mounted installation with four different depths (250, 350, 600, 800 and 1000 mm) and with degree of protection IP31 (without front door), IP41 (with front door and ventilated side panels) or IP65 (with front door and blind side panels), in which it is possible to mount System pro M modular devices, the whole range of moulded-case circuit–breakers Tmax and Isomax, and Emax circuit-breakers E1, E2, E3 and E4.
ArTu switchboards have three functional widths:
- 400 mm, for the installation of moulded-case circuit-breakers up to 630 A (T5);
- 600 mm, which is the basic dimension for the installation of all the apparatus;
- 800 mm, for the creation of the side cable container within the structure of the floor-mounted switchboard or for the use of panels with the same width.

The available internal space varies in height from 600 mm (wall-mounted L series) to 2000 mm (floor-mounted M series and K series), thus offering a possible solution for the most varied application requirements.

6 Switchboards

ArTu PB Series (Panelboard and Pan Assembly)

The ArTu line is now upgraded with the new ArTu PB Panelboard solution.
The ArTu PB Panelboard is suitable for distribution applications with an incomer up to 800A and outgoing feeders up to 250A.
The ArTu PB Panelboard is extremely sturdy thanks to its new designed framework and it is available both in the wall-mounted version as well as in the floor-mounted one.
ArTu PB Panelboard customisation is extremely flexible due to the smart design based on configurations of 6, 12 and 18 outgoing ways and to the new ABB plug-in system that allows easy and fast connections for all T1 and T3 versions.
Upon request, extension boxes are available on all sides of the structure, for metering purposes too.
The vertical trunking system is running behind the MCCB's layer allowing easy access to every accessory wiring (SR's, UV's, AUX contacts).
The ArTu PB Panelboard, supplied as a standard with a blind door, is available with a glazed one as well.

Annex A: Protection against short-circuit effects inside low-voltage switchboards

The Std. IEC 60439-1 specifies that ASSEMBLIES (referred to hereafter as switchboards) shall be constructed so as to be capable of withstanding the thermal and dynamic stresses resulting from short-circuit currents up to the rated values.
Furthermore, switchboards shall be protected against short-circuit currents by means of circuit-breakers, fuses or a combination of both, which may either be incorporated in the switchboard or arranged upstream.
When ordering a switchboard, the user shall specify the short-circuit conditions at the point of installation.

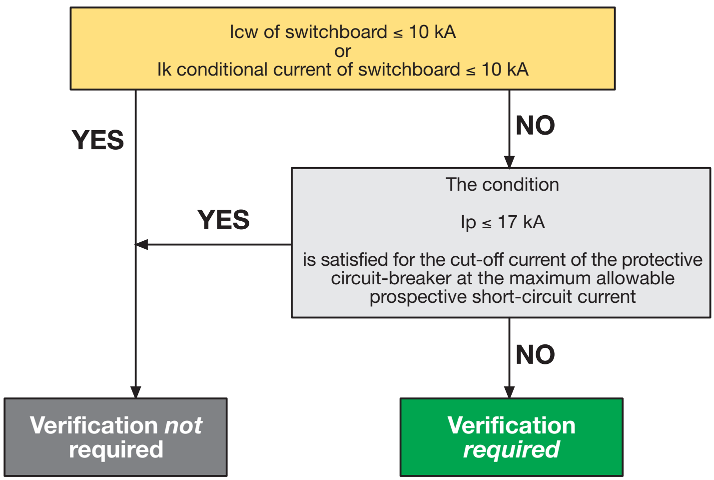
This chapter takes into consideration the following aspects:
- **The need, or not, to carry out a verification of the short-circuit withstand strength of the switchboard.**
- **The suitability of a switchboard for a plant as a function of the prospective short-circuit current of the plant and of the short-circuit parameters of the switchboard.**
- **The suitability of a busbar system as a function of the short-circuit current and of the protective devices.**

Annex A: Protection against short-circuit effects inside low-voltage switchboards

Verification of short-circuit withstand strength

The verification of the short-circuit withstand strength is dealt with in the Standard IEC 60439-1, where, in particular, the cases requiring this verification and the different types of verification are specified.
The verification of the short-circuit withstand strength is not required if the following conditions are fulfilled:
- For switchboards having a rated short-time current (Icw) or rated conditional current (Ik) not exceeding 10 kA.
- For switchboards protected by current limiting devices having a cut-off current not exceeding 17 kA at the maximum allowable prospective short-circuit current at the terminals of the incoming circuit of the switchboard.
- For auxiliary circuits of switchboards intended to be connected to transformers whose rated power does not exceed 10 kVA for a rated secondary voltage of not less than 110 V, or 1.6 kVA for a rated secondary voltage less than 110 V, and whose short-circuit impedance is not less than 4%.
- For all the parts of switchboards (busbars, busbar supports, connections to busbars, incoming and outgoing units, switching and protective devices, etc.) which have already been subjected to type tests valid for conditions in the switchboard.

Therefore, from an engineering point of view, the need to verify of the short-circuit withstand strength may be viewed as follows:



As regards the details of the test performance, reference shall be made directly to the Standard IEC 60439-1.

Annex A: Protection against short-circuit effects inside low-voltage switchboards

Short-circuit current and suitability of the switchboard for the plant

The verification of the short-circuit withstand strength is based on two values stated by the manufacturer in alternative to each other:
- the rated short-time current Icw
- the rated conditional short-circuit current Ik
Based on one of these two values, it is possible to determine whether the switchboard is suitable to be installed in a particular point of the system.

It shall be necessary to verify that the breaking capacities of the apparatus inside the switchboard are compatible with the short-circuit values of the system.

The rated short-time withstand current Icw is a predefined r.m.s. value of test current, to which a determined peak value applied to the test circuit of the switchboard for a specified time (usually 1s) corresponds. The switchboard shall be able to withstand the thermal and electro-dynamical stresses without damages or deformations which could compromise the operation of the system. From this test (if passed) it is possible to obtain the specific let-through energy (I^2t) which can be carried by the switchboard:

$$I^2t = Icw^2t$$

The test shall be carried out at a power factor value specified below in the Table 4 of the Std. IEC 60439-1. A factor "n" corresponding at this cosφ value allows to determine the peak value of the short-circuit current withstood by the switchboard through the following formula:

$$Ip = Icw \cdot n$$

Table 4

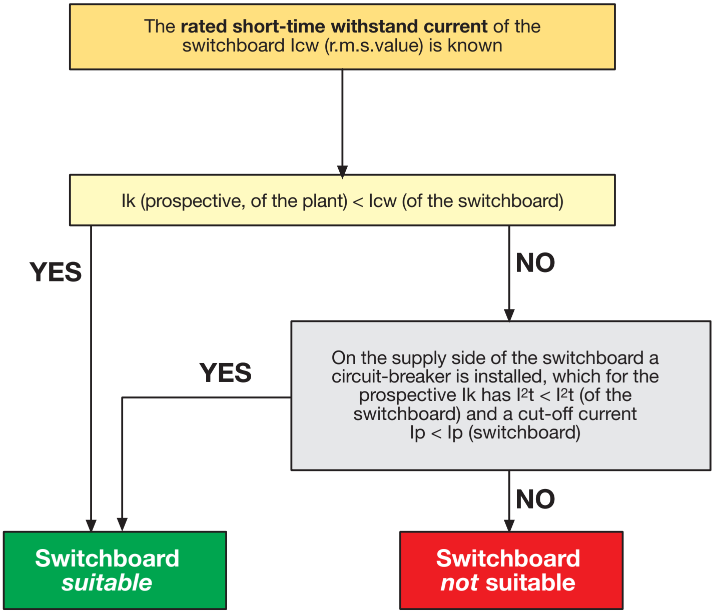
r.m.s. value of short-circuit current	power factor cosφ	n
I ≤ 5 kA	0.7	1.5
5<I ≤ 10 kA	0.5	1.7
10<I ≤ 20 kA	0.3	2
20<I ≤ 50 kA	0.25	2.1
50<I	0.2	2.2

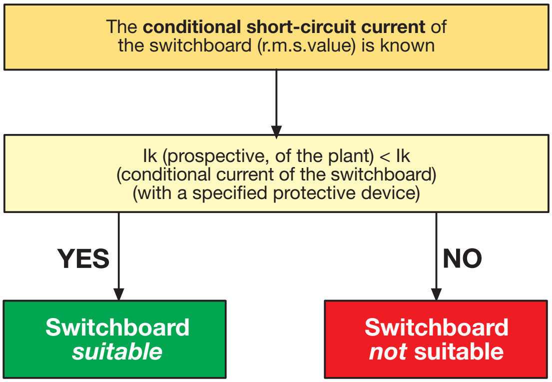
The values of this table represent the majority of applications. In special locations, for example in the vicinity of transformers or generators, lower values of power factor may be found, whereby the maximum prospective peak current may become the limiting value instead of the r.m.s. value of the short-circuit current.

The conditional short-circuit current is a predetermined r.m.s. value of test current to which a defined peak value corresponds and which can be withstand by the switchboard during the operating time of a specified protective device. This devices is usually the main circuit-breaker of the switchboard.

By comparing the two values Icw and Ip with the prospective short-circuit current of the plant, it is possible to establish whether the switchboard is suitable to be installed at a specified point of the system.
The following diagrams show the method to determine the compatibility of the switchboard with the plant.

Annex A: Protection against short-circuit effects inside low-voltage switchboards





The breaking capacities of the apparatus inside the switchboard shall be verified to be compatible with the short-circuit values of the plant.

Annex A: Protection against short-circuit effects inside low-voltage switchboards

Example

Plant data: Rated voltage Ur=400 V
Rated frequency fr=50Hz
Short-circuit current Ik=35kA

Assume that in an existing system there is a switchboard with Icw equal to 35kA and that, at the installation point of the switchboard, the prospective short-circuit current is equal to 35kA.

Now assume that an increase in the power supply of a plant is decided and that the short-circuit value rises to 60 kA.
Plant data after the increase: Rated voltage Ur=400 V
Rated frequency fr=50Hz
Short-circuit current Ik=60kA

Since the Icw of the switchboard is lower than the short-circuit current of the system, in order to verify that the actual switchboard is still compatible, it is necessary to:
- determine the I^2t and Ip values let-through by the circuit-breaker on the supply side of the switchboard
- verify that the protective devices installed inside the switchboard have a sufficient breaking capacity (separately or in back-up)

Icw = 35kA from which:
$I^2t_{switchboard} = 35^2x1 = 1225\ MA^2s$
$Ip_{switchboard}$ = 73.5 kA (according to Table 4)

Assuming that on the supply side of the switchboard a circuit-breaker type Tmax T5H **(Icu=70kA@415V)** is installed
$I^2t_{CB} < 4MA^2s$
$Ip_{CB} < 40kA$

since
$I^2t_{switchboard} > I^2t_{CB}$
$Ip_{switchboard} > Ip_{CB}$

it results that the switchboard (structure and busbar system) is suitable.

Assume that the circuit-breakers installed inside the switchboard are circuit-breakers type T1, T2 and T3 version N with **Icu=36kA@415V**. From the back-up tables (see Chapter 4.3), it results that the circuit-breakers inside the switchboard are suitable for the plant, since their breaking capacity is increased to 65 kA thanks to the circuit-breaker type T5H on the supply side.

Annex A: Protection against short-circuit effects inside low-voltage switchboards

Selection of the distribution system in relation to short-circuit withstand strength

The dimensioning of the distribution system of the switchboard is obtained by taking into consideration the rated current flowing through it and the prospective short-circuit current of the plant.
The manufacturer usually provides tables which allow the choice of the busbar cross-section as a function of the rated current and give the mounting distances of the busbar supports to ensure the short-circuit withstand strength.

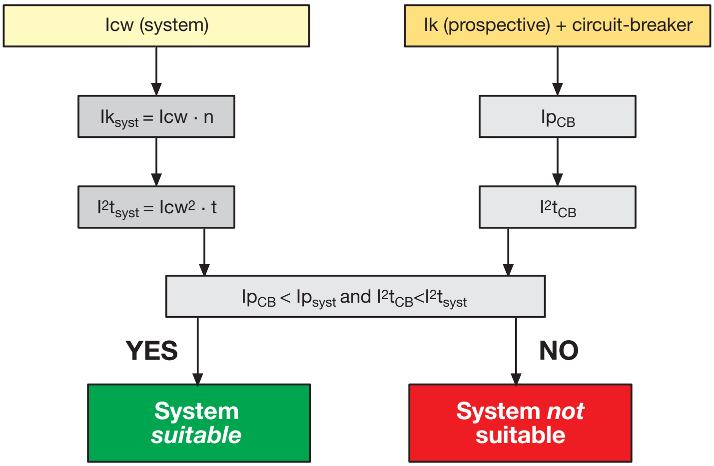
To select a distribution system compatible with the short-circuit data of the plant, one of these procedures shall be followed:

- **If the protective device on the supply side of the distribution system is known**

  From the Icw value of the distribution system it results:

  $Ik_{syst} = Icw \cdot n$ where n is the factor deduced from the Table 4
  $I^2t_{syst} = Icw^2 \cdot t$ where t is equal to 1 s

  In correspondence with the prospective short-circuit current value of the plant the following values can be determined:
  the cut-off current of the circuit-breaker Ip_{CB}
  the specific let-through energy of the circuit-breaker I^2t_{CB}
  If $Ip_{CB} < Ip_{syst}$ and $I^2t_{CB} < I^2t_{syst}$, then the distribution system is suitable.



- **If the protective device on the supply side of the distribution system is not known**

  The following condition must be fulfilled:

  Ik (prospective) < Icw (system)

Annex A: Protection against short-circuit effects inside low-voltage switchboards

Example

Plant data: Rated voltage U_r=400 V
Rated frequency f_r=50Hz
Short-circuit current I_k=65kA

By considering the need of using a system of 400 A busbars with shaped form, in the ABB SACE catalogue "ArTu distribution switchboards" the following choice is possible:
BA0400 In=400 A (IP65) Icw=35kA.

By assuming to have on the supply side of the busbar system a moulded-case circuit-breaker type

ABB SACE Tmax T5400 In400

from the Icw of the busbar system, it derives:

$I_{p\ syst} = I_{cw} \cdot n = 35 \cdot 2.1 = 73.5$ [kA]
$I^2t_{\ syst} = I_{cw}^2 \cdot t = 35^2 \cdot 1 = 1225$ [(kA)^2 s]

From the curves
- at page 118
  Ik 65kA corresponds at about I_{pCB}=35 kA

- at page 144
  Ik 65kA corresponds at about I^2t_{CB}=4 [(kA)^{2}s]= 4 [MA^{2}sec]

Thus, since
$I_{pCB} < I_{psyst}$
and
$I^2t_{CB} < I^2t_{syst}$
it results that the busbar system is compatible with the switchboard.

Annex A: Protection against short-circuit effects inside low-voltage switchboards

Selection of conductors on the supply side of the protective devices

The Standard IEC 60439-1 prescribes that in a switchboard, the active conductors (distribution busbars included) positioned between the main busbars and the supply side of the single functional units, as well as the constructional components of these units, can be dimensioned according to the reduced short-circuit stresses which occur on the load side of the short-circuit protective device of the unit.

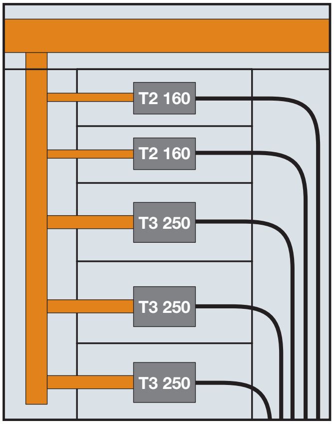
This may be possible if the conductors are installed in such a way throughout the switchboard that, under normal operating conditions, an internal short-circuit between phases and/or between phase and earth is only a remote possibility. It is advisable that such conductors are of solid rigid manufacture.
As an example, this Standard gives conductor types and installation requirements which allow to consider a short-circuit between phases and/or between phase and earth only a remote possibility.

<table>
<tr><th>Type of conductor</th><th>Requirements</th></tr>
<tr><td>Bare conductors or single-core conductors with basic insulation, for example cables according to IEC 60227-3.</td><td>Mutual contact or contact with conductive parts shall be avoided, for example by use of spacers.</td></tr>
<tr><td>Single-core conductors with basic insulation and a maximum permissible conductor-operating temperature above 90°C, for example cables according to IEC 60245-3, or heat-resistant PVC insulated cables according to IEC 60227-3.</td><td>Mutual contact or contact with conductive parts is permitted where there is no applied external pressure. Contact with sharp edges must be avoided. There must be no risk of mechanical damage.
These conductors may only be loaded such that an operating temperature of 70°C is not exceeded.</td></tr>
<tr><td>Conductors with basic insulation, for example cables according to IEC 60227-3, having additional secondary insulation, for example individually covered cables with shrink sleeving or individually run cables in plastic conduits.</td><td rowspan="3">No additional requirements if there is no risk of mechanical damage.</td></tr>
<tr><td>Conductors insulated with a very high mechanical strength material, for example FTFE insulation, or double-insulated conductors with an enhanced outer sheath rated for use up to 3 kV, for example cables according to IEC 60502.</td></tr>
<tr><td>Single or multi-core sheathed cables, for example cables according to IEC 60245-4 or 60227-4.</td></tr>
</table>

Under these conditions or if anyway the integral short-circuit may be considered a remote possibility, the above described procedure shall be used to verify the suitability of the distribution system to the short-circuit conditions, when these are determined as a function of the characteristics of the circuit-breakers on the load side of the busbars.

Annex A: Protection against short-circuit effects inside low-voltage switchboards

Example



Plant data:
Rated voltage Ur=400 V
Rated frequency fr=50Hz
Short-circuit current Ik=45kA

In the switchboard shown in the figure, the vertical distribution busbars are derived from the main busbars.
These are 800 A busbars with shaped section and with the following characteristics:
In (IP65) = 800 A,
Icw max = 35 kA
Since it is a "rigid" system with spacers, according to the Std. IEC 60439-1 a short-circuit between busbars is a remote possibility.
Anyway, a verification that the stresses reduced by the circuit-breakers on the load side of the system are compatible with the system is required.
Assuming that in the cubicles there are the following circuit-breakers:

ABB SACE T3S250
ABB SACE T2S160

it is necessary to verify that, in the case of a short-circuit on any outgoing conductor, the limitations created by the circuit-breaker are compatible with the busbar system; to comply with this requirement, at the maximum allowable prospective short-circuit current, the circuit-breaker with higher cut-off current and let-through energy must have an adequate current limiting capability for the busbar system.

In this case the circuit-breaker is type ABB SACE T3S250 In250.
The verification shall be carried out as in the previous paragraph:

From the Icw of the busbar system, it derives:

$Ip_{syst} = Icw \cdot n = 35 \cdot 2.1 = 73.5$ [kA]
$I^2t_{syst} = Icw^2 \cdot t = 35^2 \cdot 1 = 1225$ $[(kA)^2 s]$

From the limitation and let-through energy curves
- at page 116
  Ik = 45kA corresponds at about Ip_{CB}=30 kA
- at page 142
  Ik = 45kA corresponds at about $I^2t_{CB}=2$ $[(kA)^2s]$

Thus, since
$Ip_{CB}<Ip_{syst}$
and
$I^2t_{CB}< I^2t_{syst}$

it results that the busbar system is compatible with the switchboard.

Annex B: Temperature rise evaluation according to IEC 60890

The calculation method suggested in the Standard IEC 60890 makes it possible to evaluate the temperature rise inside an assembly (PTTA); this method is applicable only if the following conditions are met:

- there is an approximately even distribution of power losses inside the enclosure;
- the installed equipment is arranged in a way that air circulation is only slightly impeded;
- the equipment installed is designed for direct current or alternating current up to and including 60 Hz with the total of supply currents not exceeding 3150 A;
- conductors carrying high currents and structural parts are arranged in a way that eddy-current losses are negligible;
- for enclosures with ventilating openings, the cross-section of the air outlet openings is at least 1.1 times the cross-section of the air inlet openings;
- there are no more than three horizontal partitions in the PTTA or a section of it;
- where enclosures with external ventilation openings have compartments, the surface of the ventilation openings in each horizontal partition shall be at least 50% of the horizontal cross section of the compartment.

The data necessary for the calculation are:

- dimensions of the enclosure: height, width, depth;
- the type of installation of the enclosure (see Table 8);
- presence of ventilation openings;
- number of internal horizontal partitions;
- the power loss of the equipment installed in the enclosure (see Tables 13 and 14);
- the power loss of the conductors inside the enclosure, equal to the sum of the power loss of every conductor, according to Tables 1, 2 and 3.

For equipment and conductors not fully loaded, it is possible to evaluate the power loss as:

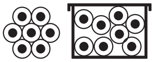
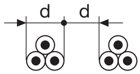
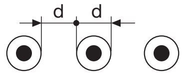
$$P = P_n \left(\frac{I_b}{I_n} \right)^2 \quad (1)$$

where:

P is the actual power loss;
P_n is the rated power loss (at I_r);
I_b is the actual current;
I_n is the rated current.

Annex B: Temperature rise evaluation according to IEC 60890

Table 1: Operating current and power losses of insulated conductors

Cross-section (Cu)	Maximum permissible conductor temperature 70 °C											
	 1)											
	Air temperature inside the enclosure around the conductors											
	35 °C		55 °C		35 °C		55 °C		35 °C		55 °C	
	operating current	power losses 2)	operating current	power losses 2)	operating current	power losses 2)	operating current	power losses 2)	operating current	power losses 2)	operating current	power losses 2)
mm 2	A	W/m	A	W/m	A	W/m	A	W/m	A	W/m	A	W/m
1.5	12	2.1	8	0.9	12	2.1	8	0.9	12	2.1	8	0.9
2.5	17	2.5	11	1.1	20	3.5	12	1.3	20	3.5	12	1.3
4	22	2.6	14	1.1	25	3.4	18	1.8	25	3.4	20	2.2
6	28	2.8	18	1.2	32	3.7	23	1.9	32	3.7	25	2.3
10	38	3.0	25	1.3	48	4.8	31	2.0	50	5.2	32	2.1
16	52	3.7	34	1.6	64	5.6	42	2.4	65	5.8	50	3.4
25					85	6.3	55	2.6	85	6.3	65	3.7
35					104	7.5	67	3.1	115	7.9	85	5.0
50					130	7.9	85	3.4	150	10.5	115	6.2
70					161	8.4	105	3.6	175	9.9	149	7.2
95					192	8.7	125	3.7	225	11.9	175	7.2
120					226	9.6	147	4.1	250	11.7	210	8.3
150					275	11.7	167	4.3	275	11.7	239	8.8
185					295	10.9	191	4.6	350	15.4	273	9.4
240					347	12.0	225	5.0	400	15.9	322	10.3
300					400	13.2	260	5.6	460	17.5	371	11.4

Conductors for auxiliary circuits

					Diam.
0.12	2.6	1.2	1.7	0.5	0.4
0.14	2.9	1.3	1.9	0.6	-
0.20	3.2	1.1	2.1	0.5	-
0.22	3.6	1.3	2.3	0.5	0.5
0.30	4.4	1.4	2.9	0.6	0.6
0.34	4.7	1.4	3.1	0.6	0.6
0.50	6.4	1.8	4.2	0.8	0.8
0.56		1.6		0.7	-
0.75	8.2	1.9	5.4	0.8	1.0
1.00	9.3	1.8	6.1	0.8	-

1) Any arrangement desired with the values specified referring to six cores in a multi-core bundle with a simultaneous load 100%

2) single length

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Annex B: Temperature rise evaluation according to IEC 60890

Table 2: Operating current and power losses of bare conductors, in vertical arrangement without direct connections to apparatus

Width x Thickness	Cross-section (Cu)	Maximum permissible conductor temperature 85 °C															
		Air temperature inside the enclosure around the conductors 35 °C								Air temperature inside the enclosure around the conductors 55 °C							
		50 Hz to 60 Hz ac				dc and ac to 16 2/3 Hz				50 Hz to 60 Hz ac				dc and ac to 16 2/3 Hz			
		operating current	**power losses 1)**	**operating current**	**power losses 1)**	**operating current**	**power losses 1)**	**operating current**	**power losses 1)**	**operating current**	**power losses 1)**	**operating current**	**power losses 1)**	**operating current**	**power losses 1)**	**operating current**	**power losses 1)**
mm x mm	mm^2	A*	W/m	A**	W/m	A*	W/m	A**	W/m	A*	W/m	A**	W/m	A*	W/m	A**	W/m
12 x 2	23.5	144	19.5	242	27.5	144	19.5	242	27.5	105	10.4	177	14.7	105	10.4	177	14.7
15 x 2	29.5	170	21.7	282	29.9	170	21.7	282	29.9	124	11.6	206	16.0	124	11.6	206	16.0
15 x 3	44.5	215	23.1	375	35.2	215	23.1	375	35.2	157	12.3	274	18.8	157	12.3	274	18.8
20 x 2	39.5	215	26.1	351	34.8	215	26.1	354	35.4	157	13.9	256	18.5	157	12.3	258	18.8
20 x 3	59.5	271	27.6	463	40.2	271	27.6	463	40.2	198	14.7	338	21.4	198	14.7	338	21.4
20 x 5	99.1	364	29.9	665	49.8	364	29.9	668	50.3	266	16.0	485	26.5	266	16.0	487	26.7
20 x 10	199	568	36.9	1097	69.2	569	36.7	1107	69.6	414	19.6	800	36.8	415	19.5	807	37.0
25 x 5	124	435	34.1	779	55.4	435	34.1	78	55.6	317	18.1	568	29.5	317	18.1	572	29.5
30 x 5	149	504	38.4	894	60.6	505	38.2	899	60.7	368	20.5	652	32.3	369	20.4	656	32.3
30 x 10	299	762	44.4	1410	77.9	770	44.8	1436	77.8	556	27.7	1028	41.4	562	23.9	1048	41.5
40 x 5	199	641	47.0	1112	72.5	644	47.0	1128	72.3	468	25.0	811	38.5	469	24.9	586	38.5
40 x 10	399	951	52.7	1716	88.9	968	52.6	1796	90.5	694	28.1	1251	47.3	706	28.0	1310	48.1
50 x 5	249	775	55.7	1322	82.9	782	55.4	1357	83.4	566	29.7	964	44.1	570	29.4	989	44.3
50 x 10	499	1133	60.9	2008	102.9	1164	61.4	2141	103.8	826	32.3	1465	54.8	849	32.7	1562	55.3
60 x 5	299	915	64.1	1530	94.2	926	64.7	1583	94.6	667	34.1	1116	50.1	675	34.4	1154	50.3
60 x 10	599	1310	68.5	2288	116.2	1357	69.5	2487	117.8	955	36.4	1668	62.0	989	36.9	1814	62.7
80 x 5	399	1170	80.7	1929	116.4	1200	80.8	2035	116.1	858	42.9	1407	61.9	875	42.9	1484	61.8
80 x 10	799	1649	85.0	2806	138.7	1742	85.1	3165	140.4	1203	45.3	2047	73.8	1271	45.3	1756	74.8
100 x 5	499	1436	100.1	2301	137.0	1476	98.7	2407	121.2	1048	53.3	1678	72.9	1077	52.5	1756	69.8
100 x 10	999	1982	101.7	3298	164.2	2128	102.6	3844	169.9	1445	54.0	2406	84.4	1552	54.6	2803	90.4
120 x 10	1200	2314	115.5	3804	187.3	2514	115.9	4509	189.9	1688	61.5	2774	99.6	1833	61.6	3288	101.0

*) one conductor per phase **) two conductors per phase 1) single length

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Annex B: Temperature rise evaluation according to IEC 60890

Table 3: Operating current and power losses of bare conductors used as connections between apparatus and busbars

Width x Thickness	Cross-section (Cu)	Maximum permissible conductor temperature 65 °C							
		Air temperature inside the enclosure around the conductors 35 °C 50 Hz to 60 Hz ac and dc				Air temperature inside the enclosure around the conductors 55 °C 50 Hz to 60 Hz ac and dc			
		operating current	power losses 1)	operating current	power losses 1)	operating current	power losses 1)	operating current	power losses 1)
mm x mm	mm 2	A*	W/m	A**	W/m	A*	W/m	A**	W/m
12 x 2	23.5	82	5.9	130	7.4	69	4.2	105	4.9
15 x 2	29.5	96	6.4	150	7.8	88	5.4	124	5.4
15 x 3	44.5	124	7.1	202	9.5	102	4.8	162	6.1
20 x 2	39.5	115	6.9	184	8.9	93	4.5	172	7.7
20 x 3	59.5	152	8.0	249	10.8	125	5.4	198	6.8
20 x 5	99.1	218	9.9	348	12.7	174	6.3	284	8.4
20 x 10	199	348	12.8	648	22.3	284	8.6	532	15.0
25 x 5	124	253	10.7	413	14.2	204	7.0	338	9.5
30 x 5	149	288	11.6	492	16.9	233	7.6	402	11.3
30 x 10	299	482	17.2	960	32.7	402	11.5	780	21.6
40 x 5	199	348	12.8	648	22.3	284	8.6	532	15.0
40 x 10	399	648	22.7	1245	41.9	532	15.3	1032	28.8
50 x 5	249	413	14.7	805	27.9	338	9.8	655	18,5
50 x 10	499	805	28.5	1560	53.5	660	19.2	1280	36.0
60 x 5	299	492	17.2	960	32.7	402	11.5	780	21.6
60 x 10	599	960	34.1	1848	63.2	780	22.5	1524	43.0
80 x 5	399	648	22.7	1256	42.6	532	15.3	1032	28.8
80 x 10	799	1256	45.8	2432	85.8	1032	30.9	1920	53.5
100 x 5	499	805	29.2	1560	54.8	660	19.6	1280	36.9
100 x 10	999	1560	58.4	2680	86.2	1280	39.3	2180	57.0
120 x 10	1200	1848	68.3	2928	85.7	1524	46.5	2400	57.6

*) one conductor per phase **) two conductors per phase 1) single length

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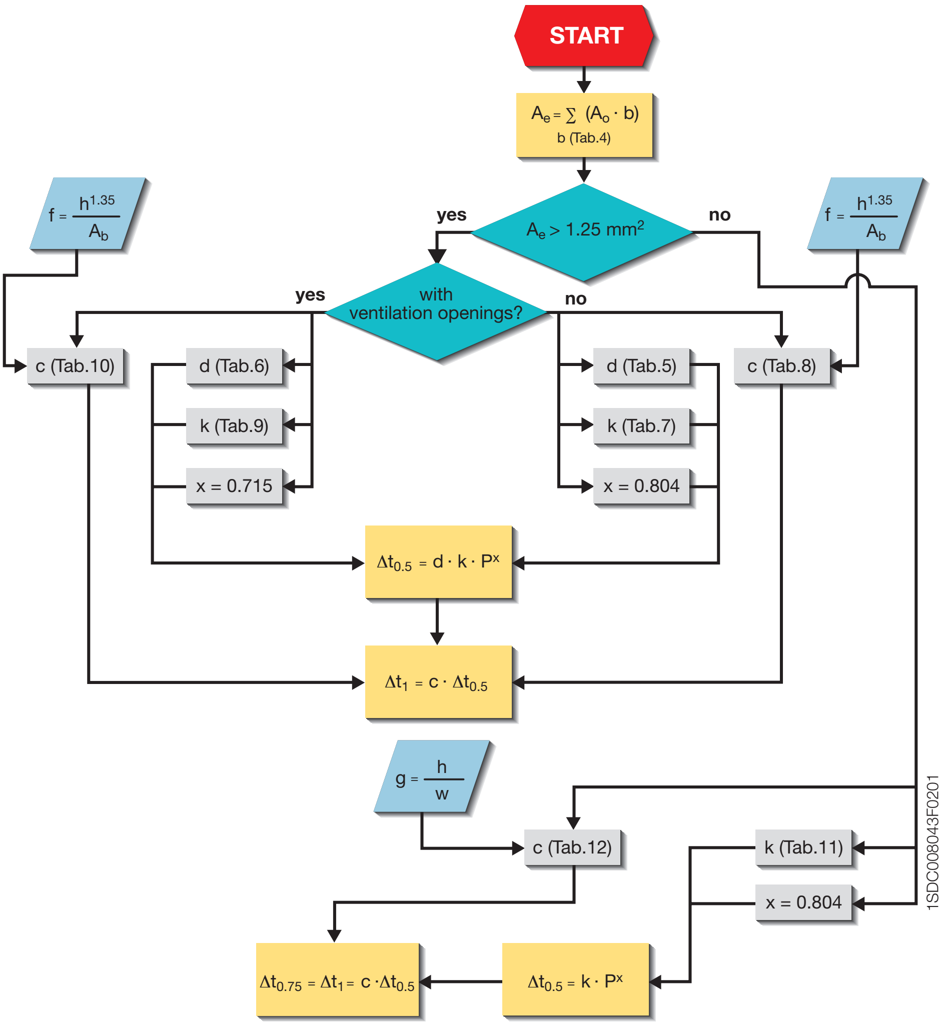
Annex B: Temperature rise evaluation according to IEC 60890

Where enclosures without vertical partitions or individual sections have an effective cooling surface greater than about 11.5 m or a width grater than about 1.5 m, they should be divided for the calculation into fictitious sections, whose dimensions approximate to the foregoing values.

The following diagram shows the procedure to evaluate the temperature rise.



Annex B: Temperature rise evaluation according to IEC 60890

Table 4: Surface factor *b* according to the type of installation

Type of installation	Surface factor *b*
Exposed top surface	1.4
Covered top surface, e.g. of built-in enclosures	0.7
Exposed side faces, e.g. front, rear and side walls	0.9
Covered side faces, e.g. rear side of wall-mounted enclosures	0.5
Side faces of central enclosures	0.5
Floor surface	Not taken into account

Fictitious side faces of sections which have been introduced only for calculation purposes are not taken into account

Table 5: Factor *d* for enclosures without ventilation openings and with an effective cooling surface A_e > 1.25 m²

Number of horizontal partitions *n*	Factor *d*
0	1
1	1.05
2	1.15
3	1.3

Table 6: Factor *d* for enclosures with ventilation openings and with an effective cooling surface A_e > 1.25 m²

Number of horizontal partitions *n*	Factor *d*
0	1
1	1.05
2	1.1
3	1.15

Table 7: Enclosure constant *k* for enclosures without ventilation openings, with an effective cooling surface A_e > 1.25 m²

A_e [m²]	k	A_e [m²]	k
1.25	0.524	6.5	0.135
1.5	0.45	7	0.13
2	0.35	7.5	0.125
2.5	0.275	8	0.12
3	0.225	8.5	0.115
3.5	0.2	9	0.11
4	0.185	9.5	0.105
4.5	0.17	10	0.1
5	0.16	10.5	0.095
5.5	0.15	11	0.09
6	0.14	11.5	0.085

Annex B: Temperature rise evaluation according to IEC 60890

Table 8: Temperature distribution factor *c* for enclosures without ventilation openings, with an effective cooling surface A_e > 1.25 m²

$f = \frac{h^{1.35}}{A_b}$	Type of installation 1	2	3	4	5
0.6	1.225	1.21	1.19	1.17	1.113
1	1.24	1.225	1.21	1.185	1.14
1.5	1.265	1.245	1.23	1.21	1.17
2	1.285	1.27	1.25	1.23	1.19
2.5	1.31	1.29	1.275	1.25	1.21
3	1.325	1.31	1.295	1.27	1.23
3.5	1.35	1.33	1.315	1.29	1.255
4	1.37	1.355	1.34	1.32	1.275
4.5	1.395	1.375	1.36	1.34	1.295
5	1.415	1.395	1.38	1.36	1.32
5.5	1.435	1.415	1.4	1.38	1.34
6	1.45	1.435	1.42	1.395	1.355
6.5	1.47	1.45	1.435	1.41	1.37
7	1.48	1.47	1.45	1.43	1.39
7.5	1.495	1.48	1.465	1.44	1.4
8	1.51	1.49	1.475	1.455	1.415
8.5	1.52	1.505	1.49	1.47	1.43
9	1.535	1.52	1.5	1.48	1.44
9.5	1.55	1.53	1.515	1.49	1.455
10	1.56	1.54	1.52	1.5	1.47
10.5	1.57	1.55	1.535	1.51	1.475
11	1.575	1.565	1.549	1.52	1.485
11.5	1.585	1.57	1.55	1.525	1.49
12	1.59	1.58	1.56	1.535	1.5
12.5	1.6	1.585	1.57	1.54	1.51

where h is the height of the enclosure, and A_b is the area of the base.
For "Type of installation":

Type of installation n°	
1	Separate enclosure, detached on all sides
2	First or last enclosure, detached type
3	Separate enclosure for wall-mounting
	Central enclosure, detached type
4	First or last enclosure, wall-mounting type
	Central enclosure for wall-mounting and with covered top surface
5	Central enclosure, wall-mounting type

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Annex B: Temperature rise evaluation according to IEC 60890

Table 9: Enclosure constant *k* for enclosures with ventilation openings and an effective cooling surface A_e > 1.25 m²

Ventilation opening in cm²	A_e [m²]												
	1	**1.5**	**2**	**2.5**	**3**	**4**	**5**	**6**	**7**	**8**	**10**	**12**	**14**
50	0.36	0.33	0.3	0.28	0.26	0.24	0.22	0.208	0.194	0.18	0.165	0.145	0.135
100	0.293	0.27	0.25	0.233	0.22	0.203	0.187	0.175	0.165	0.153	0.14	0.128	0.119
150	0.247	0.227	0.21	0.198	0.187	0.173	0.16	0.15	0.143	0.135	0.123	0.114	0.107
200	0.213	0.196	0.184	0.174	0.164	0.152	0.143	0.135	0.127	0.12	0.11	0.103	0.097
250	0.19	0.175	0.165	0.155	0.147	0.138	0.13	0.121	0.116	0.11	0.1	0.095	0.09
300	0.17	0.157	0.148	0.14	0.133	0.125	0.118	0.115	0.106	0.1	0.093	0.088	0.084
350	0.152	0.141	0.135	0.128	0.121	0.115	0.109	0.103	0.098	0.093	0.087	0.082	0.079
400	0.138	0.129	0.121	0.117	0.11	0.106	0.1	0.096	0.091	0.088	0.081	0.078	0.075
450	0.126	0.119	0.111	0.108	0.103	0.099	0.094	0.09	0.086	0.083	0.078	0.074	0.07
500	0.116	0.11	0.104	0.1	0.096	0.092	0.088	0.085	0.082	0.078	0.073	0.07	0.067
550	0.107	0.102	0.097	0.093	0.09	0.087	0.083	0.08	0.078	0.075	0.07	0.068	0.065
600	0.1	0.095	0.09	0.088	0.085	0.082	0.079	0.076	0.073	0.07	0.067	0.065	0.063
650	0.094	0.09	0.086	0.083	0.08	0.077	0.075	0.072	0.07	0.068	0.065	0.063	0.061
700	0.089	0.085	0.08	0.078	0.076	0.074	0.072	0.07	0.068	0.066	0.064	0.062	0.06

Table 10: Temperature distribution factor *c* for enclosures with ventilation openings and an effective cooling surface A_e > 1.25 m²

Ventilation opening in cm²	$f = \dfrac{h^{1.35}}{A_b}$									
	1.5	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
50	1.3	1.35	1.43	1.5	1.57	1.63	1.68	1.74	1.78	1.83
100	1.41	1.46	1.55	1.62	1.68	1.74	1.79	1.84	1.88	1.92
150	1.5	1.55	1.63	1.69	1.75	1.8	1.85	1.9	1.94	1.97
200	1.56	1.61	1.67	1.75	1.8	1.85	1.9	1.94	1.97	2.01
250	1.61	1.65	1.73	1.78	1.84	1.88	1.93	1.97	2.01	2.04
300	1.65	1.69	1.75	1.82	1.86	1.92	1.96	2	2.03	2.06
350	1.68	1.72	1.78	1.85	1.9	1.94	1.97	2.02	2.05	2.08
400	1.71	1.75	1.81	1.87	1.92	1.96	2	2.04	2.07	2.1
450	1.74	1.77	1.83	1.88	1.94	1.97	2.02	2.05	2.08	2.12
500	1.76	1.79	1.85	1.9	1.95	1.99	2.04	2.06	2.1	2.13
550	1.77	1.82	1.88	1.93	1.97	2.01	2.05	2.08	2.11	2.14
600	1.8	1.83	1.88	1.94	1.98	2.02	2.06	2.09	2.12	2.15
650	1.81	1.85	1.9	1.95	1.99	2.04	2.07	2.1	2.14	2.17
700	1.83	1.87	1.92	1.96	2	2.05	2.08	2.12	2.15	2.18

Annex B: Temperature rise evaluation according to IEC 60890

Table 11: Enclosure constant *k* for enclosures without ventilation openings and with an effective cooling surface $A_e \leq 1.25\ m^2$

A_e [m²]	k	A_e [m²]	k
0.08	3.973	0.65	0.848
0.09	3.643	0.7	0.803
0.1	3.371	0.75	0.764
0.15	2.5	0.8	0.728
0.2	2.022	0.85	0.696
0.25	1.716	0.9	0.668
0.3	1.5	0.95	0.641
0.35	1.339	1	0.618
0.4	1.213	1.05	0.596
0.45	1.113	1.1	0.576
0.5	1.029	1.15	0.557
0.55	0.960	1.2	0.540
0.6	0.9	1.25	0.524

Table 12: Temperature distribution factor *c* for enclosures without ventilation openings and with an effective cooling surface $A_e \leq 1.25\ m^2$

g	c	g	c
0	1	1.5	1.231
0.1	1.02	1.6	1.237
0.2	1.04	1.7	1.24
0.3	1.06	1.8	1.244
0.4	1.078	1.9	1.246
0.5	1.097	2	1.249
0.6	1.118	2.1	1.251
0.7	1.137	2.2	1.253
0.8	1.156	2.3	1.254
0.9	1.174	2.4	1.255
1	1.188	2.5	1.256
1.1	1.2	2.6	1.257
1.2	1.21	2.7	1.258
1.3	1.22	2.8	1.259
1.4	1.226		

where g is the ratio of the height and the width of the enclosure.

Annex B: Temperature rise evaluation according to IEC 60890

Total (3/4 poles) power loss in W

Table 13: MCCB power losses

Releases	In[A]	T11P	T1	T2		T3		T4		T5		S6		S7		S8
		F	F	F	P	F	P	F	P/W	F	P/W	F	W	F	W	F
	1			4.5	5.1											
	1.6			6.3	7.5											
	2			7.5	8.7											
	2.5			7.8	9											
	3.2			8.7	10.2											
	4			7.8	9											
	5			8.7	10.5											
	6.3			10.5	12.3											
	8			8.1	9.6											
	10			9.3	10.8											
	12.5			3.3	3.9											
	16	1.5	4.5	4.2	4.8											
TMF	20	1.8	5.4	5.1	6			10.8	10.8							
TMD	25	2	6	6.9	8.4											
TMA	32	2.1	6.3	8.1	9.6			11.1	11.1							
MF	40	2.6	7.8	11.7	13.8											
MA	50	3.7	11.1	12.9	15			11.7	12.3							
	63	4.3	12.9	15.3	18	12.9	15.3									
	80	4.8	14.4	18.3	21.6	14.4	17.4	13.8	15							
	100	7	21	25.5	30	16.8	20.4	15.6	17.4							
	125	10.7	32.1	36	44.1	19.8	23.7	18.6	21.6							
	160	15	45	51	60	23.7	28.5	22.2	27							
	200					39.6	47.4	29.7	37.2							
	250					53.4	64.2	41.1	52.8							
	320							61.8	81	40.8	62.7					
	400									58.5	93					
	500									86.4	110.1					
	630									132	169.8					
	800											93	119			
	10			1.5	1.8											
	25			3	3.6											
	63			10.5	12											
	100			24	27.2			5.1	6.9							
	160			51	60			13.2	18							
PR211	250							32.1	43.8							
PR212	320							52.8	72	31.8	53.7					
PR221	400									49.5	84					
PR222	630									123	160.8					
	800											96	125			
	1000													102	140	
	1250													160	220	
	1600													260	360	
	2000															200
	2500															315
	3200															500

The values indicated in the table refer to balanced loads, with a current flow equal to the In, and are valid for both circuit-breakers and switch-disconnectors, three-pole and four-pole versions.
For the latter, the current of the neutral is nil by definition.

Annex B: Temperature rise evaluation according to IEC 60890

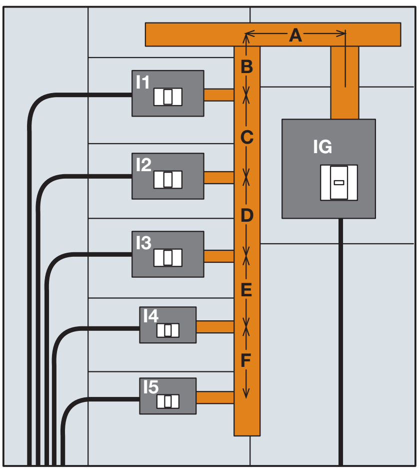
Table 14: Emax power losses

Total (3/4 poles)	E1B-N		E2B-N		E2L		E3N-S-H		E3L		E4S-H		E6H-V	
power loss in W	F	W	F	W	F	W	F	W	F	W	F	W	F	W
In=250	6	9	3	5	4	7	2	4	3	5				
In=400	16	24	7	13	11	17	6	9	9	13				
In=800	65	95	29	54	43	68	25	38	34	53				
In=1000	96	147	45	84	67	106	38	59	54	83				
In=1250	150	230	70	130	105	165	60	90	84	129				
In=1600			115	215	170	265	85	150	138	211				
In=2000			180	330			130	225	215	330	92	166		
In=2500							205	350	335	515				
In=3200							330	570			235	425	170	290
In=4000											360	660	265	445
In=5000													415	700
In=6300													650	1100

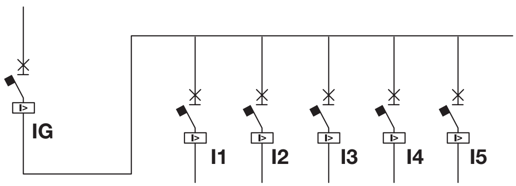
Example

Hereunder an example of temperature rise evaluation for a switchboard with the following characteristics:
- enclosure without ventilation openings
- no internal segregation
- separate enclosure for wall-mounting
- one main circuit-breaker
- 5 circuit-breakers for load supply
- busbars and cable systems

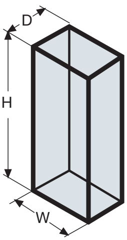
Enclosure



Circuit diagram



Dimensions [mm]			Number of horizontal partitions = 0
Height	Width	Depth	
2000	1440	840	Separate enclosure for wall-mounting



Annex B: Temperature rise evaluation according to IEC 60890

The power losses from each component of the above switchboard are evaluated hereunder.

For the circuit-breakers, the power losses are calculated as $P = Pn\left(\frac{Ib}{In}\right)^2$, with In and Pn given in the Tables 14 and 15.

The table below shows the values relevant to each circuit-breaker of the switchboard in question:

Circuit-breakers		In CB [A]	Ib [A]	Power losses [W]
IG	E2 1600 EL	1600	1340	80.7
I1	T5 400 EL	400	330	33.7
I2	T5 400 EL	400	330	33.7
I3	T5 400 EL	400	330	33.7
I4	T3 250 TMD	250	175	26.2
I5	T3 250 TMD	250	175	26.2
Total power loss of circuit-breakers [W]				**234**

For the busbars, the power losses are calculated as $P = Pn\left(\frac{Ib}{In}\right)^2 \cdot (3 \cdot \text{Length})$ with In and Pn given in the Table 2.

The table below shows the power losses of busbars:

Busbars	Cross-section nx[mm]x[mm]	Length [m]	Ib [A]	Power losses [W]
A	2x60x10	0.393	1340	47.2
B	80x10	0.332	1340	56
C	80x10	0.300	1010	28.7
D	80x10	0.300	680	13
E	80x10	0.300	350	3.5
F	80x10	0.300	175	0.9
Total power loss of busbars [W]				**149**

For the bare conductors connecting the busbars to the circuit-breakers, the power losses are calculated as $P = Pn\left(\frac{Ib}{In}\right)^2 \cdot (3 \cdot \text{Length})$, with In and Pn given in the Table 2. Here below the values for each section:

Connection bare conductors	Cross-section nx[mm]x[mm]	Length [m]	Ib [A]	Power losses [W]
Ig	2x60x10	0.450	1340	54
I1	30x10	0.150	330	3.8
I2	30x10	0.150	330	3.8
I3	30x10	0.150	330	3.8
I4	20x10	0.150	175	1.6
I5	20x10	0.150	175	1.6
Total power loss of bare conductors [W]				**68**

Annex B: Temperature rise evaluation according to IEC 60890

For the cables connecting the circuit-breakers to the supply and the loads, the power losses are calculated as $P = Pn\left(\frac{Ib}{In}\right)^2 \cdot (3 \cdot \text{Length})$, with In and Pn given in the Table 4.

Here below the power losses for each connection:

Cables	**Cross-section**	**Length**	**Ib**	**Power losses**
	[n]xmm^2	[m]	[A]	[W]
IG	4x240	1.0	1340	133.8
I1	240	2.0	330	64.9
I2	240	1.7	330	55.2
I3	240	1.4	330	45.4
I4	120	1.1	175	19
I5	120	0.8	175	13.8
Total power loss of cables [W]				**332**

Thus, the total power loss inside the enclosure is: **P = 784 [W]**

From the geometrical dimensions of the switchboard, the effective cooling surface Ae is determined below:

	Dimensions[m]x[m]	$A_0[m^2]$	b factor	A_0
Top	0.840x1.44	1.21	1.4	1.69
Front	2x1.44	1.64	0.9	2.59
Rear	2x1.44	1.64	0.5	1.44
Left-hand side	2x0.840	1.68	0.9	1.51
Right-hand side	2x0.840	1.68	0.9	1.51
			$Ae=\Sigma(A_0 \cdot b)$	8.75

Making reference to the procedure described in the diagram at page 294, it is possible to evaluate the temperature rise inside the switchboard.

Annex B: Temperature rise evaluation according to IEC 60890

From Table 7, k results 0.112 (value interpolated)

Since x = 0.804, the temperature rise at half the height of the enclosure is:

$\Delta t_{0.5} = d \cdot k \cdot P^x = 1 \cdot 0.112 \cdot 784^{0.804} = 23.8$ k

For the evaluation of the temperature rise at the top of the enclosure, it is necessary to determine the *c* factor by using the *f* factor:

$f = \frac{h^{1.35}}{A_b} = \frac{2^{1.35}}{1.44 \cdot 0.84} = 2.107$ (A_b is the base area of the switchboard)

From Table 8, column 3 (separate enclosure for wall-mounting), c results to be equal to1.255 (value interpolated).

$\Delta t_1 = c \cdot \Delta t_{0.5} = 1.255 \cdot 23.8 = 29.8$ k

Considering 35°C ambient temperature, as prescribed by the Standard, the following temperatures shall be reached inside the enclosure:

$t_{0.5} = 35 + 23.8 \approx 59°C$
$t_1 = 35 + 29.8 \approx 65°C$

Assuming that the temperature derating of the circuit-breakers inside the switchboard can be compared to the derating at an ambient temperature different from 40°C, through the tables of Chapter 3.5, it is possible to verify if the selected circuit-breakers can carry the required currents:

E2 1600	at 65°C	In=1538[A]	>	Ig = 1340 [A]
T5 400	at 65°C	In=384 [A]	>	I1 = I2 = I3 = 330 [A]
T3 250	at 60° C	In=216 [A]	>	I4 = I5 = 175 [A]

Due to possible developments of standards as well as of materials, the characteristics and dimensions specified in this document may only be considered binding after confirmation by ABB SACE.

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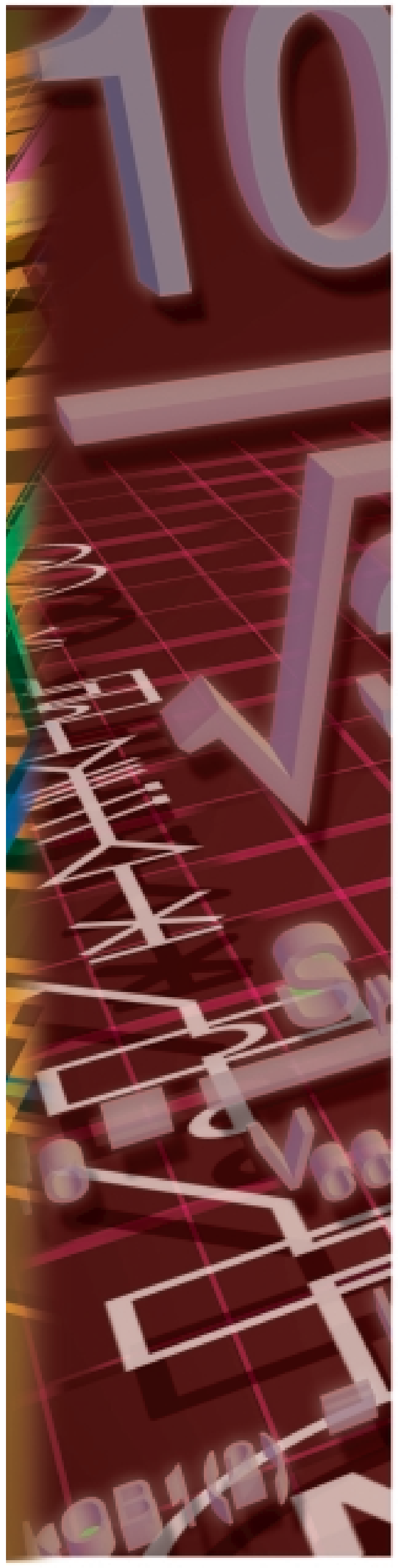

Electrical installation handbook

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Volume 2

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Electrical devices

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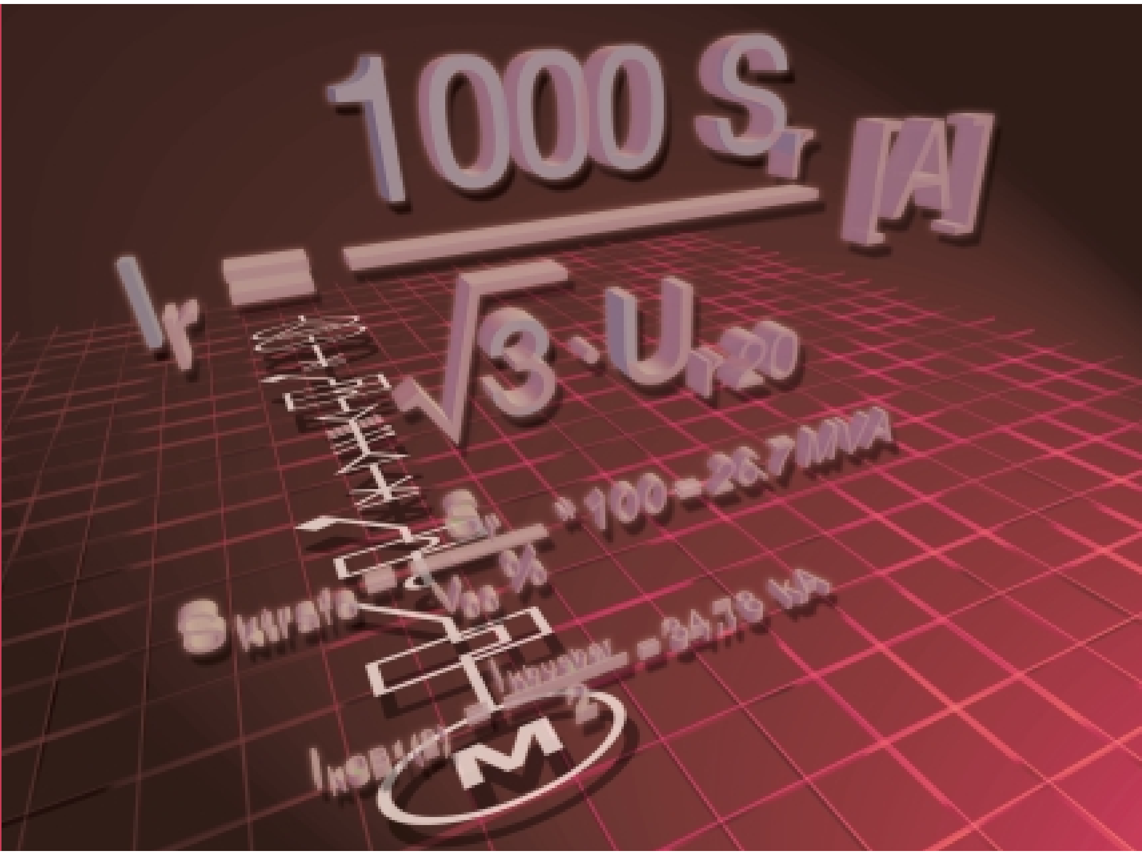

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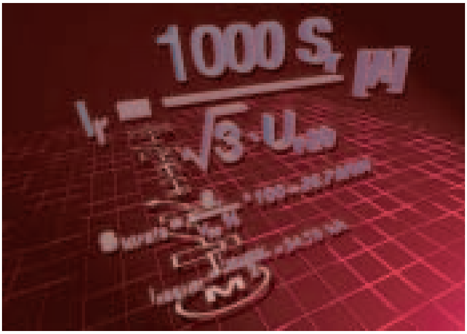
Electrical installation handbook

Volume 2

Electrical devices



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Index

Introduction 2

1 Standards
- 1.1 General aspects 3
- 1.2 IEC Standards for electrical installation 15

2 Protection of feeders
- 2.1 Introduction 22
- 2.2 Installation and dimensioning of cables 25
  - 2.2.1 Current carrying capacity and methods of installation 25
    - Installation not buried in the ground 31
    - Installation in ground 44
  - 2.2.2 Voltage drop 55
  - 2.2.3 Joule-effect losses 66
- 2.3 Protection against overload 67
- 2.4 Protection against short-circuit 70
- 2.5 Neutral and protective conductors 78
- 2.6 Busbar trunking systems 86

3 Protection of electrical equipment
- 3.1 Protection and switching of lighting circuits 101
- 3.2 Protection and switching of generators 110
- 3.3 Protection and switching of motors 115
- 3.4 Protection and switching of transformers 131

4 Power factor correction
- 4.1 General aspects 146
- 4.2 Power factor correction method 152
- 4.3 Circuit-breakers for the protection and swiching of capacitor banks 159

5 Protection of human beings
- 5.1 General aspects: effects of current on human beings 162
- 5.2 Distribution systems 165
- 5.3 Protection against both direct and indirect contact 168
- 5.4 TT system 171
- 5.5 TN system 174
- 5.6 IT system 177
- 5.7 Residual current devices 179
- 5.8 Maximum protected length for the protection of human beings ... 182

Annex A: Calculation tools
- A.1 Slide rules 200
- A.2 DOCWin 205

Annex B: Calculation of load current I_b 209

Annex C: Calculation of short-circuit current 213

Annex D: Calculation of the coefficient k for the cables 227

Annex E: Main physical quantities and electro technical formulas 230

Introduction

Scope and objectives

The scope of this electrical installation handbook is to provide the designer and user of electrical plants with a quick reference, immediate-use working tool. This is not intended to be a theoretical document, nor a technical catalogue, but, in addition to the latter, aims to be of help in the correct definition of equipment, in numerous practical installation situations.

The dimensioning of an electrical plant requires knowledge of different factors relating to, for example, installation utilities, the electrical conductors and other components; this knowledge leads the design engineer to consult numerous documents and technical catalogues. This electrical installation handbook, however, aims to supply, in a single document, tables for the quick definition of the main parameters of the components of an electrical plant and for the selection of the protection devices for a wide range of installations. Some application examples are included to aid comprehension of the selection tables.

Electrical installation handbook users

The electrical installation handbook is a tool which is suitable for all those who are interested in electrical plants: useful for installers and maintenance technicians through brief yet important electrotechnical references, and for sales engineers through quick reference selection tables.

Validity of the electrical installation handbook

Some tables show approximate values due to the generalization of the selection process, for example those regarding the constructional characteristics of electrical machinery. In every case, where possible, correction factors are given for actual conditions which may differ from the assumed ones. The tables are always drawn up conservatively, in favour of safety; for more accurate calculations, the use of DOCWin software is recommended for the dimensioning of electrical installations.

1 Standards

1.1 General aspects

In each technical field, and in particular in the electrical sector, a condition sufficient (even if not necessary) for the realization of plants according to the **“status of the art”** and a requirement essential to properly meet the demands of customers and of the community, is the respect of all the relevant laws and technical standards.
Therefore, a precise knowledge of the standards is the fundamental premise for a correct approach to the problems of the electrical plants which shall be designed in order to guarantee that **“acceptable safety level”** which is never absolute.

Juridical Standards
These are all the standards from which derive rules of behavior for the juridical persons who are under the sovereignty of that State.

Technical Standards
These standards are the whole of the prescriptions on the basis of which machines, apparatus, materials and the installations should be designed, manufactured and tested so that efficiency and function safety are ensured.
The technical standards, published by national and international bodies, are circumstantially drawn up and can have legal force when this is attributed by a legislative measure.

Application fields

	Electrotechnics and Electronics	Telecommunications	Mechanics, Ergonomics and Safety
International Body	IEC	ITU	ISO
European Body	CENELEC	ETSI	CEN

This technical collection takes into consideration only the bodies dealing with electrical and electronic technologies.

IEC International Electrotechnical Commission

The *International Electrotechnical Commission* (IEC) was officially founded in 1906, with the aim of securing the international co-operation as regards standardization and certification in electrical and electronic technologies. This association is formed by the International Committees of over 40 countries all over the world.
The IEC publishes international standards, technical guides and reports which are the bases or, in any case, a reference of utmost importance for any national and European standardization activity.
IEC Standards are generally issued in two languages: English and French.
In 1991 the IEC has ratified co-operation agreements with CENELEC (European standardization body), for a common planning of new standardization activities and for parallel voting on standard drafts.

1 Standards

CENELEC European Committee for Electrotechnical Standardization

The *European Committee for Electrotechnical Standardization* (CENELEC) was set up in 1973. Presently it comprises 27 countries (Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Portugal, Poland, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom) and cooperates with 8 affiliates (Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Romania, Turkey, Ukraine) which have first maintained the national documents side by side with the CENELEC ones and then replaced them with the Harmonized Documents (HD). CENELEC hopes and expects Cyprus to become the 28th members before May 2004.
There is a difference between EN Standards and Harmonization Documents (HD): while the first ones have to be accepted at any level and without additions or modifications in the different countries, the second ones can be amended to meet particular national requirements.
EN Standards are generally issued in three languages: English, French and German.
From 1991 CENELEC cooperates with the IEC to accelerate the standards preparation process of International Standards.
CENELEC deals with specific subjects, for which standardization is urgently required.
When the study of a specific subject has already been started by the IEC, the European standardization body (CENELEC) can decide to accept or, whenever necessary, to amend the works already approved by the International standardization body.

EC DIRECTIVES FOR ELECTRICAL EQUIPMENT

Among its institutional roles, the European Community has the task of promulgating directives which must be adopted by the different member states and then transposed into national law.
Once adopted, these directives come into juridical force and become a reference for manufacturers, installers, and dealers who must fulfill the duties prescribed by law.
Directives are based on the following principles:
- harmonization is limited to essential requirements;
- only the products which comply with the essential requirements specified by the directives can be marketed and put into service;
- the harmonized standards, whose reference numbers are published in the Official Journal of the European Communities and which are transposed into the national standards, are considered in compliance with the essential requirements;
- the applicability of the harmonized standards or of other technical specifications is facultative and manufacturers are free to choose other technical solutions which ensure compliance with the essential requirements;
- a manufacturer can choose among the different conformity evaluation procedure provided by the applicable directive.

The scope of each directive is to make manufacturers take all the necessary steps and measures so that the product does not affect the safety and health

1 Standards

of persons, animals and property.

"Low Voltage" Directive 73/23/CEE – 93/68/CEE

The Low Voltage Directive refers to any electrical equipment designed for use at a rated voltage from 50 to 1000 V for alternating current and from 75 to 1500 V for direct current.
In particular, it is applicable to any apparatus used for production, conversion, transmission, distribution and use of electrical power, such as machines, transformers, devices, measuring instruments, protection devices and wiring materials.
The following categories are outside the scope of this Directive:
- electrical equipment for use in an explosive atmosphere;
- electrical equipment for radiology and medical purposes;
- electrical parts for goods and passenger lifts;
- electrical energy meters;
- plugs and socket outlets for domestic use;
- electric fence controllers;
- radio-electrical interference;
- specialized electrical equipment, for use on ships, aircraft or railways, which complies with the safety provisions drawn up by international bodies in which the Member States participate.

Directive EMC 89/336/EEC ("Electromagnetic Compatibility")

The Directive on electromagnetic compatibility regards all the electrical and electronic apparatus as well as systems and installations containing electrical and/or electronic components. In particular, the apparatus covered by this Directive are divided into the following categories according to their characteristics:
- domestic radio and TV receivers;
- industrial manufacturing equipment;
- mobile radio equipment;
- mobile radio and commercial radio telephone equipment;
- medical and scientific apparatus;
- information technology equipment (ITE);
- domestic appliances and household electronic equipment;
- aeronautical and marine radio apparatus;
- educational electronic equipment;
- telecommunications networks and apparatus;
- radio and television broadcast transmitters;
- lights and fluorescent lamps.

The apparatus shall be so constructed that:
a) the electromagnetic disturbance it generates does not exceed a level allowing radio and telecommunications equipment and other apparatus to operate as intended;
b) the apparatus has an adequate level of intrinsic immunity to electromagnetic disturbance to enable it to operate as intended.

An apparatus is declared in conformity to the provisions at points a) and b) when the apparatus complies with the harmonized standards relevant to its product family or, in case there aren't any, with the general standards.

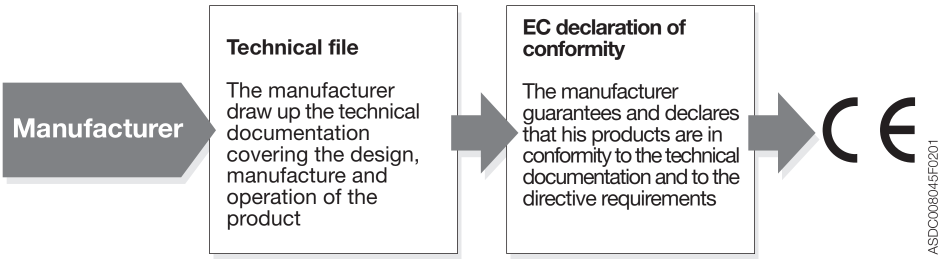
1 Standards

CE conformity marking

The CE conformity marking shall indicate conformity to all the obligations imposed on the manufacturer, as regards his products, by virtue of the European Community directives providing for the affixing of the CE marking.

When the CE marking is affixed on a product, it represents a declaration of the manufacturer or of his authorized representative that the product in question conforms to all the applicable provisions including the conformity assessment procedures. This prevents the Member States from limiting the marketing and putting into service of products bearing the CE marking, unless this measure is justified by the proved non-conformity of the product.

Flow diagram for the conformity assessment procedures established by the Directive 73/23/EEC on electrical equipment designed for use within particular voltage range:



Naval type approval

The environmental conditions which characterize the use of circuit breakers for on-board installations can be different from the service conditions in standard industrial environments; as a matter of fact, marine applications can require installation under particular conditions, such as:
- environments characterized by high temperature and humidity, including salt-mist atmosphere (damp-heat, salt-mist environment);
- on board environments (engine room) where the apparatus operate in the presence of vibrations characterized by considerable amplitude and duration.

In order to ensure the proper function in such environments, the shipping registers require that the apparatus has to be tested according to specific type approval tests, the most significant of which are vibration, dynamic inclination, humidity and dry-heat tests.

1 Standards

ABB SACE circuit-breakers (Isomax-Tmax-Emax) are approved by the following shipping registers:

• **RINA**	Registro Italiano Navale	Italian shipping register
• **DNV**	Det Norske Veritas	Norwegian shipping register
• **BV**	Bureau Veritas	French shipping register
• **GL**	Germanischer Lloyd	German shipping register
• **LRs**	Lloyd's Register of Shipping	British shipping register
• **ABS**	American Bureau of Shipping	American shipping register

It is always advisable to ask ABB SACE as regards the typologies and the performances of the certified circuit-breakers or to consult the section certificates in the website **http://bol.it.abb.com**.

Marks of conformity to the relevant national and international Standards

The international and national marks of conformity are reported in the following table, for information only:

COUNTRY	Symbol	Mark designation	Applicability/Organization
EUROPE		–	Mark of compliance with the harmonized European standards listed in the ENEC Agreement.
AUSTRALIA		AS Mark	Electrical and non-electrical products. It guarantees compliance with SAA (Standard Association of Australia).
AUSTRALIA		S.A.A. Mark	Standards Association of Australia (S.A.A.). The Electricity Authority of New South Wales Sydney Australia
AUSTRIA		Austrian Test Mark	Installation equipment and materials

1 Standards

COUNTRY	Symbol	Mark designation	Applicability/Organization
AUSTRIA		ÖVE Identification Thread	Cables
BELGIUM	CEBEC	CEBEC Mark	Installation materials and electrical appliances
BELGIUM	CEBEC	CEBEC Mark	Conduits and ducts, conductors and flexible cords
BELGIUM	CEBEC *	Certification of Conformity	Installation material and electrical appliances (in case there are no equivalent national standards or criteria)
CANADA	SA ®	CSA Mark	Electrical and non-electrical products. This mark guarantees compliance with CSA (Canadian Standard Association)
CHINA		CCEE Mark	Great Wall Mark Commission for Certification of Electrical Equipment
Czech Republic	E C	EZU' Mark	Electrotechnical Testing Institute
Slovakia Republic	E S	EVPU' Mark	Electrotechnical Research and Design Institute

1 Standards

COUNTRY	Symbol	Mark designation	Applicability/Organization
CROATIA	KONČAR	KONKAR	Electrical Engineering Institute
DENMARK	D	DEMKO Approval Mark	Low voltage materials. This mark guarantees the compliance of the product with the requirements (safety) of the “Heavy Current Regulations”
FINLAND	SÄHKÖTARKASTUSLAITOKSEN HYVÄKSYMÄ GODKÄND AV ELEKTRISKA INSPEKTORATET *	Safety Mark of the Elektriska Inspektoratet	Low voltage material. This mark guarantees the compliance of the product with the requirements (safety) of the “Heavy Current Regulations”
FRANCE	CONTRÔLE NF LIMITÈ À LA SÈCURITÈ	ESC Mark	Household appliances
FRANCE	NF USE	NF Mark	Conductors and cables – Conduits and ducting – Installation materials
FRANCE		NF Identification Thread	Cables
FRANCE	OUTILLAGE NF ÉLECTRICITÉ	NF Mark	Portable motor-operated tools
FRANCE	NF ÉLECTRICITÉ	NF Mark	Household appliances

1 Standards

COUNTRY	Symbol	Mark designation	Applicability/Organization
GERMANY		VDE Mark	For appliances and technical equipment, installation accessories such as plugs, sockets, fuses, wires and cables, as well as other components (capacitors, earthing systems, lamp holders and electronic devices)
GERMANY		VDE Identification Thread	Cables and cords
GERMANY		VDE Cable Mark	For cables, insulated cords, installation conduits and ducts
GERMANY		VDE-GS Mark for technical equipment	Safety mark for technical equipment to be affixed after the product has been tested and certified by the VDE Test Laboratory in Offenbach; the conformity mark is the mark VDE, which is granted both to be used alone as well as in combination with the mark GS
HUNGARY		MEEI	Hungarian Institute for Testing and Certification of Electrical Equipment
JAPAN	JIS GIAPPONE	JIS Mark	Mark which guarantees compliance with the relevant Japanese Industrial Standard(s).
IRELAND	IIRS IRLANDA	IIRS Mark	Electrical equipment
IRELAND		IIRS Mark	Electrical equipment

1 Standards

COUNTRY	Symbol	Mark designation	Applicability/Organization
ITALY		IMQ Mark	Mark to be affixed on electrical material for non-skilled users; it certifies compliance with the European Standard(s).
NORWAY		Norwegian Approval Mark	Mandatory safety approval for low voltage material and equipment
NETHERLANDS	KEMA-KEUR	KEMA-KEUR	General for all equipment
POLAND		KWE	Electrical products
RUSSIA		Certification of Conformity	Electrical and non-electrical products. It guarantees complance with national standard (Gosstandard of Russia)
SINGAPORE		SISIR	Electrical and non-electrical products
SLOVENIA	SIQ - Slovenia	SIQ	Slovenian Institute of Quality and Metrology
SPAIN		AEE	Electrical products. The mark is under the control of the Asociación Electrotécnica Española (Spanish Electrotechnical Association)

1 Standards

COUNTRY	Symbol	Mark designation	Applicability/Organization
SPAIN	AENOR Producto Certificado	AENOR	Asociación Española de Normalización y Certificación. (Spanish Standarization and Certification Association)
SWEDEN		SEMKO Mark	Mandatory safety approval for low voltage material and equipment.
SWITZERLAND	* PZ 1	Safety Mark	Swiss low voltage material subject to mandatory approval (safety).
SWITZERLAND	+ S + S + S	–	Cables subject to mandatory approval
SWITZERLAND		SEV Safety Mark	Low voltage material subject to mandatory approval
UNITED KINGDOM		ASTA Mark	Mark which guarantees compliance with the relevant “British Standards”
UNITED KINGDOM		BASEC Mark	Mark which guarantees compliance with the “British Standards” for conductors, cables and ancillary products.
UNITED KINGDOM		BASEC Identification Thread	Cables

1 Standards

COUNTRY	Symbol	Mark designation	Applicability/Organization
UNITED KINGDOM		BEAB Safety Mark	Compliance with the “British Standards” for household appliances
UNITED KINGDOM		BSI Safety Mark	Compliance with the “British Standards”
UNITED KINGDOM		BEAB Kitemark	Compliance with the relevant “British Standards” regarding safety and performances
U.S.A.		UNDERWRITERS LABORATORIES Mark	Electrical and non-electrical products
U.S.A.		UNDERWRITERS LABORATORIES Mark	Electrical and non-electrical products
U.S.A.		UL Recognition	Electrical and non-electrical products
CEN		CEN Mark	Mark issued by the European Committee for Standardization (CEN): it guarantees compliance with the European Standards.
CENELEC		Mark	Cables

1 Standards

COUNTRY	Symbol	Mark designation	Applicability/Organization
CENELEC		Harmonization Mark	Certification mark providing assurance that the harmonized cable complies with the relevant harmonized CENELEC Standards – identification thread
EC		Ex EUROPEA Mark	Mark assuring the compliance with the relevant European Standards of the products to be used in environments with explosion hazards
CEEel		CEEel Mark	Mark which is applicable to some household appliances (shavers, electric clocks, etc).

EC - Declaration of Conformity

The EC Declaration of Conformity is the statement of the manufacturer, who declares under his own responsibility that all the equipment, procedures or services refer and comply with specific standards (directives) or other normative documents.
The EC Declaration of Conformity should contain the following information:
- name and address of the manufacturer or by its European representative;
- description of the product;
- reference to the harmonized standards and directives involved;
- any reference to the technical specifications of conformity;
- the two last digits of the year of affixing of the CE marking;
- identification of the signer.

A copy of the EC Declaration of Conformity shall be kept by the manufacturer or by his representative together with the technical documentation.

1.2 IEC Standards for electrical installation

STANDARD	YEAR	TITLE
IEC 60027-1	1992	Letter symbols to be used in electrical technology - Part 1: General
IEC 60034-1	1999	Rotating electrical machines - Part 1: Rating and performance
IEC 60617-DB-12M	2001	Graphical symbols for diagrams - 12-month subscription to online database comprising parts 2 to 11 of IEC 60617
IEC 61082-1	1991	Preparation of documents used in electrotechnology - Part 1: General requirements
IEC 61082-2	1993	Preparation of documents used in electrotechnology - Part 2: Function-oriented diagrams
IEC 61082-3	1993	Preparation of documents used in electrotechnology - Part 3: Connection diagrams, tables and lists
IEC 61082-4	1996	Preparation of documents used in electrotechnology - Part 4: Location and installation documents
IEC 60038	1983	IEC standard voltages
IEC 60664-1	2000	Insulation coordination for equipment within low-voltage systems - Part 1: Principles, requirements and tests
IEC 60909-0	2001	Short-circuit currents in three-phase a.c. systems - Part 0: Calculation of currents
IEC 60865-1	1993	Short-circuit currents - Calculation of effects - Part 1: Definitions and calculation methods
IEC 60781	1989	Application guide for calculation of short-circuit currents in low-voltage radial systems
IEC 60076-1	2000	Power transformers - Part 1: General
IEC 60076-2	1993	Power transformers - Part 2: Temperature rise
IEC 60076-3	2000	Power transformers - Part 3: Insulation levels, dielectric tests and external clearances in air
IEC 60076-5	2000	Power transformers - Part 5: Ability to withstand short circuit
IEC/TR 60616	1978	Terminal and tapping markings for power transformers
IEC 60726	1982	Dry-type power transformers
IEC 60445	1999	Basic and safety principles for man-machine interface, marking and identification - Identification of equipment terminals and of terminations of certain designated conductors, including general rules for an alphanumeric system

1 Standards

STANDARD	YEAR	TITLE
IEC 60073	1996	Basic and safety principles for man-machine interface, marking and identification – Coding for indication devices and actuators
IEC 60446	1999	Basic and safety principles for man-machine interface, marking and identification - Identification of conductors by colours or numerals
IEC 60447	1993	Man-machine-interface (MMI) - Actuating principles
IEC 60947-1	2001	Low-voltage switchgear and controlgear - Part 1: General rules
IEC 60947-2	2001	Low-voltage switchgear and controlgear - Part 2: Circuit-breakers
IEC 60947-3	2001	Low-voltage switchgear and controlgear - Part 3: Switches, disconnectors, switch-disconnectors and fuse-combination units
IEC 60947-4-1	2000	Low-voltage switchgear and controlgear - Part 4-1: Contactors and motor-starters – Electromechanical contactors and motor-starters
IEC 60947-4-2	2002	Low-voltage switchgear and controlgear - Part 4-2: Contactors and motor-starters – AC semiconductor motor controllers and starters
IEC 60947-4-3	1999	Low-voltage switchgear and controlgear - Part 4-3: Contactors and motor-starters – AC semiconductor controllers and contactors for non-motor loads
IEC 60947-5-1	2000	Low-voltage switchgear and controlgear - Part 5-1: Control circuit devices and switching elements - Electromechanical control circuit devices
IEC 60947-5-2	1999	Low-voltage switchgear and controlgear - Part 5-2: Control circuit devices and switching elements – Proximity switches
IEC 60947-5-3	1999	Low-voltage switchgear and controlgear - Part 5-3: Control circuit devices and switching elements – Requirements for proximity devices with defined behaviour under fault conditions
IEC 60947-5-4	1996	Low-voltage switchgear and controlgear - Part 5: Control circuit devices and switching elements – Section 4: Method of assessing the performance of low energy contacts. Special tests
IEC 60947-5-5	1997	Low-voltage switchgear and controlgear - Part 5-5: Control circuit devices and switching elements - Electrical emergency stop device with mechanical latching function

1 Standards

STANDARD	YEAR	TITLE
IEC 60947-5-6	1999	Low-voltage switchgear and controlgear - Part 5-6: Control circuit devices and switching elements – DC interface for proximity sensors and switching amplifiers (NAMUR)
IEC 60947-6-1	1998	Low-voltage switchgear and controlgear - Part 6-1: Multiple function equipment – Automatic transfer switching equipment
IEC 60947-6-2	1999	Low-voltage switchgear and controlgear - Part 6-2: Multiple function equipment - Control and protective switching devices (or equipment) (CPS)
IEC 60947-7-1	1999	Low-voltage switchgear and controlgear - Part 7: Ancillary equipment - Section 1: Terminal blocks
IEC 60947-7-2	1995	Low-voltage switchgear and controlgear - Part 7: Ancillary equipment - Section 2: Protective conductor terminal blocks for copper conductors
IEC 60439-1	1999	Low-voltage switchgear and controlgear assemblies - Part 1: Type-tested and partially type-tested assemblies
IEC 60439-2	2000	Low-voltage switchgear and controlgear assemblies - Part 2: Particular requirements for busbar trunking systems (busways)
IEC 60439-3	2001	Low-voltage switchgear and controlgear assemblies - Part 3: Particular requirements for low-voltage switchgear and controlgear assemblies intended to be installed in places where unskilled persons have access for their use - Distribution boards
IEC 60439-4	1999	Low-voltage switchgear and controlgear assemblies - Part 3: Particular requirements for low-voltage switchgear and controlgear assemblies intended to be installed in places where unskilled persons have access for their use - Distribution boards
IEC 60439-5	1999	Low-voltage switchgear and controlgear assemblies - Part 3: Particular requirements for low-voltage switchgear and controlgear assemblies intended to be installed in places where unskilled persons have access for their use - Distribution boards
IEC 61095	2000	Low-voltage switchgear and controlgear assemblies - Part 3: Particular requirements for low-voltage switchgear and controlgear assemblies intended to be installed in places where unskilled persons have access for their use - Distribution boards

1 Standards

STANDARD	YEAR	TITLE
IEC 60890	1987	A method of temperature-rise assessment by extrapolation for partially type-tested assemblies (PTTA) of low-voltage switchgear and controlgear
IEC 61117	1992	A method for assessing the short-circuit withstand strength of partially type-tested assemblies (PTTA)
IEC 60092-303	1980	Electrical installations in ships. Part 303: Equipment - Transformers for power and lighting
IEC 60092-301	1980	Electrical installations in ships. Part 301: Equipment - Generators and motors
IEC 60092-101	1994	Electrical installations in ships - Part 101: Definitions and general requirements
IEC 60092-401	1980	Electrical installations in ships. Part 401: Installation and test of completed installation
IEC 60092-201	1994	Electrical installations in ships - Part 201: System design - General
IEC 60092-202	1994	Electrical installations in ships - Part 202: System design - Protection
IEC 60092-302	1997	Electrical installations in ships - Part 302: Low-voltage switchgear and controlgear assemblies
IEC 60092-350	2001	Electrical installations in ships - Part 350: Shipboard power cables - General construction and test requirements
IEC 60092-352	1997	Electrical installations in ships - Part 352: Choice and installation of cables for low-voltage power systems
IEC 60364-5-52	2001	Electrical installations of buildings - Part 5-52: Selection and erection of electrical equipment – Wiring systems
IEC 60227		Polyvinyl chloride insulated cables of rated voltages up to and including 450/750 V
	1998	Part 1: General requirements
	1997	Part 2: Test methods
	1997	Part 3: Non-sheathed cables for fixed wiring
	1997	Part 4: Sheathed cables for fixed wiring
	1998	Part 5: Flexible cables (cords)
	2001	Part 6: Lift cables and cables for flexible connections
	1995	Part 7: Flexible cables screened and unscreened with two or more conductors
IEC 60228	1978	Conductors of insulated cables
IEC 60245		Rubber insulated cables - Rated voltages up to and including 450/750 V
	1998	Part 1: General requirements
	1998	Part 2: Test methods
	1994	Part 3: Heat resistant silicone insulated cables

1 Standards

STANDARD	YEAR	TITLE
	1994	Part 5: Lift cables
	1994	Part 6: Arc welding electrode cables
	1994	Part 7: Heat resistant ethylene-vinyl acetate rubber insulated cables
	1998	Part 8: Cords for applications requiring high flexibility
IEC 60309-2	1999	Plugs, socket-outlets and couplers for industrial purposes - Part 2: Dimensional interchangeability requirements for pin and contact-tube accessories
IEC 61008-1	1996	Residual current operated circuit-breakers without integral overcurrent protection for household and similar uses (RCCBs) - Part 1: General rules
IEC 61008-2-1	1990	Residual current operated circuit-breakers without integral overcurrent protection for household and similar uses (RCCB's). Part 2-1: Applicability of the general rules to RCCB's functionally independent of line voltage
IEC 61008-2-2	1990	Residual current operated circuit-breakers without integral overcurrent protection for household and similar uses (RCCB's). Part 2-2: Applicability of the general rules to RCCB's functionally dependent on line voltage
IEC 61009-1	1996	Residual current operated circuit-breakers with integral overcurrent protection for household and similar uses (RCBOs) - Part 1: General rules
IEC 61009-2-1	1991	Residual current operated circuit-breakers with integral overcurrent protection for household and similar uses (RCBO's) Part 2-1: Applicability of the general rules to RCBO's functionally independent of line voltage
IEC 61009-2-2	1991	Residual current operated circuit-breakers with integral overcurrent protection for household and similar uses (RCBO's) - Part 2-2: Applicability of the general rules to RCBO's functionally dependent on line voltage
IEC 60670	1989	General requirements for enclosures for accessories for household and similar fixed electrical installations
IEC 60669-2-1	2000	Switches for household and similar fixed electrical installations - Part 2-1: Particular requirements – Electronic switches
IEC 60669-2-2	2000	Switches for household and similar fixed electrical installations - Part 2: Particular requirements – Section 2: Remote-control switches (RCS)
IEC 606692-3	1997	Switches for household and similar fixed electrical installations - Part 2-3: Particular requirements – Time-delay switches (TDS)

1 Standards

STANDARD	YEAR	TITLE
IEC 60079-10	1995	Electrical apparatus for explosive gas atmospheres - Part 10: Classification of hazardous areas
IEC 60079-14	1996	Electrical apparatus for explosive gas atmospheres - Part 14: Electrical installations in hazardous areas (other than mines)
IEC 60079-17	1996	Electrical apparatus for explosive gas atmospheres - Part 17: Inspection and maintenance of electrical installations in hazardous areas (other than mines)
IEC 60269-1	1998	Low-voltage fuses - Part 1: General requirements
IEC 60269-2	1986	Low-voltage fuses. Part 2: Supplementary requirements for fuses for use by authorized persons (fuses mainly for industrial application)
IEC 60269-3-1	2000	Low-voltage fuses - Part 3-1: Supplementary requirements for fuses for use by unskilled persons (fuses mainly for household and similar applications) - Sections I to IV
IEC 60127-1/10		Miniature fuses -
	1999	Part 1: Definitions for miniature fuses and general requirements for miniature fuse-links
	1989	Part 2: Cartridge fuse-links
	1988	Part 3: Sub-miniature fuse-links
	1996	Part 4: Universal Modular Fuse-Links (UMF)
	1988	Part 5: Guidelines for quality assessment of miniature fuse-links
	1994	Part 6: Fuse-holders for miniature cartridge fuse-links
	2001	Part 10: User guide for miniature fuses
IEC 60730-2-7	1990	Automatic electrical controls for household and similar use. Part 2: Particular requirements for timers and time switches
IEC 60364-1	2001	Electrical installations of buildings - Part 1: Fundamental principles, assessment of general characteristics, definitions
IEC 60364-4	2001	Electrical installations of buildings - Part 4: Protection for safety
IEC 60364-5	2001…2002	Electrical installations of buildings - Part 5: Selection and erection of electrical equipment
IEC 60364-6	2001	Electrical installations of buildings - Part 6: Verification
IEC 60364-7	1983…2002	Electrical installations of buildings. Part 7: Requirements for special installations or locations
IEC 60529	2001	Degrees of protection provided by enclosures (IP Code)

1 Standards

STANDARD	YEAR	TITLE
IEC 61032	1997	Protection of persons and equipment by enclosures - Probes for verification
IEC 61000-1-1	1992	Electromagnetic compatibility (EMC) - Part 1: General - Section 1: Application and interpretation of fundamental definitions and terms
IEC 61000-1-2	2001	Electromagnetic compatibility (EMC) - Part 1-2: General - Methodology for the achievement of the functional safety of electrical and electronic equipment with regard to electromagnetic phenomena
IEC 61000-1-3	2002	Electromagnetic compatibility (EMC) - Part 1-3: General - The effects of high-altitude EMP (HEMP) on civil equipment and systems

2 Protection of feeders

2.1 Introduction

The following definitions regarding electrical installations are derived from the Standard IEC 60050.

Characteristics of installations

Electrical installation (of a building) An assembly of associated electrical equipment to fulfil a specific purpose and having coordinated characteristics.

Origin of an electrical installation The point at which electrical energy is delivered to an installation.

Neutral conductor (symbol N) A conductor connected to the neutral point of a system and capable of contributing to the transmission of electrical energy.

Protective conductor PE A conductor required by some measures for protection against electric shock for electrically connecting any of the following parts:
- exposed conductive parts;
- extraneous conductive parts;
- main earthing terminal;
- earth electrode;
- earthed point of the source or artificial neutral.

PEN conductor An earthed conductor combining the functions of both protective conductor and neutral conductor

Ambient temperature The temperature of the air or other medium where the equipment is to be used.

Voltages

Nominal voltage (of an installation) Voltage by which an installation or part of an installation is designated.
Note: the actual voltage may differ from the nominal voltage by a quantity within permitted tolerances.

Currents

Design current (of a circuit) The current intended to be carried by a circuit in normal service.

Current-carrying capacity (of a conductor) The maximum current which can be carried continuously by a conductor under specified conditions without its steady-state temperature exceeding a specified value.

Overcurrent Any current exceeding the rated value. For conductors, the rated value is the current-carrying capacity.

Overload current (of a circuit) An overcurrent occurring in a circuit in the absence of an electrical fault.

Short-circuit current An overcurrent resulting from a fault of negligible impedance between live conductors having a difference in potential under normal

2 Protection of feeders

operating conditions.

Conventional operating current (of a protective device) A specified value of the current which cause the protective device to operate within a specified time, designated conventional time.

Overcurrent detection A function establishing that the value of current in a circuit exceeds a predetermined value for a specified length of time.

Leakage current Electrical current in an unwanted conductive path other than a short circuit.

Fault current The current flowing at a given point of a network resulting from a fault at another point of this network.

Wiring systems

Wiring system An assembly made up of a cable or cables or busbars and the parts which secure and, if necessary, enclose the cable(s) or busbars.

Electrical circuits

Electrical circuit (of an installation) An assembly of electrical equipment of the installation supplied from the same origin and protected against overcurrents by the same protective device(s).

Distribution circuit (of buildings) A circuit supplying a distribution board.

Final circuit (of building) A circuit connected directly to current using equipment or to socket-outlets.

Other equipment

Electrical equipment Any item used for such purposes as generation, conversion, transmission, distribution or utilization of electrical energy, such as machines, transformers, apparatus, measuring instruments, protective devices, equipment for wiring systems, appliances.

Current-using equipment Equipment intended to convert electrical energy into another form of energy, for example light, heat, and motive power

Switchgear and controlgear Equipment provided to be connected to an electrical circuit for the purpose of carrying out one or more of the following functions: protection, control, isolation, switching.

Portable equipment Equipment which is moved while in operation or which can easily be moved from one place to another while connected to the supply.

Hand-held equipment Portable equipment intended to be held in the hand during normal use, in which the motor, if any, forms an integral part of the equipment.

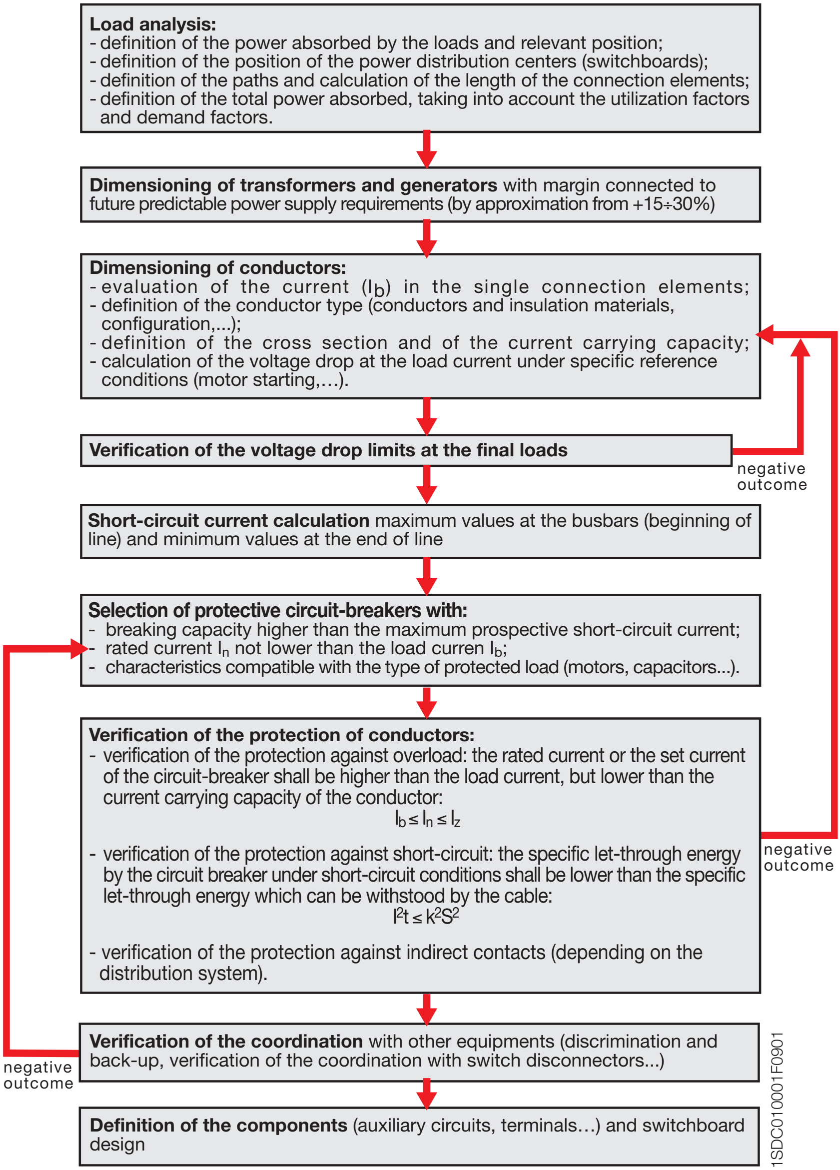
Stationary equipment Either fixed equipment or equipment not provided with a carrying handle and having such a mass that it cannot easily be moved.

Fixed equipment Equipment fastened to a support or otherwise secured in a specific location.

2 Protection of feeders

Installation dimensioning

The flow chart below suggests the procedure to follow for the correct dimensioning of a plant.



2.2 Installation and dimensioning of cables

For a correct dimensioning of a cable, it is necessary to:
- choose the type of cable and installation according to the environment;
- choose the cross section according to the load current;
- verify the voltage drop.

2.2.1 Current carrying capacity and methods of installation

Selection of the cable

The international reference Standard ruling the installation and calculation of the current carrying capacity of cables in residential and industrial buildings is IEC 60364-5-52 *"Electrical installations of buildings – Part 5-52 Selection and Erection of Electrical Equipment- Wiring systems".*
The following parameters are used to select the cable type:
- conductive material (copper or aluminium): the choice depends on cost, dimension and weight requirements, resistance to corrosive environments (chemical reagents or oxidizing elements). In general, the carrying capacity of a copper conductor is about 30% greater than the carrying capacity of an aluminium conductor of the same cross section. An aluminium conductor of the same cross section has an electrical resistance about 60% higher and a weight half to one third lower than a copper conductor.

- insulation material (none, PVC, XLPE-EPR): the insulation material affects the maximum temperature under normal and short-circuit conditions and therefore the exploitation of the conductor cross section [see Chapter 2.4 "Protection against short-circuit"].

- the type of conductor (bare conductor, single-core cable without sheath, single-core cable with sheath, multi-core cable) is selected according to mechanical resistance, degree of insulation and difficulty of installation (bends, joints along the route, barriers...) required by the method of installation.

Table 1 shows the types of conductors permitted by the different methods of installation.

Table 1: Selection of wiring systems

Conductors and cables		Method of installation: Without fixings	Clipped direct	Conduit	Cable trunking (including skirting trunking, flush floor trunking)	Cable ducting	Cable ladder Cable tray Cable brackets	On insulators	Support wire
Bare conductors		-	-	-	-	-	-	+	-
Insulated conductors		-	-	+	+	+	-	+	-
Sheathed cables (including armoured and mineral insulated)	Multi-core	+	+	+	+	+	+	0	+
	Single-core	0	+	+	+	+	+	0	+

\+ Permitted.
– Not permitted.
0 Not applicable, or not normally used in practice.

2 Protection of feeders

For industrial installations, multi-core cables are rarely used with cross section greater than 95 mm^2.

Methods of installation

To define the current carrying capacity of the conductor and therefore to identify the correct cross section for the load current, the standardized method of installation that better suits the actual installation situation must be identified among those described in the mentioned reference Standard.
From Tables 2 and 3 it is possible to identify the installation identification number, the method of installation (A1, A2, B1, B2, C, D, E, F, G) and the tables to define the theoretical current carrying capacity of the conductor and any correction factors required to allow for particular environmental and installation situations.

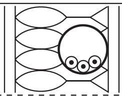
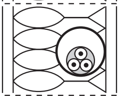
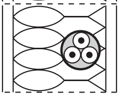
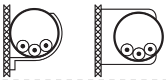
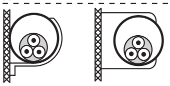
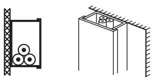
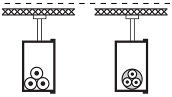
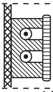
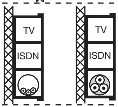
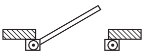
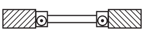
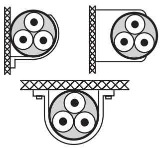
Table 2: Method of installation

	Method of installation							
Situations	**Without fixings**	**With fixings**	**Conduit**	**Cable trunking (including skirting trunking, flush floor trunking)**	**Cable ducting**	**Cable ladder Cable tray Cable brackets**	**On insulators**	**Support wire**
Building voids	40, 46, 15, 16	0	15, 16	-	0	30, 31, 32, 33, 34	-	-
Cable channel	56	56	54, 55	0	44	30, 31, 32, 33, 34	-	-
Buried in Ground	72, 73	0	70, 71	-	70, 71	0	-	-
Embedded in Structure	57, 58	3	1, 2 59, 60	50, 51, 52, 53	44, 45	0	-	-
Surface Mounted	-	20, 21	4, 5	6, 7, 8, 9, 12, 13, 14	6, 7, 8, 9	30, 31, 32, 33, 34	36	-
Overhead	-	-	0	10, 11	-	30, 31, 32, 33, 34	36	35

The number in each box indicates the item number in Table 3.
- Not permitted.
0 Not applicable or not normally used in practice.

2 Protection of feeders

Table 3: Examples of methods of installation

Methods of installation	Item n.	Description	Reference method of installation to be used to obtain current-carrying capacity
	1	Insulated conductors or single-core cables in conduit in a thermally insulated wall	A1
	2	Multi-core cables in conduit in a thermally insulated wall	A2
	3	Multi-core cable direct in a thermally insulated wall	A1
	4	Insulated conductors or single-core cables in conduit on a wooden, or masonry wall or spaced less than 0.3 times conduit diameter from it	B1
	5	Multi-core cable in conduit on a wooden, or masonry wall or spaced less than 0.3 times conduit diameter from it	B2
	6 7	Insulated conductors or single-core cables in cable trunking on a wooden wall – run horizontally (6) – run vertically (7)	B1
	8 9	Insulated conductors or single-core cable in suspended cable trunking (8) Multi-core cable in suspended cable trunking (9)	B1 (8) or B2 (9)
	12	Insulated conductors or single-core cable run in mouldings	A1
	13 14	Insulated conductors or single-core cables in skirting trunking (13) Multi-core cable in skirting trunking (14)	B1 (13) or B2 (14)
	15	Insulated conductors in conduit or single-core or multi-core cable in architrave	A1
	16	Insulated conductors in conduit or single-core or multi-core cable in window frames	A1
	20 21	Single-core or multi-core cables: – fixed on, or spaced less than 0.3 times (20) cable diameter from a wooden wall – fixed directly under a wooden ceiling (21)	C

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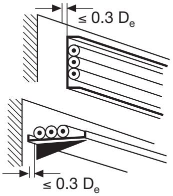
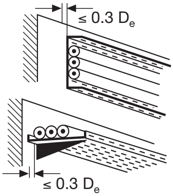
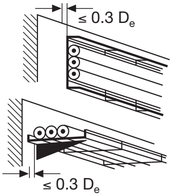
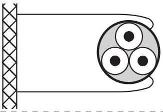
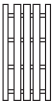
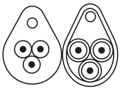
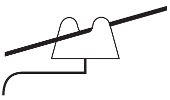
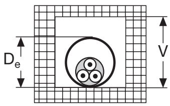
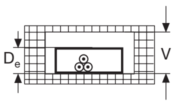
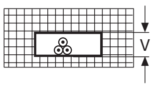
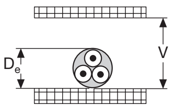
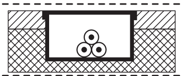
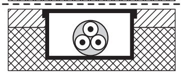
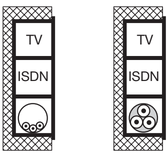
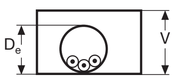
2 Protection of feeders

Methods of installation	Item n.	Description	Reference method of installation to be used to obtain current-carrying capacity
	30	On unperforated tray [1]	C
	31	On perforated tray [1]	E or F
	32	On brackets or on a wire mesh [1]	E or F
	33	Spaced more than 0.3 times cable diameter from a wall	E or F or G
	34	On ladder	E or F
	35	Single-core or multi-core cable suspended from or incorporating a support wire	E or F
	36	Bare or insulated conductors on insulators	G

2 Protection of feeders

Methods of installation	Item n.	Description	Reference method of installation to be used to obtain current-carrying capacity
	40	Single-core or multi-core cable in a building void [2]	$1.5\,D_e \le V < 20\,D_e$ B2 $V \ge 20\,D_e$ B1
	24	Insulated conductors in cable ducting in a building void [2]	$1.5\,D_e \le V < 20\,D_e$ B2 $V \ge 20\,D_e$ B1
	44	Insulated conductors in cable ducting in masonry having a thermal resistivity not greater than 2 Km/W	$1.5\,D_e \le V < 5\,D_e$ B2 $5\,D_e \le V < 50\,D_e$ B1
	46	Single-core or multi-core cable: – in a ceiling void – in a suspended floor [1]	$1.5\,D_e \le V < 5\,D_e$ B2 $5\,D_e \le V < 50\,D_e$ B1
	50	Insulated conductors or single-core cable in flush cable trunking in the floor	B1
	51	Multi-core cable in flush cable trunking in the floor	B2
	52 53	Insulated conductors or single-core cables in embedded trunking (52) Multi-core cable in embedded trunking (53)	B1 (52) or B2 (53)
	54	Insulated conductors or single-core cables in conduit in an unventilated cable channel run horizontally or vertically [2]	$1.5\,D_e \le V < 20\,D_e$ B2 $V \ge 20\,D_e$ B1

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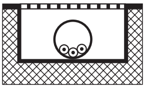
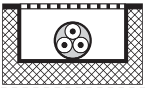
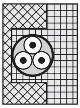
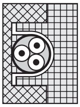
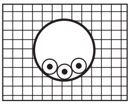
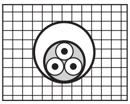
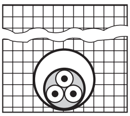
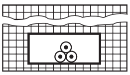
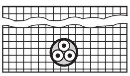
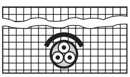
2 Protection of feeders

Methods of installation	Item n.	Description	Reference method of installation to be used to obtain current-carrying capacity
	55	Insulated conductors in conduit in an open or ventilated cable channel in the floor	B1
	56	Sheathed single-core or multi-core cable in an open or ventilated cable channel run horizontally or vertically	B1
	57	Single-core or multi-core cable direct in masonry having a thermal resistivity not greater than 2 Km/W Without added mechanical protection	C
	58	Single-core or multi-core cable direct in masonry having a thermal resistivity not greater than 2 Km/W With added mechanical protection	C
	59	Insulated conductors or single-core cables in conduit in masonry	B1
	60	Multi-core cables in conduit in masonry	B2
	70	Multi-core cable in conduit or in cable ducting in the ground	D
	71	Single-core cable in conduit or in cable ducting in the ground	D
	72	Sheathed single-core or multi-core cables direct in the ground – without added mechanical protection	D
	73	Sheathed single-core or multi-core cables direct in the ground – with added mechanical protection	D

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[1]D_e is the external diameter of a multi-core cable:
– 2.2 x the cable diameter when three single core cables are bound in trefoil, or
– 3 x the cable diameter when three single core cables are laid in flat formation.
[2] D_e is the external diameter of conduit or vertical depth of cable ducting.
V is the smaller dimension or diameter of a masonry duct or void, or the vertical depth of a rectangular duct, floor or ceiling void. The depth of the channel is more important than the width.

2 Protection of feeders

Installation not buried in the ground: choice of the cross section according to cable carrying capacity and type of installation

The cable carrying capacity of a cable that is not buried in the ground is obtained by using this formula:

$$I_z = I_0 k_1 k_2 = I_0 k_{tot}$$

where:

- I_0 is the current carrying capacity of the single conductor at 30 °C reference ambient temperature;
- k_1 is the correction factor if the ambient temperature is other than 30 °C;
- k_2 is the correction factor for cables installed bunched or in layers or for cables installed in a layer on several supports.

Correction factor k_1

The current carrying capacity of the cables that are not buried in the ground refers to 30 °C ambient temperature. If the ambient temperature of the place of installation is different from this reference temperature, the correction factor k_1 on Table 4 shall be used, according to the insulation material.

Table 4: Correction factor for ambient air temperature other than 30 °C

Ambient temperature [a] °C	Insulation			
			Mineral [a]	
	PVC	XLPE and EPR	PVC covered or bare and exposed to touch 70 °C	Bare not exposed to touch 105 °C
10	1.22	1.15	1.26	1.14
15	1.17	1.12	1.20	1.11
20	1.12	1.08	1.14	1.07
25	1.06	1.04	1.07	1.04
35	0.94	0.96	0.93	0.96
40	0.87	0.91	0.85	0.92
45	0.79	0.87	0.87	0.88
50	0.71	0.82	0.67	0.84
55	0.61	0.76	0.57	0.80
60	0.50	0.71	0.45	0.75
65	–	0.65	–	0.70
70	–	0.58	–	0.65
75	–	0.50	–	0.60
80	–	0.41	–	0.54
85	–	–	–	0.47
90	–	–	–	0.40
95	–	–	–	0.32

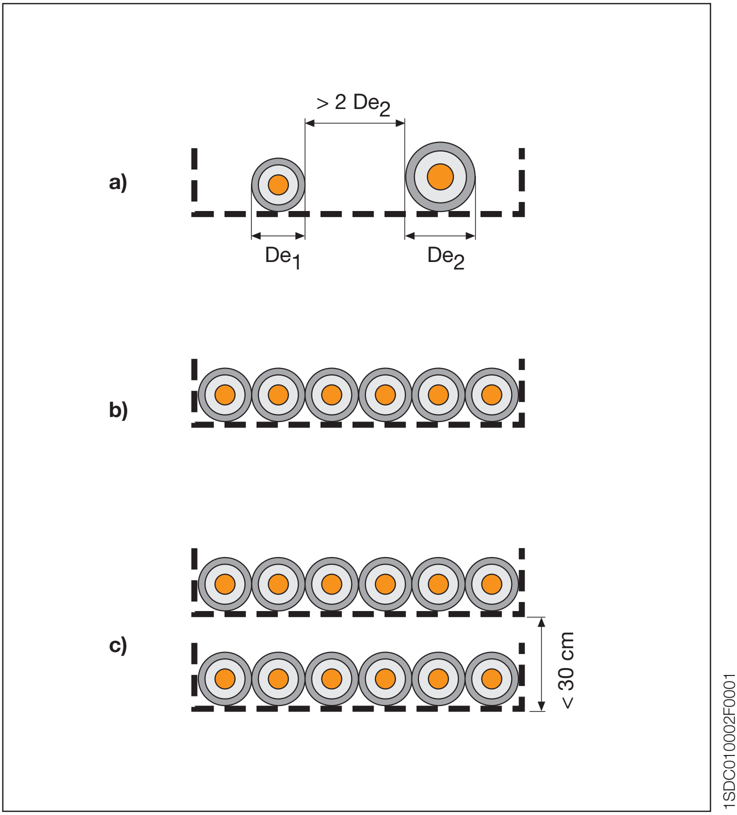
[a] For higher ambient temperatures, consult manufacturer.

2 Protection of feeders

Correction factor k_2

The cable current carrying capacity is influenced by the presence of other cables installed nearby. The heat dissipation of a single cable is different from that of the same cable when installed next to the other ones. The factor k_2 is tabled according to the installation of cables laid close together in layers or bunches.

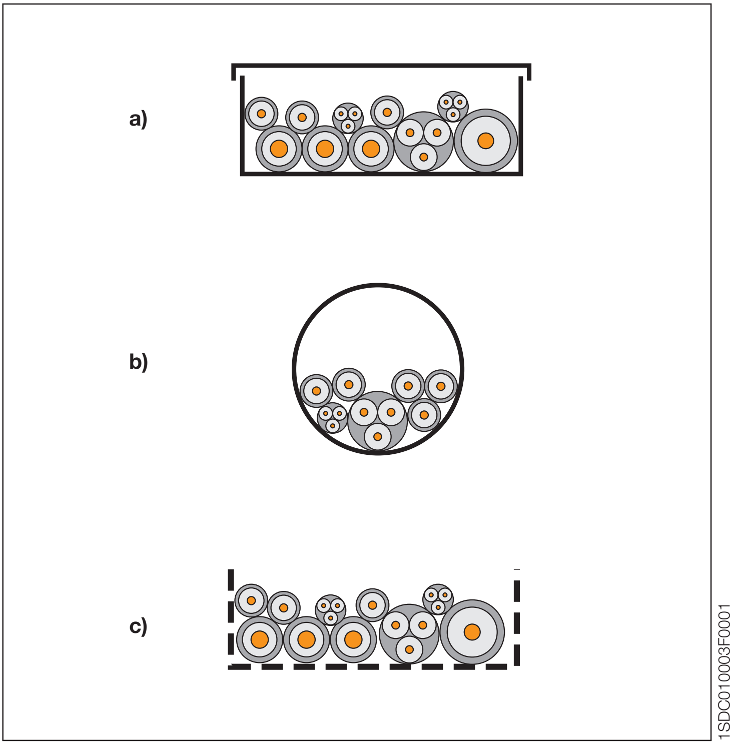
Definition of layer or bunch
layer: several circuits constituted by cables installed one next to another, spaced or not, arranged horizontally or vertically. The cables on a layer are installed on a wall, tray, ceiling, floor or on a cable ladder;



Cables in layers: a) spaced; b) not spaced; c) double layer

bunch: several circuits constituted by cables that are not spaced and are not installed in a layer; several layers superimposed on a single support (e.g. tray) are considered to be a bunch.

2 Protection of feeders



Bunched cables: a) in trunking; b) in conduit; c) on perforated tray

The value of correction factor k_2 is 1 when:
• the cables are spaced:
  - two single-core cables belonging to different circuits are spaced when the distance between them is more than twice the external diameter of the cable with the larger cross section;
  - two multi-core cables are spaced when the distance between them is at least the same as the external diameter of the larger cable;
• the adjacent cables are loaded less than 30 % of their current carrying capacity.

The correction factors for bunched cables or cables in layers are calculated by assuming that the bunches consist of similar cables that are equally loaded. A group of cables is considered to consist of similar cables when the calculation of the current carrying capacity is based on the same maximum allowed operating temperature and when the cross sections of the conductors is in the range of three adjacent standard cross sections (e.g. from 10 to 25 mm^2).
The calculation of the reduction factors for bunched cables with different cross sections depends on the number of cables and on their cross sections. These factors have not been tabled, but must be calculated for each bunch or layer.

2 Protection of feeders

The reduction factor for a group containing different cross sections of insulated conductors or cables in conduits, cable trunking or cable ducting is:

$$k_2 = \frac{1}{\sqrt{n}}$$

where:

• k_2 is the group reduction factor;

• n is the number of circuits of the bunch.

The reduction factor obtained by this equation reduces the danger of overloading of cables with a smaller cross section, but may lead to under utilization of cables with a larger cross section. Such under utilization can be avoided if large and small cables are not mixed in the same group.

The following tables show the reduction factor (k_2).

Table 5: Reduction factor for grouped cables

Item	Arrangement (cables touching)	Number of circuits or multi-core cables: 1	2	3	4	5	6	7	8	9	12	16	20	To be used with current-carrying capacities, reference
1	Bunched in air, on a surface, embedded or enclosed	1.00	0.80	0.70	0.65	0.60	0.57	0.54	0.52	0.50	0.45	0.41	0.38	Methods A to F
2	Single layer on wall, floor or unperforated tray	1.00	0.85	0.79	0.75	0.73	0.72	0.72	0.71	0.70				Method C
3	Single layer fixed directly under a wooden ceiling	0.95	0.81	0.72	0.68	0.66	0.64	0.63	0.62	0.61	No further reduction factor for more than nine circuits or multicore cables			
4	Single layer on a perforated horizontal or vertical tray	1.00	0.88	0.82	0.77	0.75	0.73	0.73	0.72	0.72				Methods E and F
5	Single layer on ladder support or cleats etc.	1.00	0.87	0.82	0.80	0.80	0.79	0.79	0.78	0.78				

NOTE 1 These factors are applicable to uniform groups of cables, equally loaded.

NOTE 2 Where horizontal clearances between adjacent cables exceeds twice their overall diameter, no reduction factor need be applied.

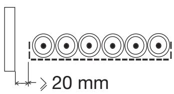
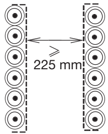
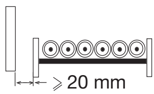
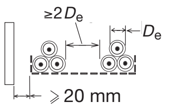
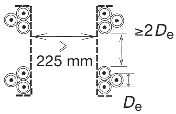
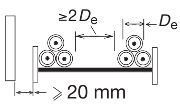
NOTE 3 The same factors are applied to:
- groups of two or three single-core cables;
- multi-core cables.

NOTE 4 If a system consists of both two- and three-core cables, the total number of cables is taken as the number of circuits, and the corresponding factor is applied to the tables for two loaded conductors for the two-core cables, and to the tables for three loaded conductors for the three-core cables.

NOTE 5 If a group consists of n single-core cables it may either be considered as n/2 circuits of two loaded conductors or n/3 circuits of three loaded conductors.

2 Protection of feeders

Table 6: Reduction factor for single-core cables with method of installation F

Method of installation in Table 3			Number of trays	Number of three-phase circuits (note 4)			Use as a multiplier to rating for
				1	2	3	
Perforated trays (note 2)	31	Touching 	1 2 3	0.98 0.96 0.95	0.91 0.87 0.85	0.87 0.81 0.78	Three cables in horizontal formation
Vertical perforated trays (note 3)	31	Touching 	1 2	0.96 0.95	0.86 0.84	– –	Three cables in vertical formation
Ladder supports, cleats, etc. (note 2)	32 33 34	Touching 	1 2 3	1.00 0.98 0.97	0.97 0.93 0.90	0.96 0.89 0.86	Three cables in horizontal formation
Perforated trays (note 2)	31		1 2 3	1.00 0.97 0.96	0.98 0.93 0.92	0.96 0.89 0.86	
Vertical perforated trays (note 3)	31	Spaced 	1 2	1.00 1.00	0.91 0.90	0.89 0.86	Three cables in trefoil formation
Ladder supports, cleats, etc. (note 2)	32 33 34		1 2 3	1.00 0.97 0.96	1.00 0.95 0.94	1.00 0.93 0.90	

NOTE 1 Factors are given for single layers of cables (or trefoil groups) as shown in the table and do not apply when cables are installed in more than one layer touching each other. Values for such installations may be significantly lower and must be determined by an appropriate method.

NOTE 2 Values are given for vertical spacings between trays of 300 mm. For closer spacing the factors should be reduced.

NOTE 3 Values are given for horizontal spacing between trays of 225 mm with trays mounted back to back and at least 20 mm between the tray and any wall. For closer spacing the factors should be reduced.

NOTE 4 For circuits having more than one cable in parallel per phase, each three phase set of conductors should be considered as a circuit for the purpose of this table.

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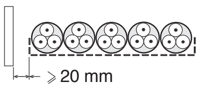
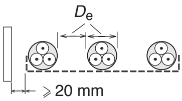
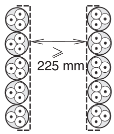
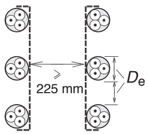
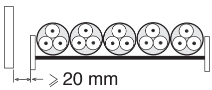
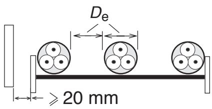
2 Protection of feeders

Table 7: Reduction factor for multi-core cables with method of installation E

Method of installation in Table 3			Number of trays	Number of cables: 1	2	3	4	6	9
Perforated trays (note 2)	31	Touching 	1	1.00	0.88	0.82	0.79	0.76	0.73
			2	1.00	0.87	0.80	0.77	0.73	0.68
			3	1.00	0.86	0.79	0.76	0.71	0.66
		Spaced 	1	1.00	1.00	0.98	0.95	0.91	–
			2	1.00	0.99	0.96	0.92	0.87	–
			3	1.00	0.98	0.95	0.91	0.85	–
Vertical perforated trays (note 3)	31	Touching 	1	1.00	0.88	0.82	0.78	0.73	0.72
			2	1.00	0.88	0.81	0.76	0.71	0.70
		Spaced 	1	1.00	0.91	0.89	0.88	0.87	–
			2	1.00	0.91	0.88	0.87	0.85	–
Ladder supports, cleats, etc. (note 2)	32 33 34	Touching 	1	1.00	0.87	0.82	0.80	0.79	0.78
			2	1.00	0,86	0.80	0.78	0.76	0.73
			3	1.00	0.85	0.79	0.76	0.73	0.70
		Spaced 	1	1.00	1.00	1.00	1.00	1.00	–
			2	1.00	0.99	0.98	0.97	0.96	–
			3	1.00	0.98	0.97	0.96	0.93	–

NOTE 1 Factors apply to single layer groups of cables as shown above and do not apply when cables are installed in more than one layer touching each other. Values for such installations may be significantly lower and must be determined by an appropriate method.

NOTE 2 Values are given for vertical spacings between trays of 300 mm and at least 20 mm between trays and wall. For closer spacing the factors should be reduced.

NOTE 3 Values are given for horizontal spacing between trays of 225 mm with trays mounted back to back. For closer spacing the factors should be reduced.

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2 Protection of feeders

To summarize:

The following procedure shall be used to determine the cross section of the cable:

1. from Table 3 identify the method of installation;

2. from Table 4 determine the correction factor k_1 according to insulation material and ambient temperature;

3. use Table 5 for cables installed in layer or bunch, Table 6 for single-core cables in a layer on several supports, Table 7 for multi-core cables in a layer on several supports or the formula shown in the case of groups of cables with different sections to determine the correction factor k_2 appropriate for the numbers of circuits or multi-core cables;

4. calculate the value of current I'_b by dividing the load current I_b (or the rated current of the protective device) by the product of the correction factors calculated:

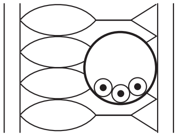
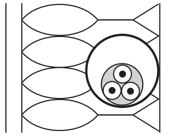
$$I'_b = \frac{I_b}{k_1 k_2} = \frac{I_b}{k_{tot}}$$

5. from Table 8 or from Table 9, depending on the method of installation, on insulation and conductive material and on the number of live conductors, determine the cross section of the cable with capacity $I_0 \geq I'_b$;

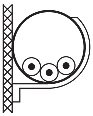
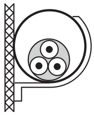
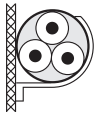
6. the actual cable current carrying capacity is calculated by $I_Z = I_0 \, k_1 \, k_2$.

2 Protection of feeders

Table 8: Current carrying capacity of cables with PVC or EPR/XLPE insulation (method A-B-C)

Installation method	A1								A2									
																		
Conductor	Cu				Al				Cu				Al				Cu	
Insulation	XLPE EPR		PVC		XLPE EPR		PVC		XLPE EPR		PVC		XLPE EPR		PVC		XLPE EPR	
S[mm^2] / Loaded conductors	2	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3
1.5	19	17	14.5	13.5					18.5	16.5	14	13					23	20
2.5	26	23	19.5	18	20	19	14.5	14	25	22	18.5	17.5	19.5	18	14.5	13.5	31	28
4	35	31	26	24	27	25	20	18.5	33	30	25	23	26	24	20	17.5	42	37
6	45	40	34	31	35	32	26	24	42	38	32	29	33	31	25	23	54	48
10	61	54	46	42	48	44	36	32	57	51	43	39	45	41	33	31	75	66
16	81	73	61	56	64	58	48	43	76	68	57	52	60	55	44	41	100	88
25	106	95	80	73	84	76	63	57	99	89	75	68	78	71	58	53	133	117
35	131	117	99	89	103	94	77	70	121	109	92	83	96	87	71	65	164	144
50	158	141	119	108	125	113	93	84	145	130	110	99	115	104	86	78	198	175
70	200	179	151	136	158	142	118	107	183	164	139	125	145	131	108	98	253	222
95	241	216	182	164	191	171	142	129	220	197	167	150	175	157	130	118	306	269
120	278	249	210	188	220	197	164	149	253	227	192	172	201	180	150	135	354	312
150	318	285	240	216	253	226	189	170	290	259	219	196	230	206	172	155		
185	362	324	273	245	288	256	215	194	329	295	248	223	262	233	195	176		
240	424	380	321	286	338	300	252	227	386	346	291	261	307	273	229	207		
300	486	435	367	328	387	344	289	261	442	396	334	298	352	313	263	237		
400																		
500																		
630																		

2 Protection of feeders

B1						B2								C							
																					
		Al				Cu				Al				Cu				Al			
PVC		XLPE EPR		PVC		XLPE EPR		PVC		XLPE EPR		PVC		XLPE EPR		PVC		XLPE/EPR		PVC	
2	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3
17.5	15.5					22	19.5	16.5	15					24	22	19.5	17.5				
24	21	25	22	18.5	16.5	30	26	23	20	23	21	17.5	15.5	33	30	27	24	26	24	21	18.5
32	28	33	29	25	22.0	40	35	30	27	31	28	24	21	45	40	36	32	35	32	28	25
41	36	43	38	32	28	51	44	38	34	40	35	30	27.0	58	52	46	41	45	41	36	32
57	50	59	52	44	39	69	60	52	46	54	48	41	36	80	71	63	57	62	57	49	44
76	68	79	71	60	53	91	80	69	62	72	64	54	48	107	96	85	76	84	76	66	59
101	89	105	93	79	70	119	105	90	80	94	84	71	62	138	119	112	96	101	90	83	73
125	110	130	116	97	86	146	128	111	99	115	103	86	77	171	147	138	119	126	112	103	90
151	134	157	140	118	104	175	154	133	118	138	124	104	92	209	179	168	144	154	136	125	110
192	171	200	179	150	133	221	194	168	149	175	156	131	116	269	229	213	184	198	174	160	140
232	207	242	217	181	161	265	233	201	179	210	188	157	139	328	278	258	223	241	211	195	170
269	239	281	251	210	186	305	268	232	206	242	216	181	160	382	322	299	259	280	245	226	197
														441	371	344	299	324	283	261	227
														506	424	392	341	371	323	298	259
														599	500	461	403	439	382	352	305
														693	576	530	464	508	440	406	351

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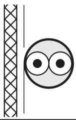
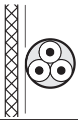
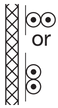
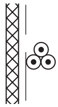
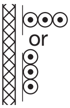
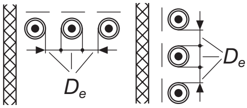
2 Protection of feeders

Table 8: Current carrying capacity of cables with PVC or EPR/XLPE insulation (method E-F-G)

	Installation method	E								F							
																	
		Cu		Al		Cu		Al		Cu		Al		Cu		Al	
	Insulation	XLPE EPR	PVC	XLPE EPR	PVC	XLPE EPR	PVC	XLPE EPR	PVC	XLPE EPR	PVC	XLPE EPR	PVC	XLPE EPR	PVC	XLPE EPR	PVC
S[mm^2]	Loaded conductors	2				3				2				3			
1.5		26	22			23	18.5										
2.5		36	30	28	23	32	2	24	19.5								
4		49	40	38	31	42	34	32	26								
6		63	51	49	39	54	43	42	33								
10		86	70	67	54	75	60	58	46								
16		115	94	91	73	100	80	77	61								
25		149	119	108	89	127	101	97	78	161	131	121	98	13	110	103	845
35		185	148	135	111	158	126	120	96	200	162	150	122	169	137	129	105
50		225	180	164	135	192	153	146	117	242	196	184	149	207	167	159	128
70		289	232	211	173	246	196	187	150	310	251	237	192	268	216	206	166
95		352	282	257	210	298	238	227	183	377	304	289	235	328	264	253	203
120		410	328	300	244	346	276	263	212	437	352	337	273	383	308	296	237
150		473	379	346	282	399	319	304	245	504	406	389	316	444	356	343	274
185		542	434	397	322	456	364	347	280	575	463	447	363	510	409	395	315
240		641	514	470	380	538	430	409	330	679	546	530	430	607	485	471	375
300		741	593	543	439	621	497	471	381	783	629	613	497	703	561	547	434
400										940	754	740	600	823	656	663	526
500										1083	868	856	694	946	749	770	610
630										1254	1005	996	808	1088	855	899	711

2 Protection of feeders

				G							
											
Cu		Al		Cu				Al			
XLPE EPR	PVC	XLPE EPR	PVC	XLPE EPR		PV		XLPE EPR		PV	
3				3H	3V	3H	3V	3H	3V	3H	3V
141	114	107	87	182	161	146	130	138	122	112	99
176	143	135	109	226	201	181	162	172	153	139	124
216	174	165	133	275	246	219	197	210	188	169	152
279	225	215	173	353	318	281	254	271	244	217	196
342	275	264	212	430	389	341	311	332	300	265	241
400	321	308	247	500	454	396	362	387	351	308	282
464	372	358	287	577	527	456	419	448	408	356	327
533	427	413	330	661	605	521	480	515	470	407	376
634	507	492	392	781	719	615	569	611	561	482	447
736	587	571	455	902	833	709	659	708	652	557	519
868	689	694	552	1085	1008	852	795	856	792	671	629
998	789	806	640	1253	1169	982	920	991	921	775	730
1151	905	942	746	1454	1362	1138	1070	1154	1077	900	852

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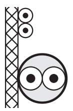
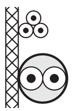
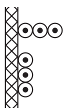
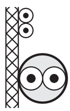
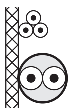
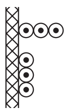
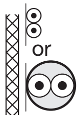
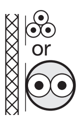
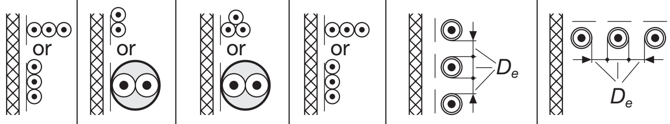
2 Protection of feeders

Table 9: Current carrying capacity of cables with mineral insulation

	Installation method	C							
	Sheath	Metallic sheath temperature 70 °C			Metallic sheath temperature 105 °C			Metallic sheath temperature	
		PVC covered or bare exposed to touch			Bare cable not exposed to touch			PVC covered or bare exposed to touch	
	Loaded conductors								
	S[mm^2]	2	3	3	2	3	3	2	3
500 V	1.5	23	19	21	28	24	27	25	21
	2.5	31	26	29	38	33	36	33	28
	4	40	35	38	51	44	47	44	37
750 V	1.5	25	21	23	31	26	30	26	22
	2.5	34	28	31	42	35	41	36	30
	4	45	37	41	55	47	53	47	40
	6	57	48	52	70	59	67	60	51
	10	77	65	70	96	81	91	82	69
	16	102	86	92	127	107	119	109	92
	25	133	112	120	166	140	154	142	120
	35	163	137	147	203	171	187	174	147
	50	202	169	181	251	212	230	215	182
	70	247	207	221	307	260	280	264	223
	95	296	249	264	369	312	334	317	267
	120	340	286	303	424	359	383	364	308
	150	388	327	346	485	410	435	416	352
	185	440	371	392	550	465	492	472	399
	240	514	434	457	643	544	572	552	466

Note 1 For single-core cables the sheaths of the cables of the circuit are connected together at both ends.
Note 2 For bare cables exposed to touch, values should be multiplied by 0.9.
Note 3 D_e is the external diameter of the cable.
Note 4 For metallic sheath temperature 105 °C no correction for grouping need to be applied.

2 Protection of feeders

E or F				G			
70 °C	Metallic sheath temperature 105 °C			Metallic sheath temperature 70 °C		Metallic sheath temperature 105 °C	
	Bare cable not exposed to touch			PVC covered or bare exposed to touch		Bare cable not exposed to touch	
							
3	2	3	3	3	3	3	3
23	31	26	29	26	29	33	37
31	41	35	39	34	39	43	49
41	54	46	51	45	51	56	64
26	33	28	32	28	32	35	40
34	45	38	43	37	43	47	54
45	60	50	56	49	56	61	70
57	76	64	71	62	71	78	89
77	104	87	96	84	95	105	120
102	137	115	127	110	125	137	157
132	179	150	164	142	162	178	204
161	220	184	200	173	197	216	248
198	272	228	247	213	242	266	304
241	333	279	300	259	294	323	370
289	400	335	359	309	351	385	441
331	460	385	411	353	402	441	505
377	526	441	469	400	454	498	565
426	596	500	530	446	507	557	629
496	697	584	617	497	565	624	704

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2 Protection of feeders

Installation in ground: choice of the cross section according to cable carrying capacity and type of installation

The current carrying capacity of a cable buried in the ground is calculated by using this formula:

$$I_z = I_0 k_1 k_2 k_3 = I_0 k_{tot}$$

where:
- I_0 is the current carrying capacity of the single conductor for installation in the ground at 20°C reference temperature;
- k_1 is the correction factor if the temperature of the ground is other than 20°C;
- k_2 is the correction factor for adjacent cables;
- k_3 is the correction factor if the soil thermal resistivity is different from the reference value, 2.5 Km/W.

Correction factor k_1

The current carrying capacity of buried cables refers to a ground temperature of 20 °C. If the ground temperature is different, use the correction factor k_1 shown in Table 10 according to the insulation material.

Table 10: Correction factors for ambient ground temperatures other than 20 °C

Ground temperature °C	Insulation	
	PVC	XLPE and EPR
10	1.10	1.07
15	1.05	1.04
25	0.95	0.96
30	0.89	0.93
35	0.84	0.89
40	0.77	0.85
45	0.71	0.80
50	0.63	0.76
55	0.55	0.71
60	0.45	0.65
65	–	0.60
70	–	0.53
75	–	0.46
80	–	0.38

2 Protection of feeders

Correction factor k_2

The cable current carrying capacity is influenced by the presence of other cables installed nearby. The heat dissipation of a single cable is different from that of the same cable installed next to the other ones.
The correction factor k_2 is obtained by the formula:

$$k_2 = k_2' \cdot k_2''$$

Tables 11, 12, and 13 show the factor k_2' values for single-core and multi-core cables that are laid directly in the ground or which are installed in buried ducts, according to their distance from other cables or the distance between the ducts.

Table 11: Reduction factors for cables laid directly in the ground

	Cable to cable clearance (a)				
Number of circuits	**Nil (cables touching)**	**One cable diameter**	**0.125 m**	**0.25 m**	**0.5 m**
2	0.75	0.80	0.85	0.90	0.90
3	0.65	0.70	0.75	0.80	0.85
4	0.60	0.60	0.70	0.75	0.80
5	0.55	0.55	0.65	0.70	0.80
6	0.50	0.55	0.60	0.70	0.80

Multi-core cables

Single-core cables

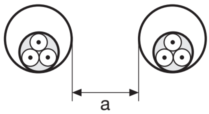
NOTE The given values apply to an installation depth of 0.7 m and a soil thermal resistivity of 2.5 Km/W.

2 Protection of feeders

Table 12: Reduction factors for multi-core cables laid in single way ducts in the ground

Number of circuits	Cable to cable clearance (a) Nil (cables touching)	0.25 m	0.5 m	1.0 m
2	0.85	0.90	0.95	0.95
3	0.75	0.85	0.90	0.95
4	0.70	0.80	0.85	0.90
5	0.65	0.80	0.85	0.90
6	0.60	0.80	0.80	0.90

Multi-core cables

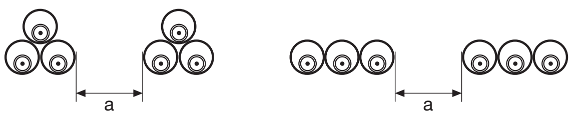


NOTE The given values apply to an installation depth of 0.7 m and a soil thermal resistivity of 2.5 Km/W.

Table 13: Reduction factors for single-core cables laid in single way ducts in the ground

Number of single-core circuits of two or three cables	Duct to duct clearance (a) Nil (ducts touching)	0.25 m	0.5 m	1.0 m
2	0.80	0.90	0.90	0.95
3	0.70	0.80	0.85	0.90
4	0.65	0.75	0.80	0.90
5	0.60	0.70	0.80	0.90
6	0.60	0.70	0.80	0.90

Single-core cables



NOTE The given values apply to an installation depth of 0.7 m and a soil thermal resistivity of 2.5 Km/W.

2 Protection of feeders

For correction factor k_2”:
- for cables laid directly in the ground or if there are not other conductors within the same duct, the value of k_2” is 1;
- if several conductors of similar sizes are present in the same duct (for the meaning of “group of similar conductors”, see the paragraphs above), k_2” is obtained from the first row of Table 5;
- if the conductors are not of similar size, the correction factor is calculated by using this formula:

$$k_2'' = \frac{1}{\sqrt{n}}$$

where:
n is the number of circuits in the duct.

Correction factor k_3

Soil thermal resistivity influences the heat dissipation of the cable. Soil with low thermal resistivity facilitates heat dissipation, whereas soil with high thermal resistivity limits heat dissipation. IEC 60364-5-52 states as reference value for the soil thermal resistivity 2.5 Km/W.

Table 14: Correction factors for soil thermal resistivities other than 2.5 Km/W

Thermal resistivities Km/W	1	1.5	2	2.5	3
Correction factor	1.18	1.1	1.05	1	0.96

Note 1: the overall accuracy of correction factors is within ±5%.
Note 2: the correction factors are applicable to cables drawn into buried ducts; for cables laid direct in the ground the correction factors for thermal resistivities less than 2.5 Km/W will be higher. Where more precise values are required they may be calculated by methods given in IEC 60287.
Note 3: the correction factors are applicable to ducts buried at depths of up to 0.8 m.

2 Protection of feeders

To summarize:

Use this procedure to determine the cross section of the cable:

1. from Table 10, determine the correction factor k_1 according to the insulation material and the ground temperature;

2. use Table 11, Table 12, Table 13 or the formula for groups of non-similar cables to determine the correction factor k_2 according to the distance between cables or ducts;

3. from Table 14 determine factor k_3 corresponding to the soil thermal resistivity;

4. calculate the value of the current I'_b by dividing the load current I_b (or the rated current of the protective device) by the product of the correction factors calculated:

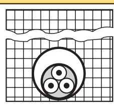
$$I'_b = \frac{I_b}{k_1 k_2 k_3} = \frac{I_b}{k_{tot}}$$

5. from Table 15, determine the cross section of the cable with $I_0 \geq I'_b$, according to the method of installation, the insulation and conductive material and the number of live conductors;

6. the actual cable current carrying capacity is calculated by.

$$I_z = I_0 k_1 k_2 k_3$$

Table 15: Current carrying capacity of cables buried in the ground

	Installation method	D							
									
	Conductor	Cu				Al			
	Insulation	XLPE EPR		PVC		XLPE EPR		PVC	
S[mm²]	Loaded conductors	2	3	2	3	2	3	2	3
1.5		26	22	22	18				
2.5		34	29	29	24	26	22	22	18.5
4		44	37	38	31	34	29	29	24
6		56	46	47	39	42	36	36	30
10		73	61	63	52	56	47	48	40
16		95	79	81	67	73	61	62	52
25		121	101	104	86	93	78	80	66
35		146	122	125	103	112	94	96	80
50		173	144	148	122	132	112	113	94
70		213	178	183	151	163	138	140	117
95		252	211	216	179	193	164	166	138
120		287	240	246	203	220	186	189	157
150		324	271	278	230	249	210	213	178
185		363	304	312	258	279	236	240	200
240		419	351	361	297	322	272	277	230
300		474	396	408	336	364	308	313	260

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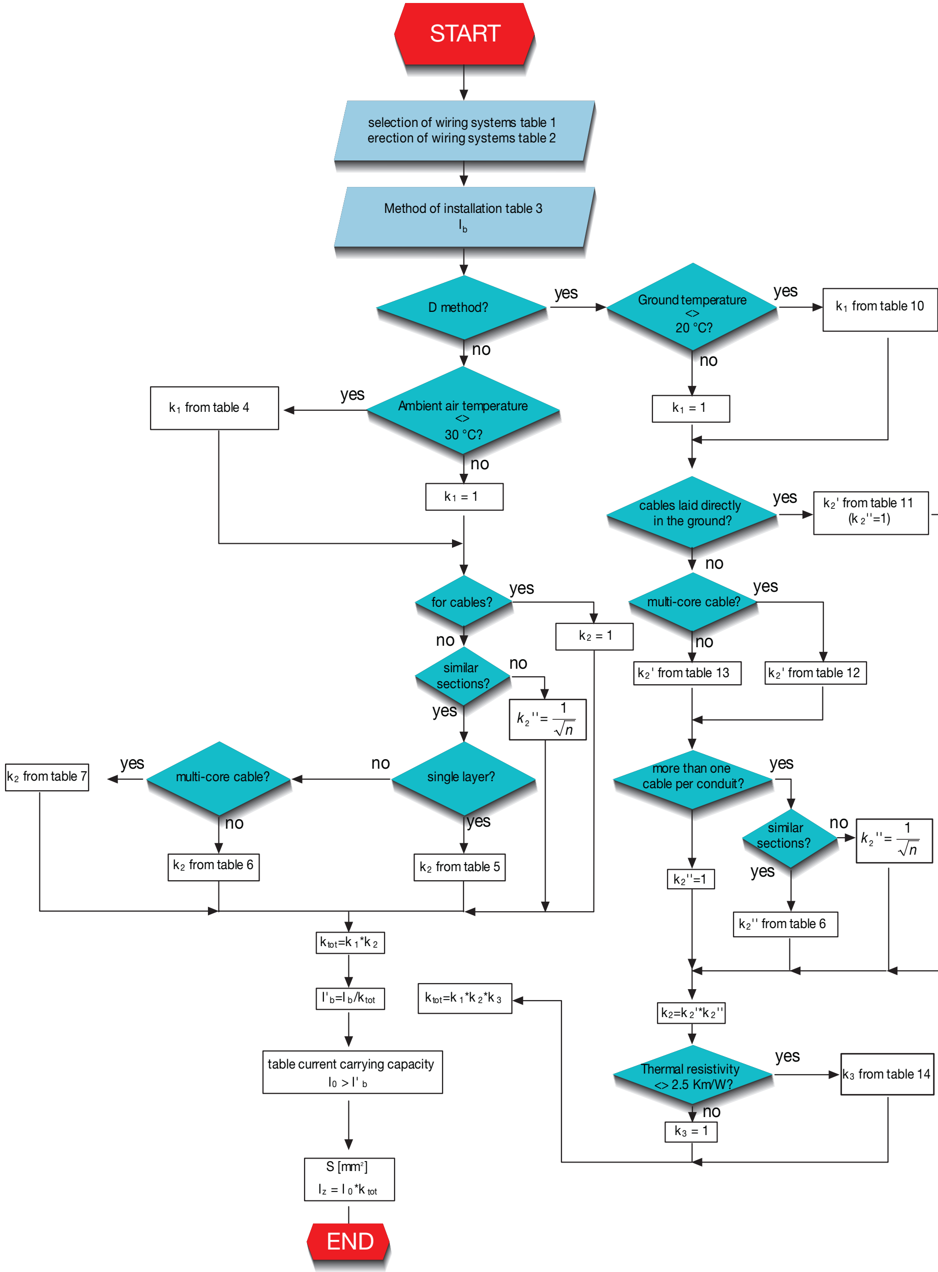
2 Protection of feeders



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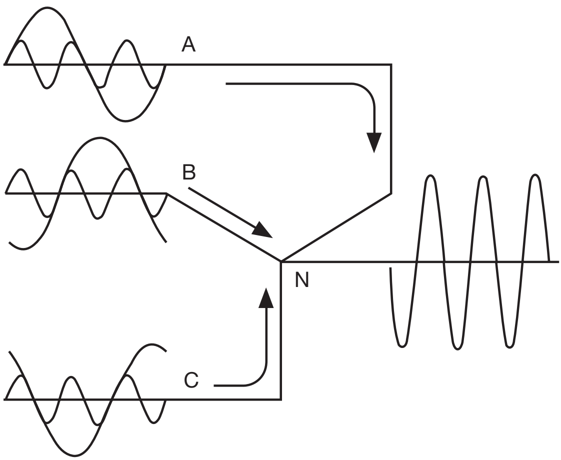
2 Protection of feeders

Note on current carrying capacity tables and loaded conductors

Tables 8, 9 and 15 provide the current carrying capacity of loaded conductors (current carrying conductors) under normal service conditions.
In single-phase circuits, the number of loaded conductors is two.
In balanced or slightly unbalanced three-phase circuits the number of loaded conductors is three, since the current in the neutral conductor is negligible.
In three-phase systems with high unbalance, where the neutral conductor in a multi-core cable carries current as a result of an unbalance in the phase currents the temperature rise due to the neutral current is offset by the reduction in the heat generated by one or more of the phase conductors. In this case the conductor size shall be chosen on the basis of the highest phase current. In all cases the neutral conductor shall have an adequate cross section.

Effect of harmonic currents on balanced three-phase systems: reduction factors for harmonic currents in four-core and five-core cables with four cores carrying current

Where the neutral conductor carries current without a corresponding reduction in load of the phase conductors, the current flowing in the neutral conductor shall be taken into account in ascertaining the current-carrying capacity of the circuit.
This neutral current is due to the phase currents having a harmonic content which does not cancel in the neutral. The most significant harmonic which does not cancel in the neutral is usually the third harmonic. The magnitude of the neutral current due to the third harmonic may exceed the magnitude of the power frequency phase current. In such a case the neutral current will have a significant effect on the current-carrying capacity of the cables in the circuit.



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2 Protection of feeders

Equipment likely to cause significant harmonic currents are, for example, fluorescent lighting banks and dc power supplies such as those found in computers (for further information on harmonic disturbances see the IEC 61000).
The reduction factors given in Table 16 only apply in the balanced three-phase circuits (the current in the fourth conductor is due to harmonics only) to cables where the neutral conductor is within a four-core or five-core cable and is of the same material and cross-sectional area as the phase conductors. These reduction factors have been calculated based on third harmonic currents. If significant, i.e. more than 10 %, higher harmonics (e.g. 9th, 12th, etc.) are expected or there is an unbalance between phases of more than 50 %, then lower reduction factors may be applicable: these factors can be calculated only by taking into account the real shape of the current in the loaded phases.
Where the neutral current is expected to be higher than the phase current then the cable size should be selected on the basis of the neutral current.
Where the cable size selection is based on a neutral current which is not significantly higher than the phase current, it is necessary to reduce the tabulated current carrying capacity for three loaded conductors.
If the neutral current is more than 135 % of the phase current and the cable size is selected on the basis of the neutral current, then the three phase conductors will not be fully loaded. The reduction in heat generated by the phase conductors offsets the heat generated by the neutral conductor to the extent that it is not necessary to apply any reduction factor to the current carrying capacity for three loaded conductors.

Table 16: Reduction factors for harmonic currents in four-core and five-core cables

Third harmonic content of phase current	**Reduction factor**			
%	**Size selection is based on phase current**	**Current to take in account for the cable selection I_b'**	**Size selection is based on neutral current**	**Current to take in account for the cable selection I_b'**
0 ÷ 15	1	$I_b' = \frac{I_b}{k_{tot}}$	-	-
15 ÷ 33	0.86	$I_b' = \frac{I_b}{k_{tot} \cdot 0.86}$	-	-
33 ÷ 45	-	-	0.86	$I_b' = \frac{I_N}{0.86}$
> 45	-	-	1	$I_b' = I_N$

Where I_N is the current flowing in the neutral calculated as follows: $I_N = \frac{I_b}{k_{tot}} \cdot 3 \cdot k_{III}$

I_b is the load current;
k_{tot} is the total correction factor;
k_{III} is the third harmonic content of phase current;

2 Protection of feeders

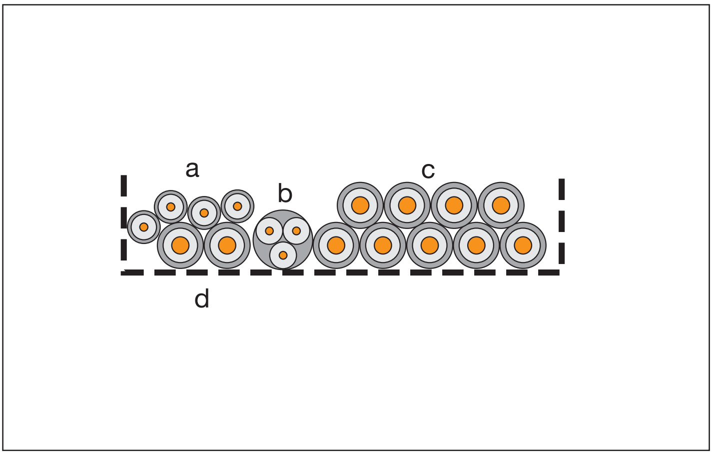
Example of cable dimensioning in a balanced three-phase circuit without harmonics

Dimensioning of a cable with the following characteristics:

- conductor material: : copper
- insulation material: : PVC
- type of cable: : multi-core
- installation: : cables bunched on horizontal perforated tray
- load current: : 100 A

Installation conditions:

- ambient temperature: : 40 °C
- adjacent circuits with
  - a) three-phase circuit consisting of 4 single-core cables, 4x50 mm^2;
  - b) three-phase circuit consisting of one multi-core cable, 1x(3x50) mm^2;
  - c) three-phase circuit consisting of 9 single-core (3 per phase) cables, 9x95 mm^2;
  - d) single-phase circuit consisting of 2 single-core cables, 2x70 mm^2.



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2 Protection of feeders

Procedure:

Type of installation

In Table 3, it is possible to find the reference number of the installation and the method of installation to be used for the calculations. In this example, the reference number is 31, which corresponds to method E (multi-core cable on tray).

Correction factor of temperature k_1

From Table 4, for a temperature of 40 °C and PVC insulation material, k_1 = 0.87.

$$k_1 = 0.87$$

Correction factor for adjacent cables k_2

For the multi-core cables grouped on the perforated tray see Table 5.
As a first step, the number of circuits or multi-core cables present shall be determined; given that:

- each circuit a), b) and d) constitute a separate circuit;
- circuit c) consists of three circuits, since it is composed by three cables in parallel per phase;
- the cable to be dimensioned is a multi-core cable and therefore constitutes a single circuit;
  the total number of circuits is 7.
  Referring to the row for the arrangement (cables bunched) and to the column for the number of circuits (7)

$$k_2 = 0.54$$

After k_1 and k_2 have been determined, I'_b is calculated by:

$$I'_b = \frac{I_b}{k_1 k_2} = \frac{100}{0.87 \cdot 0.54} = 212.85\text{A}$$

From Table 8, for a multi-core copper cable with PVC insulation, method of installation E, with three loaded conductors, a cross section with current carrying capacity of $I_0 \geq I'_b$ = 212.85 A, is obtained. A 95 mm^2 cross section cable can carry, under Standard reference conditions, 238 A.
The current carrying capacity, according to the actual conditions of installation, is I_z = 238 · 0.87· 0.54 = 111.81 A

2 Protection of feeders

Example of dimensioning a cable in a balanced three-phase circuit with a significant third-harmonic content

Dimensioning of a cable with the following characteristics:

- conductor material: : copper
- insulation material: : PVC
- type of cable: : multi-core
- installation: : layer on horizontal perforated tray
- load current: : 115 A

Installation conditions:

- ambient temperature: : 30 °C
- no adjacent circuits.

Procedure:

Type of installation

On Table 3, it is possible to find the reference number of the installation and the method of installation to be used for the calculations. In this example, the reference number is 31, which corresponds to method E (multi-core cable on tray).

Temperature correction factor k_1

From Table 4, for a temperature of 30 °C and PVC insulation material

$$k_1 = 1$$

Correction factor for adjacent cables k_2

As there are no adjacent cables, so

$$k_2 = 1$$

After k_1 and k_2 have been determined, I'_b is calculated by:

$$I'_b = \frac{I_b}{k_1 k_2} = 115\text{A}$$

2 Protection of feeders

If no harmonics are present, from Table 8, for a multi-core copper cable with PVC insulation, method of installation E, with three loaded conductors, a cross section with current carrying capacity of $I_0 \geq I'_b = 115$ A, is obtained. A 35 mm^2 cross section cable can carry, under Standard reference conditions, 126 A. The current carrying capacity, according to the actual conditions of installation, is still 126 A, since the value of factors k_1 and k_2 is 1.

The third harmonic content is assumed to be 28%.
Table 16 shows that for a third harmonic content of 28% the cable must be dimensioned for the current that flows through the phase conductors, but a reduction factor of 0.86 must be applied. The current I'_b becomes:

$$I'_b = \frac{I_b}{k_1 \cdot k_2 \cdot 0.86} = \frac{115}{0.86} = 133.7\,\text{A}$$

From Table 8, a 50 mm^2 cable with carrying capacity of 153 A shall be selected.

If the third harmonic content is 40 %, Table 16 shows that the cable shall be dimensioned according to the current of the neutral conductor and a reduction factor of 0.86 must be applied.
The current in the neutral conductor is:

$$I_N = \frac{I_b}{k_{tot}} \cdot 3 \cdot k_{III} = 115 \cdot 3 \cdot 0.4 = 138\,\text{A}$$

and the value of current I'_b is:

$$I'_b = \frac{I_N}{0.86} = \frac{138}{0.86} = 160.5\,\text{A}$$

From Table 8, a 70 mm^2 cable with 196 A current carrying capacity shall be selected.
If the third harmonic content is 60 %, Table 16 shows that the cable shall be dimensioned according to the current of the neutral conductor, but a reduction factor of 1 must be applied.
The current in the neutral conductor is:

$$I_N = \frac{I_b}{k_{tot}} \cdot 3 \cdot k_{III} = 115 \cdot 3 \cdot 0.6 = 207\,\text{A}$$

and current I'_b is:

$$I'_b = I_N = 207\,\text{A}$$

From Table 8, a 95 mm^2 cable with current carrying capacity of 238 A must be selected.

2 Protection of feeders

2.2.2 Voltage drop

In an electrical installation it is important to evaluate voltage drops from the point of supply to the load.
The performance of a device may be impaired if supplied with a voltage different from its rated voltage. For example:

- *motors*: the torque is proportional to the square of the supply voltage; therefore, if the voltage drops, the starting torque shall also decrease, making it more difficult to start up motors; the maximum torque shall also decrease;
- *incandescent lamps:* the more the voltage drops the weaker the beam becomes and the light takes on a reddish tone;
- *discharge lamps*: in general, they are not very sensitive to small variations in voltage, but in certain cases, great variation may cause them to switch off;
- *electronic appliances*: they are very sensitive to variations in voltage and that is why they are fitted with stabilizers;
- *electromechanical devices:* the reference Standard states that devices such as contactors and auxiliary releases have a minimum voltage below which their performances cannot be guaranteed. For a contactor, for example, the holding of the contacts becomes unreliable below 85% of the rated voltage.

To limit these problems the Standards set the following limits:

- IEC 60364-5-52 *"Electrical installations of buildings. Selection and erection of electrical equipment - Wiring systems"* Clause 525 states that *"in the absence of other considerations it is recommended that in practice the voltage drop between the origin of consumer's installation and the equipment should not be greater than 4% of the rated voltage of the installation. Other considerations include start-up time for motors and equipment with high inrush current. Temporary conditions such as voltage transients and voltage variation due to abnormal operation may be disregarded".*
- IEC 60204-1*"Safety of machinery – Electrical equipment of machines – General requirements"* Clause 13.5 recommends that: *"the voltage drop from the point of supply to the load shall not exceed 5% of the rated voltage under normal operating conditions".*
- IEC 60364-7-714 *"Electrical installations of buildings - Requirements for special installations or locations - External lighting installations"* Clause 714.512 requires that *"the voltage drop in normal service shall be compatible with the conditions arising from the starting current of the lamps".*

2 Protection of feeders

Voltage drop calculation

For an electrical conductor with impedance Z, the voltage drop is calculated by the following formula:

$$\Delta U = kZI_b = kI_b \frac{L}{n}(r\cos\varphi + x\sin\varphi) \ [V] \qquad (1)$$

where

- k is a coefficient equal to:
  - 2 for single-phase and two-phase systems;
  - $\sqrt{3}$ for three-phase systems;
- I_b [A] is the load current; if no information are available, the cable carrying capacity I_z shall be considered;
- L [km] is the length of the conductor;
- n is the number of conductors in parallel per phase;
- r [Ω/km] is the resistance of the single cable per kilometre;
- x [Ω/km] is the reactance of the single cable per kilometre;
- cosφ is the power factor of the load: $\sin\varphi = \sqrt{1-\cos^2\varphi}$.

Normally, the percentage value in relation to the rated value U_r is calculated by:

$$\Delta u\% = \frac{\Delta U}{U_r}100 \qquad (2)$$

Resistance and reactance values per unit of length are set out on the following table by cross-sectional area and cable formation, for 50 Hz; in case of 60 Hz, the reactance value shall be multiplied by 1.2.

2 Protection of feeders

Table 1: Resistance and reactance per unit of length of copper cables

	single-core cable		two-core/three-core cable	
S [mm²]	**r[Ω/km] @ 80 [°C]**	**x[Ω/km]**	**r[Ω/km] @ 80 [°C]**	**x[Ω/km]**
1.5	14.8	0.168	15.1	0.118
2.5	8.91	0.156	9.08	0.109
4	5.57	0.143	5.68	0.101
6	3.71	0.135	3.78	0.0955
10	2.24	0.119	2.27	0.0861
16	1.41	0.112	1.43	0.0817
25	0.889	0.106	0.907	0.0813
35	0.641	0.101	0.654	0.0783
50	0.473	0.101	0.483	0.0779
70	0.328	0.0965	0.334	0.0751
95	0.236	0.0975	0.241	0.0762
120	0.188	0.0939	0.191	0.074
150	0.153	0.0928	0.157	0.0745
185	0.123	0.0908	0.125	0.0742
240	0.0943	0.0902	0.0966	0.0752
300	0.0761	0.0895	0.078	0.075

Table 2: Resistance and reactance per unit of length of aluminium cables

	single-core cable		two-core/three-core cable	
S [mm²]	**r[Ω/km] @ 80 [°C]**	**x[Ω/km]**	**r[Ω/km] @ 80 [°C]**	**x[Ω/km]**
1.5	24.384	0.168	24.878	0.118
2.5	14.680	0.156	14.960	0.109
4	9.177	0.143	9.358	0.101
6	6.112	0.135	6.228	0.0955
10	3.691	0.119	3.740	0.0861
16	2.323	0.112	2.356	0.0817
25	1.465	0.106	1.494	0.0813
35	1.056	0.101	1.077	0.0783
50	0.779	0.101	0.796	0.0779
70	0.540	0.0965	0.550	0.0751
95	0.389	0.0975	0.397	0.0762
120	0,310	0.0939	0.315	0.074
150	0.252	0.0928	0.259	0.0745
185	0.203	0.0908	0.206	0.0742
240	0.155	0.0902	0.159	0.0752
300	0.125	0.0895	0.129	0.075

2 Protection of feeders

The following tables show the ΔU_x [V/(A·km)] values by cross section and formation of the cable according to the most common cosφ values.

Table 3: Specific voltage drop at cosφ = 1 for copper cables

	cosφ = 1			
	single-core cable		two-core cable	three-core cable
S[mm²]	single-phase	three-phase	single-phase	three-phase
1.5	29.60	25.63	30.20	26.15
2.5	17.82	15.43	18.16	15.73
4	11.14	9.65	11.36	9.84
6	7.42	6.43	7.56	6.55
10	4.48	3.88	4.54	3.93
16	2.82	2.44	2.86	2.48
25	1.78	1.54	1.81	1.57
35	1.28	1.11	1.31	1.13
50	0.95	0.82	0.97	0.84
70	0.66	0.57	0.67	0.58
95	0.47	0.41	0.48	0.42
120	0.38	0.33	0.38	0.33
150	0.31	0.27	0.31	0.27
185	0.25	0.21	0.25	0.22
240	0.19	0.16	0.19	0.17
300	0.15	0.13	0.16	0.14

Table 4: Specific voltage drop at cosφ = 0.9 for copper cables

	cosφ = 0.9			
	single-core cable		two-core cable	three-core cable
S[mm²]	single-phase	three-phase	single-phase	three-phase
1.5	26.79	23.20	27.28	23.63
2.5	16.17	14.01	16.44	14.24
4	10.15	8.79	10.31	8.93
6	6.80	5.89	6.89	5.96
10	4.14	3.58	4.16	3.60
16	2.64	2.28	2.65	2.29
25	1.69	1.47	1.70	1.48
35	1.24	1.08	1.25	1.08
50	0.94	0.81	0.94	0.81
70	0.67	0.58	0.67	0.58
95	0.51	0.44	0.50	0.43
120	0.42	0.36	0.41	0.35
150	0.36	0.31	0.35	0.30
185	0.30	0.26	0.29	0.25
240	0.25	0.22	0.24	0.21
300	0.22	0.19	0.21	0.18

2 Protection of feeders

Table 5: Specific voltage drop at cosφ = 0.85 for copper cables

	cosφ = 0.85			
	single-core cable		two-core cable	three-core cable
S[mm²]	single-phase	three-phase	single-phase	three-phase
1.5	25.34	21.94	25.79	22.34
2.5	15.31	13.26	15.55	13.47
4	9.62	8.33	9.76	8.45
6	6.45	5.59	6.53	5.65
10	3.93	3.41	3.95	3.42
16	2.51	2.18	2.52	2.18
25	1.62	1.41	1.63	1.41
35	1.20	1.04	1.19	1.03
50	0.91	0.79	0.90	0.78
70	0.66	0.57	0.65	0.56
95	0.50	0.44	0.49	0.42
120	0.42	0.36	0.40	0.35
150	0.36	0.31	0.35	0.30
185	0.30	0.26	0.29	0.25
240	0.26	0.22	0.24	0.21
300	0.22	0.19	0.21	0.18

Table 6: Specific voltage drop at cosφ = 0.8 for copper cables

	cosφ = 0.8			
	single-core cable		two-core cable	three-core cable
S[mm²]	single-phase	three-phase	single-phase	three-phase
1.5	23.88	20.68	24.30	21.05
2.5	14.44	12.51	14.66	12.69
4	9.08	7.87	9.21	7.98
6	6.10	5.28	6.16	5.34
10	3.73	3.23	3.74	3.23
16	2.39	2.07	2.39	2.07
25	1.55	1.34	1.55	1.34
35	1.15	0.99	1.14	0.99
50	0.88	0.76	0.87	0.75
70	0.64	0.55	0.62	0.54
95	0.49	0.43	0.48	0.41
120	0.41	0.36	0.39	0.34
150	0.36	0.31	0.34	0.29
185	0.31	0.26	0.29	0.25
240	0.26	0.22	0.24	0.21
300	0.23	0.20	0.21	0.19

2 Protection of feeders

Table 7: Specific voltage drop at cosφ=0.75 for copper cables

	cosφ = 0.75			
	single-core cable		two-core cable	three-core cable
S[mm²]	single-phase	three-phase	single-phase	three-phase
1.5	22.42	19.42	22.81	19.75
2.5	13.57	11.75	13.76	11.92
4	8.54	7.40	8.65	7.49
6	5.74	4.97	5.80	5.02
10	3.52	3.05	3.52	3.05
16	2.26	1.96	2.25	1.95
25	1.47	1.28	1.47	1.27
35	1.10	0.95	1.08	0.94
50	0.84	0.73	0.83	0.72
70	0.62	0.54	0.60	0.52
95	0.48	0.42	0.46	0.40
120	0.41	0.35	0.38	0.33
150	0.35	0.31	0.33	0.29
185	0.30	0.26	0.29	0.25
240	0.26	0.23	0.24	0.21
300	0.23	0.20	0.22	0.19

Table 8: Specific voltage drop at cosφ = 1 for aluminium cables

	cosφ = 1			
	single-core cable		two-core cable	three-core cable
S[mm²]	single-phase	three-phase	single-phase	three-phase
1.5	48.77	42.23	49.76	43.09
2.5	29.36	25.43	29.92	25.91
4	18.35	15.89	18.72	16.21
6	12.22	10.59	12.46	10.79
10	7.38	6.39	7.48	6.48
16	4.65	4.02	4.71	4.08
25	2.93	2.54	2.99	2.59
35	2.11	1.83	2.15	1.87
50	1.56	1.35	1.59	1.38
70	1.08	0.94	1.10	0.95
95	0.78	0.67	0.79	0.69
120	0.62	0.54	0.63	0.55
150	0.50	0.44	0.52	0.45
185	0.41	0.35	0.41	0.36
240	0.31	0.27	0.32	0.28
300	0.25	0.22	0.26	0.22

2 Protection of feeders

Table 9: Specific voltage drop at cosφ = 0.9 for aluminium cables

	cosφ = 0.9			
	single-core cable		two-core cable	three-core cable
S[mm²]	single-phase	three-phase	single-phase	three-phase
1.5	44.04	38.14	44.88	38.87
2.5	26.56	23.00	27.02	23.40
4	16.64	14.41	16.93	14.66
6	11.12	9.63	11.29	9.78
10	6.75	5.84	6.81	5.89
16	4.28	3.71	4.31	3.73
25	2.73	2.36	2.76	2.39
35	1.99	1.72	2.01	1.74
50	1.49	1.29	1.50	1.30
70	1.06	0.92	1.06	0.91
95	0.78	0.68	0.78	0.68
120	0.64	0.55	0.63	0.55
150	0.53	0.46	0.53	0.46
185	0.44	0.38	0.44	0.38
240	0.36	0.31	0.35	0.30
300	0.30	0.26	0.30	0.26

Table 10: Specific voltage drop at cosφ = 0.85 for aluminium cables

	cosφ = 0.85			
	single-core cable		two-core cable	three-core cable
S[mm²]	single-phase	three-phase	single-phase	three-phase
1.5	41.63	36.05	42.42	36.73
2.5	25.12	21.75	25.55	22.12
4	15.75	13.64	16.02	13.87
6	10.53	9.12	10.69	9.26
10	6.40	5.54	6.45	5.58
16	4.07	3.52	4.09	3.54
25	2.60	2.25	2.63	2.27
35	1.90	1.65	1.91	1.66
50	1.43	1.24	1.43	1.24
70	1.02	0.88	1.01	0.88
95	0.76	0.66	0.76	0.65
120	0.63	0.54	0.61	0.53
150	0.53	0.46	0.52	0.45
185	0.44	0.38	0,43	0.37
240	0.36	0.31	0.35	0.30
300	0.31	0.27	0.30	0.26

2 Protection of feeders

Table 11: Specific voltage drop at cosφ = 0.8 for aluminium cables

	cosφ = 0.8			
	single-core cable		two-core cable	three-core cable
S[mm²]	single-phase	three-phase	single-phase	three-phase
1.5	39.22	33.96	39.95	34.59
2.5	23.67	20.50	24.07	20.84
4	14.85	12.86	15.09	13.07
6	9.94	8.61	10.08	8.73
10	6.05	5.24	6.09	5.27
16	3.85	3.34	3.87	3.35
25	2.47	2.14	2.49	2.16
35	1.81	1.57	1.82	1.57
50	1.37	1.18	1.37	1.18
70	0.98	0.85	0.97	0.84
95	0.74	0.64	0.73	0.63
120	0.61	0.53	0.59	0.51
150	0.51	0.45	0.50	0.44
185	0.43	0.38	0.42	0.36
240	0.36	0.31	0.34	0.30
300	0.31	0.27	0.30	0.26

Table 12: Specific voltage drop at cosφ = 0.75 for aluminium cables

	cosφ = 0.75			
	single-core cable		two-core cable	three-core cable
S[mm²]	single-phase	three-phase	single-phase	three-phase
1.5	36.80	31.87	37.47	32.45
2.5	22.23	19.25	22.58	19.56
4	13.95	12.08	14.17	12.27
6	9.35	8.09	9.47	8.20
10	5.69	4.93	5.72	4.96
16	3.63	3.15	3.64	3.15
25	2.34	2.02	2.35	2.03
35	1.72	1.49	1.72	1.49
50	1.30	1.13	1.30	1.12
70	0.94	0.81	0.92	0.80
95	0.71	0.62	0.70	0.60
120	0.59	0.51	0.57	0.49
150	0.50	0.43	0.49	0.42
185	0.42	0.37	0.41	0.35
240	0.35	0.31	0.34	0.29
300	0.31	0.27	0.29	0.25

2 Protection of feeders

Example 1

To calculate a voltage drop on a three-phase cable with the following specifications:
- rated voltage: 400 V;
- cable length: 25 m;
- cable formation: single-core copper cable, 3x50 mm^2;
- load current I_b: 100 A;
- power factor cosφ: 0.9.

From Table 4, for a 50 mm^2 single-core cable it is possible to read that a ΔU_x voltage drop corresponds to 0.81 V/(A·km). By multiplying this value by the length in km and by the current in A, it results:

$$\Delta U = \Delta U_x \cdot I_b \cdot L = 0.81 \cdot 100 \cdot 0.025 = 2.03 \text{ V}$$

which corresponds to this percentage value:

$$\Delta u\% = \frac{\Delta U}{U_r} \cdot 100 = \frac{2.03}{400} \cdot 100 = 0.51\%$$

Example 2

To calculate a voltage drop on a three-phase cable with the following specifications:
- rated voltage: 690 V;
- cable length: 50 m;
- cable formation: multi-core copper cable, 2x(3x10) mm^2;
- load current I_b: 50 A;
- power factor cosφ: 0.85.

From Table 5, for a multi-core 10 mm^2 cable it is possible to read that ΔU_x voltage drop corresponds to 3.42 V/(A·km). By multiplying this value by the length in km and by the current in A, and by dividing it by the number of cables in parallel, it results:

$$\Delta U = \Delta U_x \cdot I_b \cdot \frac{L}{2} = 3.42 . 50 \cdot \frac{0.05}{2} = 4.28 \text{ V}$$

which corresponds to this percentage value:

$$\Delta u\% = \frac{\Delta U}{U_r} \cdot 100 = \frac{4.28}{690} \cdot 100 = 0.62\%$$

2 Protection of feeders

Method for defining the cross section of the conductor according to voltage drop in the case of long cables

In the case of long cables, or if particular design specifications impose low limits for maximum voltage drops, the verification using as reference the cross section calculated on the basis of thermal considerations (calculation according to chapter 2.2.1 “Current carrying capacity and methods of installation”) may have a negative result.
To define the correct cross section, the maximum ΔU_{xmax} value calculated by using the formula:

$$\Delta U_{xmax} = \frac{\Delta u\% \cdot U_r}{100 \cdot I_b \cdot L} \quad (3)$$

is compared with the corresponding values on Tables 4÷12 by choosing the smallest cross section with a ΔU_x value lower than ΔU_{xmax}.

Example:
Supply of a three-phase load with P_u = 35 kW (U_r=400 V, f_r= 50 Hz, cosφ=0.9) with a 140 m cable installed on a perforated tray, consisting of a multi-core copper cable with EPR insulation.
Maximum permitted voltage drop 2%.

Load current I_b is:

$$I_b = \frac{P_u}{\sqrt{3} \cdot U_r \cdot \cos\varphi} = \frac{35000}{\sqrt{3} \cdot 400 \cdot 0.9} = 56\ \text{A}$$

The Table 8 of Chapter 2.2.1 shows S = 10 mm^2.
From Table 4, for the multi-core 10 mm^2 cable it is possible to read that the voltage drop per A and per km is 3.60 V/(A·km). By multiplying this value by the length in km and by the current in A, it results:

$$\Delta U = 3.60 \cdot I_b \cdot L = 3.6 \cdot 56 \cdot 0.14 = 28.2\ \text{V}$$

which corresponds to this percentage value:

$$\Delta u\% = \frac{\Delta U}{U_r} \cdot 100 = \frac{28.2}{400} \cdot 100 = 7.05\%$$

This value is too high.
Formula (3) shows:

$$\Delta U_{xmax} = \frac{\Delta u\% \cdot U_r}{100 \cdot I_b \cdot L} = \frac{2\% \cdot 400}{100 \cdot 56 \cdot 0.14} = 1.02\ \text{V/(A} \cdot \text{km)}$$

2 Protection of feeders

From Table 4 a cross section of 50 mm^2 can be chosen.
For this cross section $\Delta U_x = 0.81 < 1.02$ V/(A·km).
By using this value it results:

$$\Delta U = \Delta U_x \cdot I_b \cdot L = 0.81 \cdot 56 \cdot 0.14 = 6.35 \text{ V}$$

This corresponds to a percentage value of:

$$\Delta u\% = \frac{\Delta U}{U_r} \cdot 100 = \frac{6.35}{400} \cdot 100 = 1.6\%$$

2.2.3 Joule-effect losses

Joule-effect losses are due to the electrical resistance of the cable.
The lost energy is dissipated in heat and contributes to the heating of the conductor and of the environment.
A first estimate of three-phase losses is:

$$P_j = \frac{3 \cdot r \cdot I_b^2 \cdot L}{1000} \text{ [W]}$$

whereas single-phase losses are:

$$P_j = \frac{2 \cdot r \cdot I_b^2 \cdot L}{1000} \text{ [W]}$$

where:
- I_b is the load current [A];
- r is the phase resistance per unit of length of the cable at 80 °C [Ω/km] (see Table 1);
- L is the cable length [m].

Table 1: Resistance values [Ω/km] of single-core and multi-core cables in copper and aluminium at 80 °C

S [mm²]	Single-core cable Cu	Single-core cable Al	Two-core/three-core cable Cu	Two-core/three-core cable Al
1.5	14.8	24.384	15.1	24.878
2.5	8.91	14.680	9.08	14.960
4	5.57	9.177	5.68	9.358
6	3.71	6.112	3.78	6.228
10	2.24	3.691	2.27	3.740
16	1.41	2.323	1.43	2.356
25	0.889	1.465	0.907	1.494
35	0.641	1.056	0.654	1.077
50	0.473	0.779	0.483	0.796
70	0.328	0.540	0.334	0.550
95	0.236	0.389	0.241	0.397
120	0.188	0.310	0.191	0.315
150	0.153	0.252	0.157	0.259
185	0.123	0.203	0.125	0.206
240	0.0943	0.155	0.0966	0.159
300	0.0761	0.125	0.078	0.129

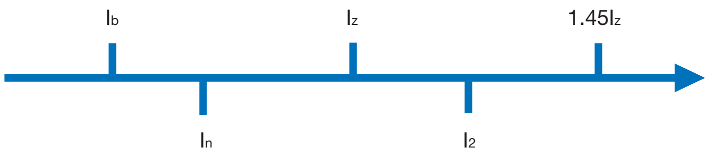
2.3 Protection against overload

The Standard IEC 60364-4-43 *"Electrical installation of buildings - Protection against overcurrent"* specifies coordination between conductors and overload protective devices (normally placed at the beginning of the conductor to be protected) so that it shall satisfy the two following conditions:

$$I_b \leq I_n \leq I_z \qquad (1)$$

$$I_2 \leq 1.45 \cdot I_z \qquad (2)$$

Where:
- I_b is the current for which the circuit is dimensioned;
- I_z is the continuous current carrying capacity of the cable;
- I_n is the rated current of the protective device; for adjustable protective releases, the rated current I_n is the set current;
- I_2 is the current ensuring effective operation in the conventional time of the protective device.



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According to condition (1) to correctly choose the protective device, it is necessary to check that the circuit-breaker has a rated (or set) current that is:
- higher than the load current, to prevent unwanted tripping;
- lower than the current carrying capacity of the cable, to prevent cable overload.

The Standard allows an overload current that may be up to 45% greater than the current carrying capacity of the cable but only for a limited period (conventional trip time of the protective device).
The verification of condition (2) is not necessary in the case of circuit-breakers because the protective device is automatically tripped if:
- $I_2 = 1.3 \cdot I_n$ for circuit-breakers complying with IEC 60947-2 (circuit-breakers for industrial use);
- $I_2 = 1.45 \cdot I_n$ for circuit-breakers complying with IEC 60898 (circuit-breakers for household and similar installations).

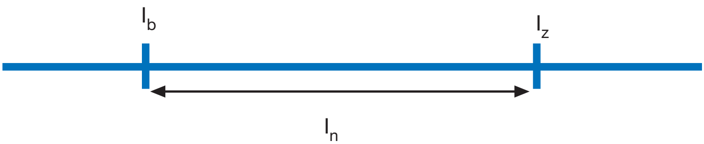
Therefore, for circuit-breakers, if $I_n \leq I_z$, the formula $I_2 \leq 1.45 \cdot I_z$ will also be verified.
When the protective device is a fuse, it is also essential to check formula (2) because IEC 60269-2-1 on *"Low-voltage fuses"* states that a $1.6 \cdot I_n$ current must automatically melt the fuse. In this case, formula (2) becomes $1.6 \cdot I_n \leq 1.45 \cdot I_z$ or $I_n \leq 0.9 \cdot I_z$.
To sum up: to carry out protection against overload by a fuse, the following

2 Protection of feeders

To summarize: to carry out by a fuse protection against overload, the following must be achieved:

$$I_b \leq I_n \leq 0.9 \cdot I_z$$

and this means that the cable is not fully exploited.



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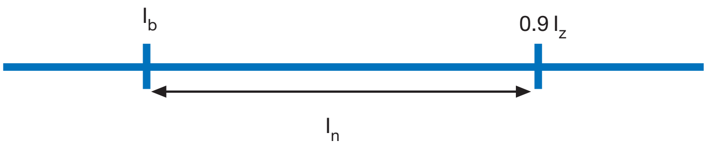
Circuit-breaker: choice of rated current



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Fuse: choice of rated current

Where the use of a single conductor per phase is not feasible, and the currents in the parallel conductors are unequal, the design current and requirements for overload protection for each conductor shall be considered individually.

Examples

Example 1

Load specifications

P_r = 70 kW; U_r = 400 V; cosφ = 0.9; three-phase load so I_b = 112 A

Cable specifications

I_z = 134 A

Protective device specifications

T1B160 TMD I_n 125; set current I1 = 125 A

2 Protection of feeders

Example 2

Load specifications

P_r = 80 kW; cosφ = 0.9; U_r = 400 V; three-phase load so I_b = 128 A

Cable specifications

I_z = 171 A

Protective device specifications

T2N160 PR221DS-LS I_n 160; set current I1 = 0.88 x I_n = 140.8 A

Example 3

Load specifications

P_r = 100 kW; cosφ = 0.9; U_r = 400 V ; three-phase load so I_b = 160 A

Cable specifications

I_z = 190 A

Protective device specifications

T3N250 TMD R200 I_n 200; set current I1 = 0.9 x I_n = 180 A

Example 4

Load specifications

P_r = 25 kW; cosφ = 0.9; U_r = 230 V ; single-phase load so I_b = 121 A

Cable specifications

I_z = 134 A

Protective device specifications

T1B160 1P TMF I_n 125

2.4 Protection against short-circuit

A cable is protected against short-circuit if the specific let-through energy of the protective device (I^2t) is lower or equal to the withstood energy of the cable (k^2S^2):

$$I^2t \leq k^2S^2 \quad (1)$$

where

- I^2t is the specific let-through energy of the protective device which can be read on the curves supplied by the manufacturer (see Electrical installation handbook, Vol. 1, Chapter 3.4 “Specific let-through energy curves”) or from a direct calculation in the case of devices that are not limiting and delaying;
- S is the cable cross section [mm^2]; in the case of conductors in parallel it is the cross section of the single conductor;
- k is a factor that depends on the cable insulating and conducting material. The values of the most common installations are shown in Table 1; for a more detailed calculation, see Annex D.

Table 1: Values of k for phase conductor

	Conductor insulation					
	PVC ≤300 mm^2	PVC >300 mm^2	EPR XLPE	Rubber 60 °C	Mineral	
					PVC	Bare
Initial temperature °C	70	70	90	60	70	105
Final temperature °C	160	140	250	200	160	250
Material of conductor:						
Copper	115	103	143	141	115	135/115 [a]
Aluminium	76	68	94	93	-	-
tin-soldered joints in copper conductors	115	-	-	-	-	-

[a] This value shall be used for bare cables exposed to touch.

NOTE 1 Other values of k are under consideration for.
- small conductors (particularly for cross section less than 10 mm^2);
- duration of short-circuit exceeding 5 s;
- other types of joints in conductors;
- bare conductors.

NOTE 2 The nominal current of the short-circuit protective device may be greater than the current carrying capacity of the cable.

NOTE 3 The above factors are based on IEC 60724.

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2 Protection of feeders

Table 2 shows the maximum withstood energy for cables according to the cross section, the conductor material and the type of insulation, which are calculated by using the parameters of Table 1.

Table 2: Maximum withstood energy for cables $k^2 S^2$ [(kA)^2 s]

			Cross section [mm²]							
Cable		**k**	1.5	2.5	4	6	10	16	25	35
PVC	Cu	115	$2.98\cdot10^{-2}$	$8.27\cdot10^{-2}$	$2.12\cdot10^{-1}$	$4.76\cdot10^{-1}$	1.32	3.39	8.27	$1.62\cdot10^{1}$
	Al	76	$1.30\cdot10^{-2}$	$3.61\cdot10^{-2}$	$9.24\cdot10^{-2}$	$2.08\cdot10^{-1}$	$5.78\cdot10^{-1}$	1.48	3.61	7.08
EPR/XLPE	Cu	143	$4.60\cdot10^{-2}$	$1.28\cdot10^{-1}$	$3.27\cdot10^{-1}$	$7.36\cdot10^{-1}$	2.04	5.23	$1.28\cdot10^{1}$	$2.51\cdot10^{1}$
	Al	94	$1.99\cdot10^{-2}$	$5.52\cdot10^{-2}$	$1.41\cdot10^{-1}$	$3.18\cdot10^{-1}$	$8.84\cdot10^{-1}$	2.26	5.52	$1.08\cdot10^{1}$
Rubber	Cu	141	$4.47\cdot10^{-2}$	$1.24\cdot10^{-1}$	$3.18\cdot10^{-1}$	$7.16\cdot10^{-1}$	1.99	5.09	$1.24\cdot10^{1}$	$2.44\cdot10^{1}$
	Al	93	$1.95\cdot10^{-2}$	$5.41\cdot10^{-2}$	$1.38\cdot10^{-1}$	$3.11\cdot10^{-1}$	$8.65\cdot10^{-1}$	2.21	5.41	$1.06\cdot10^{1}$

			Cross section [mm²]							
Cable		**k**	50	70	95	120	150	185	240	300
PVC	Cu	115	$3.31\cdot10^{1}$	$6.48\cdot10^{1}$	$1.19\cdot10^{2}$	$1.90\cdot10^{2}$	$2.98\cdot10^{2}$	$4.53\cdot10^{2}$	$7.62\cdot10^{2}$	$1.19\cdot10^{3}$
	Al	76	$1.44\cdot10^{1}$	$2.83\cdot10^{1}$	$5.21\cdot10^{1}$	$8.32\cdot10^{1}$	$1.30\cdot10^{2}$	$1.98\cdot10^{2}$	$3.33\cdot10^{2}$	$5.20\cdot10^{2}$
EPR/XLPE	Cu	143	$5.11\cdot10^{1}$	$1.00\cdot10^{1}$	$1.85\cdot10^{1}$	$2.94\cdot10^{2}$	$4.60\cdot10^{2}$	$7.00\cdot10^{2}$	$1.18\cdot10^{3}$	$1.84\cdot10^{3}$
	Al	94	$2.21\cdot10^{1}$	$4.33\cdot10^{1}$	$7.97\cdot10^{1}$	$1.27\cdot10^{2}$	$1.99\cdot10^{2}$	$3.02\cdot10^{2}$	$5.09\cdot10^{2}$	$7.95\cdot10^{2}$
G2	Cu	141	$4.97\cdot10^{1}$	$9.74\cdot10^{1}$	$1.79\cdot10^{1}$	$2.86\cdot10^{2}$	$4.47\cdot10^{2}$	$6.80\cdot10^{2}$	$1.15\cdot10^{3}$	$1.79\cdot10^{3}$
	Al	93	$2.16\cdot10^{1}$	$4.24\cdot10^{1}$	$7.81\cdot10^{1}$	$1.25\cdot10^{2}$	$1.95\cdot10^{2}$	$2.96\cdot10^{2}$	$4.98\cdot10^{2}$	$7.78\cdot10^{2}$

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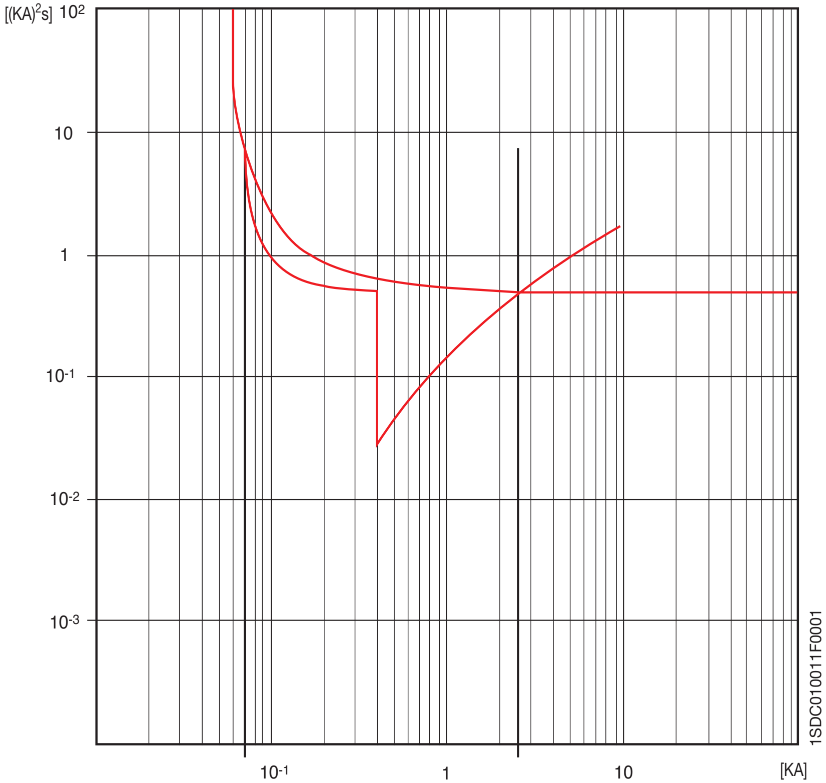
The formula (1) must be verified along the whole length of the cable. Due to the shape of the specific let-through energy curve of a circuit breaker, it is generally sufficient to verify formula (1) only for the maximum and minimum short-circuit current that may affect the cable. The maximum value is normally the value of the three-phase short-circuit current at the beginning of the line, while the minimum value is the value of the phase to neutral short-circuit current (phase to phase if the neutral conductor is not distributed) or phase to earth at the end of the cable.

2 Protection of feeders



This verification can be simplified by comparing only the let-through energy value of the circuit-breaker at the maximum short-circuit current with the withstood energy of the cable and by ensuring that the circuit breaker trips instantaneously at the minimum short-circuit current: the threshold of the short-circuit protection (taking into consideration also the tolerances) shall therefore be lower than the minimum short-circuit current at the end of the conductor.

2 Protection of feeders

Calculation of short-circuit current at end of the conductor

Minimum short-circuit current can be calculated by the following approximate formulas:

$$I_{kmin} = \frac{0.8 \cdot U_r \cdot k_{sec} \cdot k_{par}}{1.5 \cdot \rho \cdot \frac{2L}{S}}$$ with non-distributed neutral conductor (2.1)

$$I_{kmin} = \frac{0.8 \cdot U_0 \cdot k_{sec} \cdot k_{par}}{1.5 \cdot \rho \cdot (1+m) \cdot \frac{L}{S}}$$ with distributed neutral conductor (2.2)

where:

- I_{kmin} is the minimum value of the prospective short-circuit current [kA];
- U_r is the supply voltage [V];
- U_0 is the phase to earth supply voltage [V];
- ρ is the resistivity at 20 °C of the material of the conductors in $\Omega mm^2/m$ and is:
  - 0.018 for copper;
  - 0.027 for aluminium;
- L is the length of the protected conductor [m];
- S is the cross section of the conductor [mm^2];
- k_{sec} is the correction factor which takes into account the reactance of the cables with cross section larger than 95 mm^2:

S[mm^2]	120	150	180	240	300
k_{sec}	0.9	0.85	0.80	0.75	0.72

- k_{par} is the correcting coefficient for conductors in parallel:

number of parallel conductors	2	3	4	5
k_{par}*	2	2.7	3	3.2

*k_{par} = 4 (n-1)/n where: n = number of conductors in parallel per phase

- m is the ratio between the resistances of the neutral conductor and the phase conductor (if they are made of the same material m is the ratio between the cross section of the phase conductor and the cross section of the neutral conductor).

After calculating the minimum short-circuit current, verify that

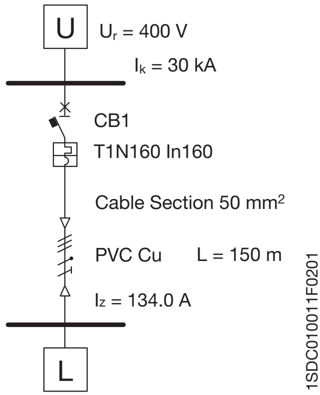
$$I_{kmin} > 1.2 \cdot I_3 \quad (3)$$

where:

- I_3 is the current that trips the magnetic protection of the circuit-breaker;
- 1.2 is the tolerance at the trip threshold.

2 Protection of feeders

Example



Choice of CB1

System data:
Rated voltage 400 V
I_K = 30 kA

Cable data:
Insulated copper conductor in PVC
Length = 150 m
S = 50 mm^2
I_Z = 134 A

Protection against short-circuit at the beginning of the conductor

T1N160 In160 (breaking capacity 36 kA@400 V)
I^2t (@30 kA) = 7.5 10^{-1} (kA)^{2}s (for the curves of specific let-through energy, see Volume 1, Chapter 3.4)
$k^2S^2 = 115^2 \cdot 50^2 = 3.31 \cdot 10^1$ (kA)^{2}s
The cable is therefore protected against short-circuit at the beginning of the conductor.

Protection against short-circuit at end of the conductor

The minimum short-circuit current at end of the conductor (k_{sec}=1 and k_{par}=1) is:

$$I_{kmin} = \frac{0.8 \cdot U \cdot k_{sec} \cdot k_{par}}{1.5 \cdot \rho \cdot \frac{2L}{S}} = 1.98 \text{ kA}$$

The magnetic threshold of the circuit breaker T1N160 In160 is set at 1600 A. If tolerance is 20%, the circuit breaker shall definitely trip if the values exceed 1920 A; the cable is therefore fully protected against short-circuit.

Maximum protected length

The formula (3), when solved for the length, enables the maximum length protected by the protective device to be obtained for a precise instantaneous trip threshold. In Table 3, the maximum protected length can be identified for a given cross section of the cable and for the setting threshold of the instantaneous protection of the circuit breaker against short-circuit:
- three-phase system, 400 V rated voltage;
- non-distributed neutral;
- copper conductor with resistivity equal to 0.018 Ωmm^2/m.

The values on the table below take into account the 20% tolerance coefficient for the magnetic trip value, the increase in cable resistivity due to heating caused by the short-circuit current and the reduction of voltage due to the fault.
The correction factors shown after the table must be applied if the system conditions are different from the reference conditions.

2 Protection of feeders

Table 3: Maximum protected length

section [mm²] I_3[A]	1.5	2.5	4	6	10	16	25	35	50	70	95	120	150	185	240	300
20	370	617														
30	246	412	658													
40	185	309	494	741												
50	148	247	395	593												
60	123	206	329	494												
70	105	176	282	423	705											
80	92	154	246	370	617											
90	82	137	219	329	549											
100	74	123	197	296	494	790										
120	61	102	164	246	412	658										
140	52	88	141	211	353	564										
150	49	82	131	197	329	527										
160	46	77	123	185	309	494	772									
180	41	68	109	164	274	439	686									
200	37	61	98	148	247	395	617									
220	33	56	89	134	224	359	561	786								
250	29	49	79	118	198	316	494	691								
280	26	44	70	105	176	282	441	617								
300	24	41	65	98	165	263	412	576								
320	23	38	61	92	154	247	386	540	772							
350	21	35	56	84	141	226	353	494	705							
380	19	32	52	78	130	208	325	455	650							
400	18	30	49	74	123	198	309	432	617							
420	17	29	47	70	118	188	294	412	588							
450	16	27	43	65	110	176	274	384	549	768						
480	15	25	41	61	103	165	257	360	514	720						
500	14	24	39	59	99	158	247	346	494	691						
520	14	23	38	57	95	152	237	332	475	665						
550	13	22	35	53.	90	144	224	314	449	629						
580	12	21	34	51	85	136	213	298	426	596	809					
600	12	20	32	49	82	132	206	288	412	576	782					
620	11	19	31	47	80	127	199	279	398	558	757					
650	11	19	30	45	76	122	190	266	380	532	722					
680	10	18	29	43	73	116	182	254	363	508	690					
700	10	17	28	42	71	113	176	247	353	494	670	847				
750		16	26	39	66	105	165	230	329	461	626	790	840			
800		15	24	37	62	99	154	216	309	432	586	667	787			
850		14	23	34	58	93	145	203	290	407	552	627	741			
900		13	21	32	55	88	137	192	274	384	521	593	700			
950		13	20	31	52	83	130	182	260	364	494	561	663			
1000		12	19	29	49	79	123	173	247	346	469	533	630	731		
1250			15	23	40	63	99	138	198	277	375	427	504	585	711	
1500			13	19	33	53	82	115	165	230	313	356	420	487	593	
1600			12	18	31	49	77	108	154	216	293	333	394	457	556	667
2000				14	25	40	62	86	123	173	235	267	315	365	444	533
2500				11	20	32	49	69	99	138	188	213	252	292	356	427
3000					16	26	41	58	82	115	156	178	210	244	296	356
3200					15	25	39	54	77	108	147	167	197	228	278	333
4000					12	20	31	43	62	86	117	133	157	183	222	267
5000					10	16	25	35	49	69	94	107	126	146	178	213
6300						13	20	27	39	55	74	85	100	116	141	169
8000						10	15	22	31	43	59	67	79	91	111	133
9600							13	18	26	36	49	56	66	76	93	111
10000							12	17	25	35	47	53	63	73	89	107
12000							10	14	21	29	39	44	52	61	74	89
15000								12	16	23	31	36	42	49	59	71
20000									12	17	23	27	31	37	44	53
24000									10	14	20	22	26	30	37	44
30000										12	16	20	25	30	40	49

2 Protection of feeders

Correction factor for voltage other than 400 V: k_v

Multiply the length value obtained from the table by the correction factor k_v:

U_r [V] (three-phase value)	k_v
230[1]	0.58
400	1
440	1.1
500	1.25
690	1.73

[1] 230 V single-phase is the equivalent of a three-phase 400 V system with distributed neutral and with the cross section of the phase conductor the same as the cross section area of the neutral conductor, so that k_v is 0.58.

Correction factor for distributed neutral: k_d

Multiply the length value obtained from the table by the correction factor k_d:

$$k_d = \frac{2}{\sqrt{3}} \cdot \frac{1}{1+\dfrac{S}{S_N}}$$

where
- S is the phase cross section [mm²];
- S_N is the neutral cross section [mm²].

In particular:

$$\text{if } S = S_N \longrightarrow k_d \text{ is } 0.58;$$

$$\text{if } S = 2 \cdot S_N \longrightarrow k_d \text{ is } 0.39.$$

Correction factor for aluminium conductors: k_r

If the cable is in aluminium, multiply the length value obtained from the table above by the correction factor k_r = 0.67.

2 Protection of feeders

To summarize:

On the table, for the cross section and magnetic trip threshold it is possible to read a maximum protected value L_0. This length shall then be multiplied, if necessary, by the correction factors in order to obtain a value that is compatible with the installation operating conditions:

$$L = L_0 k_v k_d k_r$$

Example 1

Neutral not distributed
Rated voltage = 400 V
Protective device: T2N160 TMD In100
Magnetic threshold: I_3 = 1000 A
Phase cross section = Neutral cross section = 70 mm^2
The table shows that at I_3 = 1000 A, the 70 mm^2 cable is protected up to 346 m.

Example 2

Neutral distributed
Rated voltage = 400 V
Protective device: T3S250 In200
Magnetic threshold: I_3 = 2000 A
Phase cross section = 300 mm^2
Neutral cross section = 150 mm^2
For I_3 = 2000 A and S = 300 mm^2, a protected length equivalent of L_0= 533 m is obtained.

By applying the correction factor k_d required when the neutral is distributed:

$$k_d = \frac{2}{\sqrt{3}} \cdot \frac{1}{1+\frac{S}{S_N}} = \frac{2}{\sqrt{3}} \cdot \frac{1}{1+\frac{300}{150}} = 0.39$$

L= $L_0 \cdot 0.39 = 533 \cdot 0.39 = 207.9$ m
This is the maximum protected length with neutral distributed.

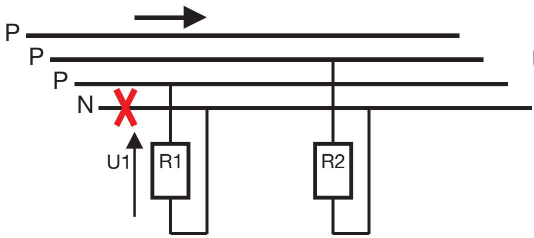
2.5 Neutral and protective conductors

Neutral conductor

The neutral conductor is a conductor that is connected to the system neutral point (which generally but not necessarily coincides with the star centre of the secondary windings of the transformer or the windings of the generator); it is able to contribute to the transmission of electric power, thereby making available a voltage that is different from the phase to phase voltage. In certain cases and under specific conditions, the functions of neutral conductor and protective conductor can be combined in a single conductor (PEN).

Protection and disconnection of the neutral conductor

If fault conditions arise, a voltage to earth may occur on the neutral conductor. This may be caused by a phase to neutral short-circuit and by the disconnection of the neutral conductor due to accidental breaking or to tripping of single-pole devices (fuses or single-pole circuit breakers).
If the neutral conductor only is disconnected in a four-conductor circuit the supply voltage to the single-phase loads may be altered so that they are supplied by a voltage different from the U_0 phase to neutral voltage (as shown in Fig. 1). Therefore, all the necessary measures to prevent this type of fault shall be taken, e.g. by not protecting the neutral conductor with single-pole devices.



$$U_1 = \frac{\sqrt{3} \cdot U_0 \cdot R_1}{R_1 + R_2}$$

Figure 1: Disconnection of the neutral conductor

Moreover, in TN-C systems, voltage to earth arising on the neutral conductor constitutes a hazard for people; in fact, since this conductor is also a protective conductor, this voltage reaches the connected exposed conductive parts. For TN-C systems, the Standards specify minimum cross sections (see next clause) for the neutral conductor in order to prevent accidental breaking and they forbid the use of any device (single-pole or multi-pole) that could disconnect the PEN.
The need for protection on the neutral conductor and the possibility of disconnecting the circuit depend on the distribution system:

2 Protection of feeders

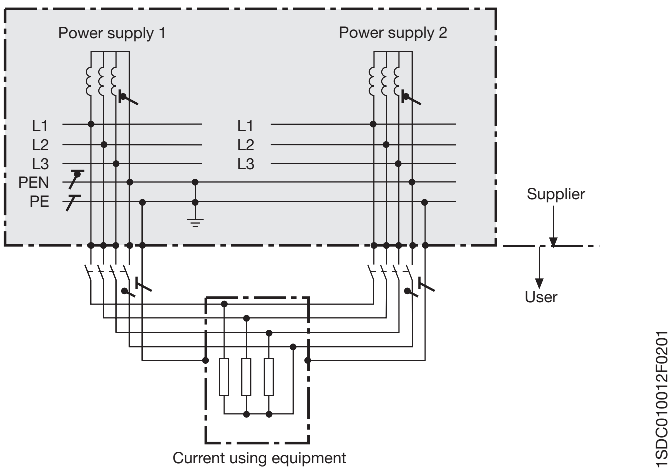
TT or TN systems:

- if the cross section of the neutral conductor is the same or larger than the cross section of the phase conductor, there is neither the need to detect overcurrents on the neutral conductor nor to use a breaking device (neutral conductor is not protected or disconnected); this requirement applies only if there are no harmonics that may, at any instant, cause r.m.s. current values on the neutral conductor higher than the maximum current detected on the phase conductors;
- if the cross section of the neutral conductor is less than the cross section of the phase conductor, overcurrents on the neutral conductor must be detected so as to have the phase conductors, but not necessarily the neutral conductor, disconnected (neutral conductor protected but not disconnected): in this case the overcurrents on the neutral conductor do not need to be detected if the following conditions are simultaneously fulfilled:
  1. the neutral conductor is protected against short-circuit by the protective device of the phase conductors;
  2. the maximum current that can flow through the neutral conductor during normal service is lower than the neutral current carrying capacity.

In TN-S systems, the neutral need not be disconnected if the supply conditions are such that the neutral conductor can be considered to be reliable at earth potential.
As already mentioned, in TN-C systems, the neutral conductor is also a protective conductor and cannot therefore be disconnected. Furthermore, if the neutral conductor is disconnected, the exposed conductive parts of the single-phase equipment could take the system rated voltage to earth.
In certain specific cases, the neutral conductor has to be disconnected to prevent currents circulating between parallel supply sources (see Figures 2 and 3)

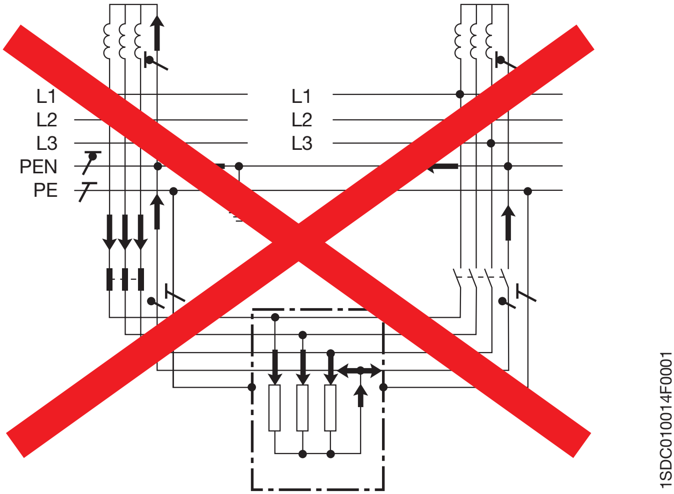
NOTE - This method prevents electromagnetic fields due to stray currents in the main supply system of an installation. The sum of the currents within one cable must be zero. This ensures that the neutral current will flow only in the neutral conductor of the respective switched on circuit. The 3rd harmonic (150 Hz) current of the line conductors will be added with the same phase angle to the neutral conductor current.

Figure 2: Three-phase alternative power supply with a 4-pole switch



2 Protection of feeders

Figure 3: Three-phase alternative power supply with non-suitable 3-pole switch

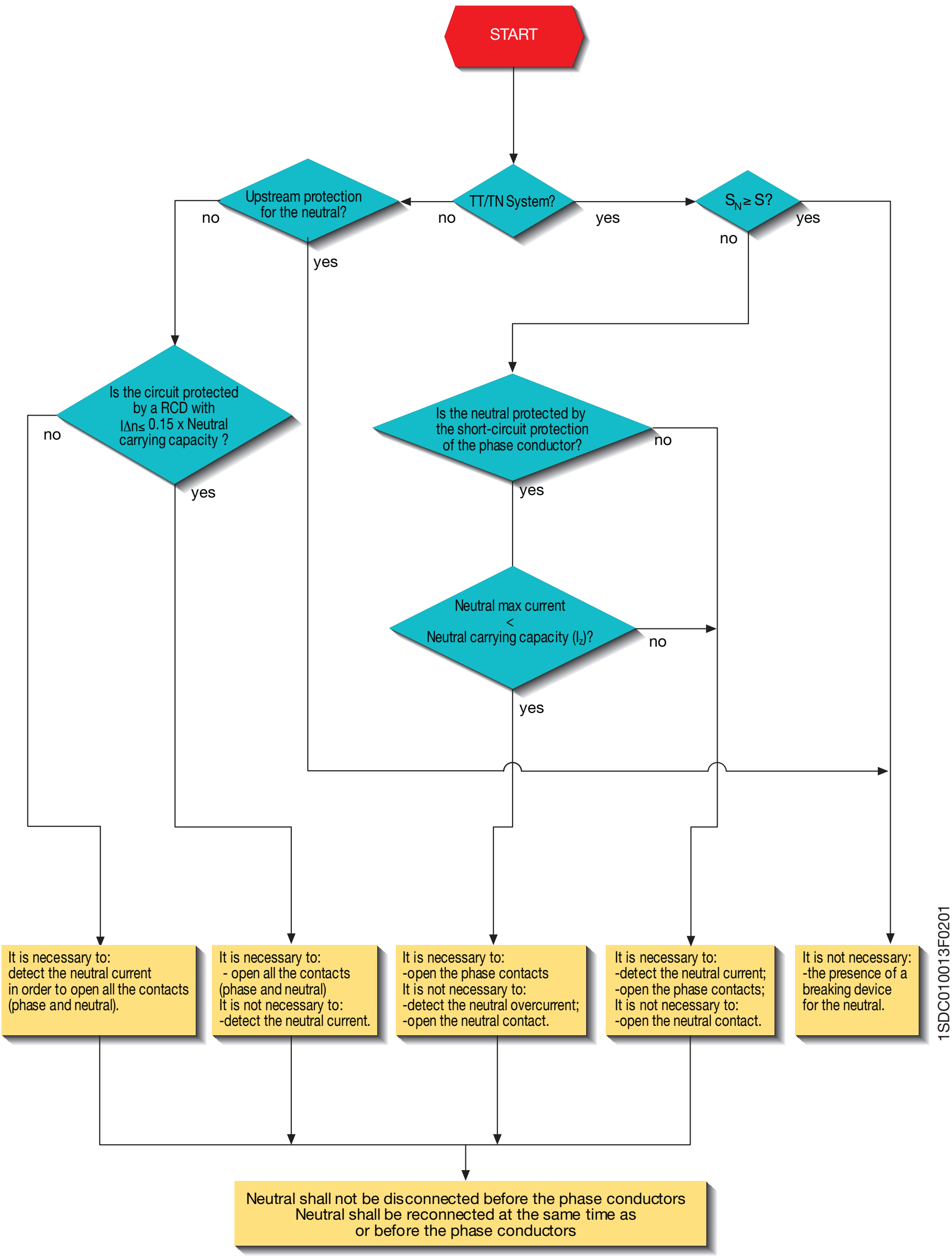


NOTE – A three-phase alternative power supply with a non-suitable 3-pole switch, due to unintentional circular stray currents generating electromagnetic fields.

IT system:
The Standard advises against distributing the neutral conductor in IT systems. If the neutral conductor is distributed, the overcurrents must be detected on the neutral conductor of each circuit in order to disconnect all the live conductors on the corresponding circuit, including the neutral one (neutral conductor protected and disconnected).
Overcurrents do not need to be detected on the neutral conductor in any of the following cases:
- the neutral conductor is protected against short-circuit by a protective device fitted upstream;
- the circuit is protected by a residual current device with rated residual current lower than 0.15 times the current carrying capacity of the corresponding neutral conductor. This device must disconnect all the live conductors, the neutral conductor included.

For all distribution systems, whenever necessary, connection and disconnection of the neutral conductor, shall ensure that:
- the neutral conductor is not disconnected before the phase conductor;
- the neutral conductor is connected at the same moment or before the phase conductor.

2 Protection of feeders



2 Protection of feeders

Determination of the minimum cross section of the neutral conductor

The neutral conductor, if any, shall have the same cross section as the line conductor:
- in single-phase, two-wire circuits whatever the section;
- in polyphase and single-phase three-wire circuits, when the size of the line conductors is less than or equal to 16 mm^2 in copper, or 25 mm^2 in aluminium.[1]

The cross section of the neutral conductor can be less than the cross section of the phase conductor when the cross section of the phase conductor is greater than 16 mm^2 with a copper cable, or 25 mm^2 with an aluminium cable, if both the following conditions are met:
- the cross section of the neutral conductor is at least 16 mm^2 for copper conductors and 25 mm^2 for aluminium conductors;
- there is no high harmonic distortion of the load current. If there is high harmonic distortion (the harmonic content is greater than 10%), as for example in equipment with discharge lamps, the cross section of the neutral conductor cannot be less than the cross section of the phase conductors.

Table 1: Minimum cross sections of the neutral conductor

	Phase cross section S [mm^2]	**Min. neutral cross section S_N [mm^2]**
Single-phase/two-phase circuits		
Cu/Al	Any	S*
Three-phase circuits	S ≤ 16	S*
Cu	S > 16	16
Three-phase circuits	S ≤ 25	S*
Al	S > 25	25

*for TN-C systems, the Standards specify a minimum cross section of 10 mm^2 for copper and 16 mm^2 for aluminium conductors

[1] The cross section of phase conductors shall be dimensioned in compliance with the instructions of the Chapter 2.2.1 “Current carrying capacity and methods of installation”

2 Protection of feeders

Protective conductor

Determination of the minimum cross sections

The minimum cross section of the protective conductor can be determined by using the following table:

Table 2: Cross section of the protective conductor

Cross section of line conductor S [mm²]	Minimum cross section of the corresponding protective conductor [mm²]	
	If the protective conductor is of the same material as the line conductor	If the protective conductor is not of the same material as the line conductor
$S \leq 16$	S	$\frac{k_1}{k_2} \cdot S$
$16 < S \leq 25$	16^*	$\frac{k_1}{k_2} \cdot 16$
$S > 25$	$\frac{S}{2}^*$	$\frac{k_1}{k_2} \cdot \frac{S}{2}$

Where

k_1 is the value of k for the line conductor, selected from Table 1 Chapter 2.4 according to the materials of the conductor and insulation;

k_2 is the value of k for the protective conductor.

* For a PEN conductor, the reduction of the cross section is permitted only in accordance with the rules for sizing of the neutral conductor.

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For a more accurate calculation and if the protective conductor is subjected to adiabatic heating from an initial known temperature to a final specified temperature (applicable for fault extinction time no longer than 5s), the minimum cross section of the protective conductor S_{PE} can be obtained by using the following formula:

$$S_{PE} = \frac{\sqrt{I^2 t}}{k} \quad (1)$$

where:
- S_{PE} is the cross section of the protective conductor [mm²];
- I is the r.m.s. current flowing through the protective conductor in the event of a fault with low impedance [A];
- t is the trip time of the protective device [s];

2 Protection of feeders

- k is a constant which depends on the material of the protective conductor, on the type of insulation and on initial and final temperature. The most common values can be taken from Tables 3 and 4.

Table 3: Values of *k* for insulated protective conductors not incorporated in cables and not bunched with other cables

Conductor insulation	Temperature °C [b]		Material of conductor		
			Copper	Aluminium	Steel
	Initial	Final	Values for k		
70 °C PVC	30	160/140 [a]	143/133 [a]	95/88 [a]	52/49 [a]
90 °C PVC	30	143/133 [a]	143/133 [a]	95/88 [a]	52/49 [a]
90 °C thermosetting	30	250	176	116	64
60 °C rubber	30	200	159	105	58
85 °C rubber	30	220	168	110	60
Silicon rubber	30	350	201	133	73

[a] The lower value applies to PVC insulated conductors of cross section greater than 300 mm^2.
[b] Temperature limits for various types of insulation are given in IEC 60724.

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Table 4: Values of *k* for protective conductors as a core incorporated in a cable or bunched with other cables or insulated conductors

Conductor insulation	Temperature °C [b]		Material of conductor		
			Copper	Aluminium	Steel
	Initial	Final	Values for k		
70 °C PVC	70	160/140 [a]	115/103 [a]	76/68 [a]	42/37 [a]
90 °C PVC	90	160/140 [a]	100/86 [a]	66/57 [a]	36/31 [a]
90 °C thermosetting	90	250	143	94	52
60 °C rubber	60	200	141	93	51
85 °C rubber	85	220	134	89	48
Silicon rubber	180	350	132	87	47

[a] The lower value applies to PVC insulated conductors of cross section greater than 300 mm^2.
[b] Temperature limits for various types of insulation are given in IEC 60724.

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2 Protection of feeders

Further values of k can be taken from the Tables in Annex D, which provides the formula for accurate calculation of the value of k.

If Table 2 or formula (1) do not provide a standardized cross section, a larger standardized cross section shall be chosen.

Regardless of whether Table 2 or formula (1) are used, the cross section of the protective conductor, which is not part of the supply cable, shall be at least:

- 2.5 mm^2 Cu/16 mm^2 Al, if a mechanical protection is provided;
- 4 mm^2 Cu/16 mm^2 Al, if no mechanical protection ise provided.

For current using equipment intended for permanent connection and with a protective conductor current exceeding 10 mA, reinforced protective conductors shall be designed as follows:

- either the protective conductor shall have a cross-sectional area of at least 10 mm^2 Cu or 16 mm^2 Al, through its total run;
- or a second protective conductor of at least the same cross-sectional area as required for protection against indirect contact shall be laid up to a point where the protective conductor has a cross-sectional area not less than 10 mm^2 Cu or 16 mm^2 Al. This requires that the appliance has a separate terminal for a second protective conductor;

When overcurrent protective devices are used for protection against electric shock, the protective conductor shall be incorporated in the same wiring system as the live conductors or be located in their immediate proximity.

2.6 Busbar trunking systems (BTSs)

In electrical installations for industrial environments, busbar trunking systems (BTSs) optimize the power distribution despite the inevitable modifications that are carried out (additions, displacements, replacement of loads) and to facilitate maintenance work and safety verifications.
They are mainly used for:
- supplying sources of light, safety and low power distribution;
- lighting lines (medium power);
- power supply and distribution (medium and large power);
- supplying moving equipment (bridge cranes).

Busbar trunking systems are subject to the following Standards:
- IEC 60439 – 1 *"Low-voltage switchgear and controlgear assemblies – Part 1: Type-tested and partially type-tested assemblies"*
- IEC 60439 – 2 *"Low-voltage switchgear and controlgear assemblies – Part 2: Particular requirements for busbar trunking systems (busways)"*.

BTSs consist of:

- *conductors/busbars;*
- *coupling:* electrical and mechanical connecting elements for different elements;
- *straight elements:* base elements of the line for carrying energy from the source to the loads;
- *routing elements:* flexible joints for the creation of curves or overcoming obstacles, horizontal and vertical angles, tee joints and cross elements to create any type of route;
- *pull boxes:* elements that enable lamps or operating machines to be supplied directly with integrated protection (fuses or circuit breakers);
- *suspensions/accessories*: hanging and fixing elements for BTS and for any support required for special loads (lighting components, etc).

Dimensioning of a BTS

To dimension a BTS, the load current must be determined using the following data:

Power supply

- General type of load supply:
  - single-phase
  - three-phase.
- Type of BTS supply:
  - from one end;
  - from both ends;
  - central power supply.
- Rated voltage
- Short-circuit current at the supply point
- Ambient temperature.

Loads

- Number, distribution, power and cosφ and type of loads supplied by the same BTS

2 Protection of feeders

BTS geometry

- Type of installation:
  - flat;
  - edge-on;
  - vertical.
- Length.

NOTE: BTSs shall be placed at a distance from the walls and the ceilings in such a way as to enable visual inspection of connections during assembly and to facilitate insertion of the branch units.
If possible, it is preferable to install the BTS edge-on so as to improve mechanical resistance and reduce any possible deposit of powder and polluting substances that might affect the level of internal insulation.

Load current calculation for three-phase system

Load current I_b for a three-phase system is calculated by the following formula:

$$I_b = \frac{P_t \cdot b}{\sqrt{3} \cdot U_r \cdot \cos\varphi_m} \text{ [A]} \qquad (1)$$

where:
- P_t is the sum of the active power of all the installed loads [W];
- b is the supply factor, which is:
  - 1 if the BTS is supplied from one side only;
  - 1/2 if the BTS is supplied from the centre or from both ends simultaneously;
- U_r is the operating voltage [V];
- $\cos\varphi_m$ is the average power factor of the loads.

Choice of BTS current carrying capacity

A BTS shall be chosen so that its current carrying capacity I_z complies with the following formula:

$$I_b \leq I_{Z0} \cdot k_t = I_Z \qquad (2)$$

where:
- I_{Z0} is the current that the BTS can carry for an indefinite time at the reference temperature (40 °C);
- I_b is the load current;
- k_t is the correction factor for ambient temperature values other than the reference ambient temperature shown on Table 1.

Table 1: Correction factor k_t for ambient temperature other than 40 °C

Ambient Temperature [°C]	15	20	25	30	35	40	45	50
k_t	1.2	1.17	1.12	1.08	1.05	1	0.95	0.85

2 Protection of feeders

Note: the following tables refer to Zucchini S.p.A. products

Table 2: Current carrying capacity I_{Z0} of copper BTS

Size	Type	Number of conductors	I_{Z0} [A]	r_{ph}* [mΩ/m]	x_{ph} [mΩ/m]	U_r [V]
25	LB254 25A 4 cond. Cu	4	25	6.964	1.144	400
25	HL254 25A 4 cond. Cu	4	25	6.876	1.400	400
25	HL2544 25A 4+4 cond. Cu	4+4	25	6.876	1.400	400
40	LB404 40A 4 cond. Cu	4	40	3.556	0.792	400
40	HL404 40A 4 cond. Cu	4	40	3.516	1.580	400
40	HL4044 40A 4+4 cond. Cu	4+4	40	3.516	1.580	400
40	SL 40A 4 cond. Cu	4	40	2.173	0.290	400
63	SL 63A 4 cond. Cu	4	63	1.648	0.637	400
100	MS 100A 4 cond. Cu	4	100	0.790	0.366	400
160	MS 160A 4 cond. Cu	4	160	0.574	0.247	400
160	SB4 160A 4 cond. Cu	4	160	0.335	0.314	500
160	SB5 160A 5 cond. Cu	5	160	0.335	0.314	500
160	SB6 160A 5 cond. Cu	5	160	0.335	0.314	500
160	SB7 160A 4 cond. Cu	4	160	0.335	0.314	500
250	MR 250A 4 cond. Cu	4	250	0.285	0.205	1000
250	MRf 250A 5 cond. Cu	5	250	0.285	0.205	1000
250	SB4 250A 4 cond. Cu	4	250	0.194	0.205	500
250	SB5 250A 5 cond. Cu	5	250	0.194	0.205	500
250	SB6 250A 5 cond. Cu	5	250	0.194	0.205	500
250	SB7 250A 4 cond. Cu	4	250	0.194	0.205	500
315	MR 315A 4 cond. Cu	4	315	0.216	0.188	1000
315	MRf 315A 5 cond. Cu	5	315	0.216	0.188	1000
350	SB4 350A 4 cond. Cu	4	350	0.142	0.188	500
350	SB5 350A 5 cond. Cu	5	350	0.142	0.188	500
350	SB6 350A 5 cond. Cu	5	350	0.142	0.188	500
350	SB7 350A 4 cond. Cu	4	350	0.142	0.188	500
400	MR 400A 4 cond. Cu	4	400	0.115	0.129	1000
400	MRf 400A 5 cond. Cu	5	400	0.115	0.129	1000
500	SB4 500A 4 cond. Cu	4	500	0.092	0.129	500
500	SB5 500A 5 cond. Cu	5	500	0.092	0.129	500
500	SB6 500A 5 cond. Cu	5	500	0.092	0.129	500
500	SB7 500A 4 cond. Cu	4	500	0.092	0.129	500
630	MR 630A 4 cond. Cu	4	630	0.073	0.122	1000
630	MRf 630A 5 cond. Cu	5	630	0.073	0.122	1000
700	SB4 700A 4 cond. Cu	4	700	0.077	0.122	500
700	SB5 700A 5 cond. Cu	5	700	0.077	0.122	500

2 Protection of feeders

Size	Type	Number of conductors	I_{Z0} [A]	r_{ph}* [mΩ/m]	x_{ph} [mΩ/m]	U_r [V]
700	SB6 700A 5 cond. Cu	5	700	0.077	0.122	500
700	SB7 700A 4 cond. Cu	4	700	0.077	0.122	500
800	MR 800A 4 cond. Cu	4	800	0.047	0.122	1000
800	MRf 800A 5 cond. Cu	5	800	0.047	0.122	1000
800	SC 800A 4 cond. Cu	4	800	0.038	0.027	1000
800	SB4 800A 4 cond. Cu	4	800	0.072	0.122	500
800	SB5 800A 5 cond. Cu	5	800	0.072	0.122	500
800	SB6 800A 5 cond. Cu	5	800	0.072	0.122	500
800	SB7 800A 4 cond. Cu	4	800	0.072	0.122	500
1000	MR 1000A 4 cond. Cu	4	1000	0.038	0.120	1000
1000	MRf 1000A 5 cond. Cu	5	1000	0.038	0.120	1000
1000	SC 1000A 4 cond. Cu	4	1000	0.037	0.026	1000
1000	HRC1 1000A 4 cond. Cu	4	1000	0.038	0.097	1000
1000	SB4 1000A 4 cond. Cu	4	1000	0.068	0.120	500
1000	SB5 1000A 5 cond. Cu	5	1000	0.068	0.120	500
1000	SB6 1000A 5 cond. Cu	5	1000	0.068	0.120	500
1000	SB7 1000A 4 cond. Cu	4	1000	0.068	0.120	500
1200	SC 1200A 4 cond. Cu	4	1200	0.035	0.021	1000
1250	SC 1250A 4 cond. Cu	4	1250	0.034	0.023	1000
1250	HRC1 1250A 4 cond. Cu	4	1250	0.035	0.076	1000
1500	SC 1500A 4 cond. Cu	4	1500	0.030	0.022	1000
1600	SC 1600A 4 cond. Cu	4	1600	0.025	0.018	1000
1600	HRC1 1600A 4 cond. Cu	4	1600	0.034	0.074	1000
2000	SC 2000A 4 cond. Cu	4	2000	0.020	0.015	1000
2000	HRC1 2000A 4 cond. Cu	4	2000	0.025	0.074	1000
2400	SC 2400A 4 cond. Cu	4	2400	0.019	0.012	1000
2500	SC 2500A 4 cond. Cu	4	2500	0.016	0.011	1000
2500	HRC1 2500A 4 cond. Cu	4	2500	0.019	0.040	1000
3000	SC 3000A 4 cond. Cu	4	3000	0.014	0.011	1000
3000	HRC2 3000A 4 cond. Cu	4	3000	0.017	0.031	1000
3200	SC 3200A 4 cond. Cu	4	3200	0.013	0.009	1000
3200	HRC2 3200A 4 cond. Cu	4	3200	0.015	0.031	1000
4000	SC 4000A 4 cond. Cu	4	4000	0.011	0.007	1000
4000	HRC2 4000A 4 cond. Cu	4	4000	0.011	0.026	1000
5000	SC 5000A 4 cond. Cu	4	5000	0.008	0.005	1000
5000	HRC2 5000A 4 cond. Cu	4	5000	0.008	0.023	1000

*phase resistance at I_{z0}

2 Protection of feeders

Table 3: Current carrying capacity I_{Z0} of aluminium BTS

Size	Type	Number of conductors	I_{Z0} [A]	r_{ph}* [mΩ/m]	x_{ph} [mΩ/m]	U_r [V]
160	MR 160A 4 cond. Al	4	160	0.591	0.260	1000
160	MRf 160A 5 cond. Al	5	160	0.591	0.260	1000
160	SB4 160A 4 cond. Al	4	160	0.431	0.260	500
160	SB5 160A 5 cond. Al	5	160	0.431	0.260	500
160	SB6 160A 5 cond. Al	5	160	0.431	0.260	500
160	SB7 160A 4 cond. Al	4	160	0.431	0.260	500
250	MR 250A 4 cond. Al	4	250	0.394	0.202	1000
250	MRf 250A 5 cond. Al	5	250	0.394	0.202	1000
250	SB4 250A 4 cond. Al	4	250	0.226	0.202	500
250	SB5 250A 5 cond. Al	5	250	0.226	0.202	500
250	SB6 250A 5 cond. Al	5	250	0.226	0.202	500
250	SB7 250A 4 cond. Al	4	250	0.226	0.202	500
315	MR 315A 4 cond. Al	4	315	0.236	0.186	1000
315	MRf 315A 5 cond. Al	5	315	0.236	0.186	1000
315	SB4 315A 4 cond. Al	4	315	0.181	0.186	500
315	SB5 315A 5 cond. Al	5	315	0.181	0.186	500
315	SB6 315A 5 cond. Al	5	315	0.181	0.186	500
315	SB7 315A 4 cond. Al	4	315	0.181	0.186	500
400	MR 400A 4 cond. Al	4	400	0.144	0.130	1000
400	MRf 400A 5 cond. Al	5	400	0.144	0.130	1000
400	SB4 400A 4 cond. Al	4	400	0.125	0.130	500
400	SB5 400A 5 cond. Al	5	400	0.125	0.130	500
400	SB6 400A 5 cond. Al	5	400	0.125	0.130	500
400	SB7 400A 4 cond. Al	4	400	0.125	0.130	500
500	SB4 500A 4 cond. Al	4	500	0.102	0.127	500
500	SB5 500A 5 cond. Al	5	500	0.102	0.127	500
500	SB6 500A 5 cond. Al	5	500	0.102	0.127	500
500	SB7 500A 4 cond. Al	4	500	0.102	0.127	500
630	MR 630A 4 cond. Al	4	630	0.072	0.097	1000
630	MRf 630A 5 cond. Al	5	630	0.072	0.097	1000
630	SC 630A 4 cond. Al	4	630	0.072	0.029	1000

2 Protection of feeders

Size	Type	Number of conductors	I_{Z0} [A]	r_{ph}* [mΩ/m]	x_{ph} [mΩ/m]	U_r [V]
630	SB4 630A 4 cond. Al	4	630	0.073	0.097	500
630	SB5 630A 5 cond. Al	5	630	0.073	0.097	500
630	SB6 630A 5 cond. Al	5	630	0.073	0.097	500
630	SB7 630A 4 cond. Al	4	630	0.073	0.097	500
800	MR 800A 4 cond. Al	4	800	0.062	0.096	1000
800	MRf 800A 5 cond. Al	5	800	0.062	0.096	1000
800	SC 800A 4 cond. Al	4	800	0.067	0.027	1000
800	SB4 800A 4 cond. Al	4	800	0.071	0.096	500
800	SB5 800A 5 cond. Al	5	800	0.071	0.096	500
800	SB6 800A 5 cond. Al	5	800	0.071	0.096	500
800	SB7 800A 4 cond. Al	4	800	0.071	0.096	500
1000	SC 1000A 4 cond. Al	4	1000	0.062	0.023	1000
1000	HRC1 1000A 4 cond. Al	4	1000	0.068	0.087	1000
1200	SC 1200A 4 cond. Al	4	1200	0.054	0.023	1000
1250	SC 1250A 4 cond. Al	4	1250	0.044	0.021	1000
1250	HRC1 1250A 4 cond. Al	4	1250	0.044	0.066	1000
1500	SC 1500A 4 cond. Al	4	1500	0.041	0.023	1000
1600	SC 1600A 4 cond. Al	4	1600	0.035	0.017	1000
1600	HRC1 1600A 4 cond. Al	4	1600	0.041	0.066	1000
2000	SC 2000A 4 cond. Al	4	2000	0.029	0.016	1000
2000	HRC1 2000A 4 cond. Al	4	2000	0.034	0.053	1000
2250	HRC2 2250A 4 cond. Al	4	2250	0.032	0.049	1000
2400	SC 2400A 4 cond. Al	4	2400	0.028	0.012	1000
2500	SC 2500A 4 cond. Al	4	2500	0.022	0.011	1000
2500	HRC2 2500A 4 cond. Al	4	2500	0.022	0.034	1000
3000	SC 3000A 4 cond. Al	4	3000	0.020	0.011	1000
3200	SC 3200A 4 cond. Al	4	3200	0.017	0.009	1000
3200	HRC2 3200A 4 cond. Al	4	3200	0.020	0.034	1000
4000	SC 4000A 4 cond. Al	4	4000	0.014	0.008	1000
4000	HRC2 4000A 4 cond. Al	4	4000	0.017	0.024	1000
4500	HRC2 4500A 4 cond. Al	4	4500	0.014	0.024	1000

*phase resistance at I_{z0}

2 Protection of feeders

BTS protection

Protection against overload

BTSs are protected against overload by using the same criterion as that used for the cables. The following formula shall be verified:

$$I_b \leq I_n \leq I_z \qquad (3)$$

where:
- I_b is the current for which the circuit is designed;
- I_n is the rated current of the protective device; for adjustable protective devices, the rated current I_n is the set current;
- I_z is the continuous current carrying capacity of the BTS.

Protection against short-circuit[1]

1 The protection against short-circuit does not need to be checked if MCBs up to 63 A are used whenever correctly dimensioned for overload protection. In such cases, in fact, protection against both thermal and electrodynamic effects is certainly adequate because of the energy and peak limitations offered by these protective devices.

The BTS must be protected against thermal overload and electrodynamic effects due to the short-circuit current.

Protection against thermal overload
The following formula shall be fulfilled:

$$I^2t_{CB} \leq I^2t_{BTS} \quad (4)$$

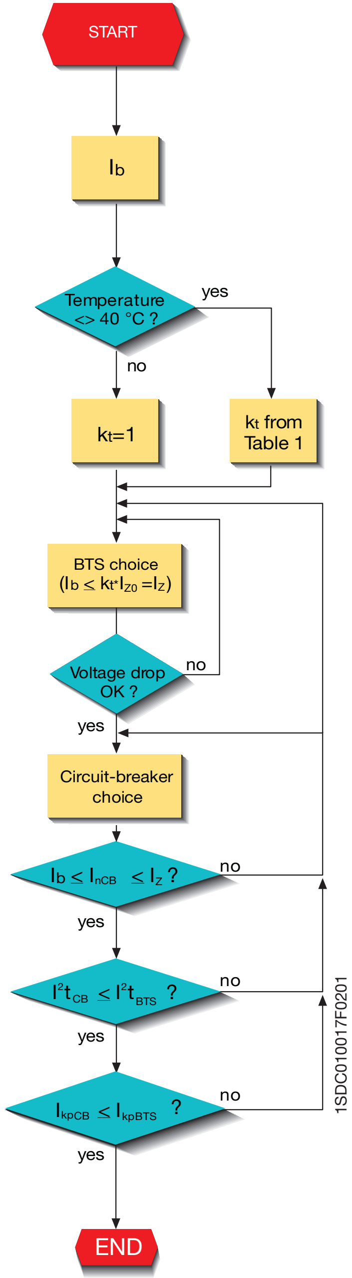
where:
- I^2t_{CB} is the specific let-through energy of the circuit-breaker at the maximum short-circuit current value at the installation point. This can be extrapolated from the curves shown in Volume 1 Chapter 3.4;
- I^2t_{BTS} is the withstood energy of the BTS and it is normally given by the manufacturer (see Tables 4 and 5).

Protection against electrodynamic effects
The following formula shall be fulfilled:

$$I_{kp\ CB} \leq I_{kp\ BTS} \quad (5)$$

where:
- $I_{kp\ CB}$ is the peak limited by the circuit-breaker at the maximum short-circuit current value at the installation point. This can be extrapolated from the limitation curves shown in Volume 1, Chapter 3.3;
- $I_{kp\ BTS}$ is the maximum peak current value of the BTS (see Tables 4 and 5).

2 Protection of feeders



2 Protection of feeders

Table 4: Values of the withstood energy and peak current of copper BTS

Size	Type	I^2t_{ph} [(kA)²s]	I^2t_N [(kA)²s]	I^2t_{PE} [(kA)²s]	I_{peakph} [kA]	I_{peakN} [kA]
25	LB254 25A 4 cond. Cu	0.48	0.48	0.48	10	10
25	HL254 25A 4 cond. Cu	0.64	0.64	0.64	10	10
25	HL2544 25A 4+4 cond. Cu	0.64	0.64	0.64	10	10
40	LB404 40A 4 cond. Cu	0.73	0.73	0.73	10	10
40	HL404 40A 4 cond. Cu	1	1	1	10	10
40	HL4044 40A 4+4 cond. Cu	1	1	1	10	10
40	SL 40A 4 cond. Cu	7.29	7.29	7.29	10	10
63	SL 63A 4 cond. Cu	7.29	7.29	7.29	10	10
100	MS 100A 4 cond. Cu	20.25	20.25	20.25	10	10
160	MS 160A 4 cond. Cu	30.25	30.25	30.25	10	10
160	SB4 160A 4 cond. Cu	100	60	60	17	10.2
160	SB5 160A 5 cond. Cu	100	100	100	17	10.2
160	SB6 160A 5 cond. Cu	100	100	100	17	10.2
160	SB7 160A 4 cond. Cu	100	100	100	17	10.2
250	MR 250A 4 cond. Cu	312.5	187.5	187.5	52.5	31.5
250	MRf 250A 5 cond. Cu	312.5	312.5	312.5	52.5	31.5
250	SB4 250A 4 cond. Cu	169	101.4	101.4	26	15.6
250	SB5 250A 5 cond. Cu	169	169	169	26	15.6
250	SB6 250A 5 cond. Cu	169	169	169	26	15.6
250	SB7 250A 4 cond. Cu	169	169	169	26	15.6
315	MR 315A 4 cond. Cu	312.5	187.5	187.5	52.5	31.5
315	MRf 315A 5 cond. Cu	312.5	312.5	312.5	52.5	31.5
350	SB4 350A 4 cond. Cu	169	101.4	101.4	26	15.6
350	SB5 350A 5 cond. Cu	169	169	169	26	15.6
350	SB6 350A 5 cond. Cu	169	169	169	26	15.6
350	SB7 350A 4 cond. Cu	169	169	169	26	15.6
400	MR 400A 4 cond. Cu	900	540	540	63	37.8
400	MRf 400A 5 cond. Cu	900	900	900	63	37.8
500	SB4 500A 4 cond. Cu	756.25	453.75	453.75	58	34.8
500	SB5 500A 5 cond. Cu	756.25	756.25	756.25	58	34.8
500	SB6 500A 5 cond. Cu	756.25	756.25	756.25	58	34.8
500	SB7 500A 4 cond. Cu	756.25	756.25	756.25	58	34.8
630	MR 630A 4 cond. Cu	1296	777.6	777.6	75.6	45.4
630	MRf 630A 5 cond. Cu	1296	1296	1296	75.6	45.4
700	SB4 700A 4 cond. Cu	756.25	453.75	453.75	58	34.8
700	SB5 700A 5 cond. Cu	756.25	756.25	756.25	58	34.8

2 Protection of feeders

Size	Type	I^2t_{ph} [(kA)²s]	I^2t_N [(kA)²s]	I^2t_{PE} [(kA)²s]	I_{peakph} [kA]	I_{peakN} [kA]
700	SB6 700A 5 cond. Cu	756.25	756.25	756.25	58	34.8
700	SB7 700A 4 cond. Cu	756.25	756.25	756.25	58	34.8
800	MR 800A 4 cond. Cu	1296	777.6	777.6	75.6	45.4
800	MRf 800A 5 cond. Cu	1296	1296	1296	75.6	45.4
800	SC 800A 4 cond. Cu	3969	3969	2381.4	139	83.4
800	SB4 800A 4 cond. Cu	756.25	453.75	453.75	58	34.8
800	SB5 800A 5 cond. Cu	756.25	756.25	756.25	58	34.8
800	SB6 800A 5 cond. Cu	756.25	756.25	756.25	58	34.8
800	SB7 800A 4 cond. Cu	756.25	756.25	756.25	58	34.8
1000	MR 1000A 4 cond. Cu	1296	777.6	777.6	75.6	45.4
1000	MRf 1000A 5 cond. Cu	1296	1296	1296	75.6	45.4
1000	SC 1000A 4 cond. Cu	3969	3969	2381.4	139	83.4
1000	HRC1 1000A 4 cond. Cu	1600	1600	960	84	50.4
1000	SB4 1000A 4 cond. Cu	1024	614.4	614.4	60	36
1000	SB5 1000A 5 cond. Cu	1024	1024	1024	60	36
1000	SB6 1000A 5 cond. Cu	1024	1024	1024	60	36
1000	SB7 1000A 4 cond. Cu	1024	1024	1024	60	36
1200	SC 1200A 4 cond. Cu	7744	7744	4646.4	194	116.4
1250	SC 1250A 4 cond. Cu	7744	7744	4646.4	194	116.4
1250	HRC1 1250A 4 cond. Cu	2500	2500	1500	105	63
1500	SC 1500A 4 cond. Cu	7744	7744	4646.4	194	116.4
1600	SC 1600A 4 cond. Cu	7744	7744	4646.4	194	116.4
1600	HRC1 1600A 4 cond. Cu	2500	2500	1500	105	63
2000	SC 2000A 4 cond. Cu	7744	7744	4646.4	194	116.4
2000	HRC1 2000A 4 cond. Cu	3600	3600	2160	132	79.2
2400	SC 2400A 4 cond. Cu	7744	7744	4646.4	194	116.4
2500	SC 2500A 4 cond. Cu	7744	7744	4646.4	194	116.4
2500	HRC1 2500A 4 cond. Cu	4900	4900	2940	154	92.4
3000	SC 3000A 4 cond. Cu	30976	30976	18585.6	387	232.2
3000	HRC2 3000A 4 cond. Cu	8100	8100	4860	198	118.8
3200	SC 3200A 4 cond. Cu	30976	30976	18585.6	387	232.2
3200	HRC2 3200A 4 cond. Cu	8100	8100	4860	198	118.8
4000	SC 4000A 4 cond. Cu	30976	30976	18585.6	387	232.2
4000	HRC2 4000A 4 cond. Cu	8100	8100	4860	198	118.8
5000	SC 5000A 4 cond. Cu	30976	30976	18585.6	387	232.2
5000	HRC2 5000A 4 cond. Cu	10000	10000	6000	220	132

2 Protection of feeders

Table 5: Values of the withstood energy and peak current of aluminium BTS

Size	Type	I^2t_{ph} [(kA)²s]	I^2t_N [(kA)²s]	I^2t_{PE} [(kA)²s]	I_{peakph} [kA]	I_{peakN} [kA]
160	MR 160A 4 cond. Al	112.5	67.5	67.5	30	18
160	MRf 160A 5 cond. Al	112.5	112.5	112.5	30	18
160	SB4 160A 4 cond. Al	100	60	60	17	10.2
160	SB5 160A 5 cond. Al	100	100	100	17	10.2
160	SB6 160A 5 cond. Al	100	100	100	17	10.2
160	SB7 160A 4 cond. Al	100	100	100	17	10.2
250	MR 250A 4 cond. Al	312.5	187.5	187.5	52.5	31.5
250	MRf 250A 5 cond. Al	312.5	312.5	312.5	52.5	31.5
250	SB4 250A 4 cond. Al	169	101.4	101.4	26	15.6
250	SB5 250A 5 cond. Al	169	169	169	26	15.6
250	SB6 250A 5 cond. Al	169	169	169	26	15.6
250	SB7 250A 4 cond. Al	169	169	169	26	15.6
315	MR 315A 4 cond. Al	625	375	375	52.5	31.5
315	MRf 315A 5 cond. Al	625	625	625	52.5	31.5
315	SB4 315A 4 cond. Al	169	101.4	101.4	26	15.6
315	SB5 315A 5 cond. Al	169	169	169	26	15.6
315	SB6 315A 5 cond. Al	169	169	169	26	15.6
315	SB7 315A 4 cond. Al	169	169	169	26	15.6
400	MR 400A 4 cond. Al	900	540	540	63	37.8
400	MRf 400A 5 cond. Al	900	900	900	63	37.8
400	SB4 400A 4 cond. Al	625	375	375	52.5	31.5
400	SB5 400A 5 cond. Al	625	625	625	52.5	31.5
400	SB6 400A 5 cond. Al	625	625	625	52.5	31.5
400	SB7 400A 4 cond. Al	625	625	625	52.5	31.5
500	SB4 500A 4 cond. Al	625	375	375	52.5	31.5
500	SB5 500A 5 cond. Al	625	625	625	52.5	31.5
500	SB6 500A 5 cond. Al	625	625	625	52.5	31.5
500	SB7 500A 4 cond. Al	625	625	625	52.5	31.5
630	MR 630A 4 cond. Al	1296	777.6	777.6	75.6	45.4
630	MRf 630A 5 cond. Al	1296	1296	1296	75.6	45.4
630	SC 630A 4 cond. Al	1444	1444	866.4	80	48

2 Protection of feeders

Size	Type	I^2t_{ph} [(kA)²s]	I^2t_N [(kA)²s]	I^2t_{PE} [(kA)²s]	I_{peakph} [kA]	I_{peakN} [kA]
630	SB4 630A 4 cond. Al	1024	614.4	614.4	67.5	40.5
630	SB5 630A 5 cond. Al	1024	1024	1024	67.5	40.5
630	SB6 630A 5 cond. Al	1024	1024	1024	67.5	40.5
630	SB7 630A 4 cond. Al	1024	1024	1024	67.5	40.5
800	MR 800A 4 cond. Al	1296	777.6	777.6	75.6	45.4
800	MRf 800A 5 cond. Al	1296	1296	1296	75.6	45.4
800	SC 800A 4 cond. Al	1764	1764	1058.4	88	52.8
800	SB4 800A 4 cond. Al	1024	614.4	614.4	67.5	40.5
800	SB5 800A 5 cond. Al	1024	1024	1024	67.5	40.5
800	SB6 800A 5 cond. Al	1024	1024	1024	67.5	40.5
800	SB7 800A 4 cond. Al	1024	1024	1024	67.5	40.5
1000	SC 1000A 4 cond. Al	6400	6400	3840	176	105.6
1000	HRC1 1000A 4 cond. Al	1600	1600	960	84	50.4
1200	SC 1200A 4 cond. Al	6400	6400	3840	176	105.6
1250	SC 1250A 4 cond. Al	6400	6400	3840	176	105.6
1250	HRC1 1250A 4 cond. Al	2500	2500	1500	105	63
1500	SC 1500A 4 cond. Al	6400	6400	3840	176	105.6
1600	SC 1600A 4 cond. Al	6400	6400	3840	176	105.6
1600	HRC1 1600A 4 cond. Al	2500	2500	1500	105	63
2000	SC 2000A 4 cond. Al	6400	6400	3840	176	105.6
2000	HRC1 2000A 4 cond. Al	3600	3600	2160	132	79.2
2250	HRC2 2250A 4 cond. Al	4900	4900	2940	154	92.4
2400	SC 2400A 4 cond. Al	25600	25600	15360	352	211.2
2500	SC 2500A 4 cond. Al	25600	25600	15360	352	211.2
2500	HRC2 2500A 4 cond. Al	8100	8100	4860	198	118.8
3000	SC 3000A 4 cond. Al	25600	25600	15360	352	211.2
3200	SC 3200A 4 cond. Al	25600	25600	15360	352	211.2
3200	HRC2 3200A 4 cond. Al	8100	8100	4860	198	118.8
4000	SC 4000A 4 cond. Al	25600	25600	15360	352	211.2
4000	HRC2 4000A 4 cond. Al	8100	8100	4860	198	118.8
4500	HRC2 4500A 4 cond. Al	10000	10000	6000	220	132

2 Protection of feeders

Protection of the outgoing feeders

If the outgoing feeder, which generally consists of cable duct, is not already protected against short-circuit and overload by the device located upstream of the cable, the following measures shall be taken:

- *protection against short-circuit:*
there is no need to protect the feeder against the short-circuit if simultaneously:
a. the length does not exceed 3 metres;
b. the risk of short-circuit is minimized;
c. there is no inflammable material nearby.

In explosive environments and environments with greater risk of fire, protection against short-circuit is always required;

- *protection against overload:*
the current carrying capacity of the feeder is generally lower than that of the BTS. It is therefore necessary to protect also the feeder against overload.
The protection device against overload can be placed inside the pull box or on the incoming panel.
In the latter case, protection against overload can also be provided by the circuit breakers protecting the single outgoing feeder from the panel only if the sum of their rated currents is lower or equal to the current carrying capacity I_z of the outgoing feeder.
In locations with greater risk of fire, the overload protection device shall be installed at the outgoing point, i.e. inside the pull box.

Voltage drop

If a BTS is particularly long, the value of the voltage drop must be verified.
For three-phase systems with a power factor ($\cos\varphi_m$) not lower than 0.8, the voltage drop can be calculated by using the following simplified formula:

$$\Delta u = \frac{a \cdot \sqrt{3} \cdot I_b \cdot L \cdot (r_t \cdot \cos\varphi_m + x \cdot \sin\varphi_m)}{1000} \text{ [V]} \qquad (6a)$$

For single-phase BTS the formula is:

$$\Delta u = \frac{a \cdot 2 \cdot I_b \cdot L \cdot (r_t \cdot \cos\varphi_m + x \cdot \sin\varphi_m)}{1000} \text{ [V]} \qquad (6b)$$

where:
- *a* is the current distribution factor, which depends on the circuit supply and the arrangement of the electric loads along the BTS, as shown in Table 6:

2 Protection of feeders

Table 6: Current distribution factor

Type of supply	Arrangement of loads	Current distribution factor
From one end only	Load concentrated at the end	1
	Evenly distributed load	0.5
From both ends	Evenly distributed load	0.25
Central	Load concentrated at the ends	0.25
	Evenly distributed load	0.125

- I_b is the load current [A];
- L is the BTS length [m];
- r_t is the phase resistance per unit of length of BTS, measured under thermal steady-state conditions [mΩ/m];
- x is the phase reactance per unit of length of BTS [mΩ/m];
- $\cos\varphi_m$ is average power factor of the loads.

Percentage voltage drop is obtained from:

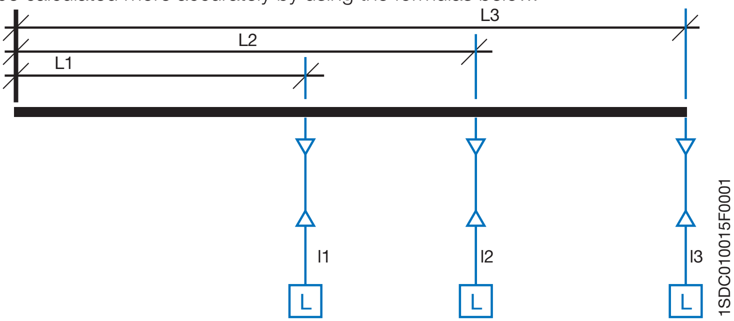
$$\Delta u\% = \frac{\Delta u}{U_r} \cdot 100 \qquad (7)$$

where U_r is rated voltage.

To reduce the voltage drop in very long BTS the power can be supplied at an intermediate position rather than at the end (see Table 6).

Calculation of voltage drop for unevenly distributed loads

If the loads cannot be considered to be evenly distributed, the voltage drop can be calculated more accurately by using the formulas below.



For the distribution of the three-phase loads shown in the figure, the voltage drop can be calculated by the following formula if the BTS has a constant cross section (as usual):

$$\Delta u = \sqrt{3}[r_t(I_1 L_1 \cos\varphi_1 + I_2 L_2 \cos\varphi_2 + I_3 L_3 \cos\varphi_3) + x(I_1 L_1 \sin\varphi_1 + I_2 L_2 \sin\varphi_2 + I_3 L_3 \sin\varphi_3)]$$

2 Protection of feeders

Generally speaking, this formula becomes:

$$\Delta u = \frac{\sqrt{3}\ r_t \cdot \sum I_i \cdot L_i \cdot \cos\varphi_{mi} + x \cdot \sum I_i \cdot L_i \cdot \sin\varphi_{mi}}{1000} \ [\mathrm{V}] \qquad (8)$$

where:
- r_t is the phase resistance per unit of length of BTS, measured under thermal steady-state conditions [mΩ/m];
- x is the phase reactance per unit of length of BTS [mΩ/m];
- $\cos\varphi_m$ is average power factor of the i-th load;
- I_i is i-th load current [A];
- L_i is the distance of the i-th load from the beginning of the BTS [m].

Joule-effect losses

Joule-effect losses are due to the electrical resistance of the BTS.
The losses are dissipated in heat and contribute to the heating of the trunking and of the environment. Calculation of power losses is useful for correctly dimensioning the air-conditioning system for the building.
Three-phase losses are:

$$P_j = \frac{3 \cdot r_t \cdot I_b^2 \cdot L}{1000} \ [\mathrm{W}] \qquad (9a)$$

while single-phase losses are:

$$P_j = \frac{2 \cdot r_t \cdot I_b^2 \cdot L}{1000} \ [\mathrm{W}] \qquad (9b)$$

where:
- I_b is the current used [A];
- r_t is the phase resistance per unit of length of BTS measured under thermal steady-state conditions [mΩ/m];
- L is the length of BTS [m].

For accurate calculations, losses must be assessed section by section on the basis of the currents flowing through them; e.g. in the case of distribution of loads shown in the previous figure:

	Length	Current	Losses
1° section	L_1	$I_1+I_2+I_3$	$P_1=3r_tL_1(I_1+I_2+I_3)^2$
2° section	L_2-L_1	I_2+I_3	$P_2=3r_t(L_2-L_1)(I_2+I_3)^2$
3° section	L_3-L_2	I_3	$P_3=3r_t(L_3-L_2)(I_3)^2$
Total losses in BTS			$P_{tot}=P_1+P_2+P_3$

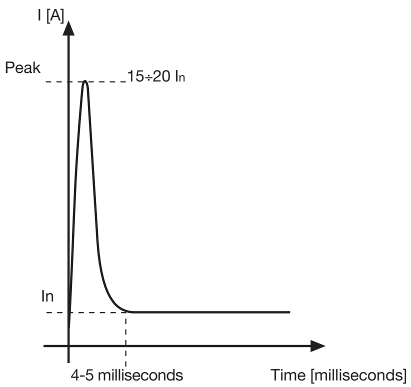
3 Protection of electrical equipment

3.1 Protection and switching of lighting circuits

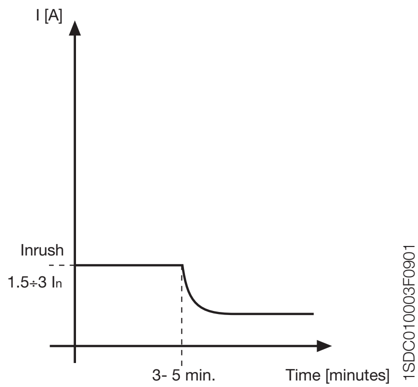
Introduction

Upon supply of a lighting installation, for a brief period an initial current exceeding the rated current (corresponding to the power of the lamps) circulates on the network. This possible peak has a value of approximately 15÷20 times the rated current, and is present for a few milliseconds; there may also be an inrush current with a value of approximately 1.5÷3 times the rated current, lasting up to some minutes. The correct dimensioning of the switching and protection devices must take these problems into account.

Peak current diagram



Inrush current diagram



The most commonly used lamps are of the following types:
- incandescent;
- halogen;
- fluorescent;
- high intensity discharge: mercury vapour, metal halide and sodium vapour.

Incandescent lamps

Incandescent lamps are made up of a glass bulb containing a vacuum or inert gas and a tungsten filament. The current flows through this filament, heating it until light is emitted.
The electrical behaviour of these lamps involves a high peak current, equal to approximately 15 times the rated current; after a few milliseconds the current returns to the rated value. The peak is caused by the lamp filament which, initially cold, presents a very low electrical resistance. Subsequently, due to the very fast heating of the element, the resistance value increases considerably, causing the decrease in the current absorbed.

3 Protection of electrical equipment

Halogen lamps

Halogen lamps are a special type of incandescent lamp in which the gas contained within the bulb prevents the vaporized material of the tungsten filament from depositing on the surface of the bulb and forces re-deposition on the filament. This phenomenon slows the deterioration of the filament, improves the quality of the light emitted and increases the life of the lamp.
The electrical behaviour of these lamps is the same as that of incandescent lamps.

Fluorescent lamps

Fluorescent lamps are a so-called discharge light source. The light is produced by a discharge within a transparent enclosure (glass, quartz, etc. depending on the type of lamp) which contains mercury vapour at low pressure.
Once the discharge has started, the gas within the enclosure emits energy in the ultraviolet range which strikes the fluorescent material; in turn, this material transforms the ultraviolet radiation into radiation which has a wavelength within the visible spectrum. The colour of the light emitted depends upon the fluorescent material used.
The discharge is created by an appropriate peak in voltage, generated by a starter. Once the lamp has been switched on, the gas offers an ever lower resistance, and it is necessary to stabilize the intensity of the current, using a controller (reactor); this lowers the power factor to approximately 0.4÷0.6; normally a capacitor is added to increase the power factor to a value of more than 0.9
There are two types of controllers, magnetic (conventional) and electronic, which absorb from 10% to 20% of the rated power of the lamp. Electronic controllers offer specific advantages such as a saving in the energy absorbed, a lower dissipation of heat, and ensure a stable, flicker-free light. Some types of fluorescent lamps with electronic reactors do not need a starter.
Compact fluorescent lamps are made up of a folded tube and a plastic base which contains, in some cases, a conventional or electronic controller.
The value of the inrush current depends upon the presence of a power factor correction capacitor:
- non PFC lamps have inrush currents equal to approximately twice the rated current and a turn-on time of about ten seconds;
- in PFC lamps, the presence of the capacitor allows the reduction of the turn-on time to a few seconds, but requires a high peak current, determined by the charge of the capacitor, which can reach 20 times the rated current.

If the lamp is fitted with an electronic controller, the initial transient current may lead to peak currents equal to, at maximum, 10 times the rated current.

3 Protection of electrical equipment

High intensity discharge lamps: mercury vapour, metal halide and sodium vapour

The functioning of high intensity discharge lamps is the same as that of fluorescent lamps with the difference that the discharge occurs in the presence of a gas at high pressure. In this case, the arc is able to vaporize the metallic elements contained in the gas, releasing energy in the form of radiation which is both ultraviolet and within the visible spectrum. The special type of bulb glass blocks the ultraviolet radiation and allows only the visible radiation to pass through. There are three main types of high intensity discharge lamps: mercury vapour, metal halide and sodium vapour. The colour characteristics and the efficiency of the lamp depend upon the different metallic elements present in the gas, which are struck by the arc.
High intensity discharge lamps require a suitably sized controller and a heating period which can last some minutes before the emission of the rated light output. A momentary loss of power makes the restarting of the system and the heating necessary.
Non PFC lamps have inrush currents of up to twice the rated current for approximately 5 minutes.
PFC lamps have a peak current equal to 20 times the rated current, and an inrush current of up to twice the rated current for approximately 5 minutes.

Lamp type		Peak current	Inrush current	Turn-on time
Incandescent lamps		15In	-	-
Halogen lamps		15In	-	-
Fluorescent lamp	Non PFC	–	2In	10 s
	PFC	20In		1÷6 s
High intensity discharge lamps	Non PFC	–	2In	2÷8 min
	PFC	20In	2In	2÷8 min

Protection and switching devices

IEC 60947-4-1 identifies two specific utilization categories for lamp control contactors:
- AC-5a switching of electric discharge lamps;
- AC-5b switching of incandescent lamps.

The documentation supplied by the manufacturer includes tables for contactor selection, according to the number of lamps to be controlled, and to their type.

3 Protection of electrical equipment

For the selection of a protection device the following verifications shall be carried out:

- the trip characteristic curve shall be above the turning-on characteristic curve of the lighting device to avoid unwanted trips; an approximate example is shown in Figure1;

- coordination shall exist with the contactor under short-circuit conditions (lighting installations are not generally characterized by overloads).

With reference to the above verification criteria, the following tables show the maximum number of lamps per phase which can be controlled by the combination of ABB circuit breakers and contactors for some types of lamps, according to their power and absorbed current I_b[1] , for three phase installations with a rated voltage of 400 V and a maximum short-circuit current of 15 kA.

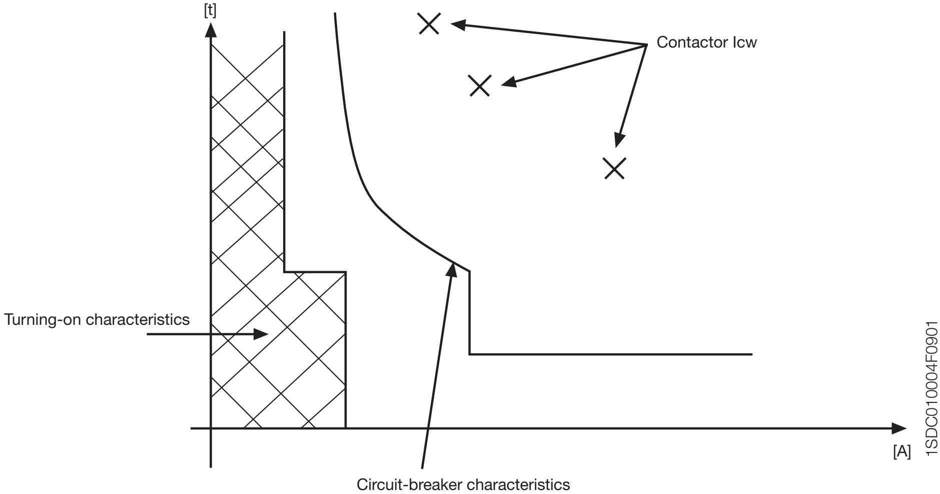
[1] For calculation see Annex B Calculation of load current I_b

Table 1: Incandescent and halogen lamps

U_r= 400 V	I_k= 15 kA						
Incandescent/halogen lamps							
Circuit-Breaker type		S270 D20	S270 D20	S270 D25	S270 D32	S270 D50	
Setting PR221 DS		----	----	----	----	----	
Contactor type		A26	A26	A26	A26	A30	
Rated Power [W]	Rated current I_b [A]						
60	0.27	57	65	70	103	142	
100	0.45	34	38	42	62	85	
200	0.91	17	19	20	30	42	
300	1.37	11	12	13	20	28	
500	2.28	6	7	8	12	16	
1000	4.55	3	4	4	6	8	

3 Protection of electrical equipment

Figure 1: Approximate diagram for the coordination of lamps with protection and switching devices



	T2N160 In63	T2N160 In63	T2N160 In100	T2N160 In100	T2N160 In100	T2N160 In160
	L= 0.68- A S= 8- B	L= 0.92- A S= 10- B	L= 0.68- A S= 8- B	L= 0.76- A S= 8- B	L= 1- A S= 10- B	L= 0.68- A S= 7- B
	A40	A50	A63	A75	A95	A110
	N° lamps per phase					
	155	220	246	272	355	390
	93	132	147	163	210	240
	46	65	73	80	105	120
	30	43	48	53	70	80
	18	26	29	32	42	48
	9	13	14	16	21	24

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3 Protection of electrical equipment

Table 2: Fluorescent lamps

U_r= 400 V	I_k= 15 kA					
Fluorescent lamps non PFC						
Circuit-Breaker type		S270 D16	S270 D20	S270 D20	S270 D32	S270 D40
Setting PR221 DS						
Contactor type		A26	A26	A26	A26	A30
Rated Power [W]	Rated current I_b [A]					
20	0.38	40	44	50	73	100
40	0.45	33	37	42	62	84
65	0.7	21	24	27	40	54
80	0.8	18	21	23	35	47
100	1.15	13	14	16	24	33
110	1.2	12	14	15	23	31

U_r= 400 V	I_k= 15 kA						
Fluorescent lamps PFC							
Circuit-Breaker type			S270 D25	S270 D25	S270 D32	S270 D40	S270 D63
Setting PR221 DS			---	---	---	---	---
Contactor type			A26	A26	A26	A26	A30
Rated Power [W]	Rated current I_b [A]	Capacitor [μF]					
20	0.18	5	83	94	105	155	215
40	0.26	5	58	65	75	107	150
65	0.42	7	35	40	45	66	92
80	0.52	7	28	32	36	53	74
100	0.65	16	23	26	29	43	59
110	0.7	18	21	24	27	40	55

3 Protection of electrical equipment

S270 D50	S270 D63	T2N160 In100	T2N160 In100	T2N160 In100	T2N160 In160
		L= 0.68- A S= 10- B	L= 0.76- A S= 10- B	L= 0.96- A- S= 10- B	S= 0.68- A S= 10- B
A40	A50	A63	A75	A95	A110
N° lamps per phase					
110	157	173	192	250	278
93	133	145	162	210	234
60	85	94	104	135	150
52	75	82	91	118	132
36	52	57	63	82	92
35	50	55	60	79	88

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T2N160 In63	T2N160 In63	T2N160 In100	T2N160 In100	T2N160 In100
L= 0.68- A S= 8- B	L= 1- A S= 10- B	L= 0.68- A S= 10- B	L= 0.76- A S= 10- B	L= 0.96- A S= 10- B
A40	A50	A63	A75	A95
N° lamps per phase				
233	335	360	400	530
160	230	255	280	365
100	142	158	173	225
80	115	126	140	180
64	92	101	112	145
59	85	94	104	135

3 Protection of electrical equipment

Table 3: High intensity discharge lamps

U_r= 400 V	I_k= 15 kA						
Fluorescent lamps non PFC							
Circuit-Breaker type		S270 D16	S270 D2	S270 D20	S270 D32	S270 D40	
Setting PR221 DS							
Contactor type		A26	A26	A26	A26	A30	
Rated Power [W]	Rated current I_b [A]						
150	1.8	6	7	8	11	15	
250	3	4	4	5	7	9	
400	4.4	3	3	3	4	6	
600	6.2	1	2	2	3	4	
1000	10.3	-	1	1	2	3	

U_r= 400 V		I_k= 15 kA						
Fluorescent lamps PFC								
Circuit-Breaker type			S270 D16	S270 D20	S270 D20	S270 D32	S270 D40	
Setting PR221 DS			---	---	---	---	---	
Contactor type			A26	A26	A26	A26	A30	
Rated Power [W]	Rated current I_b [A]	Capacitor [μF]						
150	1	20	13	14	15	23	28	
250	1.5	36	8	9	10	15	18	
400	2.5	48	5	5	6	9	11	
600	3.3	65	4	4	5	7	8	
1000	6.2	100	-	-	-	4	4	

3 Protection of electrical equipment

S270 D40	S270 D50	S270 D63	T2N160 In100	T2N160 In100	T2N160 In160
			L= 0.8- B S= 6.5- B	L= 1- B S= 8- B	L= 0.8- B S= 6.5- B
A40	A50	A63	A75	A95	A110
N° lamps per phase					
17	23	26	29	38	41
10	14	16	17	23	25
7	9	10	12	15	17
5	7	8	8	11	12
3	4	5	5	6	7

S270 D40	T2N160 In100	T2N160 In100	T2N160 In100	T2N160 In160	T2N160 In160
---	L= 0.8- B S= 6.5- B	L= 0.88- B S= 6.5- B	L= 1- B S= 6.5- B	L= 0.84- B S= 4.5- B	L= 0.88- B S= 4.5- B
A40	A50	A63	A75	A95	A110
N° lamps per phase					
30	50	58	63	81	88
20	33	38	42	54	59
12	20	23	25	32	36
9	15	17	19	24	27
5	8	9	10	13	14

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Example:

Switching and protection of a lighting system, supplied by a three phase network at 400 V 15 kA, made up of 55 incandescent lamps, of 200 W each, per phase. In table 1, on the row corresponding to 200 W, select the cell showing the number of controllable lamps immediately above the number of lamps per phase present in the installation. In the specific case, corresponding to the cell for 65 lamps per phase the following equipment are suggested:

- ABB Tmax T2N160 In63 circuit breaker with PR221/DS type electronic release, with protection L set at 0.92, curve A and protection S set at 10, curve B;
- A50 contactor.

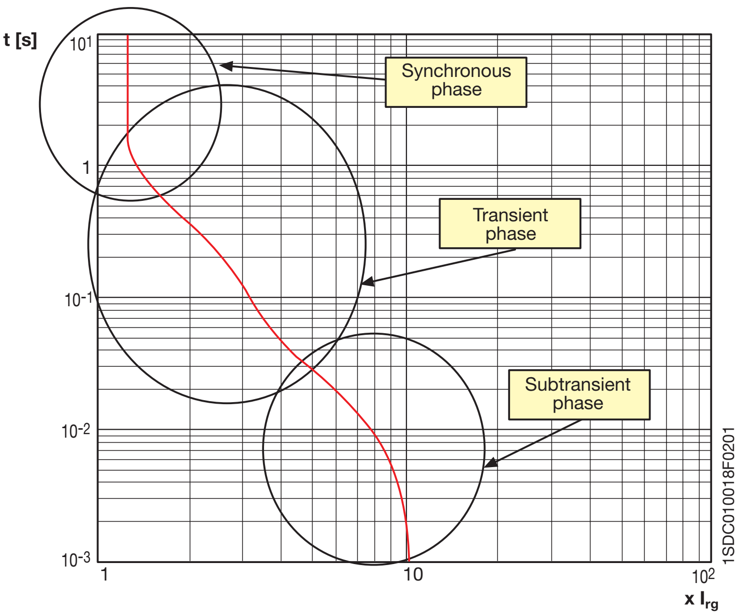
3.2 Protection and switching of generators

The need to guarantee an ever greater continuity of service has led to an increase in the use of emergency supply generators, either as an alternative to, or in parallel with the public utility supply network.

Typical configurations include:
- "Island supply" (independent functioning) of the priority loads in the case of a lack of energy supply through the public network;
- Supply to the user installation in parallel with the public supply network.

Unlike the public supply network, which has a constant contribution, in case of a short-circuit, the current supplied by the generator is a function of the parameters of the machine itself, and decreases with time; it is possible to identify the following successive phases:

1. a subtransient phase: with a brief duration (10÷50 ms), characterized by the subtransient reactance X''_d (5÷20% of the rated impedance value), and by the subtransient time constant T''_d (5÷30 ms);
2. a transitory phase: may last up to some seconds (0.5÷2.5 s), and is characterized by the transitory reactance X'_d (15÷40% of the rated impedance value), and by the transitory time constant T'_d (0.03÷2.5 s);
3. a synchronous phase: may persist until the tripping of external protection, and is characterized by the synchronous reactance X_d (80÷300% of the rated impedance value).



3 Protection of electrical equipment

As a first approximation, it can be estimated that the maximum value of the short-circuit current of a generator, with rated power S_{rg}, at the rated voltage of the installation U_r, is equal to:

$$I_{kg} = \frac{I_{rg} \cdot 100}{X''_d \%}$$

where

I_{rg} is the rated current of the generator:

$$I_{rg} = \frac{S_{rg}}{\sqrt{3} \cdot U_r}$$

The circuit breaker for the protection of the generator shall be selected according to the following criteria:

- the set current higher than the rated current of the generator: $I_1 \geq I_{rg}$;
- breaking capacity I_{cu} or I_{cs} higher than the maximum value of short-circuit current at the installation point:
  - in the case of a single generator: $I_{cu}(I_{cs}) \geq I_{kg}$;
  - in the case of *n* identical generators in parallel: $I_{cu}(I_{cs}) \geq I_{kg} \cdot (n-1)$;
  - in the case of operation in parallel with the network: $I_{cu}(I_{cs}) \geq I_{kNet}$, as the short-circuit contribution from the network is normally greater than the contribution from the generator;
- for circuit breakers with thermomagnetic releases: low magnetic trip threshold: $I_3 = 2.5/3 \cdot I_n$;
- for circuit breakers with electronic releases:
  - trip threshold of the delayed short-circuit protection function (S), set between 1.5 and 4 times the rated current of the generator, in such away as to “intercept” the decrement curve of the generator: $I_2 = (1.5 \div 4) \cdot I_{rg}$; if the function S is not present, function I can be set at the indicated values $I_3 = (1.5 \div 4) \cdot I_{rg}$;
  - trip threshold of the instantaneous short-circuit protection function (I) set at a value greater than the rated short-circuit current of the generator, so as to achieve discrimination with the devices installed downstream, and to allow fast tripping in the event of a short-circuit upstream of the device (working in parallel with other generators or with the network):

$$I_3 \geq I_{kg}$$

3 Protection of electrical equipment

The following tables give ABB SACE suggestions for the protection and switching of generators; the tables refer to 400 V (Table 1), 440 V (Table 2), 500 V (Table 3) and 690 V (Table 4).

Table 1 400 V

<table>
<tr><th>S_{rg} [kVA]</th><th>MCB</th><th>MCCB</th><th>ACB</th></tr>
<tr><td>4</td><td>S20L/S260 B6</td><td rowspan="3">T2 160 In=10</td><td rowspan="38"></td></tr>
<tr><td>6</td><td rowspan="2">S20L/S260 B10</td></tr>
<tr><td>7</td></tr>
<tr><td>9</td><td>S20L/S260 B13</td><td rowspan="4">T2 160 In=25</td></tr>
<tr><td>11</td><td>S20L/S260 B16</td></tr>
<tr><td>14</td><td rowspan="2">S20L/S260 B25</td></tr>
<tr><td>17</td></tr>
<tr><td>19</td><td rowspan="3">S20L/S260 B32</td><td rowspan="8">T2 160 In=63</td></tr>
<tr><td>21</td></tr>
<tr><td>22</td></tr>
<tr><td>28</td><td rowspan="2">S20L/S260 B50</td></tr>
<tr><td>31</td></tr>
<tr><td>35</td><td rowspan="3">S20L/S260 B63</td></tr>
<tr><td>38</td></tr>
<tr><td>42</td></tr>
<tr><td>44</td><td rowspan="3">S280 B80</td><td rowspan="4">T2 160 In=100</td></tr>
<tr><td>48</td></tr>
<tr><td>55</td></tr>
<tr><td>69</td><td>S280 B100</td></tr>
<tr><td>80</td><td rowspan="33"></td><td rowspan="2">T2 160 In=160</td></tr>
<tr><td>87</td></tr>
<tr><td>100</td><td>T2 160</td></tr>
<tr><td>111</td><td rowspan="2">T4 250</td></tr>
<tr><td>138</td></tr>
<tr><td>159</td><td rowspan="2">T3 250
T4 250</td></tr>
<tr><td>173</td></tr>
<tr><td>180</td><td rowspan="4">T4 320</td></tr>
<tr><td>190</td></tr>
<tr><td>208</td></tr>
<tr><td>218</td></tr>
<tr><td>242</td><td rowspan="2">T5 400</td></tr>
<tr><td>277</td></tr>
<tr><td>308</td><td rowspan="6">T5 630
S6 800</td></tr>
<tr><td>311</td></tr>
<tr><td>346</td></tr>
<tr><td>381</td></tr>
<tr><td>415</td></tr>
<tr><td>436</td></tr>
<tr><td>484</td><td rowspan="2">S6 800
S7 1250</td><td rowspan="4">E1/E2 1250</td></tr>
<tr><td>554</td></tr>
<tr><td>692</td><td rowspan="3">S7 1250</td></tr>
<tr><td>727</td></tr>
<tr><td>865</td><td>E2/E3 1600</td></tr>
<tr><td>1107</td><td>S7 1600</td><td>E2/E3 2000</td></tr>
<tr><td>1730</td><td rowspan="3">S8 3200</td><td>E3 3200</td></tr>
<tr><td>2180</td><td>E3 3200/E4 4000</td></tr>
<tr><td>2214</td><td rowspan="3">E4 4000</td></tr>
<tr><td>2250</td><td rowspan="5"></td></tr>
<tr><td>2500</td></tr>
<tr><td>2800</td><td rowspan="3">E6 5000/6300</td></tr>
<tr><td>3150</td></tr>
<tr><td>3500</td></tr>
</table>

Table 2 440 V

<table>
<tr><th>S_{rg} [kVA]</th><th>MCB</th><th>MCCB</th><th>ACB</th></tr>
<tr><td>4</td><td>S20L/S260 B6</td><td rowspan="3">T2 160 In=10</td><td rowspan="38"></td></tr>
<tr><td>6</td><td>S20L/S260 B8</td></tr>
<tr><td>7</td><td>S20L/S260 B10</td></tr>
<tr><td>9</td><td>S20L/S260 B13</td><td rowspan="4">T2 160 In=25</td></tr>
<tr><td>11</td><td>S20L/S260 B16</td></tr>
<tr><td>14</td><td>S20L/S260 B20</td></tr>
<tr><td>17</td><td>S20L/S260 B25</td></tr>
<tr><td>19</td><td rowspan="3">S20L/S260 B32</td><td rowspan="10">T2 160 In=63</td></tr>
<tr><td>21</td></tr>
<tr><td>22</td></tr>
<tr><td>28</td><td>S20L/S260 B40</td></tr>
<tr><td>31</td><td rowspan="2">S20L/S260 B50</td></tr>
<tr><td>35</td></tr>
<tr><td>38</td><td rowspan="3">S20L/S260 B63</td></tr>
<tr><td>42</td></tr>
<tr><td>44</td></tr>
<tr><td>48</td><td rowspan="2">S280 B80</td></tr>
<tr><td>55</td><td rowspan="2">T2 160 In=100</td></tr>
<tr><td>69</td><td>S280 B100</td></tr>
<tr><td>80</td><td rowspan="33"></td><td rowspan="2">T2 160 In=160</td></tr>
<tr><td>87</td></tr>
<tr><td>100</td><td rowspan="2">T2 160 In=160</td></tr>
<tr><td>111</td></tr>
<tr><td>138</td><td>T4 250</td></tr>
<tr><td>159</td><td rowspan="2">T3 250
T4 250</td></tr>
<tr><td>173</td></tr>
<tr><td>180</td><td rowspan="5">T4 320</td></tr>
<tr><td>190</td></tr>
<tr><td>208</td></tr>
<tr><td>218</td></tr>
<tr><td>242</td></tr>
<tr><td>277</td><td>T5 400</td></tr>
<tr><td>308</td><td rowspan="6">T5 630
S6 800</td></tr>
<tr><td>311</td></tr>
<tr><td>346</td></tr>
<tr><td>381</td></tr>
<tr><td>415</td></tr>
<tr><td>436</td></tr>
<tr><td>484</td><td rowspan="2">S6 800
S7 1000</td><td rowspan="5">E1/E2 1250</td></tr>
<tr><td>554</td></tr>
<tr><td>692</td><td rowspan="2">S7 1000</td></tr>
<tr><td>727</td></tr>
<tr><td>865</td><td>S7 1250</td></tr>
<tr><td>1107</td><td>S7 1600</td><td>E2/E3 1600</td></tr>
<tr><td>1730</td><td rowspan="3">S8 3200</td><td>E3 2500</td></tr>
<tr><td>2180</td><td rowspan="3">E3 3200</td></tr>
<tr><td>2214</td></tr>
<tr><td>2250</td><td rowspan="5"></td></tr>
<tr><td>2500</td><td>E4 3600</td></tr>
<tr><td>2800</td><td>E4 4000</td></tr>
<tr><td>3150</td><td rowspan="2">E6 5000/6300</td></tr>
<tr><td>3500</td></tr>
</table>

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3 Protection of electrical equipment

Table 3 500 V

<table>
<tr><th>S_{rg} [kVA]</th><th>MCB</th><th>MCCB</th><th>ACB</th></tr>
<tr><td>4</td><td rowspan="52"></td><td rowspan="3">T2 160 In=10</td><td rowspan="38"></td></tr>
<tr><td>6</td></tr>
<tr><td>7</td></tr>
<tr><td>9</td><td rowspan="6">T2 160 In=25</td></tr>
<tr><td>11</td></tr>
<tr><td>14</td></tr>
<tr><td>17</td></tr>
<tr><td>19</td></tr>
<tr><td>21</td></tr>
<tr><td>22</td><td rowspan="8">T2 160 In=63</td></tr>
<tr><td>28</td></tr>
<tr><td>31</td></tr>
<tr><td>35</td></tr>
<tr><td>38</td></tr>
<tr><td>42</td></tr>
<tr><td>44</td></tr>
<tr><td>48</td></tr>
<tr><td>55</td><td rowspan="3">T2 160 In=100</td></tr>
<tr><td>69</td></tr>
<tr><td>80</td></tr>
<tr><td>87</td><td rowspan="4">T2 160 In=160</td></tr>
<tr><td>100</td></tr>
<tr><td>111</td></tr>
<tr><td>138</td></tr>
<tr><td>159</td><td rowspan="2">T3 250
T4 250</td></tr>
<tr><td>173</td></tr>
<tr><td>180</td><td rowspan="3">T4 250</td></tr>
<tr><td>190</td></tr>
<tr><td>208</td></tr>
<tr><td>218</td><td rowspan="3">T4 320</td></tr>
<tr><td>242</td></tr>
<tr><td>277</td></tr>
<tr><td>308</td><td rowspan="3">T5 400</td></tr>
<tr><td>311</td></tr>
<tr><td>346</td></tr>
<tr><td>381</td><td rowspan="4">T5 630
S6 800</td></tr>
<tr><td>415</td></tr>
<tr><td>436</td></tr>
<tr><td>484</td><td rowspan="5">E1/E2 1250</td></tr>
<tr><td>554</td><td rowspan="2">S6 800
S7 1000</td></tr>
<tr><td>692</td></tr>
<tr><td>727</td><td rowspan="2">S7 1250</td></tr>
<tr><td>865</td></tr>
<tr><td>1107</td><td>S7 1600</td><td>E2/E3 1600</td></tr>
<tr><td>1730</td><td>S8 2500</td><td>E3 2500</td></tr>
<tr><td>2180</td><td rowspan="4">S8 3200</td><td rowspan="4">E3 3200</td></tr>
<tr><td>2214</td></tr>
<tr><td>2250</td></tr>
<tr><td>2500</td></tr>
<tr><td>2800</td><td rowspan="3"></td><td rowspan="2">E4 4000</td></tr>
<tr><td>3150</td></tr>
<tr><td>3500</td><td>E6 5000/6300</td></tr>
</table>

Table 4 690 V

<table>
<tr><th></th><th>MCB</th><th>MCCB</th><th>ACB</th></tr>
<tr><td>4</td><td rowspan="52"></td><td rowspan="5">T2 160 In=10</td><td rowspan="38"></td></tr>
<tr><td>6</td></tr>
<tr><td>7</td></tr>
<tr><td>9</td></tr>
<tr><td>11</td></tr>
<tr><td>14</td><td rowspan="6">T2 160 In=25</td></tr>
<tr><td>17</td></tr>
<tr><td>19</td></tr>
<tr><td>21</td></tr>
<tr><td>22</td></tr>
<tr><td>28</td></tr>
<tr><td>31</td><td rowspan="8">T2 160 In=63</td></tr>
<tr><td>35</td></tr>
<tr><td>38</td></tr>
<tr><td>42</td></tr>
<tr><td>44</td></tr>
<tr><td>48</td></tr>
<tr><td>55</td></tr>
<tr><td>69</td></tr>
<tr><td>80</td><td rowspan="4">T2 160 In=100</td></tr>
<tr><td>87</td></tr>
<tr><td>100</td></tr>
<tr><td>111</td></tr>
<tr><td>138</td><td rowspan="3">T2 160 In=160</td></tr>
<tr><td>159</td></tr>
<tr><td>173</td></tr>
<tr><td>180</td><td rowspan="2">T3 250</td></tr>
<tr><td>190</td></tr>
<tr><td>208</td><td rowspan="4">T4 250</td></tr>
<tr><td>218</td></tr>
<tr><td>242</td></tr>
<tr><td>277</td></tr>
<tr><td>308</td><td rowspan="4">T4 320</td></tr>
<tr><td>311</td></tr>
<tr><td>346</td></tr>
<tr><td>381</td></tr>
<tr><td>415</td><td rowspan="2">T5 400</td></tr>
<tr><td>436</td></tr>
<tr><td>484</td><td>T5 630</td><td rowspan="5">E1 800</td></tr>
<tr><td>554</td><td rowspan="3">T5 630
S6 800</td></tr>
<tr><td>692</td></tr>
<tr><td>727</td></tr>
<tr><td>865</td><td>S6 800</td></tr>
<tr><td>1107</td><td>S7 1000</td><td>E1/E2 1250</td></tr>
<tr><td>1730</td><td>S7 1600</td><td>E2/E3 1600</td></tr>
<tr><td>2180</td><td rowspan="5">S8 2500</td><td rowspan="3">E2 2000
E3 2500</td></tr>
<tr><td>2214</td></tr>
<tr><td>2250</td></tr>
<tr><td>2500</td><td rowspan="2">E3 2500</td></tr>
<tr><td>2800</td></tr>
<tr><td>3150</td><td rowspan="2">S8 3200</td><td rowspan="2">E3 3200</td></tr>
<tr><td>3500</td></tr>
</table>

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Note: It is always advisable to check that the settings of the releases are correct with respect to the effective decrement curve of the current of the generator to be protected.

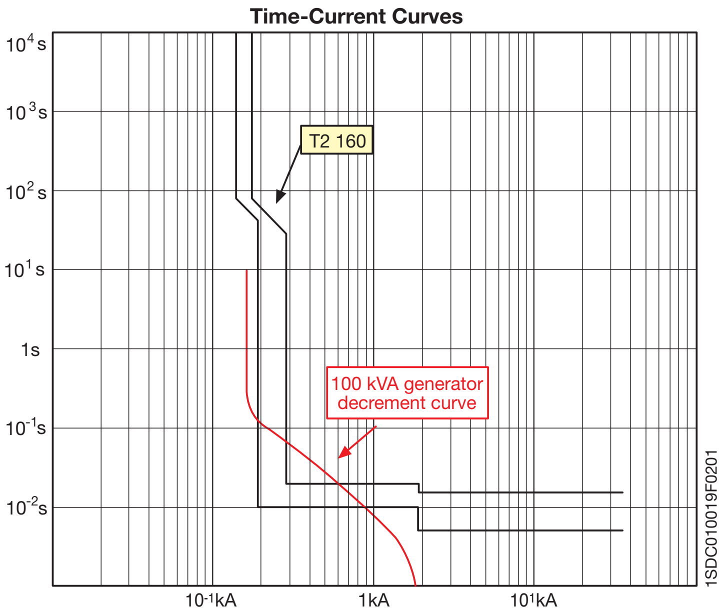
3 Protection of electrical equipment

Example:

Protection of a generator with S_{rg} = 100 kVA, in a system with a rated voltage of 440 V
The generator parameters are:
U_r = 440 V
S_{rg} = 100 kVA
f = 50 Hz
I_{rg} = 131.2 A
X''_d = 6.5 % (subtransient reactance)
X'_d = 17.6 % (transient reactance)
X_d = 230 % (synchronous reactance)
T''_d = 5.5 ms (subtransient time constant)
T'_d = 39.3 ms (transient time constant)

From table 2, an ABB SACE T2N160 circuit-breaker is selected, with I_n = 160 A, with electronic release PR221-LS. For correct protection of the generator, the following settings are selected:

function L: 0.84 – A, corresponding to 134.4 A, value greater than I_{rg} .
function I: 1.5



3.3 Protection and switching of motors

Electromechanical starter

The starter is designed to:
- start motors;
- ensure continuous functioning of motors;
- disconnect motors from the supply line;
- guarantee protection of motors against working overloads.

The starter is typically made up of a switching device (contactor) and an overload protection device (thermal release).
The two devices must be coordinated with equipment capable of providing protection against short-circuit (typically a circuit breaker with magnetic release only), which is not necessarily part of the starter.

The characteristics of the starter must comply with the international Standard IEC 60947-4-1, which defines the above as follows:

Contactor: a mechanical switching device having only one position of rest, operated otherwise than by hand, capable of making, carrying and breaking currents under normal circuit conditions including operating overload conditions.

Thermal release: thermal overload relay or release which operates in the case of overload and also in case of loss of phase.

Circuit-breaker: defined by IEC 60947-2 as a mechanical switching device, capable of making, carrying and breaking currents under normal circuit conditions and also making, carrying for a specified time and breaking currents under specified abnormal circuit conditions.

The main types of motor which can be operated and which determine the characteristics of the starter are defined by the following utilization categories:

Table 1: Utilization categories and typical applications

Current type	Utilization categories	Typical applications
Alternating Current ac	AC-2	Slip-ring motors: starting, switching off
	AC-3	Squirrel-cage motors: starting, switching off during running[1]
	AC-4	Squirrel-cage motors: starting, plugging, inching

[1] AC-3 categories may be used for occasionally inching or plugging for limited time periods such as machine set-up; during such limited time periods the number of such operations should not exceed five per minutes or more than ten in a 10 minutes period.

3 Protection of electrical equipment

The choice of the starting method and also, if necessary, of the type of motor to be used depends on the typical resistant torque of the load and on the short-circuit power of the motor supplying network.

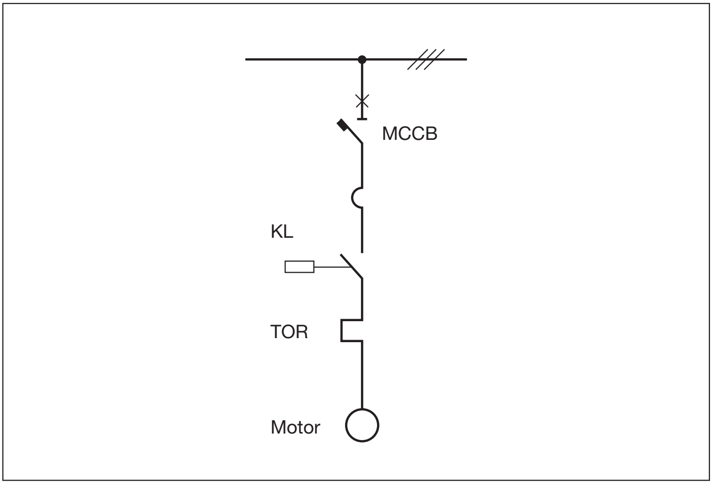
With alternating current, the most commonly used motor types are as follows:
- asynchronous three-phase squirrel-cage motors (AC-3): the most widespread type due to the fact that they are of simple construction, economical and sturdy; they develop high torque with short acceleration times, but require elevated starting currents;
- slip-ring motors (AC-2): characterized by less demanding starting conditions, and have quite a high starting torque, even with a supply network of low power.

Starting methods

The most common starting methods for asynchronous squirrel-cage motors are detailed below:

Direct starting

With direct starting, the DOL (Direct On Line) starter, with the closing of line contactor KL, the line voltage is applied to the motor terminals in a single operation. Hence a squirrel-cage motor develops a high starting torque with a relatively reduced acceleration time. This method is generally used with small and medium power motors which reach full working speed in a short time. These advantages are, however, accompanied by a series of drawbacks, including, for example:
- high current consumption and associated voltage drop which may cause damages to the other parts of the system connected to the network;
- violent acceleration which has negative effects on mechanical transmission components (belts, chains and mechanical joints), reducing working life.



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3 Protection of electrical equipment

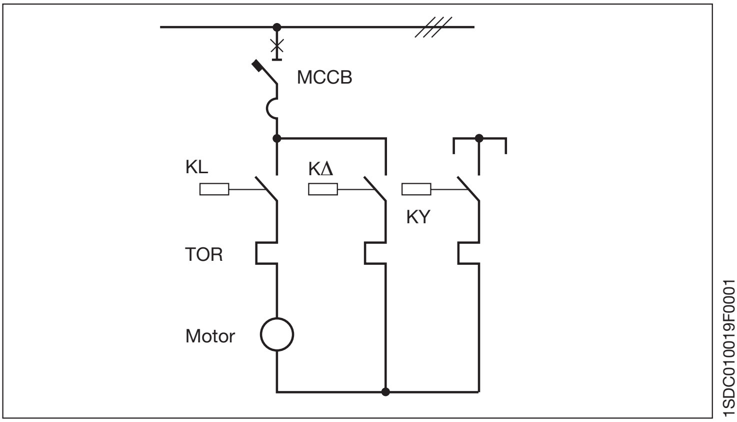
Other types of starting for squirrel-cage motors are accomplished by reducing the supply voltage of the motor: this leads to a reduction in the starting current and of the motor torque, and an increase in the acceleration time.

Star-Delta starter

The most common reduced voltage starter is the Star-Delta starter (Y-Δ), in which:
- on starting, the stator windings are star-connected, thus achieving the reduction of peak inrush current;
- once the normal speed of the motor is nearly reached, the switchover to delta is carried out.

After the switchover, the current and the torque follow the progress of the curves associated with normal service connections (delta).

As can be easily checked, starting the motor with star-connection gives a voltage reduction of $\sqrt{3}$, and the current absorbed from the line is reduced by 1/3 compared with that absorbed with delta-connection.
The start-up torque, proportional to the square of the voltage, is reduced by 3 times, compared with the torque that the same motor would supply when delta-connected.
This method is generally applied to motors with power from 15 to 355 kW, but intended to start with a low initial resistant torque.



Starting sequence

By pressing the start button, contactors KL and KY are closed. The timer starts to measure the start time with the motor connected in star. Once the set time has elapsed, the first contact of the timer opens the KY contactor and the second contact, delayed by approximately 50 ms, closes the KΔ contactor. With this new configuration, contactors KL and KΔ closed, the motor becomes delta-connected.

3 Protection of electrical equipment

The thermal release TOR, inserted in the delta circuit, can detect any 3rd harmonic currents, which may occur due to saturation of the magnetic pack and by adding to the fundamental current, overload the motor without involving the line.

With reference to the connection diagram, the equipment used for a Star/Delta starter must be able to carry the following currents:

$\frac{I_r}{\sqrt{3}}$ KL line contactor and KΔ delta contactor

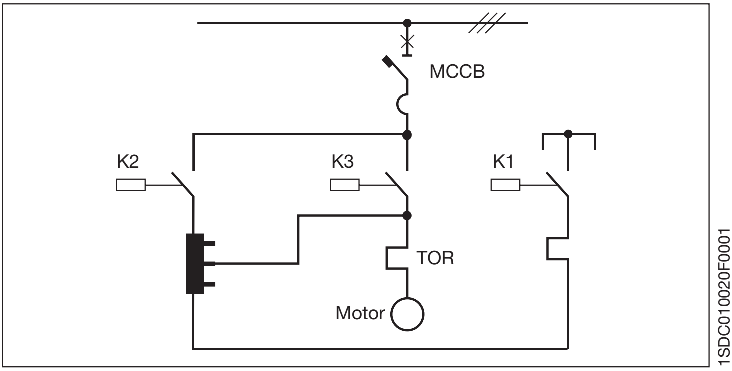
$\frac{I_r}{3}$ KY star contactor

$\frac{I_r}{\sqrt{3}}$ overload protection release

where I_r is the rated current of the motor.

Starting with autotransformers

Starting with autotransformers is the most functional of the methods used for reduced voltage starting, but is also the most expensive. The reduction of the supply voltage is achieved by using a fixed tap autotransformer or a more expensive multi tap autotransformer.
Applications can be found with squirrel-cage motors which generally have a power from 50 kW to several hundred kilowatts, and higher power double-cage motors.



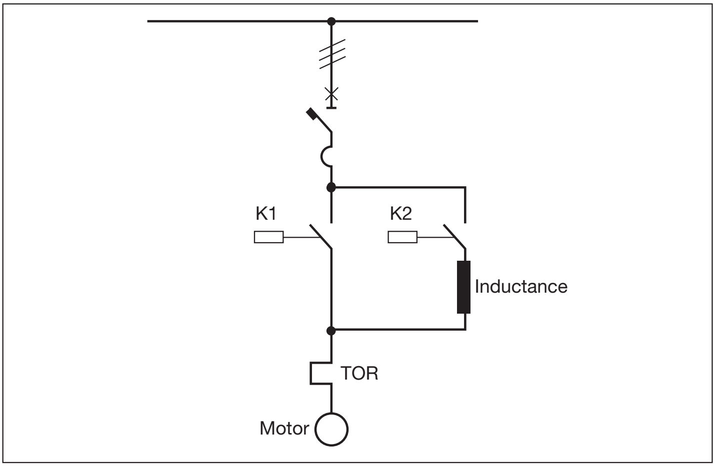
The autotransformer reduces the network voltage by the factor K (K=1.25÷1.8), and as a consequence the start-up torque is reduced by K^2 times compared with the value of the full rated voltage.
On starting, the motor is connected to the taps of the autotransformer and the contactors K2 and K1 are closed.

3 Protection of electrical equipment

Therefore, the motor starts at a reduced voltage, and when it has reached approximately 80% of its normal speed, contactor K1 is opened and main contactor K3 is closed. Subsequently, contactor K2 is opened, excluding the autotransformer so as to supply the full network voltage.

Starting with inductive reactors or resistors

This type of starting is used for simple or double-cage rotors. The reduction of the supply voltage is achieved by the insertion of inductive reactors or resistors, in series to the stator. On start-up, the current is limited to 2.5÷3.5 times the rated value.
On starting, the motor is supplied via contactor K2; once the normal speed is reached, the reactors are short-circuited by the closing of contactor K1, and are then excluded by the opening of contactor K2.
It is possible to achieve exclusions by step of the resistors or reactors with time-delayed commands, even for motors with power greater than 100 kW.
The use of reactors notably reduces the power factor, while the use of resistors causes the dissipation of a high power (Joule effect), even if limited to the starting phase.
For a reduction K (0.6÷0.8) of the motor voltage, the torque is reduced by K^2 times (0.36÷0.64).



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In compliance with the above mentioned Standard, starters can also be classified according to tripping time (trip classes), and according to the type of coordination achieved with the short-circuit protection device (Type 1 and Type 2).

3 Protection of electrical equipment

Trip classes

The trip classes differentiate between the thermal releases according to their trip curve.
The trip classes are defined in the following table 2:

Table 2: Trip class

Trip Class	Tripping time in seconds (Tp)
10A	2 < Tp ≤ 10
10	4 < Tp ≤ 10
20	6 < Tp ≤ 20
30	9 < Tp ≤ 30

where Tp is the cold trip time of the thermal release at 7.2 times the set current value (for example: a release in class 10 at 7.2 times the set current value must not trip within 4 s, but must trip within 10 s).
It is normal procedure to associate class 10 with a normal start-up type, and class 30 with a heavy duty start-up type.

Coordination type

Type 1

It is acceptable that in the case of short-circuit the contactor and the thermal release may be damaged. The starter may still not be able to function and must be inspected; if necessary, the contactor and/or the thermal release must be replaced, and the breaker release reset.

Type 2

In the case of short-circuit, the thermal release must not be damaged, while the welding of the contactor contacts is allowed, as they can easily be separated (with a screwdriver, for example), without any significant deformation.

In order to clearly determine a coordination type, and therefore the equipment necessary to achieve it, the following must be known:
- power of the motor in kW and type;
- rated system voltage;
- rated motor current;
- short-circuit current at installation point;
- starting type: DOL or Y/Δ - normal or heavy duty – Type 1 or Type 2.

The requested devices shall be coordinated with each other in accordance with the prescriptions of the Standard.
For the most common voltages and short-circuit values (400 V - 440 V - 500 V - 690 V 35 kA - 50 kA) and for the most frequently used starting types, such as direct starting and Star/Delta starting, for asynchronous squirrel-cage motor (AC-3), ABB supplies solutions with:
- magnetic circuit-breaker - contactor - thermal release;
- thermomagnetic circuit-breaker - contactor;
- thermomagnetic circuit-breaker with PR212 MP electronic release – contactor.

3 Protection of electrical equipment

The following is an example of the type of tables available:

Table 3: 400 V 50 kA DOL Normal Type 2
(Tmax, Isomax – Contactor – Thermal release)

Motor		MCCB		Contactor	Thermal Overload Relay		
						Current setting	
P_e [kW]	I_r [A]	Type	I_3 [A]	Type	Type	min. [A]	max. [A]
0.37	1.1	**T2S160 MF 1.6**	21	**A9**	**TA25DU1.4**	1	1.4
0.55	1.5	**T2S160 MF 1.6**	21	**A9**	**TA25DU1.8**	1.3	1.8
0.75	1.9	**T2S160 MF 2**	26	**A9**	**TA25DU2.4**	1.7	2.4
1.1	2.8	**T2S160 MF 3.2**	42	**A9**	**TA25DU4**	2.8	4
1.5	3.5	**T2S160 MF 4**	52	**A16**	**TA25DU5**	3.5	5
2.2	5	**T2S160 MF 5**	65	**A26**	**TA25DU6.5**	4.5	6.5
3	6.6	**T2S160 MF 8.5**	110	**A26**	**TA25DU8.5**	6	8.5
4	8.6	**T2S160 MF 11**	145	**A30**	**TA25DU11**	7.5	11
5.5	11.5	**T2S160 MF 12.5**	163	**A30**	**TA25DU14**	10	14
7.5	15.2	**T2S160 MA 20**	210	**A30**	**TA25DU19**	13	19
11	22	**T2S160 MA 32**	288	**A30**	**TA42DU25**	18	25
15	28.5	**T2S160 MA 52**	392	**A50**	**TA75DU42**	29	42
18.5	36	**T2S160 MA 52**	469	**A50**	**TA75DU52**	36	52
22	42	**T2S160 MA 52**	547	**A50**	**TA75DU52**	36	52
30	56	**T2S160 MA 80**	840	**A63**	**TA75DU80**	60	80
37	68	**T2S160 MA 80**	960	**A75**	**TA75DU80**	60	80
45	83	**T2S160 MA 100**	1200	**A95**	**TA110DU110**	80	110
55	98	**T3S250 MA 160**	1440	**A110**	**TA110DU110**	80	110
75	135	**T3S250 MA 200**	1800	**A145**	**TA200DU175**	130	175
90	158	**T3S250 MA 200**	2400	**A185**	**TA200DU200**	150	200
110	193	**T4S320 PR221-I In320**	2720	**A210**	**E320DU320**	100	320
132	232	**T5S400 PR221-I In400**	3200	**A260**	**E320DU320**	100	320
160	282	**T5S400 PR221-I In400**	4000	**A300**	**E320DU320**	100	320
200	349	**T5S630 PR221-I In630**	5040	**AF400**	**E500DU500**	150	500
250	430	**T5S630 PR221-I In630**	6300	**AF460**	**E500DU500**	150	500
290	520	**S6S800 PR211-I In800**	8000	**AF580**	**E800DU800**	250	800
315	545	**S6S800 PR211-I In800**	9600	**AF580**	**E800DU800**	250	800
355	610	**S6S800 PR211-I In800**	9600	**AF750**	**E800DU800**	250	800

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MA: magnetic only adjustable release
MF: fixed magnetic only release

3 Protection of electrical equipment

Table 4: 400 V 50 kA DOL Heavy duty Type 2 (Tmax, Isomax – Contactor – Thermal release)

Motor		MCCB		Contactor	Thermal Overload Relay			
P_e [kW]	I_r [A]	Type	Setting of the magnetic release [A]	Type	Type**	No. of turns of the CT primary coil	Setting range min. [A]	Setting range max. [A]
0.37	1.1	**T2S160 MF 1.6**	21	**A9**	**TA25DU1.4***		1	1.4
0.55	1.5	**T2S160 MF 1.6**	21	**A9**	**TA25DU1.8***		1.3	1.8
0.75	1.9	**T2S160 MF 2**	26	**A9**	**TA25DU2.4***		1.7	2.4
1.1	2.8	**T2S160 MF 3.2**	42	A9	TA25DU4*		2.8	4
1.5	3.5	**T2S160 MF 4**	52	**A16**	**TA25DU5***		3.5	5
2.2	5	**T2S160 MF 5**	65	**A26**	**TA25DU6.5***		4.5	6.5
3	6.6	**T2S160 MF 8.5**	110	**A26**	**TA25DU8.5***		6	8.5
4	8.6	**T2S160 MF 11**	145	**A30**	**TA25DU11***		7.5	11
5.5	11.5	**T2S160 MF 12.5**	163	**A30**	**TA450SU60**	**4**	10	15
7.5	15.2	**T2S160 MA 20**	210	**A30**	**TA450SU60**	**3**	13	20
11	22	**T2S160 MA 32**	288	**A30**	**TA450SU60**	**2**	20	30
15	28.5	**T2S160 MA 52**	392	**A50**	**TA450SU80**	**2**	23	40
18.5	36	**T2S160 MA 52**	469	**A50**	**TA450SU80**	**2**	23	40
22	42	**T2S160 MA 52**	547	**A50**	**TA450SU60**		40	60
30	56	**T2S160 MA 80**	840	**A63**	**TA450SU80**		55	80
37	68	**T2S160 MA 80**	960	**A95**	**TA450SU80**		55	80
45	83	**T2S160 MA 100**	1200	**A110**	**TA450SU105**		70	105
55	98	**T3S250 MA 160**	1440	**A145**	**TA450SU140**		95	140
75	135	**T3S250 MA 200**	1800	**A185**	**TA450SU185**		130	185
90	158	**T3S250 MA 200**	2400	**A210**	**TA450SU185**		130	185
110	193	**T4S320 PR221-I In320**	2720	**A260**	**E320DU320**		100	320
132	232	**T5S400 PR221-I In400**	3200	**A300**	**E320DU320**		100	320
160	282	**T5S400 PR221-I In400**	4000	**AF400**	**E500DU500**		150	500
200	349	**T5S630 PR221-I In630**	5040	**AF460**	**E500DU500**		150	500
250	430	**T5S630 PR221-I In630**	6300	**AF580**	**E500DU500*** **		150	500
290	520	**S6S800 PR211-I In800**	8000	**AF750**	**E800DU800**		250	800
315	545	**S6S800 PR211-I In800**	9600	**AF750**	**E800DU800**		250	800
355	610	**S6S800 PR211-I In800**	9600	**AF750**	**E800DU800**		250	800

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* Provide a by-pass contactor of the same size during motor start-up
** For type E releases choose tripping class 30
*** Connecting kit not available. To use the connecting kit, replacement with release E800DU800 is necessary

MA: magnetic only adjustable release
MF: fixed magnetic only release

3 Protection of electrical equipment

Table 4: 400 V 50 kA Y/Δ Normal Type 2 (Tmax, Isomax – Contactor – Thermal release)

MOTOR		MCCB		Contactor			Thermal Overload Relay	
P_e [kW]	I_r [A]	Type	I3 [A]	LINE Type	DELTA Type	STAR Type	Type	[A]
18.5	36	**T2S160 MA52**	469	**A50**	**A50**	**A26**	**TA75DU25**	18-25
22	42	**T2S160 MA52**	547	**A50**	**A50**	**A26**	**TA75DU32**	22-32
30	56	**T2S160 MA80**	720	**A63**	**A63**	**A30**	**TA75DU42**	29-42
37	68	**T2S160 MA80**	840	**A75**	**A75**	**A30**	**TA75DU52**	36-52
45	83	**T2S160 MA100**	1050	**A75**	**A75**	**A30**	**TA75DU63**	45 - 63
55	98	**T2S160 MA100**	1200	**A75**	**A75**	**A40**	**TA75DU63**	45 - 63
75	135	**T3S250 MA160**	1700	**A95**	**A95**	**A75**	**TA110DU90**	66 - 90
90	158	**T3S250 MA200**	2000	**A110**	**A110**	**A95**	**TA110DU110**	80 - 110
110	193	**T3S250 MA200**	2400	**A145**	**A145**	**A95**	**TA200DU135**	100 - 135
132	232	**T4S320 PR221-I In320**	2880	**A145**	**A145**	**A110**	**E200DU200**	60 - 200
160	282	**T5S400 PR221-I In400**	3600	**A185**	**A185**	**A145**	**E200DU200**	60 - 200
200	349	**T5S630 PR221-I In630**	4410	**A210**	**A210**	**A185**	**E320DU320**	100 - 320
250	430	**T5S630 PR221-I In630**	5670	**A260**	**A260**	**A210**	**E320DU320**	100 - 320

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MA : magnetic only adjustable release

3 Protection of electrical equipment

Table 6: 440 V 50 kA DOL Normal Type 2 (Tmax, Isomax – Contactor – Thermal release)

Motor		MCCB		Contactor	Thermal Overload Relay		
						Current setting	
P_e [kW]	I_r [A]	Type	I3 [A]	Type	Type	min. [A]	max. [A]
0,37	1	**T2H160 MF 1**	13	**A9**	**TA25DU1.4**	1	1,4
0,55	1,4	**T2H160 MF 1.6**	21	**A9**	**TA25DU1.8**	1,3	1,8
0,75	1,7	**T2H160 MF 2**	26	**A9**	**TA25DU2.4**	1,7	2,4
1,1	2,2	**T2H160 MF 2.5**	33	**A9**	**TA25DU3.1**	2,2	3,1
1,5	3	**T2H160 MF 3.2**	42	**A16**	**TA25DU4**	2,8	4
2,2	4,4	**T2H160 MF 5**	65	**A26**	**TA25DU5**	3,5	5
3	5,7	**T2H160 MF 6.5**	84	**A26**	**TA25DU6.5**	4,5	6,5
4	7,8	**T2H160 MF 8.5**	110	**A30**	**TA25DU11**	7,5	11
5,5	10,5	**T2H160 MF 11**	145	**A30**	**TA25DU14**	10	14
7,5	13,5	**T2H160 MA 20**	180	**A30**	**TA25DU19**	13	19
11	19	**T2H160 MA 32**	240	**A30**	**TA42DU25**	18	25
15	26	**T2H160 MA 32**	336	**A50**	**TA75DU32**	22	32
18,5	32	**T2H160 MA 52**	469	**A50**	**TA75DU42**	29	42
22	38	**T2H160 MA 52**	547	**A50**	**TA75DU52**	36	52
30	52	**T2H160 MA 80**	720	**A63**	**TA75DU63**	45	63
37	63	**T2H160 MA 80**	840	**A75**	**TA75DU80**	60	80
45	75	**T2H160 MA 100**	1050	**A95**	**TA110DU90**	65	90
55	90	**T4H250 PR221-I In160**	1200	**A110**	**TA110DU110**	80	110
75	120	**T4H250 PR221-I In250**	1750	**A145**	**E200DU200**	60	200
90	147	**T4H250 PR221-I In250**	2000	**A185**	**E200DU200**	60	200
110	177	**T4H250 PR221-I In250**	2500	**A210**	**E320DU320**	100	320
132	212	**T4H320 PR221-I In320**	3200	**A260**	**E320DU320**	100	320
160	260	**T5H400 PR221-I In400**	3600	**A300**	**E320DU320**	100	320
200	320	**T5H630 PR221-I In630**	4410	**AF 400**	**E500DU500**	150	500
250	410	**T5H630 PR221-I In630**	5355	**AF 460**	**E500DU500**	150	500
290	448	**S6H630 PR211-I In630**	7560	**AF 580**	**E500DU500***	150	500
315	500	**S6H800 PR211-I In800**	8000	**AF 580**	**E800DU800**	250	800
355	549	**S6H800 PR211-I In800**	9600	**AF 580**	**E800DU800**	250	800

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* Connection kit not available
MA: magnetic only adjustable release
MF: fixed magnetic only release

3 Protection of electrical equipment

Table 7: 440 V 50 kA DOL Heavy duty Type 2
(Tmax, Isomax – Contactor – Thermal release)

Motor		MCCB		Contactor	Thermal Overload Relay			
P_e [kW]	I_r [A]	Type	Setting of the magnetic release [A]	Type	Type**	No. of turns of the CT primary coil	Setting range min. [A]	Setting range max. [A]
0.37	1	**T2H160 MF 1**	13	**A9**	**TA25DU1.4***		1	1.4
0.55	1.4	**T2H160 MF 1.6**	21	**A9**	**TA25DU1.8***		1.3	1.8
0.75	1.7	**T2H160 MF 2**	26	**A9**	**TA25DU2.4***		1.7	2.4
1.1	2.2	**T2H160 MF 2.5**	33	**A9**	**TA25DU3.1***		2.2	3.1
1.5	3	**T2H160 MF 3.2**	42	**A16**	**TA25DU4***		2.8	4
2.2	4.4	**T2H160 MF 5**	65	**A26**	**TA25DU5***		3.5	5
3	5.7	**T2H160 MF 6.5**	84	**A26**	**TA25DU6.5***		4.5	6.5
4	7.8	**T2H160 MF 8.5**	110	**A30**	**TA25DU11***		7.5	11
5.5	10.5	**T2H160 MF 11**	145	**A30**	**TA25DU14***		10	14
7.5	13.5	**T2H160 MA 20**	180	**A30**	**TA450SU60**	**4**	10	15
11	19	**T2H160 MA 32**	240	**A30**	**TA450SU80**	**3**	18	27
15	26	**T2H160 MA 32**	336	**A50**	**TA450SU60**	**2**	20	30
18.5	32	**T2H160 MA 52**	469	**A50**	**TA450SU80**	**2**	28	40
22	38	**T2H160 MA 52**	547	**A50**	**TA450SU80**	**2**	28	40
30	52	**T2H160 MA 80**	720	**A63**	**TA450SU60**		40	60
37	63	**T2H160 MA 80**	840	**A95**	**TA450SU80**		55	80
45	75	**T2H160 MA 100**	1050	**A110**	**TA450SU105**		70	105
55	90	**T4H250 PR221-I In160**	1200	**A145**	**E200DU200**		60	200
75	120	**T4H250 PR221-I In250**	1750	**A185**	**E200DU200**		60	200
90	147	**T4H250 PR221-I In250**	2000	**A210**	**E320DU320**		100	320
110	177	**T4H250 PR221-I In250**	2500	**A260**	**E320DU320**		100	320
132	212	**T4H320 PR221-I In320**	3200	**A300**	**E320DU320**		100	320
160	260	**T5H400 PR221-I In400**	3600	**AF400**	**E500DU500**		150	500
200	320	**T5H630 PR221-I In630**	4410	**AF460**	**E500DU500**		150	500
250	410	**T5H630 PR221-I In630**	5355	**AF580**	**E500DU500*** **		150	500
290	448	**S6H630 PR211-I In630**	7560	**AF750**	**E500DU500*** **		150	500
315	500	**S6H800 PR211-I In800**	8000	**AF 750**	**E800DU800**		250	800
355	549	**S6H800 PR211-I In800**	9600	**AF 750**	**E800DU800**		250	800

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* Provide a by-pass contactor of the same size during motor start-up
** For type E releases choose tripping class 30
*** Connecting kit not available. To use the connecting kit, replacement with release E800DU800 is necessary

MA: magnetic only adjustable release
MF: fixed magnetic only release

3 Protection of electrical equipment

Table 8: 440 V 50 kA Y/Δ Normal Type 2 (Tmax, Isomax – Contactor – Thermal release)

MOTOR		MCCB		Contactor			Thermal Overload Relay	
P_e [kW]	I_r [A]	Type	I3 [A]	LINE Type	DELTA Type	STAR Type	Type	[A]
18.5	32	**T2H160 MA52**	392	**A 50**	**A 50**	**A 16**	**TA75DU25**	18-25
22	38	**T2H160 MA52**	469	**A 50**	**A 50**	**A 26**	**TA75DU25**	18-25
30	52	**T2H160 MA80**	720	**A 63**	**A 63**	**A 26**	**TA75DU42**	29-42
37	63	**T2H160 MA80**	840	**A 75**	**A 75**	**A 30**	**TA75DU42**	29-42
45	75	**T2H160 MA80**	960	**A 75**	**A 75**	**A30**	**TA75DU52**	36-52
55	90	**T2H160 MA100**	1150	**A 75**	**A 75**	**A40**	**TA75DU63**	45 - 63
75	120	**T4H250 PR221-I In250**	1625	**A95**	**A95**	**A75**	**TA80DU80**	60-80
90	147	**T4H250 PR221-I In250**	1875	**A95**	**A95**	**A75**	**TA110DU110**	80-110
110	177	**T4H250 PR221-I In250**	2250	**A145**	**A145**	**A95**	**E200DU200**	60-200
132	212	**T4H320 PR221-I In320**	2720	**A145**	**A145**	**A110**	**E200DU200**	60-200
160	260	**T5H400 PR221-I In400**	3200	**A185**	**A185**	**A145**	**E200DU200**	60-200
200	320	**T5H630 PR221-I In630**	4095	**A210**	**A210**	**A185**	**E320DU320**	100-320
250	410	**T5H630 PR221-I In630**	5040	**A260**	**A260**	**A210**	**E320DU320**	100-320

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MA : Magnetic only adjustable release

3 Protection of electrical equipment

Table 9: 500 V 50 kA DOL Normal Type 2 (Tmax, Isomax – Contactor – Thermal release)

Motor		MCCB		Contactor	Thermal Overload Relay		
		Type		Type	Type	Current setting	
P_e [kW]	I_r [A]		I3 [A]			min. [A]	max. [A]
0.37	0.88	**T2L160 MF 1**	13	**A9**	**TA25DU1.0**	0.63	1
0.55	1.2	**T2L160 MF 1.6**	21	**A9**	**TA25DU1.4**	1	1.4
0.75	1.5	**T2L160 MF 1.6**	21	**A9**	**TA25DU1.8**	1.3	1.8
1.1	2.2	**T2L160 MF 2.5**	33	**A9**	**TA25DU3.1**	2.2	3.1
1.5	2.8	**T2L160 MF 3.2**	42	**A16**	**TA25DU4**	2.8	4
2.2	4	**T2L160 MF 4**	52	**A26**	**TA25DU5**	3.5	5
3	5.2	**T2L160 MF 6.5**	84	**A26**	**TA25DU6.5**	4.5	6.5
4	6.9	**T2L160 MF 8.5**	110	**A30**	**TA25DU8.5**	6	8.5
5.5	9.1	**T2L160 MF 11**	145	**A30**	**TA25DU11**	7.5	11
7.5	12.2	**T2L160 MF 12.5**	163	**A30**	**TA25DU14**	10	14
11	17.5	**T2L160 MA 20**	240	**A30**	**TA25DU19**	13	19
15	23	**T2L160 MA 32**	336	**A50**	**TA75DU25**	18	25
18.5	29	**T2L160 MA 52**	392	**A50**	**TA75DU32**	22	32
22	34	**T2L160 MA 52**	469	**A50**	**TA75DU42**	29	42
30	45	**T2L160 MA 52**	624	**A63**	**TA75DU52**	36	52
37	56	**T2L160 MA 80**	840	**A75**	**TA75DU63**	45	63
45	67	**T2L160 MA 80**	960	**A95**	**TA80DU80**	60	80
55	82	**T2L160 MA 100**	1200	**A110**	**TA110DU90**	65	90
75	110	**T4H250 PR221-I In160**	1440	**A145**	**E200DU200**	60	200
90	132	**T4H250 PR221-I In250**	1875	**A145**	**E200DU200**	60	200
110	158	**T4H250 PR221-I In250**	2250	**A185**	**E200DU200**	60	200
132	192	**T4H320 PR221-I In320**	2720	**A210**	**E320DU320**	100	320
160	230	**T5H400 PR221-I In400**	3600	**A260**	**E320DU320**	100	320
200	279	**T5H400 PR221-I In400**	4000	**A300**	**E320DU320**	100	320
250	335	**T5H630 PR221-I In630**	4725	**AF 400**	**E 500DU500**	150	500
290	394	**T5H630 PR221-I In630**	5040	**AF 460**	**E 500DU500**	150	500
315	440	**S6L630 PR211-I In630**	7560	**AF 580**	**E 500DU500***	150	500
355	483	**S6L630 PR211-I In630**	7560	**AF 580**	**E 800DU800**	250	800

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* Connection kit not available
MA: magnetic only adjustable release
MF: fixed magnetic only release

3 Protection of electrical equipment

Table 10: 500 V 50 kA DOL Heavy duty Type 2 (Tmax, Isomax – Contactor – Thermal release)

Motor		MCCB		Contactor	Thermal Overload Relay			
P_e [kW]	I_r [A]	Type	Setting of the magnetic release [A]	Type	Type**	No. of turns of the CT primary coil	Setting range min. [A]	Setting range max. [A]
0.37	0.88	**T2L160 MF 1**	13	**A9**	**TA25DU1.0***		0.63	1
0.55	1.2	**T2L160 MF 1.6**	21	**A9**	**TA25DU1.4***		1	1.4
0.75	1.5	**T2L160 MF 1.6**	21	**A9**	**TA25DU1.8***		1.3	1.8
1.1	2.2	**T2L160 MF 2.5**	33	**A9**	**TA25DU3.1***		2.2	3.1
1.5	2.8	**T2L160 MF 3.2**	42	**A16**	**TA25DU4***		2.8	4
2.2	4	**T2L160 MF 4**	52	**A26**	**TA25DU5***		3.5	5
3	5.2	**T2L160 MF 6.5**	84	**A26**	**TA25DU6.5***		4.5	6.5
4	6.9	**T2L160 MF 8.5**	110	**A30**	**TA25DU8.5***		6	8.5
5.5	9.1	**T2L160 MF 11**	145	**A30**	**TA25DU11***		7.5	11
7.5	12.2	**T2L160 MF 12.5**	163	**A30**	**TA450SU60**	**4**	10	15
11	17.5	**T2L160 MA 20**	240	**A30**	**TA450SU60**	**3**	13	20
15	23	**T2L160 MA 32**	336	**A50**	**TA450SU60**	**2**	20	30
18.5	29	**T2L160 MA 52**	392	**A50**	**TA450SU80**	**2**	27.5	40
22	34	**T2L160 MA 52**	469	**A50**	**TA450SU80**	**2**	27.5	40
30	45	**T2L160 MA 52**	624	**A63**	**TA450SU60**		40	60
37	56	**T2L160 MA 80**	840	**A75**	**TA450SU60**		40	60
45	67	**T2L160 MA 80**	960	**A95**	**TA450SU80**		55	80
55	82	**T2L160 MA 100**	1200	**A145**	**TA450SU105**		70	105
75	110	**T4H250 PR221-I In160**	1440	**A145**	**E200DU200**		60	200
90	132	**T4H250 PR221-I In250**	1875	**A185**	**E200DU200**		60	200
110	158	**T4H250 PR221-I In250**	2123	**A210**	**E320DU320**		100	320
132	192	**T4H320 PR221-I In320**	2720	**A260**	**E320DU320**		100	320
160	230	**T5H400 PR221-I In400**	3200	**A300**	**E320DU320**		100	320
200	279	**T5H400 PR221-I In400**	3600	**AF400**	**E500DU500**		150	500
250	335	**T5H630 PR221-I In630**	4725	**AF460**	**E500DU500**		150	500
290	394	**T5H630 PR221-I In630**	5040	**AF580**	**E500DU500*****		150	500
315	440	**S6L630 PR211-I In630**	7560	**AF750**	**E500DU500*****		150	500
355	483	**S6L630 PR211-I In630**	7560	**AF750**	**E500DU500**		150	500

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* Provide a by-pass contactor of the same size during motor start-up
** For type E releases choose tripping class 30
*** Connecting kit not available. To use the connecting kit, replacement with release E800DU800 is necessary

MA: magnetic only adjustable release
MF: fixed magnetic only release

3 Protection of electrical equipment

Table 11: 500 V 50 kA Y/Δ Normal Type 2
(Tmax, Isomax – Contactor – Thermal release)

MOTOR		MCCB		Contactor			Thermal Overload Relay	
P_e [kW]	I_r [A]	Type	I3 [A]	LINE Type	DELTA Type	STAR Type	Type	[A]
22	34	**T2L160 MA52**	430	**A 50**	**A 50**	**A 16**	**TA75DU25**	18-25
30	45	**T2L160 MA52**	547	**A 63**	**A 63**	**A 26**	**TA75DU32**	22-32
37	56	**T2L160 MA80**	720	**A 75**	**A 75**	**A 30**	**TA75DU42**	29-42
45	67	**T2L160 MA80**	840	**A 75**	**A 75**	**A30**	**TA75DU52**	36 - 52
55	82	**T2L160 MA100**	1050	**A 75**	**A 75**	**A30**	**TA75DU52**	36 - 52
75	110	**T4H250 PR221-I In250**	1375	**A95**	**A95**	**A50**	**TA80DU80**	60-80
90	132	**T4H250 PR221-I In250**	1750	**A95**	**A95**	**A75**	**TA110DU90**	65-90
110	158	**T4H250 PR221-I In250**	2000	**A110**	**A110**	**A95**	**TA110DU110**	80-110
132	192	**T4H320 PR221-I In320**	2560	**A145**	**A145**	**A95**	**E200DU200**	60-200
160	230	**T4H320 PR221-I In320**	2880	**A145**	**A145**	**A110**	**E200DU200**	60-200
200	279	**T5H400 PR221-I In400**	3400	**A210**	**A210**	**A145**	**E320DU320**	100-320
250	335	**T5H630 PR221-I In630**	4410	**A210**	**A210**	**A185**	**E320DU320**	100-320
290	394	**T5H630 PR221-I In630**	5040	**A260**	**A260**	**A210**	**E320DU320**	100-320

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MA: magnetic only adjustable release

3 Protection of electrical equipment

Example:

For a Y/Δ Normal starting Type 2, of a three phase asynchronous squirrel-cage motor with the following data:
rated voltage U_r = 400 V
short-circuit current I_k = 50 kA
rated motor power P_e = 200 kW
from Table 5, on the relevant row, the following information can be found:

- I_r (rated current): 349 A;
- short-circuit protection device: circuit breaker T5S630 PR221-I In630;
- magnetic trip threshold: I_3 = 4410 A;
- line contactor: A210;
- delta contactor: A210;
- star contactor: A185;
- thermal release E320DU320, setting range 100-320 A (to be set at $\frac{I_r}{\sqrt{3}} = 202$ A).

3.4 Protection and switching of transformers

General aspects

Transformers are used to achieve a change in the supply voltage, for both medium and low voltage supplies.
The choice of the protection devices must take into account transient insertion phenomena, during which the current may reach values higher than the rated full load current; the phenomenon decays in a few seconds.

The curve which represents these transient phenomena in the time-current diagram, termed “inrush current I0”, depends on the size of the transformer and can be evaluated with the following formula (the short-circuit power of the network is assumed equal to infinity)

$$I_0 = \frac{K \cdot I_{r1} \cdot e^{(-t/\tau)}}{\sqrt{2}}$$

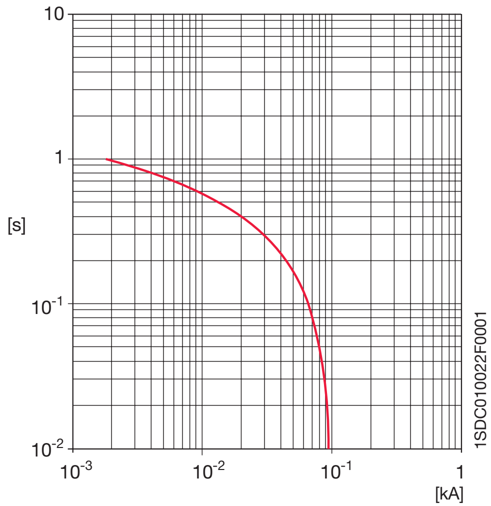
where:

K ratio between the maximum peak inrush current value (I_0) and the rated current of the transformer (I_{1r}): ($K = I_0 / I_{1r}$);
τ time constant of the inrush current;
I_{1r} rated current of the primary;
t time.

The table below shows the indicative values for t and K parameters referred to rated power Sr for oil transformers.

Sr [kVA]	50	100	160	250	400	630	1000	1600	2000
$K = I_o/I_{1r}$	15	14	12	12	12	11	10	9	8
τ [s]	0.10	0.15	0.20	0.22	0.25	0.30	0.35	0.40	0.45

Further to the above consideration, the follwing diagram shows the inrush current curve for a 20/0.4kV of 400kVA transformer. This transformer has an inrush current during the very first moments equal to about 8 times the rated current; this transient phenomenon stops after a few tenths of a second.



3 Protection of electrical equipment

The transformer protection devices must also guarantee that the transformer cannot operate above the point of maximum thermal overload under short-circuit conditions; this point is defined on the time-current diagram by the value of short-circuit current which can pass through the transformer and by a time equal to 2 s, as stated by Standard IEC 60076-5. The short-circuit current (I_k) flowing for a fault with low impedance at the LV terminals of the transformer is calculated by using the following formula:

$$I_k = \frac{U_r}{\sqrt{3}\cdot(Z_{Net}+Z_t)} \text{ [A]} \qquad (1)$$

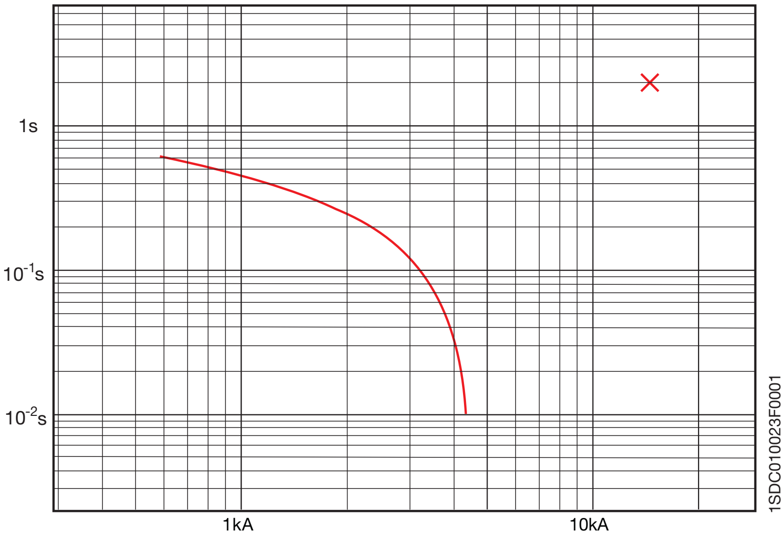
where:
- U_r is the rated voltage of the transformer [V];
- Z_{Net} is the short-circuit impedance of the network [Ω];
- Z_t is the short-circuit impedance of the transformer; from the rated power of the transformer (S_r [VA]) and the percentage short-circuit voltage (u_k%) is equal to:

$$Z_t = \frac{u_k\%}{100}\cdot\frac{U_r^2}{S_r} \text{ [Ω]} \qquad (2)$$

Considering the upstream short-circuit power of the network to be infinite (Z_{Net}=0), formula (1) becomes:

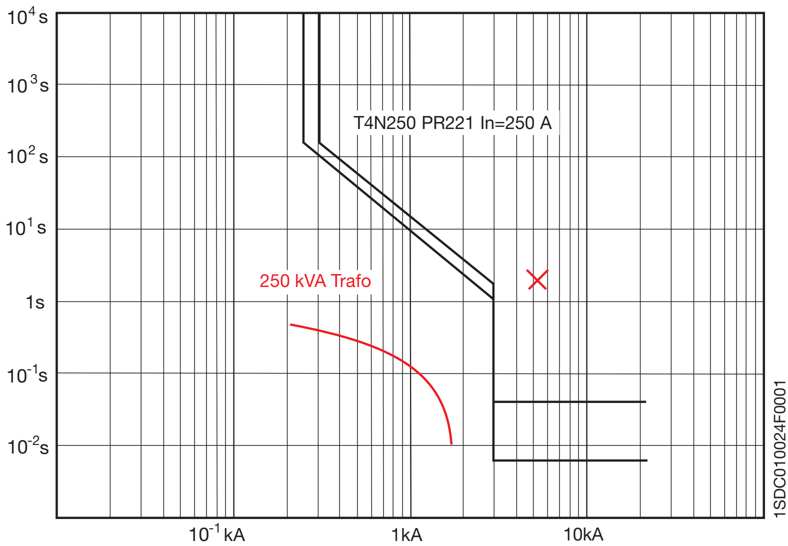
$$I_k = \frac{U_r}{\sqrt{3}\cdot(Z_t)} = \frac{U_r}{\sqrt{3}\cdot\left(\frac{u_k\%}{100}\cdot\frac{U_r^2}{S_r}\right)} = \frac{100\ S_r}{\sqrt{3}\cdot u_k\%\cdot U_r} \text{ [A]} \qquad (3)$$

The diagram below shows the inrush current curve for a 20/0.4 kV of 400 kVA transformer (u_k% = 4 %) and the point referred to the thermal ability to with the short-circuit current (Ik; 2 sec.).



3 Protection of electrical equipment

In summary: for the correct protection of the transformer and to avoid unwanted trips, the trip curve of the protection device must be above the inrush current curve and below the overload point.
The diagram below shows a possible position of the time-current curve of an upstream protection device of a 690/400 V, 250 kVA transformer with $u_k\% = 4\ \%$.



Criteria for the selection of protection devices

For the protection at the LV side of MV/LV transformers, the selection of a circuit breaker shall take into account:
- the rated current at LV side of the protected transformer (this value is the reference value for the rated current of the circuit breaker and the setting of the protections);
- the maximum short-circuit current at the point of installation (this value determines the minimum breaking capacity (I_{cu}/I_{cs}) of the protection device).

MV/LV unit with single transformer
The rated current at the LV side of the transformer (I_r) is determined by the following formula:

$$I_r = \frac{1000 \cdot S_r}{\sqrt{3} \cdot U_{r20}} \ [A] \qquad (4)$$

where:
- S_r is the rated power of the transformer [kVA];
- U_{r20} is the rated LV no-load voltage of the transformer [V].

3 Protection of electrical equipment

The full voltage three-phase short-circuit current (I_k), at the LV terminals of the transformer, can be expressed as (assuming that the short-circuit power of the network is infinite):

$$I_k = \frac{100 \cdot I_r}{u_k\%} \text{ [A]} \qquad (5)$$

where:
$u_k\%$ is the short-circuit voltage of the transformer, in %.

The protection circuit-breaker must have:
$I_n \geq I_r$;
I_{cu} (I_{cs}) $\geq I_k$.

If the short-circuit power of the upstream network is not infinite and cable or busbar connections are present, it is possible to obtain a more precise value for I_k by using formula (1), where Z_{Net} is the sum of the impedance of the network and of the impedance of the connection.

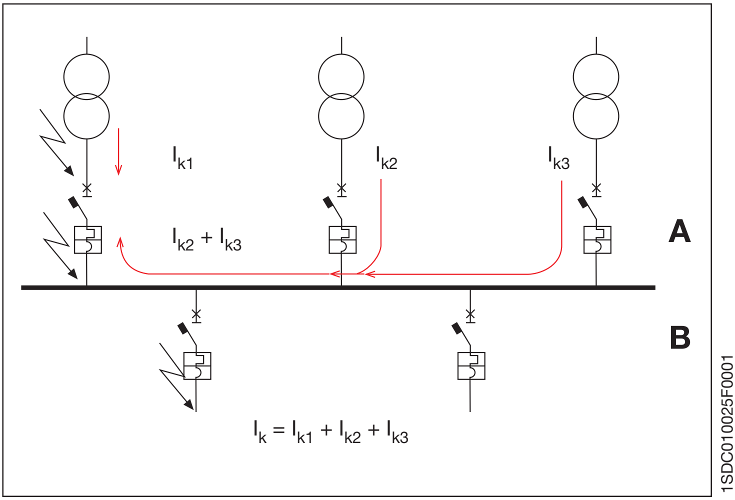
MV/LV substation with more than one transformer in parallel
For the calculation of the rated current of the transformer, the above applies (formula 4).

The breaking capacity of each protection circuit-breaker on the LV side shall be higher than the short-circuit current equivalent to the short-circuit current of each equal transformer multiplied by the number of them minus one.
As can be seen from the diagram below, in the case of a fault downstream of a transformer circuit-breaker (circuit-breaker A), the short-circuit current that flows through the circuit-breaker is equal to the contribution of a single transformer. In the case of a fault upstream of the same circuit-breaker, the short-circuit current that flows is equal to the contribution of the other two transformers in parallel.

3 Protection of electrical equipment

For a correct dimensioning, a circuit-breaker with a breaking capacity higher than twice the short-circuit current of one of the transformers must be chosen (assuming that all the transformers are equal and the loads are passive).

The circuit-breakers positioned on the outgoing feeders (circuit-breakers B) shall have a breaking capacity higher than the sum of the short-circuit currents of the three transformers, according to the hypothesis that the upstream network short-circuit power is 750 MVA and the loads are passive.



3 Protection of electrical equipment

Selection of the circuit-breaker

The following tables show some possible choices of ABB SACE circuit-breakers, according to the characteristics of the transformer to be protected.

Table 1: Protection and switching of 230 V transformers

Transformer				Circuit Breaker "A" (LV side)								
Sr	uk	Trafo Ir	Busbar Ib	Trafo Feeder Ik	ABB SACE Circuit Breaker	Release		Busbar Ik				
[kVA]	%	[A]	[A]	[kA]		size	setting	[kA]	32 A	63 A	125 A	160 A
1 x 63	4	158	158	3.9	T1B160	In=160	1	3.9	S250/S260		T1B160	
2 x 63		158	316	3.9	T1B160	In=160	1	7.9	S250/S260		T1B160	
1 x 100	4	251	251	6.3	T4N320	In=320	0.9	6.3	S250/S260		T1B160	
2 x 100		251	502	6.2	T4N320	In=320	0.9	12.5	S250/S260		T1B160	
1 x 125	4	314	314	7.8	T5N400	In=400	0.9	7.8	S250/S260		T1B160	
2 x 125		314	628	7.8	T5N400	In=400	0.9	15.6	S250/S260		T1B160	
1 x 160	4	402	402	10.0	T5N630	In=630	0.7	10.0	S250/S260		T1B160	
2 x 160		402	803	9.9	T5N630	In=630	0.7	19.9	T1B160			
1 x 200	4	502	502	12.5	T5N630	In=630	0.9	12.5	S250/S260		T1B160	
2 x 200		502	1004	12.4	T5N630	In=630	0.9	24.8	T1B160			
1 x 250	4	628	628	15.6	T5N630	In=630	1	15.6	S250/S260		T1B160	
2 x 250		628	1255	15.4	T5N630	In=630	1	30.9	T1C160			
1 x 315	4	791	791	19.6	S6N800	In=800	1	19.6	T1B160			
2 x 315		791	1581	19.4	S6N800	In=800	1	38.7	T1C160			
1 x 400	4	1004	1004	24.8	S7S1250/E1B1250	In=1250	0.9	24.8	T1B160			
2 x 400		1004	2008	24.5	S7S1250/E1B1250	In=1250	0.9	48.9	T1N160			
1 x 500	4	1255	1255	30.9	S7S1600/E2B1600	In=1600	0.9	30.9	T1C160			
2 x 500		1255	2510	30.4	S7S1600/E2B1600	In=1600	0.9	60.7	T2N160			
1 x 630	4	1581	1581	38.7	S7S1600/E2B1600	In=1600	1	38.7	T1C160			
2 x 630		1581	3163	37.9	S7S1600/E2B1600	In=1600	1	75.9	T2S160			
3 x 630		1581	4744	74.4	S7S1600/E3S1600	In=1600	1	111.6	T2L160			
1 x 800	5	2008	2008	39.3	E3N2500	In=2500	0.9	39.3	T1C160			
2 x 800		2008	4016	38.5	E3N2500	In=2500	0.9	77.0	T2S160			
3 x 800		2008	6025	75.5	E3H2500	In=2500	0.9	113.2	T2L160			
1 x 1000	5	2510	2510	48.9	E3N3200	In=3200	0.8	48.9	T1N160			
2 x 1000		2510	5020	47.7	E3N3200	In=3200	0.8	95.3	T2H160			
3 x 1000		2510	7531	93.0	E3H3200	In=3200	0.8	139.5	T4L250			
1 x 1250	5	3138	3138	60.7	E3N3200	In=3200	1	60.7	T2N160			
2 x 1250		3138	6276	58.8	E3N3200	In=3200	1	117.7	T2L160			
3 x 1250		3138	9413	114.1	S8V3200/E6V3200	In=3200	1	171.2	T4L250			

3 Protection of electrical equipment

Circuit Breaker "B" (Feeder Circuit Breaker)									
Feeder Circuit Breaker type and rated current									
250 A	400 A	630 A	800 A	1250 A	1600 A	2000 A	2500 A	3200 A	4000 A
T3N250									
T3N250	T5N400								
T3N250									
T3N250	T5N400								
T3N250									
T3N250	T5N400	T5N630							
T3N250	T5N400								
T3N250	T5N400	T5N630							
T3N250	T5N400								
T3N250	T5N400	T5N630	S6N800						
T3N250	T5N400	T5N630							
T3N250	T5N400	T5N630	S6N800	S7S1250					
T3N250	T5N400	T5N630	S6N800						
T3N250	T5N400	T5N630	S6N800	S7S1250/E1N1250	S7S1600/E2N1600				
T3N250	T5N400	T5N630	S6N800						
T3S250	T5N400	T5N630	S6N800	S7S1250/E2N1250	S7S1600/E2N1600	E2N2000			
T3N250	T5N400	T5N630	S6N800	S7S1250/E1N1250					
T3S250	T5S400	T5S630	S6S800	S7S1250/E2L1250	S7S1600/E2L1600	E3H2000	E3H2500		
T4L250	T5L400	T5L630	S6L800	S7L1250/E2L1250	S7L1600/E2L1600	E3L2000	E3L2500	E6V3200	
T3N250	T5N400	T5N630	S6N800	S7S1250/E1B1250	S7S1600/E2B1600				
T3S250	T5S400	T5S630	S6S800	S7S1250/E2L1250	S7S1600/E2L1600	E3H2000	E3H2500	E3H3200	
T4L250	T5L400	T5L630	S6L800	S7L1250/E2L1250	S7L1600/E2L1600	E3L2000	E3L2500	E6V3200	E6V4000
T3N250	T5N400	T5N630	S6N800	S7S1250/E1N1250	S7S1600/E2N1600	E2N2000			
T4H250	T5H400	T5H630	S6H800	S7H1250/E2L1250	S7H1600/E2L1600	E3H2000	E3H2500	E3H3200	E4H4000
T4L250	T5L400	T5L630	S6L800	S7L1250	S7L1600	E6V3200	E6V3200	E6V3200	E6V4000
T3S250	T5N400	T5N630	S6N800	S7S1250/E2N1250	S7S1600/E2N1600	E2N2000	E3N2500		
T4L250	T5L400	T5L630	S6L800	S7L1250/E2L1250	S7L1600/E2L1600	E3L2000	E3L2500	E6V3200	E6V4000
T4L250	T5L400	T5L630	S6L800	S7L1250	S7L1600				

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3 Protection of electrical equipment

Table 2: Protection and switching of 400 V transformers

Transformer				Circuit Breaker "A" (LV side)									
S_r	u_k	Trafo I_r	Busbar I_b	Trafo Feeder I_k	ABB SACE Circuit Breaker	Release		Busbar I_k					
[kVA]	%	[A]	[A]	[kA]		size	setting	[kA]	32 A	63 A	125 A	160 A	250 A
1 x 63	4	91	91	2.2	T1B/T2N160	In=100	0.96	2.2	S250/S260				
2 x 63		91	182	2.2	T1B/T2N160	In=100	0.96	4.4	S250/S260		T1B160		
1 x 100	4	144	144	3.6	T1B/T2N160	In=160	0.92	3.6	S250/S260		T1B160		
2 x 100		144	288	3.6	T1B/T2N160	In=160	0.92	7.2	S250/S260		T1B160		
1 x 125	4	180	180	4.5	T3N250	In=250	0.95/0.8	4.5	S250/S260		T1B160		
2 x 125		180	360	4.4	T3N250	In=250	0.95/0.8	8.8	S250/S260		T1B160		
1 x 160	4	231	231	5.7	T3N250	In=250	0.95/0.95	5.7	S250/S260		T1B160		
2 x 160		231	462	5.7	T3N250	In=250	0.95/0.95	11.4	T1B160				T3N250
1 x 200	4	289	289	7.2	T4N320	In=320	0.95	7.2	S250/S260		T1B160		T3N250
2 x 200		289	578	7.1	T4N320	In=320	0.95	14.2	T1B160				T3N250
1 x 250	4	361	361	8.9	T5N400	In=400	0.95	8.9	S250/S260		T1B160		T3N250
2 x 250		361	722	8.8	T5N400	In=400	0.95	17.6	T1C160				T3N250
1 x 315	4	455	455	11.2	T5N630	In=630	0.8	11.2	T1B160				T3N250
2 x 315		455	910	11.1	T5N630	In=630	0.8	22.2	T1C160				T3N250
1 x 400	4	577	577	14.2	T5N630/S6N800	In=630/800	0.95/0.8	14.2	T1B160				T3N250
2 x 400		577	1154	14	T5N630/S6N800	In=630/800	0.95/0.8	28	T1N160				T3N250
1 x 500	4	722	722	17.7	S6N800/S7S1250	In=800/1000	0.95/0.8	17.7	T1C160				T3N250
2 x 500		722	1444	17.5	S6N800/S7S1250	In=800/1000	0.95/0.8	35.9	T1N160				T3N250
1 x 630	4	909	909	22.3	S7S1250/E1B1250	In=1000	0.95	22.3	T1C160				T3N250
2 x 630		909	1818	21.8	S7S1250/E1B1250	In=1000	0.95	43.6	T2S160				T3S250
3 x 630		909	2727	42.8	S7S1250/E1N1250	In=1000	0.95	64.2	T2H160				T4H250
1 x 800	5	1155	1155	22.6	S7S1250/E1B1250	In=1250	0.95	22.6	T1C160				T3N250
2 x 800		1155	2310	22.1	S7S1250/E1B1250	In=1250	0.95	44.3	T2S160				T3S250
3 x 800		1155	3465	43.4	S7S1250/E1N1250	In=1250	0.95	65	T2H160				T4H250
1 x 1000	5	1443	1443	28.1	S7S1600/E2B1600	In=1600	0.95	28.1	T1N160				T3N250
2 x 1000		1443	2886	27.4	S7S1600/E2B1600	In=1600	0.95	54.8	T2H160				T4H250
3 x 1000		1443	4329	53.5	S7H1600/E2N1600	In=1600	0.95	80.2	T2L160				T4L250
1 x 1250	5	1804	1804	34.9	E2B2000	In=2000	0.95	34.9	T1N160				T3N250
2 x 1250		1804	3608	33.8	E2B2000	In=2000	0.95	67.7	T2H160				T4H250
3 x 1250		1804	5412	65.6	E3S2000	In=2000	0.95	98.4	T4L250				T4L250
1 x 1600	6.25	2309	2309	35.7	E3N2500	In=2500	0.95	35.7	T2N160				T3N250
2 x 1600		2309	4618	34.6	E3N2500	In=2500	0.95	69.2	T2H160				T4H250
3 x 1600		2309	6927	67	E3S2000	In=2500	0.95	100.6	T4L250				T4L250
1 x 2000	6.25	2887	2887	44.3	E3N3200	In=3200	0.95	44.3	T2S160				T3S250
2 x 2000		2887	5774	42.6	E3N3200	In=3200	0.95	85.1	T4L250				T4L250
3 x 2000		2887	8661	81.9	E3H3200	In=3200	0.95	122.8	T4L250				T4V250
1 x 2500	6.25	3608	3608	54.8	E4S4000	In=4000	1	54.8	T2H160				T4H250
1 x 3125	6.25	4510	4510	67.7	E6H5000	In=5000	1	67.7	T2H160				T4H250

3 Protection of electrical equipment

Circuit Breaker "B" (Feeder Circuit Breaker)								
Feeder Circuit Breaker type and rated current								
400 A	630 A	800 A	1250 A	1600 A	2000 A	2500 A	3200 A	4000 A
T5N400								
T5N400								
T5N400								
T5N400	T5N630							
T5N400								
T5N400	T5N630							
T5N400	T5N630							
T5N400	T5N630	S6N800						
T5N400	T5N630	S6N800/E1B800						
T5S400	T5S630	S6S800/E1N800	S7S1250/E1N1250					
T5H400	T5H630	S6L800/E2N1250	S7L1250/E2N1250	S7L1600/E2N1600				
T5N400	T5N630	S6N800/E1B800						
T5S400	T5S630	S6S800/E1N800	S7S1250/E1N1250	S7S1600/E2N1600				
T5H400	T5H630	S6L800/E2N1250	S7L1250/E2N1250	S7L1600/E2N1600	E2N2000	E3N2500		
T5N400	T5N630	S6N800/E1B800	S7S1250/E1B1250					
T5H400	T5H400	S6H800/E2N1250	S7H1250/E2N1250	S7H1600/E2N1600	E2N2000			
T5L400	T5L630	S6L800/E3H1250	S7L1250/E3H1250	S7L1600/E3H1600	E3H2000	E3H2500	E3H3200	
T5N400	T5N630	S6N800/E1B800	S7S1250/E1B1250	S7S1600/E2B1600				
T5H400	T5H630	S6L800/E3H1250	S7L1250/E3S1250	S7L1600/E3S1600	E3S2000	E3S2500	E3S3200	
T5L400	T5L630	S6L800/E3H1250	S7L1250/E3H1250	S7L1600/E3H1600	E3H2000	E3H2500	E3H3200	E4H4000
T5N400	T5N630	S6N800/E1B800	S7S1250/E1B1250	S7S1600/E2B1600				
T5H400	T5H630	S6L800/E3S1250	S7L1250/E3S1250	S7L1600/E3S1600	E3S2000	E3S2500	E3S3200	E4S4000
T5L400	T5L630	S8V2000/E2L1250		S8V2000/E2L1600	E3L2000	E3L2500	E6V3200	E6V4000
T5S400	T5S630	S6S800/E1N800	S7S1250/E1N1250	S7S1600/E2N1600	E2N2000			
T5L400	T5L630	S6L800/E3H1250	S7L1250/E3H1250	S7L1600/E3H1600	E3H2000	E3H2500	E3H3200	E4H4000
T5V400	T5V630	E2L1250		E2L1600	E3L2000	E3L2500	E6V3200	E6V4000
T5H400	T5H630	S6H800/E2N1250	S7H1250/E2N1250	S7H1600/E2N1600	E2N2000	E3N2500	E3N3200	
T5H400	T5H630	S6L800/E3S1250	S7L1250/E3S1250	S7L1600/E3S1600	E3S2000	E3S2500	E3S3200	E4S4000

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3 Protection of electrical equipment

Table 3: Protection and switching of 440 V transformers

<table>
<tr><th colspan="4">Transformer</th><th colspan="4">Circuit Breaker "A" (LV side)</th><th colspan="6"></th></tr>
<tr><th>S_r</th><th>u_k</th><th>Trafo I_r</th><th>Busbar I_b</th><th>Trafo Feeder I_k</th><th rowspan="2">ABB SACE Circuit Breaker</th><th colspan="2">Release</th><th>Busbar I_k</th><th colspan="5"></th></tr>
<tr><th>[kVA]</th><th>%</th><th>[A]</th><th>[A]</th><th>[kA]</th><th>size</th><th>setting</th><th>[kA]</th><th>32 A</th><th>63 A</th><th>125 A</th><th>160 A</th><th>250 A</th></tr>
<tr><td>1 x 63</td><td rowspan="2">4</td><td>83</td><td>83</td><td>2.1</td><td>T1B/T2N160</td><td>In=100</td><td>0.9/0.88</td><td>2.1</td><td colspan="2">S250/S260</td><td></td><td></td><td></td></tr>
<tr><td>2 x 63</td><td>83</td><td>165</td><td>2.1</td><td>T1B/T2N160</td><td>In=100</td><td>0.9/0.88</td><td>4.1</td><td colspan="2">S250/S260</td><td>T1B160</td><td></td><td></td></tr>
<tr><td>1 x 100</td><td rowspan="2">4</td><td>131</td><td>131</td><td>3.3</td><td>T1B/T2N160</td><td>In=160</td><td>0.85/0.88</td><td>3.3</td><td colspan="2">S250/S260</td><td></td><td></td><td></td></tr>
<tr><td>2 x 100</td><td>131</td><td>262</td><td>3.3</td><td>T1B/T2N160</td><td>In=160</td><td>0.85/0.88</td><td>6.5</td><td colspan="4">T1B160</td><td></td></tr>
<tr><td>1 x 125</td><td rowspan="2">4</td><td>164</td><td>164</td><td>4.1</td><td>T3N/T4N250</td><td>In=250</td><td>0.9/0.7</td><td>4.1</td><td colspan="2">S250/S260</td><td>T1B160</td><td></td><td></td></tr>
<tr><td>2 x 125</td><td>164</td><td>328</td><td>4.1</td><td>T3N/T4N250</td><td>In=250</td><td>0.9/0.7</td><td>8.1</td><td colspan="4">T1B160</td><td>T3N250</td></tr>
<tr><td>1 x 160</td><td rowspan="2">4</td><td>210</td><td>210</td><td>5.2</td><td>T3N/T4N250</td><td>In=250</td><td>0.9</td><td>5.2</td><td colspan="2">S250/S260</td><td colspan="2">T1B160</td><td></td></tr>
<tr><td>2 x 160</td><td>210</td><td>420</td><td>5.2</td><td>T3N/T4N250</td><td>In=250</td><td>0.9</td><td>10.4</td><td colspan="4">T1C160</td><td>T3N250</td></tr>
<tr><td>1 x 200</td><td rowspan="2">4</td><td>262</td><td>262</td><td>6.5</td><td>T5N400</td><td>In=320</td><td>0.9</td><td>6.5</td><td colspan="4">T1B160</td><td></td></tr>
<tr><td>2 x 200</td><td>262</td><td>525</td><td>6.5</td><td>T5N400</td><td>In=320</td><td>0.9</td><td>12.9</td><td colspan="4">T1C160</td><td>T3N250</td></tr>
<tr><td>1 x 250</td><td rowspan="2">4</td><td>328</td><td>328</td><td>8.1</td><td>T5N400</td><td>In=400</td><td>0.9</td><td>8.1</td><td colspan="4">T1B160</td><td>T3N250</td></tr>
<tr><td>2 x 250</td><td>328</td><td>656</td><td>8.1</td><td>T5N400</td><td>In=400</td><td>0.9</td><td>16.1</td><td colspan="4">T1N160</td><td>T3N250</td></tr>
<tr><td>1 x 315</td><td rowspan="2">4</td><td>413</td><td>413</td><td>10.2</td><td>T5N630</td><td>In=630</td><td>0.7</td><td>10.2</td><td colspan="4">T1C160</td><td>T3N250</td></tr>
<tr><td>2 x 315</td><td>413</td><td>827</td><td>10.1</td><td>T5N630</td><td>In=630</td><td>0.7</td><td>20.2</td><td colspan="4">T1N160</td><td>T3N250</td></tr>
<tr><td>1 x 400</td><td rowspan="2">4</td><td>525</td><td>525</td><td>12.9</td><td>T5N630</td><td>In=630</td><td>0.9</td><td>12.9</td><td colspan="4">T1C160</td><td>T3N250</td></tr>
<tr><td>2 x 400</td><td>525</td><td>1050</td><td>12.8</td><td>T5N630</td><td>In=630</td><td>0.9</td><td>25.6</td><td colspan="4">T2N160</td><td>T3S250</td></tr>
<tr><td>1 x 500</td><td rowspan="2">4</td><td>656</td><td>656</td><td>16.1</td><td>S6N800</td><td>In=800</td><td>0.9</td><td>16.1</td><td colspan="4">T1N160</td><td>T3N250</td></tr>
<tr><td>2 x 500</td><td>656</td><td>1312</td><td>15.9</td><td>S6N800</td><td>In=800</td><td>0.9</td><td>31.7</td><td colspan="4">T2S160</td><td>T3S250</td></tr>
<tr><td>1 x 630</td><td rowspan="3">4</td><td>827</td><td>827</td><td>20.2</td><td>S7S1250/E1B1250</td><td>In=1000</td><td>0.9</td><td>20.2</td><td colspan="4">T1N160</td><td>T3N250</td></tr>
<tr><td>2 x 630</td><td>827</td><td>1653</td><td>19.8</td><td>S7S1250/E1B1250</td><td>In=1000</td><td>0.9</td><td>39.7</td><td colspan="4">T2S160</td><td>T3S250</td></tr>
<tr><td>3 x 630</td><td>827</td><td>2480</td><td>38.9</td><td>S7S1250/E1B1250</td><td>In=1000</td><td>0.9</td><td>58.3</td><td colspan="4">T2L160</td><td>T4H250</td></tr>
<tr><td>1 x 800</td><td rowspan="3">5</td><td>1050</td><td>1050</td><td>20.6</td><td>S7S1250/E1B1250</td><td>In=1250</td><td>0.9</td><td>20.6</td><td colspan="4">T1N160</td><td>T3N250</td></tr>
<tr><td>2 x 800</td><td>1050</td><td>2099</td><td>20.1</td><td>S7S1250/E1B1250</td><td>In=1250</td><td>0.9</td><td>40.3</td><td colspan="4">T2S160</td><td>T4H250</td></tr>
<tr><td>3 x 800</td><td>1050</td><td>3149</td><td>39.5</td><td>S7S1250/E1B1250</td><td>In=1250</td><td>0.9</td><td>59.2</td><td colspan="4">T2L160</td><td>T4H250</td></tr>
<tr><td>1 x 1000</td><td rowspan="3">5</td><td>1312</td><td>1312</td><td>25.6</td><td>S7S1600/E2B1600</td><td>In=1600</td><td>0.9</td><td>25.6</td><td colspan="4">T2N160</td><td>T3S250</td></tr>
<tr><td>2 x 1000</td><td>1312</td><td>2624</td><td>24.9</td><td>S7S1600/E2B1600</td><td>In=1600</td><td>0.9</td><td>49.8</td><td colspan="4">T2H160</td><td>T4H250</td></tr>
<tr><td>3 x 1000</td><td>1312</td><td>3936</td><td>48.6</td><td>S7H1600/E2N1600</td><td>In=1600</td><td>0.9</td><td>72.9</td><td colspan="4">T2L160</td><td>T4L250</td></tr>
<tr><td>1 x 1250</td><td rowspan="3">5</td><td>1640</td><td>1640</td><td>31.7</td><td>E2B2000</td><td>In=2000</td><td>0.9</td><td>31.7</td><td colspan="4">T2S160</td><td>T3S250</td></tr>
<tr><td>2 x 1250</td><td>1640</td><td>3280</td><td>30.8</td><td>E2B2000</td><td>In=2000</td><td>0.9</td><td>61.5</td><td colspan="4">T2L160</td><td>T4H250</td></tr>
<tr><td>3 x 1250</td><td>1640</td><td>4921</td><td>59.6</td><td>E2N2000</td><td>In=2000</td><td>0.9</td><td>89.5</td><td colspan="4">T4L250</td><td>T4L250</td></tr>
<tr><td>1 x 1600</td><td rowspan="3">6.25</td><td>2099</td><td>2099</td><td>32.5</td><td>E2N2500</td><td>In=2500</td><td>0.9</td><td>32.5</td><td colspan="4">T2S160</td><td>T3S250</td></tr>
<tr><td>2 x 1600</td><td>2099</td><td>4199</td><td>31.4</td><td>E2N2500</td><td>In=2500</td><td>0.9</td><td>62.9</td><td colspan="4">T2L160</td><td>T4H250</td></tr>
<tr><td>3 x 1600</td><td>2099</td><td>6298</td><td>60.9</td><td>E2N2500</td><td>In=2500</td><td>0.9</td><td>91.4</td><td colspan="4">T4L250</td><td>T4L250</td></tr>
<tr><td>1 x 2000</td><td rowspan="3">6.25</td><td>2624</td><td>2624</td><td>40.3</td><td>E3N3200</td><td>In=3200</td><td>0.9</td><td>40.3</td><td colspan="4">T2S160</td><td>T4H250</td></tr>
<tr><td>2 x 2000</td><td>2624</td><td>5249</td><td>38.7</td><td>E3N3200</td><td>In=3200</td><td>0.9</td><td>77.4</td><td colspan="4">S4L160</td><td>T4L250</td></tr>
<tr><td>3 x 2000</td><td>2624</td><td>7873</td><td>74.4</td><td>E3S3200</td><td>In=3200</td><td>0.9</td><td>111.7</td><td colspan="4">T4V250</td><td>T4V250</td></tr>
<tr><td>1 x 2500</td><td>6.25</td><td>3280</td><td>3280</td><td>49.8</td><td>E4S4000</td><td>In=4000</td><td>0.9</td><td>49.8</td><td colspan="4">T2H160</td><td>T4H250</td></tr>
<tr><td>1 x 3125</td><td>6.25</td><td>4100</td><td>4100</td><td>61.5</td><td>E6H5000</td><td>In=5000</td><td>0.9</td><td>61.5</td><td colspan="4">T2L160</td><td>T4H250</td></tr>
</table>

3 Protection of electrical equipment

Circuit Breaker "B" (Feeder Circuit Breaker)								
Feeder Circuit Breaker type and rated current								
400 A	630 A	800 A	1250 A	1600 A	2000 A	2500 A	3200 A	4000 A
T5N400								
T5N400								
T5N400	T5N630							
T5N400								
T5N400	T5N630							
T5N400								
T5S400	T5S630	S6S800						
T5N400	T5N630							
T5S400	T5S630	S6S800/E1B800	S7S1250/E1B1250					
T5H400	T5H630	S6L800/E2N1250	S7L1250/E2N1250	S7L1600/E2N1600	E2N2000			
T5N400	T5N630	S6N800/E1B800						
T5H400	T5H630	S6S800/E1B800	S7H1250/E1B1250	S7H1600/E2B1600				
T5H400	T5H630	S6L800/E2N1250	S7L1250/E2N1250	S7L1600/E2N1600	E2N2000	E3N2500	E3N3200	E4S4000
T5N400	T5N630	S6N800/E1B800						
T5H400	T5H630	S6L800/E2N1250	S7H1250/E1N1250	S7H1600/E2N1600	E2N2000			
T5L400	T5L630	S6L800/E3S1250	S7L1250/E3S1250	S7L1600/E3S1600	E3S2000	E3S2500	E3S3200	
T5S400	T5S630	S6S800/E1B800	S7S1250/E1B1250					
T5H400	T5H630	S6L800/E2N1250	S7L1250/E2N1250	S7L1600/E2N1600	E2N2000	E3N2500		
T5L400	T5L630	S8V2000/E2L1250		S8V2000/E2L1600	E3H2000	E3H2500	E3H3200	E4H4000
T5S400	T5S630	S6S800/E1B800	S7S1250/E1B1250	S7S1600/E2B1600				
T5H400	T5H630	S6L800/E2N1250	S7L1250/E2N1250	S7L1600/E2N1600	E2N2000	E3N2500	E3N3200	
T5L400	T5L630	S8V2000/E2L1250		S8V2000/E2L1600	E3H2000	E3H2500	E3H3200	E4H4000
T5H400	T5H630	S6S800/E1B800	S7H1250/E1N1250	S7H1600/E2B1600	E2B2000			
T5L400	T5L630	S6L800/E3H1250	S7L1250/E3H1250	S7L1600/E3H1600	E3H2000	E3H2500	E3H3200	E4H4000
T5V400	T5V630				E6V3200			E6V4000
T5H400	T5H630	S6L800/E2N1250	S7H1250/E1N1250	S7H1600/E2N1600	E2N2000	E3N2500		
T5H400	T5H630	S6L800/E2N1250	S7L1250/E2N1250	S7L1600/E2N1600	E2N2000	E3N2500	E3N3200	

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3 Protection of electrical equipment

Table 4: Protection and switching of 690 V transformers

Transformer				Circuit Breaker "A" (LV side)									
S_r	u_k	Trafo I_r	Busbar I_b	Trafo Feeder I_k	ABB SACE Circuit Breaker	Release		Busbar I_k					
[kVA]	%	[A]	[A]	[kA]		size	setting	[kA]	32 A	63 A	125 A	160 A	250 A
1 x 63	4	53	53	1.3	T1B/T2N160	In=63	0.9/0.88	1.3	T1B160				
2 x 63		53	105	1.3	T1B/T2N160	In=63	0.9/0.88	2.6	T1B160				
1 x 100	4	84	84	2.1	T1B/T2N160	In=100	0.9/0.92	2.1	T1B160				
2 x 100		84	167	2.1	T1B/T2N160	In=100	0.9/0.92	4.2	T1N160				
1 x 125	4	105	105	2.6	T1B/T2N160	In=160	0.9/0.72	2.6	T1B160				
2 x 125		105	209	2.6	T1B/T2N160	In=160	0.9/0.72	5.2	T1N160				
1 x 160	4	134	134	3.3	T1C/T2N160	In=160	0.9/0.88	3.3	T1C160				
2 x 160		134	268	3.3	T1C/T2N160	In=160	0.9/0.88	6.6	T2S160				
1 x 200	4	167	167	4.2	T3N250/T4N250	In=250	0.9/0.8	4.2	T1N160				
2 x 200		167	335	4.1	T3N250/T4N250	In=250	0.9/0.8	8.3	T2L160				T4N250
1 x 250	4	209	209	5.2	T3S250/T4N250	In=250	0.9	5.2	T1N160				
2 x 250		209	418	5.1	T3S250/T4N250	In=250	0.9	10.3	T4N250				T4N250
1 x 315	4	264	264	6.5	T4N320	In=320	0.9	6.5	T2S160				
2 x 315		264	527	6.5	T4N320	In=320	0.9	12.9	T4N250				T4N250
1 x 400	4	335	335	8.3	T5N400	In=400	0.9	8.3	T2L160				T4N250
2 x 400		335	669	8.2	T5N400	In=400	0.9	16.3	T4N250				T4N250
1 x 500	4	418	418	10.3	T5N630	In=630	0.7	10.3	T4N250				T4N250
2 x 500		418	837	10.1	T5N630	In=630	0.7	20.2	T4S250				T4S250
1 x 630	4	527	527	12.9	T5N630	In=630	0.9	12.9	T4N250				T4N250
2 x 630		527	1054	12.6	T5N630	In=630	0.9	25.3	T4H250				T4H250
3 x 630		527	1581	24.8	T5S630	In=630	0.9	37.2	T4H250				T4H250
1 x 800	5	669	669	13.1	S6N800	In=800	0.9	13.1	T4N250				T4N250
2 x 800		669	1339	12.8	S6N800	In=800	0.9	25.7	T4H250				T4H250
3 x 800		669	2008	25.2	S6L800	In=800	0.9	37.7	T4H250				T4H250
1 x 1000	5	837	837	16.3	S7S1250/E1B1250	In=1000	0.9	16.3	T4N250				T4N250
2 x 1000		837	1673	15.9	S7S1250/E1B1250	In=1000	0.9	31.8	T4H250				T4H250
3 x 1000		837	2510	31.0	S7L1250/E1B1250	In=1000	0.9	46.5	T4L250				T4L250
1 x 1250	5	1046	1046	20.2	S7H1250/E1B1250	In=1250	0.9	20.2	T4S250				T4S250
2 x 1250		1046	2092	19.6	S7S1250/E1B1250	In=1250	0.9	39.2	T4H250				T4H250
3 x 1250		1046	3138	38.0	E2B1250	In=1600	0.7	57.1	T4L250				T4L250
1 x 1600	6.25	1339	1339	20.7	E2B1600	In=1600	0.9	20.7	T4S250				T4S250
2 x 1600		1339	2678	20.1	E2B1600	In=1600	0.9	40.1	T4L250				T4L250
3 x 1600		1339	4016	38.9	E2B1600	In=1600	0.9	58.3	T4L250				T4L250
1 x 2000	6.25	1673	1673	25.7	E2B2000	In=2000	0.9	25.7	T4H250				T4H250
2 x 2000		1673	3347	24.7	E2B2000	In=2000	0.9	49.3	T4L250				T4L250
3 x 2000		1673	5020	47.5	E2B2000	In=2000	0.9	71.2	T4V250				T4V250
1 x 2500	6.25	2092	2092	31.8	E3N2500	In=2500	0.9	31.8	T4H250				T4H250
1 x 3125	6.25	2615	2615	39.2	E3N3200	In=3200	0.9	39.2	T4H250				T4H250

3 Protection of electrical equipment

Circuit Breaker "B" (Feeder Circuit Breaker)								
Feeder Circuit Breaker type and rated current								
400 A	630 A	800 A	1250 A	1600 A	2000 A	2500 A	3200 A	4000 A
T5N400								
T5N400								
T5S400	T5S630							
T5N400								
T5H400	T5H630							
T5H400	T5H630	E2B1600						
T5N400								
T5H400	T5H630	S6L800						
T5H400	T5H630	E2B1600						
T5N400	T5N630							
T5H400	T5H630	S7L1250/E1B800	S7L1250/E1B1250					
T5L400	T5L630	S8V2000/E2N1250		S8V2000/E2N1600	E2N2000			
T5S400	T5S630	S6S800/E1B800						
T5H400	T5H630	S8H2000/E2B1250		S8H2000/E2B1600				
T5L400	T5L630	E3N2500						
T5S400	T5S630	S6S800/E1B800						
T5L400	T5L630	S8V2000/E2B1250		S8V2000/E2B1600	E2B2000			
T5L400	T5L630	E3N2500					E3N3200	
T5H400	T5H630	S6L800/E1B800	S7L1250/E1B1250					
T5L400	T5L630	S8V2000/E2N1250		S8V2000/E2N1600	E2N2000	E3N2500		
T5V400	T5V630	E2L1250		E2L1600	E3S2000	E3S2500	E3S3200	E4S4000
T5H400	T5H630	S7L1250/E1B800	S7L1250/E1B1250	S7L1600/E2B1600				
T5H400	T5H630	S8H2000/E2B1250		S8H2000/E2B1600	E2B2000			

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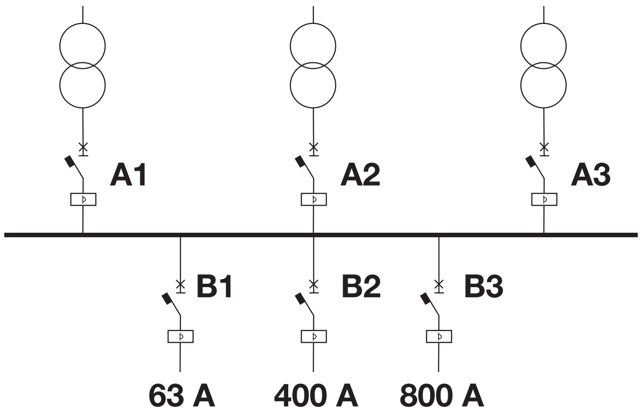
3 Protection of electrical equipment

NOTE

The tables refer to the previously specified conditions; the information for the selection of circuit-breakers is supplied only with regard to the current in use and the prospective short-circuit current. For a correct selection, other factors such as selectivity, back-up protection, the decision to use limiting circuit-breakers etc. must also be considered. Therefore, it is essential that the design engineers carry out precise checks.
It must also be noted that the short-circuit currents given are determined using the hypothesis of 750 MVA power upstream of the transformers, disregarding the impedances of the busbars or the connections to the circuit-breakers.

Example:

Supposing the need to size breakers A1/A2/A3, on the LV side of the three transformers of 630 kVA 20/0.4 kV with u_k% equal to 4% and outgoing feeder circuit-breakers B1/B2/B3 of 63-400-800 A:



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3 Protection of electrical equipment

From Table 2, corresponding to the row relevant to 3x630 kVA transformers, it can be read that:

Level A circuit-breakers (LV side of transformer)

- Trafo I_r (909 A) is the current that flows through the transformer circuit-breakers;
- Busbar I_b (2727 A) is the maximum current that the transformers can supply;
- Trafo Feeder I_k (42.8 kA) is the value of the short-circuit current to consider for the choice of the breaking capacity of each of the transformer circuit-breakers;
- S7S1250 or E1N1250 is the size of the transformer circuit-breaker;
- In (1000 A) is the rated current of the transformer circuit-breaker (electronic release chosen by the user);
- Setting (0.95) indicates the set value of function L of the electronic release.

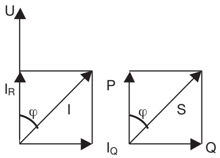
Level B circuit-breakers (outgoing feeder)

- Busbar I_k (64.2 kA) is the short-circuit current due to the contribution of all three transformers;
- corresponding to 63 A, read circuit-breaker B1 Tmax T2H160;
- corresponding to 400 A, read circuit-breaker B2 Tmax T5H400;
- corresponding to 800 A, read circuit-breaker B3 Isomax S6L800 or E2N1250.

The choice made does not take into account discrimination/back-up requirements. Refer to the relevant chapters for selections appropriate to the various cases.

4 Power factor correction

4.1 General aspects



In alternating current circuits, the current absorbed by the user can be represented by two components:

- the active component I_R, in phase with the supply voltage, is directly correlated to the output (and therefore to the part of electrical energy transformed into energy of a different type, usually electrical with different characteristics, mechanical, light and/or thermal);
- the reactive component I_Q, in quadrature to the voltage, is used to produce the flow necessary for the conversion of powers through the electric or magnetic field. Without this, there could be no flow of power, such as in the core of a transformer or in the air gap of a motor.

In the most common case, in the presence of ohmic-inductive type loads, the total current (I) lags in comparison with the active component I_R.
In an electrical installation, it is necessary to generate and transmit, other than the active power P, a certain reactive power Q, which is essential for the conversion of electrical energy, but not available to the user. The complex of the power generated and transmitted constitutes the apparent power *S*.

Power factor (cosφ) is defined as the ratio between the active component I_R and the total value of the current I; φ is the phase shifting between the voltage U and the current I.
It results:

$$\cos\varphi = \frac{I_R}{I} = \frac{P}{S} \quad (1)$$

The reactive demand factor (tanφ) is the relationship between the reactive power and the active power:

$$\tan\varphi = \frac{Q}{P} \quad (2)$$

4 Power factor correction

Table 1 shows some typical power factors:

Table 1: Typical power factor

Load	**cosφ power factor**	**tanφ reactive demand factor**
Transformers (no load condition)	0.1÷0.15	9.9÷6.6
Motor (full load)	0.7÷0.85	1.0÷0.62
Motor (no load)	0.15	6.6
Metal working apparatuses:		
- Arc welding	0.35÷0.6	2.7÷1.3
- Arc welding compensated	0.7÷0.8	1.0÷0.75
- Resistance welding:	0.4÷0.6	2.3÷1.3
- Arc melting furnace	0.75÷0.9	0.9÷0.5
Fluorescent lamps		
- compensated	0.9	0.5
- uncompensated	0.4÷0.6	2.3÷1.3
Mercury vapour lamps	0.5	1.7
Sodium vapour lamp	0.65÷0.75	1.2÷0.9
AC DC converters	0.6÷0.95	1.3÷0.3
DC drives	0.4÷0.75	2.3÷0.9
AC drives	0.95÷0.97	0.33÷0.25
Resistive load	1	0

The power factor correction is the action increasing the power factor in a specific section of the installation by locally supplying the necessary reactive power, so as to reduce the current value to the equivalent of the power required, and therefore the total power absorbed from the upstream side. Thus, both the line as well as the supply generator can be sized for a lower apparent power value required by the load.
In detail, as shown by Figure 1 and Figure 2, increasing the power factor of the load:
- decreases the relative voltage drop u_{rp} per unit of active power transmitted;
- increases the transmittable active power and decreases the losses, the other dimensioning parameters remaining equal.

4 Power factor correction

Figure 1: Relative voltage drop

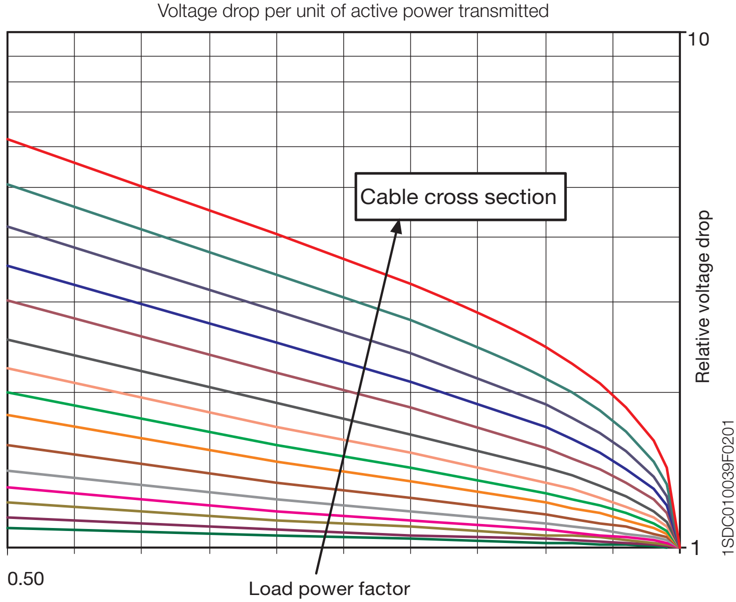
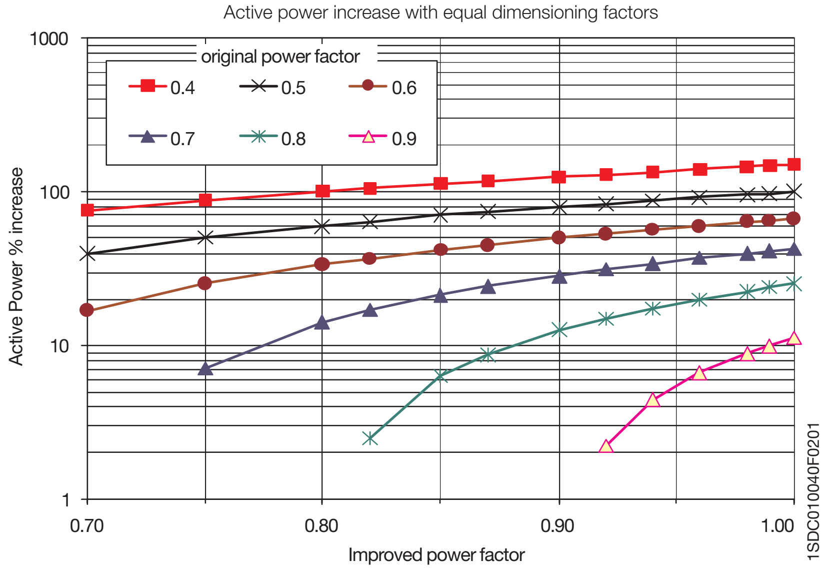


Figure 2: Transmittable active power



4 Power factor correction

The distribution authority is responsible for the production and transmission of the reactive power required by the user installations, and therefore has a series of further inconveniences which can be summarized as:
- oversizing of the conductors and and of the components of the transmission lines;
- higher Joule-effect losses and higher voltage drops in the components and lines.

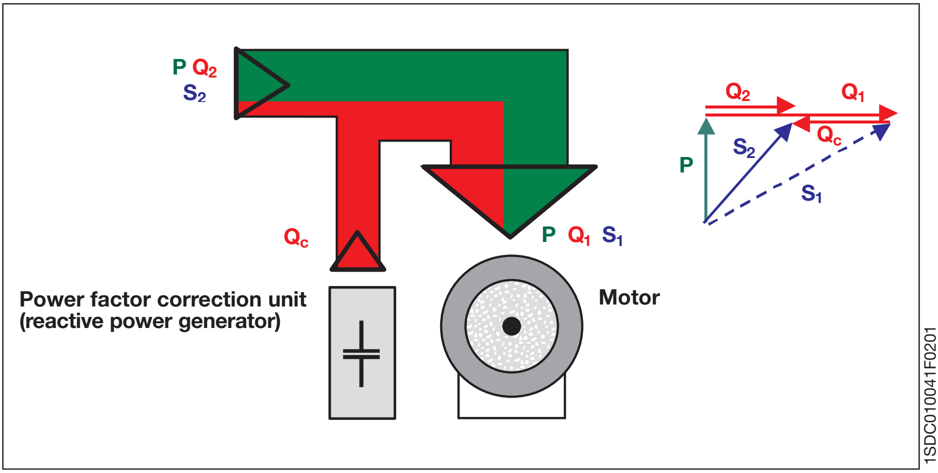
The same inconveniences are present in the distribution installation of the final user. The power factor is an excellent index of the size of the added costs and is therefore used by the distribution authority to define the purchase price of the energy for the final user.
The ideal situation would be to have a $\cos\varphi$ slightly higher than the set reference so as to avoid payment of legal penalties, and at the same time not to risk having, with a $\cos\varphi$ too close to the unit, a leading power factor when the power factor corrected device is working with a low load.
The distribution authority generally does not allow others to supply reactive power to the network, also due to the possibility of unexpected overvoltages.

In the case of a sinusoidal waveform, the reactive power necessary to pass from one power factor $\cos\varphi_1$ to a power factor $\cos\varphi_2$ is given by the formula:

$$Q_c = Q_2 - Q_1 = P \cdot (\tan\varphi_1 - \tan\varphi_2) \quad (3)$$

where:

P	is the active power;
Q_1,φ_1	are the reactive power and the phase shifting before power factor correction;
Q_2,φ_2	are the reactive power and the phase shifting after power factor correction;
Q_c	is the reactive power for the power factor correction.



4 Power factor correction

Table 2 shows the value of the relationship

$$K_c = \frac{Q_c}{P} = \tan\varphi_1 - \tan\varphi_2 \quad (4)$$

for different values of the power factor before and after the correction.

Table 2: Factor K_c

K_c						$\cos\varphi_2$							
$\cos\varphi_1$	0.80	0.85	0.90	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1
0.60	0.583	0.714	0.849	0.878	0.907	0.938	0.970	1.005	1.042	1.083	1.130	1.191	1.333
0.61	0.549	0.679	0.815	0.843	0.873	0.904	0.936	0.970	1.007	1.048	1.096	1.157	1.299
0.62	0.515	0.646	0.781	0.810	0.839	0.870	0.903	0.937	0.974	1.015	1.062	1.123	1.265
0.63	0.483	0.613	0.748	0.777	0.807	0.837	0.870	0.904	0.941	0.982	1.030	1.090	1.233
0.64	0.451	0.581	0.716	0.745	0.775	0.805	0.838	0.872	0.909	0.950	0.998	1.058	1.201
0.65	0.419	0.549	0.685	0.714	0.743	0.774	0.806	0.840	0.877	0.919	0.966	1.027	1.169
0.66	0.388	0.519	0.654	0.683	0.712	0.743	0.775	0.810	0.847	0.888	0.935	0.996	1.138
0.67	0.358	0.488	0.624	0.652	0.682	0.713	0.745	0.779	0.816	0.857	0.905	0.966	1.108
0.68	0.328	0.459	0.594	0.623	0.652	0.683	0.715	0.750	0.787	0.828	0.875	0.936	1.078
0.69	0.299	0.429	0.565	0.593	0.623	0.654	0.686	0.720	0.757	0.798	0.846	0.907	1.049
0.70	0.270	0.400	0.536	0.565	0.594	0.625	0.657	0.692	0.729	0.770	0.817	0.878	1.020
0.71	0.242	0.372	0.508	0.536	0.566	0.597	0.629	0.663	0.700	0.741	0.789	0.849	0.992
0.72	0.214	0.344	0.480	0.508	0.538	0.569	0.601	0.635	0.672	0.713	0.761	0.821	0.964
0.73	0.186	0.316	0.452	0.481	0.510	0.541	0.573	0.608	0.645	0.686	0.733	0.794	0.936
0.74	0.159	0.289	0.425	0.453	0.483	0.514	0.546	0.580	0.617	0.658	0.706	0.766	0.909
0.75	0.132	0.262	0.398	0.426	0.456	0.487	0.519	0.553	0.590	0.631	0.679	0.739	0.882
0.76	0.105	0.235	0.371	0.400	0.429	0.460	0.492	0.526	0.563	0.605	0.652	0.713	0.855
0.77	0.079	0.209	0.344	0.373	0.403	0.433	0.466	0.500	0.537	0.578	0.626	0.686	0.829
0.78	0.052	0.183	0.318	0.347	0.376	0.407	0.439	0.474	0.511	0.552	0.599	0.660	0.802
0.79	0.026	0.156	0.292	0.320	0.350	0.381	0.413	0.447	0.484	0.525	0.573	0.634	0.776
0.80		0.130	0.266	0.294	0.324	0.355	0.387	0.421	0.458	0.499	0.547	0.608	0.750
0.81		0.104	0.240	0.268	0.298	0.329	0.361	0.395	0.432	0.473	0.521	0.581	0.724
0.82		0.078	0.214	0.242	0.272	0.303	0.335	0.369	0.406	0.447	0.495	0.556	0.698
0.83		0.052	0.188	0.216	0.246	0.277	0.309	0.343	0.380	0.421	0.469	0.530	0.672
0.84		0.026	0.162	0.190	0.220	0.251	0.283	0.317	0.354	0.395	0.443	0.503	0.646
0.85			0.135	0.164	0.194	0.225	0.257	0.291	0.328	0.369	0.417	0.477	0.620
0.86			0.109	0.138	0.167	0.198	0.230	0.265	0.302	0.343	0.390	0.451	0.593
0.87			0.082	0.111	0.141	0.172	0.204	0.238	0.275	0.316	0.364	0.424	0.567
0.88			0.055	0.084	0.114	0.145	0.177	0.211	0.248	0.289	0.337	0.397	0.540
0.89			0.028	0.057	0.086	0.117	0.149	0.184	0.221	0.262	0.309	0.370	0.512
0.90				0.029	0.058	0.089	0.121	0.156	0.193	0.234	0.281	0.342	0.484

4 Power factor correction

Example

Supposing the need to change from 0.8 to 0.93 the power factor of a three-phase installation (U_r= 400 V) which absorbs an average power of 300 kW. From Table 2, at the intersection of the column corresponding to the final power factor (0.93), and the row corresponding to the starting power factor (0.8), the value of K_c (0.355) can be read. The reactive power Q_c which must be generated locally shall be:

$$Q_c = K_c \cdot P = 0.355 \cdot 300 = 106.5 \text{ kvar}$$

Due to the effect of power factor correction, the current absorbed decreases from 540 A to 460 A (a reduction of approximately 15%).

Characteristics of power factor correction capacitor banks

The most economical means of increasing the power factor, especially for an installation which already exists, is installing capacitors.
Capacitors have the following advantages:
- low cost compared with synchronous compensators and electronic power converters;
- ease of installation and maintenance;
- reduced losses (less than 0.5 W/kvar in low voltage);
- the possibility of covering a wide range of powers and different load profiles, simply supplying in parallel different combinations of components, each with a relatively small power.

The disadvantages are sensitivity to overvoltages and to the presence of non-linear loads.

The Standards applicable to power factor correction capacitors are as follows:

- IEC 60831-1 *"Shunt power capacitors of the self-healing type for a.c. systems having a rated voltage up to and including 1000 V - Part 1: General - Performance, testing and rating - Safety requirements - Guide for installation and operation";*

- IEC 60931-1 *"Shunt power capacitors of the non-self-healing type for a.c. systems having a rated voltage up to and including 1000 V - Part 1: General-Performance, testing and rating - Safety requirements - Guide for installation and operation".*

4 Power factor correction

The characteristics of a capacitor, given on its nameplate, are:

- rated voltage U_r, which the capacitor must withstand indefinitely;
- rated frequency f_r (usually equal to that of the network);
- rated power Q_c, generally expressed in kvar (reactive power of the capacitor bank).

From this data it is possible to find the size characteristics of the capacitors by using the following formulae (5):

	Single-phase connection	Three-phase star-connection	Three-phase delta-connection
Capacity of the capacitor bank	$C = \frac{Q_c}{2\pi f_r \cdot U_r^2}$	$C = \frac{Q_c}{2\pi f_r \cdot U_r^2}$	$C = \frac{Q_c}{2\pi f_r \cdot U_r^2 \cdot 3}$
Rated current of the components	$I_{rc} = 2\pi f_r \cdot C \cdot U_r$	$I_{rc} = 2\pi f_r \cdot C \cdot U_r / \sqrt{3}$	$I_{rc} = 2\pi f_r \cdot C \cdot U_r$
Line current	$I_l = I_{rc}$	$I_l = I_{rc}$	$I_l = I_{rc} \cdot \sqrt{3}$

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With three-phase systems, for the same reactive power, the star-connection requires a capacity 3 times larger and subjects the capacitors to a voltage and a current times less than the analogous delta-connection.
Capacitors are generally supplied with connected discharge resistance, calculated so as to reduce the residual voltage at the terminals to 75 V in 3 minutes, as stated in the reference Standard.

4.2 Power factor correction method

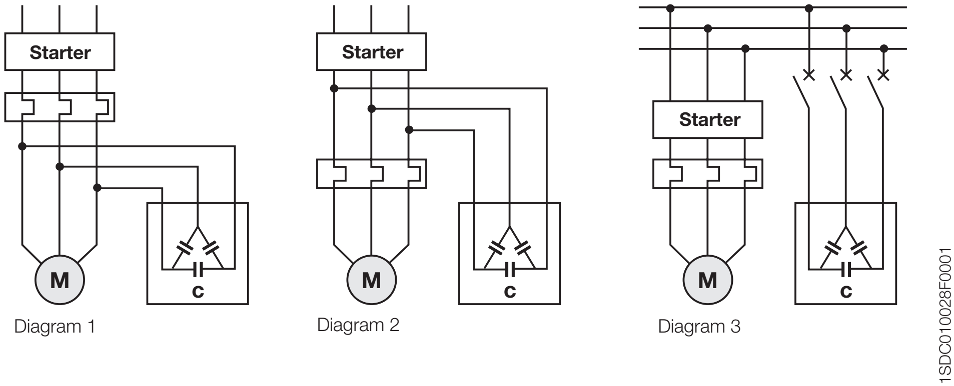
Single PFC

Single or individual power factor correction is carried out by connecting a capacitor of the correct value directly to the terminals of the device which absorbs reactive power.
Installation is simple and economical: capacitors and load can use the same overload and short-circuit protection, and are connected and disconnected simultaneously.
The adjustment of cosφ is systematic and automatic with benefit not only to the energy distribution authority, but also to the whole internal distribution system of the user.
This type of power factor correction is advisable in the case of large users with constant load and power factor and long connection times.
Individual PFC is usually applied to motors and fluorescent lamps. The capacitor units or small lighting capacitors are connected directly to loads.

4 Power factor correction

Individual PFC of motors

The usual connection diagrams are shown in the following Figure:



In the case of direct connection (diagrams 1 and 2) there is a risk that after disconnection of the supply, the motor will continue to rotate (residual kinetic energy) and self-excite with the reactive energy supplied by the capacitor bank, acting as an asynchronous generator. In this case, the voltage is maintained on the load side of the switching and control device, with the risk of dangerous overvoltages of up to twice the rated voltage value.

However, in the case of diagram 3, to avoid the risk detailed above, the normal procedure is to connect the PFC bank to the motor only when it is running, and to disconnect it before the disconnection of the motor supply.

As a general rule, for a motor with power P_r, it is advisable to use a PFC with reactive power Q_c below 90% of the reactive power absorbed by the no-load motor Q_0, at rated voltage U_r, to avoid a leading power factor.
Considering that under no-load conditions, the current absorbed I_0 [A] is solely reactive, if the voltage is expressed in volts, it results:

$$Q_c = 0.9 \cdot Q_0 = 0.9 \cdot \frac{\sqrt{3} \cdot U_r \cdot I_0}{1000} \text{ [kvar] (6)}$$

The current I_0 is generally given in the documentation supplied by the manufacturer of the motor.

4 Power factor correction

Table 3 shows the values of reactive power for power factor correction of some ABB motors, according to the power and the number of poles.

Table 3: Reactive power for power factor motor correction

P_r [kW]	Q_c [kvar]	Before PFC $\cos\varphi_r$	Before PFC I_r [A]	After PFC $\cos\varphi_2$	After PFC I_2 [A]
400V / 50 Hz / 2 poles / 3000 r/min					
7.5	2.5	0.89	13.9	0.98	12.7
11	2.5	0.88	20	0.95	18.6
15	5	0.9	26.5	0.98	24.2
18.5	5	0.91	32	0.98	29.7
22	5	0.89	38.5	0.96	35.8
30	10	0.88	53	0.97	47.9
37	10	0.89	64	0.97	58.8
45	12.5	0.88	79	0.96	72.2
55	15	0.89	95	0.97	87.3
75	15	0.88	131	0.94	122.2
90	15	0.9	152	0.95	143.9
110	20	0.86	194	0.92	181.0
132	30	0.88	228	0.95	210.9
160	30	0.89	269	0.95	252.2
200	30	0.9	334	0.95	317.5
250	40	0.92	410	0.96	391.0
315	50	0.92	510	0.96	486.3
400V / 50 Hz / 4 poles / 1500 r/min					
7.5	2.5	0.86	14.2	0.96	12.7
11	5	0.81	21.5	0.96	18.2
15	5	0.84	28.5	0.95	25.3
18.5	7.5	0.84	35	0.96	30.5
22	10	0.83	41	0.97	35.1
30	15	0.83	56	0.98	47.5
37	15	0.84	68	0.97	59.1
45	20	0.83	83	0.97	71.1
55	20	0.86	98	0.97	86.9
75	20	0.86	135	0.95	122.8
90	20	0.87	158	0.94	145.9
110	30	0.87	192	0.96	174.8
132	40	0.87	232	0.96	209.6
160	40	0.86	282	0.94	257.4
200	50	0.86	351	0.94	320.2
250	50	0.87	430	0.94	399.4
315	60	0.87	545	0.93	507.9

4 Power factor correction

P_r [kW]	Q_c [kvar]	Before PFC $\cos\varphi_r$	Before PFC I_r [A]	After PFC $\cos\varphi_2$	After PFC I_2 [A]
		400V / 50 Hz / 6 poles / 1000 r/min			
7.5	5	0.79	15.4	0.98	12.4
11	5	0.78	23	0.93	19.3
15	7.5	0.78	31	0.94	25.7
18.5	7.5	0.81	36	0.94	30.9
22	10	0.81	43	0.96	36.5
30	10	0.83	56	0.94	49.4
37	12.5	0.83	69	0.94	60.8
45	15	0.84	82	0.95	72.6
55	20	0.84	101	0.96	88.7
75	25	0.82	141	0.93	123.9
90	30	0.84	163	0.95	144.2
110	35	0.83	202	0.94	178.8
132	45	0.83	240	0.95	210.8
160	50	0.85	280	0.95	249.6
200	60	0.85	355	0.95	318.0
250	70	0.84	450	0.94	404.2
315	75	0.84	565	0.92	514.4
		400V / 50 Hz / 8 poles / 750 r/min			
7.5	5	0.7	18.1	0.91	13.9
11	7.5	0.76	23.5	0.97	18.4
15	7.5	0.82	29	0.97	24.5
18.5	7.5	0.79	37	0.93	31.5
22	10	0.77	45	0.92	37.5
30	12.5	0.79	59	0.93	50.0
37	15	0.78	74	0.92	62.8
45	20	0.78	90	0.93	75.4
55	20	0.81	104	0.93	90.2
75	30	0.82	140	0.95	120.6
90	30	0.82	167	0.93	146.6
110	35	0.83	202	0.94	178.8
132	50	0.8	250	0.93	214.6

4 Power factor correction

Example

For a three-phase asynchronous motor, 110 kW (400 V - 50 Hz - 4 poles), the PFC power suggested in the table is 30 kvar.

Individual power factor correction of three-phase transformers

A transformer is an electrical device of primary importance which, due to the system requirements, is often constantly in service.
In particular, in installations constituted by several transformer substations, it is advisable to carry out power factor correction directly at the transformer.
In general, the PFC power (Q_c) for a transformer with rated power S_r [kVA] should not exceed the reactive power required under minimum reference load conditions.
Reading the data from the transformer nameplate, the percentage value of the no-load current $i_0\%$, the percentage value of the short-circuit voltage $u_k\%$, the iron losses P_{fe} and the copper losses P_{cu} [kW], the PFC power required is approximately:

$$Q_c = \sqrt{\left(\frac{i_0\%}{100}\cdot S_r\right)^2 - P_{fe}^{\,2}} + K_L^{\,2}\cdot\sqrt{\left(\frac{u_k\%}{100}\cdot S_r\right)^2 - P_{cu}^{\,2}} \approx \left(\frac{i_0\%}{100}\cdot S_r\right) + K_L^{\,2}\cdot\left(\frac{u_k\%}{100}\cdot S_r\right) \text{ [kvar]} \quad (7)$$

where K_L is the load factor, defined as the relationship between the minimum reference load and the rated power of the transformer.

Example

Supposing the need for PFC of a 630 kVA oil-distribution transformer which supplies a load which is less than 60% of its rated power.
From the data on the transformer nameplate:
$i_0\% = 1.8\%$
$u_k\% = 4\%$
$P_{cu} = 8.9$ kW
$P_{fe} = 1.2$ kW
The PFC power of the capacitor bank connected to the transformer is:

$$Q_c = \sqrt{\left(\frac{i_0\%}{100}\cdot S_r\right)^2 - P_{fe}^{\,2}} + K_L^{\,2}\cdot\sqrt{\left(\frac{u_k\%}{100}\cdot S_r\right)^2 - P_{cu}^{\,2}} = \sqrt{\left(\frac{1.8\%}{100}\cdot 630\right)^2 - 1.2^2} + 0.6^2\cdot\sqrt{\left(\frac{4\%}{100}\cdot 630\right)^2 - 8.9^2} = 19.8 \text{ kvar}$$

while, when using the simplified formula, the result is:

$$Q_c = \left(\frac{i_0\%}{100}\cdot S_r\right) + K_L^{\,2}\cdot\left(\frac{u_k\%}{100}\cdot S_r\right) = \left(\frac{1.8\%}{100}\cdot 630\right) + 0.6^2\cdot\left(\frac{4\%}{100}\cdot 630\right) = 20.4 \text{ kvar}$$

4 Power factor correction

Table 4 shows the reactive power of the capacitor bank Q_C [kvar] to be connected on the secondary side of an ABB transformer, according to the different minimum estimated load levels.

Table 4: PFC reactive power for ABB transformers

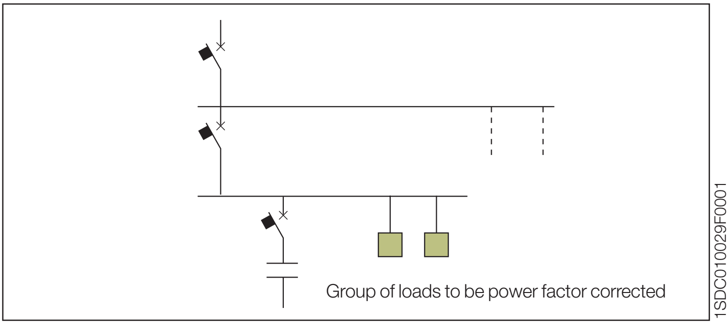
S_r [kVA]	u_k% [%]	i_o% [%]	P_{fe} [kW]	P_{cu} [kW]	Q_c [kvar] load factor K_L 0	0.25	0.5	0.75	1
Oil Distribution Transformer MV-LV									
50	4	2.9	0.25	1.35	1.4	1.5	1.8	2.3	2.9
100	4	2.5	0.35	2.30	2.5	2.7	3.3	4.3	5.7
160	4	2.3	0.48	3.20	3.6	4	5	6.8	9.2
200	4	2.2	0.55	3.80	4.4	4.8	6.1	8.3	11
250	4	2.1	0.61	4.50	5.2	5.8	7.4	10	14
315	4	2	0.72	5.40	6.3	7	9.1	13	18
400	4	1.9	0.85	6.50	7.6	8.5	11	16	22
500	4	1.9	1.00	7.40	9.4	11	14	20	28
630	4	1.8	1.20	8.90	11	13	17	25	35
800	6	1.7	1.45	10.60	14	16	25	40	60
1000	6	1.6	1.75	13.00	16	20	31	49	74
1250	6	1.6	2.10	16.00	20	24	38	61	93
1600	6	1.5	2.80	18.00	24	30	47	77	118
2000	6	1.2	3.20	21.50	24	31	53	90	142
2500	6	1.1	3.70	24.00	27	37	64	111	175
3150	7	1.1	4.00	33.00	34	48	89	157	252
4000	7	1.4	4.80	38.00	56	73	125	212	333
Cast Resin Distribution Transformer MV-LV									
100	6	2.3	0.50	1.70	2.2	2.6	3.7	5.5	8
160	6	2	0.65	2.40	3.1	3.7	5.5	8.4	12
200	6	1.9	0.85	2.90	3.7	4.4	6.6	10	15
250	6	1.8	0.95	3.30	4.4	5.3	8.1	13	19
315	6	1.7	1.05	4.20	5.3	6.4	9.9	16	24
400	6	1.5	1.20	4.80	5.9	7.3	12	19	29
500	6	1.4	1.45	5.80	6.8	8.7	14	23	36
630	6	1.3	1.60	7.00	8	10	17	29	45
800	6	1.1	1.94	8.20	8.6	12	20	35	56
1000	6	1	2.25	9.80	9.7	13	25	43	69
1250	6	0.9	3.30	13.00	11	15	29	52	85
1600	6	0.9	4.00	14.50	14	20	38	67	109
2000	6	0.8	4.60	15.50	15	23	45	82	134
2500	6	0.7	5.20	17.50	17	26	54	101	166
3150	8	0.6	6.00	19.00	18	34	81	159	269

Example

For a 630 kVA oil-distribution transformer with a load factor of 0.5, the necessary PFC power is 17 kvar.

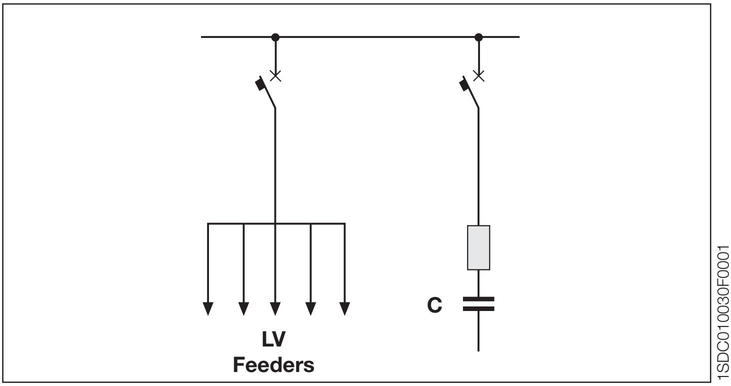
4 Power factor correction

PFC in groups



This consists of local power factor correction of groups of loads with similar functioning characteristics by installing a dedicated capacitor bank.
This method achieves a compromise between the economical solution and the correct operation of the installation, since only the line downstream of the installation point of the capacitor bank is not correctly exploited.

Centralized PFC



The daily load profile is of fundamental importance for the choice of the most suitable type of power factor correction.
In installations, in which not all loads function simultaneously and/or in which some loads are connected for only a few hours a day, the solution of using single PFC becomes unsuitable as many of the capacitors installed could stay idle for long periods.
In the case of installations with many loads occasionally functioning, thus having a high installed power and a quite low average power absorption by the loads which function simultaneously, the use of a single PFC system at the installation origin ensures a remarkable decrease in the total power of the capacitors to be installed.

4 Power factor correction

Centralized PFC normally uses automatic units with capacitor banks divided into several steps, directly installed in the main distribution switchboards; the use of a permanently connected capacitor bank is only possible if the absorption of reactive energy is fairly regular throughout the day.
The main disadvantage of centralized PFC is that the distribution lines of the installation, downstream of the PFC device, must be dimensioned taking into account the full reactive power required by the loads.

4.3 Circuit-breakers for the protection and switching of capacitor banks

The circuit-breakers for the protection and switching of capacitor banks in LV shall:

1. withstand the transient currents which occur when connecting and disconnecting the banks. In particular, the instantaneous magnetic and electronic releases shall not trip due to these peak currents;
2. withstand the periodic or permanent overcurrents due to the voltage harmonics and to the tolerance (+15%) of the rated value of capacity;
3. perform a high number of no-load and on-load operations, also with high frequency;
4. be coordinated with any external device (contactors).

Furthermore, the making and breaking capacity of the circuit-breaker must be adequate to the short- circuit current values of the installation.

Standards IEC 60831-1 and 60931-1 state that:
- the capacitors shall normally function with an effective current value up to 130% of their rated current I_{rc} (due to the possible presence of voltage harmonics in the network);
- a tolerance of +15% on the value of the capacity is allowed.

The maximum current which can be absorbed by the capacitor bank I_{cmax} is:

$$I_{c\,max} = 1.3 \cdot 1.15 \cdot \frac{Q_c}{\sqrt{3} \cdot U_r} \approx 1.5 \cdot I_{rc} \quad (8)$$

Therefore:
- the rated current of the circuit-breaker shall be greater than $1.5 \cdot I_{rc}$;
- the overload protection setting shall be equal to $1.5 \cdot I_{rc}$.

The connection of a capacitor bank, similar to a closing operation under short-circuit conditions, associated with transient currents with high frequency (1÷15 kHz), of short duration (1÷3 ms), with high peak (25÷200 I_{rc}).
Therefore:
- the circuit-breaker shall have an adequate making capacity;
- the setting of the instantaneous short-circuit protection must not cause unwanted trips.

4 Power factor correction

The second condition is generally respected:

- for thermomagnetic releases, the magnetic protection shall be set at a value not less than $10 \cdot I_{cmax}$

$$I_3 \geq 10 \cdot I_{cmax} = 15 \cdot I_{rc} = 15 \cdot \frac{Q_r}{\sqrt{3} \cdot U_r} \quad (9)$$

- for electronic releases, the instantaneous short-circuit protection shall be deactivated (I_3 = OFF).

Hereunder, the selection tables for circuit-breakers: for the definition of the version according to the required breaking capacity, refer to Volume 1, Chapter 3.1 "General characteristics".

The following symbols are used in the tables (they refer to maximum values):

- I_{nCB} = rated current of the protection release [A];
- I_{rc}= rated current of the connected capacitor bank [A];
- Q_C= power of the capacitor bank which can be connected [kvar] with reference to the indicated voltage and 50 Hz frequency;
- N_{mech} = number of mechanical operations;
- f_{mech} = frequency of mechanical operations [op/h];
- N_{el} = number of electrical operations with reference to a voltage of 415 V for Tmax and Isomax moulded-case circuit breakers (Tables 5 and 6), and to a voltage of 440 V for Emax air circuit-breakers (Table 7);
- f_{el} = frequency of electrical operations [op/h].

Table 5: Selection table for Tmax moulded-case circuit-breakers

	I_{nCB}	I_{rc}	Q_C [kvar]				N_{mech}	f_{mech}	N_{el}	f_{el}
CB Type	[A]	[A]	400 V	440 V	500 V	690 V		[op/h]		[op/h]
T1 B-C-N 160	160	107	74	81	92	127	25000	240	8000	120
T2 N-S-H-L 160*	160	107	74	81	92	127	25000	240	8000	120
T3 N-S 250*	250	167	115	127	144	199	25000	240	8000	120
T4 N-S-H-L-V 250	250	167	115	127	144	199	20000	240	8000	120
T4 N-S-H-L-V 320	320	213	147	162	184	254	20000	240	6000	120
T5 N-S-H-L-V 400	400	267	185	203	231	319	20000	120	7000	60
T5 N-S-H-L-V 630	630	420	291	320	364	502	20000	120	5000	60

* for plug-in version reduce the maximum power of the capacitor bank by 10%

Table 6: Selection table for SACE Isomax S moulded-case circuit-breakers

	I_{nCB}	I_{rc}	Q_C [kvar]				N_{mech}	f_{mech}	N_{el}	f_{el}
S6 N-S-H-L 800	800	533	369	406	462	637	20000	120	5000	60
S7 S-H-L 1250	1250	833	577	635	722	996	10000	120	7000	20
S7 S-H-L 1600	1600	1067	739	813	924	1275	10000	120	5000	20
S8 H-V 2000	2000	1333	924	1016	1155	1593	10000	120	3000	20
S8 H-V 2500	2500	1667	1155	1270	1443	1992	10000	120	2500	20
S8 H-V 3200	3200	2133	1478	1626	1847	2550	10000	120	1500	10

4 Power factor correction

Table 7: Selection table for SACE Emax air circuit-breakers

CB Type	I_{nCB} [A]	I_{rc} [A]	Q_C [kvar] 400 V	440 V	500 V	690 V	N_{mech}	f_{mech} [op/h]	N_{el}	f_{el} [op/h]
E1 B N	1250	834	578	636	722	997	25000	60	10000	30
E2 B-N	1250	834	578	636	722	997	25000	60	15000	30
E2 B-N	1600	1067	739	813	924	1275	25000	60	12000	30
E2 B-N	2000	1334	924	1017	1155	1594	25000	60	10000	30
E3 N-S-H	1250	834	578	636	722	997	20000	60	12000	20
E3 N-S-H	1600	1067	739	813	924	1275	20000	60	10000	20
E3 N-S-H	2000	1334	924	1017	1155	1594	20000	60	9000	20
E3 N-S-H	2500	1667	1155	1270	1444	1992	20000	60	8000	20
E3 N-S-H	3200	2134	1478	1626	1848	2550	20000	60	6000	20
E4 S-H	3200	2134	1478	1626	1848	2550	15000	60	7000	10
E6 H-V	3200	2134	1478	1626	1848	2550	12000	60	5000	10

5 Protection of human beings

5.1 General aspects: effects of current on human beings

Danger to persons due to contact with live parts is caused by the flow of the current through the human body. The effects are:

- **tetanization:** the muscles affected by the current flow involuntary contract and letting go of gripped conductive parts is difficult. Note: very high currents do not usually induce muscular tetanization because, when the body touches such currents, the muscular contraction is so sustained that the involuntary muscle movements generally throw the subject away from the conductive part;

- **breathing arrest:** if the current flows through the muscles controlling the lungs, the involuntary contraction of these muscles alters the normal respiratory process and the subject may die due to suffocation or suffer the consequences of traumas caused by asphyxia;

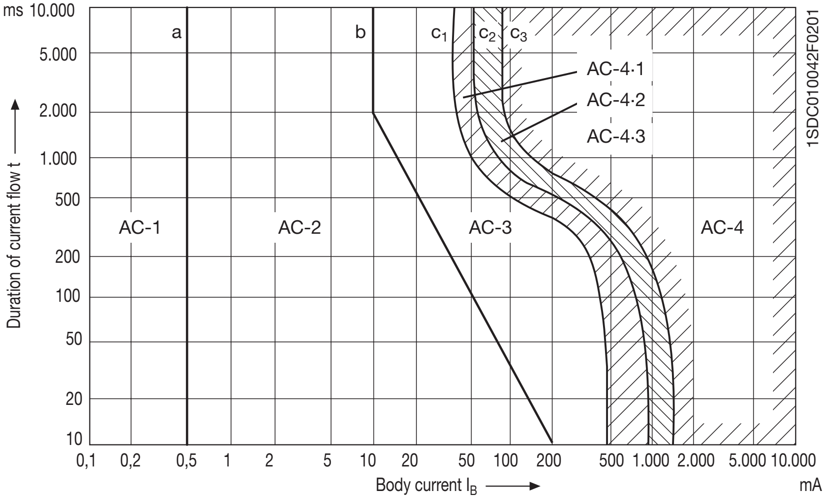
- **ventricular fibrillation:** the most dangerous effect is due to the superposition of the external currents with the physiological ones which, by generating uncontrolled contractions, induce alterations of the cardiac cycle. This anomaly may become an irreversible phenomenon since it persists even when the stimulus has ceased;

- **burns:** they are due to the heating deriving, by Joule effect, from the current passing through the human body.

The Standard IEC 60479-1 *"Effects of current on human being and livestock"* is a guide about the effects of current passing through the human body to be used for the definition of electrical safety requirements. This Standard shows, on a time-current diagram, four zones to which the physiological effects of alternating current (15 ÷100 Hz) passing through the human body have been related.

5 Protection of human beings

Figure 1: Time-current zones of the effects of alternating current on the human body



Zone designation	Zone limits	Physiological effects
AC-1	Up to 0.5 mA line a	Usually no reaction.
AC-2	0.5 mA up to line b*	Usually no harmful physiological effects.
AC-3	Line b up to curve c_1	Usually no organic damage to be expected. Likelihood of cramplike muscular contractions and difficulty in breathing for durations of current-flow longer than 2 s. Reversible disturbances of formation and conduction of impulses in the heart, including atrial fibrillation and transient cardiac arrest without ventricular fibrillation increasing with current magnitude and time.
AC-4	Above curve c_1	Increasing with magnitude and time, dangerous pathophysiological effects such as cardiac arrest, breathing arrest and severe burns may occur in addition to the effects of zone 3.
AC-4.1	c_1 - c_2	Probability of ventricular fibrillation increasing up to about 5%.
AC-4.2	c_2 - c_3	Probability of ventricular fibrillation up to about 50%.
AC-4.3	Beyond curve c_3	Probability of ventricular fibrillation above 50%.

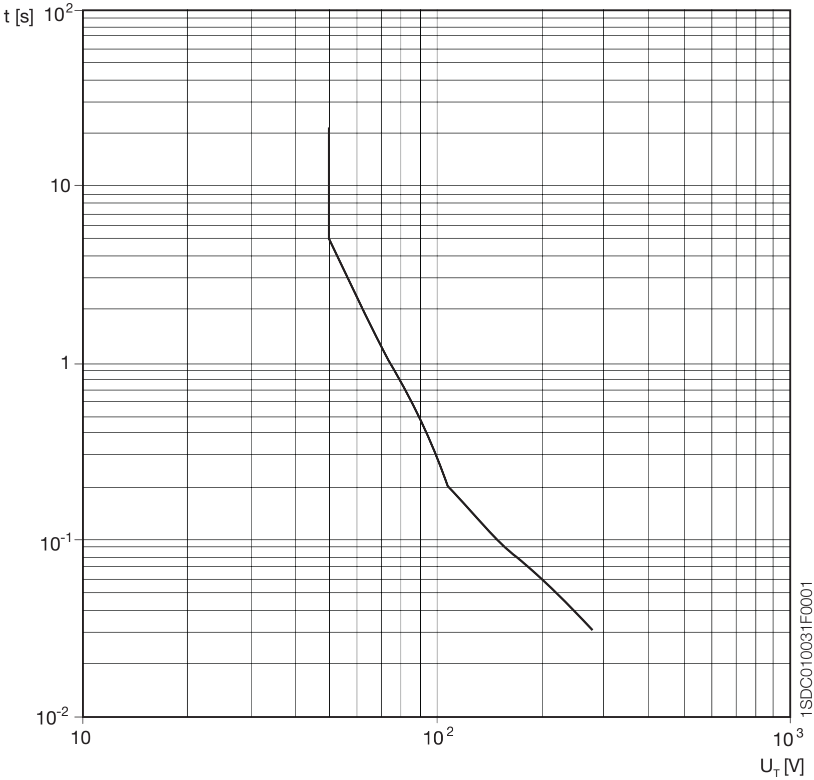
* For durations of current-flow below 10 ms, the limit for the body current for line b remains constant at a value of 200 mA.

This Standard gives also a related figure for direct current.
By applying Ohm's law it is possible to define the safety curve for the allowable voltages, once the human body impedance has been calculated. The electrical impedance of the human body depends on many factors. The above mentioned Standard gives different values of impedance as a function of the touch voltage and of the current path.

5 Protection of human beings

The Standard IEC 60479-1 has adopted precautionary values for the impedance reported in the figure so as to get the time-voltage safety curve (Figure 2) related to the total touch voltage U_T (i.e. the voltage which, due to an insulation failure, is present between a conductive part and a point of the ground sufficiently far, with zero potential).
This represents the maximum no-load touch voltage value; thus, the most unfavorable condition is taken into consideration for safety's sake.

Figure 2: Safety curve



From this safety curve it results that for all voltage values below 50 V, the tolerance time is indefinite; at 50 V the tolerance time is 5 s. The curve shown in the figure refers to an ordinary location; in particular locations, the touch resistance of the human body towards earth changes and consequently the tolerable voltage values for an indefinite time shall be lower than 25 V.
Therefore, if the protection against indirect contact is obtained through the disconnection of the circuit, it is necessary to ensure that such breaking is carried out in compliance with the safety curve for any distribution system.

5.2 Distribution systems

The earth fault modalities and the consequences caused by contact with live parts, are strictly related to the neutral conductor arrangement and to the connections of the exposed conductive parts.

For a correct choice of the protective device, it is necessary to know which is the distribution system of the plant.
IEC 60364-1 classifies the distribution systems with two letters.

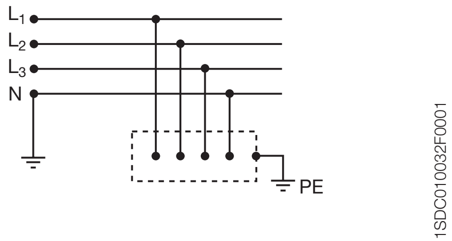
The first letter represents the relationship of the power system to earth:
- T: direct connection of one point to earth, in alternating current systems, generally the neutral point;
- I: all live parts isolated from earth, or one point, in alternating current systems, generally the neutral point, connected to earth through an impedance.

The second letter represents the relationship of the exposed conductive parts of the installation to earth:
- T: direct electrical connection of the exposed conductive parts to earth;
- N: direct electrical connection of the exposed conductive parts to the earthed point of the power system.

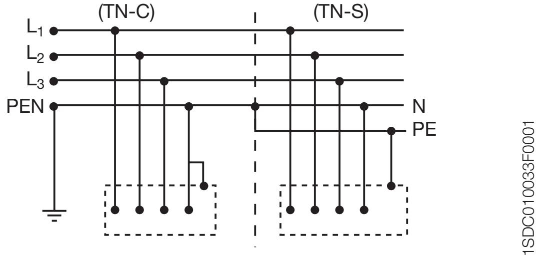
Subsequent letters, if any, represent the arrangement of neutral and protective conductors:
- S: protective function is provided by a conductor separate from the neutral conductor;
- C: neutral and protective functions combined as a single conductor (PEN conductor).

Three types of distribution system are considered:

TT System

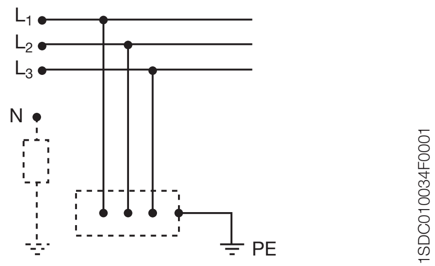


TN System



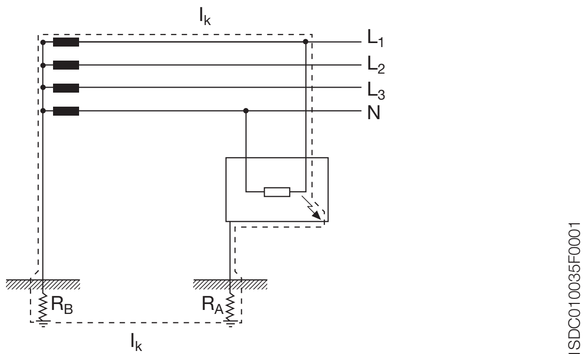
5 Protection of human beings

IT System



In **TT** systems, the neutral conductor and the exposed conductive parts are connected to earth electrodes electrically independent; the fault current flows towards the power supply neutral point through earth (Fig. 1):

Figure 1: Earth fault in TT systems



In **TT** installations, the neutral conductor is connected to the supply star center, it is usually distributed and has the function of making the phase voltage (e.g. 230 V) available, useful for single-phase load supply. The exposed conductive parts, on the contrary, singularly or collectively, are locally connected to earth. **TT** systems are generally used for civil installations.

TN systems are typically used when the power supply is distributed to loads having their own electrical substation. The neutral conductor is directly earthed in the substation; the exposed conductive parts are connected to the same earthing point of the neutral conductor, and can be locally earthed.

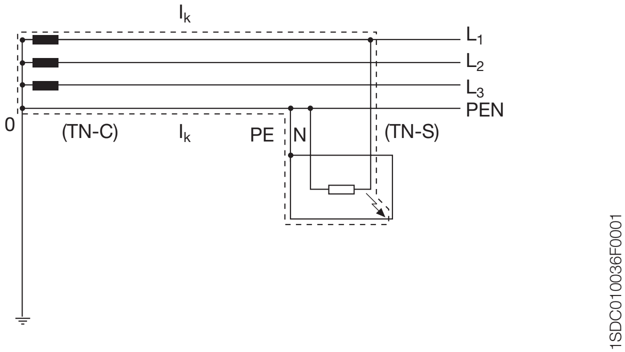
Three types of TN system are considered according to the arrangement of neutral and protective conductors:

1. TN-C neutral and protective functions are combined in a single conductor (PEN conductor);
2. TN-S neutral and protective conductors are always separated;
3. TN-C-S neutral and protective functions are combined in a single conductor in a part of the system (PEN) and are separated in another part (PE + N).

5 Protection of human beings

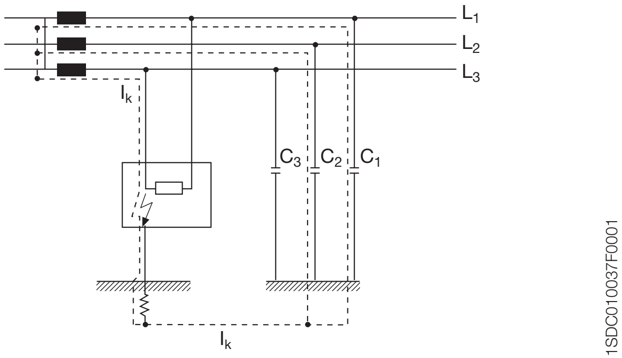
In **TN** systems, the fault current flows towards the power supply neutral point through a solid metallic connection, practically without involving the earth electrode (Figure 2).

Figure 2: Earth fault in TN systems



IT systems have no live parts directly connected to earth, but they can be earthed through a sufficiently high impedance. Exposed conductive parts shall be earthed individually, in groups or collectively to an independent earthing electrode.
The earth fault current flows towards the power supply neutral point through the earthing electrode and the line conductor capacitance (Figure 3).

Figure 3: Earth fault in IT systems



These distribution systems are used for particular plants, where the continuity of supply is a fundamental requirement, where the absence of the supply can cause hazards to people or considerable economical losses, or where a low value of a first earth fault is required. In these cases, an insulation monitoring device shall be provided for optical or acoustic signalling of possible earth faults, or failure of the supplied equipment.

5.3 Protection against both direct and indirect contact

Contacts of a person with live parts can be divided in two categories:
- direct contacts;
- indirect contacts.

A direct contact occurs when a part of the human body touches a part of the plant, usually live (bare conductors, terminals, etc.).
A contact is indirect when a part of the human body touches an exposed conductive parts, usually not live, but with voltage presence due to a failure or wear of the insulating materials.

The measures of protection against **direct contact** are:
- insulation of live parts with an insulating material which can only be removed by destruction (e.g. cable insulation);
- barriers or enclosures: live parts shall be inside enclosures or behind barriers providing at least the degree of protection IPXXB or IP2X; for horizontal surfaces the degree of protection shall be of at least IPXXD or IP4X (for the meaning of the degree of protection codes please refer to Volume 1, Chapter 6.1 Electrical switchboards);
- obstacles: the interposition of an obstacle between the live parts and the operator prevents unintentional contacts only, but not an intentional contact by the removal of the obstacle without particular tools;
- placing out of reach: simultaneously accessible parts at different potentials shall not be within arm's reach.

An additional protection against direct contact can be obtained by using residual current devices with a rated operating residual current not exceeding 30 mA. It must be remembered that the use of a residual current device as a mean of protection against direct contacts does not obviate the need to apply one of the above specified measures of protection.

The measures of protection against **indirect contact** are:
- automatic disconnection of the supply: a protective device shall automatically disconnect the supply to the circuit so that the touch voltage on the exposed conductive part does not persist for a time sufficient to cause a risk of harmful physiological effect for human beings;
- supplementary insulation or reinforced insulation, e.g. by the use of Class II components;

5 Protection of human beings

- non-conducting locations: locations with a particular resistance value of insulating floors and walls (≥ 50 kΩ for U_r ≤ 500 V; ≥ 100 kΩ for U_r > 500 V) and without protective conductors inside
- electrical separation, e.g. by using an isolating transformer to supply the circuit;
- earth-free local equipotential bonding: locations where the exposed conductive parts are connected together but not earthed.

Finally, the following measures provide combined protection against both direct and indirect contact:
- SELV (Safety Extra Low Voltage) system and PELV (Protective Extra Low Voltage) system;
- FELV (Functional Extra Low Voltage) system.

The protection against both direct and indirect contact is ensured if the requirements stated in 411 from IEC 60364-4-41 are fulfilled; particularly:
- the rated voltage shall not exceeds 50 V ac r.m.s. and 120 V ripple-free dc;
- the supply shall be a SELV or PELV source;
- all the installation conditions provided for such types of electrical circuits shall be fulfilled.

A SELV circuit has the following characteristics:
1) it is supplied by an independent source or by a safety source. Independent sources are batteries or diesel-driven generators. Safety sources are supplies obtained through an isolating transformer;
2) there are no earthed points. The earthing of both the exposed conductive parts as well as of the live parts of a SELV circuit is forbidden;
3) it shall be separated from other electrical systems. The separation of a SELV system from other circuits shall be guaranteed for all the components; for this purpose, the conductors of the SELV circuit may be contained in multi-conductor cables or may be provided with an additional insulating sheath.

A PELV circuit has the same prescription of a SELV system, except for the prohibition of earthed points; in fact in PELV circuits, at least one point is always earthed.

5 Protection of human beings

FELV circuits are used when for functional reasons the requirements for SELV or PELV circuits cannot be fulfilled; they require compliance with the following rules:

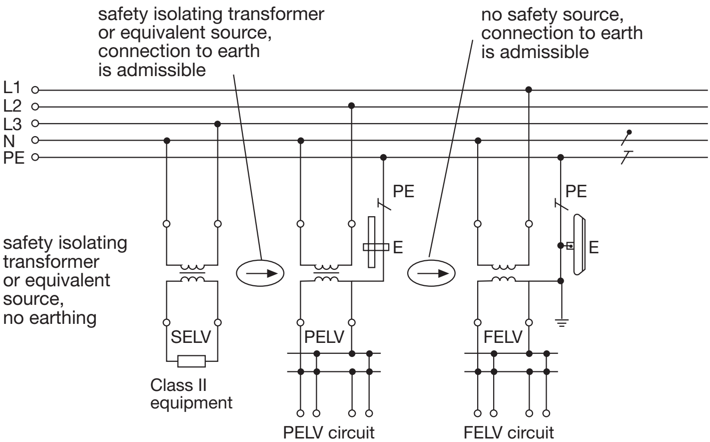
a) protection against direct contact shall be provided by either:
   - barriers or enclosures with degree of protection in accordance with what stated above (measures of protection against direct contact);
   - insulation corresponding to the minimum test voltage specified for the primary circuit. If this test is not passed, the insulation of accessible non-conductive parts of the equipment shall be reinforced during erection so that it can withstand a test voltage of 1500 V ac r.m.s. for 1 min.;

b) protection against indirect contact shall be provided by:
   - connection of the exposed conductive parts of the equipment of the FELV circuit to the protective conductor of the primary circuit, provided that the latter is subject to one of the measures of protection against direct contact;
   - connection of a live conductor of the FELV circuit to the protective conductor of the primary circuit provided that an automatic disconnection of the supply is applied as measure of protection;

c) plugs of FELV systems shall not be able to enter socket-outlets of other voltage systems, and plugs of other voltage systems shall not be able to enter socket-outlets of FELV systems.

Figure 1 shows the main features of SELV, PELV and FELV systems.

Figure 1: SELV, PELV, FELV systems



voltage limits for extra-low voltages:	E	earth connections by estraneous conductive parts, e.g. by metal pipe or structural steelwork
50 V ac 120 V dc	PE ⏚	protective conductor earth electrode

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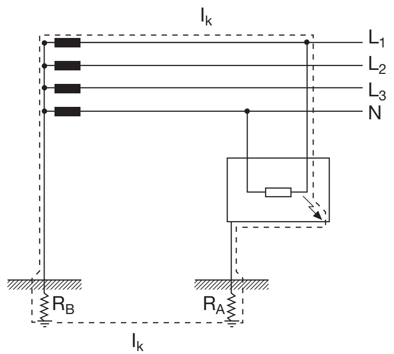
Note 1: Overcurrent protective devices are not shown in this figure.

5.4 TT System

An earth fault in a TT system involves the circuit represented in Figure 1:

Figure 1: Earth fault in TT system



The fault current involves the secondary winding of the transformer, the phase conductor, the fault resistance, the protective conductor and the earth electrode resistance (plant earthing system (R_A) and earthing system which the neutral is connected to (R_B)).
According to IEC 60364-4 requirements, the protective devices must be co-ordinated with the earthing system in order to rapidly disconnect the supply, if the touch voltage reaches harmful values for the human body.
Assuming 50 V (25 V for particular locations) as limit voltage value, the condition to be fulfilled in order to limit the touch voltage on the exposed conductive parts under this limit value is:

$$R_t \leq \frac{50}{I_a} \quad \text{or} \quad R_t \leq \frac{50}{I_{\Delta n}}$$

where:

- R_t is the total resistance, equal to the sum of the earth electrode (R_A) and the protective conductor for the exposed conductive parts [Ω];
- I_a is the current causing the automatic operation within 5 s of the overcurrent protective device, read from the tripping curve of the device [A];
- $I_{\Delta n}$ is the rated residual operating current, within one second, of the circuit-breaker [A].

5 Protection of human beings

From the above, it is clear that R_t value is considerably different when using automatic circuit breakers instead of residual current devices.
In fact, with the former, it is necessary to obtain very low earth resistance values (usually less than 1 Ω) since the 5 s tripping current is generally high, whereas, with the latter, it is possible to realize earthing systems with resistance value of thousands of ohms, which are easier to be carried out.

Table 1 reports the maximum earth resistance values which can be obtained using residual current devices, with reference to an ordinary location (50 V):

Table 1: Earth resistance values

$I_{\Delta n}$ [A]	R_t [Ω]
0.01	5000
0.03	1666
0.1	500
0.3	166
0.5	100
3	16
10	5
30	1.6

Example:
Assuming to provide protection by using an automatic circuit breaker Tmax T1B160 In125, the trip current value in less than 5 s, read from the tripping characteristic curve, is about 750 A, when starting from cold conditions (the worst case for thermomagnetic releases).

So:

$$R_t \leq \frac{50}{750} = 0.06\,\Omega$$

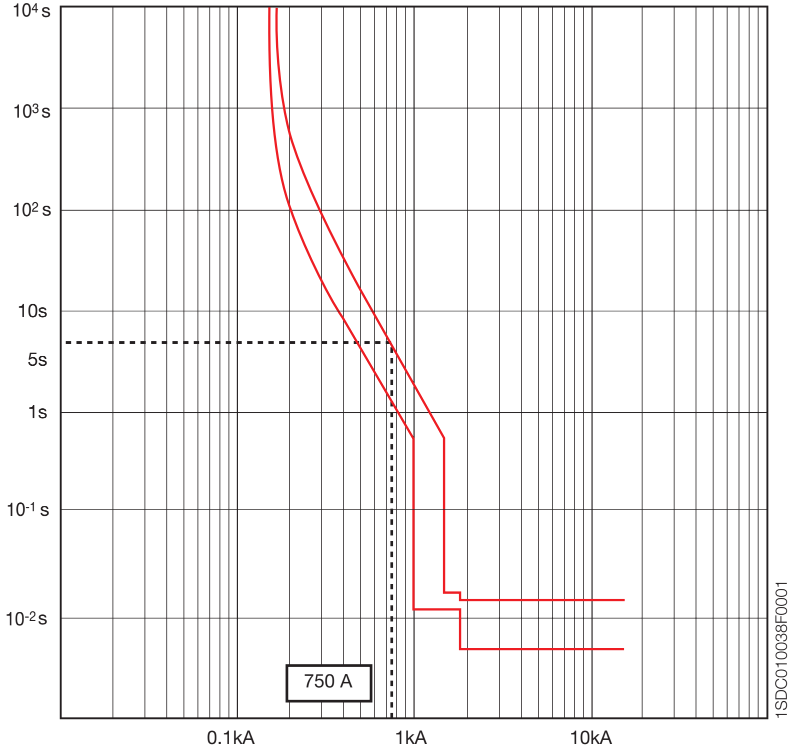
In order to provide the required protection, it must be necessary to carry out an earthing system with an earth resistance $R_t \leq 0.06$ Ω, which is not an easily obtainable value.

On the contrary, by using the same circuit breaker mounting ABB SACE RC221 residual current release, with rated residual operating current $I_{\Delta n} = 0.03$ A, the required value of earth resistance is:

$$R_t \leq \frac{50}{0.03} = 1666.6\,\Omega$$

which can be easily obtained in practice.

5 Protection of human beings



In an electrical installation with a common earthing system and loads protected by devices with different tripping currents, for the achievement of the coordination of all the loads with the earthing system, the worst case - represented by the device with the highest tripping current - shall be considered.

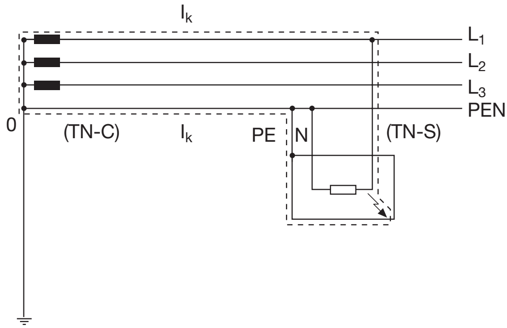
As a consequence, when some feeders are protected by overcurrent devices and some others by residual current devices, all the advantages deriving from the use of residual current releases are nullified, since the R_t shall be calculated on the basis of the I_{5s} of the overcurrent device and since it is the highest tripping current between these two kind of devices.

Therefore, it is advisable to protect all the loads of a TT system by means of residual current circuit-breakers coordinated with the earthing system to obtain the advantages of both a quick disconnection of the circuit when the fault occurs as well as an earthing system which can be easily accomplished.

5.5 TN System

An earth fault in a TN system involves the circuit represented in Figure 1:

Figure 1: Earth fault in TN system



The fault loop does not affect the earthing system and is basically formed by the connection in series of the phase conductor and of the protective conductor. To provide a protection with automatic disconnection of the circuit, according to IEC 60364-4 prescriptions, the following condition shall be fulfilled:

$$Z_s \cdot I_a \leq U_0$$

where:

Z_S is the impedance of the fault loop comprising the source, the live conductor up to the point of the fault and the protective conductor between the point of the fault and the source [Ω];

U_0 is the nominal ac r.m.s. voltage to earth [V];

I_a is the current causing the automatic operation of the disconnecting protective device within the time stated in Table 1, as a function of the rated voltage U_0 or, for distribution circuits, a conventional disconnecting time not exceeding 5 s is permitted [A]; if the protection is provided by means of a residual current device, I_a is the rated residual operating current $I_{\Delta n}$.

Table 1: Maximum disconnecting times for TN system

U_0 [V]	Disconnecting time [s]
120	0.8
230	0.4
400	0.2
> 400	0.1

5 Protection of human beings

In TN installations, an earth fault with low impedance occurring on the LV side causes a short circuit current with quite high value, due to the low value of the impedance of the fault loop. The protection against indirect contact can be provided by automatic circuit-breakers: it is necessary to verify that the operating current within the stated times is lower than the short-circuit current.

The use of residual current devices improves the conditions for protection in particular when the fault impedance doesn't have a low value, thus limiting the short-circuit current; this current can persist for quite long time causing overheating of the conductors and fire risks.

Finally, it is important to highlight the fact that the residual current devices cannot be used in TN-C system, since the neutral and protective functions are provided by a unique conductor: this configuration prevents the residual current device from working.

Example:

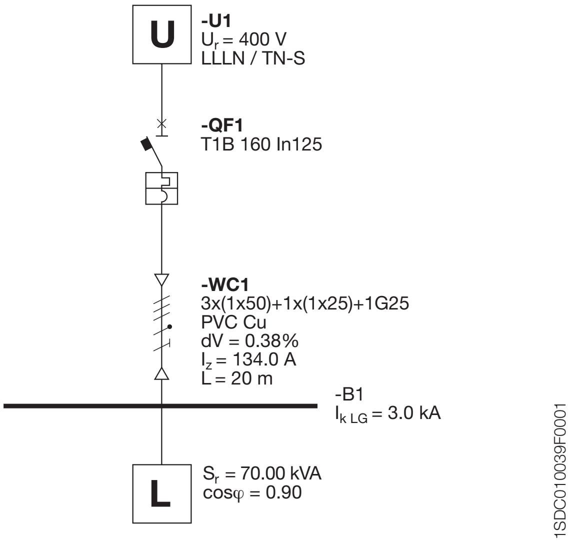
In the plant represented in Figure 2, the earth fault current is:

$$I_{kLG} = 3 \text{ kA}$$

The rated voltage to earth is 230 V, therefore, according to Table 1, it shall be verified that:

$$I_a\,(0.4\text{s}) \leq \frac{U_0}{Z_s} = I_{kLG} = 3 \text{ kA}$$

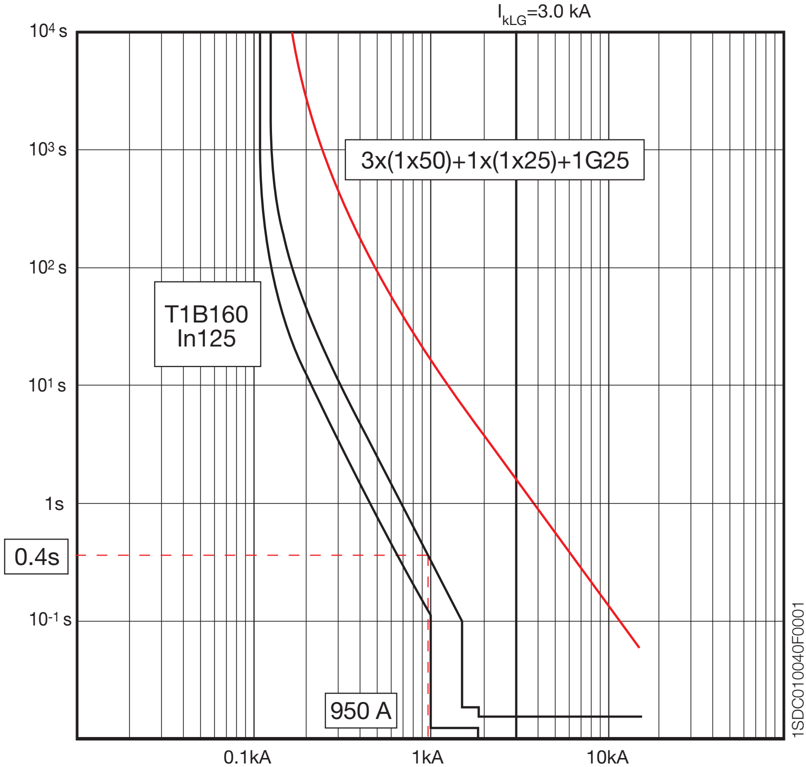
Figure 2



5 Protection of human beings

From the tripping curve (Figure 3), it is clear that the circuit-breaker trips in 0.4 s for a current value lower than 950 A. As a consequence, the protection against indirect contact is provided by the same circuit-breaker which protects the cable against short-circuit and overload, without the necessity of using an additional residual current device.

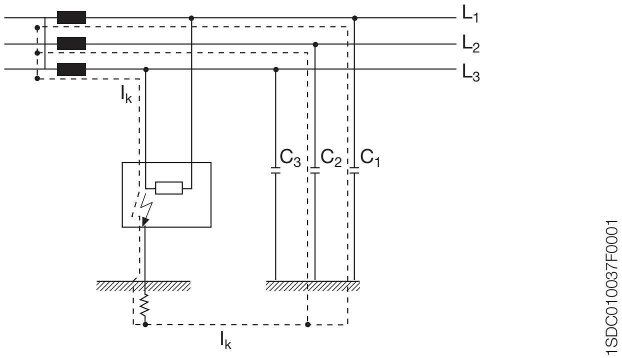
Figure 3: LG Time-Current curves



5.6 IT System

As represented in Figure 1, the earth fault current in an IT system flows through the line conductor capacitance to the power supply neutral point. For this reason, the first earth fault is characterized by such an extremely low current value to prevent the overcurrent protections from disconnecting; the deriving touch voltage is very low.

Figure1: Earth fault in IT system



According to IEC 60364-4, the automatic disconnection of the circuit in case of the first earth fault is not necessary only if the following condition is fulfilled:

$$R_t \cdot I_d \leq U_L$$

where:

- R_t is the resistance of the earth electrode for exposed conductive parts [Ω];
- I_d is the fault current, of the first fault of negligible impedance between a phase conductor and an exposed conductive part [A];
- U_L is 50 V for ordinary locations (25 V for particular locations).

If this condition is fulfilled, after the first fault, the touch voltage value on the exposed conductive parts is lower than 50 V, tolerable by the human body for an indefinite time, as shown in the safety curve (see Chapter 5.1 “General aspects: effects of current on human beings”).

In IT system installations, an insulation monitoring device shall be provided to

5 Protection of human beings

indicate the occurrence of a first earth fault; in the event of a second fault, the supply shall be disconnected according to the following modalities:

a) where exposed conductive parts are earthed in groups or individually, the conditions for protection are the same as for TT systems (see Chapter 5.4 “TT system”);
b) where exposed conductive parts are interconnected by a protective conductor collectively earthed, the conditions of a TN system apply; in particular, the following conditions shall be fulfilled:
if the neutral is not distributed:

$$Z_s \leq \frac{U_r}{2 \cdot I_a}$$

if the neutral is distributed:

$$Z'_s \leq \frac{U_0}{2 \cdot I_a}$$

where
- U_0 is the rated voltage between phase and neutral [V];
- U_r is the rated voltage between phases [V];
- Z_S is the impedance of the fault loop comprising the phase conductor and the protective conductor of the circuit [Ω];
- Z'_S is the impedance of the fault loop comprising the neutral conductor and the protective conductor of the circuit [Ω];
- I_a is the operating current of the protection device in the disconnecting time specified in Table 1, or within 5 s for distribution circuits.

Table 1: Maximum disconnecting time in IT systems

Rated voltage U_0/U_r [V]	disconnecting time [s] neutral not distributed	neutral distributed
120/240	0.8	5
230/400	0.4	0.8
400/690	0.2	0.4
580/1000	0.1	0.2

IEC 60364-4 states that, if the requirements mentioned at point b) cannot be fulfilled by using an overcurrent protective device, the protection of every supplied load shall be provided by means of a residual current device.

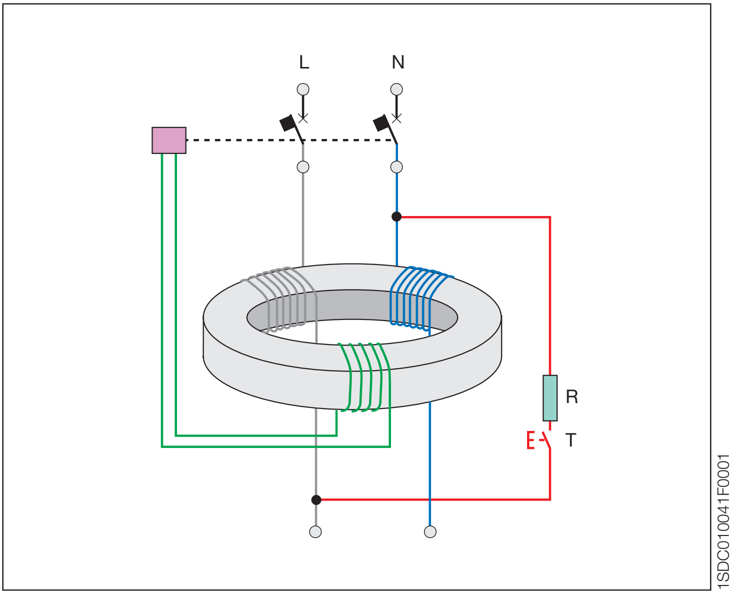
The residual current device threshold shall be carefully chosen in order to avoid unwanted tripping, due also to the particular path followed by the first fault current through the line conductor capacitance to the power supply neutral point (instead of the faulted line, another sound line with higher capacitance could be affected by a higher fault current value).

5.7 Residual current devices (RCDs)

Generalities on residual current circuit-breakers

The operating principle of the residual current release is basically the detection of an earth fault current, by means of a toroid transformer which embraces all the live conductors, included the neutral if distributed.

Figure 1: Operating principle of the residual current device



In absence of an earth fault, the vectorial sum of the currents I_{Δ} is equal to zero; in case of an earth fault if the I_{Δ} value exceeds the rated residual operating current $I_{\Delta n}$, the circuit at the secondary side of the toroid sends a command signal to a dedicated opening coil causing the tripping of the circuit-breaker.
A first classification of RCDs can be made according to the type of the fault current they can detect:
- AC type: the tripping is ensured for residual sinusoidal alternating currents, whether suddenly applied or slowly rising;
- A type: tripping is ensured for residual sinusoidal alternating currents and residual pulsating direct currents, whether suddenly applied or slowly rising;
- B type: tripping is ensured for residual direct currents, for residual sinusoidal alternating currents and residual pulsating direct currents, whether suddenly applied or slowly rising.

Another classification referred to the operating time delay is:
- undelayed type;
- time delayed S-type.

5 Protection of human beings

RCDs can be coupled, or not, with other devices; it is possible to distinguish among:

- pure residual current circuit-breakers (RCCBs): they have only the residual current release and can protect only against earth fault. They must be coupled with thermomagnetic circuit-breakers or fuses, for the protection against thermal and dynamical stresses;
- residual current circuit-breakers with overcurrent protection (RCBOs): they are the combination of a thermomagnetic circuit-breaker and a RCD; for this reason, they provide the protection against both overcurrents as well as earth fault current;
- residual current circuit-breakers with external toroid: they are used in industrial plants with high currents. They are composed by a release connected to an external toroid with a winding for the detection of the residual current; in case of earth fault, a signal commands the opening mechanism of a circuit-breaker or a line contactor.

Given $I_{\Delta n}$ the operating residual current, a very important parameter for residual current devices is the residual non-operating current, which represents the maximum value of the residual current which does not cause the circuit breaker trip; it is equal to 0.5 $I_{\Delta n}$. Therefore, it is possible to conclude that:

- for $I_{\Delta} < 0.5 \cdot I_{\Delta n}$ the RCD shall not operate;
- for $0.5 \cdot I_{\Delta n} < I_{\Delta} < I_{\Delta n}$ the RCD could operate;
- for $I_{\Delta} > I_{\Delta n}$ the RCD shall operate.

For the choice of the rated operating residual current, it is necessary to consider, in addition to the coordination with the earthing system, also the whole of the leakage currents in the plant; their vectorial sums on each phase shall not be greater than $0.5 \cdot I_{\Delta n}$. in order to avoid unwanted tripping.

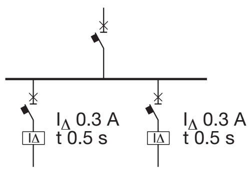
Discrimination between RCDs

The Standard IEC 60364-5-53 states that discrimination between residual current protective devices installed in series may be required for service reasons, particularly when safety is involved, to provide continuity of supply to the parts of the installation not involved by the fault, if any. This discrimination can be achieved by selecting and installing RCDs in order to provide the disconnection from the supply by the RCD closest to the fault.

There are two types of discrimination between RCDs:

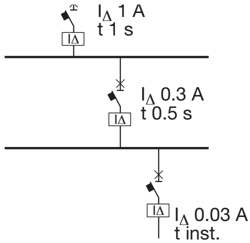
- horizontal discrimination: it provides the protection of each line by using a dedicated residual current circuit-breaker; in this way, in case of earth fault, only the faulted line is disconnected, since the other RCDs do not detect any fault current. However, it is necessary to provide protective measures against indirect contacts in the part of the switchboard and of the plant upstream the RCD;
- vertical discrimination: it is realized by using RCDs connected in series.

Figure 2: Horizontal discrimination between RCDs



5 Protection of human beings

Figure 3: Vertical discrimination between RCDs



According to IEC 60364-5-53, to ensure discrimination between two residual current protective devices in series, these devices shall satisfy both the following conditions:
- the non-actuating time-current characteristic of the residual current protective device located on the supply side (upstream) shall lie above the total operating time-current characteristic of the residual current protective device located on the load side (downstream);
- the rated residual operating current on the device located on the supply side shall be higher than that of the residual current protective device located on the load side.

The non-actuating time-current characteristic is the curve reporting the maximum time value during which a residual current greater than the residual non-operating current (equal to $0.5 \cdot I_{\Delta n}$) involves the residual current circuit-breaker without causing the tripping.
As a conclusion, discrimination between two RCDs connected in series can be achieved:
- for S type residual current circuit-breakers, located on the supply side, (complying with IEC 61008-1 and IEC 61009), time-delayed type, by choosing general type circuit-breakers located downstream with $I_{\Delta n}$ equal to one third of $I_{\Delta n}$ of the upstream ones;
- for electronic residual current releases (RC221/222/223, RCQ) by choosing the upstream device with time and current thresholds directly greater than the downstream device, keeping carefully into consideration the tolerances (see Vol. 1, Chapter 2.3: Type of release).

For the protection against indirect contacts in distribution circuits in TT system, the maximum disconnecting time at $I_{\Delta n}$ shall not exceed 1 s (IEC 60364-4-41,§ 413.1)

5.8 Maximum protected length for the protection of human beings

As described in the previous chapters, the Standards give indications about the maximum disconnecting time for the protective devices, in order to avoid pathophysiological effects for people touching live parts.
For the protection against indirect contact, it shall be verified that the circuit-breaker trips within a time lower than the maximum time stated by the Standard; this verification is carried out by comparing the minimum short-circuit current of the exposed conductive part to be protected with the operating current corresponding to the time stated by the Standard.
The minimum short-circuit current occurs when there is a short-circuit between the phase and the protective conductors at the farthest point on the protected conductor.
For the calculation of the minimum short-circuit current, an approximate method can be used, assuming that:

- a 50 % increasing of the conductors resistance, with respect to the 20 °C value, is accepted, due to the overheating caused by the short-circuit current;
- a 80 % reduction of the supply voltage is considered as effect of the short-circuit current;
- the conductor reactance is considered only for cross sections larger than 95 mm².

The formula below is obtained by applying Ohm's law between the protective device and the fault point.

Legend of the symbols and constants of the formula:

- 0.8 is the coefficient representing the reduction of the voltage;
- 1.5 is the coefficient representing the increasing in the resistance;
- U_r is the rated voltage between phases;
- U_0 is the rated voltage between phase and ground;
- S is the phase conductor cross section;
- S_N is the neutral conductor cross section;
- S_{PE} is the protection conductor cross section;
- ρ is the conductor resistivity at 20 °C;
- L is the length of the cable;
- $m = \frac{S \cdot n}{S_{PE}}$ is the ratio between the total phase conductor cross section (single phase conductor cross section S multiplied by n, number of conductors in parallel) and the protective conductor cross section S_{PE} assuming they are made of the same conductor material;
- $m_1 = \frac{S_N \cdot n}{S_{PE}}$ is the ratio between the total neutral conductor cross section (single neutral conductor cross section S_N multiplied by n, number of conductors in parallel) and the protective conductor cross section S_{PE} assuming they are made of the same conductor material;
- k_1 is the correction factor which takes into account the reactance of cables with cross section larger than 95 mm², obtainable from the following table:

Phase conductor cross section [mm²]	120	150	185	240	300
k_1	0.90	0.85	0.80	0.75	0.72

5 Protection of human beings

- k_2 is the correction factor for conductors in parallel, obtainable by the following formula:

$$k_2 = 4\frac{n-1}{n}$$

  where n is the number of conductor in parallel per phase;
- 1.2 is the magnetic threshold tolerance allowed by the Standard.

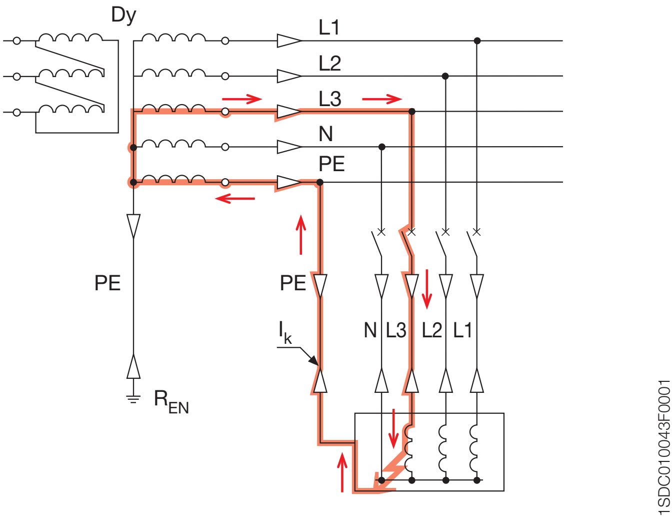
TN system

The formula for the evaluation of the minimum short circuit current is:

$$I_{k\,min} = \frac{0.8 \cdot U_0 \cdot S}{1.5 \cdot 1.2 \cdot \rho \cdot (1+m) \cdot L} \cdot k_1 \cdot k_2$$

and consequently:

$$L = \frac{0.8 \cdot U_0 \cdot S}{1.5 \cdot 1.2 \cdot \rho \cdot (1+m) \cdot I_{k\,min}} \cdot k_1 \cdot k_2$$



IT system

The formulas below are valid when a second fault turns the IT system into a TN system.
It is necessary to separately examine installations with neutral not distributed and neutral distributed.

5 Protection of human beings

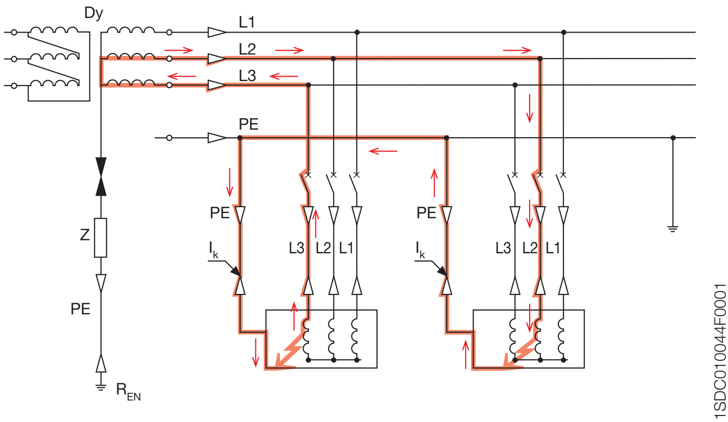
Neutral not distributed

When a second fault occurs, the formula becomes:

$$I_{k\,min} = \frac{0.8 \cdot U_r \cdot S}{2 \cdot 1.5 \cdot 1.2 \cdot \rho \cdot (1+m) \cdot L} \cdot k_1 \cdot k_2$$

and consequently:

$$L = \frac{0.8 \cdot U_r \cdot S}{2 \cdot 1.5 \cdot 1.2 \cdot \rho \cdot (1+m) \cdot I_{k\,min}} \cdot k_1 \cdot k_2$$



Neutral distributed

Case A: three-phase circuits in IT system with neutral distributed
The formula is:

$$I_{k\,min} = \frac{0.8 \cdot U_0 \cdot S}{2 \cdot 1.5 \cdot 1.2 \cdot \rho \cdot (1+m) \cdot L} \cdot k_1 \cdot k_2$$

and consequently:

$$L = \frac{0.8 \cdot U_0 \cdot S}{2 \cdot 1.5 \cdot 1.2 \cdot \rho \cdot (1+m) \cdot I_{k\,min}} \cdot k_1 \cdot k_2$$

Case B: three-phase + neutral circuits in IT system with neutral distributed

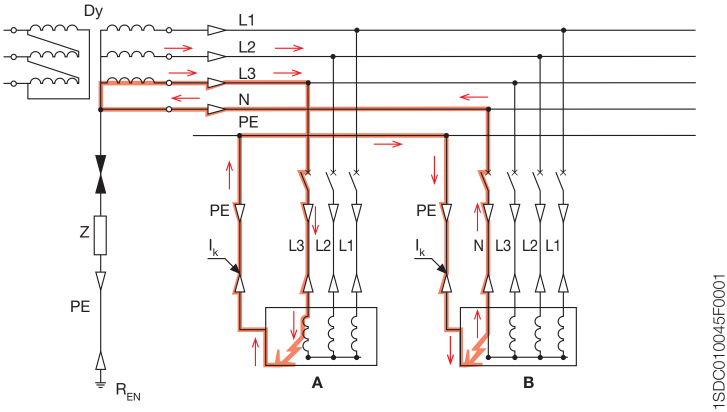
The formula is:

$$I_{k\,min} = \frac{0.8 \cdot U_0 \cdot S_N}{2 \cdot 1.5 \cdot 1.2 \cdot \rho \cdot (1+m_1) \cdot L} \cdot k_1 \cdot k_2$$

and consequently:

$$L = \frac{0.8 \cdot U_0 \cdot S_N}{2 \cdot 1.5 \cdot 1.2 \cdot \rho \cdot (1+m_1) \cdot I_{k\,min}} \cdot k_1 \cdot k_2$$

5 Protection of human beings



Note for the use of the tables

The tables showing the maximum protected length (MPL) have been defined considering the following conditions:

- one cable per phase;
- rated voltage equal to 400 V (three-phase system);
- copper cables;
- neutral not distributed, for IT system only;
- protective conductor cross section according to Table 1:

Table 1: Protective conductor cross section

Phase conductor cross section S [mm²]	Protective conductor cross section S_{PE} [mm²]
S ≤ 16	S
16 < S ≤ 35	16
S > 35	S/2

Note: phase and protective conductors having the same isolation and conductive materials

Whenever the S function (delayed short-circuit) of electronic releases is used for the definition of the maximum protected length, it is necessary to verify that the tripping time is lower than the time value reported in Chapter 5.5 Table 1 for TN systems and in Chapter 5.6 Table 1 for IT systems.

For conditions different from the reference ones, the following correction factors shall be applied.

5 Protection of human beings

Correction factors

Correction factor for cable in parallel per phase: the value of the maximum protected length read in Table 2 (TN system) or Table 3 (IT system) shall be multiplied by the following factor:

n	2	3	4	5	6	7	8
k_p	2	2.7	3	3.2	3.3	3.4	3.5

n is the number of conductors in parallel per phase.

Correction factor for three-phase voltage different from 400 V: the value of the maximum protected length read in Table 2 (TN system) or Table 3 (IT system) shall be multiplied by the following factor:

voltage [V]	230	400	440	500	690
k_V	0.58	1	1.1	1.25	1.73

For 230 V single-phase systems, no correction factor is necessary.

Correction factor for aluminium cables: the value of the maximum protected length read in Table 2 (TN system) or Table 3 (IT system) shall be multiplied by the following factor:

k_{Al}	0.64

Correction factor for protective conductor cross section S_{PE} different from the cross sections stated in Table 1: the value of the maximum protected length shall be multiplied by the coefficient corresponding to the phase conductor cross section and to the ratio between the protective conductor (PE) and the phase cross sections:

S_{PE}/S	0.5	0.55	0.6	0.66	0.75	0.87	1	1.25	1.5	2
S					k_{PE}					
≤16 mm²	0.67	0.71	0.75	0.80	0.86	0.93	1.00	1.11	1.20	1.33
25 mm²	0.85	0.91	0.96	1.02	1.10	1.19	1.28	1.42	1.54	1.71
35 mm²	1.06	1.13	1.20	1.27	1.37	1.48	1.59	1.77	1.91	2.13
>35 mm²	1.00	1.06	1.13	1.2	1.29	1.39	1.5	1.67	1.8	2.00

Correction factor for neutral distributed in IT system (for Table 3 only): the value of the maximum protected length shall be multiplied by 0.58.

5 Protection of human beings

TN system MPL by MCB

Table 2.1: Curve Z

CURVE		Z	Z	Z	Z	Z	Z	Z	Z	Z
In		**≤10**	**13**	**16**	**20**	**25**	**32**	**40**	**50**	**63**
I3		**30**	**39**	**48**	**60**	**75**	**96**	**120**	**150**	**189**
S	**S_{PE}**									
1.5	1.5	173	133	108	86	69	54	43		
2.5	2.5	288	221	180	144	115	90	72	58	45
4	4	461	354	288	231	185	144	115	92	72
6	6	692	532	432	346	277	216	173	138	108
10	10	1153	886	721	577	461	360	288	231	180
16	16	1845	1419	1153	923	738	577	461	369	288
25	16	2250	1730	1406	1125	900	703	563	450	352

Table 2.2: Curve B

CURVE		B	B	B	B	B	B	B	B	B	B	B	B	B
In		**≤6**	**8**	**10**	**13**	**16**	**20**	**25**	**32**	**40**	**50**	**63**	**80**	**100**
I3		**30**	**40**	**50**	**65**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**
S	**S_{PE}**													
1.5	1.5	173	130	104	80	65	52	42	32	26				
2.5	2.5	288	216	173	133	108	86	69	54	43	35	27		
4	4	461	346	277	213	173	138	111	86	69	55	44	35	28
6	6	692	519	415	319	259	208	166	130	104	83	66	52	42
10	10	1153	865	692	532	432	346	277	216	173	138	110	86	69
16	16	1845	1384	1107	852	692	554	443	346	277	221	176	138	111
25	16	2250	1688	1350	1039	844	675	540	422	338	270	214	169	135
35	16												190	152

Table 2.3: Curve C

CURVE		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
In		**≤3**	**4**	**6**	**8**	**10**	**13**	**16**	**20**	**25**	**32**	**40**	**50**	**63**	**80**	**100**	**125**
I3		**30**	**40**	**60**	**80**	**100**	**130**	**160**	**200**	**250**	**320**	**400**	**500**	**630**	**800**	**1000**	**1250**
S	**S_{PE}**																
1.5	1.5	173	130	86	65	52	40	32	26	21	16	13					
2.5	2.5	288	216	144	108	86	67	54	43	35	27	22	17	14			
4	4	461	346	231	173	138	106	86	69	55	43	35	28	22	17	14	11
6	6	692	519	346	259	208	160	130	104	83	65	52	42	33	26	21	17
10	10	1153	865	577	432	346	266	216	173	138	108	86	69	55	43	35	28
16	16	1845	1384	923	692	554	426	346	277	221	173	138	111	88	69	55	44
25	16	2250	1688	1125	844	675	519	422	338	270	211	169	135	107	84	68	54
35	16														95	76	61

5 Protection of human beings

TN system MPL by MCB

Table 2.4: Curve K

CURVE		K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K
In		≤2	≤3	4	4.2	5.8	6	8	10	11	13	15	16	20	25	26	32	37	40	41	45	50	63
I3		28	42	56	59	81	84	112	140	154	182	210	224	280	350	364	448	518	560	574	630	700	882
S	S_{PE}																						
1.5	1.5	185	123	92	88	64	62	46	37	34	28	25	23	18	15	14	12	10	9				
2.5	2.5	308	205	154	146	106	103	77	62	56	47	41	38	31	25	24	19	17	15	15	14		
4	4	492	328	246	234	170	164	123	98	89	76	66	62	49	39	38	31	27	25	24	22	20	16
6	6	738	492	369	350	255	246	185	148	134	114	98	92	74	59	57	46	40	37	36	33	30	23
10	10	1231	820	615	584	425	410	308	246	224	189	164	154	123	98	95	77	67	62	60	55	49	39
16	16	1969	1313	984	934	681	656	492	394	358	303	263	246	197	158	151	123	106	98	96	88	79	63
25	16	2401	1601	1201	1140	830	800	600	480	437	369	320	300	240	192	185	150	130	120	117	107	96	76

Table 2.5: Curve D

CURVE		D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
In		≤2	3	4	6	8	10	13	16	20	25	32	40	50	63	80	100
I3		40	60	80	120	160	200	260	320	400	500	640	800	1000	1260	1600	2000
S	S_{PE}																
1.5	1.5	130	86	65	43	32	26	20	16	13	10	8	6				
2.5	2.5	216	144	108	72	54	43	33	27	22	17	14	11	9	7		
4	4	346	231	173	115	86	69	53	43	35	28	22	17	14	11	9	7
6	6	519	346	259	173	130	104	80	65	52	42	32	26	21	16	13	10
10	10	865	577	432	288	216	173	133	108	86	69	54	43	35	27	22	17
16	16	1384	923	692	461	346	277	213	173	138	111	86	69	55	44	35	28
25	16	1688	1125	844	563	422	338	260	211	169	135	105	84	68	54	42	34
35	16															47	38

5 Protection of human beings

TN system MPL by MCCB

Table 2.6: TmaxT1 TMD

		T1	T1	T1	T1	T1	T1
	In	≤50	63	80	100	125	160
	I3	500 A	10 In	10 In	10 In	10 In	10 In
S	S_{PE}						
1.5	1.5	6					
2.5	2.5	10					
4	4	15	12	10	8	6	
6	6	23	18	14	12	9	7
10	10	38	31	24	19	15	12
16	16	62	49	38	31	25	19
25	16	75	60	47	38	30	23
35	16	84	67	53	42	34	26
50	25	128	102	80	64	51	40
70	35	179	142	112	90	72	56
95	50	252	200	157	126	101	79

Table 2.7: Tmax T2 TMD

		T2	T2	T2	T2	T2	T2	T2	T2	T2	T2	T2	T2	T2	T2	T2	T2
	In	1.6	2	2.5	3.2	4	5	6.3	8	10	12.5	16÷50	63	80	100	125	160
	I3	10 In	10 In	10 In	10 In	10 In	10 In	10 In	10 In	10 In	10 In	500 A	10 In	10 In	10 In	10 In	10 In
S	S_{PE}																
1.5	1.5	246	197	157	123	98	79	62	49	39	31	8					
2.5	2.5	410	328	262	205	164	131	104	82	66	52	13					
4	4	655	524	419	328	262	210	166	131	105	84	21	17	13	10	8	
6	6	983	786	629	491	393	315	250	197	157	126	31	25	20	16	13	10
10	10	1638	1311	1048	819	655	524	416	328	262	210	52	42	33	26	21	16
16	16	2621	2097	1677	1311	1048	839	666	524	419	335	84	67	52	42	34	26
25	16				1598	1279	1023	812	639	511	409	102	81	64	51	41	32
35	16						1151	914	720	576	460	115	91	72	58	46	36
50	25								1092	874	699	175	139	109	87	70	55
70	35										979	245	194	153	122	98	76
95	50											343	273	215	172	137	107
120	70											417	331	261	209	167	130
150	95											518	411	324	259	207	162
185	95											526	418	329	263	211	165

5 Protection of human beings

TN system MPL by MCCB

Table 2.8: Tmax T3 TMD

		T3	T3	T3	T3	T3	T3	T3
	In	**63**	**80**	**100**	**125**	**160**	**200**	**250**
	I3	**10 In**	**10 In**	**10 In**	**10 In**	**10 In**	**10 In**	**10 In**
S	**S_{PE}**							
4	4	17	13	10	8			
6	6	25	20	16	13	10	8	
10	10	42	33	26	21	16	13	10
16	16	67	52	42	34	26	21	17
25	16	81	64	51	41	32	26	20
35	16	91	72	58	46	36	29	23
50	25	139	109	87	70	55	44	35
70	35	194	153	122	98	76	61	49
95	50	273	215	172	137	107	86	69
120	70	331	261	209	167	130	104	83
150	95	411	324	259	207	162	130	104
185	95	418	329	263	211	165	132	105
240	120	499	393	315	252	197	157	126

Table 2.9: Tmax T4 TMD/TMA

		T4	T4	T4	T4	T4	T4	T4	T4	T4	T4
	In	**20**	**32**	**50**	**80**	**100**	**125**	**160**	**200**	**250**	**320**
	I_3	**320 A**	**10 In**	**10 In**	**5...10 In**	**5...10 In**	**5...10 In**	**5...10 In**	**5...10 In**	**5...10 In**	**5...10 In**
S	**S_{PE}**										
1.5	1.5	14	14	9	11…5	9…4	7…3	5…3	4…2	3…2	3…1
2.5	2.5	23	23	14	18…9	14…7	12…6	9…5	7…4	6…3	5…2
4	4	36	36	23	29…14	23…12	18…9	14…7	12…6	9…5	7…4
6	6	54	54	35	43…22	35…17	28…14	22…11	17…9	14…7	11…5
10	10	90	90	58	72…36	58…29	46…23	36…18	29…14	23…12	18…9
16	16	144	144	92	115…58	92…46	74…37	58…29	46…23	37…18	29…14
25	16	176	176	113	141…70	113…56	90…45	70…35	56…28	45…23	35…18
35	16	198	198	127	158…79	127…63	101…51	79…40	63…32	51…25	40…20
50	25	300	300	192	240…120	192…96	154…77	120…60	96…48	77…38	60…30
70	35	420	420	269	336…168	269…135	215…108	168…84	135…67	108…54	84…42
95	50	590	590	378	472…236	378…189	302…151	236…118	189…94	151…76	118…59
120	70	717	717	459	574…287	459…229	367…184	287…143	229…115	184…92	143…72
150	95	891	891	570	713…356	570…285	456…228	356…178	285…143	228…114	178…89
185	95	905	905	579	724…362	579…290	463…232	362…181	290…145	232…116	181…90
240	120	1081	1081	692	865…432	692…346	554…277	432…216	346…173	277…138	216…108
300	150	1297	1297	830	1038…519	830…415	664…332	519…259	415…208	332…166	259…130

5 Protection of human beings

TN system MPL by MCCB

Table 2.10: Tmax T5 TMA

		T5	T5	T5	T5
	In	**320**	**400**	**500**	**630**
	I_3	**5...10 In**	**5...10 In**	**5...10 In**	**5...10 In**
S	**S_{PE}**				
1,5	1,5	3…1	2…1	2…1	1…1
2,5	2,5	5…2	4…2	3…1	2…1
4	4	7…4	6…3	5…2	4…2
6	6	11…5	9…4	7…3	5…3
10	10	18…9	14…7	12…6	9…5
16	16	29…14	23…12	18…9	15…7
25	16	35…18	28…14	23…11	18…9
35	16	40…20	32…16	25…13	20…10
50	25	60…30	48…24	38…19	31…15
70	35	84…42	67…34	54…27	43…21
95	50	118…59	94…47	76…38	60…30
120	70	143…72	115…57	92…46	73…36
150	95	178…89	143…71	114…57	91…45
185	95	181…90	145…72	116…58	92…46
240	120	216…108	173…86	138…69	110…55
300	150	259…130	208…104	166…83	132…66

Table 2.11: Tmax T2 with PR221 DS-LS

		T2	T2	T2	T2	T2
	In	**10**	**25**	**63**	**100**	**160**
	I3	**5.5 In**	**5.5 In**	**5.5 In**	**5.5 In**	**5.5 In**
S	**S_{PE}**					
1.5	1.5	79	31	12		
2.5	2.5	131	52	21		
4	4	210	84	33	21	
6	6	315	126	50	31	20
10	10	524	210	83	52	33
16	16	839	335	133	84	52
25	16	1023	409	162	102	64
35	16	1151	460	183	115	72
50	25	1747	699	277	175	109
70	35	2446	979	388	245	153
95	50	3434	1374	545	343	215
120	70	4172	1669	662	417	261
150	95	5183	2073	823	518	324
185	95	5265	2106	836	526	329

Note: if the setting of function I is different from the reference value (5.5) the value of the MPL shall be multiplied by the ratio between the reference value and the set value.

5 Protection of human beings

TN system MPL by MCCB

Table 2.12: Tmax T4-T5 with PR221 - PR222

		T4	T4	T4	T4	T5	T5	T5
	In	100	160	250	320	320	400	630
	I_3	6.5 In	6.5 In	6.5 In	6.5 In	6.5 In	6.5 In	6.5 In
S	S_{PE}							
1,5	1,5							
2,5	2,5							
4	4							
6	6	29	18					
10	10	48	30	19				
16	16	77	48	31	24	24	19	
25	16	94	59	38	30	30	24	15
35	16	106	66	43	33	33	27	17
50	25	161	101	65	50	50	40	26
70	35	226	141	90	71	71	56	36
95	50	317	198	127	99	99	79	50
120	70	385	241	154	120	120	96	61
150	95	478	299	191	150	150	120	76
185	95	486	304	194	152	152	121	77
240	120	581	363	232	181	181	145	92
300	150	697	435	279	218	218	174	111

Note: if the setting of function I is different from the reference value (6.5) the value of the MPL shall be multiplied by the ratio between the reference value and the set value.

Table 2.13: SACE Isomax S6÷S8 with PR211- PR212

		S6	S7	S7	S7	S8	S8	S8	S8
	In	800	1000	1250	1600	1600	2000	2500	3200
	I3	6 In	6 In	6 In	6 In	6 In	6 In	6 In	6 In
S	S_{PE}								
2.5	2.5								
4	4								
6	6								
10	10								
16	16								
25	16								
35	16								
50	25	20							
70	35	28	22	18	14	14			
95	50	39	31	25	20	20	16	13	10
120	70	48	38	31	24	24	19	15	12
150	95	59	48	38	30	30	24	19	15
185	95	60	48	39	30	30	24	19	15
240	120	72	58	46	36	36	29	23	18
300	150	86	69	55	43	43	35	28	22

Note: if the setting of function S or I is different from the reference value (6) the MPL value shall be multiplied by the ratio between the reference value and the set value. Besides, using function S the MPL shall be multiplied by 1.1.

5 Protection of human beings

IT system MPL by MCB

Table 3.1: Curve Z

CURVE		Z	Z	Z	Z	Z	Z	Z	Z	Z	Z
In		**≤8**	**10**	**13**	**16**	**20**	**25**	**32**	**40**	**50**	**63**
I3		**30**	**30**	**39**	**48**	**60**	**75**	**96**	**120**	**150**	**189**
S	**S_{PE}**										
1.5	1.5	150	150	115	94	75	60	47	37		
2.5	2.5	250	250	192	156	125	100	78	62	50	40
4	4	400	400	307	250	200	160	125	100	80	63
6	6	599	599	461	375	300	240	187	150	120	95
10	10	999	999	768	624	499	400	312	250	200	159
16	16	1598	1598	1229	999	799	639	499	400	320	254
25	16	1949	1949	1499	1218	974	780	609	487	390	309

Table 3.2: Curve B

CURVE		B	B	B	B	B	B	B	B	B	B	B	B	B
In		**≤6**	**8**	**10**	**13**	**16**	**20**	**25**	**32**	**40**	**50**	**63**	**80**	**100**
I3		**30**	**40**	**50**	**65**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**
S	**S_{PE}**													
1.5	1.5	150	112	90	69	56	45	36	28	22				
2.5	2.5	250	187	150	115	94	75	60	47	37	30	24		
4	4	400	300	240	184	150	120	96	75	60	48	38	30	24
6	6	599	449	360	277	225	180	144	112	90	72	57	45	36
10	10	999	749	599	461	375	300	240	187	150	120	95	75	60
16	16	1598	1199	959	738	599	479	384	300	240	192	152	120	96
25	16	1949	1462	1169	899	731	585	468	365	292	234	186	146	117
35	16												165	132

Table 3.3: Curve C

CURVE		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
In		**≤3**	**4**	**6**	**8**	**10**	**13**	**16**	**20**	**25**	**32**	**40**	**50**	**63**	**80**	**100**	**125**
I3		**30**	**40**	**60**	**80**	**100**	**130**	**160**	**200**	**250**	**320**	**400**	**500**	**630**	**800**	**1000**	**1250**
S	**S_{PE}**																
1.5	1.5	150	112	75	56	45	35	28	22	18	14	11					
2.5	2.5	250	187	125	94	75	58	47	37	30	23	19	15	12			
4	4	400	300	200	150	120	92	75	60	48	37	30	24	19	15	12	10
6	6	599	449	300	225	180	138	112	90	72	56	45	36	29	22	18	14
10	10	999	749	499	375	300	230	187	150	120	94	75	60	48	37	30	24
16	16	1598	1199	799	599	479	369	300	240	192	150	120	96	76	60	48	38
25	16	1949	1462	974	731	585	450	365	292	234	183	146	117	93	73	58	47
35	16														82	66	53

5 Protection of human beings

IT system MPL by MCB

Table 3.4: Curve K

CURVE		K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K
In		**≤2**	**≤3**	**4**	**4.2**	**5.8**	**6**	**8**	**10**	**11**	**13**	**15**	**16**	**20**	**25**	**26**	**32**	**37**	**40**	**41**	**45**	**50**	**63**
I3		**28**	**42**	**56**	**59**	**81**	**84**	**112**	**140**	**154**	**182**	**210**	**224**	**280**	**350**	**364**	**448**	**518**	**560**	**574**	**630**	**700**	**882**
S	**S_{PE}**																						
1.5	1.5	161	107	80	76	55	54	40	32	29	25	21	20	16	13	12	10	9	8				
2.5	2.5	268	178	134	127	92	89	67	54	49	41	36	33	27	21	21	17	14	13	13	12		
4	4	428	285	214	204	148	143	107	86	78	66	57	54	43	34	33	27	23	21	21	19	17	14
6	6	642	428	321	306	221	214	161	128	117	99	86	80	64	51	49	40	35	32	31	29	26	20
10	10	1070	713	535	510	369	357	268	214	195	165	143	134	107	86	82	67	58	54	52	48	43	34
16	16	1712	1141	856	815	590	571	428	342	311	263	228	214	171	137	132	107	93	86	84	76	68	54
25	16	2088	1392	1044	994	720	696	522	418	380	321	278	261	209	167	161	130	113	104	102	93	84	66

Table 3.5: Curve D

CURVE		D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
In		**≤2**	**3**	**4**	**6**	**8**	**10**	**13**	**16**	**20**	**25**	**32**	**40**	**50**	**63**	**80**	**100**
I3		**40**	**60**	**80**	**120**	**160**	**200**	**260**	**320**	**400**	**500**	**640**	**800**	**1000**	**1260**	**1600**	**2000**
S	**S_{PE}**																
1.5	1.5	112	75	56	37	28	22	17	14	11	9	7	6				
2.5	2.5	187	125	94	62	47	37	29	23	19	15	12	9	7	6		
4	4	300	200	150	100	75	60	46	37	30	24	19	15	12	10	7	6
6	6	449	300	225	150	112	90	69	56	45	36	28	22	18	14	11	9
10	10	749	499	375	250	187	150	115	94	75	60	47	37	30	24	19	15
16	16	1199	799	599	400	300	240	184	150	120	96	75	60	48	38	30	24
25	16	1462	974	731	487	365	292	225	183	146	117	91	73	58	46	37	29
35																41	33

5 Protection of human beings

IT system MPL by MCCB

Table 3.6: Tmax T1 TMD

		T1	T1	T1	T1	T1	T1
	In	**≤50**	**63**	**80**	**100**	**125**	**160**
	I3	**500 A**	**10 In**	**10 In**	**10 In**	**10 In**	**10 In**
S	**S_{PE}**						
1.5	1.5	5					
2.5	2.5	8					
4	4	13	11	8	7	5	
6	6	20	16	12	10	8	6
10	10	33	26	21	17	13	10
16	16	53	42	33	27	21	17
25	16	65	52	41	32	26	20
35	16	73	58	46	37	29	23
50	25	111	88	69	55	44	35
70	35	155	123	97	78	62	49
95	50	218	173	136	109	87	68

Table 3.7: Tmax T2 TMD

		T2	T2	T2	T2	T2	T2	T2	T2	T2	T2	T2	T2	T2	T2	T2	T2
	In	**1.6**	**2**	**2.5**	**3.2**	**4**	**5**	**6.3**	**8**	**10**	**12.5**	**16÷50**	**63**	**80**	**100**	**125**	**160**
	I3	**10 In**	**10 In**	**10 In**	**10 In**	**10 In**	**10 In**	**10 In**	**10 In**	**10 In**	**10 In**	**500 A**	**10 In**	**10 In**	**10 In**	**10 In**	**10 In**
S	**S_{PE}**																
1.5	1.5	213	170	136	106	85	68	54	43	34	27	7					
2.5	2.5	355	284	227	177	142	113	90	71	57	45	11					
4	4	567	454	363	284	227	182	144	113	91	73	18	14	11	9	7	
6	6	851	681	545	426	340	272	216	170	136	109	27	22	17	14	11	9
10	10	1419	1135	908	709	567	454	360	284	227	182	45	36	28	23	18	14
16	16	2270	1816	1453	1135	908	726	576	454	363	291	73	58	45	36	29	23
25	16				1384	1107	886	703	554	443	354	89	70	55	44	35	28
35	16						997	791	623	498	399	100	79	62	50	40	31
50	25								946	757	605	151	120	95	76	61	47
70	35										847	212	168	132	106	85	66
95	50											297	236	186	149	119	93
120	70											361	287	226	181	145	113
150	95											449	356	281	224	180	140
185	95											456	362	285	228	182	142

5 Protection of human beings

IT system MPL by MCCB

Table 3.8: Tmax T3 TMD

		T3	T3	T3	T3	T3	T3	T3
In		**63**	**80**	**100**	**125**	**160**	**200**	**250**
I3		**10 In**	**10 In**	**10 In**	**10 In**	**10 In**	**10 In**	**10 In**
S	**S_{PE}**							
4	4	14	11	9	7			
6	6	22	17	14	11	9	7	
10	10	36	28	23	18	14	11	9
16	16	58	45	36	29	23	18	15
25	16	70	55	44	35	28	22	18
35	16	79	62	50	40	31	25	20
50	25	120	95	76	61	47	38	30
70	35	168	132	106	85	66	53	42
95	50	236	186	149	119	93	74	59
120	70	287	226	181	145	113	90	72
150	95	356	281	224	180	140	112	90
185	95	362	285	228	182	142	114	91
240	120	432	340	272	218	170	136	109

Table 3.9: Tmax T4 TMD/TMA

		T4	T4	T4	T4	T4	T4	T4	T4	T4	T4
	In	**20**	**32**	**50**	**80**	**100**	**125**	**160**	**200**	**250**	**320**
	I_3	**320 A**	**10 In**	**10 In**	**5...10 In**	**5...10 In**	**5...10 In**	**5...10 In**	**5...10 In**	**5...10 In**	**5...10 In**
S	**S_{PE}**										
1,5	1,5	12	12	7	9…5	7…4	6…3	5…2	4…2	3…1	2…1
2,5	2,5	20	20	12	16…8	12…6	10…5	8…4	6…3	5…2	4…2
4	4	31	31	20	25…12	20…10	16…8	12…6	10…5	8…4	6…3
6	6	47	47	30	37…19	30…15	24…12	19…9	15…7	12…6	9…5
10	10	78	78	50	62…31	50…25	40…20	31…16	25…12	20…10	16…8
16	16	125	125	80	100…50	80…40	64…32	50…25	40…20	32…16	25…12
25	16	152	152	97	122…61	97…49	78…39	61…30	49…24	39…19	30…15
35	16	171	171	110	137…69	110…55	88…44	69…34	55…27	44…22	34…17
50	25	260	260	166	208…104	166…83	133…67	104…52	83…42	67…33	52…26
70	35	364	364	233	291…146	233…117	186…93	146…73	117…58	93…47	73…36
95	50	511	511	327	409…204	327…164	262…131	204…102	164…82	131…65	102…51
120	70	621	621	397	497…248	397…199	318…159	248…124	199…99	159…79	124…62
150	95	772	772	494	617…309	494…247	395…198	309…154	247…123	198…99	154…77
185	95	784	784	502	627…313	502…251	401…201	313…157	251…125	201…100	157…78
240	120	936	936	599	749…375	599…300	479…240	375…187	300…150	240…120	187…94
300	150	1124	1124	719	899…449	719…360	575…288	449…225	360…180	288…144	225…112

5 Protection of human beings

IT system MPL by MCCB

Table 3.10: Tmax T5 TMA

		T5	T5	T5	T5
	In	**320**	**400**	**500**	**630**
	I_3	**5...10 In**	**5...10 In**	**5...10 In**	**5...10 In**
S	**S_{PE}**				
1,5	1,5	2…1	2…1	1…1	1…1
2,5	2,5	4…2	3…2	2…1	2…1
4	4	6…3	5…2	4…2	3…2
6	6	9…5	7…4	6…3	5…2
10	10	16…8	12…6	10…5	8…4
16	16	25…12	20…10	16…8	13…6
25	16	30…15	24…12	19…10	15…8
35	16	34…17	27…14	22…11	17…9
50	25	52…26	42…21	33…17	26…13
70	35	73…36	58…29	47…23	37…18
95	50	102…51	82…41	65…33	52…26
120	70	124…62	99…50	79…40	63…32
150	95	154…77	123…62	99…49	78…39
185	95	157…78	125…63	100…50	80…40
240	120	187…94	150…75	120…60	95…48
300	150	225…112	180…90	144…72	114…57

Table 3.11: Tmax T2 with PR221DS-LS

		T2	T2	T2	T2	T2
	In	**10**	**25**	**63**	**100**	**160**
	I3	**5.5 In**	**5.5 In**	**5.5 In**	**5.5 In**	**5.5 In**
S	**S_{PE}**					
1.5	1.5	68	27	11		
2.5	2.5	113	45	18		
4	4	182	73	29	18	
6	6	272	109	43	27	17
10	10	454	182	72	45	28
16	16	726	291	115	73	45
25	16	886	354	141	89	55
35	16	997	399	158	100	62
50	25	1513	605	240	151	95
70	35	2119	847	336	212	132
95	50	2974	1190	472	297	186
120	70	3613	1445	573	361	226
150	95	4489	1796	713	449	281
185	95	4559	1824	724	456	285

Note: if the setting of function I is different from the reference value (5.5) the MPL value shall be multiplied by the ratio between the reference value and the set value.

5 Protection of human beings

IT system MPL by MCCB

Table 3.12: Tmax T4-T5 with PR221-PR222

		T4	T4	T4	T4	T5	T5	T5
	In	100	160	250	320	320	400	630
	I_3	6.5 In	6.5 In	6.5 In	6.5 In	6.5 In	6.5 In	6.5 In
S	S_{PE}							
1,5	1,5							
2,5	2,5							
4	4							
6	6	25	16					
10	10	42	26	17				
16	16	67	42	27	21	21	17	
25	16	82	51	33	26	26	20	13
35	16	92	58	37	29	29	23	15
50	25	140	87	56	44	44	35	22
70	35	196	122	78	61	61	49	31
95	50	275	172	110	86	86	69	44
120	70	333	208	133	104	104	83	53
150	95	414	259	166	129	129	104	66
185	95	421	263	168	132	132	105	67
240	120	503	314	201	157	157	126	80
300	150	603	377	241	189	189	151	96

Note: if the setting of function I is different from the reference value (6.5) the value of the MPL shall be multiplied by the ratio between the reference value and the set value.

5 Protection of human beings

IT system MPL by MCCB

Table 3.13: SACE Isomax S6-S8 with PR211-212

		S6	S7	S7	S7	S8	S8	S8	S8
	In	800	1000	1250	1600	1600	2000	2500	3200
	I3	6 In	6 In	6 In	6 In	6 In	6 In	6 In	6 In
S	S_{PE}								
2.5	2.5								
4	4								
6	6								
10	10								
16	16								
25	16								
35	16								
50	25	17							
70	35	24	19	16	12	12			
95	50	34	27	22	17	17	14	11	9
120	70	41	33	26	21	21	17	13	10
150	95	51	41	33	26	26	21	16	13
185	95	52	42	33	26	26	21	17	13
240	120	62	50	40	31	31	25	20	16
300	150	75	60	48	37	37	30	24	19

Note: if the setting of function S or I is different from the reference value (6) the MPL value shall be multiplied by the ratio between the reference value and the set value. Besides, using function S, the MPL shall be multiplied by 1.1.

Annex A: Calculation tools

A.1 Slide rules

These slide rules represent a valid instrument for a quick and approximate dimensioning of electrical plants.
All the given information is connected to some general reference conditions; the calculation methods and the data reported are gathered from the IEC Standards in force and from plant engineering practice. The instruction manual enclosed with the slide rules offers different examples and tables showing the correction coefficients necessary to extend the general reference conditions to those actually required.

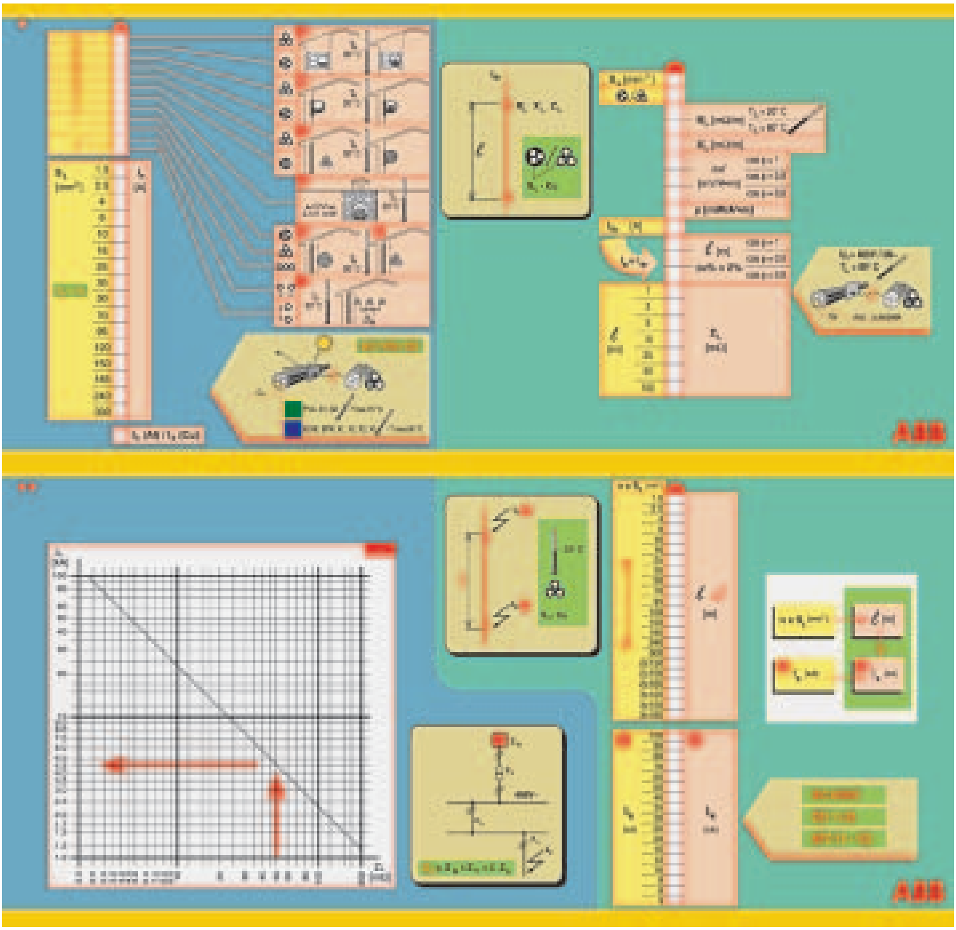
These two-sided slide rules are available in four different colors, easily identified by subject:
- yellow slide rule: cable sizing;
- orange slide rule: cable verification and protection;
- green slide rule: protection coordination;
- blue slide rule: motor and transformer protection.

Annex A: Calculation tools

Yellow slide rule: cable sizing

Side ●
Definition of the current carrying capacity, impedance and voltage drop of cables.

Side ● ●
Calculation of the short-circuit current for three-phase fault on the load side of a cable line with known cross section and length.
In addition, a diagram for the calculation of the short-circuit current on the load side of elements with known impedance.



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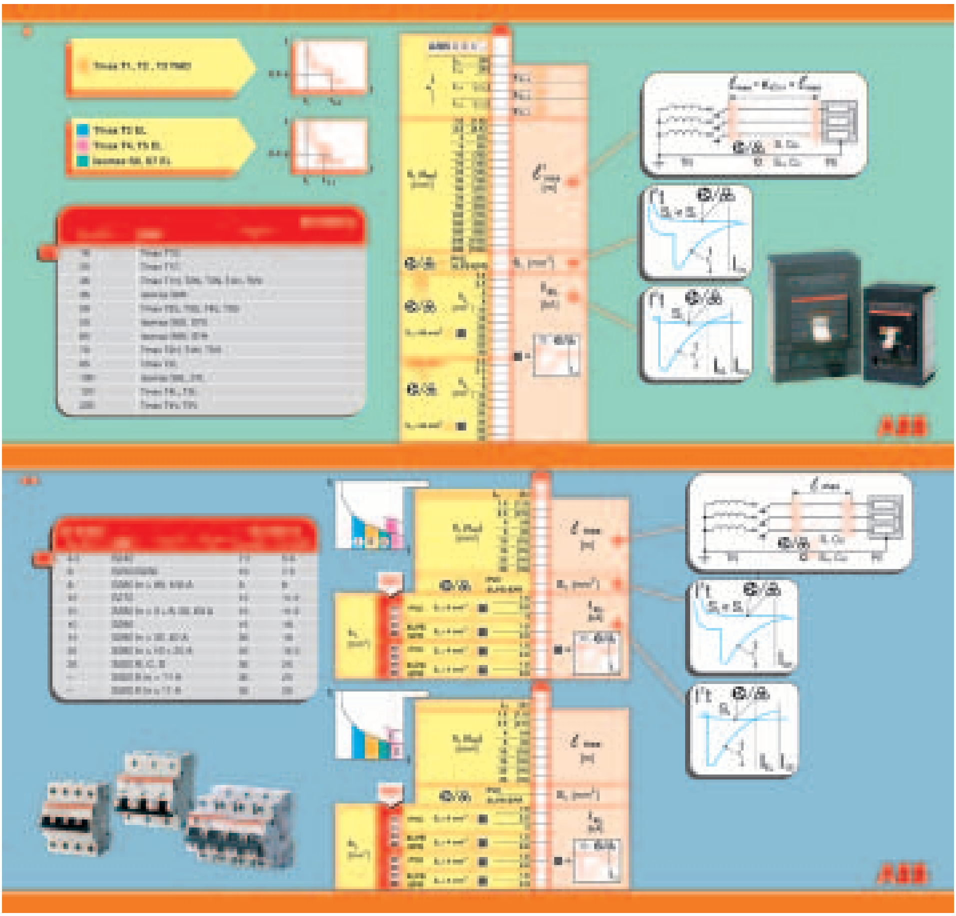
Annex A: Calculation tools

Orange slide rule: cable verification and protection

Side ●
Verification of cable protection against indirect contact and short-circuit with ABB SACE MCCBs (moulded-case circuit-breakers).

Side ● ●
Verification of cable protection against indirect contact and short-circuit with ABB MCBs (modular circuit-breakers).



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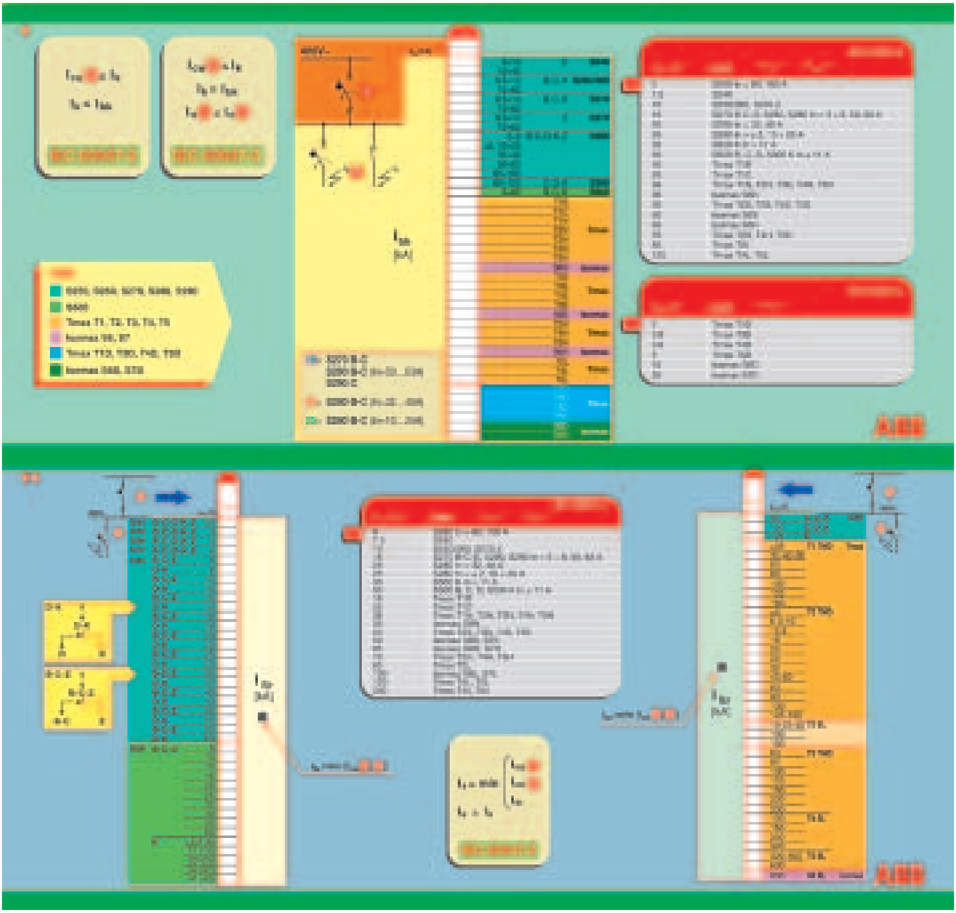
Annex A: Calculation tools

Green slide rule: protection coordination

Side ●
Selection of the circuit-breakers when back-up protection is provided.

Side ● ●
Definition of the discrimination limit current for the combination of two circuit-breakers in series.



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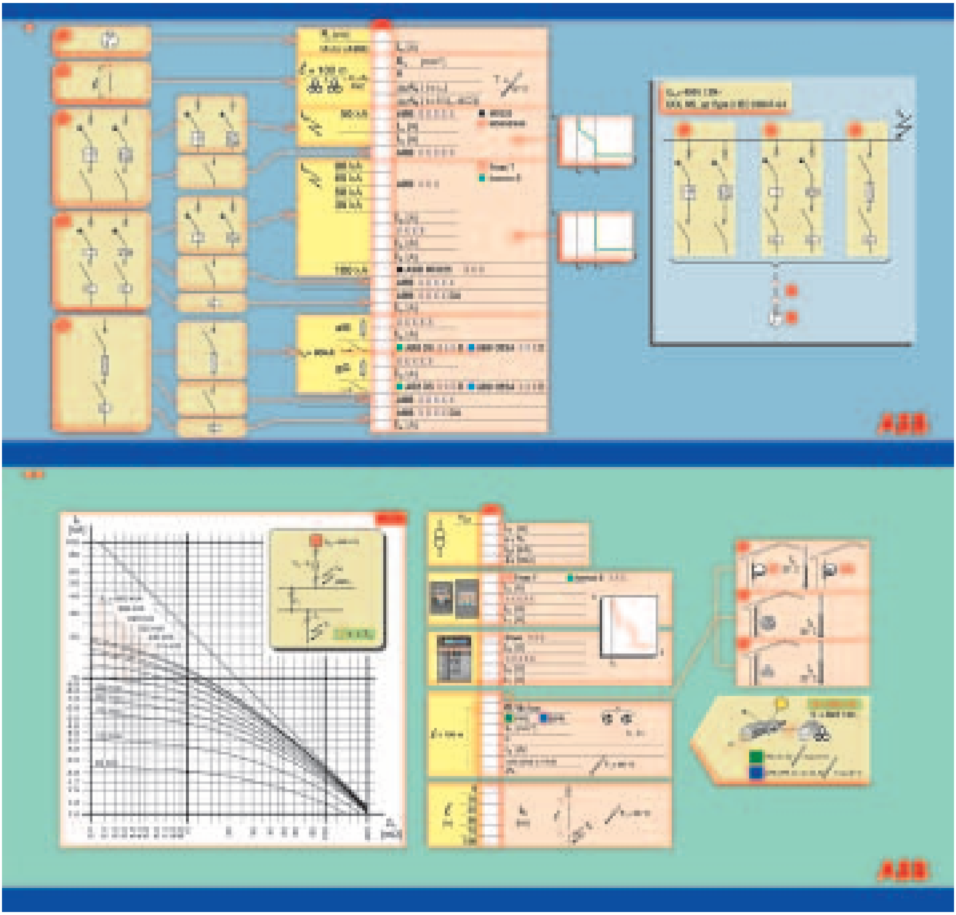
Annex A: Calculation tools

Blue slide rule: motor and transformer protection

Side ●
Selection and coordination of the protection devices for the motor starter, DOL start-up (coordination type 2 in compliance with the Standard IEC 60947-4-1).

Side ● ●
Sizing of a transformer feeder.
In addition, a diagram for the calculation of the short-circuit current on the load side of transformers with known rated power.



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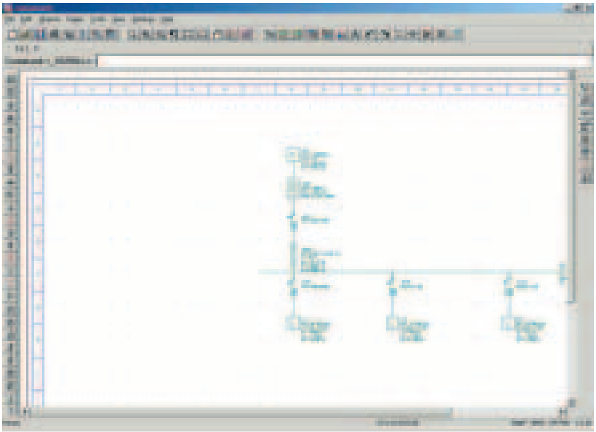
Annex A: Calculation tools

A.2 DOCWin

DOCWin is a software for the dimensioning of electrical networks, with low or medium voltage supply.
Networks can be completely calculated through simple operations starting from the definition of the single-line diagram and thanks to the drawing functions provided by an integrated CAD software.

Drawing and definition of networks

Creation of the single-line diagram, with no limits to the network complexity. Meshed networks can also be managed.
- The diagram can be divided into many pages.
- The program controls the coherence of drawings in real time.
- It is possible to enter and modify the data of the objects which form the network by using a table.
- It is possible to define different network configurations by specifying the status (open/closed) of the operating and protective devices.



Supplies

- There are no pre-defined limits: the software manages MV and LV power supplies and generators, MV/LV and LV/LV transformers, with two or three windings, with or without voltage regulator, according to the requirements.

Network calculation

- Load Flow calculation using the Newton-Raphson method. The software can manage networks with multiple slacks and unbalances due to single- or two-phase loads. Magnitude and phase shift of the node voltage and of the branch current are completely defined for each point of the network, for both MV as well as LV.
- Calculation of the active and reactive power required by each single power source.

Annex A: Calculation tools

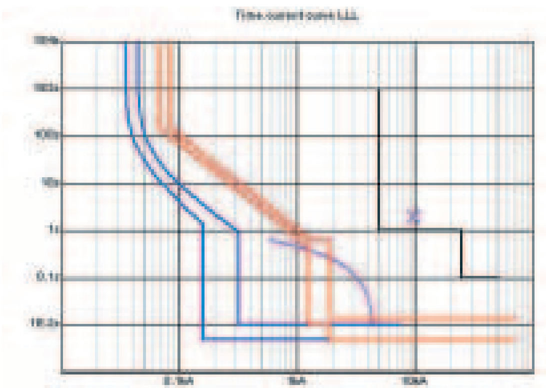
- Management of local (motors) and centralized power factor correction with capacitor banks.
- Management of the demand factor for each single node of the network and of the utilization factor on the loads.
- Short-circuit current calculation for three-phase, phase-to-phase, phase-to-neutral, phase-to-ground faults. The calculation is also carried out for MV sections, in compliance with the Standards IEC 60909-1, IEC 61363-1 (naval installations) or with the method of symmetric components, taking into account also the time-variance contribution of rotary machines (generators and motors).
- Calculation of switchboard overtemperature in compliance with Standard IEC 60890. The power dissipated by the single apparatus is automatically derived by the data files of the software, and can be considered as a function of the rated current or of the load current.

Cable line sizing

- Cable line sizing according to thermal criteria in compliance with the following Standards: CEI 64-8 (tables CEI UNEL 35024-35026), IEC 60364, VDE 298-4, NFC 15-100, IEC 60092 (naval installations) and IEC 60890.
- Possibility of setting, as additional calculation criterion, the economic criteria stated in the Standard IEC 60827-3-2.
- Possibility of setting, as additional calculation criterion, the maximum allowed voltage drop.
- Automatic sizing of busbar trunking system.
- Sizing and check on the dynamic withstand of busbars in compliance with the Standard IEC 60865.

Curves and verifications

- Representation of:
- time / current curves (I-t),
- current / let-through energy curves (I-I^2t),
- current limiting curves (peak): visual check of the effects of the settings on the trip characteristics of protection devices.

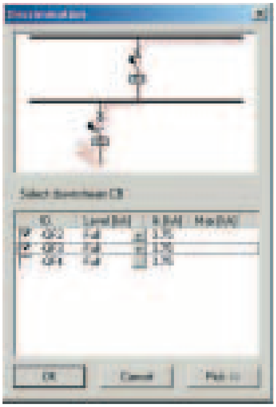


Annex A: Calculation tools

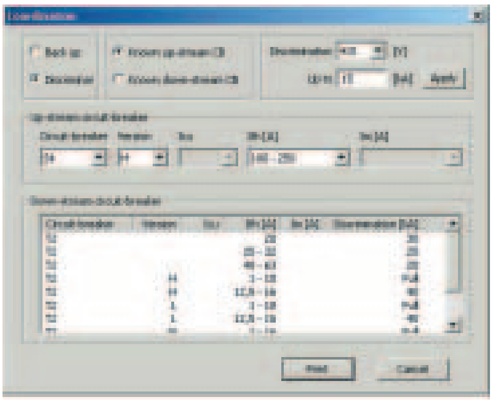
- Representation of the curves of circuit-breakers, cables, transformers, motors and generators.
- Possibility of entering the curve of the utility and of the MV components point by point, to verify the tripping discrimination of protection devices.
- Verification of the maximum voltage drop at each load.
- Verification of the protection devices, with control over the setting parameters of the adjustable releases (both thermomagnetic as well as electronic).

Selection of operating and protection devices

- Automatic selection of protection devices (circuit-breakers and fuses)
- Automatic selection of operating devices (contactors and switch disconnectors)
- Discrimination and back-up managed as selection criteria, with discrimination level adjustable for each circuit-breaker combination.

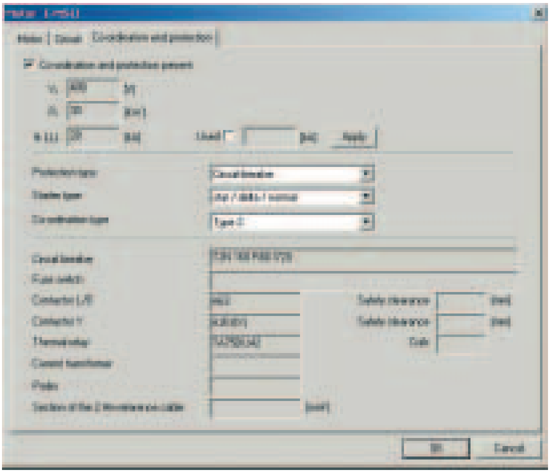


- Discrimination and back-up verification also through quick access to coordination tables.



Annex A: Calculation tools

- Motor coordination management through quick access to ABB tables.



Printouts

- Single-line diagram, curves and reports of the single components of the network can be printed by any printer supported by the hardware configuration.
- All information can be exported in the most common formats of data exchange.
- All print modes can be customized.

Annex B: Calculation of load current I_b

Generic loads

The formula for the calculation of the load current of a generic load is:

$$I_b = \frac{P}{k \cdot U_r \cdot \cos\varphi}$$

where:

- P is the active power [W];
- k is a coefficient which has the value:
  - 1 for single-phase systems or for direct current systems;
  - $\sqrt{3}$ for three-phase systems;
- U_r is the rated voltage [V] (for three-phase systems it is the line voltage, for single-phase systems it is the phase voltage);
- $\cos\varphi$ is the power factor.

Table 1 allows the load current to be determined for some power values according to the rated voltage. The table has been calculated considering $\cos\varphi$ to be equal to 0.9; for different power factors, the value from Table 1 must be multiplied by the coefficient given in Table 2 corresponding to the actual value of the power factor ($\cos\varphi_{act}$).

Table 1: Load current for three-phase systems with $\cos\varphi$ = 0.9

				U_r [V]			
	230	**400**	**415**	**440**	**500**	**600**	**690**
P [kW]				I_b **[A]**			
0.03	0.08	0.05	0.05	0.04	0.04	0.03	0.03
0.04	0.11	0.06	0.06	0.06	0.05	0.04	0.04
0.06	0.17	0.10	0.09	0.09	0.08	0.06	0.06
0.1	0.28	0.16	0.15	0.15	0.13	0.11	0.09
0.2	0.56	0.32	0.31	0.29	0.26	0.21	0.19
0.5	1.39	0.80	0.77	0.73	0.64	0.53	0.46
1	2.79	1.60	1.55	1.46	1.28	1.07	0.93
2	5.58	3.21	3.09	2.92	2.57	2.14	1.86
5	13.95	8.02	7.73	7.29	6.42	5.35	4.65
10	27.89	16.04	15.46	14.58	12.83	10.69	9.30
20	55.78	32.08	30.92	29.16	25.66	21.38	18.59
30	83.67	48.11	46.37	43.74	38.49	32.08	27.89
40	111.57	64.15	61.83	58.32	51.32	42.77	37.19
50	139.46	80.19	77.29	72.90	64.15	53.46	46.49
60	167.35	96.23	92.75	87.48	76.98	64.15	55.78
70	195.24	112.26	108.20	102.06	89.81	74.84	65.08
80	223.13	128.30	123.66	116.64	102.64	85.53	74.38
90	251.02	144.34	139.12	131.22	115.47	96.23	83.67
100	278.91	160.38	154.58	145.80	128.30	106.92	92.97
110	306.80	176.41	170.04	160.38	141.13	117.61	102.27
120	334.70	192.45	185.49	174.95	153.96	128.30	111.57
130	362.59	208.49	200.95	189.53	166.79	138.99	120.86
140	390.48	224.53	216.41	204.11	179.62	149.68	130.16
150	418.37	240.56	231.87	218.69	192.45	160.38	139.46
200	557.83	320.75	309.16	291.59	256.60	213.83	185.94

Annex B: Calculation of load current I_b

				U_r [V]			
	230	400	415	440	500	600	690
P [kW]				I_b[A]			
250	697.28	400.94	386.45	364.49	320.75	267.29	232.43
300	836.74	481.13	463.74	437.39	384.90	320.75	278.91
350	976.20	561.31	541.02	510.28	449.05	374.21	325.40
400	1115.65	641.50	618.31	583.18	513.20	427.67	371.88
450	1255.11	721.69	695.60	656.08	577.35	481.13	418.37
500	1394.57	801.88	772.89	728.98	641.50	534.58	464.86
550	1534.02	882.06	850.18	801.88	705.65	588.04	511.34
600	1673.48	962.25	927.47	874.77	769.80	641.50	557.83
650	1812.94	1042.44	1004.76	947.67	833.95	694.96	604.31
700	1952.39	1122.63	1082.05	1020.57	898.10	748.42	650.80
750	2091.85	1202.81	1159.34	1093.47	962.25	801.88	697.28
800	2231.31	1283.00	1236.63	1166.36	1026.40	855.33	743.77
850	2370.76	1363.19	1313.92	1239.26	1090.55	908.79	790.25
900	2510.22	1443.38	1391.21	1312.16	1154.70	962.25	836.74
950	2649.68	1523.56	1468.49	1385.06	1218.85	1015.71	883.23
1000	2789.13	1603.75	1545.78	1457.96	1283.00	1069.17	929.71

Table 2: Correction factors for load current with cosφ other than 0.9

$\cos\varphi_{act}$	1	0.95	0.9	0.85	0.8	0.75	0.7
$k_{\cos\varphi}$*	0.9	0.947	1	1.059	1.125	1.2	1.286

* For $\cos\varphi_{act}$ values not present in the table, $k_{\cos\varphi} = \dfrac{0.9}{\cos\varphi_{act}}$

Table 3 allows the load current to be determined for some power values according to the rated voltage. The table has been calculated considering cosφ to be equal to 1; for different power factors, the value from Table 3 must be multiplied by the coefficient given in Table 4 corresponding to the actual value of the power factor ($\cos\varphi_{act}$).

Table 3: Load current for single-phase systems with cosφ = 1 or dc systems

			U_r [V]				
	230	400	415	440	500	600	690
P [kW]			I_b [A]				
0.03	0.13	0.08	0.07	0.07	0.06	0.05	0.04
0.04	0.17	0.10	0.10	0.09	0.08	0.07	0.06
0.06	0.26	0.15	0.14	0.14	0.12	0.10	0.09
0.1	0.43	0.25	0.24	0.23	0.20	0.17	0.14
0.2	0.87	0.50	0.48	0.45	0.40	0.33	0.29
0.5	2.17	1.25	1.20	1.14	1.00	0.83	0.72
1	4.35	2.50	2.41	2.27	2.00	1.67	1.45
2	8.70	5.00	4.82	4.55	4.00	3.33	2.90
5	21.74	12.50	12.05	11.36	10.00	8.33	7.25
10	43.48	25.00	24.10	22.73	20.00	16.67	14.49
20	86.96	50.00	48.19	45.45	40.00	33.33	28.99

Annex B: Calculation of load current I_b

	U_r [V]						
	230	400	415	440	500	600	690
P [kW]	I_b [A]						
30	130.43	75.00	72.29	68.18	60.00	50.00	43.48
40	173.91	100.00	96.39	90.91	80.00	66.67	57.97
50	217.39	125.00	120.48	113.64	100.00	83.33	72.46
60	260.87	150.00	144.58	136.36	120.00	100.00	86.96
70	304.35	175.00	168.67	159.09	140.00	116.67	101.45
80	347.83	200.00	192.77	181.82	160.00	133.33	115.94
90	391.30	225.00	216.87	204.55	180.00	150.00	130.43
100	434.78	250.00	240.96	227.27	200.00	166.67	144.93
110	478.26	275.00	265.06	250.00	220.00	183.33	159.42
120	521.74	300.00	289.16	272.73	240.00	200.00	173.91
130	565.22	325.00	313.25	295.45	260.00	216.67	188.41
140	608.70	350.00	337.35	318.18	280.00	233.33	202.90
150	652.17	375.00	361.45	340.91	300.00	250.00	217.39
200	869.57	500.00	481.93	454.55	400.00	333.33	289.86
250	1086.96	625.00	602.41	568.18	500.00	416.67	362.32
300	1304.35	750.00	722.89	681.82	600.00	500.00	434.78
350	1521.74	875.00	843.37	795.45	700.00	583.33	507.25
400	1739.13	1000.00	963.86	909.09	800.00	666.67	579.71
450	1956.52	1125.00	1084.34	1022.73	900.00	750.00	652.17
500	2173.91	1250.00	1204.82	1136.36	1000.00	833.33	724.64
550	2391.30	1375.00	1325.30	1250.00	1100.00	916.67	797.10
600	2608.70	1500.00	1445.78	1363.64	1200.00	1000.00	869.57
650	2826.09	1625.00	1566.27	1477.27	1300.00	1083.33	942.03
700	3043.48	1750.00	1686.75	1590.91	1400.00	1166.67	1014.49
750	3260.87	1875.00	1807.23	1704.55	1500.00	1250.00	1086.96
800	3478.26	2000.00	1927.71	1818.18	1600.00	1333.33	1159.42
850	3695.65	2125.00	2048.19	1931.82	1700.00	1416.67	1231.88
900	3913.04	2250.00	2168.67	2045.45	1800.00	1500.00	1304.35
950	4130.43	2375.00	2289.16	2159.09	1900.00	1583.33	1376.81
1000	4347.83	2500.00	2409.64	2272.73	2000.00	1666.67	1449.28

Table 4: Correction factors for load current with cosφ other than 1

$\cos\varphi_{act}$	1	0.95	0.9	0.85	0.8	0.75	0.7
$k_{\cos\varphi}$*	1	1.053	1.111	1.176	1.25	1.333	1.429

* For $\cos\varphi_{act}$ values not present in the table, $k_{\cos\varphi} = \dfrac{1}{\cos\varphi_{act}}$

Lighting circuits

The current absorbed by the lighting system may be deduced from the lighting equipment catalogue, or approximately calculated using the following formula:

$$I_b = \frac{P_L n_L k_B k_N}{U_{rL} \cos\varphi}$$

where:

- P_L is the power of the lamp [W];
- n_L is the number of lamps per phase;
- k_B is a coefficient which has the value:
  - 1 for lamps which do not need any auxiliary starter;
  - 1.25 for lamps which need auxiliary starters;
- k_N is a coefficient which has the value:
  - 1 for star-connected lamps;
  - $\sqrt{3}$ for delta-connected lamps;
- U_{rL} is the rated voltage of the lamps;
- cosφ is the power factor of the lamps which has the value:
  - 0.4 for lamps without compensation;
  - 0.9 for lamps with compensation.

Annex B: Calculation of load current I_b

Motors

Table 5 gives the approximate values of the load current for some three-phase squirrel-cage motors, 1500 rpm at 50 Hz, according to the rated voltage.

Note: these values are given for information only, and may vary according to the motor manifacturer and depending on the number of poles

Table 5: Motor load current

Motor power		Rated current of the motor at:							
[kW]	PS = hp	220-230 V [A]	240 V [A]	380-400 V [A]	415 V [A]	440 V [A]	500 V [A]	600 V [A]	660-690 V [A]
0.06	1/12	0.38	0.35	0.22	0.20	0.19	0.16	0.12	–
0.09	1/8	0.55	0.50	0.33	0.30	0.28	0.24	0.21	–
0.12	1/6	0.76	0.68	0.42	0.40	0.37	0.33	0.27	–
0.18	1/4	1.1	1	0.64	0.60	0.55	0.46	0.40	–
0.25	1/3	1.4	1.38	0.88	0.85	0.76	0.59	0.56	–
0.37	1/2	2.1	1.93	1.22	1.15	1.06	0.85	0.77	0.7
0.55	3/4	2.7	2.3	1.5	1.40	1.25	1.20	1.02	0.9
0.75	1	3.3	3.1	2	2	1.67	1.48	1.22	1.1
1.1	1.5	4.9	4.1	2.6	2.5	2.26	2.1	1.66	1.5
1.5	2	6.2	5.6	3.5	3.5	3.03	2.6	2.22	2
2.2	3	8.7	7.9	5	5	4.31	3.8	3.16	2.9
2.5	3.4	9.8	8.9	5.7	5.5	4.9	4.3	3.59	3.3
3	4	11.6	10.6	6.6	6.5	5.8	5.1	4.25	3.5
3.7	5	14.2	13	8.2	7.5	7.1	6.2	5.2	4.4
4	5.5	15.3	14	8.5	8.4	7.6	6.5	5.6	4.9
5	6.8	18.9	17.2	10.5	10	9.4	8.1	6.9	6
5.5	7.5	20.6	18.9	11.5	11	10.3	8.9	7.5	6.7
6.5	8.8	23.7	21.8	13.8	12.5	12	10.4	8.7	8.1
7.5	10	27.4	24.8	15.5	14	13.5	11.9	9.9	9
8	11	28.8	26.4	16.7	15.4	14.4	12.7	10.6	9.7
9	12.5	32	29.3	18.3	17	15.8	13.9	11.6	10.6
11	15	39.2	35.3	22	21	19.3	16.7	14.1	13
12.5	17	43.8	40.2	25	23	21.9	19	16.1	15
15	20	52.6	48.2	30	28	26.3	22.5	19.3	17.5
18.5	25	64.9	58.7	37	35	32	28.5	23.5	21
20	27	69.3	63.4	40	37	34.6	30.6	25.4	23
22	30	75.2	68	44	40	37.1	33	27.2	25
25	34	84.4	77.2	50	47	42.1	38	30.9	28
30	40	101	92.7	60	55	50.1	44	37.1	33
37	50	124	114	72	66	61.9	54	45.4	42
40	54	134	123	79	72	67	60	49.1	44
45	60	150	136	85	80	73.9	64.5	54.2	49
51	70	168	154	97	90	83.8	73.7	61.4	56
55	75	181	166	105	96	90.3	79	66.2	60
59	80	194	178	112	105	96.9	85.3	71.1	66
75	100	245	226	140	135	123	106	90.3	82
80	110	260	241	147	138	131	112	96.3	86
90	125	292	268	170	165	146	128	107	98
100	136	325	297	188	182	162	143	119	107
110	150	358	327	205	200	178	156	131	118
129	175	420	384	242	230	209	184	153	135
132	180	425	393	245	242	214	186	157	140
140	190	449	416	260	250	227	200	167	145
147	200	472	432	273	260	236	207	173	152
160	220	502	471	295	280	256	220	188	170
180	245	578	530	333	320	289	254	212	190
184	250	590	541	340	325	295	259	217	200
200	270	626	589	370	340	321	278	235	215
220	300	700	647	408	385	353	310	260	235
250	340	803	736	460	425	401	353	295	268
257	350	826	756	475	450	412	363	302	280
295	400	948	868	546	500	473	416	348	320
315	430	990	927	580	535	505	445	370	337
355	480	1080	1010	636	580	549	483	405	366
400	545	1250	1130	710	650	611	538	450	410
450	610	1410	1270	800	740	688	608	508	460
475	645	1490	1340	850	780	730	645	540	485
500	680	1570	1420	890	830	770	680	565	510
560	760	1750	1580	1000	920	860	760	630	570
600	810	–	–	1080	990	920	810	680	610
670	910	–	–	1200	1100	1030	910	760	680

Annex C: Calculation of short-circuit current

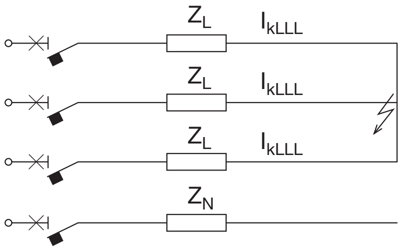
A short-circuit is a fault of negligible impedance between live conductors having a difference in potential under normal operating conditions.

Fault typologies
In a three-phase circuit the following types of fault may occur:
- three phase fault;
- two phase fault;
- phase to neutral fault;
- phase to PE fault.

In the formulas, the following symbols are used:
- I_k short-circuit current;
- U_r rated voltage;
- Z_L phase conductor impedance;
- Z_N neutral conductor impedance;
- Z_{PE} protective conductor impedance.

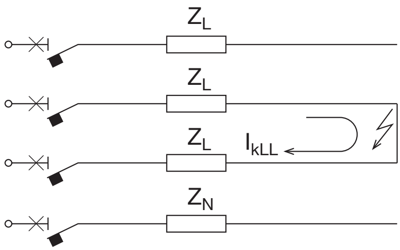
The following table briefly shows the type of fault and the relationships between the value of the short-circuit current for a symmetrical fault (three phase) and the short-circuit current for asymmetrical faults (two phase and single phase) in case of faults far from generators. For more accurate calculation, the use of DOCWin software is recommended.

Three phase fault



$$Z_C = \sqrt{R_C^2 + X_C^2}$$

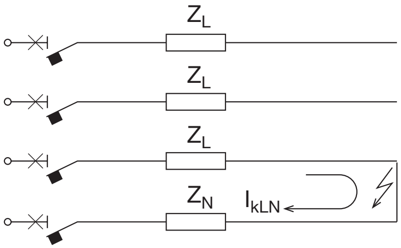
Two phase fault



$$I_{kLL} = \frac{U_r}{2Z_L} = \frac{\sqrt{3}}{2} I_{kLLL} = 0.87\, I_{kLLL}$$

Annex C: Calculation of short-circuit current

Phase to neutral fault



$$I_{kLN} = \frac{U_r}{\sqrt{3}(Z_L + Z_N)}$$

If $Z_L = Z_N$ (cross section of neutral conductor equal to the phase conductor one):

$$I_{kLN} = \frac{U_r}{\sqrt{3}(Z_L + Z_N)} = \frac{U_r}{\sqrt{3}(2Z_L)} = 0.5\,I_{kLLL}$$

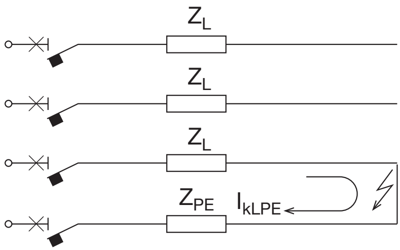
If $Z_N = 2Z_L$ (cross section of neutral conductor half the phase conductor one):

$$I_{kLN} = \frac{U_r}{\sqrt{3}(Z_L + Z_N)} = \frac{U_r}{\sqrt{3}(3Z_L)} = 0.33I_{kLLL}$$

If $Z_N \cong 0$ limit condition:

$$I_{kLN} = \frac{U_r}{\sqrt{3}(Z_L + Z_N)} = \frac{U_r}{\sqrt{3}(Z_L)} = I_{kLLL}$$

Phase to PE fault



$$I_{kLPE} = \frac{U_r}{\sqrt{3}(Z_L + Z_{PE})}$$

If $Z_L = Z_{PE}$ (cross section of protective conductor equal to the phase conductor one):

$$I_{kLPE} = \frac{U_r}{\sqrt{3}(Z_L + Z_{PE})} = \frac{U_r}{\sqrt{3}(2Z_L)} = 0.5I_{kLLL}$$

If $Z_{PE} = 2Z_L$ (cross section of protective conductor half to the phase conductor one):

$$I_{kLPE} = \frac{U_r}{\sqrt{3}(Z_L + Z_{PE})} = \frac{U_r}{\sqrt{3}(3Z_L)} = 0.33I_{kLLL}$$

If $Z_{PE} \cong 0$ limit condition:

$$I_{kLPE} = \frac{U_r}{\sqrt{3}(Z_L + Z_{PE})} = \frac{U_r}{\sqrt{3}(Z_L)} = I_{kLLL}$$

The following table allows the approximate value of a short-circuit current to be found quickly.

Note	**Three-phase short-circuit**	**Two-phase short-circuit**	**Phase to neutral short-circuit**	**Phase to PE short-circuit (TN system)**
	I_{kLLL}	I_{kLL}	I_{kLN}	I_{kLPE}
I_{kLLL}	-	$I_{kLL}=0.87I_{kLLL}$	$I_{LN}=0.5I_{kLLL}$ ($Z_L = Z_N$) $I_{LN}=0.33I_{kLLL}$ ($Z_L = 0{,}5Z_N$) $I_{LN}=I_{kLLL}$ ($Z_N \cong 0$)	$I_{LPE}=0.5I_{kLLL}$ ($Z_L = Z_{PE}$) $I_{LPE}=0.33I_{kLLL}$ ($Z_L = 0.5Z_{PE}$) $I_{LPE}=I_{kLLL}$ ($Z_{PE} \cong 0$)
I_{kLL}	$I_{kLLL}=1.16I_{kLL}$	-	$I_{kLN}=0.58I_{kLL}$ ($Z_L = Z_N$) $I_{kLN}=0.38I_{kLL}$ ($Z_L = 0{,}5Z_N$) $I_{kLN}=1.16I_{kLL}$ ($Z_N \cong 0$)	$I_{kLPE}=0.58I_{kLL}$ ($Z_L = Z_{PE}$) $I_{kLPE}=0.38I_{kLL}$ ($Z_L = 0.5Z_{PE}$) $I_{kLPE}=1.16I_{kLL}$ ($Z_{PE} \cong 0$)
I_{kLN}	$I_{kLLL}=2I_{kLN}$ ($Z_L = Z_N$) $I_{kLLL}=3I_{kLN}$ ($Z_L = 2Z_N$) $I_{kLLL}=I_{kLN}$ ($Z_N \cong 0$)	$I_{kLL}=1.73I_{kLN}$ ($Z_L = Z_N$) $I_{kLL}=2.6I_{kLN}$ ($Z_L = 2Z_N$) $I_{kLL}=0.87I_{kLN}$ ($Z_N \cong 0$)	-	

Annex C: Calculation of short-circuit current

Determination of the short-circuit current

In order to determine the short-circuit current the “short-circuit power method” can be used. This method allows the determination of the approximate short-circuit current at a point in an installation in a simple way; the resultant value is generally acceptable. However, this method is not conservative and gives more accurate values, the more similar the power factors of the considered components are (network, generators, transformers, motors and large section cables etc.).
For more accurate calculation, the use of DOCWin software for the dimensioning of installations is recommended.
The “short-circuit power method” calculates the short-circuit current I_k based on the formula:

Three-phase short-circuit $$I_k = \frac{S_k}{\sqrt{3} \cdot U_r}$$

Two-phase short-circuit $$I_k = \frac{S_k}{2 \cdot U_r}$$

where:
- S_k is the short-circuit apparent power seen at the point of the fault;
- U_r is the rated voltage.

To determine the short-circuit apparent power S_k, all the elements of the network shall be taken into account, which may be:
- elements which contribute to the short-circuit current: network, generators, motors;
- elements which limit the value of the short-circuit current: conductors and transformers.

The procedure for the calculation of the short-circuit current involves the following steps:
1. calculation of the short-circuit power for the different elements of the installation;
2. calculation of the short-circuit power at the fault point;
3. calculation of the short-circuit current.

Calculation of the short-circuit power for the different elements of the installation

The short-circuit apparent power S_k shall be determined for all the components which are part of the installation:

Network

An electrical network is considered to include everything upstream of the point of energy supply.

Annex C: Calculation of short-circuit current

Generally, the energy distribution authority supplies the short-circuit apparent power (S_{knet}) value at the point of energy supply. However, if the value of the short-circuit current I_{knet} is known, the value of the power can be obtained by using, for three-phase systems, the following formula:

$$S_{knet} = \sqrt{3} U_r I_{knet}$$

where U_r is the rated voltage at the point of energy supply.

If the aforementioned data are not available, the values for S_{knet} given in the following table can be taken as reference values:

Net voltage U_r [kV]	Short-circuit power S_{knet} [MVA]
Up to 20	500
Up to 32	750
Up to 63	1000

Generator

The short-circuit power is obtained from:

$$S_{kgen} = \frac{S_r \cdot 100}{X^*_{d\%}}$$

where $X^*_{d\%}$ is the percentage value of the subtransient reactance (X_d”) or of the transient reactance (X_d’) or of the synchronous reactance (X_d), according to the instant in which the value of the short-circuit power is to be evaluated.
In general, the reactances are expressed in percentages of the rated impedance of the generator (Z_d) given by:

$$Z_d = \frac{U_r^2}{S_r}$$

where U_r and S_r are the rated voltage and power of the generator.
Typical values can be:

- X_d” from 10 % to 20 %;
- X_d’ from 15 % to 40 %;
- X_d from 80 % to 300 %.

Normally, the worst case is considered, that being the subtransient reactance.
The following table gives the approximate values of the short-circuit power of generators (X_d” = 12.5 %):

S_r [kVA]	50	63	125	160	200	250	320	400	500	630	800	1000	1250	1600	2000	2500	3200	4000
S_{kgen} [MVA]	0.4	0.5	1.0	1.3	1.6	2.0	2.6	3.2	4.0	5.0	6.4	8.0	10.0	12.8	16.0	20.0	25.6	32.0

Annex C: Calculation of short-circuit current

Asynchronous three phase motors

Under short circuit conditions, electric motors contribute to the fault for a brief period (5-6 periods).
The power can be calculated according to the short circuit current of the motor (I_k), by using the following expression:

$$S_{kmot} = \sqrt{3} \cdot U_r \cdot I_k$$

Typical values are:
$S_{kmot} = 5 \div 7\ S_{rmot}$
(I_k is about $5 \div 7\ I_{rmot}$: 5 for motors of small size, and 7 for larger motors).

Transformers

The short circuit power of a transformer (S_{ktrafo}) can be calculated by using the following formula:

$$S_{ktrafo} = \frac{100}{u_k\,\%} \cdot S_r$$

The following table gives the approximate values of the short circuit power of transformers:

S_r [kVA]	50	63	125	160	200	250	320	400	500	630	800	1000	1250	1600	2000	2500	3200	4000
u_k%	4	4	4	4	4	4	4	4	4	4	5	5	5	6	6	6	6	6
S_{ktrafo} [MVA]	1.3	1.6	3.1	4	5	6.3	8	10	12.5	15.8	16	20	25	26.7	33.3			

Cables

A good approximation of the short-circuit power of cables is:

$$S_{kcable} = \frac{U_r^2}{Z_c}$$

where the impedance of the cable (Z_C) is:

$$Z_C = \sqrt{R_C^2 + X_C^2}$$

The following table gives the approximate values of the short-circuit power of cables, at 50 and 60 Hz, according to the supply voltage (cable length = 10 m):

Annex C: Calculation of short-circuit current

S [mm²]	230 [V]	400 [V]	440 [V]	500 [V]	690 [V]	230 [V]	400 [V]	440 [V]	500 [V]	690 [V]
	S_{kcable} [MVA] @50 Hz					S_{kcable} [MVA] @60 Hz				
1.5	0.44	1.32	1.60	2.07	3.94	0.44	1.32	1.60	2.07	3.94
2.5	0.73	2.20	2.66	3.44	6.55	0.73	2.20	2.66	3.44	6.55
4	1.16	3.52	4.26	5.50	10.47	1.16	3.52	4.26	5.50	10.47
6	1.75	5.29	6.40	8.26	15.74	1.75	5.29	6.40	8.26	15.73
10	2.9	8.8	10.6	13.8	26.2	2.9	8.8	10.6	13.7	26.2
16	4.6	14.0	16.9	21.8	41.5	4.6	13.9	16.9	21.8	41.5
25	7.2	21.9	26.5	34.2	65.2	7.2	21.9	26.4	34.1	65.0
35	10.0	30.2	36.6	47.3	90.0	10.0	30.1	36.4	47.0	89.6
50	13.4	40.6	49.1	63.4	120.8	13.3	40.2	48.7	62.9	119.8
70	19.1	57.6	69.8	90.1	171.5	18.8	56.7	68.7	88.7	168.8
95	25.5	77.2	93.4	120.6	229.7	24.8	75.0	90.7	117.2	223.1
120	31.2	94.2	114.0	147.3	280.4	29.9	90.5	109.5	141.5	269.4
150	36.2	109.6	132.6	171.2	326.0	34.3	103.8	125.6	162.2	308.8
185	42.5	128.5	155.5	200.8	382.3	39.5	119.5	144.6	186.7	355.6
240	49.1	148.4	179.5	231.8	441.5	44.5	134.7	163.0	210.4	400.7
300	54.2	164.0	198.4	256.2	488.0	48.3	146.1	176.8	228.3	434.7

With *n* cables in parallel, it is necessary to multiply the value given in the table by *n*. If the length of the cable (L_{act}) is other than 10 m, it is necessary to multiply the value given in the table by the following coefficient:

$$\frac{10}{L_{act}}$$

Calculation of the short-circuit power at the fault point

The rule for the determination of the short-circuit power at a point in the installation, according to the short-circuit power of the various elements of the circuit, is analogue to that relevant to the calculation of the equivalent admittance. In particular:

- the power of elements in series is equal to the inverse of the sum of the inverses of the single powers (as for the parallel of impedances);

$$S_k = \frac{1}{\sum \frac{1}{S_i}}$$

- the short-circuit power of elements in parallel is equal to the sum of the single short-circuit powers (as for the series of impedances).

$$S_k = \sum S_i$$

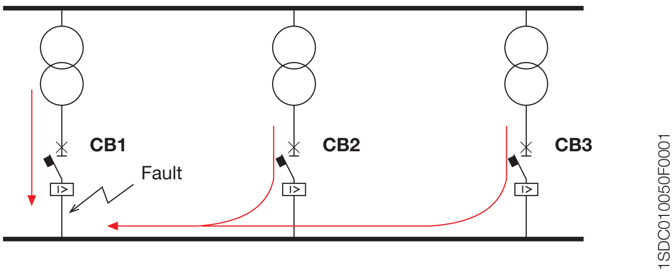
The elements of the circuit are considered to be in series or parallel, seeing the circuit from the fault point.
In the case of different branches in parallel, the distribution of the current between the different branches shall be calculated once the short-circuit current at the fault point has been calculated. This must be done to ensure the correct choice of protection devices installed in the branches.

Annex C: Calculation of short-circuit current

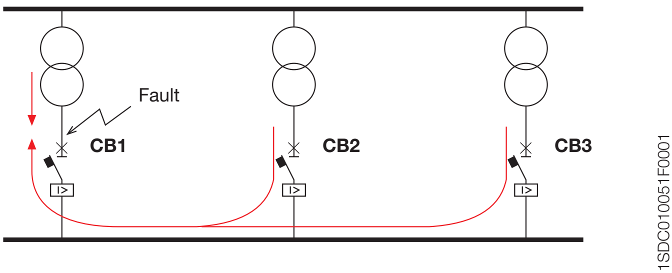
Calculation of the short-circuit current

To determine the short-circuit current in an installation, both the fault point as well as the configuration of the system which maximize the short-circuit current involving the device shall be considered. If appropriate, the contribution of the motors shall be taken into account.
For example, in the case detailed below, for circuit-breaker CB1, the worst condition occurs when the fault is right upstream of the circuit-breaker itself. To determine the breaking capacity of the circuit-breaker, the contribution of two transformers in parallel must be considered.

Fault right downstream of CB1



Fault right upstream of CB1
(worst condition for CB1)



Once the short-circuit power equivalent at the fault point has been determined, the short-circuit current can be calculated by using the following formula:

Three-phase short-circuit

$$I_k = \frac{S_k}{\sqrt{3} \cdot U_r}$$

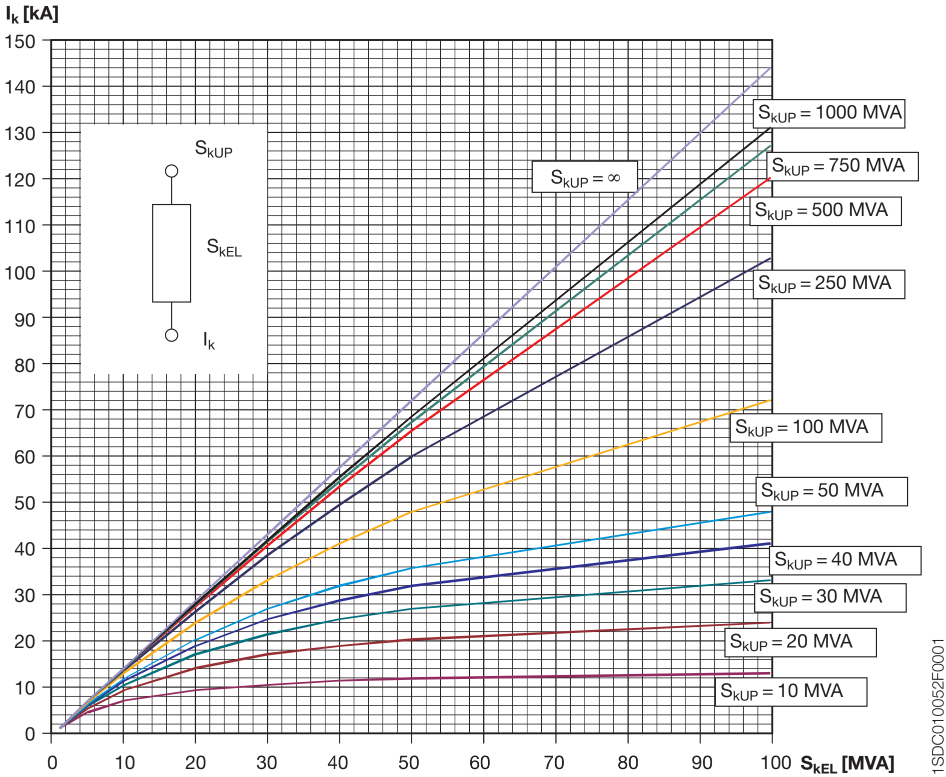
Two-phase short-circuit

$$I_k = \frac{S_k}{2 \cdot U_r}$$

Annex C: Calculation of short-circuit current

As a first approximation, by using the following graph, it is possible to evaluate the three phase short-circuit current downstream of an object with short-circuit power (S_{kEL}) known; corresponding to this value, knowing the short-circuit power upstream of the object (S_{kUP}), the value of I_k can be read on the y-axis, expressed in kA, at 400 V.

Figure 1: Chart for the calculation of the three phase short-circuit current at 400 V



Annex C: Calculation of short-circuit current

Examples:

The following examples demonstrate the calculation of the short-circuit current in some different types of installation.

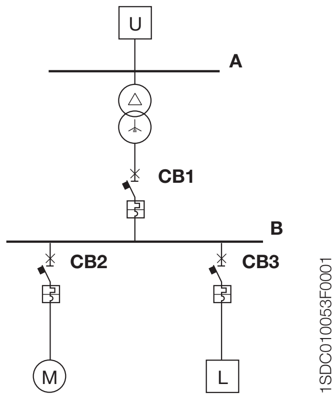
Example 1

Upstream network: U_r = 20000 V
S_{knet} = 500 MVA

Transformer: S_r = 1600 kVA
$u_k\%$ = 6%
U_{1r} / U_{2r} =20000/400

Motor: P_r = 220 kW
I_{kmot}/I_r = 6.6
$\cos\varphi_r$ = 0.9
η = 0.917

Generic load: I_{rL}= 1443.4 A
$\cos\varphi_r$= 0.9



Calculation of the short-circuit power of different elements

Network: S_{knet}= 500 MVA

Transformer: $$S_{ktrafo} = \frac{100}{u_k\%} \cdot S_r = 26.7\,\text{MVA}$$

Motor: $$S_{rmot} = \frac{P_r}{\eta \cdot \cos\varphi_r} = 267\,\text{kVA}$$

S_{kmot} = 6.6·S_{rmot} = 1.76 MVA for the first 5-6 periods (at 50 Hz about 100 ms)

Calculation of the short-circuit current for the selection of circuit-breakers

Selection of CB1
For circuit-breaker CB1, the worst condition arises when the fault occurs right downstream of the circuit-breaker itself. In the case of a fault right upstream, the circuit-breaker would be involved only by the fault current flowing from the motor, which is remarkably smaller than the network contribution.

Annex C: Calculation of short-circuit current

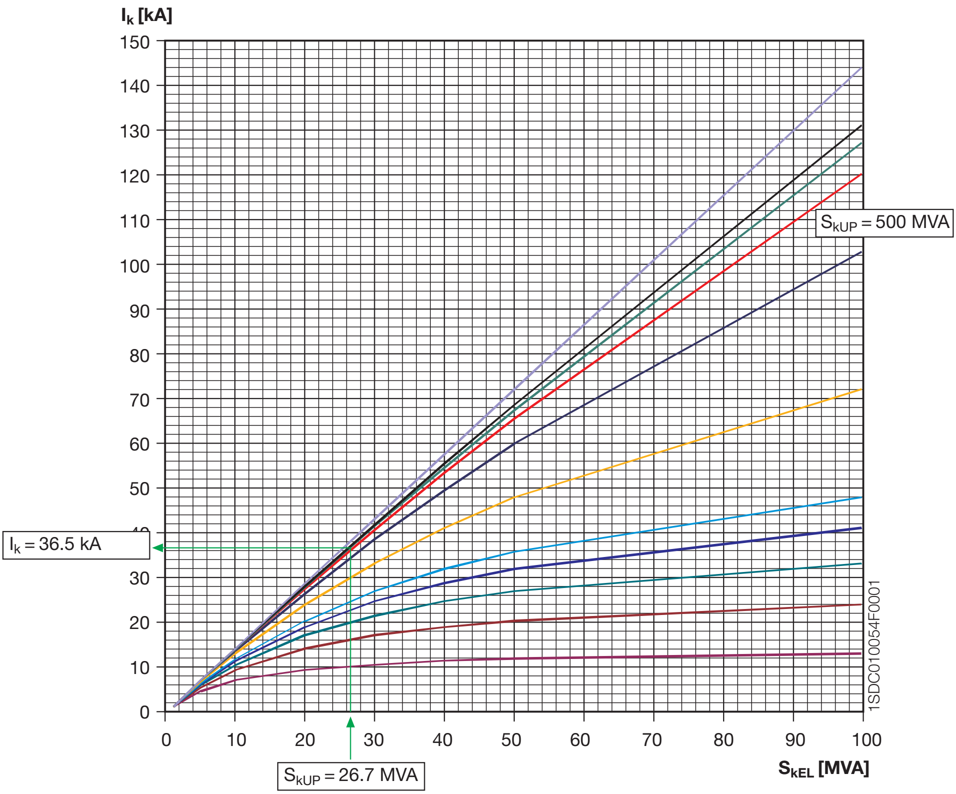
The circuit, seen from the fault point, is represented by the series of the network with the transformer. According to the previous rules, the short-circuit power is determined by using the following formula:

$$S_{kCB1} = \frac{S_{knet} \cdot S_{ktrafo}}{S_{knet} + S_{ktrafo}} = 25.35 \text{ MVA}$$

the maximum fault current is:

$$I_{kCB1} = \frac{S_{kCB1}}{\sqrt{3} \cdot U_r} = 36.6 \text{ kA}$$

The transformer LV side rated current is equal to 2309 A; therefore the circuit-breaker to select is an Emax E3N 2500.
Using the chart shown in Figure 1, it is possible to find I_{kCB1} from the curve with $S_{kUP} = S_{knet} = 500$ MVA corresponding to $S_{kEL} = S_{ktrafo} = 26.7$ MVA:



Annex C: Calculation of short-circuit current

Selection of CB2

For circuit-breaker CB2, the worst condition arises when the fault occurs right downstream of the circuit-breaker itself. The circuit, seen from the fault point, is represented by the series of the network with the transformer. The short-circuit current is the same used for CB1.

$$I_{kCB1} = \frac{S_{kCB1}}{\sqrt{3} \cdot U_r} = 36.6 \text{ kA}$$

The rated current of the motor is equal to 385 A; the circuit-breaker to select is an Isomax S5H 400.

Selection of CB3

For CB3 too, the worst condition arises when the fault occurs right downstream of the circuit-breaker itself.

The circuit, seen from the fault point, is represented by two branches in parallel: the motor and the series of the network and transformer. According to the previous rules, the short circuit power is determined by using the following formula:

Motor // (Network + Transformer)

$$S_{kCB3} = S_{kmot} + \frac{1}{\frac{1}{S_{knet}} + \frac{1}{S_{ktrafo}}} = 27.11 \text{MVA}$$

$$I_{kCB3} = \frac{S_{kCB3}}{\sqrt{3} \cdot U_r} = 39.13 \text{ kA}$$

The rated current of the load L is equal to 1443 A; the circuit-breaker to select is a SACE Isomax S7S 1600, or an Emax E2N1600.

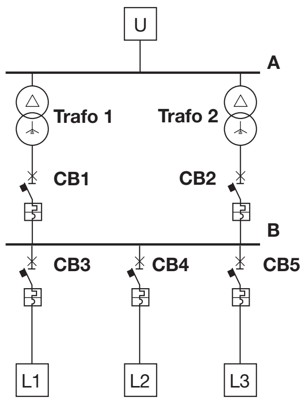
Example 2

The circuit shown in the diagram is constituted by the supply, two transformers in parallel and three loads.

Upstream network: U_{r1}=20000 V
S_{knet} = 500 MVA

Transformers 1 and 2: S_r = 1600 kVA
$u_k\%$ = 6%
U_{1r} /U_{2r} =20000/400

Load L1: S_r = 1500 kVA; cosφ = 0.9;
Load L2: S_r = 1000 kVA; cosφ = 0.9;
Load L3: S_r = 50 kVA; cosφ = 0.9.



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Annex C: Calculation of short-circuit current

Calculation of the short-circuit powers of different elements:

Network $S_{knet} = 500$ MVA

Transformers 1 and 2 $$S_{ktrafo} = \frac{S_r}{u_k\ \%} \cdot 100 = 26.7 \text{ MVA}$$

Selection of CB1 (CB2)
For circuit-breaker CB1 (CB2) the worst condition arises when the fault occurs right downstream of the circuit-breaker itself. According to the previous rules, the circuit seen from the fault point, is equivalent to the parallel of the two transformers in series with the network: Network + (Trafo 1 // Trafo 2).
The short-circuit current obtained in this way corresponds to the short-circuit current at the busbar. This current, given the symmetry of the circuit, is distributed equally between the two branches (half each). The current which flows through CB1 (CB2) is therefore equal to half of that at the busbar.

$$S_{kbusbar} = \frac{S_{knet} \cdot (S_{rtrafo1} + S_{ktrafo2})}{S_{knet} + (S_{ktrafo1} + S_{ktrafo2})} = 48.2 \text{ MVA}$$

$$I_{kbusbar} = \frac{S_{kbusbar}}{\sqrt{3} \cdot U_r} = 69.56 \text{ kA}$$

$$I_{kCB1(2)} = \frac{I_{kbusbar}}{2} = 34.78 \text{ kA}$$

The circuit-breakers CB1(CB2) to select, with reference to the rated current of the transformers, are Emax E3N 2500.

Selection of CB3-CB4-CB5
For these circuit-breakers the worst condition arises when the fault occurs right downstream of the circuit-breakers themselves. Therefore, the short-circuit current to be taken into account is that at the busbar:

$$I_{kCB3} = I_{kbusbar} = 69.56 \text{ kA}$$

The circuit-breakers to select, with reference to the current of the loads, are:
CB3: Emax E3S 2500
CB4: Emax E3S 1600
CB5: Tmax T2H 160

Annex C: Calculation of short-circuit current

Determination of the short-circuit current I_k downstream of a cable as a function of the upstream one

The table below allows the determination, in a conservative way, of the three-phase short-circuit current at a point in a 400 V network downstream of a single pole copper cable at a temperature of 20 °C. Known values:
- the three phase short-circuit current upstream of the cable;
- the length and cross section of the cable.

Cable section [mm²]	Length [m]																								
1.5																0.9	1.1	1.4	1.8	2.5	3.5	5.3	7	9.4	14
2.5													0.9	1	1.2	1.5	1.8	2.3	2.9	4.1	5.9	8.8	12	16	24
4											0.9	1.2	1.4	1.6	1.9	2.3	2.8	3.7	4.7	6.6	9.4	14	19	25	38
6									0.8	1.1	1.4	1.8	2.1	2.5	2.8	3.5	4.2	5.6	7	10	14	21	28	38	56
10							0.9	1.2	1.4	1.9	2.3	2.9	3.5	4.1	4.7	5.8	7	9.4	12	16	23	35	47	63	94
16					0.9	1.1	1.5	1.9	2.2	3	3.7	4.7	5.6	6.5	7.5	9.3	11	15	19	26	37	56	75	100	150
25			0.9	1.2	1.4	1.7	2.3	2.9	3.5	4.6	5.8	7.2	8.7	10	12	14	17	23	29	41	58	87	116	155	233
35			1.2	1.6	2	2.4	3.2	4	4.8	6.4	8	10	12	14	16	20	24	32	40	56	80	121	161	216	324
50		1.1	1.7	2.3	2.8	3.4	4.5	5.7	6.8	9	11	14	17	20	23	28	34	45	57	79	113	170	226	303	455
70	0.8	1.5	2.3	3.1	3.8	4.6	6.2	7.7	9.2	12	15	19	23	27	31	38	46	62	77	108	154	231	308	413	
95	1	2	3	4	5	6	8	10	12	16	20	25	30	35	40	50	60	80	100	140	200	300	400		
120	1.2	2.4	3.6	4.8	6	7.2	10	12	14	19	24	30	36	42	48	60	72	96	120	168	240	360	481		
150	1.4	2.8	4.2	5.6	7	8.4	11	14	17	23	28	35	42	49	56	70	84	113	141	197	281	422			
185	1.6	3.2	4.8	6.4	8	10	13	16	19	26	32	40	48	56	64	80	96	128	160	224	320	480			
240	1.8	3.7	5.5	7.3	9.1	11	15	18	22	29	37	46	55	64	73	91	110	146	183	256	366	549			
300	2	4	6	8	10	12	16	20	24	32	40	50	60	70	80	100	120	160	200	280	400				
2x120	2.4	4.8	7.2	10	12	14	19	24	29	38	48	60	72	84	96	120	144	192	240	336	481				
2x150	2.8	5.6	8.4	11	14	17	23	28	34	45	56	70	84	98	113	141	169	225	281	394	563				
2x185	3.2	6.4	10	13	16	19	26	32	38	51	64	80	96	112	128	160	192	256	320	448					
3x120	3.6	7.2	11	14	18	22	29	36	43	58	72	90	108	126	144	180	216	288	360	505					
3x150	4.2	8.4	13	17	21	25	34	42	51	68	84	105	127	148	169	211	253	338	422						
3x185	4.8	10	14	19	24	29	38	48	58	77	96	120	144	168	192	240	288	384	480						

I_k upstream [kA]	I_k downstream [kA]																								
100	96	92	89	85	82	78	71	65	60	50	43	36	31	27	24	20	17	13	11	7.8	5.6	3.7	2.7	2.0	1.3
90	86	83	81	78	76	72	67	61	57	48	42	35	31	27	24	20	17	13	11	7.8	5.6	3.7	2.7	2.0	1.3
80	77	75	73	71	69	66	62	57	53	46	40	34	30	27	24	20	17	13	10	7.7	5.5	3.7	2.7	2.0	1.3
70	68	66	65	63	62	60	56	53	49	43	38	33	29	26	23	19	16	13	10	7.6	5.5	3.7	2.7	2.0	1.3
60	58	57	56	55	54	53	50	47	45	40	36	31	28	25	23	19	16	12	10	7.5	5.4	3.7	2.7	2.0	1.3
50	49	48	47	46	45	44	43	41	39	35	32	29	26	23	21	18	15	12	10	7.3	5.3	3.6	2.6	2.0	1.3
40	39	39	38	38	37	37	35	34	33	31	28	26	24	22	20	17	15	12	10	7.1	5.2	3.6	2.6	2.0	1.3
35	34	34	34	33	33	32	32	31	30	28	26	24	22	20	19	16	14	11	10	7.1	5.1	3.5	2.6	2.0	1.3
30	30	29	29	29	28	28	28	27	26	25	23	22	20	19	18	16	14	11	9.3	7.0	5.0	3.5	2.6	1.9	1.3
25	25	24	24	24	24	24	23	23	22	21	21	19	18	17	16	14	13	11	9.0	6.8	5.0	3.4	2.6	1.9	1.3
20	20	20	20	19	19	19	19	18	18	18	17	16	15	15	14	13	12	10	8.4	6.5	4.8	3.3	2.5	1.9	1.3
15	15	15	15	15	15	14	14	14	14	14	13	13	12	12	12	11	10	8.7	7.6	6.1	4.6	3.2	2.5	1.9	1.3
12	12	12	12	12	12	12	12	11	11	11	11	11	10	10	10	9.3	8.8	7.8	7.0	5.7	4.4	3.1	2.4	1.9	1.3
10	10	10	10	10	10	10	10	9.5	9.4	9.2	9.0	8.8	8.5	8.3	8.1	7.7	7.3	6.5	5.9	5.0	3.9	2.9	2.3	1.8	1.2
8.0	8.0	7.9	7.9	7.9	7.8	7.8	7.7	7.7	7.6	7.5	7.4	7.2	7.1	6.9	6.8	6.5	6.2	5.7	5.2	4.5	3.7	2.8	2.2	1.7	1.2
6.0	6.0	5.9	5.9	5.9	5.9	5.8	5.8	5.8	5.7	5.6	5.5	5.4	5.3	5.2	5.1	4.9	4.8	4.4	4.1	3.6	3.1	2.4	2.0	1.6	1.1
3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.9	2.9	2.9	2.9	2.9	2.8	2.8	2.8	2.7	2.7	2.6	2.5	2.4	2.2	2.0	1.7	1.4	1.2	0.9

Annex C: Calculation of short-circuit current

Note:

- In the case of the I_K upstream and the length of the cable not being included in the table, it is necessary to consider:
- the value right above I_K upstream;
- the value right below for the cable length.

These approximations allow calculations which favour safety.

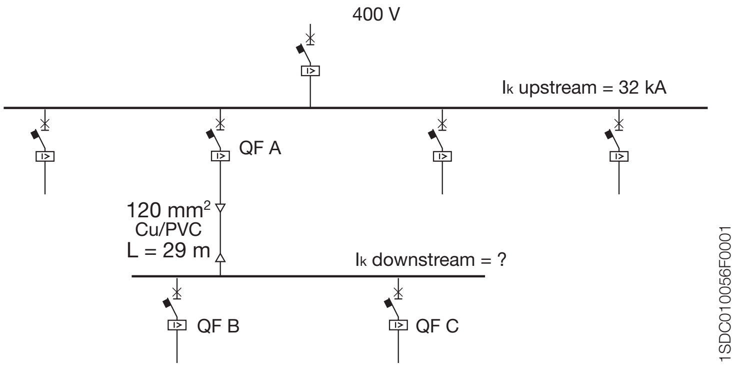
- In the case of cables in parallel not present in the table, the length must be divided by the number of cables in parallel.

Example

Data

Rated voltage =	400 V
Cable section =	120 mm^2
Conductor =	copper
Length =	29 m

Upstream short-circuit current =	32 kA



Procedure

In the row corresponding to the cable cross section 120 mm^2, it is possible to find the column for a length equal to 29 m or right below (in this case 24). In the column of upstream short-circuit current it is possible to identify the row with a value of 32 kA or right above (in this case 35). From the intersection of this last row with the previously identified column, the value of the downstream short-circuit current can be read as being equal to 26 kA.

Annex D: Calculation of the coefficient k for the cables (k^2S^2)

By using the formula (1), it is possible to determine the conductor minimum section S, in the hypothesis that the generic conductor is submitted to an adiabatic heating from a known initial temperature up to a specific final temperature (applicable if the fault is removed in less than 5 s):

$$S=\frac{\sqrt{I^2t}}{k} \qquad (1)$$

where:
- S is the cross section [mm^2];
- I is the value (r.m.s) of prospective fault current for a fault of negligible impedance, which can flow through the protective device [A];
- t is the operating time of the protective device for automatic disconnection [s];

k can be evaluated using the tables 2÷7 or calculated according to the formula (2):

$$k=\sqrt{\frac{Q_c\,(B+20)}{\rho_{20}}\ln\left(1+\frac{\theta_f-\theta_i}{B+\theta_i}\right)} \qquad (2)$$

where:
- Q_c is the volumetric heat capacity of conductor material [J/°Cmm^3] at 20 °C;
- B is the reciprocal of temperature coefficient of resistivity at 0 °C for the conductor [°C];
- ρ_{20} is the electrical resistivity of conductor material at 20 °C [Ωmm];
- θ_i initial temperature of conductor [°C];
- θ_f final temperature of conductor [°C].

Table 1 shows the values of the parameters described above.

Table 1: Value of parameters for different materials

Material	**B** [°C]	**Q_c** [J/°Cmm^3]	**ρ_{20}** [Ωmm]	$\sqrt{\frac{Q_c\,(B+20)}{\rho_{20}}}$
Copper	234.5	$3.45\cdot10^{-3}$	$17.241\cdot10^{-6}$	226
Aluminium	228	$2.5\cdot10^{-3}$	$28.264\cdot10^{-6}$	148
Lead	230	$1.45\cdot10^{-3}$	$214\cdot10^{-6}$	41
Steel	202	$3.8\cdot10^{-3}$	$138\cdot10^{-6}$	78

Annex D: Calculation of the coefficient k for the cables (k^2S^2)

Table 2: Values of *k* for phase conductor

	Conductor insulation					
	PVC ≤ 300 mm²	PVC ≤ 300 mm²	EPR XLPE	Rubber 60 °C	Mineral PVC	Mineral Bare
Initial temperature °C	70	70	90	60	70	105
Final temperature °C	160	140	250	200	160	250
Material of conductor:						
copper	115	103	143	141	115	135/115 [a]
aluminium	76	68	94	93	-	-
tin-soldered joints in copper conductors	115	-	-	-	-	-

[a] This value shall be used for bare cables exposed to touch.

Table 3: Values of *k* for insulated protective conductors not incorporated in cables and not bunched with other cables

Conductor insulation	Temperature °C [b] Initial	Temperature °C [b] Final	Material of conductor: Copper	Aluminium (Value for k)	Steel
70 °C PVC	30	160/140 [a]	143/133 [a]	95/88 [a]	52/49 [a]
90 °C PVC	30	160/140 [a]	143/133 [a]	95/88 [a]	52/49 [a]
90 °C thermosetting	30	250	176	116	64
60 °C rubber	30	200	159	105	58
85 °C rubber	30	220	166	110	60
Silicone rubber	30	350	201	133	73

[a] The lower value applies to PVC insulated conductors of cross section greater than 300 mm².
[b] Temperature limits for various types of insulation are given in IEC 60724.

Table 4: Values of *k* for bare protective conductors in contact with cable covering but not bunched with other cables

Cable covering	Temperature °C [a] Initial	Temperature °C [a] Final	Material of conductor: Copper	Aluminium (Value for k)	Steel
PVC	30	200	159	105	58
Polyethylene	30	150	138	91	50
CSP	30	220	166	110	60

[a] Temperature limits for various types of insulation are given in IEC 60724.

Annex D: Calculation of the coefficient k for the cables (k^2S^2)

Table 5: Values of *k* for protective conductors as a core incorporated in a cable or bunched with other cables or insulated conductors

	Temperature °C [b]		Material of conductor		
Conductor insulation	Initial	Final	Copper	Aluminium Value for k	Steel
70 °C PVC	70	160/140 [a]	115/103 [a]	76/68 [a]	42/37 [a]
90 °C PVC	90	160/140 [a]	100/86 [a]	66/57 [a]	36/31 [a]
90 °C thermosetting	90	250	143	94	52
60 °C rubber	60	200	141	93	51
85 °C rubber	85	220	134	89	48
Silicone rubber	180	350	132	87	47

[a] The lower value applies to PVC insulated conductors of cross section greater than 300 mm^2 .

[b] Temperature limits for various types of insulation are given in IEC 60724..

Table 6: Values of *k* for protective conductors as a metallic layer of a cable e.g. armour, metallic sheath, concentric conductor, etc.

	Temperature °C		Material of conductor			
Conductor insulation	Initial	Final	Copper	Aluminium	Lead	Steel
				Value for k		
70 °C PVC	60	200	141	93	26	51
90 °C PVC	80	200	128	85	23	46
90 °C thermosetting	80	200	128	85	23	46
60 °C rubber	55	200	144	95	26	52
85 °C rubber	75	220	140	93	26	51
Mineral PVC covered [a]	70	200	135	-	-	-
Mineral bare sheath	105	250	135	-	-	-

[a] This value shall also be used for bare conductors exposed to touch or in contact with combustible material.

Table 7: Value of *k* for bare conductors where there is no risk of damage to any neighbouring material by the temperature indicated

		Material of conductor					
		Copper		Aluminium		Steel	
Conductor insulation	Initial temperature °C	k value	Maximum temperature °C	k value	Maximum temperature °C	k value	Maximum temperature °C
Visible and in restricted area	30	228	500	125	300	82	500
Normal conditions	30	159	200	105	200	58	200
Fire risk	30	138	150	91	150	50	150

Annex E: Main physical quantities and electrotechnical formulas

The International System of Units (SI)

SI Base Units

Quantity	Symbol	Unit name
Length	m	metre
Mass	kg	kilogram
Time	s	Second
Electric Current	A	ampere
Thermodynamic Temperature	K	kelvin
Amount of Substance	mol	mole
Luminous Intensity	cd	candela

Metric Prefixes for Multiples and Sub-multiples of Units

Decimal power	Prefix	Symbol	Decimal power	Prefix	Symbol
10^{24}	yotta	Y	10^{-1}	deci	d
10^{21}	zetta	Z	10^{-2}	centi	c
10^{18}	exa	E	10^{-3}	milli	m
10^{15}	peta	P	10^{-6}	mikro	µ
10^{12}	tera	T	10^{-9}	nano	n
10^{9}	giga	G	10^{-12}	pico	p
10^{6}	mega	M	10^{-15}	femto	f
10^{3}	kilo	k	10^{-18}	atto	a
10^{2}	etto	h	10^{-21}	zepto	z
10	deca	da	10^{-24}	yocto	y

Annex E: Main physical quantities and electrotechnical formulas

Main quantities and SI units

Quantity Symbol	Name	SI unit Symbol	Name	Other units Symbol	Name	Conversion
Length, area, volume						
l	length	m	metre	in	inch	1 in = 25.4 mm
				ft	foot	i ft = 30.48 cm
				fathom	fathom	1 fathom = 6 ft = 1.8288 m
				mile	mile	1 mile = 1609.344 m
				sm	sea mile	1 sm = 1852 m
				yd	yard	1 yd = 91.44 cm
A	area	m^2	square metre	a	are	1 a = 10^2 m^2
				ha	hectare	1 ha = 10^4 m^2
V	volume	m^3	cubic metre	l	litre	1 l = 1 dm^3 = 10^{-3} m^3
				UK pt	pint	1 UK pt = 0.5683 dm^3
				UK gal	gallon	1 UK gal = 4.5461 dm^3
				US gal	gallon	1 US gal = 3.7855 dm^3
Angles						
α, β, γ	plane angle	rad	radian	°	degrees	$1° = \frac{\pi}{180} \cdot rad$
Ω	solid angle	sr	steradian			
Mass						
m	mass, weight	kg	kilogram	lb	pound	1 lb = 0.45359 kg
ρ	density	kg/m^3	kilogram			
υ	specific volume	m^3/kg	cubic metre for kilogram			
M	moment of inertia	kg·m^2	kilogram for square metre			
Time						
t	duration	s	second			
f	frequency	Hz	Hertz			1 Hz = 1/s
ω	angular frequency	1/s	reciprocal second			ω = 2pf
v	speed	m/s	metre per second	km/h	kilometre per hour	1 km/h = 0.2777 m/s
				mile/h	mile per hour	1 mile/h = 0.4470 m/s
				knot	kn	1 kn = 0.5144 m/s
g	acceleration	m/s^2	metre per second squared			
Force, energy, power						
F	force	N	newton			1 N = 1 kg·m/s^2
				kgf		1 kgf = 9.80665 N
p	pressure/stress	Pa	pascal			1 Pa = 1 N/m^2
				bar	bar	1 bar = 10^5 Pa
W	energy, work	J	joule			1 J = 1 W·s = 1 N·m
P	power	W	watt	Hp	horsepower	1 Hp = 745.7 W
Temperature and heat						
T	temperature	K	kelvin	°C	Celsius	T[K] = 273.15 + T [°C]
				°F	Fahrenheit	T[K] = 273.15 + (5/9)·(T [°F]-32)
Q	quantity of heat	J	joule			
S	entropy	J/K	joule per kelvin			
Photometric quantities						
I	luminous intensity	cd	candela			
L	luminance	cd/m^2	candela per square metre			
F	luminous flux	lm	lumen			1 lm = 1 cd·sr
E	illuminance	lux				1 lux = 1 lm/m^2

Annex E: Main physical quantities and electrotechnical formulas

Main electrical and magnetic quantities and SI units

Quantity Symbol	Name	SI unit Symbol	Name	Other units Symbol	Name	Conversion
I	current	A	ampere			
V	voltage	V	volt			
R	resistance	Ω	ohm			
G	conductance	S	siemens			$G = 1/R$
X	reactance	Ω	ohm			$X_L = \omega L$ $X_C = -1/\omega C$
B	susceptance	S	siemens			$B_L = -1/\omega L$ $B_C = \omega C$
Z	impedance	Ω	ohm			
Y	admittance	S	siemens			
P	active power	W	watt			
Q	reactive power	var	reactive volt ampere			
S	apparent power	VA	volt ampere			
Q	electric charge	C	coulomb	Ah	ampere/hour	1 C = 1 A·s 1 Ah = 3600 A·s
E	electric field strength	V/m	volt per metre			
C	electric capacitance	F	farad			1 F = 1 C/V
H	magnetic field	A/m	ampere per metre			
B	magnetic induction	T	tesla	G	gauss	$1\ T = 1\ V{\cdot}s/m^2$ $1\ G = 10^{-4}\ T$
L	inductance	H	henry			1 H = 1 Ω·s

Resistivity values, conductivity and temperature coefficient at 20 °C of the main electrical materials

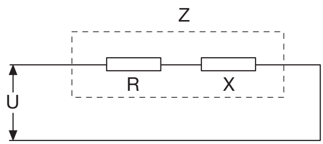
conductor	conductivity resistivity ρ_{20} [mm²Ω/m]	$\chi_{20}=1/\rho_{20}$ [m/mm²Ω]	temperature coefficient α_{20} [K⁻¹]
Aluminium	0.0287	34.84	$3.8 \cdot 10^{-3}$
Brass, CuZn 40	≤ 0.067	≥ 15	$2 \cdot 10^{-3}$
Constantan	0.50	2	$-3 \cdot 10^{-4}$
Copper	0.0175	57.14	$3.95 \cdot 10^{-3}$
Gold	0.023	43.5	$3.8 \cdot 10^{-3}$
Iron wire	0.1 to 0,15	10 to 6.7	$4.5 \cdot 10^{-3}$
Lead	0.208	4.81	$3.9 \cdot 10^{-3}$
Magnesium	0.043	23.26	$4.1 \cdot 10^{-3}$
Manganin	0.43	2.33	$4 \cdot 10^{-6}$
Mercury	0.941	1.06	$9.2 \cdot 10^{-4}$
Ni Cr 8020	1	1	$2.5 \cdot 10^{-4}$
Nickeline	0.43	2.33	$2.3 \cdot 10^{-4}$
Silver	0.016	62.5	$3.8 \cdot 10^{-3}$
Zinc	0.06	16.7	$4.2 \cdot 10^{-3}$

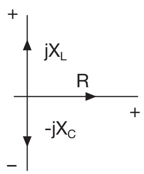
Annex E: Main physical quantities and electrotechnical formulas

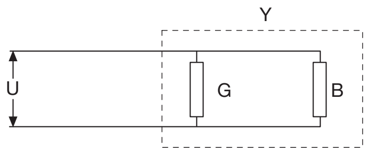
Main electrotechnical formulas

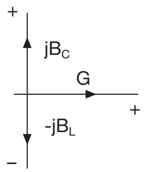
Impedance

resistance of a conductor at temperature ϑ	$R_\theta = \rho_\theta \cdot \frac{l}{S}$
conductance of a conductor at temperature ϑ	$G_\theta = \frac{1}{R_\theta} = \chi_\theta \cdot \frac{S}{l}$
resistivity of a conductor at temperature ϑ	$\rho_\vartheta = \rho_{20}\,[1 + \alpha_{20}\,(\vartheta - 20)]$
capacitive reactance	$X_C = \frac{-1}{\omega \cdot C} = - \cdot \frac{1}{2 \cdot \pi \cdot f \cdot C}$
inductive reactance	$X_L = \omega \cdot L = 2 \cdot \pi \cdot f \cdot L$
impedance	$Z = R + jX$
module impedance	$Z = \sqrt{R^2 + X^2}$
phase impedance	$\varphi = \arctan \frac{R}{X}$
conductance	$G = \frac{1}{R}$
capacitive susceptance	$B_C = \frac{-1}{X_C} = \omega \cdot C = 2 \cdot \pi \cdot f \cdot C$
inductive susceptance	$B_L = \frac{-1}{X_L} = -\frac{1}{\omega \cdot L} = -\frac{1}{2 \cdot \pi \cdot f \cdot L}$
admittance	$Y = G - jB$
module admittance	$Y = \sqrt{G^2 + B^2}$
phase admittance	$\varphi = \arctan \frac{B}{G}$





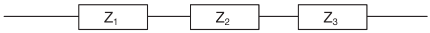




Annex E: Main physical quantities and electrotechnical formulas

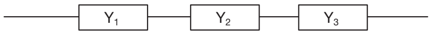
Indipendences in serie

$$Z = Z_1 + Z_2 + Z_3 + \dots$$



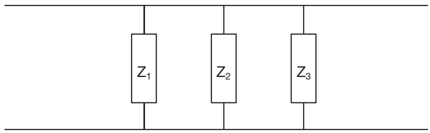
Admittances in serie

$$Y = \frac{1}{\frac{1}{Y_1} + \frac{1}{Y_2} + \frac{1}{Y_3} + \dots}$$



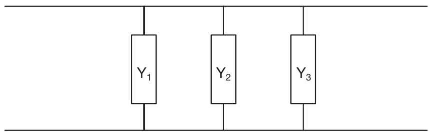
Indipendences in parallel

$$Z = \frac{1}{\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_3} + \dots}$$

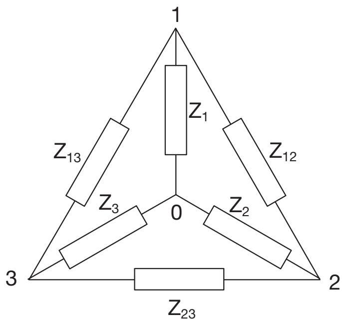


Admittances in serie

$$Y = Y_1 + Y_2 + Y_3 + \dots$$



Delta-star and star-delta transformations



Y→Δ	Δ→Y
$Z_{12} = Z_1 + Z_2 + \frac{Z_1 \cdot Z_2}{Z_3}$	$Z_1 = \frac{Z_{12} \cdot Z_{13}}{Z_{12} + Z_{13} + Z_{23}}$
$Z_{23} = Z_2 + Z_3 + \frac{Z_2 \cdot Z_3}{Z_1}$	$Z_2 = \frac{Z_{12} \cdot Z_{23}}{Z_{12} + Z_{13} + Z_{23}}$
$Z_{13} = Z_3 + Z_1 + \frac{Z_3 \cdot Z_1}{Z_2}$	$Z_3 = \frac{Z_{23} \cdot Z_{13}}{Z_{12} + Z_{13} + Z_{23}}$

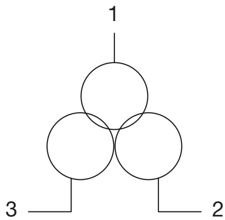
Annex E: Main physical quantities and electrotechnical formulas

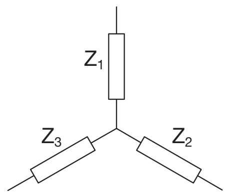
Transformers

Two-winding transformer

rated current	$I_r = \dfrac{S_r}{\sqrt{3} \cdot U_r}$
short-circuit power	$S_k = \dfrac{S_r}{u_k\%} \cdot 100$
short-circuit current	$I_k = \dfrac{S_k}{\sqrt{3} \cdot U_r} = \dfrac{I_r}{u_k\%} \cdot 100$
longitudinal impedance	$Z_T = \dfrac{u_k\%}{100} \cdot \dfrac{U^2_r}{S_r} = \dfrac{u_k\%}{100} \cdot \dfrac{S_r}{3 \cdot I^2_r}$
longitudinal resistance	$R_T = \dfrac{p_k\%}{100} \cdot \dfrac{U^2_r}{S_r} = \dfrac{p_k\%}{100} \cdot \dfrac{S_r}{3 \cdot I^2_r}$
longitudinal reactance	$X_T = \sqrt{Z^2_T - R^2_T}$

Three-winding transformer





$Z_{12} = \dfrac{u_{12}}{100} \cdot \dfrac{U^2_r}{S_{r12}}$	$Z_1 = \dfrac{1}{2}(Z_{12} + Z_{13} - Z_{23})$
$Z_{13} = \dfrac{u_{13}}{100} \cdot \dfrac{U^2_r}{S_{r13}}$	$Z_2 = \dfrac{1}{2}(Z_{12} + Z_{23} - Z_{13})$
$Z_{23} = \dfrac{u_{23}}{100} \cdot \dfrac{U^2_r}{S_{r23}}$	$Z_3 = \dfrac{1}{2}(Z_{13} + Z_{23} - Z_{12})$

Annex E: Main physical quantities and electrotechnical formulas

Voltage drop and power

	single-phase	three-phase	continuous
voltage drop	$\Delta U = 2 \cdot I \cdot l \cdot (r \cdot \cos\varphi \; x \cdot \sin\varphi)$	$\Delta U = \sqrt{3} \cdot I \cdot l \cdot (r \cdot \cos\varphi \; x \cdot \sin\varphi)$	$\Delta U = 2 \cdot I \cdot l \cdot r$
perceutage voltage drop	$\Delta u = \frac{\Delta U}{U_r} \cdot 100$	$\Delta u = \frac{\Delta U}{U_r} \cdot 100$	$\Delta u = \frac{\Delta U}{U_r} \cdot 100$
active power	$P = U \cdot I \cdot \cos\varphi$	$P = \sqrt{3} \cdot U \cdot I \cdot \cos\varphi$	$P = U \cdot I$
reactive power	$Q = U \cdot I \cdot \sin\varphi$	$Q = \sqrt{3} \cdot U \cdot I \cdot \sin\varphi$	–
apparent power	$S = U \cdot I = \sqrt{P^2 + Q^2}$	$S = \sqrt{3} \cdot U \cdot I = \sqrt{P^2 + Q^2}$	–
power factor	$\cos\varphi = \frac{P}{S}$	$\cos\varphi = \frac{P}{S}$	–
power loss	$\Delta P = 2 \cdot l \cdot r \cdot I^2$	$\Delta P = 3 \cdot l \cdot r \cdot I^2$	$\Delta P = 2 \cdot l \cdot r \cdot I^2$

Caption

ρ_{20} resistivity at 20 °C
l total length of conductor
S cross section of conductor
α_{20} temperature coefficient of conductor at 20 °C
θ temperature of conductor
$\rho\theta$ resistivity against the conductor temperature
ω angular frequency
f frequency
r resistance of conductor per length unit
x reactance of conductor per length unit
$u_k\%$ short-circuit percentage voltage of the transformer
S_r rated apparent power of the transformer
U_r rated voltage of the transformer
$p_k\%$ percentage impedance losses of the transformer under short-circuit conditions

Due to possible developments of standards as well as of materials, the characteristics and dimensions specified in this document may only be considered binding after confirmation by ABB SACE.

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