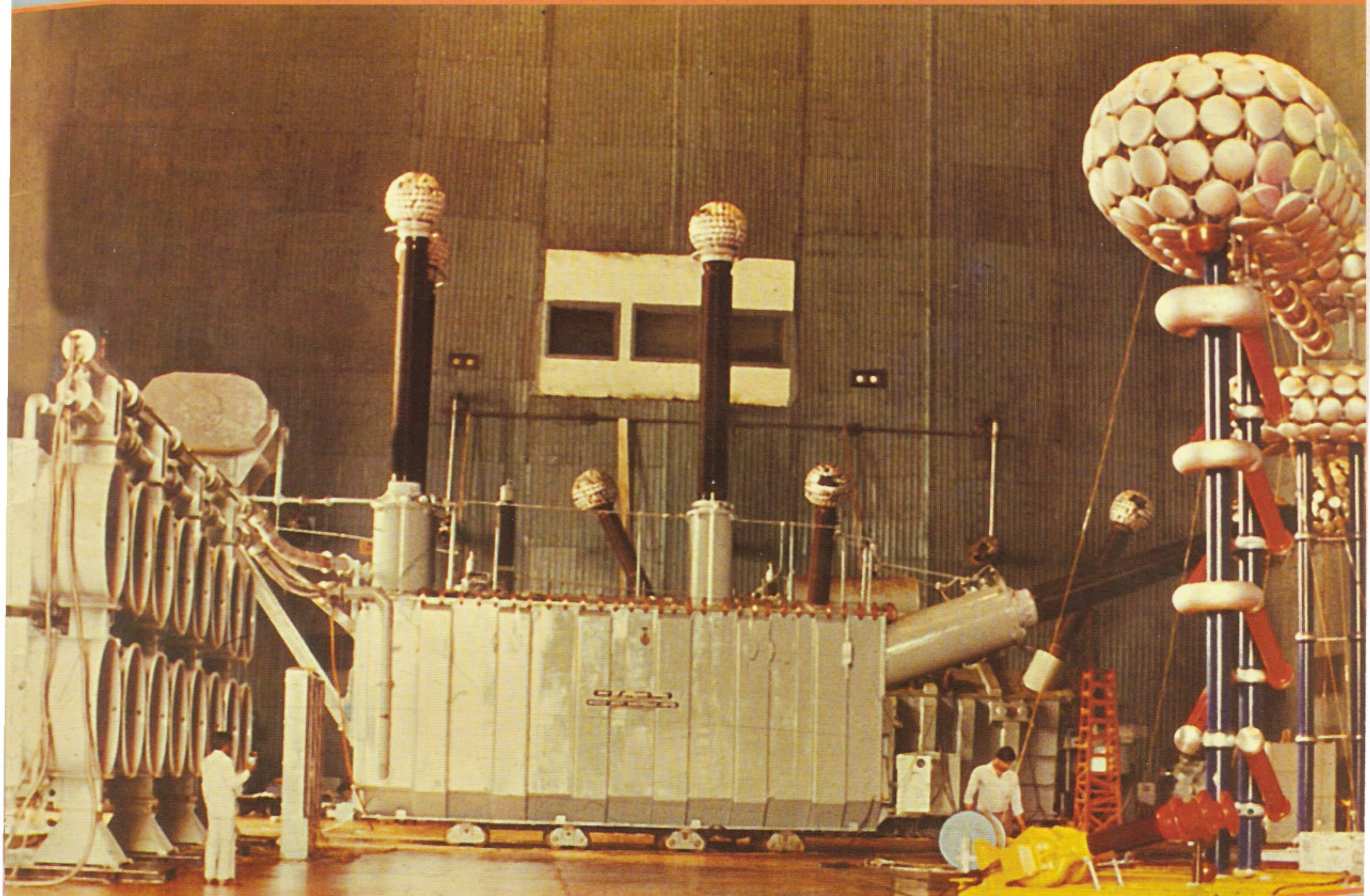
TRANSFORMERS



बी एच ई एल
BHEL

BHARAT HEAVY ELECTRICALS LIMITED
BHOPAL (INDIA)

POWER TRANSFORMER

The BHEL Bhopal plant is having ISO-9001:2000 and ISO-14001:1996 accreditation.

The range of BHEL power transformers covers the whole field from low voltage medium power transformers to extra large power transformers of 600 MVA bank in 400 KV class and HVDC Convertor Transformers of 945 MVA bank in ±500 KV DC. This brochure generally serves to illustrate the broad principles and manufacturing process involved.

In general, the main parts of a transformer - core, coils and tank are made separately. The core and coils are then assembled, and the assembly is placed in the tank. Depending on customer's requirement, an on-load tap changer or an off-circuit tap changer is fitted at this stage. The finished transformer is then ready for processing and testing, prior to despatch.

180 MVA 275/132/11kV 3-Phase Auto transformer at Skudai S/stn , Malaysia

CORE

BHEL make transformers have core-type configuration. Core is built up from cold rolled grain oriented silicon alloy sheet steel of the best magnetic properties. CNC machine is used for slitting, cropping / mitring operations with perfect control on burr level. A computer programme determines number of steps, position of oil ducts and sizes of laminations for optimum cross sections of core and yokes. In order to achieve a further reduction of Iron loss, laminations are mitred and core bolts for clamping are kept to a minimum. Bolts in core legs are completely eliminated by using resin bonded glass tape for binding or by using skin stressed cylinder.

Magnetic circuits are generally of 3 limb construction (for single phase transformers, only centre limb is provided with windings and the outer limbs provide return path for main flux). To facilitate transportation, the overall height of very large 3 phase transformers is reduced by using narrower horizontal yokes, and adding 2 vertical return limbs, thus making a 5 limb construction.

The vertical limbs are interleaved into the top and bottom yokes, and the laminations are so clamped together as to ensure freedom from vibration, and a

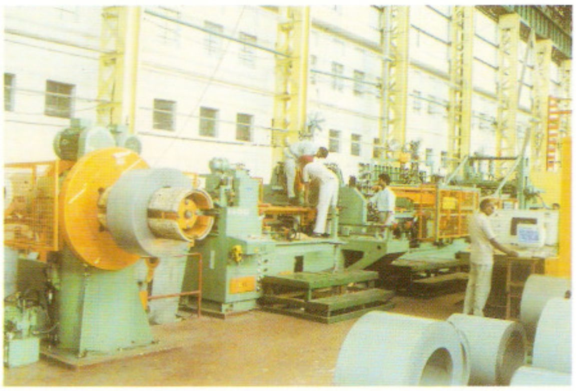
Core of a 240 MVA 15.75/420 kV Generator transformer under construction

minimum of magnetostriction noise.

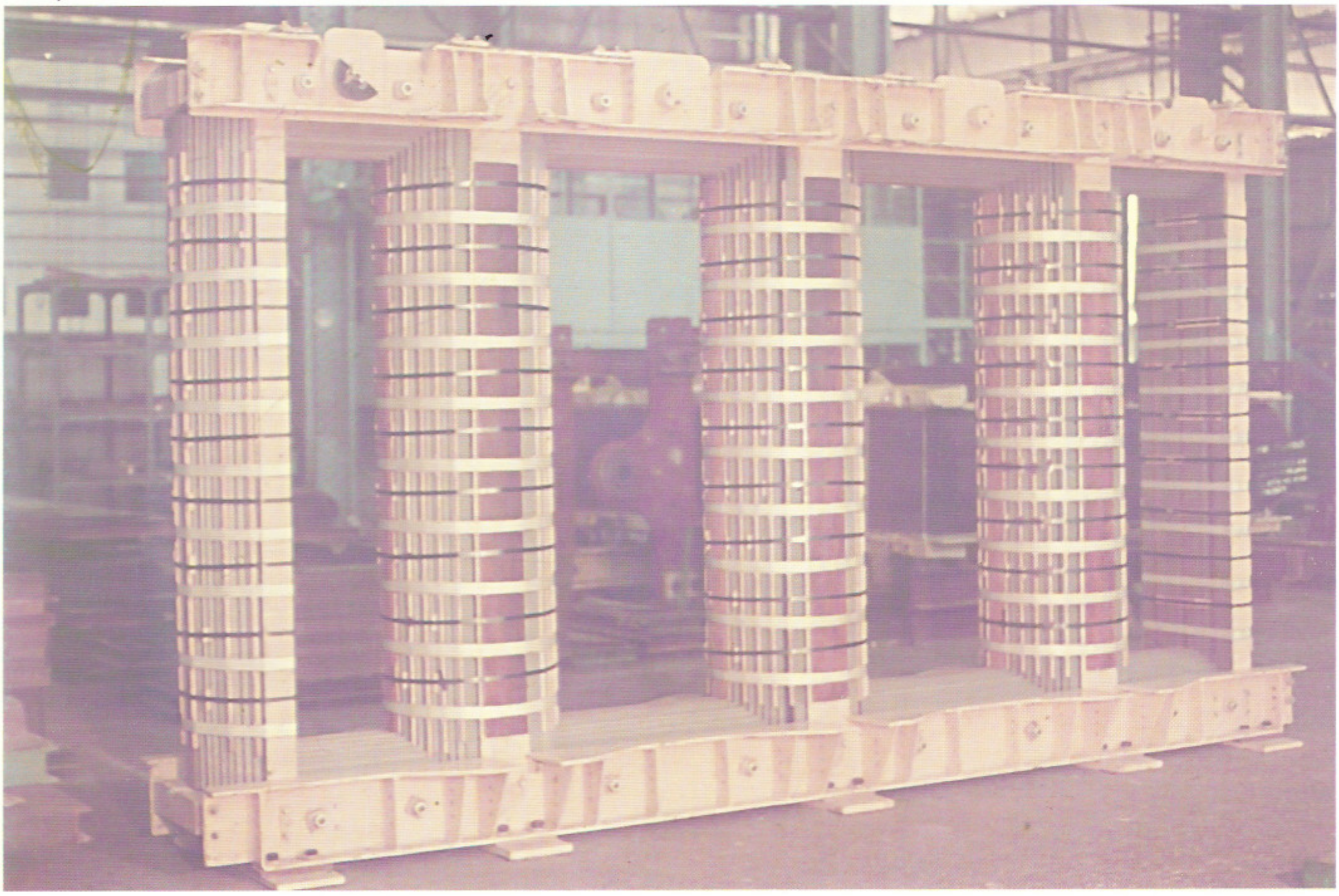
The top and bottom yokes are held securely together by welded steel end frames, provided with flanges to support the windings. The vertical limbs are securely held together by core clamping plates, which are fastened to the top and bottom end frames. This offers satisfactory arrangement for lifting the core separately or together with the winding. The windings are kept under pressure with the help of separate adjusting screws or dash pots mounted on the top end frame. In case of EHV transformers, the bottom yokes are clamped by means of screw jacks against a form fit bottom tank.

Core is assembled in horizontal position, Final lifting is done with the help of a cradle to avoid any undue strain during lifting. Cross section of core is a stepwise assembly to give a circular shape by achieving better space factor utilisation. Ducts are provided through core to allow oil circulation, thus ensuring efficient cooling.

All structural steel work associated with the core is shot blasted to remove scale, and then coated with oil-proof varnish.



Three phase five limbed core



WINDING

Transformer winding is cylindrical and arranged concentrically. This design offers substantial advantages like :

- Simplicity & elimination of weak insulation points by means of symmetrical layout.
- Great mechanical resistance to short circuit stresses.
- Free oil flow through cooling channels.

  The rating and connection of the winding largely determine the choice of the type of winding. The following 4 types of windings are generally used :

- Helical winding
- Spiral winding
- Continuous disc section winding
- Interleaved disc winding

HELICAL WINDING :

This is generally used for low voltage windings and consists of a number of parallel conductors simultaneously wound on an insulating cylinder of high mechanical strength. Where current is very high, the conductors are transposed to ensure equal current distribution in all strands, thereby reducing stray copper losses to a minimum. To provide adequate cooling, axial and radial ducts are provided by spacer blocks.

SPIRAL WINDING :

The spiral windings are generally used for voltages upto 33 KV. These are essentially same as helical windings,

Horizontal winding machine

except that turns are not separated by radial spacing blocks.

CONTINUOUS DISC SECTION WINDING :

For voltages between 33 KV and 132 KV, the winding is generally split into a number of separate coils, in order to limit the voltage per coil.

These coils are made up of one or several flat conductors wound in spiral form. These are stacked one above the other and connected in series by cross overs made alternately on their inner and outer sides, so that the windings are continuous without any joints between coils.

Such a winding is made in the simplest form, proportioning the insulation at each point to suit the power frequency and surge voltage stresses. For system voltages above 66 KV, stress rings are usually incorporated to modify the stresses at the ends of the winding.

To ensure adequate cooling, oil ducts are provided by vertical pressboards spacing strips and horizontal radial spacing blocks between sections.

INTERLEAVED DISC WINDING :

For EHV windings this type of winding is commonly used. By properly interleaving the turns within a pair of discs, the series capacitance of winding can be increased many times. This results in nearly uniform voltage

distribution under impulse conditions. Cross overs are made at the inside of the disc pair and joints are made near the outside. More often partially interleaved disc coil is used where only a part winding is interleaved and balance portion is continuous disc construction.

SHORT CIRCUIT RESISTANCE :

Circular coil offers the greatest resistance to the radial component of electromagnetic forces, since this is the shape which any coil will tend to assume under short circuit stresses.

The longitudinal stresses are reduced by proper balancing of primary and secondary ampere-turns, along the coil. In particular, the voltage adjustment taps are distributed so as to keep imbalance of ampere-turns to the minimum.

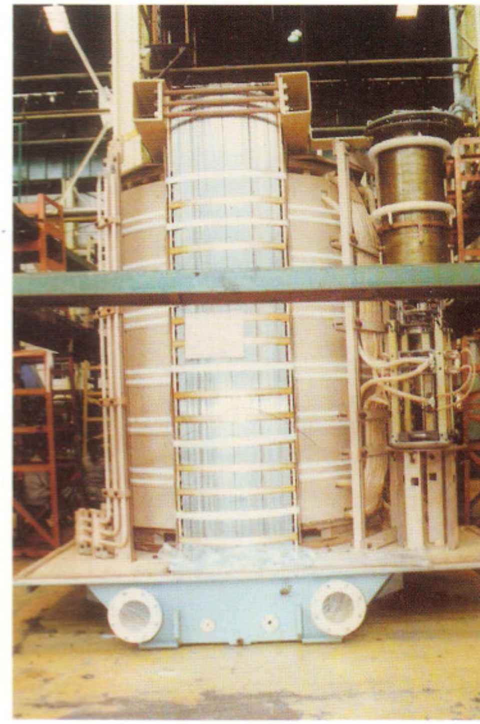
Where large range of tappings are required, these are generally arranged in a separate coil which is spread over the whole length of the coil stack, in order to preserve magnetic balance between the windings as far as practicable, and to minimise axial stresses under fault conditions.

All insulation is shrunk during manufacture to virtually preclude any shrinkage in service, which might result in looseness and movement of the windings under short circuit.

Vertical winding machine

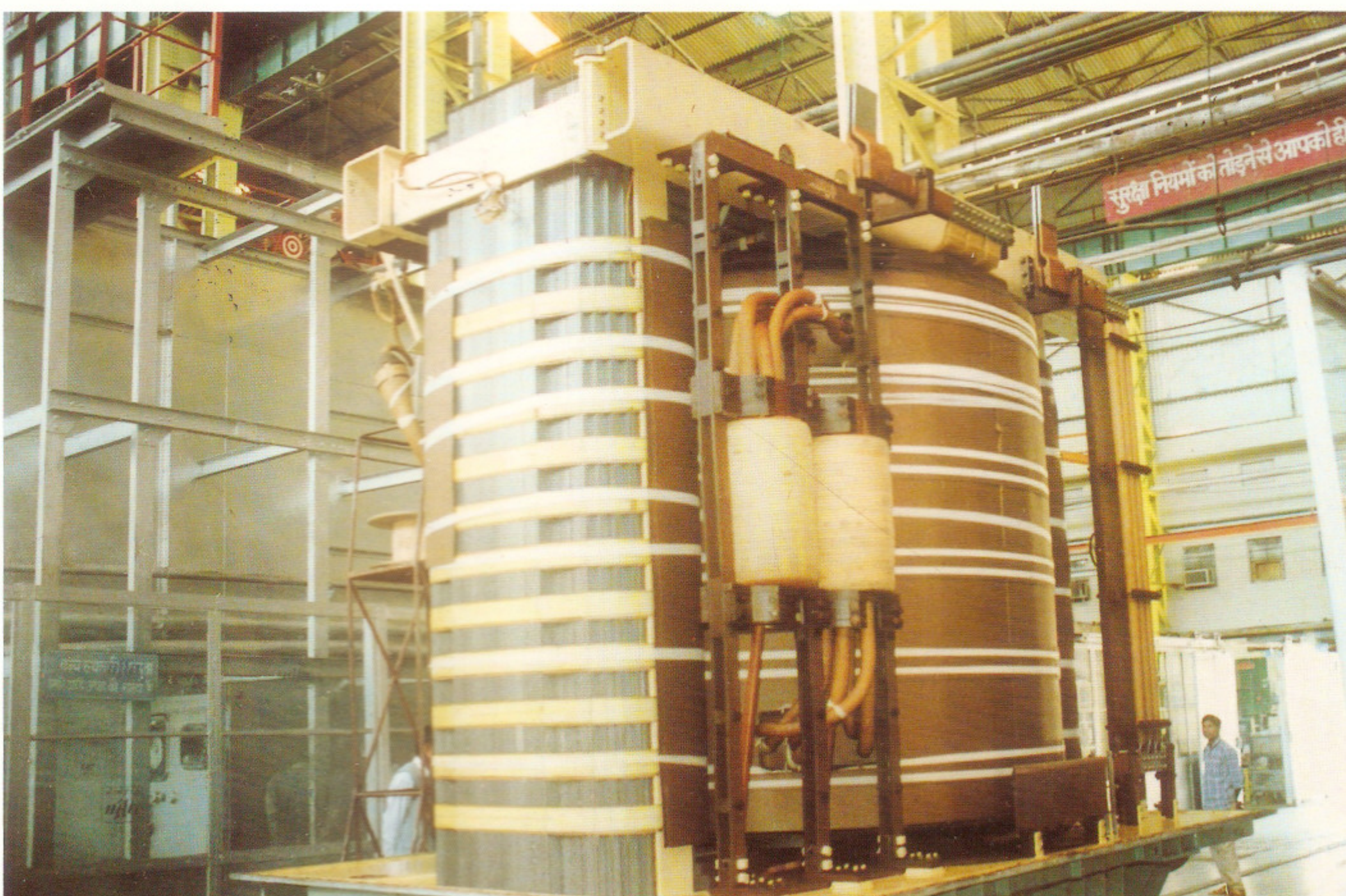
CORE AND COIL ASSEMBLY

At this stage of manufacture , the core and coils are brought together and assembled. The insulation system is so designed that the terminal major insulation and internal coil insulation are properly co-ordinated to minimise the effects of any surge voltages. Immediately after core and coil assembly, preliminary ratio and resistance tests are carried out before doing further work on the transformers.



Experimental investigations are sometimes carried out to determine the magnitude and nature of the impulse stresses, which are not distributed linearly along the legs as they are under power frequency conditions. The voltages that would be appearing between the various parts of a winding under surge conditions are found out at this stage by means of recurrent surge oscilloscope.

Core and Coil Assembly



TANK

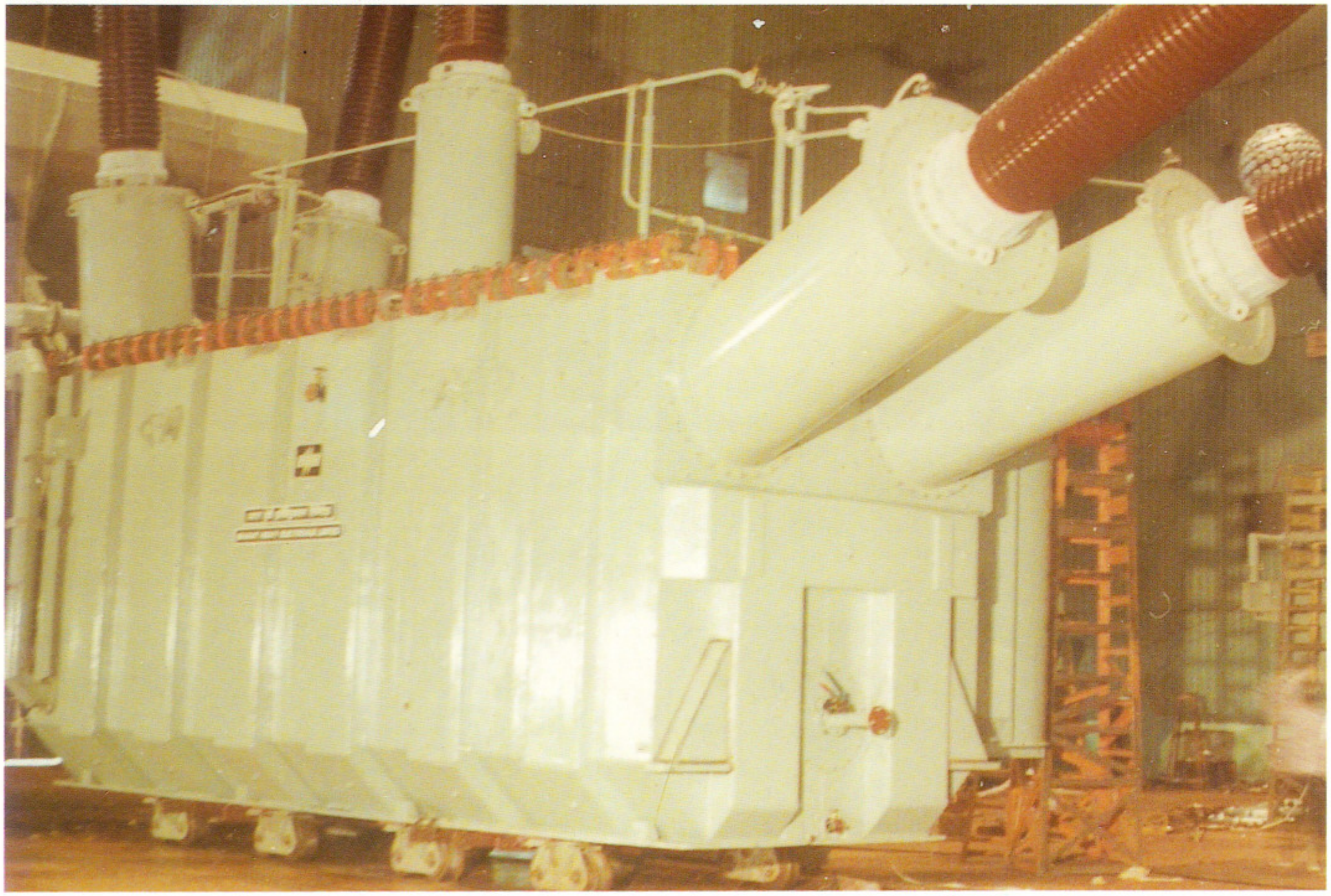
Tanks are fabricated from mild steel plates, electrically welded and are shot-blasted, inside as well as outside to remove any scales before painting. The inner surface is coated with suitable oil resistant paint whereas the outer surface is painted with high quality anticorrosive paint system comprising of 4 coats.

Tanks are designed and tested to withstand appropriate vacuum and pressure. For special designs, the mechanical stresses are analysed by Finite Element method. The weldings are checked by ultrasonic / dye penetration method for any defects.

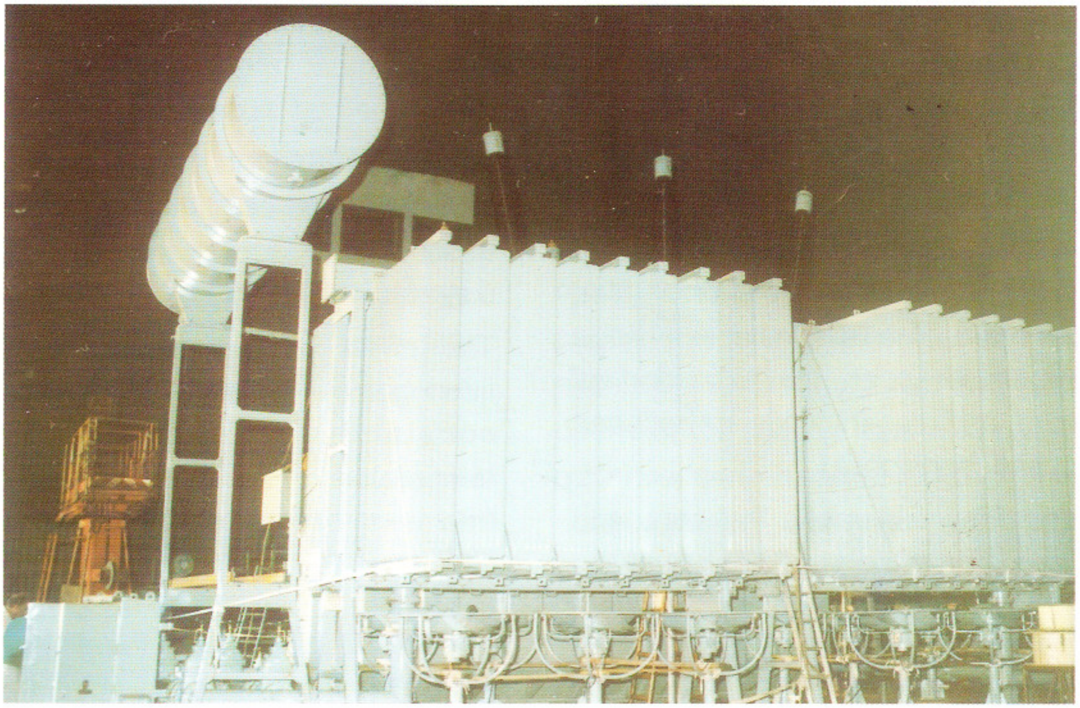
The tank fabrication shop is fully equipped to make tanks of any shape and of the largest sizes, including bell type construction. This construction allows easier access to core and winding for maintenance purposes.

The flanges are designed so as to provide adequate gasket seating for prevention of leakages. Suitable locking arrangements are provided inside the tank so as to prevent movement of core and winding in transit.

315 MVA HVDC Convertor Transformer Tank



COOLING SYSTEM



NATURAL AND AIR BLAST COOLING:

Detachable radiators are used to provide adequate cooling surface. They may be mounted directly on the tank side or built up in one or two banks placed adjacent to the transformer and connected to it by pipe work, depending on size and available space at site.

The radiator element is made from specially treated sheet steel plates. Two rolled and pressed plates are welded together along the outer edges and along the troughs between flutes. A number of such elements are welded into a mild steel header.

For increased cooling, fans are provided beneath the radiators. The fans are operated automatically when winding reaches a preset temperature by means of mercury switch contacts provided in the winding temperature indicator.

WATER COOLING :

The water cooler is usually of condenser type. Top oil is pumped around a set of tubes through which cooling water circulates. This type of cooling reduces the space requirement considerably, and is recommended specially for generator transformers where plenty of cooling water is available. To prevent any possible leakage of water into the transformer oil, oil pressure is always maintained higher than the circulating water pressure.

FORCED OIL COOLING :

Hot oil from the top of the tank is pumped into a compact cooler with built-in fans, and returned to the tank at the bottom. Alternatively a pump can be introduced to force the oil circulation between the top and bottom main radiator headers (where radiators are mounted in a separate bank). In the latter case, the pump motor and fan motor are arranged to operate automatically when winding reaches a preset temperature, by means of mercury contacts provided in the winding temperature indicator.

PROCESSING

The quality of a transformer, and consequently its performance and life, depends essentially on the factory processing, which is carried out at various stages of manufacture.

All the coils are preshrunk before assembly. After the coils are assembled on the core, the whole assembly is heated in an oven for extraction of moisture, and also the coils are reduced to proper dimensions.

After final assembly, the core and coils are kept in their own tank, and the whole unit is placed in a vacuum chamber for final drying. The chamber is heated up to about 100^0 C and a vacuum of very high degree is maintained during dry-out. Sometimes vacuum drying is done by drawing vacuum in its own tank and keeping the whole transformer inside an oven.

Besides this conventional method of drying, most modern Vapour Phase Drying method is used alternatively.

Much importance is attached to proper dry-out, as otherwise coils would become loose in service and may get distorted under short circuit conditions.

The oil is treated separately in the filtering and degerating plant, and is kept constantly under vacuum at a temperature of 80^0 C, so that moisture-free degassed oil is always available. Ten thousand gallons of oil can be treated in the plant at a time. Oil is tested for electrical strength, and moisture content before the same is let into the transformer. The oil impregnation of winding insulation is also done under high vacuum conditions. The dryness of insulation is measured in terms of insulation resistance.

ACCESSORIES

OIL CONSERVATOR :

All power transformers are invariably provided with an expansion vessel called Conservator. This is to take care of the changes in oil volume due to change in ambient temperature, or as a consequence of changes in load on the transformer. The oil level in conservator thus rises or falls, resulting in a phenomenon called 'Breathing'.

The conservator is fitted with an oil preservation system called 'Aircell', which is a bag made of nitrile rubber and it floats on the oil surface inside the conservator. The aircell inflates or deflates as the oil level in the conservator falls or rises.

The above system prevents direct contact of transformer oil with atmospheric air and retards oxidation and sludging, thereby greatly reducing the oil deterioration / maintenance problems at site. Maintenance of the system is also negligible, since once in operation it generally needs no attention other than routine visual inspection.

OIL LEVEL GUAGE :

A magnetic oil level guage is fitted to indicate oil level in the conservator, float of which is always beneath the aircell. This guage is also provided with a switch which gives alarm when oil level falls below the minimum oil level or when air cell is damaged and sinks.

BREATHER :

A breather is connected to the aircell and is used to dry the air that enters in the aircell when the transformer breathes. The breather contains an absorbent material like Silicagel for absorbing the moisture present in the atmospheric air. Air entering the breather is first drawn through an oil seal at the bottom, and passes upwards through the silicagel crystals to the connecting pipe at the top of aircell.

During the upwards passage of air, any moisture present is absorbed by the dry silicagel. The oil seal at the bottom ensures that the gel absorbs moisture only when the transformer is breathing in.

TEMPERATURE INDICATORS :

Each transformer is provided with dial type thermometers for oil and winding temperature indication. The bulb is placed in an oil filled pocket screwed into the transformer tank cover. The pocket or the bellow for winding temperature indicator has a heating coil around it, which is fed by a CT provided on one of the transformer line terminals. As such any changes in the load reflect in the heating of the winding temperature indicator pocket/bellow.

The expansion of the liquid in the bulb is transmitted throgh a capillary tube to an indicating instrument. The dial type thermometer is also provided with mercury switches for alarm and trip circuit operations in the event of excessive temperature rise and also for operation of cooling fans and oil pump motors at certain preset temperatures. A potentiometer device can also be provided for remote temperature indication.

BUCHHOLZ RELAY :

The oil and gas actuated relay (Buchholz) serves as a protection against any loss of oil, discharge inside the tank and interturn short circuit and insulation defects. Indications for the above faults are available from this relay even when the fault current is too small to operate the overcurrent and earth fault relays. This device is usually mounted in the connecting pipe between the highest point in the transformer and the oil conservator. The device accommodates two floats, of which the upper float is actuated by a build-up of gas and the lower float by a sudden oil surge. The contacts for the first float normally give an alarm signal and those of the second, cause tripping. Gas sample can be collected from the upper part of the device, and analysis of the gas gives an indication as to the nature of fault.

MARSHALLING BOX :

A weather proof marshalling box is fitted on the side of the transformer tank or mounted separately. This accommodates the oil and winding temperature indicators, starters etc for various fan and pump motors, and terminal connectors from various alarm and trip circuits provided in the transformer. A heater is provided inside the marshalling box to avoid any condensation.

PRESSURE RELIEF VALVE :

This is a spring loaded safety valve mounted on the tank cover for protection of transformers in case of sudden over pressure. Valve diaphragm is sealed against gaskets by springs. Valve operation is effected when pressure inside the tank exceeds opening pressure established by springs. The transformer pressure is then rapidly reduced to normal value and spring returns the diaphragm to closed position.

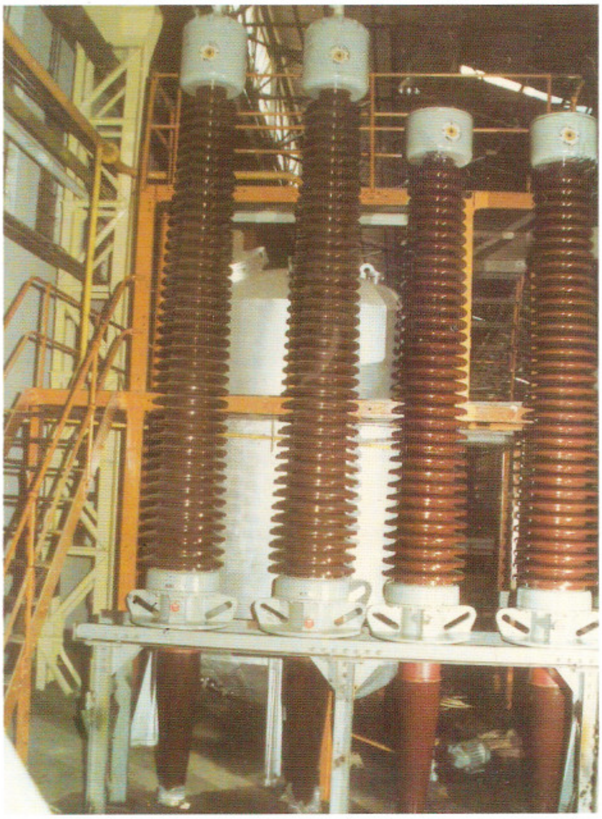
BUSHINGS :

Oil filled porcelain bushings are used for taking out the terminals for voltages up to a level of 33 KV. The bushing consists of a conductor within a porcelain jacket.

For 52 KV and above, condenser type bushings are used. The active part of these bushings consists of Oil impregnated paper (OIP) condenser core manufactured from superior grade craft paper wound on Aluminium tube. This bushing is voltage graded by suitably interposed Aluminium foils forming condenser layers. Thus the electrical stresses are controlled throughout the thickness and along the surface avoiding highly stress concentrations.

The condenser core is assembled with a mounting flange and porcelain insulators at both outdoor and oil immersed end. The wound core is vacuum dried and impregnated with high grade degassed and dehydrated transformer oil. A prismatic or magnetic oil level guage is provided to indicate the level of oil in the bushing.

A self earthed test tap arrangement is provided on the flange which is used for measurement of Tan delta and Capacitance of the bushing. Creepage distance suitable for highly polluted atmosphere is also provided.



BHEL range of inhouse manufacture of bushings covers the complete requirement upto 400 KV class and caters to requirement of both, in-house manufactured transformers as well as for other transformer manufacturers.

Depending on specific requirement of customer, Oil filled / Air / Compound filled cable boxes are also manufactured.

TAP CHANGERS :

The Tap Changers are used to vary the ratio of oil-immersed transformers under load.

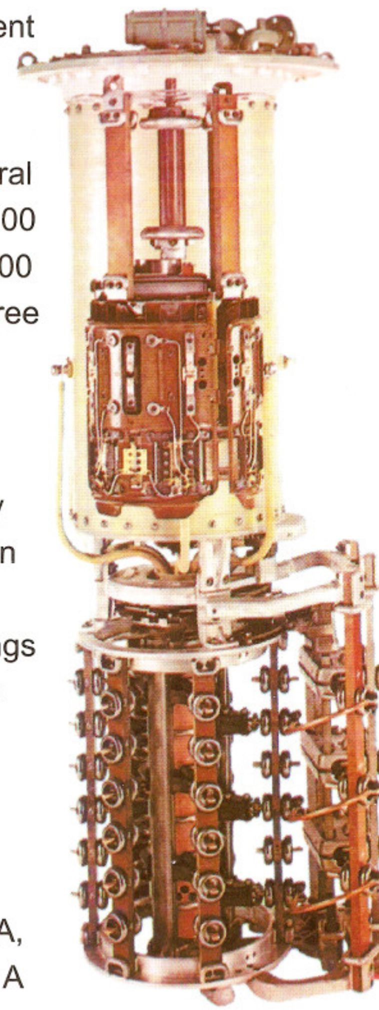
The M-type tap changer comprise a diverter switch and a tap selector in a single column design. The V-type tap changer works as a selector switch combining the features of a diverter switch and a tap selector.

Few important features of M-type tap changer are :

- High speed transition resistor type diverter switch with arc extinction at the first current zero.
- Three pole design for neutral application at 350 A, 500 A and 600 A ratings for three phase Y-connected windings.
- Three pole fully insulated design at 350 A, 500 A and 600 A ratings for three phase Delta or Auto connected windings.
- Single pole designs at 350 A, 500 A, 600 A, 800 A, 1200 A, 1500 A and 1800 A ratings for Auto connected or Single phase transformers.
- Available with ±9, ±11, ±13, ±15, ±17 steps.
- Rapid tap change operation, low thermal stresses on the transition resistors.
- Tap selector gear with steady torque during the tap chan ger operation.
- Long contact life.
- Diverter switch contacts easy to replace.

Few important features of V-type tap changers are :

- High speed transition resistor type diverter switch with arc extinction at the first current zero.
- Three pole design for neutral application at 200 A, 350 A and 500 A ratings for three phase Y-connected windings.
- Three pole fully insulated design at 200 A, 350A and 500 A ratings for three phase Delta or Auto connected windings.
- Single pole designs at 200A, 350 A and 700 A

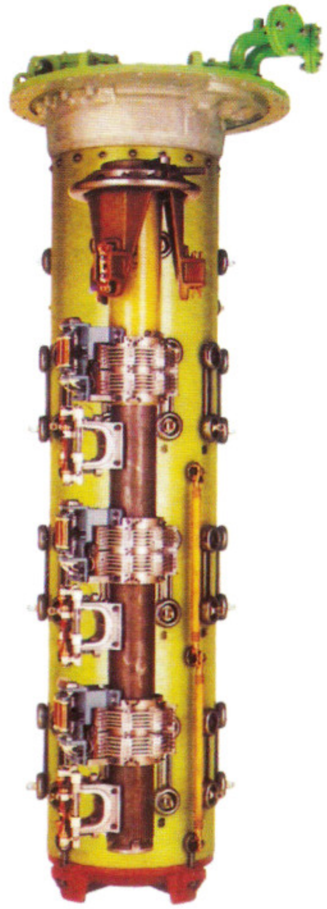


ratings for Single phase transformers.

- Available upto ±13 steps.
- Long contact life.

The technical data of tap changer type M and V have been verified by type tests according to IEC recommendations Publ. 214 (1976).

BHEL range of in house manufacture of tap changer covers the complete requirement upto 400 KV class transformers and caters to requirement of both, in-house manufactured



transformers as well as for other transformer manufacturers.

CONTROL EQUIPMENT :

The tap changer can be provided with local electrical, remote electrical independent, and remote electrical non-automatic/ automatic parallel operation. Outdoor weather- proof kiosk for mounting of local electrical control equipment and indoor control cubicle for the mounting of the remote control equipment can also be supplied.

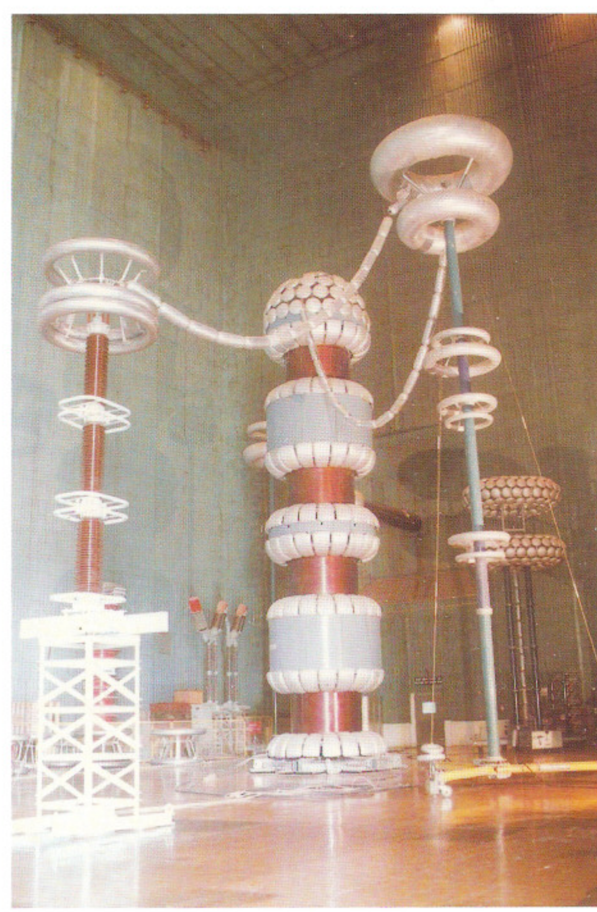
TESTING

Testing facility at BHEL works is well established for conducting routine as well as type tests as per International or Indian Standards. The tests on transformer can in general be divided briefly into following categories :

- Tests requiring sine wave voltage at variable frequencies :

  No-load loss test and over-potential tests (with partial discharge measurement) fall in this category. These tests require a large sine wave generator. A short time rated 4 MVA generator having a continuous rating of 2 MVA, with a frequency variation from 25 tc 180 Hertz has been installed for this purpose.

  It may be mentioned here, specially with regard to iron loss test, that application of sine wave voltage is absolutely important to get a

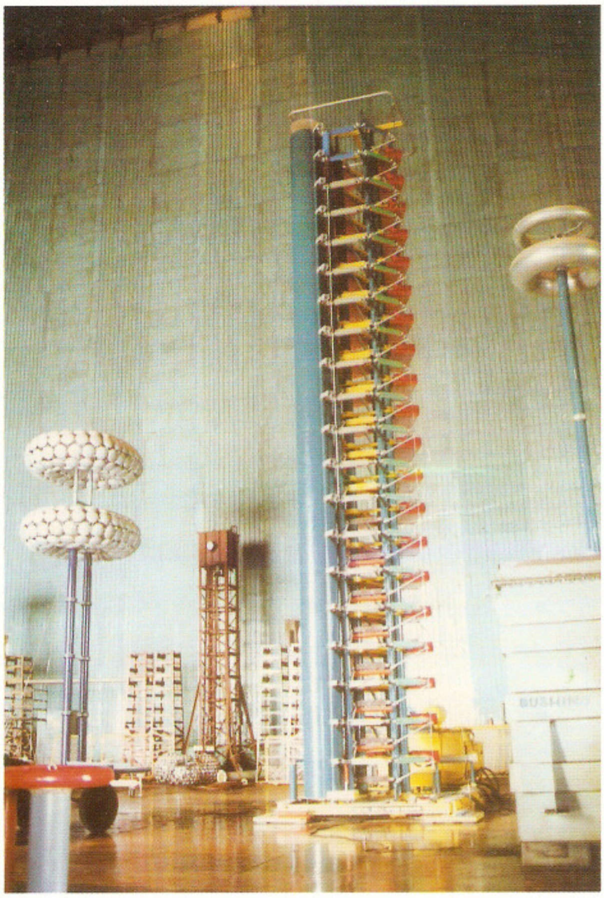


form factor as close as possible to 1.11, so that application of correction factor is avoided as far as possible.

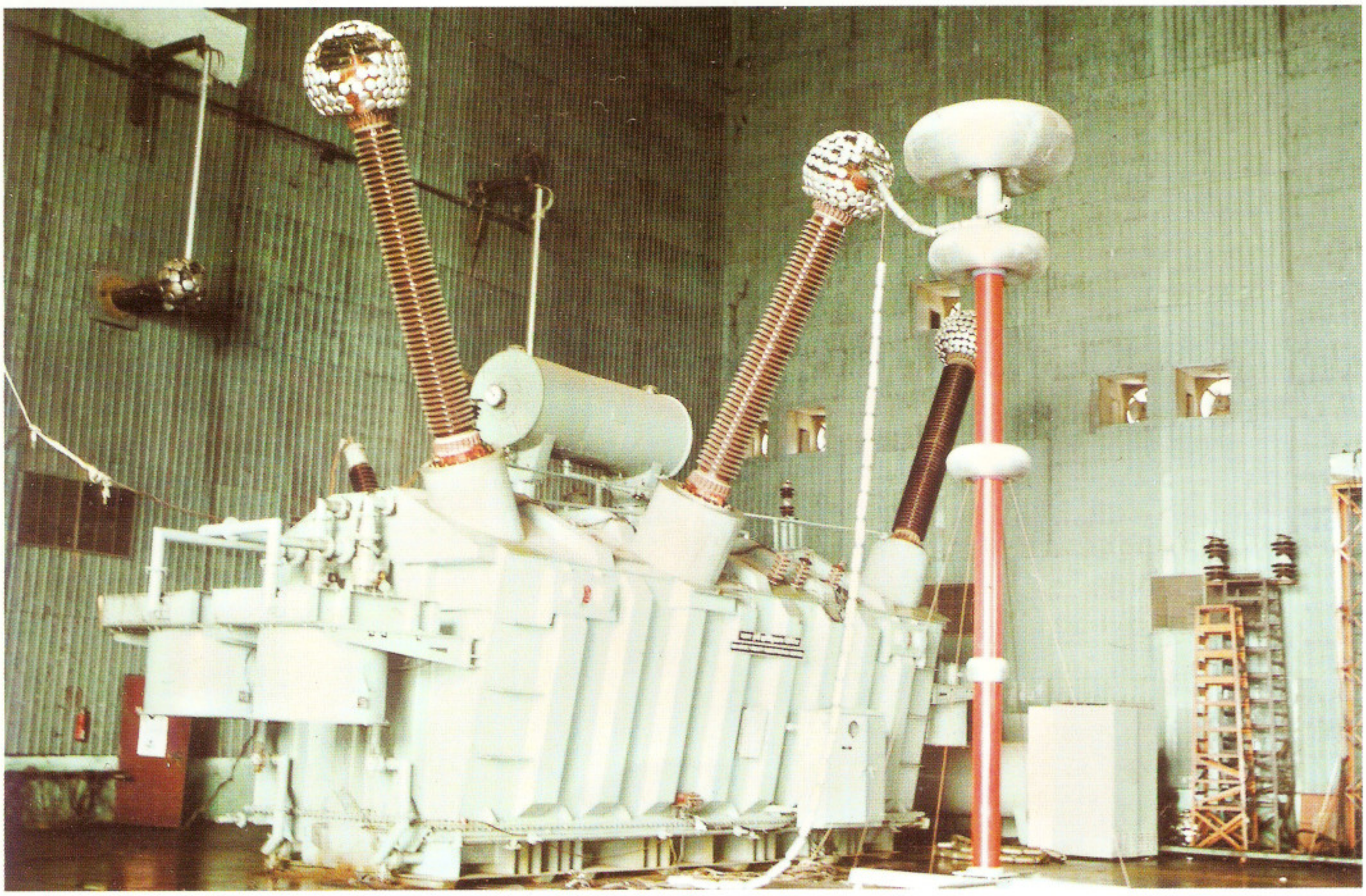
- Tests requiring power frequency voltage at full power for a transformer under test :

Load loss test, impedance voltage measurement test and temperature rise test fall in this category. For these tests, a large power output at varying voltage is necessary, to enable feed full copper and iron losses at the impedance voltage of the transformer under test. A 40 MVA motor generator set and a matching transformer have been installed for this purpose, which can give full output at voltages from 6 to 37 KV, thus enabling testing of even large transformers at full load.

- Tests requiring Impulse voltage such as Lightening and Switching.
- Special tests such as RIV, Noise level, Vibration test, Stress measurement etc.



160 MVA 66/650 kV 3 Phase testing transformer



MANUFACTURING FACILITIES

SALIENT FEATURES

- Slitting line for CRGO steel (width of roll 1100 mm).
- Hydraulic & Pneumatic Cropping line (Lamination size 750 mm).
- CNC Cropping line (Lamination size - 1050mm).
- 200 T Core building platform.
- 20 T Vertical winding machine.
- 16 T Horizontal winding machine.
- High frequency brazing machine.
- 300 T Hydraulic press.
- 400 KW Vapour phase processing plant.
- 8000 LPH Oil Filteration plant.
- 250 T Crane lifting capacity.
- Railway wagons of 92T, 150T, 180T and 250 T capacity.
- Inhouse manufacturing & testing facility for Bushings, Tap changers, Radiators, OFAF Coolers, OFWF Coolers, Control panels, Machine shop, Insulation Shop.

TESTING FACILITIES

SALIENT FEATURES

In order to meet the country's demand of a testing facility at par with international standards, we have established an Ultra High Voltage (UHV) laboratory, which is having Certificate of Accreditation as per ISO/IEC 17025:1999 standards from National Accreditation Board for Testing and Calibration Laboratories (N.A.B.L), Department of Science & Technology, India. Testing of transformers of rating 315 MVA 3-phase ; 200 MVA 1-phase in 400 KV class, Shunt reactors of rating 80 MVAR 3-phase in 400 KV class, ±500 KV DC 1-phase Converter transformers, 800 KV Bushings and CVT have been satisfactorily established.

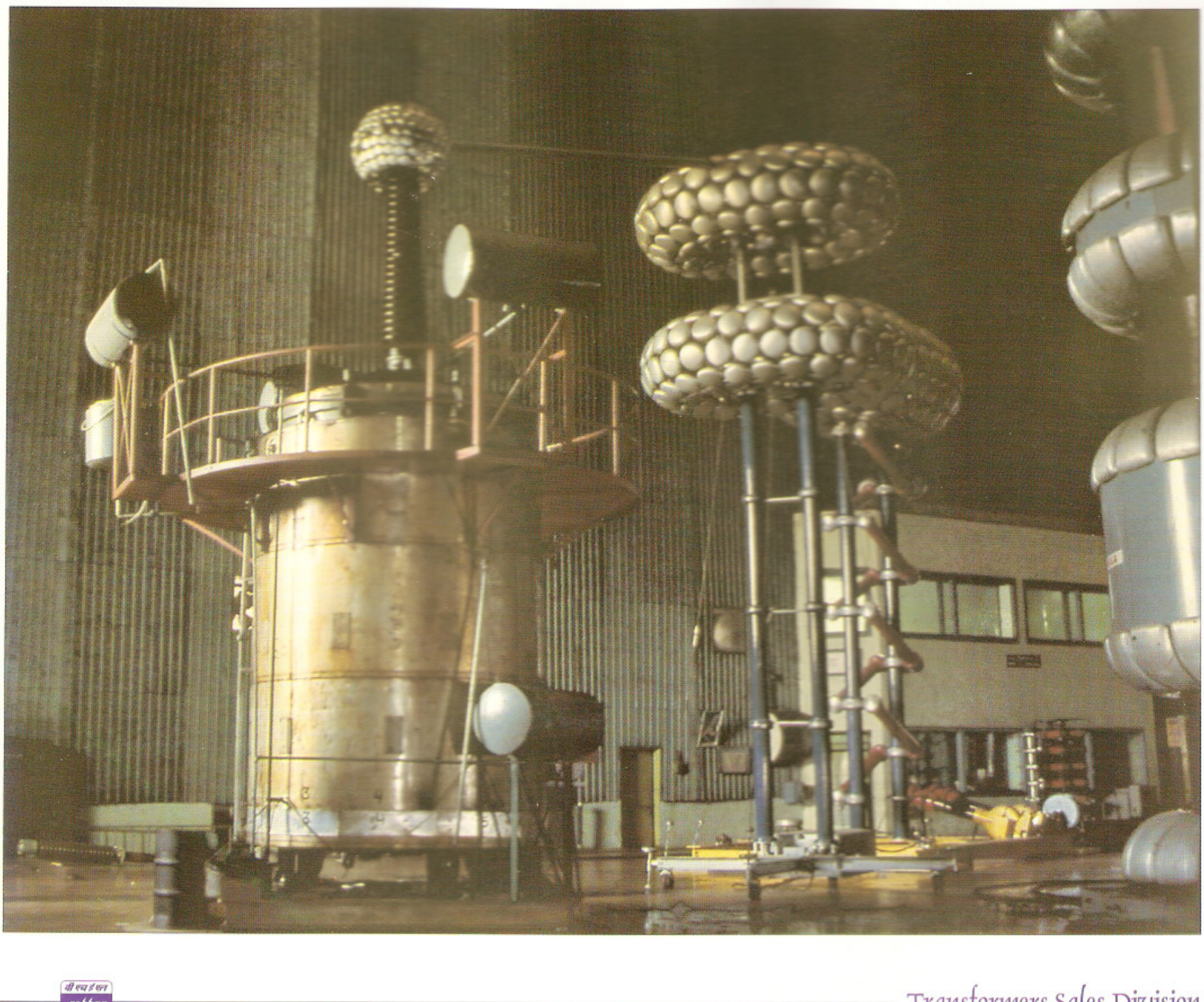
This UHV lab is having internal clear dimensions of 67 M (L) x 35 M (W) x 35 M (H) and is one of the largest screened laboratories in the world, attached to a transformer manufacturing plant.

The major test equipments / facilities in our UHV laboratory are :

- 4.0 Million-volt, 400 KW Impulse Generator.
- 500 Kilo-volt, 15 KW Impulse Generator.
- 3.6 Million-volt, 400 pF Impulse Voltage divider.
- 3.0 Million-volt Multiple Chopping gap.

- 1500 KVA, 1500 KV Cascade Connected testing transformer.
- 160 MVA, 66/650 KV 3-phase Testing Transformer.
- 3x13.33 MVA, 11/90 KV, 1-phase Transformers.
- 3x3.33 KVAr, 11 KV, 1-phase Reactors.
- 100 MVAr, 13-156 KV 3-phase Capacitor bank.
- 1.2 Million-volt, 30 mA DC voltage generator.
- 40 MVA, 0-11 KV, 50 Hz, 3-phase MG set.
- 9 MVA, 0-11 KV, 50-200 Hz, 3-phase MG set.
- 7 MVA, 0-11 KV, 50 HZ, 3-phase MG set.
- 2 MVA, 0-11 KV, 30-180 Hz, 3-phase MG set.
- Partial Discharge detector and RIV meter.
- 2.5M dia x 3.6M high Oil tank for Dielectric and Thermal Stability tests on Bushings.
- 800 KV, 71.5 pF SF6 filled standard capacitor.
- Frequency Response Analyser equipment.

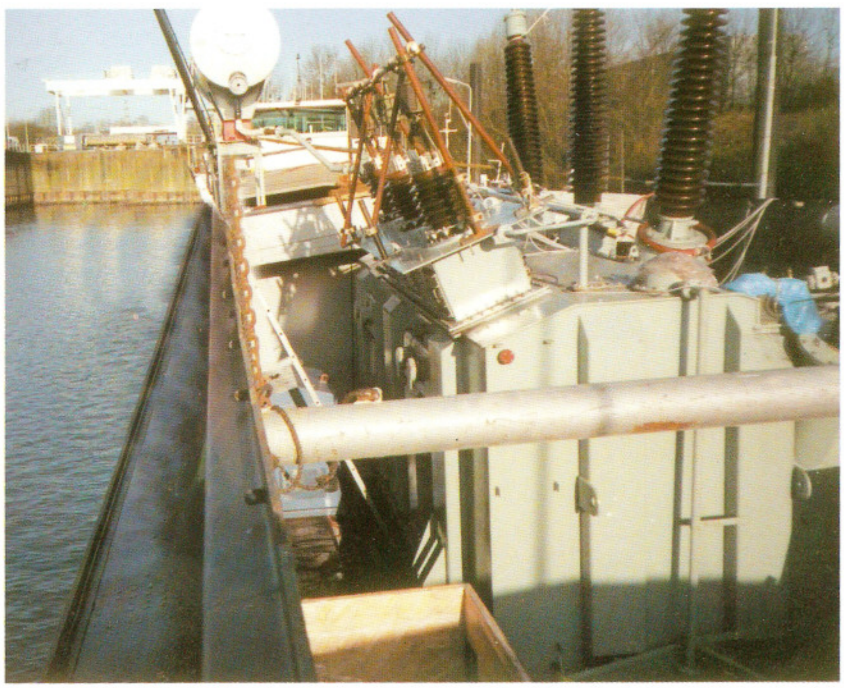
400 kV Bushsing under test



MAJOR LANDMARKS INHOUSE R&D PROJECTS

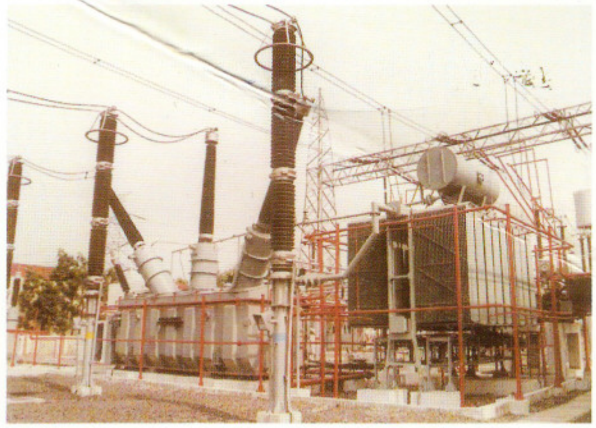
- Complete range of products are type tested as per IS/IEC.
- 2 nos. 200 MVA, 1-phase, 400 KV Generator Transformer tested for Short Circuit at KEMA-Netherlands for M/s NTPC, India in 2002.
- 186.2 MVA, 3-phase, 220 KV Generator Transformer tested for Short Circuit at KEMA-Netherlands for M/s NTPC, India in 2000..
- 167 MVA, 1-phase, 400 KV Auto Transformer tested for Short Circuit at KEMA-Netherlands for M/s NTPC, India in 2002.
- 102 MVA, 1-phase, 400 KV Generator Transformer tested for Short Circuit at KEMA-Netherlands for M/s NJPC, India in 1999.
- 100 MVA, 3-phase, 400 KV Tie Transformer tested for Short Circuit at KEMA-Netherlands for M/s NTPC, India in 2003.
- 70 MVA, 1-phase, 400 KV Generator Transformer tested for Short Circuit at KEMA-Netherlands for M/s THPA, Bhutan in 2003.
- 50 MVA, 3-phase, 400 KV Station Transformer tested for Short Circuit at KEMA-Netherlands for M/s NTPC, India in 2000.
- Other Transformers of rating 80 MVA, 63 MVA, 45 MVA, 40 MVA, 25 MVA tested for Short Circuit at CPRI-Bangalore & Bhopal for M/s NTPC, MSEB.

70 MVA Single phase and 186.2 MVA Three phase Transformer on Short Circuit Test barge at KEMA, Netherlands



- 50 MVAR, 3-phase, 400 KV Controlled Shunt Reactor developed inhouse and installed at 400 KV Itarsi s/stn of M/s PGCIL, India in 2001.
- 2 MVA, 3-phase, 33 KV Phase Shifting Transformer developed inhouse and installed at BHEL R&D complex at Hyderabad, India in 2002.
- 160 MVA, 3-phase, 66/650 KV OFAF cooled testing transformer developed inhouse and installed in BHEL-Bhopal UHV lab since 1987.
- On-load tap changer type tested at CESI-Italy and KEMA-Netherlands.
- 800 KV, 1250 Ampere Bushing and 800 KV, 3000 pF CVT developed and tested inhouse.

50 MVAR, 400kV 3- phase Controlled Shunt Reactor



- Export to more than 20 countries including Europe and Middle east.
- Inhouse development of computer software to analyse behaviour of transformer under Short Circuit conditions, distribution of voltage under Lightening/Switching impulse conditions etc.

View of Ultra High Voltage Test Lab

COMMERCIAL ENQUIRIES :

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