Sustainable Energy Plan of a Village in Punjab for Self Energy Generation

Dissertation submitted in partial fulfilment of the requirement for the award of degree

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in

Power Systems and Electric Drives

By:

Rahul Mishra

(Roll No. 801141021)

Under Supervision of:

Mr. Shakti Singh

Assistant Professor, EIED

ELECTRICAL AND INSTRUMENTATION ENGINEERING DEPARTMENT

THAPAR UNIVERSITY

PATIALA-147004

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CERTIFICATE

I hereby certify that the work which is being presented in this dissertation entitled **"Sustainable Energy Plan of a Village in Punjab for Self Energy Generation"** in partial fulfillment of the requirement for the award of the degree of Master of Engineering in Power Systems & Electric Drives submitted in Electrical & Instrumentation Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under supervision of Mr. Shakti Singh, Assistant Professor, EIED.

The matter presented in this report has not been submitted for the award of any other degree of this or any other University.

Rahul Mishra
Roll No. 801141021

It is certified that the above statement made by the student is correct to the best of my knowledge and brief.

Mr. Shakti Singh
Assistant Professor,
EIED, Thapar University

Dr. Smarajit Ghosh
Professor & Head, EIED
Thapar University
Patiala

Dr. S.K. Mohapatra
Sr. Professor & Dean (Academic Affairs)
Thapar University
Patiala

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Rahul

Rahul Mishra

Roll No. 801141021

ABSTRACT

Increasing electricity demand, hike in fuel prices, environmental concerns are the main factors which motivate the use of renewable energy sources in India. In past few year India has shown a significantly growth in utilization of renewable energy sources. Today the share of Renewable energy sources is almost 12% in total electricity generation. According to Ministry of Power in India so far thousands of villages are still unelectrified. In this work the potential of renewable energy sources (solar + biomass) is estimated in a village in Punjab, India. Based on a survey conducted in an Indian village named "Kaidupur" situated in district Patiala in Punjab, the available bio mass resources like agro-waste, animal dung, and solar energy are identified and a complete solution to meet energy demand of a village by renewable energy sources is provided. The optimization (biomass + solar) is done by Hybrid Optimization Model for Electric Renewable (HOMER). Hybrid energy system is becoming popular in area where grid extension is considered uneconomical or not feasible. The work provides a better understanding of utilization of renewable resources in an isolated /off grid locations.

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ABBREVIATIONS

AC	ALTERNATING CURRENT
DC	DIRECT CURRENT
IEEE	INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS
COE	COST OF ENERGY
NPC	NET PRESENT COST
PV	PHOTOVOLTAIC
HRES	HYBRID RENEWABLE ENERGY SYSTEM
O & M	OPERATION AND MAINTENANCE
NREL	NATIONAL RENEWABLE ENERGY LABORATORY
MNRE	MINISTRY OF NEW AND RENEWABLE ENERGY
PEDA	PUNJAB ENERGY DEVELOPMENT AGENCY
NASA	NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

Less than 3000 out of 0.56 million villages in India had electricity when the British left India in 1947 [1]. The total installed capacity in the entire country at that time was about 2300 MW which has increased to 2,11,766.22 MW since then. Unfortunately, rural electrification has not directly benefited from such a high growth and according to Ministry of Power in India so far about thousands of villages are still unelectrified. There are number of technical problems which have risen from a non-uniformly and unplanned growth as a result there is inconvenient supply in electrified rural areas. However, the use of renewable resources could be one of the best solutions which can be provided to make village electrified and self sustained in its energy requirements.

Solar resources, animal wastes and crop residues are some of the major renewable sources available in rural areas that can be harnessed in an efficient way to meet the energy demand. Exploiting these resources will eliminate the requirement of electricity transfer to rural areas and improve the quality of life of the rural people by providing electricity for productive use in agriculture, ensuring the clean energy environment and also a less burden on conventional grid. The use of crop residues for electricity generation not only mitigates the problem of electricity but also resists the practice of burning crop residue openly in the field. This practice emits trace gases like carbon dioxide, methane, carbon monoxide, nitrogen oxide, sulphur oxide and large amount of particulate matters, which adversely affect human health as well as the environment making the soil less fertile [6]. Government of Punjab has banned the burning of agriculture wastes so plenty of biomass is available for utilization.

In order to formulate sustainable plan and provide feasible solution, analysis has to be done on the existing utilization of resources in the village for supplying the clean form of energy to the village itself. In the present work a survey is conducted in a village, “Kaidupur” of district Patiala in India and planning is done in a village to utilize the local resources available in a most economical and efficient way to meet the various energy demands. This village comprises of 80 households and the energy needs of the village based on the survey are noted down. According to the site available bio mass resources like agro-waste, animal dung, and solar energy are identified and the plan is proposed for complete solution to meet energy demand of a village by renewable energy sources. The optimization of hybrid renewable energy system (biomass + solar), used to provide the electricity demand, is done by Hybrid Optimization Model for Electric Renewable (HOMER) and various other solutions such as community type biogas plant for meeting the cooking gas demand, solar pump for irrigation and village water supply and solar street lights are also proposed and their cost analysis is also done.

1.2 RURAL ELECTRIFICATION AND RELATED ISSUES

Bringing electrical power to rural areas or the process of electrifying the rural areas is rural electrification. The two major technical problems that could be stated are:

i. Rural electrification in India has almost being done by extending the grid and the available local resources are very rarely utilized for power generation.
ii. Distribution network to the villages is grown in unplanned manner so there are very much transmission losses and very low reliability of supply.

The location and the problem in connecting a village with grid, collection of electricity bill, power theft and funding for distributed generation are also some of the main issues in electrification of a village.

1.3 CHALLENGES AND NEED OF RENEWABLE ENERGY DEVELOPMENT

Renewable energy development is vital factor that could be used for meeting the increasing energy demand and there are factors which are the challenges for its development.

i. High initial and capital costs, as most of the renewable energy technologies are not cost competitive without subsidies.
ii. Lack of finance and therefore very less private industries are taking part in rural electrification as cost recovery is not easy.
iii. Lacks of awareness and planning as most of the resources such as biomass are treated as waste.

1.4 LITERATURE REVIEW

A large amount of research is carried out in the field of renewable sources of energy. A brief literature review related to renewable sources of energy and modelling of hybrid energy sources is presented as follows:

Gupta, [1] summarized some of the achievements and highlighted some of the shortcomings of rural electrification programme in India and discussed the problems related with the use of renewable technologies in India. Proposed that renewable energy resources had to be utilized and supplemented wherever feasible in rural energy programme.

Sharma, [2] presented overall energy scenario in India and founded that renewable energies are also gaining importance and showed that government is making impressive efforts for its growth. He stated that the nongovernmental sector had shown that decentralized, off-grid power generation through biomass based gasifiers and solar photovoltaic offers a viable, long-term solution to rural electrification and proposed that a policy is needed for lighting rural India.

Upadhyay and Sharma [3] suggested that rural electrification has became a household necessity for eradicating energy crises faced by peoples living in villages and hybrid energy system could mitigate these problems in the best way and showed comparative analysis on various load conditions.

Lim, *et al.* [4] simulated and emphasised the utilisation of biomass as a vital source of renewable energy and suggested that if these are used then dependency on fossil fuels will be reduced. Reviewed the key aspects of utilization of rice husk and straw as important sources of energy and suggested that further research is required in optimal allocation of resources and commercialization of technology.

Kishore, *et al.* [5] addressed the potential and role of biomass resources in developing countries and also highlighted global climatic change with the help of case study in India. Village power was discussed in detail with the use of biomass technologies and focused the fact that biomass energy technology has lowest carbon abatement cost among other technologies.

Kharol, *et al.* [6] analyzed the variations in black carbon (BC) aerosol mass concentration over Patiala city, Punjab, India which was associated with agriculture crop residue burning activities. Black carbon (BC) aerosol mass concentration was observed to be high on certain days during October/November months which are associated with additional loading of aerosols from agricultural crop residue burning.

Sriram and Shahidehpour [7] showed Biomass as a source of energy and the ways the energy is converted as a source of power generation and also emphasised that Biomass systems can be used for village-power applications for a wide range.

Ravindranath, *et al*. [8] investigated that in India, fuel wood, crop residues and animal manure are the dominant biomass fuels, which are mostly used at very low efficiencies in the rural areas. Industrial and municipal (urban) residues such as wastewater, municipal solid wastes (MSW), and crop residues such as rice husk and bagasse posses very good potential for energy generation and can be conserved for other application.

Khambalkar, *et al.* [9] assessed bioenergy available in a village and showed that village have considerable bio energy potential from different sources available to meet the energy requirement for the sustainable development. The biomass consumption for different activities has been collected through a survey.

Bhattacharya, *et al.* [10] presented a assessment of sustainable biomass production potential in Asian countries to estimate land availability for biomass production and evaluated the biomass production options in terms of yield per hectare and financial viability, estimate sustainable biomass production for energy, and estimate the energy potential of biomass production in the six Asian countries and suggested that there is a need for policies to promote bioenergy utilities.

Chauhan, [11] assessed Punjab and found that the state have a huge potential of Biomass resource availability in the form of crop residues. Basic surplus and net surplus crop residues for power generation potential were estimated in each district. He investigated that duration between paddy harvesting and wheat cultivation is of 10 to 15 days, within this short duration farmers prefer burning the paddy stalk in the agriculture field.

Singh, *et al.* [12] surveyed and calculated that Agricultural biomass has immense potential for power production in an Indian state like Punjab and the transportation and collection cost can be reduced by properly planning the biomass collection. Availability of unused agricultural biomass evaluated and the observed area under low range, semi-medium, medium and high range is 20%, 35%, 32.5% and 12.5%, respectively.

Jain, *et al*. [13] surveyed Indian village, “Bacharam” situated near Hyderabad in India, and identified the available resources agro-waste, animal dung, and solar energy and suggested that for the development of the region, there is every need to utilize energy efficient techniques and potential of available renewable energy resources.

Kuwahata, *et al.* [14] with the help of case study presented an approach that could be adopted as a part of rural electrification. Results from the case study allow the costs of electrification by microgrids to be compared with those of extending the grid. Results from were compared with costs of electrification by microgrids with those of extending the grid

Nonhebel, [15] presented that agricultural crop, biomass crops can be grown in intensive production systems (external inputs such as pesticides and artificial fertilisers) or extensive systems with few external inputs. The choice of extensive and intensive has effect on yields and also presented a method to estimate the biomass yield in production system.

Cross and Gaunt, *et al.* [16] determined the hourly activity load curves and showed data collection was extremely difficult which results in making of many assumptions and discussed that it was extremely difficult for user to model accurate and detailed data for rural community energy system.

Dhass and Harikrishnan. [17] proposed hybrid renewable energy system which combined the generation of power through solar, wind and biomass systems and had been installed to meet the demand of the particular load centre.

Nixon, *et al.* [18] assessed the feasibility of hybrid solar-biomass power plants for various applications in India including tri-generation, electricity generation and process heat. Evaluated technical, financial and environmental criteria and proposed that hybrid plants would become an increasingly attractive option as the cost of solar thermal falls and feedstock, fossil fuel and land prices are continued to rise.

Razak, *et al.* [19] proposed that it is important to consider renewable resources for green power technology and healthy environment. The use of hybrid renewable energy power system was done. The hybrid renewable energy system was optimized and configured using Hybrid Optimization Model for Electric Renewable.

Helal, *et al.* [20] proposed stand-alone hybrid renewable energy systems to supply the electricity demand for remote areas and designed a hybrid renewable energy system that was site specific and depends on the renewable resources available and load profile demanded.

Gupta, *et al*. [21] designed a hybrid energy system consisting of wind, photovoltaic, biomass and small/micro hydro to supply continuous power to the load. The economic analysis had been done which resulted in the calculation of capital cost, cost of energy for different types of resources and optimized cost of hybrid energy system.

Chowdhury, *et al.* [22] biomass supported solar thermal hybrid power plant (STHPP) was proposed for continuous electricity generation. He suggested that biomass supported STHPP was one of the most important steps of generating electrical energy for the stable and continuous mode of operation and combined operation of biomass and solar thermal plant could be one of the most important modes to use the solar thermal and biomass power in the future.

Kumar, *et al.* [23] performed the optimal cost analysis of hybrid renewable energy system using Hybrid Optimization Model for Electric Renewable (HOMER). HOMER was used for effective cost analysis and optimization.

Al-Badi, *et al.* [24] studied and determined the optimum size of system able to fulfil the energy requirements of remote sites in Oman and identified a configuration among a set of systems that meet the desired system reliability requirements with the lowest energy cost. A comparison between the costs of electricity generated from renewable energy resources in these locations was done.

Chowdhury, *et al.* [25] proposed design for an off grid solar wind-diesel hybrid power system for a remote locality. At first availability of solar and wind resources for different locations in Bangladesh has been studied and further improvement of the total scheme is proposed by replacing diesel with biogas.

Yadav, *et al.* [26] integrated the design of hybrid system and reduces the green house gases. A simulation was done using hybrid optimization model for electric renewable and economic and operational parameters were compared.

Lalwani, et al. [27] identified that Photovoltaic (PV) is the carbon free technology and one of the fastest growing technology that converts sunlight directly into electricity and presented the effective use of solar PV systems, their specifications along with government policies and plans in India.

Nouni, *et al.* [28] concentrated on photovoltaic (PV) projects for providing decentralized power supply in remote locations in India and presented the results for Techno-economic evaluation. An analysis of the capital cost of the PV projects and sub-systems was undertaken. The initial capital investment requirement for a PV project on unit capacity basis was higher. Incentives and strategies may also have to be considered for upgrading the technology of PV cells/modules and other components for improving the delivered output of PV array and enhancing their useful lives.

Kendry, [29] showed that the potential usefulness of biomass resources was greatly increased with the conversion of biomass by gasification to a fuel suitable for gas engine and suggested that properties of biomass feedstock are the key parameters for selecting the gasifier.

Ravindranath, *et al.* [30] presented the performance and impact of a decentralized biomass gasifier based power generation system in an unelectrified village. A case study on biomass gasifier based power generation system was done in village Hosahalli of Karnataka, India which was functioned for years and met all the electricity needs of the village.

Nouni, *et al.* [31] presented the results of a techno-economic evaluation of biomass gasifier based projects for decentralized power supply for remote locations in India and analyzed the contributions of different components of diesel engine generator (DG) sets, dual fuel (DF) engine generator sets and 100% producer gas (HPG) engine generator sets to their capital costs as well as to the levelized unit cost of electricity (LUCE) delivered.

Banerjee, [32] reviewed the different technological options available for distributed generation (DG), their current status and evaluated them based on the cost of generation and future potential in India. He suggested that biomass gasifiers operated gas engines was a DG option that was cost effective and suited for rural areas and also showed that solar PV is a very good option for off-grid applications with less maintenance. He concluded that hybrids of two renewable perform better than power plants based on a single technology.

Mahdi, *et al.* [33] discussed the various types of biogas plant and their cost analysis was done based on technical failure, constructional failure. Estimation of cost and cash inflow is also presented and also showed that most of the failure of biogas plants occurred by technical reasons which had faulty design and construction, incorrect level of inlet, outlet, hydraulic chamber, moisture in pipeline, leakage/cracking in the dome.

Sumathi, *et al.* [34] proposed that the effective utilized energy was very low in rural areas. Increased demand of fuel wood for cooking and timber due to significant increase in population had resulted into a rapid depletion of forest resources. On account of availability of local resources, community biogas plant was best suited for rural sector. As the anaerobic digestion was the easiest method of producing biogas it may be utilized as a vital tool for handling the disposal of human excreta, vegetable and cooked waste in a safe and useful way.

The funds provided by the government can be utilized for erecting community plants in village to restore a clean and hygienic environment.

Roy, [35] suggested that a solar photovoltaic (PV) pumping system is an alternative to the conventional water pumping system for large, medium, and small scale applications. Solar water pump was built and experimented to observe the results with a direct connection from solar array. The PV water pumping system had a good prospect to solve the energy crisis in the irrigation season as well as it can be used to cultivate lands throughout the year and can also be used for getting pure drinking water in remote rural areas.

Khan *et al*. [36] provided the operation of a solar water pump in both the direct-coupled method and the pump-controller connected method. Water pumping scenarios for irrigation in Bangladesh is presented and suggested that government subsidy and other incentive could be made to improve the irrigation system.

1.5 OBJECTIVE OF WORK

The main objective of the work is to devise a plan for a village with a complete solution to meet energy demand of a village by renewable energy sources with the following features investigated

i. To study the existing energy situation and to identify the available resources at a village.
ii. To collect energy resources available and to carry out electrical load assessment for the specific site.
iii. To offer a continuous and reliable electricity supply and to meet other energy requirements such as cooking gas demand, irrigation demand based on local renewable sources available.

1.6 ORGANIZATION OF THE DISSERTATION

The chapter wise summary of the work is as follows

Chapter 2 Assessment of available resources and their existing use at a village is done.

Chapter 3 A plan is formulated with the available local resources and load assessment is done to meet various problems of energy needs in a village.

Chapter 4 Feasibility of plan is carried out for meeting various energy demands. A hybrid renewable energy system is modelled for supplying electricity requirement and plan to meet other energy needs of a village are also discussed.

Chapter 5 An effective cost analysis of plan is done with benefits of proposed plan.

Chapter 6 Conclusion and future scope of the work is presented.

CHAPTER 2

ASSESSMENT OF CURRENT USE OF RESOURCES AND THEIR AVAILABILITY AT A SITE

2.1 INTRODUCTION

To provide feasible solution, analysis has to be done on how the existing resources in the village are being utilized and how they can be made useful for supplying the clean form of energy to the village itself and makes it sustained in its requirements [5]. So the first work is a need to assess the renewable resources available in a village for self and sustainable development.

2.2 VILLAGE INFORMATION

In order to get the effective data related to biomass availability a survey is conducted in a village named "KAIDUPUR" in Patiala district of Punjab state. The major crops in village are paddy and wheat. The geographical area of the village is 324 hectare out of which 243 hectare is cultivable area. The village particulars are shown in Table 2.1 which includes the basic information of village is shown below.

Table 2.1 Village particulars

Name of village	Kaidupur
District, State	Patiala, Punjab
Location	$30^0 26^{'} 6^{''}$N latitude and $76^0 12^{'} 26^{''}$E longitude
Number of house hold	80
Population	500
Main occupation	Farming.
Total area	324 hectare
Main crops	Paddy/Wheat /Pulses
Cultivable area	243 hectare

2.3 CURRENT USE OF RESOURCES

There is no suitable method available for managing the crop residues in the village. Crop residues / biomass are simply burned in open field after harvesting and no utilization of available resources is done as shown in Figure 2.1. Burning not only influence the atmospheric air quality including climate, it also affects the human health and fertility of a soil [6]. The daily energy requirements like cooking are also met by LPG cylinders and fire wood.

Figure 2.1 Burning of crop residue in Punjab

Discontinuous power supply because of difficulty in connecting them with grid and increase load on conventional system is another problem for villagers so most of them are using diesel pump for irrigation purposes which are again inefficient and polluting.

Thus, for the place like Punjab where biomass and solar resources are abundantly available, the option for electricity generation to meet the demand without any environmental hazard and making the village self sustained in its energy requirement is the most suitable one. The use of renewable energy not only releases less harmful gas and pollutants but also could take good use of crop straws and wastes. It is a good way to resolve the energy stress and environmental problems in the village and helps to make village self sustained in its energy requirements.

2.4 AVAILABILITY OF BIOMASS RESOURCES

Biomass is an organic material which has stored solar energy from sunlight through a process called photosynthesis [7]. They include all water- and land-based vegetation and trees, and all waste biomass such as municipal solid waste (MSW), municipal bio solids (sewage), and animal wastes (manures), forestry and agricultural residues, and certain types of industrial wastes. Biomass can be classified into two types: woody and non-woody. Non-woody biomass comprises agro-crops, Municipal solid waste or MSW, and animal and poultry wastes are also referred to as biomass as they are biodegradable in nature. The main biomass sources which are mainly available in this village are agro residue and animal waste.

2.4.1. Availability of Agro-Residues

Agricultural residues can be divided into two groups, namely, crop residues and agro industrial residues. Crop residues are plant materials left behind in the farm after removal of the main crop that is produced. The remaining materials could be of different sizes, forms, and densities like straw, stalks etc. The agro-industrial residues are by-products of the postharvest processes of crops such as cleaning, threshing, sieving, and crushing [10]. This could be in the form of husk, dust etc. The major crop residues produced in the village are straws of paddy, wheat, and pulses. The quantity of agricultural residues produced differs from crop to crop and is affected by seasons, soil types, and irrigation conditions. Production of agricultural residues is directly related to the corresponding crop production and the ratio between the main crop product and residues varies from crop to crop, and at times, even with the variety of the seeds in one crop itself [11]. Thus, for known amount of crop production, it may be possible to estimate the amounts of agricultural residues produced using the crop to residue ratio.

In the village all the biomass was collected for estimating the biomass generation capacity of a village as a whole. The cultivable area and the biomass yield of residue available from crop were obtained by averaging the yield of previous years. Besides primary data collection, simultaneously the consumption of biomass through direct interaction with the villagers is collected and the residue generation estimation is made by using residue production ratio. Residue production ratio (RPR) can be estimated by direct measurements in the fields [37]. Air dried residue- product ratio for some crops is also available and can be used.

Table 2.2 Air dry weight of residue produced per tonne of crop produced

Crop	RESIDUE	RPR
Rice paddy	Straw	0.45-2.9
	Husk	0.22-0.5
Wheat	Straw	0.7-1.8

Residue production (tonnes/year) = Grain production (tonnes/year) × RPR (residue production ratio).

i. Estimation of agro residues from paddy crop

Estimated production of paddy crop is about 6.6 tonnes/ hectare.

Total production of a village with area of 243 hectare = 1604 tonnes/year

Straw type residue generated from paddy crop =1604 × 1.2 = 1925 tonnes/year.

Husk type residue generated from paddy crop = 1604 × 0.3 = 481.14 tonnes/year.

Residue utilized = 0 tonnes/year.

Unused or surplus residue available = 2406 tonnes/year.

ii. Estimation of agro residues from wheat crop

Estimated production of wheat crop is about 5.18 tonnes/ hectare

Total production of a village with area of 243 hectare = 1258 tonnes

Straw type residue generated from wheat crop = 1258 × 1.2 = 1509 tonnes/year.

Residue utilized or total consumption = 1387 tonnes/year

Unused or surplus residue available = 122 tonnes/year

The total biomass generated is the sum of biomass residue from all the seasons in a year. The average production that is reported was of 6.6 tonnes per hectare of rice from paddy crop and 5.18 tonnes per hectare from wheat crop. Table 2.2 shows the details of agriculture residues of a village with a total surplus residue of 2528 tonnes per year.

Most of the residue from wheat is used as fodder for livestock's and so it is found that about 2 to 3 quintal per acre is only left unused. Pulses are also sown for small area and for small duration of about 60 days, the residue left is good fertilizer and also used as fodder.

Table 2.3 Agriculture residues

Crop	Season	Total production (tonnes per year)	Residue production (tonnes per year)	Used (tonnes)	Unused residue (tonnes)
Paddy	Kharif crop	1604	2406	0	2406
Wheat	Rabi crop	1258	1509	1387	122
Total		2862	3915	1387	2528

2.4.2 Biomass Resource Available from Live Stock

The live stocks available are mainly buffalo and cow which are estimated to be 300 in numbers or about four animals per family. It is seen that there is a good population of live stocks so there is a wide scope of constructing a common biogas plant for meeting the cooking gas demand of villagers [34].

2.5 POTENTIAL OF SOLAR POWER

Blessed with about 300 sunny days in a year and receiving a scaled annual average of 5.14 kWh/m^2/day solar radiations, village is well situated to overcome its key challenges by harnessing the enormous solar potential available. So this is the key renewable energy source which could be effectively exploited. The solar radiation data is taken for village, Kaidupur located at $30^0 26' 6''$N latitude and $76^0 12' 26''$E longitude, solar radiation data are taken with the help of HOMER from NASA's Surface Solar Energy website [39] for the given sets of coordinates. This data includes information such as average daily solar radiation in (kWh/m^2/day) shown in Table 2.3, monthly average clearness index, and probability distribution information.

With such a good solar radiations the MNRE (Ministry of New and Renewable Energy) [37] and PEDA (Punjab Energy Development Agency) [40] are providing attractive subsidies and financial policies to promote the use of renewable energy and making the environment clean.

Table 2.4 Monthly averages of Clearness Index and Daily Radiations

Month	Clearness Index	Daily Radiation ($KWh/m^2/day$)
January	0.593	3.464
February	0.604	4.281
March	0.607	5.294
April	0.617	6.296
May	0.617	6.859
June	0.602	6.882
July	0.508	5.704
August	0.514	5.395
September	0.608	5.588
October	0.651	4.916
November	0.634	3.873
December	0.573	3.123
Average	0.590	5.141

Monthly Solar radiations in a whole year for selected site are presented in Figure 2.2 with an annual average of 5.14 $kWh/m^2/day$. Hourly solar radiation of a day in month of May is shown in Figure 2.3 which shows that the village is having a high solar potential. At present electricity generation from solar sources is being reached a remarkable edge and a large scale electrical energy can be generated using solar hybrid power plant with storage system. It is fact that solar plant cannot operate stably and continuously due to variability of solar irradiation. Therefore a hybrid power plant with biomass generator for continuous electricity generation is a good option available for a village.

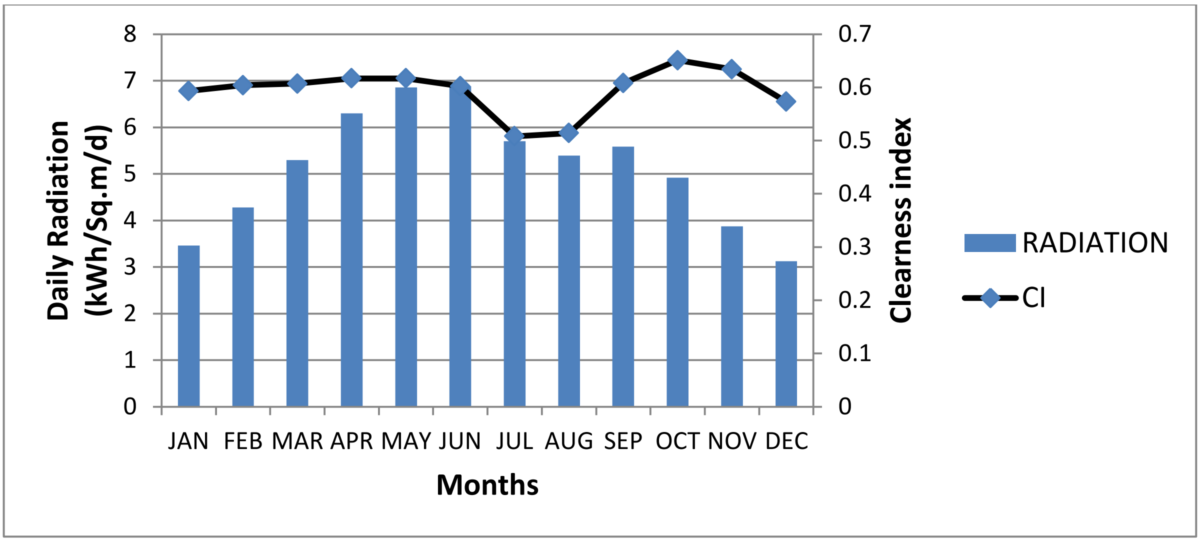

Figure 2.2 Monthly average solar radiations of a village

The Figure 2.3 shows a daily solar radiation of a day in month of May where high solar radiation value can be seen at afternoon depicting the presence of immense solar potential present in a village.

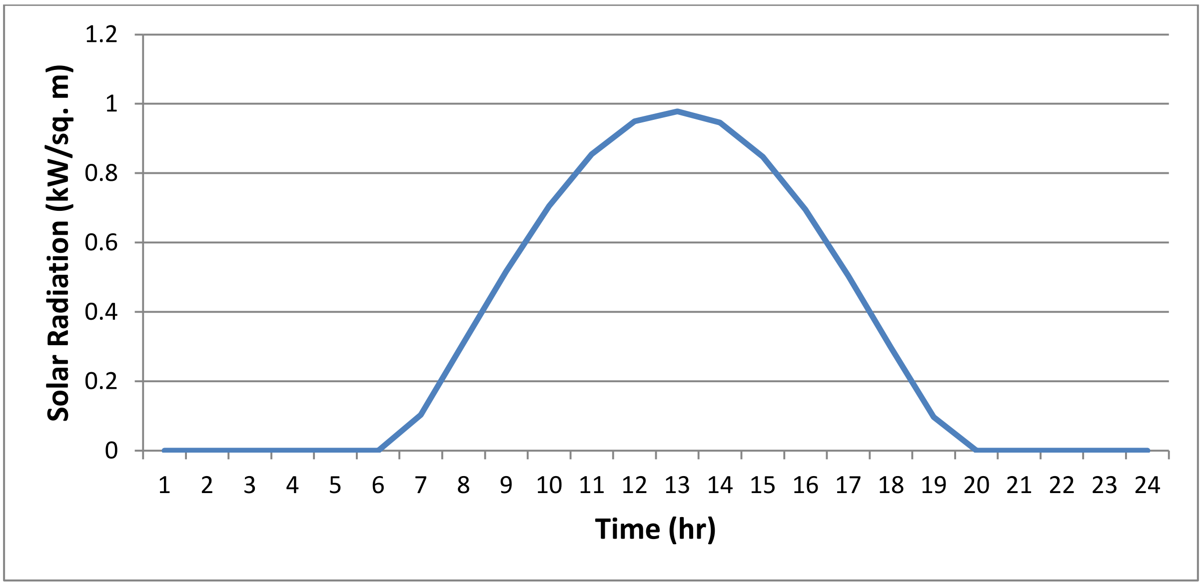

Figure 2.3 Hourly solar radiation of a day in month of May.

CHAPTER 3

PROBLEM FORMULATION

3.1 INTRODUCTION

Based on a survey conducted in an Indian village named "Kaidupur" situated near district Patiala in Punjab, the available resources like agro-waste, animal dung, and solar energy are identified. From the survey it is found that village has enormous biomass and solar energy available which could be used in an efficient way. For the development of the region there is a need to utilize energy efficient techniques and potential of available renewable energy resources. By employing energy conversion techniques, these resources can be used for various energy requirements for basic needs like electricity, cooking, irrigation etc. A hybrid energy system consists of two or more energy systems, an energy storage system, power conditioning equipment and a controller which could be best the option for off grid electrification where two or more renewable energy sources are available.

3.2 BIOMASS AS A SOURCE FOR ENERGY GENERATION

The world's energy markets have relied heavily on the fossil fuels. Biomass is the only other naturally occurring energy-containing carbon resource that is large enough in quantity to be used as a substitute for fossil fuels [16, 17]. Using biomass energy means that the total amount of carbon dioxide in the environment stays reasonably constant, unlike burning fossil fuels which increases the amount of carbon dioxide in the air.

Some of the main advantages of using biomass energy generation are

i. Biomass energy is an abundant, secure, environmental friendly and renewable source of energy. Biomass does not add carbon dioxide to the atmosphere as it absorbs the same amount of carbon in growing as it releases when consumed as a fuel.

ii. One of the major advantages of biomass is that it can be used to generate electricity with the same equipment or in the same power plants that are now burning fossil fuels.

iii. Biomass energy is not associated with environmental impacts such as mine spoils, open pits, oil spills, radioactive waste disposal or the damming of rivers.

3.2.1 Biomass Gasification for Electricity Generation

Biomasses most abundantly available in a village such as agricultural residues are suited for thermo chemical conversions using a biomass gasification in which a biomass is converted into a combustible gas. In a biomass gasifier, biomass is burned in a limited amount of air. The amount of air supplied is less than the amount of air required for complete burning. This converts the biomass (which consists of carbon, hydrogen, oxygen, etc) into an inflammable mixture of gases known as producer gas/ wood gas (box 1.2). The producer gas consists of carbon monoxide (CO), hydrogen (H_2), and methane (CH_4), along with carbon dioxide (CO_2) and nitrogen (N_2).

Fixed-bed gasifiers are the most common type of gasifiers used [29]. There are two main types of fixed bed gasifiers:

i. *Updraft Gasifier*: In this type of gasifier air enters from bottom and flows in an upward direction. The resulting producer gas is rich in hydrocarbons and has higher heating values so it is more for thermal applications.

ii. *Downdraft Gasifier*: In a downdraft design, nozzles allow air to enter at a constricted area in the middle of the level of the gasifier, and the resultant mixture of air and gas flows down into the gasifier reactor through the high temperature oxidation zone resulting in thermal cracking of volatiles resulting in a gas which has relatively lower tar content and is better suited for use in engines.

Due to this, the downdraft design is typically preferred for powering gas engines and in electrical generation.

3.3 PROPOSED ENERGY SOLUTION

In order to efficiently utilize the resources which are currently wasted a planning has to be done. This village comprises of 80 households and the energy needs of the village based on the survey are noted down. The basic electricity requirements for a rural village include domestic needs, agricultural and irrigation needs, electricity for community purposes which include medical centre, schools, panchayat offices etc. More detailed discussion, calculation and estimation on the village load demand has to be done for efficiently using the resources. The renewable sources of energy proposed to be put to use for improving the overall energy scenario includes a separate cost effective ways of utilizing these resources for different requirements like:

i. Biomass and PV based hybrid renewable energy system (HRES) [19] is proposed for meeting the electricity demand from households, other community loads which comprises the load demand of school, dispensary, shops, panchayat offices etc. A hybrid energy system is proposed for meeting the electricity demand of a village.

ii. Fire wood and LPG cylinders are currently used for cooking. The use of firewood is not environment friendly, unhealthy as well as not efficient, therefore a biogas plant with a fixed cost is best suited as animal waste is used for the producing a biogas which serves as cooking gas and it is environment healthy.

iii. A solar water pump is proposed principally for village water supply and irrigation purpose as an alternative with the diesel pump which is currently used. The PV water pumping system has a good prospect to solve the energy crisis in the irrigation season as well as it can be used to cultivate lands and can also be used for meeting the village water supply needs.

iv. Solar streets lights are suitable for village street lighting as Street lighting in the village are very few and most of the time not working so the battery powered solar street light with a very less maintenance is a very good option.

Now to find the best combination of renewable energy techniques from the available resources in a given village location that can meet the electricity demand in a sustainable manner and to see whether this is a cost effective solution or not, the application of Hybrid optimization Model for Electric Renewable (HOMER) energy software at an identified off-grid village location in Punjab has been made. Community based biogas plant, solar pumps for irrigation purpose and village water supply are also proposed as feasible solutions for the needs of the village**.** This work has mainly focussed on how a village can fulfil the majority of its demand for fuel from natural resources and the agro based material in them as the conventional practices shows an unhealthy way of living with no utilization of resources and causing a problem of environmental pollution. The aim is not only to bring a major improvement in energy management of the village but to also improve the village economy considerably. Moreover the employment opportunities are also increased because of the local labour required for maintenance and operation. A cost analysis and load assessment has been done further for effective implementation of plan.

3.4 VILLAGE LOAD ASSESSMENT

To fulfil the electricity demand in a village an assessment of load is necessary. As in villages the demand for electricity is not as high as in urban areas [17]. The basic energy requirements in such areas can be classified as domestic, agricultural, community. In the domestic sector electricity is required to use appliances like compact fluorescent lamps (CFL), fluorescent tubes (FT), ceiling fans, cooler and television. The use of irrigation machinery, water pumping, etc. comprises the demand in the agricultural sector. The community load serves the community centre, village panchayat offices, shops, schools and also the load from the dispensary. Industrial loads and agricultural loads are disregarded from the study, as there is no industry in Village.

3.4.1 Domestic Load

The load of village at domestic level vary from season to season therefore in this study the year is divided into two seasons, summer (April to October) and winter (November to March), depending on the demand and energy consumption pattern. The assumed demand of a village per hours is taken as an input to HOMER software. It has average value of 444kWh/day and having a peak value of 78.5kW. The various details of appliance that are assumed to be used in a house hold for modelling the load in an hourly basis as an input for hybrid optimization model is shown in Table 3.1 it could be seen that the demand of electricity with average operating hours varies according to the season.

Table 3.1 Domestic load data of a village

Appliance	Power(W)	No. in use	Avg. operating hours(summer)	Energy (kWh/day)	Avg.operating hours(winter)	Energy (kWh/day)
CFL	30	240	12	86.4	13	93.6
FT	40	160	4	25.6	7	44.8
COOLER	200	80	12	192	0	0
FAN	60	320	12	230.4	0	0
TELEVISION	100	80	11	88	12	96

Daily domestic load profile of the village for summer season and winter seasons based on the assumed demand and operating hours is plotted shown in Figure 3.1 and 3.2 respectively. It could be seen in the plot that the demand is maximum for peak operating hours.

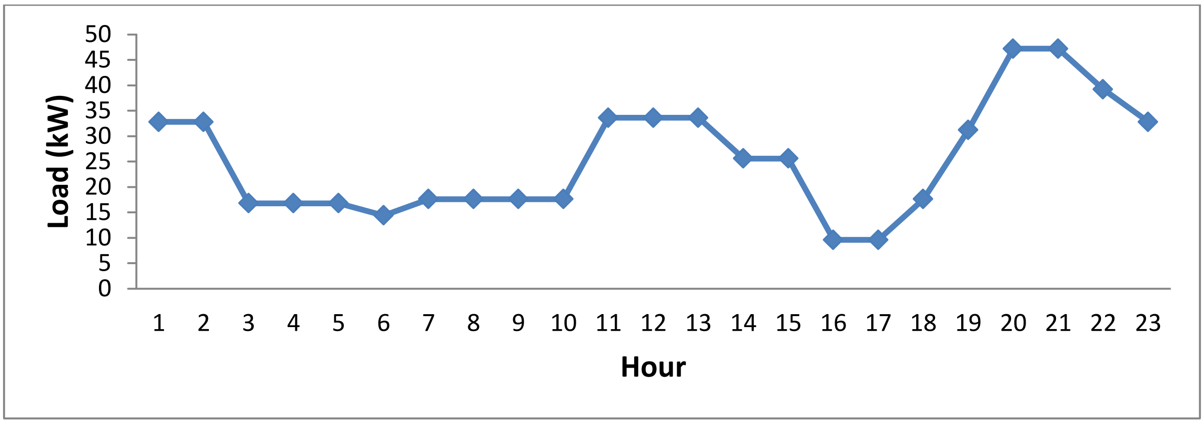

Figure 3.1 Daily domestic load profile of a village in summer season

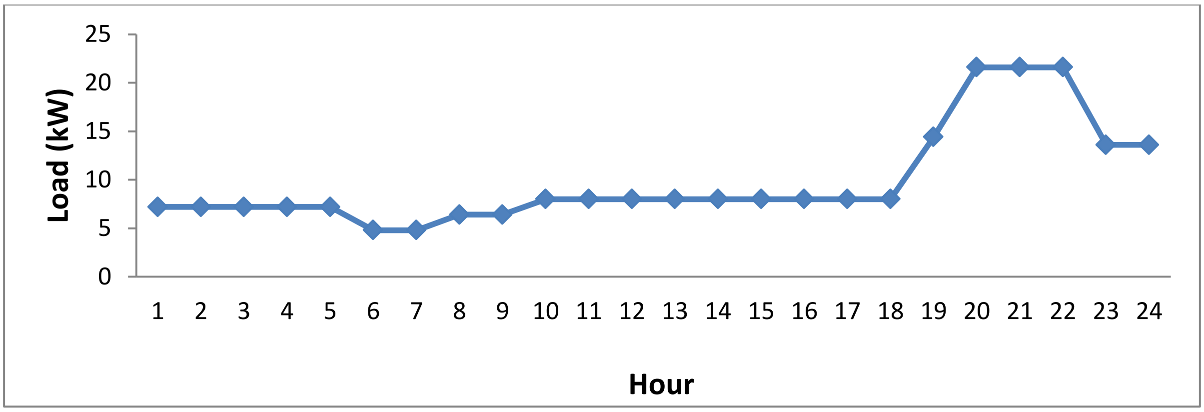

Figure 3.2 Daily domestic load profile of a village in winter season

Figure 3.3 shows the variation of domestic loads of a village for a whole year and the figure depicts that in summer the electricity demand increases as compared to winter.

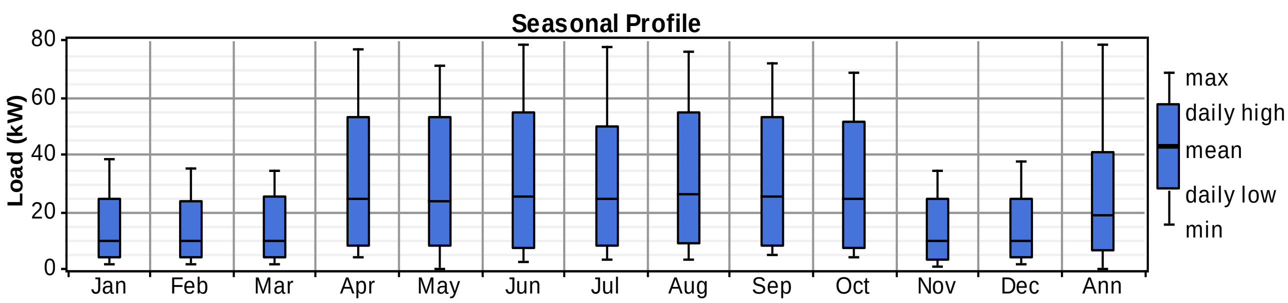

Figure 3.3 Yearly seasonal domestic load profile

3.4.2 Community Load

It comprises the shops, school, dispensary, village panchayat offices etc. The load demand is approximately 30.3 kWh/day and 5.65 kW peak. The various appliances that are assumed to be used in community and their average operating hours with details of energy used by each of them are shown in Table 3.2.

Table 3.2 Community load data of a village

Appliance	Power (W)	No. in use	Avg. operating hours.	Energy (kWh/day)
C.F.L	20	10	9	1.8
Fan	60	20	8	9.6
Refrigerator	100	2	24	4.8
Water cooler	200	1	9	1.8
Television	100	1	4	0.4
C.F.L	30	30	11	9.9
Low C.F.L.	11	4	24	1.1
Computer	300	1	8	2.4

The daily load of a community is shown in Figure 3.4 in which the load could be seen at peak in ofice hours and had a average peak value of 5.7 kW.

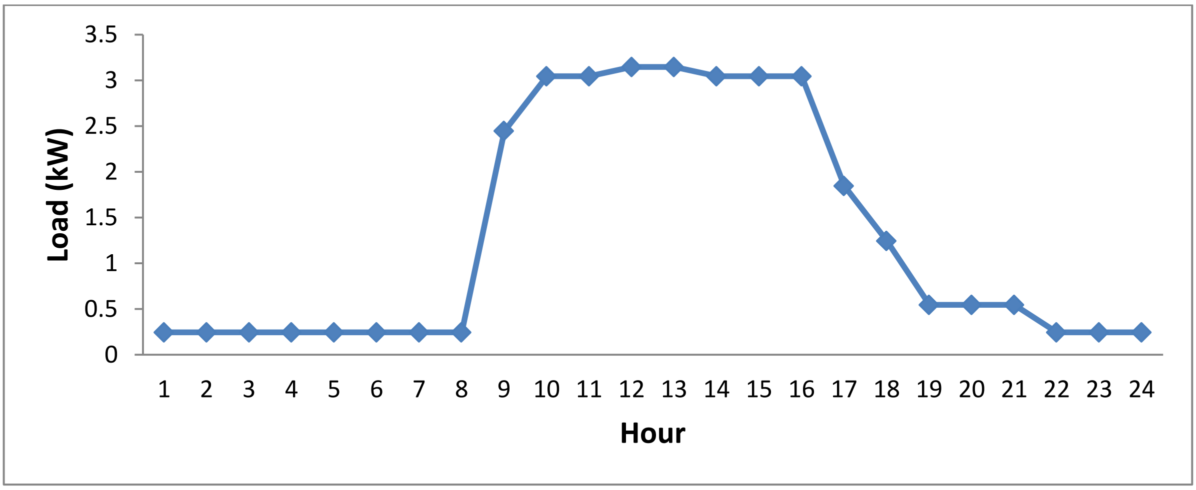

Figure 3.4 Community load profile of a village

CHAPTER 4

ENERGY PLANNING

4.1 INTRODUCTION

The plan proposes separate cost effective ways of utilizing these resources for different requirements as shown in Figure 4.1.

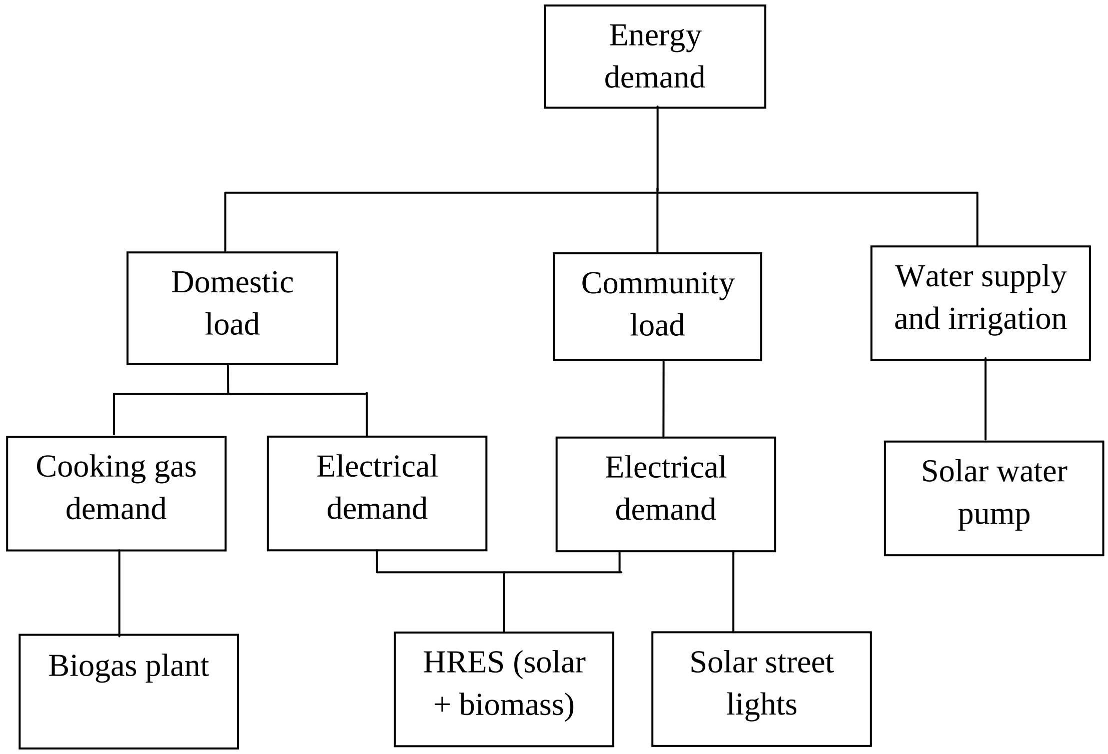

Figure 4.1 Proposed Plan to meet the demand

4.2 SYSTEM DESIGN FOR MEETING THE ELECTRICITY DEMAND

Hybrid (biomass + solar) renewable energy system (HRES) is proposed for meeting the electricity demand based on a renewable resources available [26]. The Hybrid Optimization Model for Electric Renewable (HOMER) software is used to determine the optimal sizing and operational strategy for a HRES. HOMER program is developed by National Renewable Energy Laboratory (NREL) and it is an energy modelling tool for designing and analyzing hybrid power systems comprised of conventional generators, biomass generators, solar photovoltaic, wind turbines, hydropower, batteries, and other technologies. This is done by creating a model of the system including electrical loads, energy resources, equipment and several economic inputs, then simulating the system based on each possible configuration, resource and load scenario. Depending on the complexity of the system the program may simulate between thousands and hundreds of thousands of different scenarios. The software creates a list of every possible system configuration based on the optimal sizing and related cost. HOMER can also create graphs and surface plots of output variables resulting from the input values used in the model and help to visualize the impact of changing input values on different system outputs.

Depending upon the available resources in village a model that is shown in Figure 4.2 is used for designing a hybrid renewable energy system which consists of a photovoltaic array, biomass generator, batteries and converter to meet the specified load. The further details of components are discussed further.

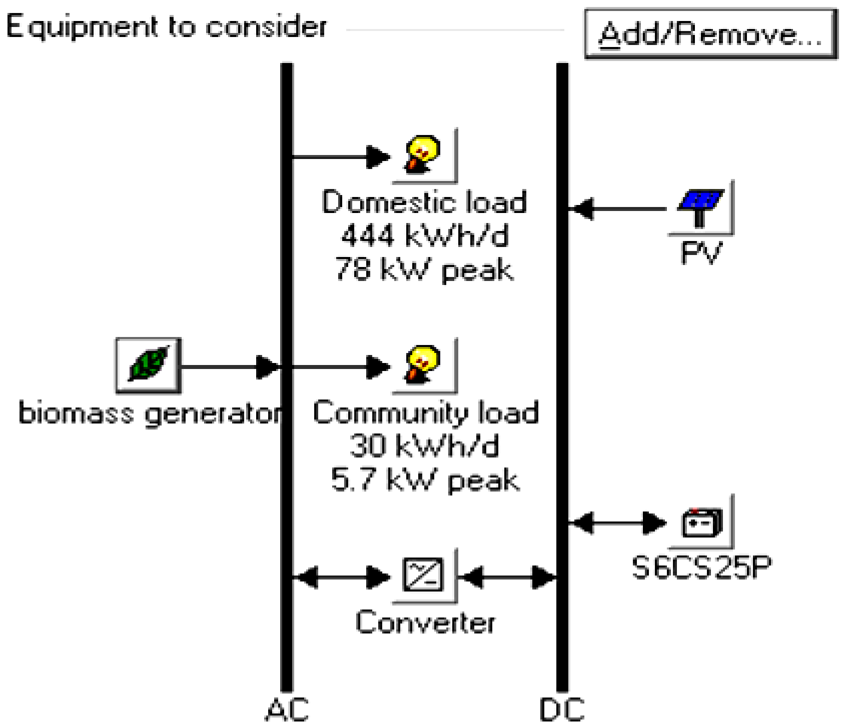

Figure 4.2 Hybrid power system design and components as modelled in HOMER

4.2.1 Components

These are the equipment and part of a system that generates, delivers, converts or stores energy. There are many types of components that can be modelled in HOMER but since this study is site specific so based on available resources the following components described below were used are used [25].

i. Photovoltaic (PV) array

In HOMER PV array is a device that produces dc electricity in direct proportion to the global radiation incident upon it, independent of its temperature and voltage to which it is exposed. The PV arrays generally have high capital cost and low operation cost with high reliability making it suitable for the considered off grid location with abundant solar radiation.

The capital cost that is to be used in HOMER includes all the cost associated with the PV system such as modules, mounting hardware and installation. The 1kW solar panel and cost [28] associated with it is shown in Table 4.1. The cost of a PV system is expressed in $ per peak watt and is defined as power at Standard Test Conditions (STC, 1000W/m^2, 25^{0}C). The specifications of PV array which are used as an input in HOMER is a lifetime of 25 years, derating factor 88%, slope 30˚ and annual operation and maintenance cost is for basic cleaning of system and is assumed to be 3% of capital expenditure. The sizes which are considered are 0 (no PV array), 0.5, 1, up to 3 kW.

ii. Biomass generator

A generator consumes fuel to produce electricity and the generator which uses biomass as its fuel is called a biomass generator [30]. HOMER assumes that the biomass feedstock is fed into a gasifier to create biogas and generator then consume the biogas to produce electricity. HOMER uses the Biomass Resource Inputs window to describe the availability of biomass feedstock. This data is then used to calculate (each hour of the year) the amount of biogas that can be supplied by the gasifier to the biogas-fuelled generator.

The cost [31] details which are considered are shown in Table 4.1 replacement cost taken is about 50% of capital cost, assuming replacement of generator and components. The capital cost depends on the size of the power plant. The unit cost ($/ kW) decreases with increase in size of the power gasifier plant. The unit cost is significantly higher for smaller sized systems less than 25 kW therefore it is economical to consider large size generator. The biomass feedstock for a gasifier is taken as 4 tonnes per day (constant availability is assumed) which is found to be sufficient for installing a 40 kW generator. Estimation of the cost of biomass feedstock for gasifier is somewhat complicated as final cost of prepared biomass comprises of several components such as cost of biomass production, its collection, transportation and preparation in required shape and size. In some situation it may be available at very low cost or free of cost depending on location. Residues are produced locally so transportation cost is neglected, and the biomass feedstock price is taken as Rs1/kg or $17 per tonne. Biogas digester other than generating a useful fuel product, it also produces a regular supply of nitrogen-enriched fertilizer which is of very much use for agriculture and additional revenue can be gained by selling the by-product.

iii. Batteries

Batteries are used in HRES to store excess electricity and to operate the system when power from system is insufficient or absent. The battery bank is a collection of one or more individual batteries. The sizing of the battery bank depends on the loads and the sizing of other components in the system, as well as the capacity of each cell and the voltage of the DC bus. A deep cycle lead acid battery that is used more frequently in renewable energy application is considered. The type of battery that is used in this system is Surrette 6CS25P of Rolls Battery Company with rating of 6 V, 1156 Ah and of very less maintenance. The capital cost, replacement cost and O&M costs for one unit of this battery were considered as $1250, $1100 and $5/year respectively. The capacity curve of a battery is shown in Figure 4.3 in which the variation of capacity with discharge current is shown.

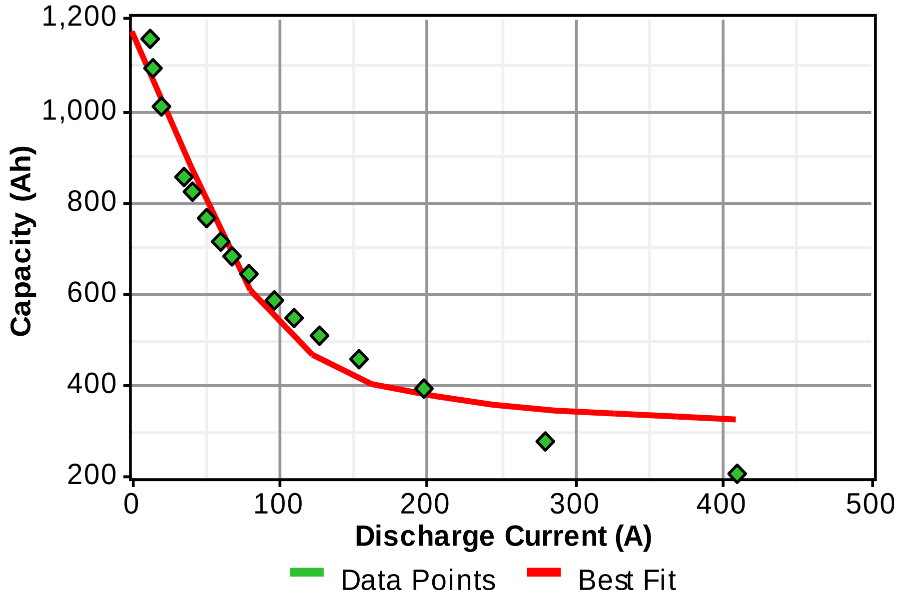

Figure 4.3 Capacity curve for deep cycle battery Surrette 6CS25P as modelled in HOMER

iv. Power converter

Any system that contains both AC and DC elements requires a converter, if the unit converts DC to AC, it is called an inverter and if from AC to DC, it is called a rectifier. So a power converter is used to maintain the flow of energy between ac and dc components. The size of power converter used in this system is 1 kW. The capital and replacement cost detail is given in Table 4.1. There are different sizes which are considered in the design of Hybrid Renewable Energy System 15, 20, 25 to 45. The lifetime for 1 unit of converter is 15 years with rated efficiency of 90%.

Table 4.1 Cost and details of components used as an input in HOMER

Component	Size	Capital cost.	Replacement cost.	O&M cost.	Details used
PV panel	1kW	$2500	$2250	$75/year	Avg. radiation: 5.14 kWh/m^2/d.
Biomass generator	9 kW 40 kW	$14429 $50321	$7215 $25161	$0.08/hr $0.3/hr	Available biomass: 4 tonnes/d
Surrette 6CS25P	1 battery	$1250	$1100	$5/year	Rolls battery company
Power Converter	1kW	$800	$750	$0/year	No maintenance

($1=Rs59)

4.2.2 Simulation Results

HOMER simulates every combination system configuration in the defined search space. Only the feasible one will be displayed at optimization result sorted based on the Net Present Cost (NPC). The combination of system components is arranged from most effective cost to the least effective cost. The proposed hybrid renewable energy system for the village consists of domestic load which is 444 kWh/d and annual peak load of 78 kW, community load which is 30 kWh/d and annual peak load of 5.7 kW. The design comprises of PV system, Biomass generator, battery and a converter serving for an AC electrical load.

According to optimization result as shown in Figure 4.4 the optimal solution is using only a biomass generator with a total net present cost of $374,186 but the feasible solution used is hybrid energy system using 0.5 kW PV array, 40 kW biomass generator, 35 kW converter and 40 batteries which is having a levelized cost of energy (COE) of $0.17/kWh and total net present cost (NPC) for such a system is $376,133.

PV (kW)	Gen (kW)	S6CS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Biomass (t)	Gen (hrs)
	40	40	35	$ 128,321	19,233	$ 374,186	0.169	1.00	272	6,224
0.5	40	40	35	$ 129,571	19,288	$ 376,133	0.170	1.00	271	6,275
1.0	40	40	35	$ 130,821	19,254	$ 376,950	0.170	1.00	270	6,251
1.5	40	40	35	$ 132,071	19,256	$ 378,229	0.171	1.00	269	6,234
	40	45	35	$ 134,571	19,067	$ 378,308	0.171	1.00	271	6,132
2.0	40	40	35	$ 133,321	19,230	$ 379,142	0.171	1.00	268	6,209
	40	40	40	$ 132,321	19,334	$ 379,477	0.171	1.00	272	6,224
0.5	40	45	35	$ 135,821	19,109	$ 380,095	0.172	1.00	271	6,168
2.5	40	40	35	$ 134,571	19,216	$ 380,216	0.172	1.00	267	6,194
0.5	40	40	40	$ 133,571	19,389	$ 381,423	0.172	1.00	271	6,275
3.0	40	40	35	$ 135,821	19,219	$ 381,502	0.172	1.00	266	6,176
1.0	40	45	35	$ 137,071	19,131	$ 381,628	0.172	1.00	270	6,159
1.0	40	40	40	$ 134,821	19,354	$ 382,233	0.173	1.00	270	6,252
	40	35	45	$ 130,071	19,746	$ 382,486	0.173	1.00	273	6,393
1.5	40	45	35	$ 138,321	19,106	$ 382,560	0.173	1.00	269	6,135

Figure 4.4 Optimization results for various PV and Biomass generator configuration as modelled in HOMER.

4.3 PLAN TO MEET COOKING GAS DEMAND

The cooking gas demand can be met by producing biogas locally [33]. Biogas is a clean and efficient fuel produced from Cattle Dung, Human Excreta and other organic matter in Biogas plant, through a process called 'Digestion'. Biogas contains 55% to 60% methane which is inflammable. The produced gas can be directly used for the cooking purpose which reduces the usage of firewood and its inefficient burning. Using generators we can generate electricity from it. Other natural resources like oil, gas etc. are limited and will be exhausting in course of time but the renewable energy sources are not limited. The sanitation in village could also be improved by linking sanitary toilets with biogas plants. Moreover the slurry which is by product is a fertilizer and can be returned to soil.

For promoting the setting up of biogas plant the central sector scheme on National Biogas and Manure Management Programme (NBMMP) provides central subsidy in fixed amounts, free maintenance warranty, financial support for repair of old-non functional plants, training of users, financial support for institutions for cattle dung based power generation plants, etc. There are numerous model designs of family type bio gas plant approved by Punjab Energy Development Agency (PEDA).

The installation design of the bio-gas plant depends on the average population of cattle and the amount of dung available. The size of a plant, cattle dung available and estimated cost is shown in Table 4.2.

Table 4.2 Details of Biogas plant capacity with its cost

Size of a plant	Quantity of cattle dung required daily	Number of cattle heads required	Estimated cost ($)
1 cubic meters	25 kg	2-3	121
2 cubic meters	50 kg	4-6	155
3 cubic meters	75 kg	7-9	181
4 cubic meters	100 kg	10-12	216
6 cubic meters	150 kg	14-16	259

As per the survey it is found that each household owns about 3-4 cattle heads on an average resulting in a total of about 14 heads for four houses, so the family type biogas plant of 6 cubic meter size for four houses is proposed to meet the cooking gas demand which would be costing about $259. So the total cooking need of a village can be met by 20 biogas plants costing to about $5200.

4.4 PLAN TO MEET IRRIGATION AND WATER SUPPLY DEMAND

A solar water pumping system is proposed principally for village water supply and irrigation purpose [35, 36]. It consists of SPV modules of capacity 1800 Wp (75 Wp modules), 2 hp solar pump, cables and switches and pumps are also available in 4 hp rating. This kind of solar water pumping system is useful for small farmers and replacement of diesel operated water pump sets. The basic operating principle is conversion of solar energy into electricity (DC) and that drives DC motor which is attached to mono block pump. SPV Pump set will have the capacity to give discharge of 1,20,000 to 1,40,000 litres on a clear sunny day (approx.) subject to variations due to solar insolation and water table condition. This discharge will be suitable for irrigating 1.6-2 hectare of land. No fuel cost as the fuel is abundantly available free sun light. The main advantage of solar water pumping set are saving of electricity, diesel, long operating life, highly reliable and trouble-free performance, easy to operate, maintenance free, environmental friendly and this makes it best suited for irrigation purpose. The successful operated Solar PV pump already installed in one of the village is shown in Figure 4.5.

The specifications of solar water pumping set provided by Punjab Government are [41]

1. Solar PV Panels : 1800 Wp comprising of (75Wp panels)
2. Motor pump sets type : 2 hp Centrifugal DC monoblock
3. Operating Voltage : 60 V DC (nominal)
4. Max. Suction Head : 7.0 m
5. Max. Dynamic head : 10.0 m
6. Bore well size (diameter) : 150 mm
7. Required shadow free area : 100 m^2

Figure 4.5 A solar pump installed in one of the village

4.4.1 Solar Pump to Meet Irrigation Demand

Chief Minister of Punjab announced 40% subsidy on solar irrigation pumps towards the promotion of state's flagship programme of agriculture diversification. The chief minister also sanctioned Rs.5crore for providing subsidy to the farmers besides fruit and vegetable growers, on these solar pumps. A solar pump costs nearly Rs. 2.5 lakh of which 40% (Rs 1 lakh) and 30% (Rs 75,000) as subsidy is borne by the state government and the union government, respectively, and the balance 30% which works out to be Rs.75,000 has to be paid by the beneficiary farmer.

Table 4.3 Cost of solar water pumping system in Punjab

Specification	Total cost	Subsidy by Central government	Subsidy by State government	Paid by farmer
2Hp solar water pumping system	$4237	$1695	$1271	$1271

($1=Rs59)

4.4.2 Village Water Supply Management

The economics of solar pumps already look attractive given the high cost of electricity and its unreliable supply at a site and therefore a solar water pump is a good option for village water supply. In village water supply, a constant water demand throughout the year occurs, although there is need to store water for periods of low insolation (low solar radiation). In environments where rainy seasons occur, rainwater harvesting can offset the reduced output of the solar pump during this period.

The use of batteries can be replaced by having a larger water storage system in the form of a tank. The water is supplied through a pipeline from the main Solar pumping system. Schematic plan as shown in Figure 4.6 can be used for effective supply of water in a village for which a village can be divided into different regions where tanks are constructed for distribution of water on the basis of equity.

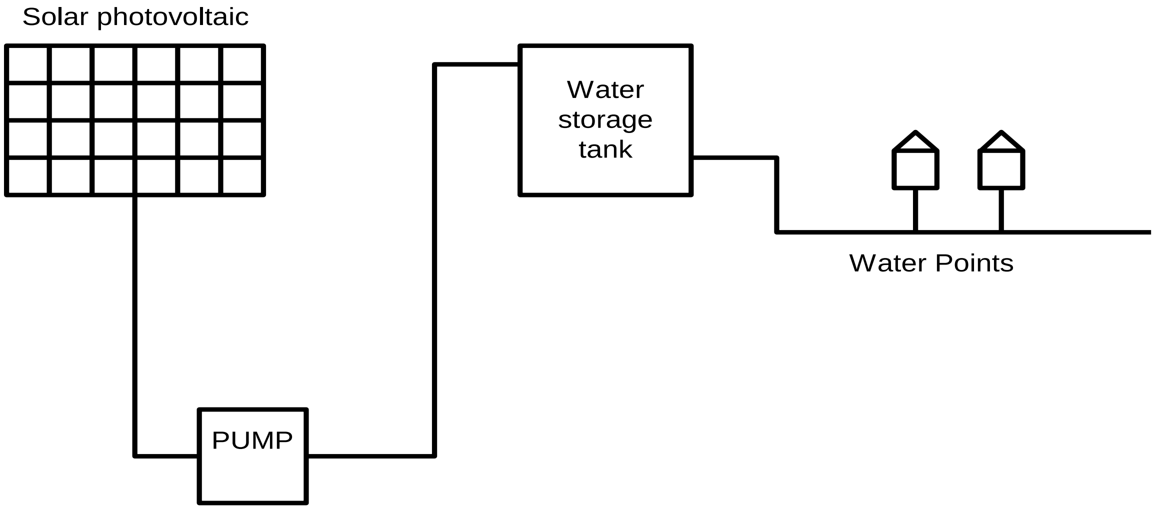

Figure 4.6 Schematic representation of village water supply system

4.5 SOLAR STREET LIGHTING

The Ministry of Non-Conventional Energy Sources (MNES), Government of India is providing support for development of photovoltaic technologies. MNES is supporting a nationwide programme for demonstration and utilization of PV systems for home lighting, street lighting, stand-alone power plants etc. Solar street lighting is ideal application for village street lights. The specification of one of the available solar lights is given in Table 4.4.

Table 4.4 Street lights specification

Parameters	Specifications.
Output light intensity	16 lux at 12 feet
Nominal power	20 W
Efficiency	86%
Lamp	9 W × 2

The system is provided with battery storage backup sufficient to operate the light for 10-11 hours daily during nights and cost to about $294 each. The village is proposed with 20 street lights which are costing about $5,880 the street lights are maintenance free and therefore they are best suited for rural areas application. Figure 4.7 shows a solar street light successfully installed in one of the village.

CHAPTER 5

ECONOMICS AND BENEFITS OF A PLAN

5.1 INTRODUCTION

The implementation of a small-scale energy system for rural electrification involves many different costs and components whose price varies with the many factors such as advancement of technologies and the use of resources etc. The most important factor to be considered is economic costs and benefits of a plan in order to make it sustainable and profitable. The chapter analyzes the configuration of Hybrid Renewable Energy System (HRES) proposed in HOMER for electrification, and the economics related with the use of bio gas plant, solar water pump and solar street lights for meeting various energy requirements.

5.2 ECONOMIC ANALYSIS OF HRES

The configuration modeled with the help of HOMER software that mostly matches the specification is 0.5 kW PV array, 40 kW biomass generator, 35 kW converter with 40 batteries and the system is having a levelized cost of energy (COE) of $0.17 per kWh and total net present cost (NPC) for such a system is $376,133. The system architecture shown in table of Hybrid Renewable Energy System (HRES) system used and other details related to cost summary is in system report presented below in Table 5.1.

Table 5.1 System Report of HRES

PV Array	0.5 kW
Biomass generator	40 kW
Battery	40 Surrettte 6CS25P
Inverter	35 kW
Rectifier	35 kW
Dispatch strategy	Cycle charging

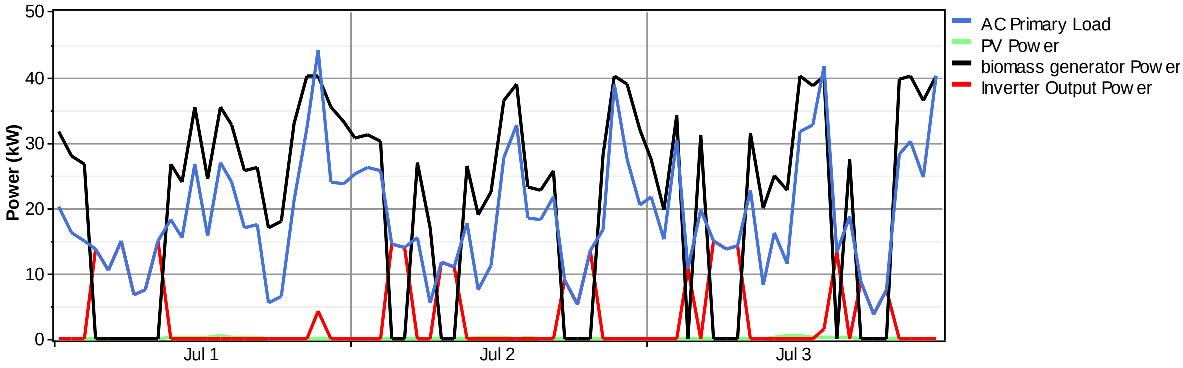

Figure 5.1 Hourly load production from various sources and primary load

In Figure 5.1 it is seen from hourly flow of power for 3 days that almost all the load is served by a biomass generator, and the PV array is mainly to supplement the generator during daytime. In many areas the biomass generator output power exceeds the AC load indicating that the generator is being used to charge the batteries which are discharged during night through the inverter. In all configurations where a gasifier is included in the system, it contributes the most significant amount to the total electricity produced, between 90 to 100 percent. This indicates that gasification has significant advantages over other generation options as far as operating costs and dispatch ability are concerned.

Cost summary of the whole HRES is shown in Table 5.2 below with details of total net present cost, levlized cost of energy and the cost related with each component used in a system.

Table 5.2 Cost Summary of HRES

PV Array	$1729
Biomass generator	$256,733
Battery (Surrette6CS25P)	$80,756
Converter	$36,914
Total net present cost	$376,133
Levelized cost of energy	$0.17/kWh
Operating cost	$19288/yr

Electrical productions are detailed in a Table 5.3 in which electrical productions of each components of a system are detailed. The total AC primary load consumption is found to be 173,094 kWh/yr.

Table 5.3 Electricity production with corresponding components used

Component	Production (kWh/yr)
PV Array	918
Biomass generator	190,014
Total	190,932

Figure 5.2 describes the average of electricity production in every month of a year by hybrid renewable energy system the main source of generations are biomass generator and PV system. This system results in 100% renewable fraction and a relatively low capacity shortage of 0.0827%

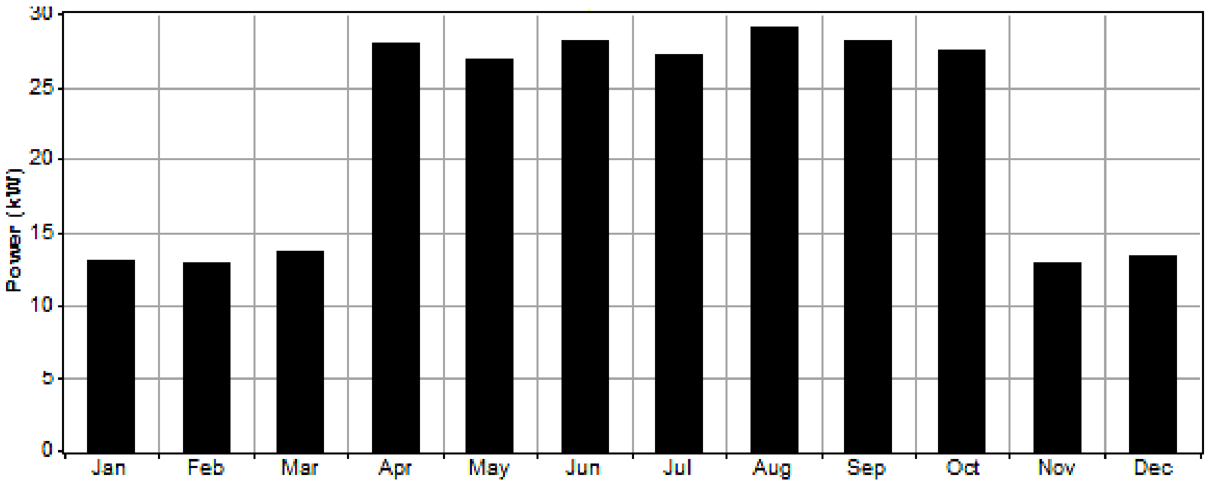

Figure 5.2 Monthly average electic production

It is seen in cash flow summary Figure 5.3 that the cost of biomass generator is dominant and most of the cost is due to the biomass gasifier, which also contributes nearly half the

O&M costs and all of the fuel costs. The total capital and replacement cost accounts to be about 80% of total net present cost.

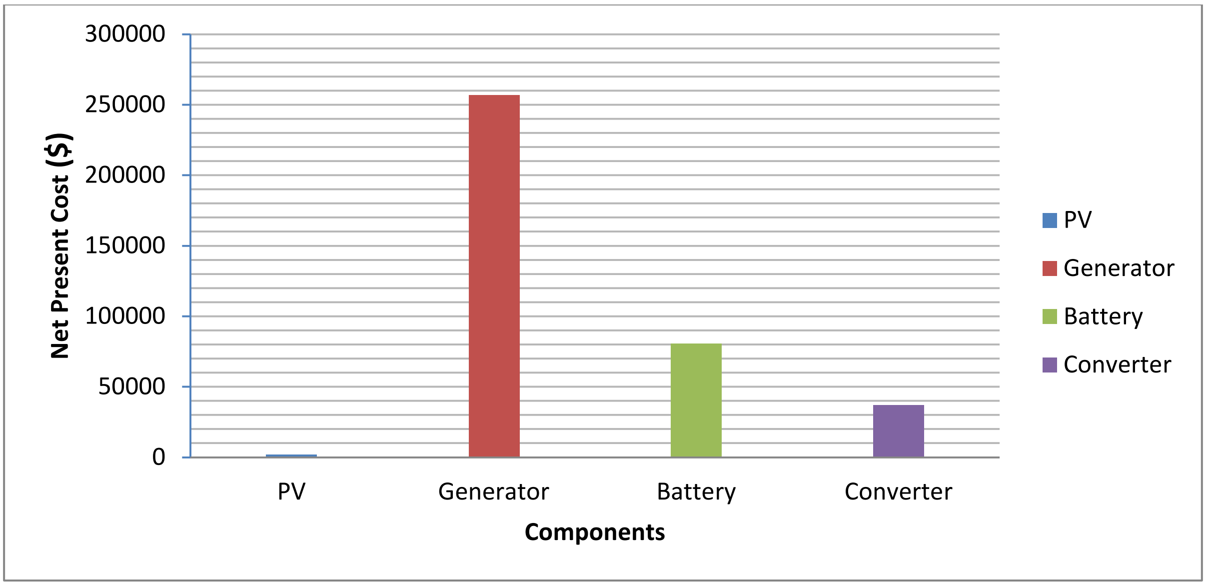

Figure 5.3 Cash Flow Summary based on cost type

5.3 ECONOMIC IMPACT OF THE PLAN FOR MEETING COOKING AND WATER DEMANDS.

Currently the households are using firewood and LPG cylinders which are not healthy and efficient. Therefore cooking gas demands are met by effective use of manure available and a family type biogas plant is proposed.

Cost of Proposed biogas plant of 6 cubic meter size for 4 houses = $259

Therefore, to meet cooking gas demand single house will pay = $259/4 = $64.75

Estimated Cost of using LPG cylinder per month by a single household = $7.24

Thus an estimated payback period of a biogas plant = $64.75/$7.24 = 9 months or 1 year.

It is found that at least 1 cylinder per month which costs $7.24 is needed by a family for cooking. So 960 cylinders would be needed for fulfilling the cooking demand of 80 families costing to about $6952 in a year and for a single household it would be $87 per year. Thus a payback period of about 9 months or a year is estimated and shown in Figure 5.4.

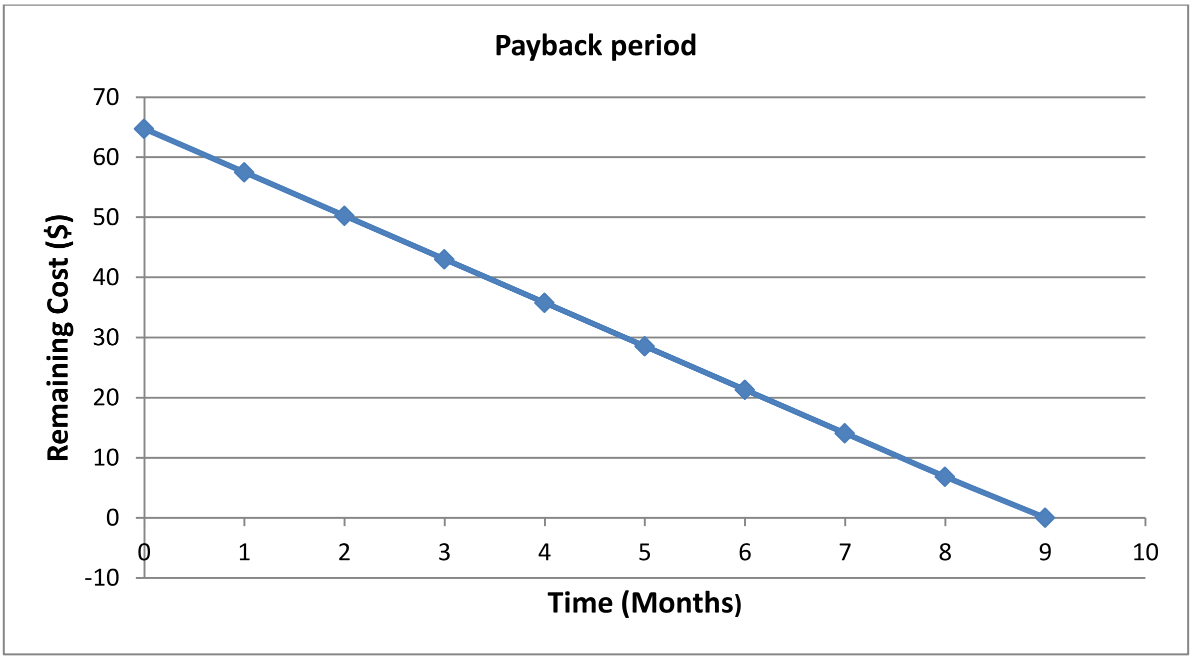

Figure 5.4 Payback period for cooking technology used

For village water supply and irrigation a subsidized solar water pump by a government of 2 hp is proposed which is costing to about $1,271 for farmers and is proved to be a very good solution for replacing the preexisting diesel pumps which are comparatively expensive and polluting. 20 solar streetlights which cost about $5,880 are found to be sufficient for whole village.

TABLE 5.4 Cost details of whole Plan proposed

Scheme proposed	Cost ($)
Hybrid renewable energy system	$376,133
Cost of total Biogas plants proposed in a village	$5,180
Cost of a solar water pump proposed	$1,271
Cost of solar lights proposed in a village	$5,880

The Table 5.5 shows the change affected by energy plan for the existed and proposed use of resources. The requirements, existing scenario and proposal of whole plan are summarized in table shown below.

Table 5.5 Proposed and Existing use of Resources

Requirements.	**Existing.**	**Proposed.**
Electrical energy for domestic and community loads.	State electricity supply which is unreliable and discontinuous.	100% renewable and continuous supply.
Cooking.	LPG cylinders and fire wood which is costly, inefficient and unhealthy.	Biogas plant which is cheap and eco-friendly. A by-product left is also a good fertilizer.
Irrigation and water supply.	Diesel pumps which are uneconomical and polluting.	Solar water pumps which are economical and have long operating life.
Street light.	Few street lights which are damaged most of the time due to low maintenance.	Solar street light which are of low power and less maintenance.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 CONCLUSION

Indian rural electrification is incomplete, insufficient and discontinuous which can be due to technical constraint or difficulty in connecting them with grid. Complete electrification of rural India could be feasible if the available local renewable resources are exploited as it will not only reduce burden on supplying grid but will also improve the quality of life and employment opportunities of the people living there. The objective to meet electricity demand of village can be achieved by making proper utilization of resources like biomass and solar and for this Hybrid system is used which has the advantages of stability and providing power on environmental friendly basis. Planning is done to integrate the abundantly available renewable resources which are a clean source of energy and are currently wasted due to lack of awareness. Efforts are made to exploit biogas, biomass and solar energy in the region and suggest some of the cost effective and environment friendly ways to meet the demand. The cost analysis predicts that in spite of having huge capital and installation cost renewable energy sources proves to be more reliable and environmental friendly source to provide electricity in remote or off grid areas. Complete uses of renewable resources are proposed to meet the various demands and in case of excess electricity it could be feedback to the grid adding to the village economy.

6.2 FUTURE SCOPE OF THE WORK

Future research which are expected to be valuable includes

i. The work discussed can be used as a road map for the effective and efficient planning of villages and modelling hybrid energy system.
ii. Successful commercialization of renewable technologies is needed for making it cost competitive without subsidies
iii. Focus should be given for making technological improvements in biomass production and processing systems especially for small scale biomass gasification.

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