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Conference Paper · November 2010
DOI: 10.1109/POWERCON.2010.5666618 · Source: IEEE Xplore

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2010 International Conference on Power System Technology

Sustainable Energy Plan for an Indian Village

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***Abstract*-- India is one of the largest countries in the world, where the people's occupation is predominantly agriculture and most of the population lives in villages. Many of these villages are remotely located and their connectivity with the grid is very difficult resulting in their being not electrified at all or lack of continuous supply. For the development of the region, there is every need to utilize energy efficient techniques and potential of available renewable energy resources. An economic solution can be achieved by proper energy management making the village self sustained in its energy requirement. By employing existing but well proven energy conversion techniques, these resources can be used for various energy requirements for basic needs like electricity, cooking, water heating etc. The aim is to generate electric power, produce cooking gas and other forms of energy locally and distribute them within the village effectively.**

Based on a survey conducted in an Indian village named "Bacharam" situated near Hyderabad in India, this paper attempts to identify the available resources like agro-waste, animal dung, and solar energy. The regular resource usage pattern has been studied and an effective solution has been proposed for proper usage to meet the daily energy requirements. Community biomass plant, biogas plant, solar cooker and heater are proposed as feasible solutions for the needs of the village. The paper also deals with the already existing technology for each that can be put to use, design aspects of each as per the requirements of this village and cost effectiveness of each proposal made.

***Index Terms*-- Biogas, Biomass, Energy Plan, Non-conventional, Renewable Energy, Solar, Survey, Sustainable, Village.**

I. Introduction

THE concept of an energy plan for a rural community by making use of locally available resources to meet electrical and other energy needs has been revisited over the years. A lot of this may owe to the slow but continuously arising awareness among national and international states, about the fast depleting conventional energy sources and the urgent need to find and implement technology for alternative energy sources. Recent work in this area [1-9] has duly stressed importance, of late, in trying to apply the idea to the rural localities given their remote location and the consequent difficulties in connecting the conventional grid. As a fast developing and densely populated country, India's energy demand is continuously raising in all sectors like industrial, transportation, agriculture, domestic etc. Although there is a huge increase in the conventional power generating capacity, still the country is facing energy crisis. On a national average energy India is facing energy shortage of 10.3% within the range of 3%-21% and is 15.4% short in peak demands [10]. For a country like India, which has agriculture as its major occupation, the overall development of villages, where an overwhelming section of the population resides in, plays an influential role in the nation's economic growth. So, more importantly, an insight should be given on the aspects of village development and their electrification is vital towards realizing this. Literature in this domain, especially concerning India [1-7], need to gain good ground. Even though India is among the largest countries, and thus has abundant renewable sources of energy, they have gone untapped for years. Palakkad district of Kerala remains India's only "total electrified district" as on Feb 11th 2010 [11].

Rural electrification is still incomplete due to technical constraints and practical difficulty in electrical power transfer to remote rural areas through grid connectivity which are usually from conventional sources. Rural electrification can be achieved predominantly if one harnesses the locally available renewable sources, namely, bio-mass, biogas and solar power. Exploiting these resources will eliminate the requirement of electricity transfer to remote rural areas and improve living standards and also ensure a clean environment. These non-conventional or renewable sources of energy can supply or in some cases more than meet the demand, without creating environmental hazards. So, this option is more suitable to cater to the problem of rural energy requirements, as these sources are abundantly available in rural areas in India. This decentralized power generation at the village level will help in addressing the problem of inadequate rural electrification. Burning of wood and agro waste for heating and cooking purposes is highly inefficient

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and gives rise to pollution owing to production of gases like CO_2.

In order to contrive an effective solution to this problem, a thorough diagnosis of the current scenario has to be chalked out. The plan to be devised depends on how the existing resources in the village are being utilized and how they can be turned into useful and clean forms of energy for the village households and the village itself in general.

Recent work or field activities have tried different approaches. Integrated Renewable Energy Systems (IRES), first proposed in [4], has gained appreciable popularity. The proposal in [2] experiments with different scenarios of renewable energy usage based on availability and feasibility, while [8] deals with not renewable sources alone, but uses hybrid technology where diesel plant is used as a supplement for hydro, solar and other non-conventional technology. The inequality in the energy consumption pattern in the rural community is studied in [3] while the potential of tapping the energy from municipal waste is discussed in detail in [6].

This paper completely deals with a survey conducted by the authors, in a village, namely "Bacharam", near Hyderabad in India. This village comprises 231 households. The energy needs of the village based on the survey are mentioned where appropriate. The renewable sources of energy proposed to be put to use for improving the overall energy scenario include biomass, biogas and solar energy.

Biomass can be produced from agro waste, mainly paddy in the case of this village, and can be utilized to generate electricity in a biomass plant. The biomass plant has been proposed as a community plant where the excess electricity generated can be fed back to the grid.

Biogas is produced from animal dung. The village has been found to have households owning cows, buffaloes and goats. The biogas plants are proposed to be common for a group of 2 or 3 households according to the villagers' need. The biogas produced supplements the gas needs of the villagers and avoids wood being used as a fuel.

Solar Power is an alternative source to biogas for cooking purposes in the form of solar cooker technology. The solar power is however proposed as an unopposed solution for the heating purposes. The solar heater and cooker are rated based on the amount of water usage for heating and average food needs for cooking, respectively.

The aim is to use the resources in the village itself to satisfy the needs as much as possible within the cost capability of the village economy. The economic analysis of proposed scheme also provides the details about the payback period of the fixed investment for electrical energy generation system.

The goal of this approach is to not only bring about a major improvement in the energy scenario of the village but also impart a considerable uplift to the village economy. This is achieved by ensuring both the complete electrification of the region and the continuous supply of energy. Moreover, the employment opportunities are enhanced because of the local labour (skilled and unskilled) required for the maintenance and operation. A number of local people are bound to find employment in the form of workers in biomass plant as well.

The proposed methodology provides a comprehensive sustainable energy solution for the village community with the present level of proven technology solutions [12-16] which are robust, reliable, easy to maintain, inexpensive and easy to handle.

II. Energy Plan

A. *Current Resource Use Scenario*

The work presented in the paper is fully based on the survey conducted, which provided the authors with enough particulars of the village like population, main occupation, literacy, land in acres, both cultivated and uncultivated, major crops, types of crop residues, livestock, electricity demand for agriculture, domestic and street lightning etc. It also revealed all the practices followed by people in order to meet their daily energy requirements. The conventional practices did indicate an unhealthy way of living with no utilization of the available renewable resources. These practices are not only energy inefficient, hazardous but also pose the problem of environmental pollution.

The current practice scenario depicted by the survey could convey:

Cooking: LPG cylinders and fire wood.

Heating: Burning fire wood.

Electricity: 10 out of 231 houses unelectrified and remaining receive highly discontinuous power.

B. *Proposed Solution in Brief*

By changing the above practices of resource management to clean and eco-friendly techniques, the dependability on conventional energy would be reduced while overcoming the energy shortage and assuring more continuity in supply. In the following sections, cost effective, reliable, eco-friendly and easily adaptable methods of energy conversion are presented.

The plan, as depicted in fig. 1, proposes separate enhanced and cost effective ways of utilizing these resources, for different requirements like:

i. Agro waste is collected and used for power generation with the help of a biomass based community plant which serves the purpose of electricity demand from households, street lighting and agriculture.

ii. Animal waste is used for the production of bio-gas which serves as cooking gas.

iii. The proposed usage of solar energy is for water heating and cooking.

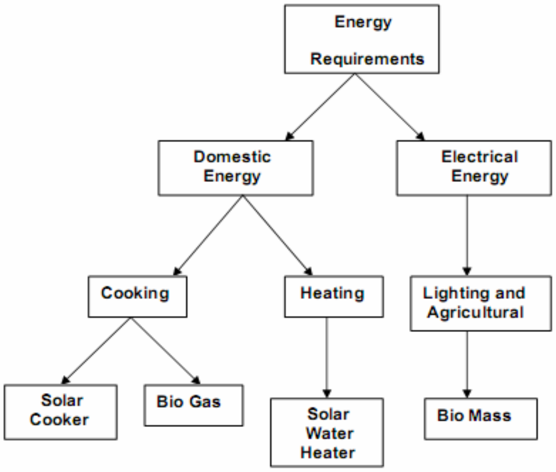

Fig. 1. Classification of Energy Requirement

The relation chart classifies the energy requirement into domestic and electrical energy. Domestic part includes the non electrical nature of energy demand for cooking and heating purposes. Electrical energy includes the households, street lighting and agricultural demands.

C. Proposal to meet electric demand

Electrical energy demand of the village can be met by the fruitful usage of abundantly available resource of biomass. The study pertains only to the agro-waste acquired from the paddy fields. So there is every scope for installing a biomass based gasifier to produce electricity for the village or community as a whole. The agricultural residues are available in adequate quantities. The biomass based power generation system for rural applications could effectively make up for both insufficient power from grid to already electrified parts, and also other completely unelectrified parts. Once both the purposes are met, the surplus energy can be supplied back to the grid, which can yield some revenue for the community on a regular basis.

1) Biomass Plant:

Biomass is a vast renewable energy which still remains relatively untapped. Through energy conversion techniques like combustion and gasification, biomass can be converted to heat, fuel and electrical power. A gasifier is a reactor that converts biomass into clean gaseous fuel called producer gas having calorific value of the order of 1000–1200 kilocalories per normalized cubic metre (cu.m) [12]. However, biomass burning has been characterized with energy inefficiency and environmental hazards.

Working towards a sustainable solution to the energy scarcity in rural India, researchers at TERI have arrived at a technological innovation to exploit the vast biomass resource and generate power in an environment-friendly and profitable proposition. TERI's biomass gasifier system shown in fig. 2, optimally utilizes biomass for power generation and ensures long uninterrupted dual fuel operation [13].

The electricity produced from a biomass-based gasifier system can be used for lighting houses, powering irrigation pumps.

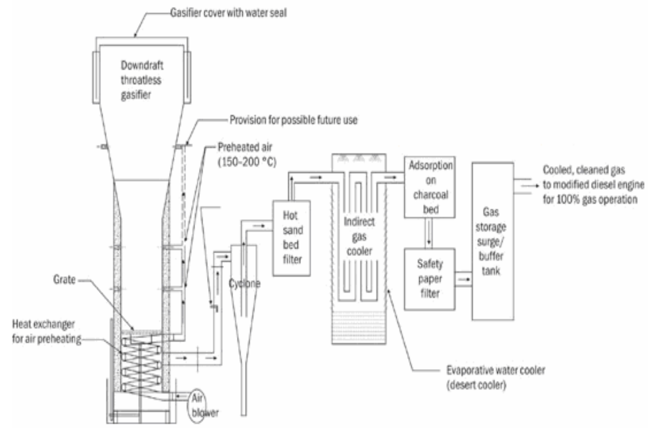

Fig. 2. Schematic of a Biomass Gasifier Plant

The plant discussed is noted to have advantages like:

a. Environment-friendly and sustainable solution due to reduction in the use of fossil fuels.
b. Made available on demand without the need for separate storage.
c. Surplus power can be sold to be supplied back to the grid.
d. Provision of job opportunities to the local population for educated-uneducated, skilled-unskilled through various activities—biomass generation, processing, and operation of the plant.

2) Feasibility of Plan:

The gasifier's design capacity depends upon the amount of agro waste available for the conversion and the electric demand. The agricultural produce is mainly paddy in the villages. The agro waste produced per acre of cultivated land of paddy was found to be around 1.5 metric tonnes. As per the information collected, the total cultivated paddy land is about 800 acres. The paddy cultivation thus yields a total of about 1200 metric tonnes of residue. Since there are two crops a year and the crop is same, the total amount on an annual basis amounts to about 2400 metric tonnes. With Kilowatt-hour (KWh) consumption in consideration, the residue available on an hourly basis is 2400 / 8760 or 0.274 metric tonnes. It can be referred from reliable statistics obtained from My Home Power Ltd., which owns a biomass plant in the vicinity of Hyderabad, India, that 1.5 metric ton is capable of yielding 1 Megawatt-hour (MWh) of energy.

Thus 0.274 metric ton gives rise to 0.274 / 1.50 or 0.182 MWh of energy. The total amount of energy generated in the year with a plant capacity factor 0.8 is thus 0.182*8760*0.8 = 1275.45 MWh.

With the price of Rs. 4 crore taken as an approximate standard for 1 MW plant installation, the cost of the 0.182

MW plant can be rounded to about Rs. 0.728 crore.

On the other hand, the total electrical consumption throughout the year is given by the sum of the agricultural and domestic loads. The total consumption noted from the billing accounts available with the village authority results in (80640+22659) KWh or 103.299 MWh. This consumption pertaining to 2 months, gives the annual consumption to be roughly about 6 times, i.e., 619.794 MWh.

The comparison shows that the biomass reserves obtained from the agro waste (paddy alone) can obtain more than required electrical demand.

D. Proposal to meet cooking gas demand

The cooking gas demand can be met by producing biogas locally or by alternatively using solar cookers.

A biogas plant processes animal dung and produces biogas. The animal dung is available in abundance in the village because it is not depleted of animals like cattle and livestock. Unlike the biomass plant which is a community plant, the biogas plant can be installed on a common basis at a lower level where every 2-3 houses can depend on a single biogas plant. The technology used in a biogas plant is first discussed.

Biogas is a mixture containing 55-65 percent of methane, 30-40 percent of carbon-dioxide and the rest being impurities [12]. It can be produced form the decomposition of animal, plant and human waste. It is clean but a slow burning gas with calorific value between 5000 to 5500 kilocalories per kilogram (Kcal / kg). The produced gas can be directly used for the cooking purpose which reduces the usage of firewood and its inefficient burning. Moreover the slurry produced retains value as a fertilizer and can be returned to soil.

1) Biogas Plant:

There are numerous models of biogas plants but the most important and familiar types used in India are fixed-dome and floating-drum plants. The fixed dome plant has been dealt with in the section due to some advantages over the floating drum type.

A fixed-dome plant is a dome-shaped digester with an immovable, rigid gas-holder [14]. The gas is stored in the upper part of the digester. When gas production commences, gas pressure increases with the volume of gas stored. If there is little gas in the gas-holder, the gas pressure is low.

For the construction of fixed dome plants, local materials can be used but is labor-intensive, creating opportunities for local employment. Care should be taken otherwise plants may not be gas-tight leading to porosity and cracks.

The fixed dome is best suited especially when daily feeding is adopted in small quantities.

The fixed dome plant is considered a viable option because of the evident advantages:

a. Relatively low costs.
b. Simple in design and is compact.
c. Long life of the plant of about 20 years or more.

2) Solar Cooker:

Instead of depending on the shared biogas plant alone, each household can own a box type solar cooker very popular in India and for which a particular amount of subsidy is available from the government too.

Box-type solar cooker consists of an insulated box, metallic cooking tray sat inside the box, double glass lid on the cooking tray, and a reflecting mirror fitted on the underside of the lid of the box [15], as shown in fig. 3. Up to four black painted vessels are placed inside the box. The heat is absorbed by the blackened surface and gets transferred to the food inside the pots to facilitate cooking.

Fig. 3. A common box type solar cooker

It is an ideal device for domestic cooking during most of the year, except for the monsoon season and cloudy days. It can effectively complement the biogas plant in meeting the household's cooking needs as both can be used alternatively according to availability of the input.

Some of the main advantages of a box type cooker are:

a. Involves no recurring expenses on fuel, as it uses solar energy that is available freely.
b. Saves time, as the cook need not be present during cooking in a solar cooker.
c. Durable and simple to operate.
d. Does not pollute the environment and conserves conventional energy.

Box type solar cookers are available both with and without electrical back up in different sizes and features. The solar cooker with an electrical back up is also designed for slow cooking. Its main advantage is that the food may also be cooked during the periods of inadequate or no sunshine with very nominal consumption of electricity.

The cost of the cooker varies from Rs. 1500 to Rs. 2500 depending on its size & features. A normal size family cooker is sufficient for a family of 4 to 6 members. It has a life of 15 to 20 years.

3) Feasibility of Plan:

The installation design of the bio-gas plant depends on the average population of cattle and the amount of dung available. A bio-gas plant can feasibly be installed to be common for 3 households. Well known statistics show that on an average, a household of 4 members can meet three meals a day with the supply of 1 cu.m of biogas. The resulting requirement is 3 cu.m of biogas for a collection of 3 households. However, the demand on the biogas plant can be put down to an approximate 2 cu.m for the plant given that the solar cookers are an evident alternative during the day time.

The details regarding the cattle heads required for different capacities of biogas plants to be installed are provided in the Table I. As per the survey conducted, the 231 households have an equivalent of 1.67 cattle heads each, on an average, resulting in a total of about 5 cattle heads for 3 houses. From the details below, a range of 4-6 cattle heads would correspond to a 2 cu.m capacity plant.

TABLE I
PLANT CAPACITY DETAILS

Size of Plant (cu.m)	Cattle Dung Quantity (kg)	Number of Cattle Heads	Estimated Cost (Rs.)
1	25	2-3	7000
2	50	4-6	9000
3	75	7-9	10500
4	100	10-12	12500

Further cooking requirements can be met by the solar cooker, especially when the sunshine is abundant.

E. Proposal to meet heating energy demand

The heating requirements, specifically of water, can be done by using the solar water heater.

The solar water heater can be proposed as a requirement for each household as a considerable number of households were found to be requiring hot water specifically for bathing. So, the installation of a solar water heater would not only meet this demand of theirs, but also rid them of the requirement of wood in plenty.

1) Solar Water Heater:

The solar water heating system can be installed on roof-top, building terrace as well as ground as suitable to the region. The heater is effective when the sun rays penetrate through a toughened glass and fall on the absorber. The heat of the sunrays is absorbed by the cold water inside the absorber thereby increasing its temperature [16]. The water temperature can be raised up to 85 degrees Celsius.
Some of the evident advantages of the system are:

a. Can be used for bathing, washing, boiler feed water and similar other purposes where hot water is required in the household.
b. No environmental pollution at all.
c. Large amount of firewood and other conventional fuels saved.
d. Plenty of time saved as there is no need to regularly collect the wood.

2) Feasibility of Plan:

The selection of capacity of the solar heater can be done based on the water requirements of the household. Assuming an average 4 persons in the household, the near amount of water required for bathing in total would be 4 buckets, which is nearly 80 litres. A capacity of 100 litre per day (lpd) can thus be chosen for a household. If the household consists of more members, the same capacity would be enough as the total quantity of water heated need not be used for bathing. The temperature which can be attained is 85 decrees C. So, a mixture of hot and cold water would suffice. On the other hand, households requiring lesser amount of hot water can adjust the temperature to lower range with the knob.

The cost of the solar water heating system ranges from Rs. 15,000 to Rs. 20,000 for a typical 100 litre system, or Rs.110/- to Rs.150/- per litre for higher capacities. The life of the system is around 10-15 years if maintained properly. The operation and maintenance cost is negligible.

III. OUTCOME OF IDEA PROPOSED

Indian rural electrification is insufficient, incomplete and discontinuous which can be due to technical constraints or practical difficulty in transmitting the electrical power to remote rural areas through grid connectivity. Complete electrification of rural India is considerably feasible if locally available non-conventional sources are exploited as it will reduce the burden on the existing grid supplying the already connected load. Also, if the un-electrified sections of the village are to be electrified, they need not depend on the conventional grid to supply them power, If found in surplus, the supply can in fact feed back into the grid.

The proposed idea considers the feasibility of tapping existing renewables, namely, biomass, biogas and solar power in the rural area and exploits them into useful, clean energy so as to make the population self sustained as indicated in Table II.

TABLE II
CHANGE AFFECTED BY ENERGY PLAN

Feature	Current Scenario	Proposed Scenario
Energy Needs	Incomplete and discontinuous	More than met
Residue Management	Completely wasted or sold	Converted to energy
Conventional Resource Dependence	Complete	Almost nil
Environmental Condition	Unhealthy	Clean
Employment Opportunities	No improvement	Local labour both skilled and unskilled
Economic Condition	Low or poor	Good uplift because of continuous supply of energy and improved employment

The proposed scheme seeds benefits for more than one party involved.

a. The village residents have ready buyers of agro-residues at a uniformly decided rate.
b. The community plant owner can obtain ready and cheap biomass available with low transportation cost. The excess amount of energy after fulfilling the local requirements can be sold to grid at good cost per unit.

c. The grid utility is now rid of the burden to supply energy. In fact it can purchase the excess energy and transmit to the needy and high tension areas.

IV. Cost Effectiveness of Energy Plan

The plan idea laid out in the paper so far comprised addressing the main concerns of the village's energy requirements. How effective enough the proposal of the idea can be deemed is understood by the observations noted below.

A. Domestic Needs like Cooking

Currently, the households are using firewood and LPG cylinders. The use of firewood is not environment friendly as well as not efficient. LPG cylinders use a conventional source of energy, gas. However, the biogas plant proposed in common for 3 households comes with a fixed initial installation cost.

A biogas plant of a capacity of about 2 cu.m costs around Rs. 3000 for a single household on an average, according to the calculation done before. On an average, the LPG gas cylinder costing around Rs. 315, as per current rates, lasts about 40 days for a family of about 4-6 members. If the fixed initial cost of the solar cooker is assumed to be around Rs. 2000, the total fixed cost of Rs. 5000 accounts for up to 16 periods of LPG cylinder usage, i.e., about 640 days. The payback cost of the plant can thus be fixed at 21-22 months or even approximately 2 years.

A graphic representation in fig. 4 shows the payback capability of the combined resource of biogas plant and solar cooker, with LPG cylinder usage taken as the reference. The cylinder usage may not tally with the same figure every month. The graph shown takes into consideration, random usage of the cylinder for a home every month and calculates the payback period on a monthly basis, for the combined cost of the plant and cooker.

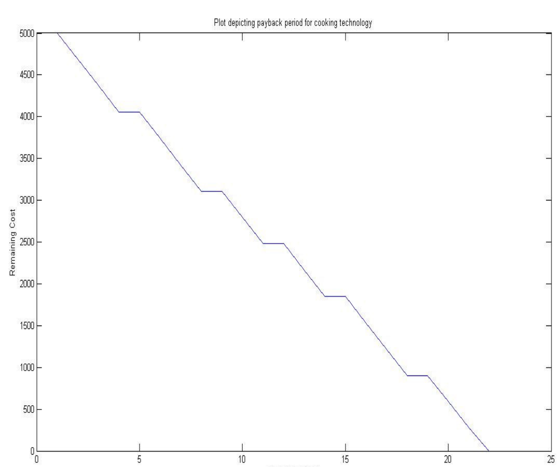

Fig. 4. Payback period for technology used for cooking

The random flat lines in the graph signify the true fact that the cylinders may last for more than a month's duration in some cases.

B. Electricity Demand for Household and Agriculture

The annual electric consumption in the village, as calculated before from the billing details, is 619.794 MWh. Meanwhile, the potential production from the community biomass plant stands at an approximate 1275.45 MWh at a plant capacity factor of 0.8. It is thus not only possible to supply the connected load but further electrification of the village is also feasible.

The plant cost calculated as before is around Rs. 0.728 crore. The fixed cost can be recovered by the community plant utility, based on two aspects, one being the current tariff at which the village connected load is currently supplied from the grid, and the other, the rate at which the excess power can be sold to the grid. In addition, the villagers benefit too as they can always sell the agro-waste at a uniform rate rather than how they do so now randomly for any kind of return.

The rate of return on the biomass plant may seem rather linear as shown in fig. 5, given it is based on the cost the grid is currently levying per unit consumed by the village. The monthly or bi-monthly consumption in the village is attainable from the billing details. Though the monthly or seasonal demand may vary, the annual amount does not deviate very much in the rural areas. The calculation done here does consider varying demand over a month's duration, but the rate of return considered annually is pictured quite uniform as shown.

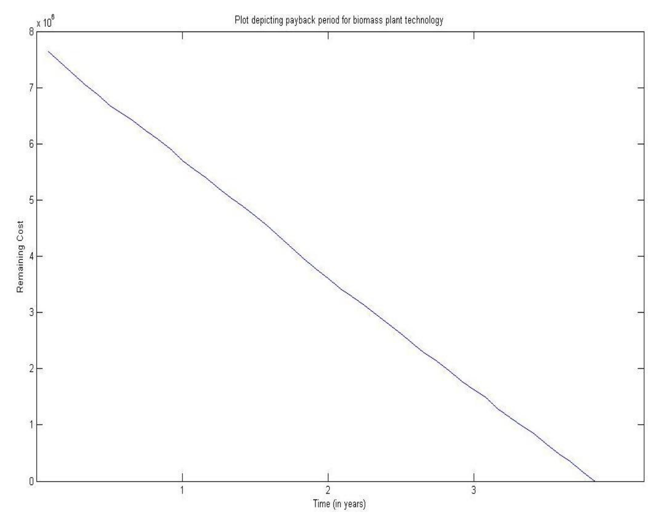

Fig. 5. Payback period for biomass community plant

V. Conclusion

The motive of the paper is to essentially draw out a plan to integrate the abundantly available renewable sources of energy which are currently discarded or untapped for no reason. A field survey compiled by the authors could reveal a clear insight into the lack of awareness to exploit free and clean sources of energy at a time of energy crisis when the energy scenario is far from acceptable. The village is not completely electrified even at the household level. Moreover, the connected load is not guaranteed continuous power even for half the day's duration.

The proposed energy plan could very well concur that the currently practiced methods of the villagers in utilizing the wastes and resources are pretty inefficient and unyielding. The plan tries to thus assess the capability of exploiting biogas, biomass and solar energy in the region at an approximate level and makes an effort to integrate them through existing but proven technology to not only meet the energy demands but also to give an economic face lift to the village. The idea's cost-effectiveness has been validated in the paper. The proposal is bound to utilize local labour for maintenance and operational tasks involved in the various technologies used and create umpteen employment opportunities.

The bid to make the village self-sufficient in their energy needs mainly comprise a common biogas plant for about 3 households, a solar cooker and heater for each household, and a community based biomass plant to supply electricity locally to the village. It also ensures feedback into the power grid, assuming electric grid availability in village, in case of excess power. The economic analysis done has shown an initial investment of around Rs. 20,000 per household which includes the biogas plant, solar cooker and heater, would serve every household's energy needs effectively and would be paid back within a reasonable payback period. The rate of return for the village community running the biomass plant is also feasible because the grid is no longer supplying the energy for even half of the time. Thus the payback is at the rate at which the grid is currently supplying the power.

The proposition chalked out in this paper thus has the potential to be beneficial in more than one way to more than one participating party.

VI. Appendix

Table III gives particulars collected during the survey, which came of use while devising the energy plan.

TABLE III
VILLAGE PARTICULARS

Aspect	Detail
Population	1481
Educated	642
Uneducated	839
Main Cultivators	120
Marginal Farmers	300
Livestock	4494
Cattle	386
Land (acres):	
Farmed	988
Unfarmed	1976
Paddy Area (acres)	800
Amount of Residue (metric ton per acre)	1.5
Connected Load (KW)::	
Agricultural	224
Domestic	220
Bi-monthly Consumption (KWh):	
Agricultural	80640
Domestic	22659
Street Lighting (KW)	6

VII. Acknowledgement

The authors gratefully acknowledge the contributions of the village authorities who helped us conduct the survey effectively and also the Mandal office staff who could part with information regarding the particulars of the village.

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IX. Biographies

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