DEVELOPMENT OF COST EFFECTIVE TECHNOLOGY FOR HARNESSING RENEWABLE ENERGY IN REMOTE AREA

A DISSERTATION

Submitted in partial fulfillment of the requirement for the award of the degree of

MASTER OF TECHNOLOGY

in

ALTERNATE HYDRO ENERGY SYSTEMS

By

Bhupender Singh Kaneri

ALTERNATE HYDRO ENERGY CENTRE
INDIAN INSTITUTE OF TECHNOLOGY, ROORKEE
ROORKEE- 247667 (INDIA)
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CANDIDATE'S DECLARATION

I hereby declare that the work presented in the dissertation entitled **"Development of Cost Effective Technology for Harnessing Renewable Energy in Remote Area"** submitted in partial fulfillment of the requirements for the award of degree of **Master of Technology** in **Alternate Hydro Energy Systems** in the Department of Alternate Hydro Energy Centre, Indian Institute of Technology Roorkee, is an authentic record of my own work carried out from July 2006 to June 2007 under the guidance and supervision of **Dr. R. P. Saini,** Associate Professor and **Dr. M. P. Sharma,** Associate Professor, AHEC, IIT, Roorkee.

The matter embodied in the dissertation has not been submitted by me for the award of any other degree.

Date: June 29, 2007

Place: Roorkee

(Bhupender Singh Kaneri)

This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

(Dr. R.P. Saini)

Associate Professor

Alternate Hydro Energy Center
Indian Institute of Technology,
Roorkee

(Dr. M.P. Sharma) 29/6/07

Associate Professor

Alternate Hydro Energy Center
Indian Institute of Technology,
Roorkee

ABSTRACT

Energy is the basic human need and critical input to the socio economic development of the country. Supply of reliable and quality power at reasonable rate is essential for overall development of a nation. The rural areas are at disadvantageous state so far its availability to them is concerned. With the realization of depleting fossil fuels and prospects of severe adverse impact of its use has led the scientists, engineers and planners to look for alternate energy resources, which are not only environmentally friendly but sustainable also. Numerous such energy sources are identified. They are found to be fairly evenly distributed and available almost free. This makes them perfect source for fulfillment of energy needs of rural masses. But some of the problems associated in harnessing them are their low density, site specific availability, costly to transport and variation over time. The dilute availability requires costly energy conversion system to harness while variations in availability over time make them unreliable. All these aspects require a careful consideration in design of integration of conversion systems to attain desire level of reliability and cost. In this context the utilization of resources efficiently plays an important role. The efficient utilization of resources would result in a system which will have the least losses.

In the dissertation report a generalized optimization model for finding optimal combination of Integrated Renewable Energy System (IRES) is developed to harness the renewable energy sources in a remote area. This model is applicable to any rural village. A goal programming method to achieve minimum cost and maximum efficiency in utilization of available resources to meet the various loads has been devised which will result in an optimal sizing of these energy conversion systems. The aforesaid method is applied to a village selected for study. Cooking, lighting and mechanical energy requirements of the village are estimated along with the available renewable resources and the method is applied to size the renewable energy conversion systems (RECS).

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Place: Roorkee

(Bhupender Singh Kaneri)

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NOMENCLATURE

w_{i-j} = Optimal amount of i[th] resource option for j[th] end use (kWh)

R_i = Total i[th] Resources end use (kWh)

w_{i-j} = Availability of i[th] resource option for j[th] end use (kWh)

η_{ij} = Conversion efficiency for i[th] resource option for j[th] end use

ABBREVIATIONS

AEG -Annual energy generation

Ah – Ampere hours

bcm - billion cubic meter.

BES – Biomass Energy Resource

BES_H – Biomass Energy Resource used for Heat energy generation

BGS_M – Biomass Energy Resource used for Mechanical energy generation

BGS_E – Biomass Energy Resource used for lighting energy generation

BGS - Biogas Digester

BIO – Biogas

CEA– Central Electricity Authority

CF- Capacity Factor

CHP - Combined Heat & Power

COE – Cost of Energy

CRF– Capital Recovery Factor

Cogen - Cogeneration.

CPWD-Central Public Works Department

DG – Diesel Generator

EPDF – Electric Power Delivery Factor

GHG – Green House Gases

hh – Households

HAWT -Horizontal Axis Wind Turbine

IRES -Integrated Renewable Energy Systems

IRES-KB – Integrated Renewable Energy System Knowledge Based

KVIC model

kW - Kilowatt,

kWp - kilowatt peak,

LEC -levelized energy cost

LCC - life cycle cost ,

LOLE – loss of load expectation

LPG – Liquefied Petroleum Gas

LP – Linear Programming

LST – Local Standard Time

LUC -Life cycle unit cost

mb - million barrel

MDOD -Maximum Depth of Discharge

MPP -Maximum Power

mt- million tones

MHP – Micro-hydro power

MHP_H - Micro-hydro power Resource used for Heat energy generation

MHP_M -Micro-hydro power Resource used for Mechanical energy generation

MHP_E -Micro-hydro power Resource used for Electrical energy generation

MHP_R - Micro Hydro Power potential available at site (kWh/year)

MNES – Ministry of Non-Conventional Energy Sources

MW – Mega Watt

NGO -Non Governmental Organization .

Ni-Cd – Nickel-Cadmium

NPIC-National Programme on Improved Chulhas

NPV -Present Value Criterion

O & M – Operation and Maintenance

OP -operating point

OREM – Optimal Renewable Energy Model

PCU - Power Conditioning Unit

pdf - Probability Density Function

PV – Photovoltaic

PLF – Plant Load Factor

RE – Renewable Energy

RES – Renewable Energy System

RGGVY -Rajiv Gandhi Grameen Vidyutikaran Yojana

R/P Ratio –Reserve to production ratio

SHP – Small Hydro Power

SPV – Solar Photovoltaic

SPV_E - Solar power Resource used for Electrical energy generation

SPV_H Solar power Resource used for Heat energy generation

SPV_M Solar power Resource used for Mechanical energy generation

SPV_R Solar power resources

SPV - Solar photovoltaic energy conversion system sq.m. - square metre

T&D - Transmission and Distribution

TSR - The tip speed ratio

TV – Television

USA – United States of America

VAWT -Vertical Axis Wind Turbine

VAT - Value Added Tax

WECS – Wind Energy Conversion System

WEG – Wind Electric Generator

WES_R Wind Energy Resources in W/m^2

WES – Wind Energy System

WTGs – Wind Turbine Generators

NOTATIONS

Symbol	Descriptions	Unit
η	Over all efficiency	
ϕ	Latitude of the location in degree	
δ	Declination angle in degree	
ρ	Density of air	kg/m^3
C	Installed (capital) cost	Rs. / Capacity
Cp	Coefficient of performance of the wind turbine	
E	Energy	kWh/yr
g	Acceleration due to gravity	m/s^2
H	Head	meter
H_o	Extra Terrestrial horizontal insolation	kWh/m^2
H_z	Global solar insolation at horizontal surface	kWh/m^2
H_{bz}	Beam radiation on horizontal Surface	kWh/m^2
H_{dz}	Diffused radiation on horizontal Surface	kWh/m^2
I_o	Extra Terrestrial irradiance	kW/m^2
I_{SC}	Solar Constant($1.367 kW/m^2$)	
P	Power Generated	kW
Q	Discharge available	m^3/sec
P	Power	kW
Q	Discharge or Flow rate	m^3/sec
r	Discount Rate	%
v	Wind Speed	m/sec
v_m	Wind Speed	m/sec

CHAPTER-1
INTRODUCTION AND LITERATURE REVIEW

1.1 GENERAL

Energy is an essential requirement for all facets of our life. It is key to accelerating economic growth, generation of employment, elimination of poverty and human development especially in the remote areas. Viable and reliable electricity services result in increased productivity in agriculture and labor, improvement in the delivery of health and education, access to communications (radio, telephone, television, mobile telephone), improved lighting after sunset, facilitating the use of time and energy-saving. Currently, the vast majority of poor rural households do not have access to electricity in India. India's achievement in the field of rural access to electricity leaves much to be desired. India is home to 35% of the global population without access to electricity and only 44% of all rural Indian households are electrified. However, with the focus being extensive (number of villages electrified) rather than intensive (% of households covered), large gaps remain in rural electrification. Although the number of electrified villages has increased rapidly, the number of households electrified has not matched the pace. The Ministry of Power states that 74% of villages are electrified, while only 44% of rural households are electrified. This inequity impedes the development of poor rural populations and underscores the fact that India's rural electrification programs have not reached the most marginalized and needy sections of society.

The broad goals of Rural Electrification referred to as AARQA goals which are as follows:

- Accessibility – electricity to all households by 2012
- Availability – adequate supply to meet demand by 2012
- Reliability- ensure 24 hour supply by 2012
- Quality- 100% quality supply by 2012
- Affordability- pricing based on consumer ability to pay

While the REP seeks to achieve 100% household electrification by 2012 primarily through grid extension, stand-alone systems are also envisioned for areas where grid extension may not be possible on account of techno-economic factors and 18000 villages have been targeted to be electrified by renewables.

Sun is the origin of all forms of energy in earth. Energy can be classified as renewable and non-renewable. Renewable energy is obtained from sources that are inexhaustible such as, wind energy, solar energy, geothermal, tidal and hydroelectric energy. Non-renewable energy is the conventional fossil fuels that are likely to deplete over time.

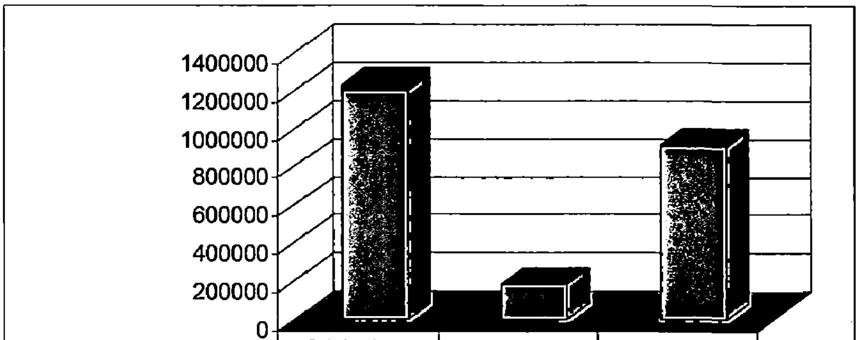
1.2 NON-RENEWABLE ENERGY

Coal, Oil, Nuclear and Hydro energy are commonly known as conventional fuels. These fuels are responsible for much of the environment degradation taken place on the earth. The burning of coal, oil and natural gas at the rate that is much faster than the rate at which they are created resulting in release of carbon stored in the fuels into the atmosphere. This is upsetting the carbon cycle by release of more carbon dioxide to the atmosphere. The carbon dioxide is key green house gas responsible for global warming. In addition to that use of fossil fuels at faster rate will lead to the exhaustion of these fuel.

As shown in figure 1.1 the global primary proven reserves of fossil fuels like Oil, natural gas and coal are 1200700 million barrel (mb), 179830 billion cu. m. (bcm) and 909064 million tones (mt), respectively. With the current production of these fuels at the annual rate of 29.59 million barrel oil, 2763 bcm of natural gas and 5852.5 mt. of coal, it is feared that the oil and natural gas will last 40 years and 65 years respectively. Only coal is likely to last over 155 years.

Figure 1.2 indicate the global use of primary energy resources such as Oil 3836.8 Mtoe (41%), natural gas 2474.7 Mtoe (27%), coal 2929.8 Mtoe (32 %) , Nuclear energy 627.2 Mtoe (6%) and hydro electric 668.7 (6%). The primary energy consumption of energy of few countries presented in the figure 1.3 indicates that the developed countries have higher consumption of energy than the developing countries in spite of the fact their population is far less than that of developing countries.

The distribution of fossil fuels is quite uneven. USA has 27.1% of world's coal reserve followed by Russia 25%. The 61.9 % of the total proven oil reserve is found in the middle east countries. The 26.6 % of the Natural gas is available with the Russian federation and 40.1 % with middle east countries. Thus it can be seen that most of the fossil fuels are available in middle east and Russian federation. In contrast to that the renewable energy sources like solar and wind are fairly evenly distributed.



	Oil (million barrel)	Natural Gas(b.cu.m.)	Coal (m.ton.)
■ Annual Production	29600	2763	5852
▣ Reserve	1200700	179830	909064

Fig. 1.1: The Status of Global Fossil Fuels Production vis-a-vis Proven Reserves (2006)[14]

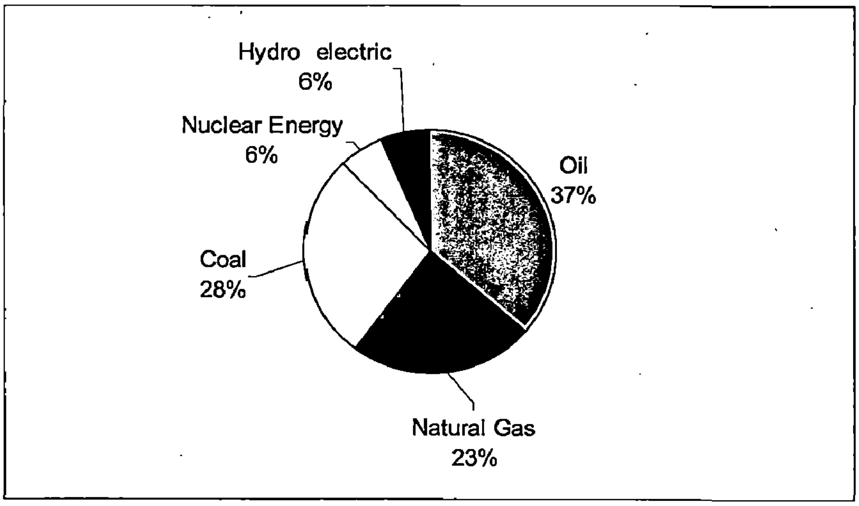


Fig. 1.2: The Global Conventional Energy Consumtion Pattern(2006) [14]

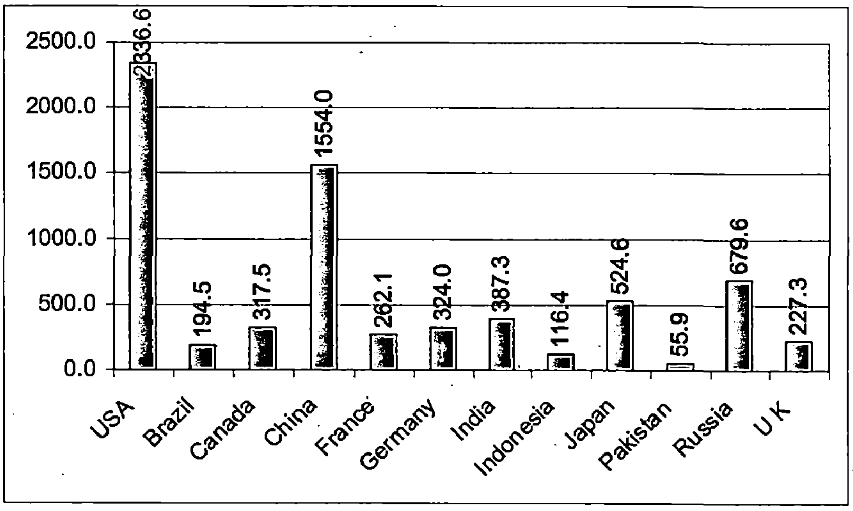


Fig. 1.3: Country Wise Primary Energy Consumption of Conventional Fuels in Mtoe (2006) [14]

The situation of conventional energy sources in India is not very promising. The table 1.1 presents the status of fossil fuels in India. It is evident that the country largely depends on import of oil for its energy requirements. Besides there is not much scope for improvement in the production of oil as the reserve to production ratio indicates that our oil and gas reserves will last 20 years and 36 years respectively at the present rate of productionmuch. The country is comfortable only in the coal sector which is expected to last 217 years. The 68% of our oil requirement is imported and it constitutes 32% of our total conventional energy consumption. The import of natural gas is 17% of our requirement and it constitutes 9% of our total energy consumption. Only the import dependency on coal sector is less which is being imported to the tune of 5 % of requirement and it is the main source of fulfilling our energy needs constituting 59%.

Table 1.1: The Estimates of fossil fuels in India (2006) [14]

Energy Source	Unit	Proven Reserve	Production	Consumption	Surplus/ Deficit	R/P Ratio
OIL	Mt	800	36.2	115.7	-79.5	20.7
NATURAL GAS	Mtoe	990	27.4	33	-5.6	36.2
COAL	Mtoe	43294	199.6	212.9	-13.3	217

Six (6) percent of India's energy needs is met by Hydro electric generation. In India generation of electricity utilizes mainly fossil fuels and coal in particular. Despite hydro being recognized as the most economic and preferred source of electricity but its contribution has declined steadily from 44 % in 1970 to 26% in 1998. The ideal ratio of hydro-thermal mix is considered to 40:60. Therefore, thermal generation, which should normally be used for base load operation, is also being used to meet peaking power requirements. This leads to non-optimal utilisation of economic and perishable resources. The pattern of primary energy consumption for electricity generation is shown in figure 1.4

It is ironical that only about 17% of our vast hydel potential of 1,50,000 MW has been tapped so far. It is evident from the table 1.6 that the countries like Norway, Canada, Brazil have all been utilising more than 30% of their hydro potential whereas India and China have lagged far behind. The Position is depicted in figure 1.5.

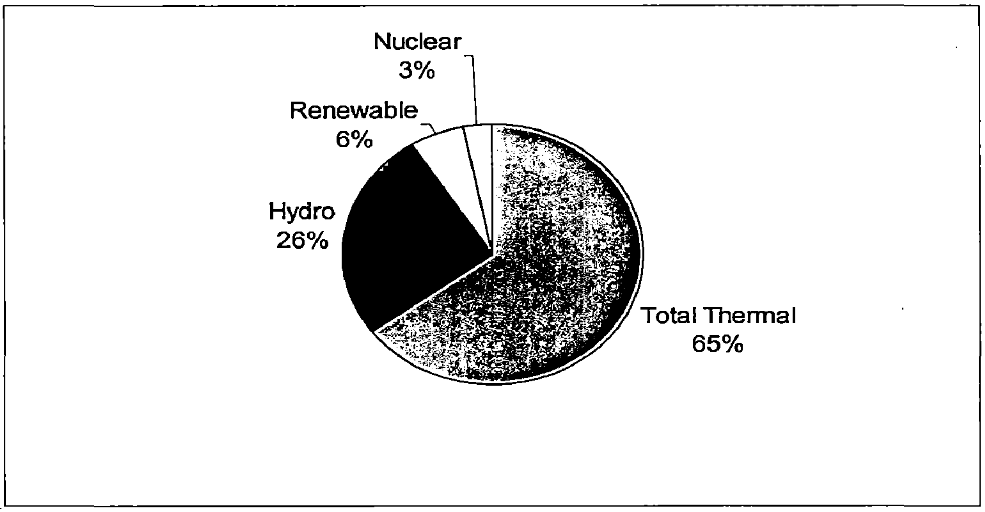


Fig. 1.4 The Energy Consumption Pattern of Electricity Generation in India (2005) [62]

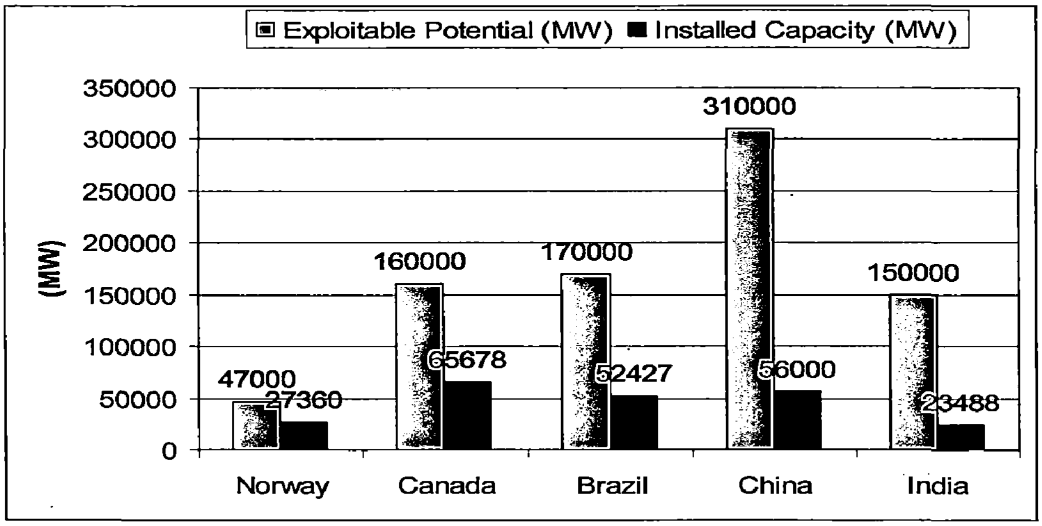


Fig. 1.5: The Status of Exploitation of Hydro Power Potential of Few Countries [62]

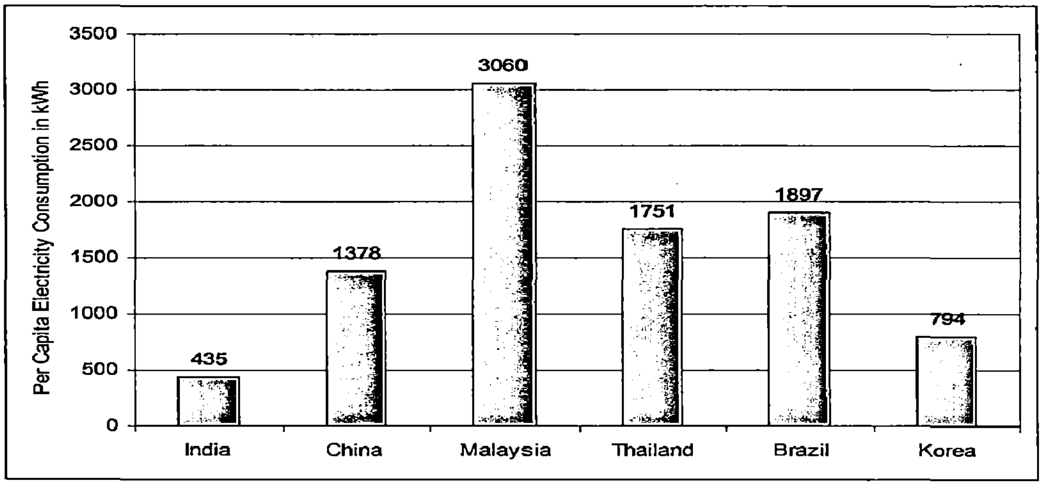


Fig. 1.6: Comparison of Per Capita Electricity Consumption of Few Countries (2003) [22]

Table 1.2: The Status of Hydro Potential in India [62]

Country	Exploitable Potential (MW)	Installed Capacity (MW)	% of Potential Utilized
Norway	47000	27360	58
Canada	160000	65678	41
Brazil	170000	52427	31
China	310000	56000	18
India	150000	23488	17

The large hydropower though considered being better than the use of fossil fuels but their long-term sustainability and claimed benefit is debatable.

The per capita consumption of electricity of India lags far behind other developing countries like China, Malaysia, Thailand, Brazil and Korea as shown in figure 1.6.

Table 1.3: Energy Consumption Pattern for Electricity Generation in India [62]

SL.No.	Energy Sources	Capacity (MW)	Percentage
1	Total Thermal		
	(i)Coal	70682	53.5
	(ii)Gas	13,691	10.4
	(iii)Oil	1,201	0.9
	Sub-Total	**85,575**	**64.7**
2	Hydro	**34,653**	**26.2**
3	Nuclear	**4,120**	**3.10**
4	Renewable	**7760**	**5.90**
	Total	**1,32,110**	

1.3 Renewable Energy

The renewable energy sources include both direct solar radiation and indirect solar energy such as wind, hydropower, ocean and biomass resources that can be managed in a sustainable manner. The advantages of renewable energy sources are:

- Renewable energy is an indigenous resource available in considerable quantities in all the nations.

- The use of renewable energy could help to conserve foreign exchange for the nation importing fossil fuels and lead to security of supplies.
- These are scattered and available in diffuse form therefore difficult to transport. Hence these can be developed locally and help in generation of local employment.
- Several renewable energy options are financially and economically competitive particularly in remote locations, where the cost of extension of grid is uneconomical or those endowed with rich biomass, hydro and geothermal.
- The renewable energy conversion systems can be produced in large numbers and can be deployed quickly. Thus requires less gestation period unlike large power stations which have very long lead times.
- As the renewable energy resources are locally available and no cost is involved in procuring them they are inflation free and secure in supply.
- They can be matched to the scale to the need and can deliver energy of the quality that is required for specific task. Thus obviating the need of unnecessary conversion.
- They are usually built close to the point of use so transmission cost and losses are avoided.
- The diversity of systems available also increases flexibility and security of supply. In contrast, over dependence on imported fuels make country vulnerable to external intrusion on internal policy matters.
- While there are physical and environmental risks associated with the construction and operation of renewable energy systems – as there are with all the energy conversion systems – they tend to be relatively modest in comparison with those associated with fossil fuels or nuclear power

The potential of renewable energy sources and achievement in India is presented on table 1.4. It can be seen that enormous prospects of development of renewable energy sources in meeting the energy requirements exists in India. These can be appropriately and optimally utilized to provide reliable supply of electricity especially for remote rural areas devoid of central grid. It is interesting to note that vast untapped potential exists in renewable energy but we continue to remain energy starve.

Table 1.4: Potential and Achievements of Renewable Energy in India[62]

Sources/Systems	Unit	Estimated Potential	Cumulative Achievements (as on 31.03.2007)	Percentage Achievements
Power From Renewables				
Grid-interactive renewable power				
Bio Power (Agro residues & Plantations)	MW	61000	524.8	0.01
Wind Power	MW	45000	7092	0.16
Small Hydro Power (up to 25 MW)	MW	15000	1975.6	0.13
Cogeneration-bagasse	MW	5000	615.83	0.12
Waste to Energy	MW	7000	43.45	0.01
Sub Total (in MW)	MW	**133000**	**10251.68**	0.08
CHP / Distributed renewable power				
Solar Power	MW	50000	2.92	0.00
Biomass / Cogen.(non-bagase)	MW		45.8	
Biomass Gasifier	MW	-	86.53	
Energy Recovery from Waste	MW	-	19.76	
Sub Total	MW	**50000**	**155.01**	
Total (A + B)	MW	**183000**	**10406.69**	
Remote Village Electrification	Nos.	18000	2821	0.16
Decentralised Energy Systems				
Family Type Biogas Plants	Nos.in lakhs	120	38.9	0.32
Solar Photovoltaic Programme	MW/Sq.km	20		
i. Solar Street Lighting System	Nos.	-	61321	
ii. Home Lighting System	Nos.	-	313859	
iii. Solar Lantern	Nos.	-	565658	
iv. Solar Power Plants	kW	-	1870	
Solar Thermal Programme		-		
i. Solar Water Heating Systems	million sq.m collector area	140	1.9	0.01
ii. Solar Cookers	Nos.in lakhs	-	6.03	
Wind Pumps	Nos.	-	1180	
Aero-generator /Hybrid Systems	kW	-	608.27	
Solar Photovoltaic Pumps	Nos.	-	7068	

MW = Megawatt, kW = Kilowatt, kWp = kilowatt peak, sq.m. = square metre CHP = Combined Heat & Power

The brief overview of various renewable energies has been given below.

1.3.1 Small Hydro Power

The potential of small hydro projects (SHP) is estimated 15000 MW in India. The progress of development of small hydropower is steady and gradual from 3MW of installed capacity in 1989 to 1975.60 MW in 2007. The micro-hydel holds excellent prospects in electrification of rural and remote areas. Installation of Forty-three portable micro-hydel sets of up to 15 kW capacity have been carried out in various parts of the country. These sets are providing electricity to unelectrified villages and are being maintained by local communities [62].

The country has also launched a programme on development and up-gradation of water mills. According to rough estimates there are nearly 500,000 water mills in the entire Himalayan region from the North Eastern states to Jammu and Kashmir. These water mills or *Gharats* are of the vertical shaft type, evolved over thousands of years and are used essentially for grinding wheat, rice and maize and also to extract oil. In the absence of appropriate technology, water mills were never used for any purpose other than grinding grains [26]. The modern upgraded water mills have the arrangements for utilizing mechanical energy for grinding grains and generation of electricity. The upgraded water mills have excellent potential to cater to the needs of the villages.

1.3.2 Biomass Energy

Biomass, a product of photosynthesis, includes all new plant growth, residues and wastes such as rotation trees, herbaceous plants, fresh water and marine algae, aquatic plants, agricultural and forest residues, kitchen and city garbage, night soil, sewage etc. Furthermore, biodegradable organic effluents from canneries, sugar mills, slaughterhouses, meat packing factories, breweries, distillers etc. are also categorised as biomass resources. The estimated potential of various biomass resources has been shown in table1.4.

Utilization of biomass for power generations is restricted due to its production being labour intensive, and scattered availability, seasonal availability, localized price sensitivity and lack of automatic feed control, tedious handling, besides having the high moisture, low energy and low bulk density (30-180 kg/m^3) needing substantial transportation cost. A wide variety of conversion technologies can be used to produce energy from biomass. Some are simple and some are well developed, while others are at different stages of development. The choice of particular process is determined by a number of factors such as location of resource, its physical conditions and the economics of competing processes and the availability of suitable market for the product. Technologies to convert biomass to energy fall into two general categories: (i) Biological: (a) Anaerobic digestion (b) Fermentation and (ii) Thermo-chemical: (a) Combustion (b) Pyrolysis (c) Gasification (iv) Liquefaction. Out of these, only two viz. (a) anaerobic digestion and (b) biomass gasification will be considered as the processes for the production of biogas and producer gas as gaseous fuels.

1.3.3 Solar Energy

India receives solar energy equivalent to over 5000 trillion kWh/year, which is far more than the total energy consumption of the country. The daily average of incident solar energy in India ranges 4 -7 kWh/m^2 depending upon the location. PV systems of about 2.92 MW aggregate capacity have been installed by March, 2007 [62].

The high cost of PV system has limited their use for critical applications only like communications and rural health clinics. However, the research and development that has taken place have broadened their applicability to areas where the power supplied by grid is unavailable and conventional fuels are expensive.

1.3.4 Wind Energy

In India the 7092 MW of capacity has been tapped (upto 2007) out of the total identified potential of 45000 MW. India ranks fourth largest wind producer in the world. The wind generation in India started with unit size of 55 kW in 1986 when the first demonstration wind farm was built. Installation of 90kW, 110kW and 150kW soon followed. When private sector entered the wind market in early 1990, unit sizes from 225 kW to 300 kW were prevalent. Now 500kW, 800 kW, 1250 and 1650 kW are the preferred choice. WEGs manufactured in India have 70% indigenization for unit capacity 500kW [15].

1.3.5 Other Renewable Energies

Other renewable energies are tidal and Geothermal. Both of these are highly site specific. Tides are a periodic rise and fall of the water level of sea due to gravitational forces of the moon and the sun on the ocean water of the earth, spinning of earth around its axis and their relative positions. The possible sites for tidal power generations in India are of Gulf of Combay, Gulf of Kutch and South Hoogly River. A preliminary study undertaken by Central Public Works Department (CPWD) for tidal station in the gulf of Combay has claimed that energy generated by tides is costlier than energy obtained from commercial sources. The world's tidal energy potential is 30 x 10^6 MW, where as it is about 15,000 MW in India.

Geothermal energy is the thermal energy contained in the interior of the earth. It is available in the form of steam and hot water along the West Coast, Ladakh, and some parts of Himachal Pradesh. The potential for generating electricity through Geo-thermal is negligible [62].

1.4 ENERGY NEEDS

1.4.1. Electricity

India is the fifth largest energy guzzler of the world (after USA, China, Russia and Japan). However, the present per capita consumption of electricity of India 606kWh/year continues to be one of the lowest in the world. So far only 74% of the total villages could be electrified and only 44% of the total households have access to the electricity as is evident from the above table 1.6 and table1.7

Table 1.5: The status of electrification in India[24]

Number of villages as per 2001 census	638365
Number of villages electrified upto May 2006	471360
Percentage Village Electrification	74

Table 1.6: The status of household electrification in India[24]

Number of Rural Households as per 2001 census	138271559
Number of Household having access to electricity	60180685
Percentage of Household Electrified	44

Realizing the importance of providing power to all the Government of India has decided to electrify all the un-electrified villages and providing access to electricity to all households in the next five years. In this direction as per the provisions of National electricity policy and as mandated in the section 6 of Electricity Act 2003in April 2005 a program "Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) is launched under common minimum programme [24].

The plan of the Government is highly ambitious considering the fact that the country is facing the energy shortage of 9.3% and Peak demand shortage is 13.9% as per the power situation from April 2006 to January 2007 as presented in table 1.7.

Table 1.8: Power Situation (From April 2006 to January 2007) [24]

Item	Unit	Demand	Demand Met	Surplus(+) /Deficit(-)
Energy	mU	572812	519656	-9.30%
Peak Demand	MW	100403	86425	-13.90%

The consumption of electricity is likely to grow and outpace the demand if the generation is not augmented. Based on the demand projections made in the 16th Electric Power Survey, over 1 , 00,000 MW additional generation capacity needs to be added by 2012 to bridge the gap between demand and supply of power.

The country is confronting the conflicting objects of providing power to all while on the other side it is facing acute power shortage. The Government of India has chalked out a massive Generation Augmentation Plan and Renewable energies have been identified as an important contributor.

1.4.2. Cooking Energy Needs

The main energy needs of the rural people is cooking, lighting, mechanical output in the form of rotating shaft for water pumping and grinding grains. Out of all these the cooking need is one of the most crucial one. Rural people largely depend upon fuel-wood, crop residues, and cattle dung for meeting the basic energy needs for cooking and heating purpose. The consumption pattern of energy for cooking need in rural areas of India reveals that 75.54% of people use fuel wood 10.62% dung and rest about 15% utilizes LPG, kerosene, coal and electricity. While the use of LPG, Kerosene, Electricity and coal constitute 70.60 % in urban areas. [53]. The use of fuel wood is associated with the drudgery in gathering and its adverse impact on the forest and village tree resources. Besides, the use of fuel wood is the cause of respiratory disease in females in rural areas. Wood, agriculture residues and cattle-dung cakes are the primary energy sources for cooking in rural areas. Traditional *chulahas* commonly used in rural areas, however are inefficient and environmentally undesirable. In contrast, improved chulhas are scientifically designed for optimal regulation of heat flow and better fuel utilization. Improved *chulhas* have heat transfer efficiency of 30-40% as compared to 10-12% in case of traditional chulhas.

The Government of India has launched a National programme on Improved Chulhas (NPIC) in 1985-86. Cumulative Achievement is over 350 lakhs improved *chulhas* up to 31st March, 2003 against an estimated target of covering 1200 lakh households in the country.

1.4.3. Mechanical Energy Needs

The major requirement of mechanical energy is in the form of rotating shaft to lift the water for irrigation and drinking water. In India there are four lakhs of irrigation pumps using electricity and fossil fuels. The electricity driven pumps consume fossil fuels as in India the major share of energy generation is from coal. In Himalayan region the use of pumps for water lifting is not common. The drinking and irrigation water needs are catered by gravity driven water supply system. However, the traditional water mill used for grinding grains in areas not connected with grid power is very common site.

1.5 STRATEGY OF ENERGY PLANNING

In order to finalize the strategy to mitigate the energy problem, it would be imperative to dwell on the various issues and concerns along with the challenges being confronted. The main issues are:

- To access to quality and reliable electricity to all household as it being identified as key input for the economic development of its people.
- To improve the per capita consumption of power. The Minimum lifeline consumption of one (1) unit per household per day as mandated in the National Power Policy.
- To provide access to energy for cooking and other needs which is not only cheap but also safe and convenient to use.
- To improve the efficiency of use of resources.

There are various challenges and risks associated with the indiscriminate use of fossil fuels to meet the energy requirements. Some of which are as follows:

Environmental degradation is the most daunting task confronted by mankind. The use of fossil fuel is identified as the main contributor in deteriorating it. Its use of at a much faster rate than they are created is releasing carbon stored in the fuels into the atmosphere and, thus upsetting the precise balance of carbon in nature. The release of carbon and other pollutants is causing the Global Warming. Similarly, the release of other pollutants like oxides of sulphur causes acid rains destroying the vegetation. The sustainability of life on earth is therefore threatened.

With increasing population, the consumption of fuel-wood has far exceeded its supply, thereby causing deforestation and desertification. Similarly, the age old practice of burning of cattle dung and crop residues for cooking purpose is depriving the agricultural lands of much needed manure and consequently causing loss of soil fertility. The inefficient burning of biomass fuel materials in traditional *chulhas* creates high level of in-door air pollution, which in turn causes eye and respiratory related diseases among women and children in the rural areas [53]. All these energy sources are available almost free of cost only the efforts are required to collect them. However, the social cost associated with adverse impact of its use is a cause of concern.

The country faces challenge to meet the cooking energy requirement of rural masses which is not only economical and convenient but also contribute to the improvement in environment.

Sustainability of energy for future use is another big challenge and concern. It is evident that at one side the country is facing the shortage of existing conventional energy resources which will not last much, while on the other hand there is a shortage of power. The gap between the two continues to be widening. With the increase in disposable income, households will tend to move to more from cheapest and least convenient fuels (fuelwood & dung) to more convenient and normally expensive kerosene and to most convenient and expensive LPG and electricity [53]. The shift of use from fuel wood and dung to fossil fuels for cooking need in rural areas, as popular in urban areas, will put additional strain on the country that is already running short of fossil fuels. It is therefore necessary to find ways or resources which will not only satisfy present needs but can be preserved for future generation.

Socio-Economic aspects of energy deprive a large people from use of energy even though it is available. The use of inflation prone fossil fuels to meet the energy needs of rural areas put the additional financial burden on the poor people inhabiting in rural area who would otherwise fulfill their requirement from the easily available fuelwood even though it depletes the forest cover. The financial burden can cause the migration of rural population to already overcrowded city leading to unpleasant conditions. The fulfillment of energy requirement to improve the economic condition rather than degrading it is the major challenge.

Security of energy supplies is necessary to the independence of economic growth. Our country is dependent on other countries for its energy needs. It imports coal- 6.25%, oil- 68.7%, and natural gas- 8.3% [14]. If the present trend of meeting the energy requirements from the import of fossil fuels continues the economy of the country will remain exposed to hazards of external price rise shock and supply fluctuations, which threaten the energy security and hence economic growth.

In order to meet the challenges of providing quality and reliable power at an affordable rate to all without jeopardizing the energy security and environment it is necessary to develop suitable strategies to meet above challenges. The various options are as follows:

i. Reduce dependence on import of fossil fuels by diversifying the energy supply using environmentally benign renewable energy sources.
ii. Improve end use efficiency by demand side management.
iii. Introduce energy efficient renewable energy conversion system.

1.6 INTEGRATED RENEWABLE ENERGY SYSTEM

The electricity being a critical input to the various activities of agriculture, industrial and commercial and its unavailability will have an adverse impact on the development of society. Rural areas are at a severely disadvantage in terms of availability of electricity. The extension of grid to rural areas is capital intensive and expensive. The installation of decentralized diesel generators is not only expensive due to higher fuel cost but also due to great transportation charges.

The renewable energies are available in a decentralized manner. They can, therefore, be developed for rural energy applications overcoming the shortcomings and drawbacks associated with the use of conventional fuels. However each of the renewable energies has unique characteristics. Most important of them is that their availability is site specific and some of them are available in highly diffused form. In addition to that the availability of some of these energies is time dependent and statistically variant. All these aspects pose challenges to the scientists, engineers and economists to develop these environmental friendly energy systems for the benefit of mankind. There lies the concept of Integrated Renewable Energy System. The strategy in IRES is to complement the shortcomings of one form of renewable energy with the strengths of other form considering their availability and energy demand. The integrated renewable energy systems (IRES) utilize two or more renewable energy resources and end use technologies to supply variety of energy needs.

A typical IRES system consists of two or more of the following: Wind energy conversion system (WES), Solar photovoltaic energy conversion system (SPV), Micro hydro energy conversion system (MHP), Biomass Energy conversion system (BES), Biogas Digester (BGS), Solar Thermal collector and energy storage devices [35].

The diverse characteristics of the renewable energy resources to the widely varying rural needs can be matched by integrating energy system. The integration approach can be cascaded and tandem. In cascade approach, the energy from a resource is utilized to meet certain requirement and the energy rejected after use which is usually in form of low-grade heat can be used to satisfy other demands. A typical example of cascaded system is shown in figure 1.7. Where the dilute solar energy is concentrated and first used in heat engine to generate electricity. The medium grade heat rejected by the heat engine can be used for water heating, space heating, cooling and maintaining temperature of biogas plant. In the tandem approach, several of energy resources are integrated to meet the several energy needs. A typical arrangement of same is shown in figure 1.8.

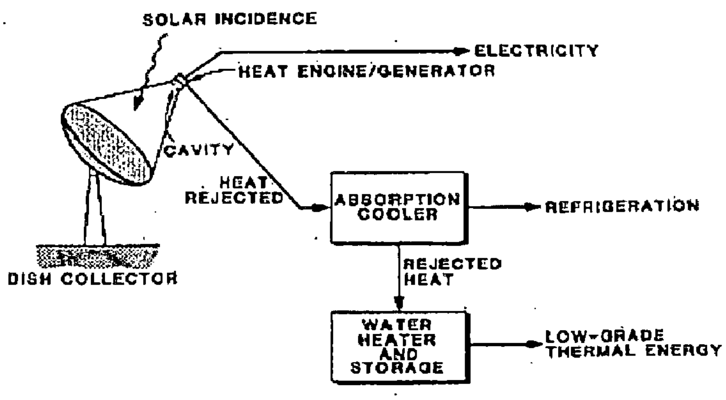


Fig. 1.7: Schematic of a Cascaded Solar System [34]

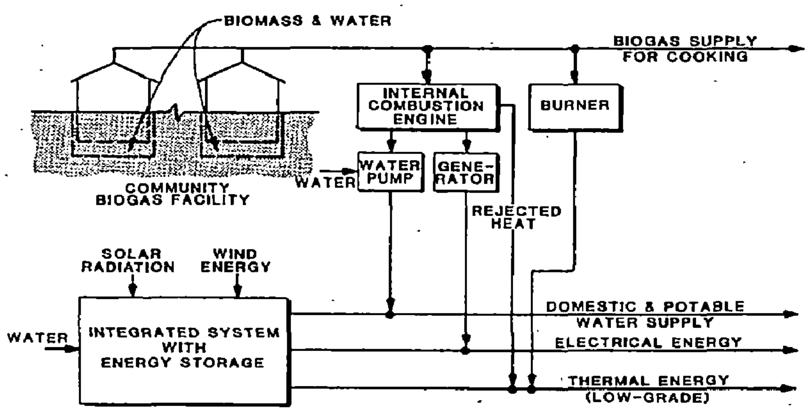


Fig. 1.8: A Typical Schematic of Integrated Renewable Energy System[34]

Two approaches can be applied for the utilization of renewable energy resources as proposed in the work of Ashenayi [34-35]. In the first approach, one form of energy is selected as the form, which is to be made available to the consumers (usually electrical). All the available resources are then converted to this form for storage and supply to the consumers. The second approach advocates the prior matching of resources and needs and achieves the integration of benefits. In the latter, the overall efficiency of utilization of is minimized. For example, Instead of converting hydro energy to electrical and then use electric motor to convert to mechanical power for water lifting, the rotary energy can be directly used for pumping needs.

1.7 LITERATURE SURVEY

Global environmental concerns and the ever-increasing need for energy coupled with steady progress in renewable energy technologies have opened up new opportunities to harness different forms of renewable energies. The renewable energies have tremendous potential to satisfy the needs of rural areas where these resources are in abundance. It is very important source of energy for the people of remote areas as they have no access to commercial fuels and facilities of the grid power.

The economics of standalone PV power system is studied to test feasibility in remote and rural areas of Bangladesh. It is observed that the life cycle cost of one unit of energy from the grid that is that is one km away from the village is much higher than the cost of energy from the PV system [38].

The studies carried out in Nigeria options to provide power to remote areas by solar powered system is compared with the conventional Diesel generator plant and connection to National grid. It is revealed that PV systems are most economically viable and least cost option per annum. [31]

Kellog, [61] has proposed a generation capacities of wind and PV system based on annual average hourly load profile, average hourly wind speed data and insolation. A battery bank is used in his system, which is sized to the capacity equal to the difference between positive and negative peaks. The periods of time with no wind and / or insolation is not taken into consideration and to account for such situation a back up diesel generator is provided. In his method the size of WECS is fixed based on the available resources and commercially available size then number of panels is increased until balance is reached.

Bogdan S. Borowy and Ziyad M. Salameh [13] have developed a methodology for optimally sizing the combination of a battery bank and PV array in a hybrid wind/ PV system for a given load and level of reliability. It is based on long term data for both wind speed and irradiance. The study is based on the perception that for stand alone applications storage cost represents the major economic restraints.

Tomas Marvart [60] described a procedure to determine the size of an array and wind turbine in a PV/ wind energy system using the measured values of solar and wind energy at a given location. A graphical method is used to determine the optimum configuration of the two energy conversion systems that satisfies the energy demands of the user throughout the year.

B.Wilchert [10] has reviewed the current state of design and operation of stand alone PV-Diesel hybrid energy systems and stressed the use of IRES/Hybrid energy system and there is a need for further improvement of the design and operation of it.

Bogdan S. Borowy and Ziyad M. Salameh [12] has further evolved a methodology for calculation of the optimum size of a PV array for a stand alone hybrid wind system using long term data of wind speed and irradiance. Using these data probability density function (pdf) have been formed and average power generated by the wind turbine and PV module is assessed based on manufacturer's specification of used energy conversion systems. The least square method is used to determine the best fit of the array and wind turbine to a given load and algorthim was developed to find the optimum size of the PV array system.

Several approaches have been proposed by several researches to optimize the cost of energy generation from IRES. Rama Kumar [50] has employed linear programming approach to design IRES that minimizes total annual cost.

Rama Kumar [49] explained the role of renewable energy sources in meeting the energy needs of developing countries. He has presented and discussed the technical and economic aspects of small scale decentralized integrated renewable energy system concepts for harnessing renewable energy sources in rural areas of developing countries. The author has proposed integrated renewable energy system concept of matching diverse energy needs of rural people employing cascade and tandem approach. The economics of cost of using conventional fuel with that of renewable system has also been compared.

B.C.Jain [9] has articulated a concept of "Integrated Rural energy center" based on renewable energy sources. The concept aims at meeting all the energy needs of all the people of rural community. In the paper the experience of implementation of IRE concept has been presented, which is based on methodology evolved for meeting various energy needs of rural areas of an Indian village from the available renewable technologies. It is inferred that Rural energy centers save money in the long run.

Santosh Rana and Rama Chandra [57] in their paper have attempted to evolve different strategies to satisfy the electrical energy demand of various villages at minimum cost by utilizing renewable energy resources to make them self sustainable in the wake of large investment and losses in grids. He has selected 83 villages of Madhya Pradesh in India for his study and six combinations of PV, Biogas and Gasifier to justify the use of renewable energy without disturbing the forest cover, cooking requirements or fertilizer applications. He concluded that the unit cost is less for villages having good potential of dung and is most where large portion of demand is to be met by PV technology.

K.Ashenayi [33-34] in a bid to minimize the initial capital investment cost has used a probabilistic approach, which utilizes the loss of power supply probability (LPSP) concept. The LPSP is utilized to minimize the initial capital investment while supplying the energy needs at a given level of reliability. A computer programme IRES has been developed utilizing the above concept.

A knowledge-based approach has been used to develop a computer program"IRES-KB" by R. Ramakumar [47]. His approach is based on concept that integrated renewable energy systems usually consists of several interconnected energy conversion technology and system performing together to satisfy a set of energy needs. These energy conversion systems together with the energy storage and re-conversion systems can be used to satisfy any of the energy needs, of course, subject to the availability of resources. However, some of the resource- need combinations are more logical than others because of the cost and efficiency considerations. In his paper a design approach orders, prioritize, matches and finds ratings of various energy conversion devices and sizes different energy storage components required.

E.S.Gavanidou and A.G.Bakirtzis [18] applied multi objective planning under uncertainty in the design of standalone system with renewable energy sources. The design is accomplished that is a reasonable compromise between the conflicting objectives. Like conflicting objectives of minimizing total cost and manimizing loss of probability, both cannot be achieved simultaneously. The author has demonstrated a method of trade off between such two conflicting objectives. The method does not find a unique solution but number of solutions the plan with inferior attributes can be eliminated leaving a small number of plans, which represents reasonable compromise.

S. Iniyan [54] has proposed reliability based socio-economic optimal renewable energy model (OREM) for India. In OREM developed for 2020-2021 the objective of minimizing cost/efficiency ratio has been based on reliability, social acceptance, potential and demand constraints.

A.K.Akella, M.P.Sharma, R.P.Saini [1] has presented a case of optimum utilization of renewable resources using IRES for a Jaunpur block of Uttaranchal in India, which can satisfy the energy needs of an area in appropriate and sustainable manner. He has used a concept of effective power delivery factor (EPDF), which is defined as ratio of power obtained per season to the maximum power available per season. The EPDF is used to improve the life cycle cost of the system. He has also made an attempt to integrate the hydro energy resource with other renewable enrgy system

A. Rajendra Prasad, E. Natarajan [5] in his paper has proposed new method for optimization of a wind-PV integrated hybrid system based on deficiency of power supply (DPSP), relative excess power generated (REPG), unutilized energy probability (UEP), life cycle cost (LCC), levelized energy cost (LEC) and life cycle unit cost (LUC) of power generation with battery bank. A simulation software code has been developed to carry out the analysis for optimizing the size of the integrated system for a site Pompuhar, Tamilnadu in India.

It is concluded from literature survey that very exhaustive studies have been carried out in mant countries with the prime focus on cost optimization of renewable energy and integrated renewable energy sources consisting mainly Solar, Biomass and

Wind. Most of the literature deals with the wind and photovoltaic system with focus on electricity requirement of the rural areas. Very few literature deals with the integration of needs with the integration of renewable energy sources Further, the incorporation of micro hydro in the Integrated Renewable Energy system is further less due to its site specific availability. *Himalaya* region, right from Kashmir to Arunachal Pradesh, is very rich in hydropower resources. There are more than 5 lakhs water mills in the Himalayan region [27]. These watermills offer excellent opportunity to provide electricity and mechanical energy to the villages [4]. There is considerable potential for electrification of remote villages using small-scale hydro power systems small scale and as a result such schemes exist in most of the developing countries. However their contribution to rural electrification is negligible. [24]

1.8 PROBLEM STATEMENT

Electricity and energy supply at globally competitive rates would also make economic activity in the country competitive in the globalized environment. The aim is to satisfy the energy needs of remote villages in cost effective, reliable and appropriate manner by a stand-alone renewable energy conversion system/ systems. One of the fundamental problems in the use of locally available Renewable Energy Systems is that there are varieties of resources that are required to meet variety of energy needs. The multiplicity of rural energy applications and the multiplicities of the renewable energy conversion technologies together with their associated characteristics such as, availability of energy in dilute form, time dependent, site specific and statistically varying, make the use of renewable energy system very difficult to conceive. One of the suitable approaches is by integrating these energy resources which is termed as Integrated Renewable Energy System (IRES). The commonly used renewable energy resources available in rural areas are:

- i Biomass
- ii Hydro energy
- iii Wind energy
- iv Solar energy

The main energy needs of the villagers are:

- i Medium grade heat energy for cooking
- ii Rotating mechanical shaft energy
- iii Electricity at 240 Volts

The demand can be met either by converting all form of energies to a single form (say electricity) and then reconvert to the utilizable form of energy for end use. But there will be loss of energy in each of the conversion and result in suboptimal utilization of precious resources. The utilization of resources can be done in a manner that demand of energy for each of the tasks is met by the resources which has the lower cost and higher conversion efficiency.

The availability of renewable energy resources has peculiar relation with the efficiency of various renewable energy conversion systems. The source that is available universally and free of cost like solar has very low collection efficiency while the system like hydro that is highly site specific has higher efficiency. Only the wind and Biomass resources have moderate efficiency. However, wind is highly stochastic only Biomass having moderate efficiency is available in moderate quantity. None of these resources is found to be able to fulfill all the energy needs of rural areas because of scarcity. The renewable energies are meager and therefore required to be utilized in most efficient manner in order to maximize the amount of energy annually produced from the available resources. This is particularly more important in a resource starved area and the objective is to exploit the highest possible energy potential of the area in order to cover the local demand.

1.9 AIMS AND OBJECTIVE OF STUDY

The basic aim of the study is to develop a cost effective technology system for harnessing renewable energies in remote areas to aid sustainable growth, achieve rising prosperity and a better quality of life. The system should not only be reliable but cost effective too.

1.10 METHODOLOGY ADOPTED

The steps adopted for addressing the objective are as follows:

- Selection of Village: As such definition of remote villages have not specified in the literature studied and no criterion has been categorically stated by Government of India for the identification of 18000 remote villages, which are to be electrified by renewable resources. For the purpose of study, the village that is far from road communication and not connected with grid is considered remote. Accordingly, a village is selected where there is enough scope of renewable resources and has characteristics to truly represent the area in terms of accessibility, socially, economically and geographically.

- Assessment of the Resources: The assessment of resources has to be seen in the context of benefit expected to accrue. The availability of long term data on solar, wind and hydro requires a good amount of time and financial resources. The benefit expected to accrue may not outweighs the cost spent on collection of data. At the same time it should be ensured that the compromise on accuracy and consistency of data in the pretext of cost involved in collection should not lead to the development of system which is over size or under size. As the collection of data for wind and solar is costly and time consuming the data of nearest wind monitoring station can be taken for wind energy potential assessment. Similarly for solar the long term data of the nearest area is available in literature. The assessment of biomass potential is made from the survey of cattle population carried category wise and sample survey of types of crop cultivated and their production. The quantity of dung excretion and its production potential of biogas is assessed by population of cattle. Similarly, the agricultural residues can be assessed by co-relating the agriculture land with the crop cultivated and their productivity. Hydro power potential is assessed measuring head and discharge.
- Assessment of energy consumption pattern and quality of energy required: The assessment of electrical load is carried out first by assessing average number of rooms available per household that has been determined by doing a sample survey of different sizes of households. The requirement of electricity is related to number of rooms and the commonly used appliances. The requirement of energy for cooking assessed by research scholars is available in the literature.
- Identification of Renewable Energy technologies: The renewable resources available in the area guide the selection of renewable energy technologies. Based upon the collected data, the unit cost of energy of each resources calculated. The efficiency for various resource need combination is also determined.
- Formulation of IRES model: Integrated Renewable Energy System (IRES) model is formulated based on objective selected for optimization. The approach employs a linear programming technique for the design of integrated renewable energy systems. The technique is based on minimizing an objective function

subject to a set of energy and power constraints related to resource availabilities and load requirements.

- Optimization: Based on the objective function and constraints, the IRES models is optimized using TORA SOFTWARE for solving linear equations. The optimization will yield optimum allocation of quantum of resources required to fulfill the energy needs in a way to utilize the available resources in most cost effective and efficient manner.
- Assessment of availability of the standard equipments suitable for the rural area needs is made and compared with the availability of the sizes of equipments selected for the area.

1.11 OVERVIEW OF THE THESIS

The thesis will comprise in six chapters.

Chapter 1 describes an introduction of energy, global and Indian energy scenario, renewable energy sources such as micro hydro, solar, wind, biomass, etc. and the energy needs of rural areas. The issues and concerns along with the challenges confronted in this sector have been presented in the Indian context. The concept of integrated renewable energy is also discussed. Review of literature related to renewable energy with emphasis on IRES is carried out. The objectives and methodology to be pursued to approach the problem are also discussed. **Chapter 2** articulates various renewable energy systems that can be applied to fulfill the energy needs of the remote village. **Chapter 3** provides a profile of the village of study in which the detail description of the village such as location, altitude and accessibility. It also covers the potential assessment of renewable energy sources and the load estimation of the village. **Chapter-4** deals with the estimation of efficiency of various resource need combinations and assessment of unit cost of energy. The size is compared with the readily available ratings of the equipments so as to configure renewable energy system for energy needs of remote village. **Chapter 5** focuses on the optimization model of integrated renewable energy system and cost of energy **Chapter 6** Concludes the main findings of the study with the suggestions for further studies.

1.12 CONCLUSION

Poor rural households and poor farmers are among the populations most in need of reliable electricity. The current state of electricity services across India can be said to be acute, if not in a crisis mode. The immediate manifestations of this crisis are severe shortcomings in: a) access to electricity for rural and urban poor, b) generation capacity that cannot meet peak demand and c) reliability of supply, in terms of predictability of outages and quality of power supply.

The generation, transmission, and distribution of electricity have been afflicted with problems. Shortages in energy demand and peak power demand have been around 9% and 14%. India, with an average annual per capita energy consumtion of 435 kWh, is far behind countries such as China (1378 kWh), Malaysia (3060 Kwh), and Thailand (1751kWh) for year 2003 [30]. Transmission and Distribution (T&D) losses in India have risen from around 35%. In countries such as China, Malaysia, and Thailand, they are less than 10%.[60] The additional generation capacity that will be needed over the next five years if this accelerated pace of rural household electrification is maintained and for sustenance of economic growth would require about one lakh MW capacity addition over the next. An addition of required generation capacity in the next five years amounts to about 20000 MW/year. This new capacity would have to be planned for, whether it comes from conservation, reduced losses, higher PLF, or new power plants. Fossil fuels will not last much. Only 17% of the enormous hydel potential of 1,50,000 MW has been tapped so far. While hydel power plants are capital intensive and can have adverse environmental fall-out if not designed properly, they have low recurring costs, are pollution free, and provide a way to lower India's dependence on imported fuel, the share of hydel generation has dropped from around 44% in the early 1980s to 26% in 2001-2002. The pace of harnessing the renewable energy sources is very slow despite of its high potential. So far only 10252 MW of the estimated renewable energy potential of 133000 MW has been harnessed which is about 1 % of the potential. It is therefore can be inferred that successes in electrification and energy needs can be achieved by harnessing of renewable energy sources.

CHAPTER-2

RENEWABLE ENERGY CONVERSION TECHNOLOGY SYSTEMS

2.1 GENERAL

The renewable energy sources such as falling water, biomass, wind, solar energy can be utilized for fulfillment of various energy needs. As already discussed in chapter -1 that each of these renewable energy sources has different characteristics and different energy conversion systems are required to use them. In order to take utilize them most effectively the integration of these energy is one of the appropriate ways and therefore it is necessary to understand characteristics and limitations of each of them. The various such systems have been described in this chapter.

2.2 SMALL HYDRO POWER SYSTEM (SHP)

The small hydro power is one of the most cost effective ways to harness the energy available in nature in the form of falling water. There are many benefits of this form of energy conversion system. The prominent amongst them are that it is environmental friendly, cheap, free from inflation and has very less gestation period.

In the Himalayan region of India the harnessing of water power is used since time immemorial as a source of energy to grind flour. The device make use of the falling water through the chutes and is popularly known as "*GHARATS*". These Gharats have very low efficiency, sluggish and requires high maintenance. As a result of which most of them are not in working condition in the original form. It has been replaced by the electricity driven flour mills except in very remote areas where grid penetration is not there. These Gharats, if converted to generate power by installing hydro generating equipment, can be an excellent source of generation of electricity.

2.2.1 General Features of SHP

There is no globally accepted standard criterion of classification of small hydro power. Different countries have categorized small hydro power in different capacities. In India the upper limit of SHP is 25 MW and break up of further classification is provided in the table 2.1. Whatever may be the criterion of categorization the components of small hydro power do not differ much which is shown in figure 2.1. The components can however be categorized in two sub-heads: Civil works and Electro-Mechanical works.

Table 2.1: The Classification of Small Hydro Power in India[8]

TYPE	STATION CAPACITY	UNIT RATING
Pico	Upto 50	Upto 10 kW
Micro	Upto100	100 Max
Mini	Upto 2000	101 to 1000
Small	Upto 25 MW	1001 – 5000

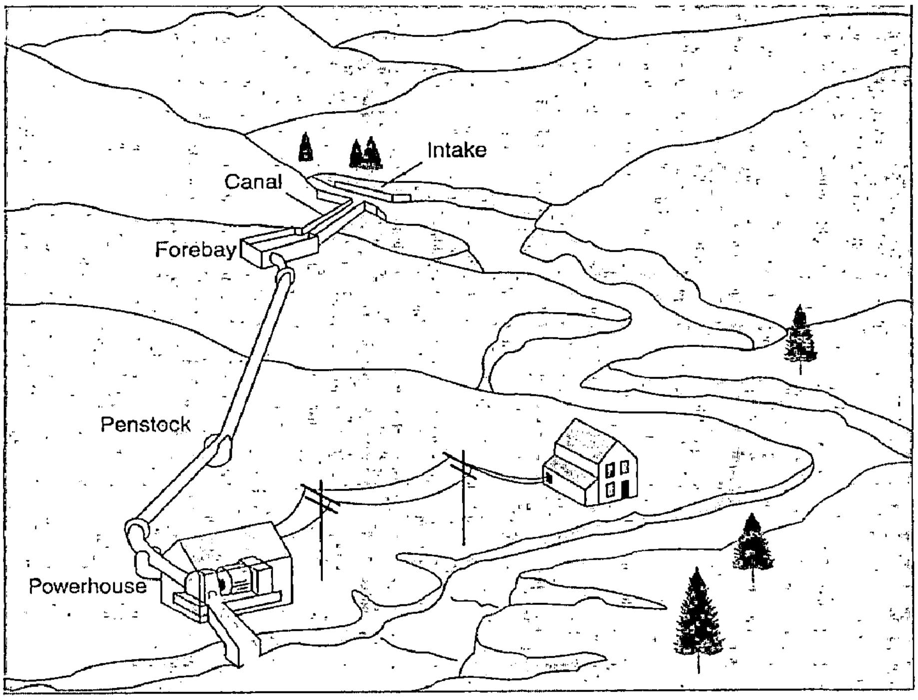


Figure 2.1: Illustration of Principle Components of Micro Hydro Power Site [7]

2.2.1.1 Civil Works

Weir is used to ensure the adequate flow of water to the intake and power channel a diversion structure of temporary or permanent type called weir is constructed. It might either channel the flow toward the intake or simply provide the required depth of water at intake fro flow to enter on its own. Where the stream bed is susceptible to erosion, a weir maintains the level of the stream bed constant near intake. Otherwise stream bed might erode so badly that the stream eventually will lead too low for water to enter the intake.

Intake permits a control flow of water from the river or stream into a power channel and penstock which eventually takes it to the turbine to generate power. The uncontrolled water if allowed to enter can cause damage to the other structures downstream.

Power Channel is a component of hydro power scheme that is used to convey water from the stream to the inlet of the penstock with minimum loss of head and minimum cost. These power channels are mostly built by excavation of soil and lined or constructed with concrete or other impervious materials to reduce seepage of water which eventually leads to increase flow and velocity. Sometimes in place of open channel closed conduit or tunnel is also made but this all depends on techno-economic aspects.

Settling basin is constructed to remove the sediment which might otherwise settle in any of the down stream civil structures through which it passes. This will eventually lead to reduced flow for power generation. The sediments if allowed to pass through the turbine can cause rapid wear and reduce operating life of turbine.

Forebay is a basin located just before the entrance of a penstock. It can be an excavated area or pond. Forebay provides enough storage to cope with the water demands created by sudden load increase and load rejection. It has several components such as spillway, scouring gate, trash racks, etc.

Penstock is a pipe that conveys water under pressure to the turbine. Penstock can be installed above or below the ground. Steel is the most commonly used penstock material but concrete, wood staves, High Density Poly Ethylene,etc are also used extensively.

Power House protects the turbine, generator and other electrical and mechanical equipments. The size of the power house should be convenient enough for the equipments, work space, etc. For micro hydro power it is enough to have power generating equipment with sufficient space on all sides to permit easy access for installation, operation, maintenance and repair.

Tail Race is usually short, open channel which leads the water from power house to the stream without coasing damage to the downstream topography.

2.2.1.2 Mechanical and Electrical Works

Turbine is a prime mover which converts the mechanical energy of falling water to the motive power that can be utilized for mechanical energy or electrical energy needs. There are large kinds of turbines designed to match the different combination of head and discharge. The turbines can be classified in two categories on the basis of principle of operation: Impulse and Reaction turbines.

The Impulse turbines which include Pelton, Turgo Impulse and cross flow utilizes the kinetic energy of the falling water through the jet to rotate the runner to obtain motive power. While reaction turbines such as Francis and Kaplan turbines utilize pressure and kinetic energy of the falling water to generate power.

The specific speed for a power available at a site is the prime criteria for determination of choice of turbine which depends on values of discharge and head. The specific speed of a turbine is defined as the speed of a geometrically similar turbine generating unit power while working at unit head. There are, however, other factors that affect the choice of turbine. Efficiency is one of them. The efficiency of about 85 to 93 % has been achieved in modern turbines but the efficiency of small turbines continues to be low.

Generator is coupled directly or through speed increaser to obtain turbine output in the form of electrical energy. There are two types of generators used commonly: Induction Generator and Synchronous Generator

Induction generators require external excitation. It is basically used for synchronizing with the grid but can be used in isolated conditions by installing capacitor of suitable size. The efficiency of Induction generator is however lower than that of a synchronous generator. The synchronous generators are expensive due to the requirement of exciter system. The output voltage and frequency of the generator are guided by the national standards. In India standard frequency is 50Hz and voltage 240V.

Auxiliaries depends on the size of the system. Smaller size turbines need not load with much sophisticated control and protection system. While in large system connected to grid required all sort of protection and control system as guided by code IEC 1116.

2.2.2 Flow Measurement and Analysis

The micro hydel units are normally installed on very small streams or rivulets where flow data are not readily available. The discharge data in the potential site for hydro generation unit can be taken using variety of standard methods depending upon the accuracy required and cost involved. Some of which are mentioned below :

i. Flow measuring structures such as notches, weirs and flumes.(IS:1193-1959)
ii. Velocity area method (IS:1192-1959): use of current meters.
iii. Slope area method (IS 2912-1964)
iv. Salt dilution method.

The daily flow is measured for at least two years for setting up a micro hydro plant (MHP). But that depends on trade off between accuracy of data required and the cost involved in obtaining that data. It should be seen that cost of obtaining data should not be so high that it affect the financial viability of the project.

The flow data are then analysed to obtain the flow duration curve, which is required for sizing of the capacity of hydro power plant. The flow duration curve represents the percentage of time the flow exceeds or equals a certain value. The governing equation of power potential assessment for a site is give by expression 2.1.

$$P = 9.81 \times Q \times H \times \eta_o \qquad 2.1$$

2.3 Biomass Energy Conversion System

Biomass is name given to the plant matter which is created by photosynthesis in which the sun's energy converts water and carbon oxide into organic matter. In other words all organic materials that originate from plants are termed as biomass. These include firewood plantations, agricultural residues, forestry residues, animal wastes, etc.

The energy that is stored in plants and animals (that eat plants or other animals) or in the wastes they produce is called biomass energy. This energy can be obtained by various ways. Combustion is one such process where biomass releases heat and carbon dioxide that was absorbed while the plant was growing. This process is reversal of photosynthesis. The biomass energy is the renewable energy that does not add carbon dioxide to the environment in contrast to the fossil fuels.

2.3.1 Biomass Resources

The rural energy needs in India are predominantly met by biomass. Among the households cooking is the major energy consuming activity. Biomass available in India comprises agricultural residue like rice husk, rice straw, bagasse, coconut shell, jute, etc.

Forest residue such as logging residue, trees, shrub residues and Aquatic plants such as algae, water weeds and water hyacinth are also included in biomass. Agricultural processing and production wastes form a large chunk of biomass energy. Biomass may be obtained by cultivation of energy plants.

2.3.2 Constraints & Benefits of Biomass

The availability of biomass is in scattered form and has a low bulk density. In order to use it is required to be transferred to the area of use which is very costly and difficult to handle. It is therefore economical to have the biomass energy conversion system at the point of use.

The incomplete combustion of fuel wood produces organic particulate matter, carbon dioxide and other organic gases. The above phenomenon is more pronounced in an inefficient conversion system. Besides, it is believed that use of forest will cause deforestation and shall have serious environmental impacts. However, it is widely accepted that the urbanization and conversion of forest land for agricultural use have done more harm to forest than other activities.

In spite of above factors some of the important benefits of use of biomass are as follows:

i. Biomass is renewable, potentially sustainable and environmentally benign source of energy. If grown and utilized in sustainable manner the energy production with biomass will result in a net reduction of GHGs gases.
ii. The natural decomposition of biomass produces Methane which is 20 times more active than carbon dioxide. There is therefore additional benefit in utilizing biomass.
iii. Biomass has negligible sulphur content in comparison to its availability in fossil fuels and therefore causes less pollution. The combustion of biomass produces less ash than coal and it can be added to the agricultural field as additive unlike that of ash of coal which faces disposal problem.
iv. The use of urban waste as biomass energy solves its disposal problem
v. Biomass is available locally and therefore not affected by international price fluctuations and offers energy independence
vi. It is available and used locally so generates employment and prevent flux of population to cities.

2.3.3 Biomass Conversion Processes

Biomass energy can be produced by various processes and technologies. However these can be categorized into two broad categories.

Biological

i. Anaerobic Digestion

ii. fermentation

Thermo Chemical

i. Combustion

ii. Pyrolysis

iii. Gasification

iv. Liquefication

2.3.4 Anaerobic Digestion

The product of anaerobic digestion is combustible gases called biogas and a value added fertilizer sludge. The process is carried out under a set of controlled conditions. The burning of cattle dung cakes/ crop residues for cooking deprives the agricultural lands of much needed manure and consequently resulting in lower soil fertility. Besides, this inefficient burning of these biomass materials in traditional devices creates high level of indoor pollution, which in turn causes respiratory diseases among women in rural areas. Therefore it is necessary to promote biogas technology to produce biogas for cooking fuels without destroying their manorial value.

Anaerobic digestion of biomass involves bacterial decomposition in three phases -The hydrolysis phase, acid phase and the methane phase. In the hydrolysis phase the break down of large molecules of substrate into smaller and simpler molecules is carried out by the bacteria. During the acid phase, complex molecules such as proteins, fats and carbohydrates are broken down by acid forming bacteria into organic acids, CO_2, hydrogen, ammonia, etc. In the final phase, the acids formed in acids phase are converted into methane and carbon dioxide along with some hydrogen.

In a biogas plant all the three phases occur simultaneously and if any one phase dominates the production of methane is adversely affected. This is especially true for the acid forming phase. Too much of acidity will prevent the methane producing bacteria from functioning. The theoretical recommended value of pH is between 6.8 to 7.2 pH. There are four groups of methane producing bacteria. All these are sensitive to temperature with optimum requirement of 35^0 C.

The composition of biogas depends on the composition of feed. A typical composition of biogas is shown in table 2.2.

Table 2.2: A Typical Composition of Biogas [8]

Component	Composition(Vol%)
Methane	50-60
Carbon Dioxide	30-40
Hydrogen Sulphide, Nitrogen & Ammonia	In Traces
Hydrogen	2-3

2.3.4.1 Operating Parameters

The Organic Loading rate for biogas plant is about 1.2 kg total solids per meter cube. For a given capacity of digester if the loading rate is increased the period of retention is correspondingly curtailed.

Solid Concentration of the feedstocks of 7-9% (weight/ volume) is considered ideal. Higher concentration retard fermentation process and lower concentration gives poorer fermentation. A mixture of four parts of dung and five parts of water gives the solid concentration to about 8%.

Retention period of feedstocks inside the reactor is between 30 to 45 days and goes upto 60 days sometime. It depends on the feedstock charactreristics and variety of other factors.

2.3.4.2 Types of Biogas Plants

There are basically two types of popular designs of biogas plants. They are floating dome type (KVIC model) and Fixed dome type (Janata model). A number of other types of biogas plants are also available.

KVIC Model (Moving dome type) plants are characterized by floating metal drum at the top which acts as a gas holder. A typical schematic of such plant is shown in figure-2.2. It consists of a circular pit with a partition wall, an inlet pipe to feed the substrate and another pipe for expulsion of slurry. The floating dome is with central guide and gas delivery pipe. The weight of gas drum provides a constant pressure of 0.1 m of water column.

These plants are daily fed digesters. As material is poured in through the inlet pipe an equal amount of digested slurry is displaced through the outlet pipe. A partition wall makes sure that the portion of most fermented slurry is pushed out.

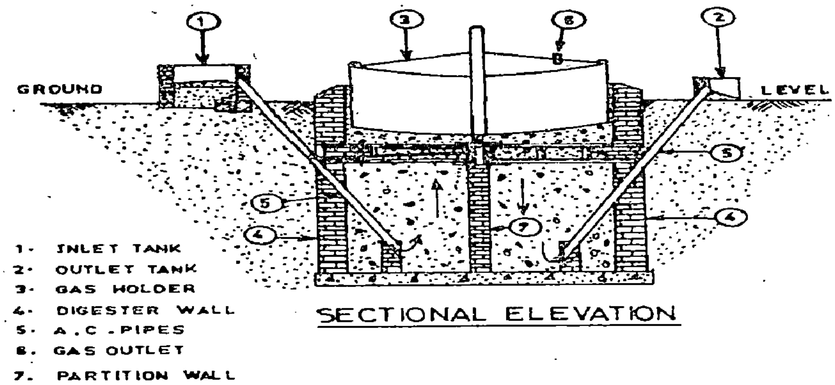


Figure 2.2: A Typical Moving Dome Type Biogas Plant [35]

Janata Model (Fixed dome type) is a fixed dome type with no moving parts as shown in figure 2.3. It is an entirely a masonary structure. It dispenses with the use of steel gas holder. Both the digester and the gas holder form a combined unit. Other parts namely gas outlet, inlet, etc. are common in both the types of biogas plants.Dung slurry is allowed to ferment in the digester. When the gas is formed it rises upwards and the pressure pushes the slurry downwards and causes its diffusion into the inlet and outlet pipe and chambers where slurry levels go up. The displaced level of the slurry provides the necessary pressure pushing the gas up to pressure ranging from 0 to 90cm of water column.The diameter and height ratio of the digestor is normally kept 1.75:1. the volume of dome is kept 60% of the plant capacity.

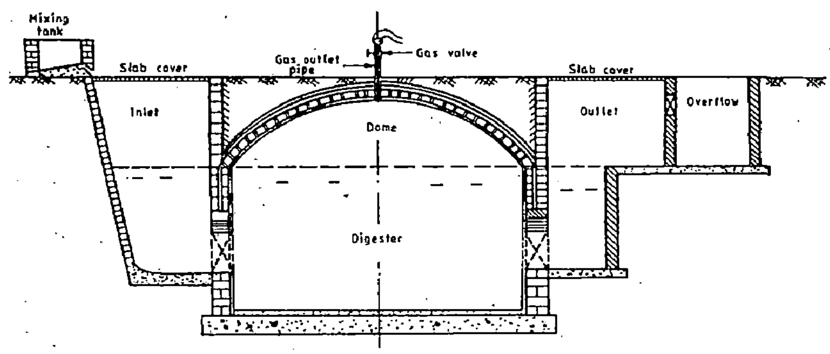


Figure 2.3: A Typical Fixed Dome Type Biogas Plant [35]

Large Community Biogas Plants are economical due to economy of scale involved in its construction. Besides, these digesters are less prone to the fluctuations of temperature and feedstock composition.

2.3.4.3 Application of Biogas

The biogas can be utilized for household cooking, lighting and operating small engines Two types of engines spark ignition petrol engine and diesel (compression ignition) engines are used to generate electricity using biogas as fuel. A spark ignition petrol engine can be operated on 100% biogas. It is, however, common practice to use pilot petrol fuel for starting. The biogas is simply introduced through the air intake pipe either through a venturi, without any modification in the carburetor or by replacing it by the gas carburetor, if the engine is to run continuously on petrol. Owing to higher cost involved in large size petrol engines and costly fuels, these engines are not economical for large scale electricity production applications.

In diesel (compression ignition) engines, the injection of pilot diesel fuel during compression stroke is necessary to ignite the gas mixture and to ensure the normal running of the engine. Once the engine is started using pilot fuel, the biogas is simply connected to the air intake port of the diesel engine. The engine automatically substitutes diesel upto 75-85% with biogas & remaining 15-25% diesel continues to be used by the engine. Thus, these diesel engines continue to run smoothly in duel fuel mode. The diesel engines, being sturdy in nature and easy to maintain, is easily available in the market compared to petrol engines. Further, the diesel engines do not require any modification as compared to petrol engines which are highly costly, if engines of the same capacities are compared. Therefore diesel engine generating set suitable to operate in dual fuel mode is one of the cheaper alternatives for the production of captive power using biogas as the main fuel & diesel as pilot fuel. These engines are now-a-days more popular & prevalent due to their costs & relatively cheaper diesel fuel and form the basis of agriculture & industrial sector for power requirement.

2.3.5 Gasification

The gasification implies converting a solid or liquid into gaseous fuel without leaving any solid carbonaceous residue. The feedstock for gasifier is a variety of biomass such as agricultural residues, agro-industrial residues and forest waste. The major agro–industrial residues include bagasse, rice husk, molasses, ground nut sheels, saw dust, etc. Its main feed is residual byproduct of many of the agro related industries. In the biomass gasifier a solid fuel is converted to a gaseous fuel (Producer gas) by a series of thermochemical processes such as drying, pyrolysis, oxidation and reduction. If atmospheric air is used as the gasification agent the producer gas will consist mainly of carbon mono-oxide, hydrogen and nitrogen. A typical composition of gas obtained from wood gasification on volumetric basis is shown in table 2.3

Table 2.3: A Typical Composition of Producer Gas [8]

Component	Composition(Vol%)
Carbon mono-oxide	15-22
Hydrogen	13-19
Methane	1-5
Heavier Hydrocarbons	0.2-0.4
Carbon dioxide	9-12
Nitrogen	45-55
Water vapour	4

The calorific value of this gas is about 900-1200kcal/Nm^3 this gas can be used for generation motive power either in dual- fuel mode or in petrol engines with some modifications. Engines operating on a spark ignition system can be made to run entirely on producer gas, whereas those using compression ignition systems can be made to operate with about 60-80% fuel oil replacement by the gas. The gas can also be burnt directly for heating applications such as cooking, heating water and space heating, drying of agricultural and industrial products.

Development work on biomass gasification was started in the country in early eighties and initially involved a few educational / R&D institutions (notably Indian Institute of science, Bangalore and Jyoti Solar Energy Institute, Vallab Vidyanagar and one or two private industries. With the passage of time, the efforts remained at low key until Ministry of Non Conventional Energy Sources (MNES) decided to give it a major thrust in 1986-87.

2.3.5.1 Types Of Gasifiers

Most of the gasifiers developed earlier were based on coal or peat or wood charcoal while the recent thrust is to develop reactor system suitable to utilize agricultural and forest residues or wood chips obtained from energy plantation programmes as feedstocks. The design characteristics of the reactor would depend upon biomass characteristics because biomass contains much more oxygen and hydrogen than coal.

Updraft Gasifiers also known as counter-current moving bed reactor having oxidation zone at the bottom and reduction zone just above it. Moving upward comes pyrolysis and drying zone. Its advantages are simplicity of operations that no solids flow rate control is necessary and that there is internal heat exchange of the products. Its disadvantages are that large amount of tars are produced, because the gase do not pass through high oxidation zone temperature and uncracked tars and oils remain associated with outgoing gases. Also channeling due to sticking tarry particles may occur, necessitating the use of rotating grids. Pelletising of fine biomass may be necessary for the preparation of feedstock for the gasifier.

Downdraft Gasifiers occupies the best position from the point of all merits and demerits. This type of reactor is simple to operate, produces an almost tar free product gasses because the pyrolysis gases are passed through high temperature oxidation zone where all bigger molecules of tar and oils are cracked to smaller molecules of gaseous products. It has high product gas temperature greater than 700^0 C and can also require feedstock pelletisation.

Cross Draft Gasifier occupies the position between up draft and downdraft gasifier and produces tar free gases and molten ash due to the prevailing high temperature conditions. However, the process is complex in operation. The gasifier requires powdered biomass and extensive heat exchange. Such type of gasifiers has been very few in operation.

Fluid Bed Gasifiers can handle wide range of feedstocks but has a high product gas temperature (example 900^0 C) with minimum tar production, limited solid conversion, severe particle entrainment and is more difficult to operate (solid flow rate control, etc). This type of reactor is suitable for high material such as chopped straw, saw dust, coffee husk, rice husks, etc. Because of turbulent mixing of fluid bed reactor the capacity is usually a function of the volume of fluid bed. The downdraft type gasifiers were most predominant during world war two and most of research is directed towards the development of down draft gasifiers which has the advantages of : Simple and safe design, Low weight (for non stationary), Simple and inexpensive installation, Small pressure drops, Low tar and oil load in the gas and Easy start up.

2.3.5.2 Application of Producer Gas

The gas can be used for generation of motive power either in dual fuel engines or 100% producer gas engines. The gas can be directly burnt in an industrial oil fired boiler. Conventional dual fuel engines (e.g biogas engines) need certain modification before it is used for producer gas because calorific value of biogas (about 5500 k cal/ N-m^3) differs widely with the calorific value of producer gas (about 1100 k cal/ N-m^3). These days engines have been developed to utilize 100% producer gas.. Kerosene engines could also be tried with producer gas. A schematic of gasifier based engine generator system is shown in figure 2.4.

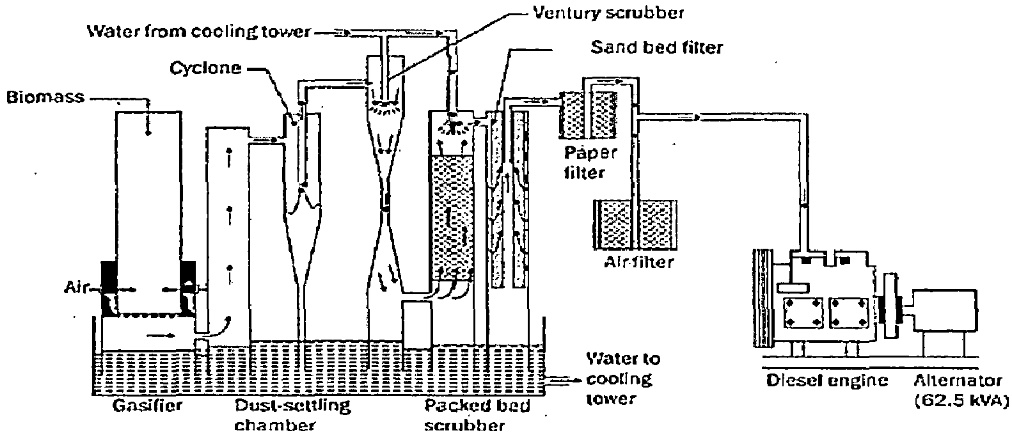


Figure 2.4: A Schematic of Down Draft Gasifier [63]

2.4 SOLAR ENERGY

Solar energy is an inexhaustible source of energy which is available everywhere and has the potential to meet the significant energy needs of the world. The average intensity of solar energy in India is 2000kWh/m^2 [8] as compared to the world average of 2500kWh/m^2.

The source of insolation is the sun which is a sphere of 1.4x10^6 diameter thermonuclear furnace fusing hydrogen atoms into helium. The surface of the sun has an effective temperature of approximately 5762 °K. The temperature in the central region is about 8 to 40 x 10^6 [24].The energy emitted by the sun travels in all direction and reaches outer surface of the earth at an intensity of 1.36 kW/m^2 , which is known as solar constant.

The main limitation in harnessing it for world energy needs is that it is present in highly diffused form and its availability is time dependent. The diffuse form or low intensity form makes it difficult to collect and large size equipment is required for it, while the time dependent availability warrants the requirement of storage. Because of the above limitations the economical viability of solar energy is disputed although it is technically feasible.

2.4.1 Solar Radiation Estimation

The earth revolves around the sun in an elliptical orbit making one revolution in 365.25 days. In addition to that it spins about its own axis which is tilted 13.45° with respect to elliptic plane.

The variation in distance is described by the relationship 2.2

$$d = 1.5 \times 10^6 \times \left\{ 1 + 0.017 Sin \frac{360(n-93)}{365} \right\} km \qquad 2.2$$

n= number of days starting Jan, 1st being one

All the above factors contribute towards the continuous variation in intensity of solar radiation falling on the earth's outer surface. Besides, the solar radiation when enters the earth's atmosphere gets attenuated by the scattering and absorption. In scattering a part of the solar radiation beam is scattered by presence of air molecules, water vapours and dust particles present in the atmosphere. While in absorption the solar radiation is absorbed by Ozone, water vapor and carbon oxide. In consequence of above the solar radiation incident on the earth's surface comprises of both beam (direct) and diffused (scattered and redirected to earth). Thus the intensity of solar radiation striking earth at any moment depends upon the following: Geographic latitude, Season of the year, Time of day and atmospheric conditions.

The radiations from the sun have been specified scientifically as follows:

- Beam Radiations and Direct Solar radiations- These are the solar radiations received from the sun without having been scattered by the atmosphere
- Diffused Radiations – the solar radiations received from the sun after its direction has been changed due to scattering by the atmosphere.

- Total Solar Radiation – These are the sum of the beam and diffused radiation
- Global Radiations – These are the total radiations on a horizontal surface
- Irradiance – The rate at which radiant energy is incident on a surface per unit area.
- Insolation – Incoming solar radiation for a given period.

The measurement of solar radiation is done by instrument called Pyranometer. The solar radiation can also be theoretically assessed for that the knowledge of geometric parameters are necessary. The model depicting the solar radiation geometry is shown in figure 2.5

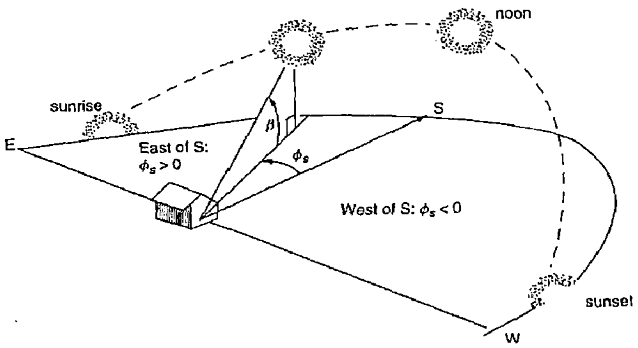


Figure 2.5: The Solar Radiation Geometry Model [19]

The various angles that describes the solar geometry are as follows:

Solar declination, δ is the angle formed between the plane of the equator and a line drawn from the center of the sun to the earth.. It varies between $\pm 23.45°$. The value of declination is given by equation 2.3

$$\delta = 23.45 Sin\left\{\frac{360(n-81)}{365}\right\} \tag{2.3}$$

n= number of days starting Jan, 1st being one

A model depicting the variation of declination is shown in fig 2.6 showing earth as fixed and the sun that moves up and down.

Alititude Angle, β_N is the angle between the sun and the local horizon directly beneath the sun and is given by $\beta_N = 90° - L + \delta$.

Azimuth Angle, ϕ_S is the angle that horizon projection makes with the south. By convention azimuth angle is positive in the morning with the sun in the east and negative in the afternoon with the sun in the west. The Azimuth angle is determined using , $Sin\phi_S = \dfrac{Cos\delta \times Sin\omega}{Cos\beta}$.

Hour angle, ω is the number of degrees that the earth must rotate before the sun will be directly over the local meridian and is depicted in figure 2.7. Hour angle is positive in the morning and negative in the afternoon. It can be found by using equation $\omega = \left(15^0 / _{hours}\right) \times (NumberOfHoursBeforeSolarNoon)$ or by equation $\omega = 15(12 - LST)$.

The availability of solar energy can be estimated to the fair degree of accuracy. The extraterrestrial solar insolation that passes perpendicularly through an imaginary surface just outside the earth's atmosphere can be calculated by an expression 2.4

$$I_o = I_{SC}\left(1 + 0.033Cos\frac{360n}{365}\right) \qquad 2.4$$

Integrating above value of insolation over time the solar energy can be estimated by expression 2.5.

$$H_o = \int_{-t_S}^{+t_S} I_o dt = \int_{-t_S}^{+t_S} I_{SC}\left(1 + 0.033Cos\frac{360n}{365}\right) Wh/m^2 \qquad 2.5$$

All these measurement and estimation is done on horizontal surface but the capturing of solar energy for energy needs is done on a tilted surface so as to obtain better yield. In addition to that the solar energy in the beam form gets attenuated by scattering and absorption when passes through the atmosphere. Thus, the earth's surface receives solar energy in the form of direct beam that passes in a straight line through atmosphere, diffuse radiation that has been scattered by molecules in the atmosphere and reflected radiation that has bounced off the ground or the other surface near the collector.

2.4.2 Application of Solar Energy and Conversion System

The solar energy can be applied for various end use applications, which can be categorized as:

- Low temperature applications
- Medium temperature applications
- Power generation using Photo Votaics

The use of solar energy for high temperature application is commonly used in solar cooker. In direct thermal conversion system the solar energy is absorbed and heat is utilized for various end use applications of low and medium grade heat requirements. The electricity energy can be directly obtained from the sun by Photvoltaic cells. They have the capabilities of directly converting the energy contained in photons of light into electrical voltage and current.

The commonly used configurations of PV system are as follows:

- PV system that feeds power to the grid
- Stand alone PV system with storage batteries
- PV systems in which load is directly connected to PV system as in case of water pumping system

2.4.3 Basic Physics of Solar Cells

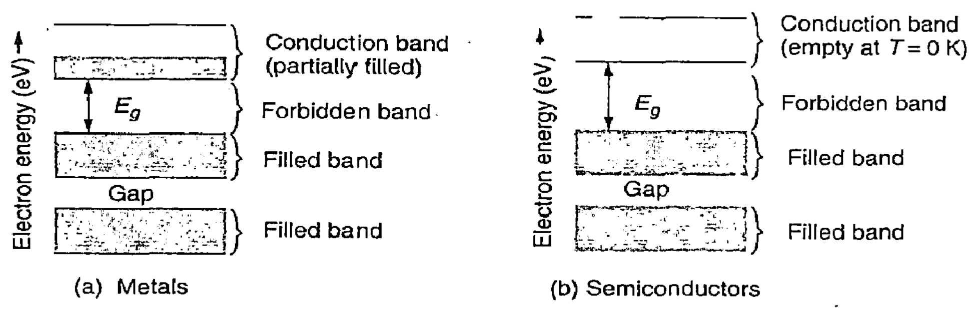


Figure 2.6: Energy Bands for (a) Metals and (b) Semiconductors.[19]

The pure crystalline silicon is the basic material used for photovoltaic cell. At absolute zero temperature Silicon is a perfect electrical insulator. Quantum theory describes the differences between conductors and semi conductors using energy band diagrams as shown in fig 2.6. Electrons have energies that must fit within certain allowable energy bands. The top energy bands is called conduction band and it is electrons in this region that contributes to current flow. The gap between conduction band from the highest filled band below it is called forbidden band. The energy that an electron requires or acquires to jump across this forbidden band is called the band-gap energy, designated as E_g. For Silicon it is 1.12 eV. For photovoltaic, the energy source is photons of electromagnetic energy coming from the sun. When a photon of energy more than 1.12eV is absorbed by a solar cell a single electron may jump over a conduction band leaving behind a positively charge Silicon cell having only three electrons. This free electron is used for generation of energy.

For Silicon photovoltaic cell, photons with wavelength greater than 1.11 μm have energy $h\upsilon$ less than 1.12eV needed to excite an electron to jump the band gap. It just heats the cells. On the other hand, photons with wave length more than 1.11 μm have more than enough energy to excite electron. Since one photon can excite only one electron any extra energy above the 1.12 eV needed is also dissipated as heat energy. The total energy that can be gained from light is represented in figure 2.7 and reflects the cause of low efficiency of the system.

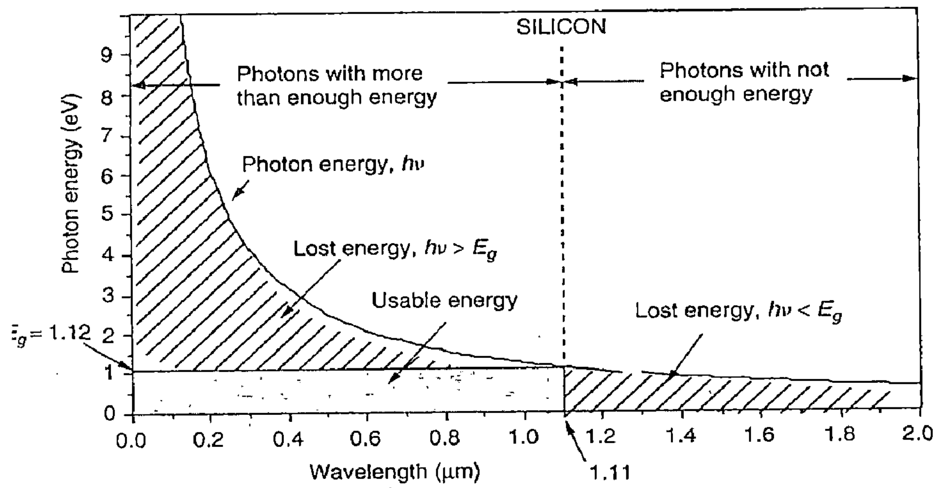


Figure 2.7: Representation of gain and loss of energy from light [19]

It is observed from the study of solar spectrum that 20.2% of the energy in the spectrum is lost due to photons having less energy than the band gap of Silicon $(h\upsilon < E_g)$ and 30.2 % is lost due to photons with $(h\upsilon > E_g)$. The remaining 49.6% represents the maximum possible fraction of the sun's energy that could be collected with a silicon solar cell. That means the constraints imposed on the efficiency of Silicon to just 50% due to Silicon band gap.

Based on the foregoing discussion it can be inferred that choosing a material with smaller band gap excite more electron, however, it will lead to wastage of more energy of photons above the threshold needed to create hole-electron pairs, which wastes their potential. High band gap materials will have opposite effect. Few photons will have enough energy to create hole-electron pair which limits the current that can be generated but higher voltage would be achieved. In other words, low band gap gives more current with less voltage while high band gap results in less current and higher voltage. Since power is the product of two a middle gap would yield highest power and efficiency. Thus the efficiency of PV is limited by

a) Photons with insufficient energy to push into the conduction band, and
b) Photons with energy in excess of what is needed to do so.

2.4.3.1 Solar Modules and Arrays

The modules can be wired in series to increase voltage and in parallel to increase current. For modules in series I-V curves are added along the voltage axis as shown in figure 2.8.

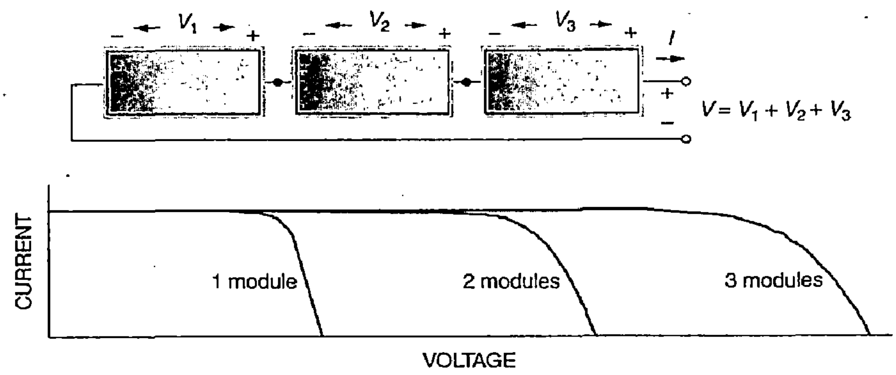


Figure 2.8: Modules in Series Voltages are Added [19]

For modules in parrallel I-V curves are added along the current axis as shown in figure 2.9.

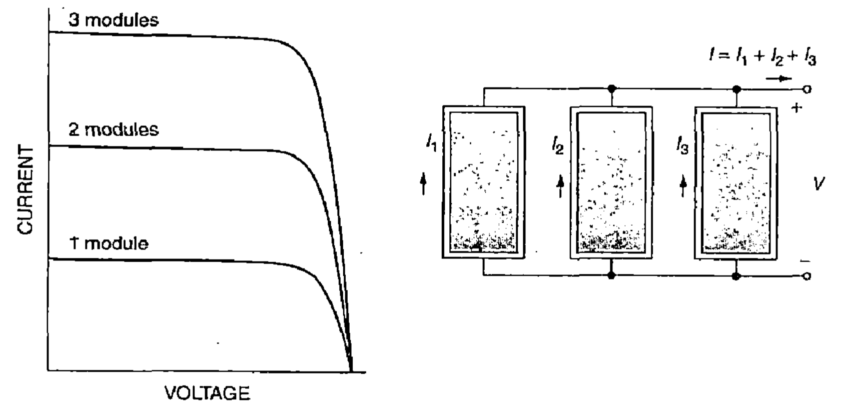


Figure 2.9: For Modules in Parallel Currents are Added [19]

Arrays are made up of some combination of series and parallel. For modules in combination of parallel and series I-V curves are added along the current and voltage axis as shown in figure 2.10

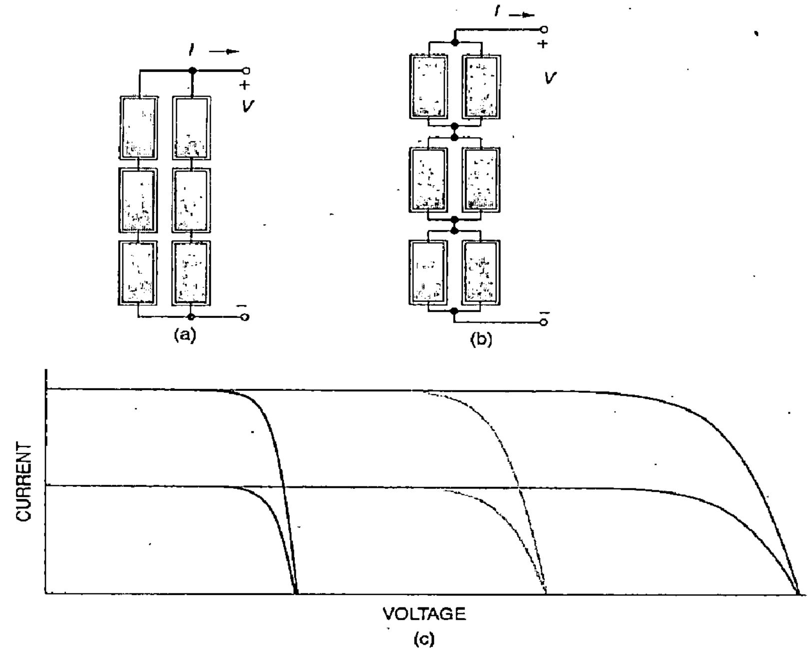


Figure 2.10: Modules in Combination of Series and Parallel [19]

2.4.4 PV System Sizing Factors

The sizing of PV system to cater to different types of load requires different approach. The vital issue involved in sizing is matching the V-I characteristics of the system with the load characteristics and the problem is complicated due to the fact that both the items have inherent tendency to vary. The main parameters that require consideration in the system sizing are as follows: Ambient Temperature, Solar intensity or Insolation, Efficiency of PCU, Reliability of power required, Capacity or Load factor and Estimated loss in the array due to the mismatch module [19]:

The impact of variation in temperature on the I-V curve of a PV array has been depicted in figure 2.11a. As the cell temperature increases the open circuit voltage , V_{OC} decreases substantially while the short circuit current, I_{SC} increases marginally. PV system, therefore, performs better on cold clear days than hot ones.

The variation of insolation causes the drop in short circuit current, and is in direct proportion to the decrease in insolation. On the other hand open circuit voltage,

V_{OC} increases in a logarithmic relationship that results in relatively modest change in V_{OC} as depicted in figure 2.11b

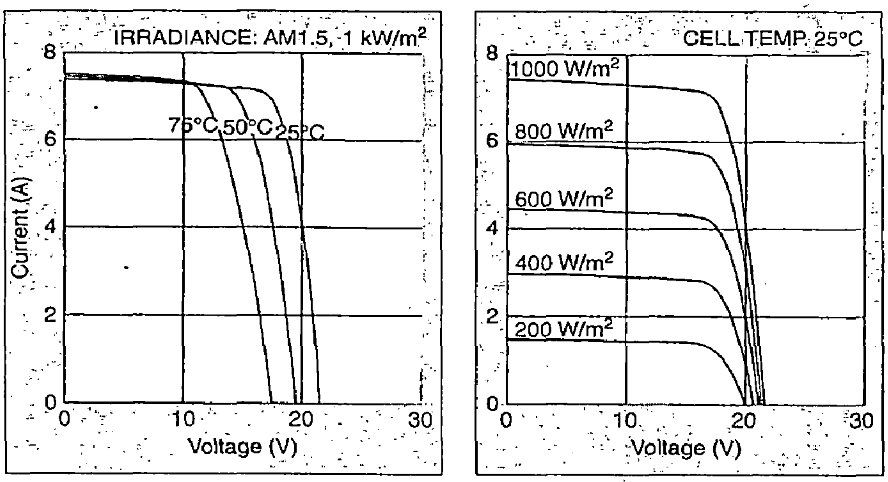


Figure 2.11a & 2.11b:Representation of impact of temperature and insolation on V-I curve [19]

The power from solar PV system is generated in dc votage if it is required to be utilized in ac a power conditioning unit (PCU) is invariably required. The conversion efficiency is an important aspect for the ac output and affect the sizing of PV system considerably. The efficiency of PCU is varies with the load. A typical PCU has a 85% efficiency.

Reliability of power required is affected by overcast conditions and situation worsens if such condition continues for a longer period. The solar energy is time dependent is not available at night when it is most needed. For a grid connected system the power can be drawn from the grid whenever the PV system does not function due to absence of solar energy. So the storage system is not necessarily required unless the reliability consideration takes into account of occasional prolonged grid failure. On the other hand a standalone system invariably requires battery storage system and/or diesel generator system which can be operated when solar energy is not available.

If the system delivers full rated power continuously the capacity factor would be unity. A Capacity Factor of 0.4 means that the system generates 40% of the maximum energy that could be generated.

The energy that could be generated in a year is determined by equation 2.6

$$Energy(kWh/year) = P_{ac}(kW) \times CF \times 8760(hrs) \qquad 2.6$$

To estimate loss in the array due to mismatch module the I-V curve of the load is overlayed over the I-V curve of the module the intersection point of the two is the operating point (OP). The module is designed to cater to the load so that the OP matches with the Maximum Power Point (MPP). At this point the maximum system utilization will take place. The problem is even if the system is designed to match the OP with that of MPP to obtain best efficiency the variation in load and insolation over time result in sub optimal performance. This problem is shown in figure 2.12.

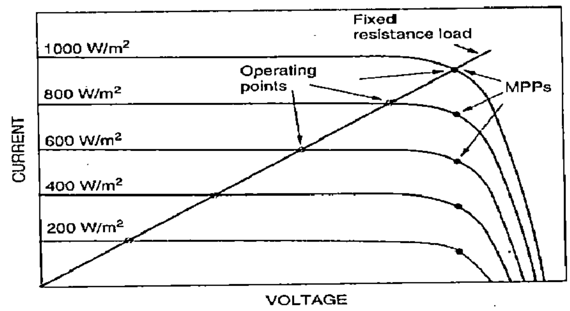


Figure 2.12: Change in efficiency with declining insolation having fixed resistance load [19]

2.4.5 Storage Sytem

Stand alone system essentially requires some arrangement to store energy to be used when solar energy is not present. The storage is necessary because of mismatch between the time of availability of solar energy and the demand. The voltage produced by PV module is almost constant and there has been insignificant variation with changing solar radiation intensity. Besides the voltage produced is in DC form. The variation due to changing solar insolation is reflected in the current output and that too changes almost linearly. All these aspects make PV system quite suitable for storage using batteries.

A battery is most commonly used for the purpose. Lead acid and Ni-Cd batteries are most commonly used. Lead acid batteries are least expensive, last longer, require less maintenance and can bear harsh weather. There are other factors that are considered for sizing of battery for a stand alone system.

The battery bank is sized to operate the loads during a sequence of below average or no insolation days called the autonomous days. During which the load is taken care of by batteries. Too large of autonomous days will have large size batteries and high cost while lesser number of autonomous days would result in low cost of batteries but unsatisfied demand of power. In order to determine autonomous days past data of spectoral distribution of overcast conditions of past few years should be studied and trade off between cost of batteries with the reliability of power required is considered.

Deep discharge batteries having thicker plates are now available which can be discharged upto 80 % of their capacity without harm. The energy of battery storage is measured in units of ampere-hour (Ah) at the some specified discharge rate. In other words the ampere-hour capacity depends on the rate at which current is withdrawn. Rapid draw down result in lower capacity while long discharge time result in higher Ah capacity. The ampere-hour capacity not only depends on the rate of discharge but also on the temperature. The performance of battery deteriorates dramatically in low temperature. The cold temperature affects the performance of battery in terms of decreased capacity, decreased output voltage and increased vulnerability to freezing.

2.5 WIND ENERGY CONVERSION SYSTEM

Wind is caused by the movement of air due to pressure gradient arises out of uneven heating of air by solar radiation and rotation of the earth about its axis. The wind is thus the manifestation of solar energy.

Wind has been utilized as a source of power for the hundreds of years for the tasks involving propelling ships, grinding grains, pumping water, etc. the wind as an electricity generation system has evolved after the world energy crises of seventies. Recent years have seen tremendous growth in wind energy generation. The wind energy conversion system commonly known as wind mill has negative as well as positive impacts on the environment. The negative one relates to the noise and disturbance to birds movements. The positive one is that it displaces more polluting energy systems.

2.5.1 Types of Wind Energy Conversion Systems

Early wind turbines were used for grinding flour and hence the name wind mill. The system that generates electricity from wind is given various name wind generator, wind turbines, wind turbine generator (WTG) and wind energy conversion system (WECS). The types of WECS can be classified on the basis of the axis of the system as shown in figure 2.13a to 2.13c.

Vertical Axis Wind Turbine (VAWT) was developed by French engineer G.M.Darries. The shape of the blade is such that which would results from holding a rope at both ends and spinning it around a vertical axis. The principal advantage of this type of system is that there is no need to have a yaw control to keep them facing to the wind. A second advantage is that generator, gear box, etc can be kept on the ground so that tower structure need not be so strong as compared to the system where equipments kept on top. The blades of VAWT are not required to be made strong and expensive as they do not have to handle the constant flexing as associated with blades of HAWT. Out of the several disadvantages associated with VAWT the main is that its blades being closer to the ground where wind velocity is low the output obtained is therefore relatively lower

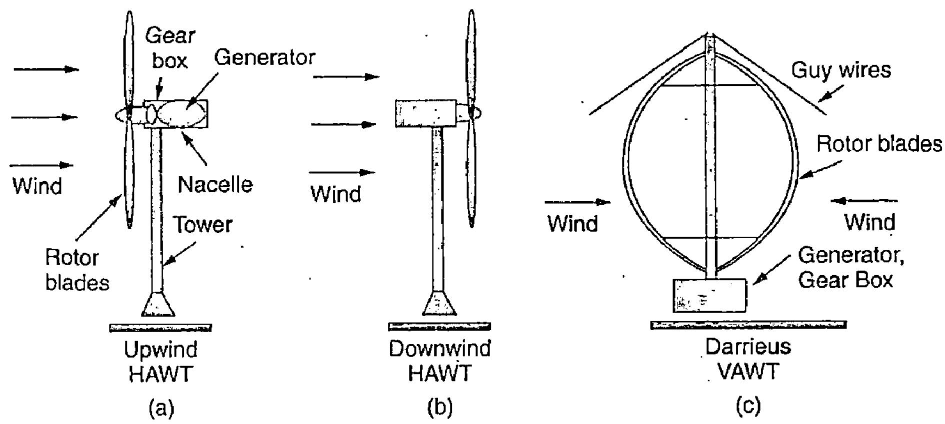


Figure 2.13:(a) Upwind HAWT wind turbine (b) Downwind HAWT wind turbine and (c) Darrieus VAWT wind turbine [19]

Horizontal Axis Wind Turbine (HAWT) are most commonly used. These types of turbines can be upwind or down wind types. The down wind turbines have an advantage of obviating the need of complex yaw mechanism and it orients itself naturally with the direction of wind. But it has the problem of slowdown effect of tower. Every time blade swings behind the tower it encounters a brief period of swing which causes the blade to flex. This flexing increases blade noise, reduces power output and may lead to failure of blade due to fatigue. Upwind HAWT needs yaw control arrangements but it operates more smoothly and generates more power.

2.5.2 Rotor Efficiency

Like all other energy conversion technologies the wind turbine rotor has limitation that restricts the complete conversion of wind energy. The German scientists is credited with finding that the maximum rotor efficiency is 59.3 % and established theoretically.

This can be explained or analyzed physically when the wind passes through rotor a part of the kinetic energy is extracted by it. The wind leaving the turbine has a lower velocity and pressure is reduced causing it to expand downward of machine. If the turbine can extract all the energy of wind passing through it then the wind at downstream would come to standstill preventing any more wind to pas through the rotor. Also, the downward wind cannot be the same as upward wind in that case no energy would be extracted. So there has to be some ideal speed of wind ratio where the power extraction would be maximum and that is known as Beltz efficiency (59.3%). This is achieved when the velocity of downward flow is slow down to one third of the incoming velocity of wind.

The rotor efficiency is represented as a function of tip speed ratio as per equation 2.7. The tip speed ratio (*TSR*) is the speed of outer tip of the rotor blade to the wind speed (v).

$$TSR = \frac{rpm \times \pi D / 60}{v} \qquad 2.7$$

For a given wind speed rotor efficiency is a function of tip speed. Lower tip speed means lower efficiency as much air passes through it without doing much work. If the TSR is too fast than also the efficiency is low because of turbulence created by blades affect the extraction of energy. The typical efficiencies of various types of WECS as a function of TSR is shown in figure 2.14.

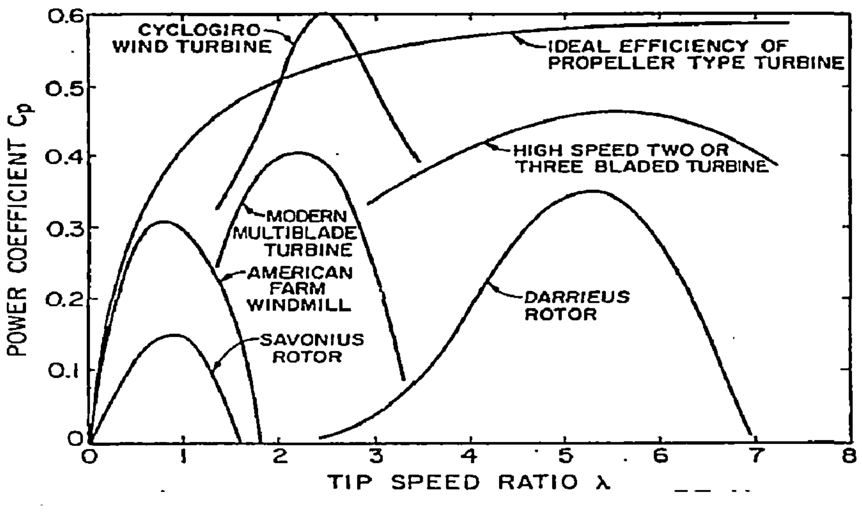


Figure 2.14: Typical efficiency curves of various WECS [19]

2.5.3 WIND POWER ASSESSMENT

The assessment of wind power and hence its feasibility starts from the measurement of velocity and its availability duration. Velocity is measured by instrument called Anemometer. The Anemometer spins at rate proportional to wind speed that has a revolution counter calibrated to indicate kilometer of wind passed. Dividing kilometer of wind passed with time gives the average wind speed.

The principal problem associated with the measurement of data is that the velocity varies with time (hourly, daily, monthly and annually) space, altitude and topography. In order to have uniformity in comparison and ease of assessment the data are collected at 10 meter height from the ground and hourly mean velocity is recorded. Wind speed is greatly affected by the friction caused by the forest, building and other obstacles, while smooth surface like ocean and plain field offers little resistance. In consequence to this the wind velocity at earth's surface is considerable lower then at higher levels or altitude. Therefore, the wind speed data recorded near the ground surface are predicted at a projected turbine hub height by using an expression 2.8

$$\frac{v}{v_i} = \left(\frac{H}{H_i}\right)^{\alpha} \qquad 2.8$$

This raw data is processed to assess the power potential in the following forms of charts and curves: Velocity – duration curve, Power- duration curve and Frequency

– duration curve. The frequency distribution curve can be a discrete wind histogram or Probability distribution curve

In discrete frequency distribution of velocity the number of hours average or mean velocity of a particular value is available. A typical histogram or a curve is shown in figure2.15.

$$\left(v^3\right)_{avg} = \frac{\sum\left[v_i^3 \times h_{vi}\right]}{\sum h} \qquad 2.9$$

The average power in wind is assessed by expression no. 2.10

$$WES_R = \frac{1}{2} \times \rho \times \left(v^3\right)_{avg} \qquad 2.10$$

WES_R Wind Energy Resources in kW/m^2

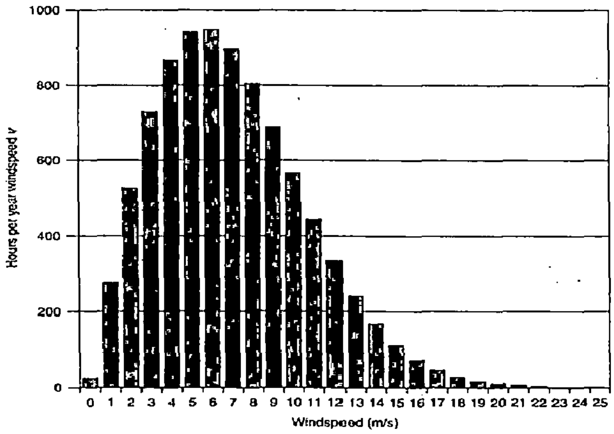
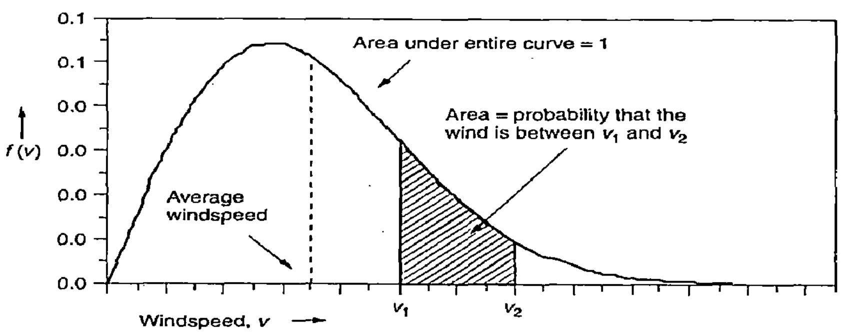


Figure 2.15: A typical frequency distribution of wind velocity [19]

The distribution of wind velocity can also be presented in the form of probability density function (pdf) [5]. A typical curve is shown in figure 2.16.



.Figure 2.16:A Typical Wind Speed Probability Distribution Curve[19]

The Weibull and Rayleigh are the two most commonly used functions to represent for the wind velocity frequency distribution. The Weibull function is found to be better than Rayleigh model as it has smaller error values in calculating the power density when compared to Rayleigh model [5]. The Weibull probability distribution function is represented by equation 2.11

$$f(v)=\left(\frac{\pi v}{2(v_m)^2}\right)\times \exp\left[\left(\frac{-\pi}{4}\right)\left(\frac{v}{v_m}\right)^2\right] \qquad 2.11$$

The mean wind speed, v_m can be calculated by expression 2.12

$$v_m=\left(\frac{\sum_{j=1}^{N_j} v_j^3}{N_j}\right)^{1/3} \qquad 2.12$$

The average power that can be produced by the available wind is the power produced at each wind speed multiplied by the fraction of the time that wind speed experienced. In integral form the equation is 2.13.

$$WES_R=\int P_w \times f(v)dv \qquad 2.13$$

The wind turbine is selected to match the power curve. The power curve depicts wind speed and generator electrical output of the WECS. A typical curve is shown in the figure 2.17. The cut in speed, V_C is speed below which power cannot be generated and that portion of wind energy cannot be utilized. Low speed wind doesn't have enough power to overcome the inertia or friction of the system. The power output increases with the increase in wind velocity above cut in speed upto the rated capacity of the generator. The speed at rated capacity is called rated speed (V_R) and power output is called rated power P_R. The WECS delivers the rated power at rated speed. When speed increases beyond rated speed a mechanism should be placed to keep the power output in the limit of rated power so as to avoid damage to the generator. When the wind is so strong that the safety of the turbine is in danger the arrangements are made to stop the turbine immediately. This speed is called Cut out or Furling wind speed, V_F.

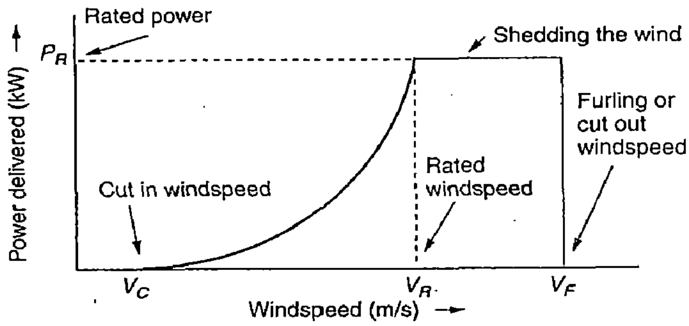


Figure 2.17 : Idealized Power Curve of Wind Turbine [19]

In case of highly unpredictable and erratic availability of wind speed and its duration makes the decision on sizing of WECS a difficult task. The problem compounded if the system is to be designed for a remote region or off grid location where the load profile is not favorable. So in order to size the equipment it is necessary to take into account the availability of resources and load with due weightage to the economic consideration.

The capacity factor (CF) is a term whose values lies between 0 and 1 is used to measure the effectiveness of sizing energy conversion system. It is given by expression 2.14.

$$CF = \frac{P_{avg}}{P_{rated}} \tag{2.14}$$

P_{avg} - Actual energy that can be generated

P_{rated} - Actual energy the system is designed to generate

CHAPTER-3

STUDY AREA, ASSESSMENT OF DEMAND AND RESOURCES

3.1 GENERAL

In *Sanskrit* 'Himalaya' means Abode of Snow, truly characterizing the vast permanent snow fields above the snow line. The economy of the Himalayas as a whole is poor with low per capita income. Much of the Himalaya areas is characterized by a very low economic growth rate combined with a high rate of population growth, which contributes to stagnation in the already low level of per capita gross national product. Most of the population is dependent on agriculture, primarily subsistence agriculture. The Himalayas has major hydroelectric potential, but the development of hydroelectric resources requires large capital investment. [30]

Uttaranchal, now rechristened as Uttarakhand, lies in the Northern part of India amidst the magnificent Himalayas. It is the 27th state of the Republic of India. (total states being 28) and carved out of Uttar Pradesh on 9th Nov 2000. The state lies in $28^0 43'$ to $31^0 28'$ North and $77^0 32'$ to $81^0 00'$ East bordering Himachal Pradesh in the north-west and Uttar Pradesh in the South and has international borders with Nepal and China The population of the state is around 8.5 million. The land area is about 55,845 sq km. Literacy level of the state is 72%[30].

The State today with 13 Districts which can be grouped into three distinct geographical regions, the High mountain region, the Mid-mountain region and the Terai region. These districts comprise: Pithoragarh, Almora, Nainital, Bageshwar, Champawat, Uttar Kashi, Udham Singh Nagar, Chamoli, Dehra Dun, Pauri Garhwal, Tehri Garhwal, Rudraprayag and Haridwar (Urban). The region is mostly hilly (approx 88 percent) and the remaining 12 percent falls in the plains. Geographically 8 districts of the new State are completely in the hilly region of this Himalayan Region with the remaining 4 districts are partly hilly and partly plain areas while one district Haridwar is completely in the plain area.

The economic viability of the new state is worrisome in the present circumstances. Though it is endowed with rich natural resources, it is unable to tap them to its advantages. The result is that about 70% of its population lives under the poverty line as against the national average of 46%. Subsistence agriculture supports about 75% of the population while 71% of the land holdings are less than 1 hectare in size [26].

Dividends can be reaped if the various rivers and streams of the state are utilized to produce hydro electricity This province have the origin of some of the ice-fed rivers like the Ganges, Yamuna, Bhagirathi, Alaknanda, Sarju, Tons, Kali and Ram Ganga. The availability of ice fed and rain fed rivers along with the natural incline make the State having a good hydro power potential and a future Energy State. At present all the electric power is being generated by hydro. The present status of large & medium identified hydro power potential in the State is about 20,000 (plus) MW. In addition to the large & medium identified hydro potential the state is also having about 1500 MW potential in the segment of Small Hydro projects upto 25 MW capacity [4].

The state is very rich in natural resources especially water and forests as it has many glaciers, rivers, forests, mountain peaks. The thick forests and mountains house a variety of wild life and plant species. The total protected wildlife area of Uttarakhand is 34,359 sq km. havinf twelve National parks and sanctuary. All these zones support many rare plants and animal communities. The agrarian people of the state depend on forest for their requirement of cooking energy. There is therefore urgent need to promote the use of non-conventional sources of energy to reduce the pressure on bio-resources.

Under the village electrification programme in the state out of total 15,761 numbers of census villages, 15199 villages have been electrified as on March, 2007. Percentage of village electrification is 96.4 %. 219 remote census villages and 14 remote hamlets have so far been electrified through installation of solar home systems in individual households. In addition, projects for electrification of 67 villages through small hydro plants, 2 villages through biomass gasifier based systems and 216 villages through solar home systems are under implementation.[4]

3.2 STUDY AREA

The study area is located in strategically significant one of the hill district of Uttarakhand, India called *Chamoli Garhwal. Chamoli,* the abode of Gods, reputed for its shrines and temples. It is the birth place of *'Chipko Movement'.* The region covered by the district of Chamoli forms part of the district of Pauri garhwal till 1960. Pauri district was established by Britishers and chamoli was a tehsil of the same. On 24th February 1960 tehsil Chamoli was upgraded to a new district. In October 1997 two complete tehsil and two other blocks (partially) of district chamoli were merged into a new formed district Rudarprayag. Chamoli lies in the Central Himalya surrounded by Uttarkashi in North-West, Pithoragarh in South-West,Almora in South East,Rudraprayag in South-West and Tehri Grahwal in West.

The geographical area of the District is around 7520 sq.kms. There are six tehsil and nine blocks in the district and 1233 numbers of vilages. The total population of the district is 3.70 lakhs and rural population is 3.19 lakhs, which indicates the dependence of the people of the district on agriculture. The literacy rate of women is 52.74 % while that of men is 75.6%. The 64% overall literacy rate of district is well below the 74% literacy rate of the state. The district head quarter is located at Gopeshwar. The six tehsil are :Joshimath, Chamoli, Karnaprayag, Tharali, Pokhari and Gairsain. The nine block head quarters are : Joshimath, Dasholi, Ghat, Karna-Prayag, Narain-Bagad, Tharali, Dewal, Pokhari and Gairsain.

The study area is located in *Ghat* block which lies in the Nandakini valley where a Nandakini river a tributary of Alaknanda flows. The river originates from one of the highest peak of the region known as Nandakini. The region lacks in modern infrastructural facilities such as road, light, telephone, medical and education. The location of the region is in extreme corner adjacent to very high snow bound mountains region close to China having inclement weather. The commercial activities are absent. The employment opportunities are almost absent. The energy need of the villagers for cooking is satisfied by forest wood, falling water is used for grinding grains, dehusking of paddy is done manually and lighting requirement is met by kerosene which has to be fetched from very far. Most of the villagers are lucky to have spring water in the village for their drinking water need. The water emanates from ground hence potable. As a whole the life is very tedious and improvement is necessarily felt. That is the reason for selection of the region for study.

3.3 SELECTION OF VILLAGE AND ITS SALIENT FEATURES

The primary criterion of selection of village for study is non availability of power due to its remote location, far away from the grid. More than one form of renewable energy resources like micro hydro, biomass and solar energy are richly available and can be integrated together to energize the area. So that there could be a possibility of satisfying various energy needs of the villagers using integrated renewable energy system (IRES). However, criteria considered for selection of villages are;

(i) The area should not be electrified.

(ii) The area should be relatively inaccessible.

(iii) More than one renewable energy sources should be available.

(iv) The people are economically poor, do not have enough avenues for employment and are totally dependent upon natural forest for their energy needs.

(v) The people should be willing to participate in the implementation of IRES program.

(vi) The village should represent the area in social, economic and geographic considerations so that the results obtained can be applied to other villages of the region.

Based upon the above criteria, *Ramani* village located in the valley of *Nandakini* river in *Ghat* block of *Chamoli* district *of Uttarakhand state* has been selected for the present study. The village Ramani (altitude 1880m, longitude 79'30° E and latitude 30°19' N) is located about 14 km from the nearest road head and 35 km from the block head quarter known as *Ghat*. The village is not electrified. The map of the region where the village lies is shown in figure 3.1a, 3.1b and 3.1 c. The general features of the village are presented on the table 2.1.

Table 3.1: General Features of the Village

Sl No.	Item	Information
1	Name of Village	Ramani
2	Name of Block	Ghat
3	Name of District	Chamoli
4	Name of State	Uttaranchal
5	Village Census Code	
6	Latitude	30°19' N
7	Longitude	79'30°E
8	Altitude	1880
9	Distance from Block office	35 Km
10	Distance from nearest road	14 km
11	Distance from 11 kV grid	5 km
12	Total Population	1150
	(i) Male	504
	(ii) Female	442
	(iii) Children	204
13	Total House hold	184
14	Total Area	441 ha
15	Cultivable Area	117 ha
16	Main occupation	Agriculture

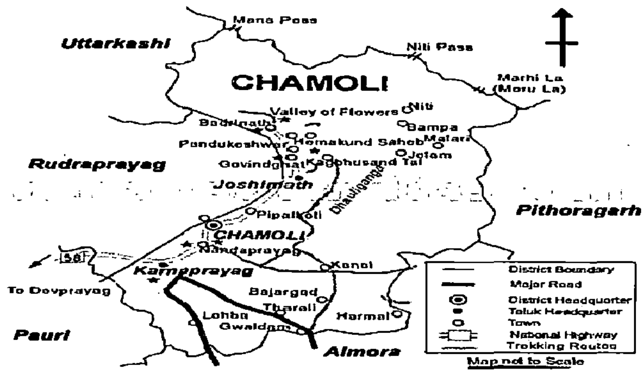


Figure 3.1a: District Map 0f Area of Study[28]

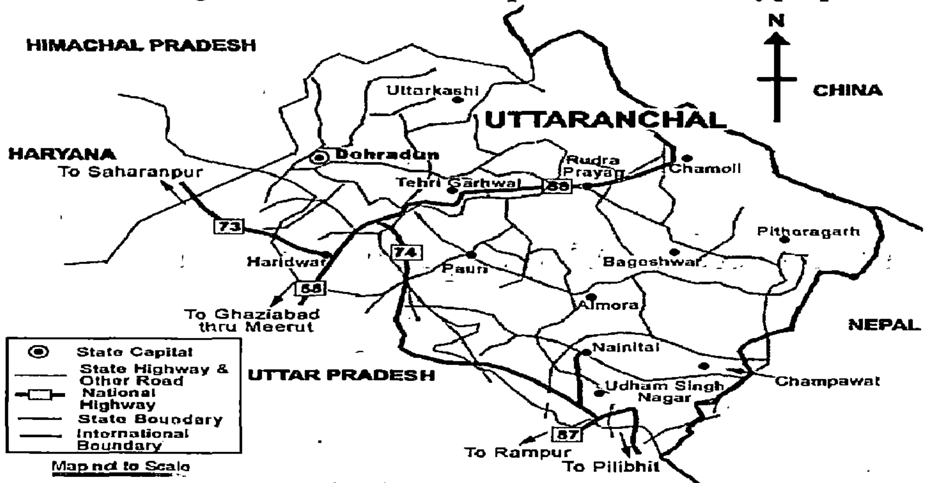


Figure 3.1b:The State Map of Area of Study[28]

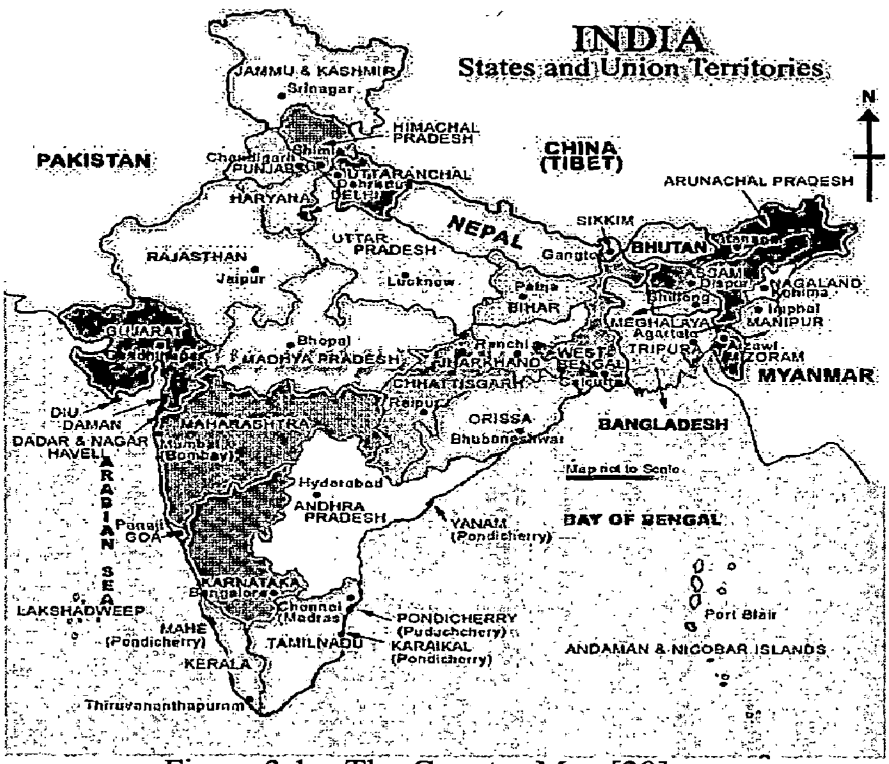


Figure 3.1c: The Country Map [29]

3.4 RESOURCE ASSESSMENT

The assessment of resources has been carried out based on the data collected from the village and the data available for wind and solar of the nearby region. The hydro power potential is estimated by measuring head and discharge.

3.4.1 Micro Hydro Power (MHP)

Hydro-turbines convert water pressure into mechanical shaft power, which can be used to drive an electricity generator, or other machinery. The power available is proportional to the product of pressure head and volume flow rate [44]. The estimation of annual hydro resource in kWh determined by equation 3.1.

$$MHP_R = g \times Q \times H \times 8760 (kWh/year) \qquad 3.1$$

Where MHP_R is the Micro Hydro Power potential available at site (kWh/year), The available resources can be utilized using turbine of suitable size and efficiency.

The *Ramani* village is quite rich in the hydro power resources. A stream locally known as *"Gat Gadera"* passes adjacent to the village and twenty two numbers of traditional *Gharats* (Water Mill) exist in it. Out of the total numbers of these water mills 11 lies in vicinity of village. While remaining eleven are located about one km downstream. It is found that the villagers are able to fulfill their requirement of grain grinding through eleven watermills that lies close to the village. But these watermills can only be operated for six to seven months due to shortage of water in lean season. For remaining six to seven months the watermills located downstream are operated. The downstream watermills, however, can be used throughout the year. Therefore at the down stream stage the potential assessment has been carried out as the water discharge is available through out the year. The following data has been collected and resource assessment made:

i. Head :85 meter
ii. Discharge during lean period :0.04m^3/sec
iii. The available energy daily :9.81x0.04x85x8760=292180 kWh/year

3.4.2 Biomass

The three prominent sources of biomass predominantly used in the villages are forest waste/residues, agricultural residues and animal waste. The forest residue and waste is the main source of fulfilling cooking need of the villagers using traditional chulha which has a very low efficiency of the order of 10%. With the increasing population and poverty demand for fuel wood is increasing putting undue strain on forest. These two characteristics of low efficiency and shrinking supplies are endangering the future of this important source of energy.

3.4.2.1 Biomass Gassification

The main sources of producer gas are fuel wood and agricultural residues. Traditionally, people of Garhwal Himalaya region, which lies in Uttaranchal, have been fulfilling their energy needs almost entirely from forests. However, the dwindling forest resources and enforced environment laws by Government agencies without provision of alternative sources of energy the very existence of the local people is being threatened.

The quantum of biomass available from forest without causing its depletion is difficult to assess. The fuelwood collected by the villagers can be ascertained by a sample survey or taken from the the literature. As per the study conducted by Negi in Uttarakhand it has been established that the total fuelwood consumption is 1.56 kg/person/day for the village that lies at altitude in the range of 1500 to 2000m, which closely matches with the similar studies conducted in Nepal Hills and Sri Lanka [3]. The fuel wood to energy conversion is taken 1 kg of fuel wood is equal to 1 kWh of energy [1]. So the fuel wood required for 946 adults is 538652kg/year. Fuel wood required for child is taken equal to half of that of required for adult which is 58648 kg/year for 206 children. So total fuel wood consumed for cooking is 597300 kg/year. This implies that the total annual energy used from fuel wood by villagers is 597300 kg/year =597300 kWh/year. As such in absence of any authentic information on the quantum of growth of forest biomass in the region and the impact of use of fuel wood on forest at current rate of consumption, it would be difficult to estimate the amount of fuel wood that can be taken from forest without threatening its sustenance. The data collected for the village indicate that the villagers use traditional stone stoves for cooking which has 10% efficiency. It can therefore be inferred that if the improved wood stove of efficiency 38-40% is used the consumption would reduce by one fourth. This would reduce the strain on forest and consumption of fuel wood will therefore reduce to 149325. Assuming this amount of fuel wood use is sustainable from the area the total annual energy available from fuelwood is 149325 kWh/year.

Agriculture is the main source of occupation of the people of Uttarakhand. They cultivate on the hill slopes mainly rice (paddy, Oryaza sativa), wheat (Triticum aestivum) people and finger millet (Eleusina coracana) as major crops and foxtail (Echinocloa Frumentocea), maize (Zea mays), mustard (Brassica juncea) and legumes as minor crop in the lower part of the hill. Potato (Solnum tuberosum), buckwheat (Fagopyrum aesculantum) and beans are important crops for the region upto 2500m altitude. Valleys are the most productive and production decreases with increasing slope and altitude. [3]

The data related to agriculture produce has been collected and it is observed that the agricultural productivity of the selected village is almost one fifth of the productivity of the plains region of the state. Besides the residue collection and carrying to the place of use has to be done manually and is a very tedious task in the hilly terrain. It can be otherwise used as manure. It is difficult to assess the benefit of using it for biomass gasification as this may outweigh the loss of it as manure. Hence due to fear of social un-acceptance it is not considered.

3.4.2.2 Biogas Energy

In Uttaranchal dry cow dung cake is not generally used as fuel as it is the only source of manure. Only in very few places it is used for generation of biogas [3]. The use of cow dung for generation of biogas holds excellent opportunity without affecting its usefulness as manure. The resource assessment of biogas is done using data presented in table 3.2.

Table 3.2: The Dung Yield of Various Animals and Expected Gas Yield[11]

Sl. No.	Type of Feed Stock	Gas Yield (m3/kg)	Manure Yield (kg/cattle/day)	Gas yield (m3/cattle/day)
1	Cattle Dung	0.036	10	0.36
2	Calf Dung	0.036	5	0.18
3	Buffalo Dung	0.036	15	0.54
4	Pig Excreta	0.078	2.25	0.18
5	Chicken Excreta	0.062	0.18	0.011
6	Human Excreta	0.07	0.4	0.028

In order to assess the biogas potential survey of cattle population of Ramani village has been carried out and the assessment of biogas has been made on the basis of dung yield as presented in table 3.3. Collection efficiency has been assumed to be 70%. Others data used for determining energy yield from dung are as follows:

Gas yield per kg of wet dung [11] = 0.036 m^3/kg

Calorific value of biogas [28] =4700 kcal/m^3

Conversion factor from k.calorie to kWh [28] =860

Table 3.3: Estimation of Biogas Yield and Energy Estimation

Cattle	Number	Dung Yield (kg/day) [11]	Total Dung (kg/day)	Total Dung (70% collection Efficiency)	Total Gas Yield* (m3)	Energy Yield** (kWh/day)	Annual Energy Yield** (kWh)
(a)	(b)	(c)	(d)=(b)x(c)	(e)=0.70x(d)	(f)=0.036x(e)	(g)=(f)x5.465	(h)=365x(g)
Cows & Oxes	546	10	5460	3822	137.59	751.94	274458.20
Buffaloes	91	15	910	637	22.93	125.32	45743.03
Calves	196	5	196	137.2	4.94	26.99	9852.35
Horses	61	10	610	427	15.37	84.01	30662.91
Goat	503	1	503	352	12.67	69.25	25277.16
TOTAL			**7679**	**5375.2**	**193.51**	**1057.52**	**385993.65**

*Gas yield per kg of wet dung[42]= 0.036 m^3/kg

**Energy Yield per kg of dung in kWh/day=(Calorific Value of gas/860)=(5.465 kWh/day/kg of dung

Annually 5357 kg of cattle dung is available which can be used for production of 385994 kWh of energy.

3.4.3 Solar

The energy source for any photovoltaic (SPV) system is the solar insolation available at the location of the installation. Knowledge of solar radiation on earth's surface is required for assessment of availability of solar energy that can be tapped for useful applications. The performance of such a SPV system is directly affected by the amount of insolation available to the system.. The available insolation at any location varies from time to time, caused by the diurnal and seasonal changes in the position of the Sun relative to the Earth. The variations in insolation caused by the position of the Sun can be determined using geometric relations. However, the dependency on the weather conditions cannot be predicted and hence there is a need to depend on long-term historical records of hourly data for this type of information. These long-term data are available for only a limited number of sites or locations. The ascertainment of solar insolation data is either by conducting direct measurements of the solar radiation pattern at the location through-out the year and over several years or obtaining the data from meteorological department, if it is available with them. The measurement of insolation data is time consuming and expensive and, therefore, will inhibit the design process of the PV system for a given location. However, the long term monthly average of daily global insolation values for a particular location are relatively constant so that past values can be used to estimate future ones [58].

The extra-terrestrial horizontal insolation per day at a given place is the insolation on a horizontal surface at the place without the atmospheric effects. This is calculated from the expression 3.2a to 3.2 d [59]

$$H_o = \frac{24 \times I_o}{\pi} \times \left[Cos\ \phi Cos\ \delta Sin\ \omega_{ST} + \left(\frac{2\pi\omega_{ST}}{360} \right) Sin\ \phi Sin\ \delta \right] \quad 3.2a$$

$$I_o = I_{SC}\left[1 + 0.033Cos\frac{360n}{365}\right] \quad 3.2b$$

$$\delta = 23.45Sin\left[\frac{360}{365}(284 + n)\right] \quad 3.2c$$

$$\omega_{ST} = Cos^{-1}(-Tan\phi \times Tan\delta) \quad 3.2d$$

It can be seen from the above expressions that the extra-terrestrial horizontal insolation is a function of latitude and the day of year only. Hence, it can be calculated for any location for any given day. However, the calculated insolation does not take any atmospheric effects into account.

The clearness index (K_T) gives a measure of the atmospheric effects at a place on the insolation [17]. However, the clearness index is a stochastic parameter, which is a function of time of year, season, climatic condition and geographic location. Therefore, to include the atmospheric effects on the insolation at a given place, the insolation on a horizontal surface for a location is measured over a period of time encompassing all seasons and climatic conditions. The values of extra-terrestrial horizontal insolation as calculated using Eq. 3.2 a to 3.2d are without any atmospheric effects. Clearness index, K_T, for any location is computed by equation 3.3. It is the ratio of the computed values of extraterrestrial horizontal insolation for locations and the measured global insolation on a horizontal surface for the same locations.[50-17]

$$K_T = \frac{H_z}{H_o} \quad 3.3$$

H_z = Global solar insolation at horizontal surface

The diffused component of solar radiation can now be ascertained using correlation equation no. 3.4 [17]

$$H_{dz} = H_z \times [0.775 + 0.00606(\omega_{ST} - 90) - \{0.505 + 0.00455(\omega_{ST} - 90)\}Cos(115K_T - 103)] \quad 3.4$$

The beam component of solar radiation is therefore given by equation 3.5

$$H_{bz} = H_z - H_{dz} \qquad 3.5$$

In addition to average daily solar radiation the output of SPV module depends on the orientation and tilt angle which is conventionally taken equal to latitude angle facing south for countries located in northern hemisphere. This orientation and tilt angle maximizes the annual radiation in the plane of SPV module and consequently its power output. All these measurement and estimation is done on horizontal so in order to estimate insolation on tilted surface the tilt factor is determined for beam, diffused and reflected radiation which are given by expressions 3.6a, 3.6b and 3.6c respectively which can be used to compute the Global radiation on tilted surface by equation 3.7.

$$R_b = \frac{H_T}{H_Z} = \frac{Sin(\phi - \beta)Sin\delta + Cos(\phi - \beta)Cos\delta Cos\omega}{Sin\phi Sin\delta + Cos\phi Cos\delta Cos\omega} \qquad 3.6a$$

$$R_d = \frac{(1 + Cos\beta)}{2} \qquad 3.6b$$

$$R_g = \frac{(1 + Cos\beta)}{2} \qquad 3.6c$$

$$H_{TT} = H_{bZ} \times R_b + H_{dZ} \times R_d + \rho \times (H_{bZ} + H_{dZ}) \times R_g \qquad 3.7$$

For the design and sizing of PV systems parameter known as "1-sun" or "Peak Sun" is accepted standard condition of irradiance, which is equivalent to 1 kW/m^2. This gives the number of hours needed at peak sun ray condition to have an equal amount of solar energy for that day. This means that in a day of average insolation of $H_{daily-av}$ *kWh/m^2/day* energy will have peak sun energy for $H_{daily-av} / H_{peak-sun}$ hours.

The estimation of energy available for harnessing is given by equation 3.8a. This above equation when multiplied by the efficiency of the system will yield the output in kWh as shown in equation 3.8b [32-36].

$$SPV_R = P_{cap} \times \frac{H_{daily-av}}{H_{peak-sun}} (kWh / day) \qquad 3.8a$$

$$E_{SPV} = \eta_{PV} \times SPV_R \qquad 3.8b$$

Solar radiation data have been taken from the solar radiation data hand book [40] for the study area at Latitude of $29^{0}38'$ N. Table 3.4 shows the daily and monthly global solar radiation.

Table 3.4: Median values of hourly and daily global solar radiation in kWh/m^2 [40]

MONTH	HOURS													Daily
	6	7	8	9	10	11	12	13	14	15	16	17	18	Total
Jan.	0.00	0.00	0.00	0.28	0.45	0.57	0.66	0.65	0.57	0.44	0.28	0	0.00	4.15
Feb.	0.00	0.00	0.17	0.38	0.56	0.69	0.77	0.77	0.69	0.56	0.38	0.17	0.00	5.19
Mar.	0.00	0.00	0.28	0.48	0.68	0.81	0.88	0.88	0.8	0.66	0.47	0.26	0.00	6.34
April	0.00	0.15	0.34	0.56	0.76	0.88	0.93	0.93	0.87	0.72	0.55	0.32	0.13	7.13
May	0.00	0.18	0.4	0.59	0.78	0.9	0.94	0.93	0.88	0.76	0.56	0.38	0.17	7.51
June	0.00	0.17	0.35	0.54	0.7	0.8	0.87	0.86	0.79	0.67	0.52	0.33	0.17	6.76
July	0.00	0.13	0.28	0.47	0.61	0.71	0.74	0.75	0.68	0.58	0.45	0.29	0.15	5.66
Aug.	0.00	0.00	0.26	0.42	0.57	0.68	0.71	0.73	0.66	0.56	0.43	0.27	0.00	5.45
Sept.	0.00	0.00	0.27	0.46	0.65	0.77	0.81	0.8	0.76	0.64	0.44	0.27	0.00	6.07
Oct.	0.00	0.00	0.19	0.42	0.59	0.71	0.79	0.79	0.7	0.57	0.41	0.19	0.00	5.5
Nov.	0.00	0.00	0.14	0.32	0.52	0.65	0.69	0.68	0.64	0.51	0.31	0.13	0.00	4.6
Dec.	0.00	0.00	0.00	0.28	0.43	0.55	0.65	0.64	0.55	0.42	0.28	0.00	0.00	4.02

The average daily value of global solar insolation can be taken as **4.15 kWh/m^2** for the area under study for the month of January. The value of insolation on tilted surface $\beta = 30^{o}19'$ (Latitude angle) comes out to be **5.01214** kWh/m^2/day for January 17.

So peak sun for 17th January is for = 5012.134/1000

= 5.012 hours

The solar energy resource can be considered unlimited and hence the capacity can be decided by knowing how much resources are required to be satisfied in a cost effective and efficient way.

Under the present study, a stand- alone SPV system of 1kW capacity plant has been considered to evaluate the unit cost of energy. The peak sun calculated for January 17 is 5.012 hrs per day. An energy potential of 1503 kWh per year has been determined for SPV system of 1 kW which is likely to produce 162 kWh/m^2/year of energy at 12 % efficiency and 300 days of sun shine and load factor of 0.9.

3.4.4 Wind

The average power in wind is assessed by expression no. 3.9

$$WES_R = \frac{1}{2} \times \rho \times (v^3)_{avg} \qquad 3.9$$

WES_R Wind Energy Resources in W/m^2

For the present study, wind data have been obtained from a nearby metrological station at Bachlikhal having the details as given in Table 3.5.[W-CET-1999]

Table 3.5: Details of Bachelikhal Metrological Station

State	Uttaranchal
District	Tehri Garhwal
Taluka	Devaprayag
Latitude	**30^0 04' N**
Longitude	**78^0 37' E**
Elevation	945 MASL
Instrument system used	NRG System
Mast height	10/20 M
Period covered by data	Jan. 1998 – Dec. 1998

Tables 3.6 gives the mean monthly wind speed in the study area which indicates that the average wind speed varies from 2.99 m/s to 6.37 m/s. To have a reliable system the wind speed of 2.95 m/s has been considered to estimate the wind potential and unit cost of energy from wind resources in the study area. A total energy potential is 16.5 W/m^2 , (ρ is the density of air = 1.225 kg/m^3). If the inclusion of only more than 200 W/m^2 power density sites in estimation of wind energy resources assessment by Center for Wind Energy Technology (C-WET) and consideration of financial assistance for demonstration projects for more than WECS 225 kW for bigger and 50kW for remote area sites are of any indication of suitability of a site for wind energy exploitation then the potential in the area is less.

Table 3.6: Wind Speed Data

Months	Mean Monthly Wind Speed (m/sec)
January	5.44
February	5.51
March	6.1
April	6.37
May	6.28
June	5.01
July	3.55
August	2.99
September	4.29
October	5.34
November	5.57
December	5.81

3.5 LOAD ASSESSMENT

The data collected from the village on number of rooms, population and general economic conditions is applied to estimate the energy demand for lighting, cooking and mechanical energy needs of the villagers. The village is agrarian and all its economy depends on the agriculture as a result there is no commercial or industrial load expected to emerge immediately.

3.5.1 Lighting Load

The lighting load can be categorized into residential and no-residential load.

Residential Load

For assessment of load the average numbers of room per house hold (hh) is determined from the data collected. Then the total average load that is likely to come up is estimated based on the number or fraction of average appliances likely to be owned by the each hh. To incorporate the utilization factor the average load is multiplied by percent of time of use to arrive at lighting load for the residential buildings.

For the ease of assessment of load the lighting load has been divided in three time zone. Day time load starts from morning 5 AM to evening 5 PM during this period the requirement of electricity would not be much because of availability of daylight and villagers will be on farms while children will be on school. Consequently requirement of domestic lighting has been considered minimally. The use of refrigerator and other appliances like TV, Transistor/ music system and iron press has been taken for this period. Evening time from 5PM to 10 PM is the period during which the requirement of electricity will be most. The use of light, Television and street light will soar. The night time from 10PM to morning 5AM is the period when the use of street light will be most and use of light will be limited to very few bulbs.

Table 3.7:Assessment of Electrical Energy Load For Average Household

Appliances	Unit Load (kW) [32]	Owned by hh	Total Load (kW)	Time (hours)	Percentage of time of use (%)	Energy Required (kWh/day)	Energy Required (kWh/year)
Day Time Load (From 5 AM TO 5 PM)							
Domestic Lighting	0.04	5	0.2	12	0.05	0.12	43.80
Cassette Recorder /Transistor	0.025	0.8	0.02	12	0.3	0.072	26.28
Refrigerator	0.13	0.2	0.026	12	0.3	0.0936	34.16
Electric Iron	0.75	0.5	0.375	12	0.01	0.045	16.43
TV Sets	0.05	0.8	0.04	12	0.2	0.096	35.04
Evening Time Load (From 5 PM TO 10 PM)							
Domestic Lighting	0.04	5	0.2	5	0.8	0.8	292.00
Refrigerator	0.13	0.2	0.026	5	0.3	0.039	14.24
TV Sets	0.05	0.8	0.04	5	0.8	0.16	58.40
Cassette Recorder /Transistor	0.025	0.8	0.02	5	0.1	0.01	3.65
Street Lighting	0.04	0.5	0.02	5	1	0.1	36.50
Night Time Load (10 PM To Morning 5 AM)							
Street Lighting	0.04	0.5	0.02	7	1	0.14	51.10
Domestic Lighting	0.04	5	0.2	7	0.1	0.14	51.10
					TOTAL	**1.70**	**662.69**

With the above mentioned approach the calculation of average load for a family is estimated in table 3.7. The population of village is 1150 and number of households (hh) are 184. The houses in the village are of 2, 4 and 6 rooms depending on the size of family and economic condition. There were 1 or 2 rooms for keeping cattles. On average rooms per households is five (5). Each of the rooms is estimated to have a bulb or tubelight having 40 W average capacities. It is assumed that each of the household will have a music system/ transistor. It is also assumed that TV shall be owned by 80% of the families and Electric iron by 50 % of the families. The street light is taken to have a density of one light per four house hold. The fan load has not been considered as the village lies in sub-temperate zone and experiences heavy snowfall during winters. The use of refrigerator by 20% of tl population is considered due to its use for preservation of milk products. The load factor incorporated by assuming the percentage of time a particular application is likely to be use

Total Annual energy requirement for 184 household = 184 x 662

=121808 kWh

Non Residential Load

The total daily requirement of non residential load is estimated to be 1.8 kWh and i presented on table 3.6.

Table 3.8: Estimation of Daily requirement of non residential load

Location	No. of Rooms	No. of Light Points	Load in kW @0.04	Use Hours per day	Annual days of use	Load (kWh/year)
Social Institution						
Primary School	5	10	0.4	8	300	960
Angan Wadi School	2	4	0.16	8	300	384
Place for Worshiping	2	4	0.16	6	365	350
				Sub Total		**1694.4**
Commercial Institution						
Horticulture Farm	4	4	0.16	8	365	467.2
Medicinal Plant Nursery	2	2	0.08	8	365	233.6
				Sub Total		**700.8**
				TOTAL		***2395.2***

The village has one place of worship, a primary school and an Anganwadi centei for pre schooling. In addition to that a medicinal plant nursery is run by a Non Governmental Organisation (NGO). A Government potato seed farm has also been established in the village periphery. The electricity load of schools and place of worship has been taken for 8 hrs for 300 days and 6 hours for 365 days respectively.

Total Annual electricity load for non residential building =2395 *kWh*

The total lighting load is therefore (121808+2395) = 124203 kWh/year considering residential and non residential load.

3.5.2 High Grade Energy for Cooking Needs

The requirement of heat energy for cooking is the prime need of the villagers and it is met by the biomass collected from the forest. The high grade heat requirement for cooking is taken 0.594kWh per person per day [48]. Energy requirement for 946 adults is 946 x 0.594, which comes out to be 561.92kWh. Energy requirement for child is taken equal to half of the energy requirement for adult and is 206 x 0.594/2 and is equal to 61.18 kWh. So total energy required for cooking is 623.10kWh/day and total annual energy required for cooking is 623.1 x 365= 227431.5kWh.

3.5.3 Mechanical Load

The water lifting for drinking and irrigation require mechanical energy. The region encompassing the village under study is rich in spring water which emanates from earth and most of the villages are established near such source. The *Ramani* village has got large number of such sources in the village itself so water lifting for drinking is not needed. The lifting of water for irrigation is not economically due to unfavorable geography of the region. In fact the natural steep inclination of the region and availability of water stream make it perfect gravity driven irrigation and water supply schemes rather than lift schemes. Hence energy for this purpose is not considered or estimated.

The villagers require mechanical energy in the form of rotating shaft for grinding flour and rice de-husking. The de-husking of rice is being done manually by hitting paddy by wooden log in stone carved container called *"Urkhyala"* in local language. The grinding floor is done in a better and convenient way than de-husking paddy. For this purpose the use traditional water mills called "*Gharats*" is very popular. These water mills are low in efficiency and difficult to maintain.

In absence of availability of any authentic data on the energy requirement and considering the difficulty in assessing the actual requirement of mechanical energy it is assumed that a flour mill of 5 kW and rice de-husking machine of 5 kW will be enough for their mechanical energy requirements. Their use is expected to be not more than 4 hours a day for 300 days a year.

Total mechanical energy required is therefore as follows:

For flour grinding:-

Energy required= 5 kW x 4 Hours = 20 *kWh/day*

For rice de-husking:-

Energy required= 3 kW x 4 Hours = 12 *kWh/day*

Total Annual Mechanical energy required = 32 x 300 *kWh/year*

=9600 *kWh/year*

3.6 SUMMARY OF RESOURCES AND ENERGY NEEDS

The total energy resources available and energy estimated have been presented i table 3.9. The estimation of energy is on the basis of values of efficiency of hydro as 65% BES 35%, WEC 35% and SPV 12 %. The load factor for hydro and BES is taken as 0.85.

Table 3.9: Total Energy Resource Potential and Energy Estimated

SL. No.	Renewable Energy Systems	Resource Available	Energy Estimated
1	Micro Hydro Power (kWh/year)	292180	149011
2	Solar Energy (kWh/year)*	1503	162
3	Wind Energy (W/m^2)**	16	5
4	Biomass Energy (Biogas) (kWh/year)	385994	347394
5	Biomass Energy (Producer Gas) (kWh/year)	149324	44423

* For one(1) kW System ** For one sq, m.

The category wise requirement of various energy needs has been shown in the tabl 3.10.

Table 3.10: Total Energy Requirements

SL. No.	Energy Need	Energy Required (kWh/year)
1	Lighting	124203
2	Heat(Cooking)Energy	227431
3	Mechanical Energy (Grinding Grains)	9600
	TOTAL	**361234**

On comparing the total energy available and total load it is apparent that electricit requirement can be met by MHP and the biomass energy conversion system (BES). Th biogas is not enough to meet the cooking need. But cooking energy can however b fulfilled by the surplus electricity from MHP or BES or by using biomass by way of direc burning in improved cook stoves.

CHAPTER-4

COST OF ENERGY AND SIZING OF SYSTEM

4.1 GENERAL

The potential of renewable energy sources such as micro hydro energy, biomass energy, wind energy and solar energy have been assessed for the study area in Chapter-3. The efficiency of conversion of various resources to various needs is estimated. The sizing of various renewable energy conversion systems has been done based on resource potential available and efficiency of utilization of resources. The cost analysis of MHP, biomass, wind and SPV system has been carried out in this chapter. Lastly the various readily available renewable energy conversion systems are looked for and comparison of size of the required system is done with that of readily available system ratings.

4.2 EFFICIENCIES OF VARIOUS ENERGY CONVERSION SYSTEMS

Each of the renewable energies can be converted to meet the variety of end needs and each of such combinations of conversion will have different efficiency. For example hydro energy can be converted to mechanical, electrical and heat energy through a series of conversions. The hydro energy can be converted to rotating shaft power by turbine which can be utilized or can be further converted to electrical energy by coupling generator for lighting use. The use of electrical energy can be done for cooking by hot plate at consumer end. At every down stage of energy conversion there will be loss of efficiency. The utilization of energy at each of the stage can be done as per the requirement of that kind of energy as it would be imprudent to first generate electricity then convert it to rotating shaft power by using electric motor and waste energy when the rotating shaft power is directly available from turbine output. This will enable us to achieve maximum possible efficient utilization of resources by avoiding some of the energy conversions.

Similarly Biogas can be used for cooking directly in gas burner or it can be used for generating rotating shaft power and electricity by Duel fuel engine. The solar PV cells are suitable for generating electricity which can be further quite conveniently used for water lifting. However the use of solar energy for cooking purpose using hot plate will be quite costly. Wind as hydro power is most suitable for rotating shaft power and electricity. In order to assess the suitability of each of the energy sources for each of the needs it will be imperative to find the energy conversion efficiency of each of the stage. In order to arrive at the efficiency at any stage the efficiency of all succeeding conversion efficiency is multiplied and is done as follows:

For Hydro

η_{hy-m} - (Efficiency of hydro to mechanical energy conversion)

$\eta_{hy-e} = \eta_{hy-m} \times \eta_{m-e}$ (Total efficiency of conversion to electrical energy)

$\eta_{hy-h} = \eta_{hy-m} \times \eta_{m-e} \times \eta_{e-h}$ (Total efficiency of conversion to heat energy)

For Biogass (BGS)

η_{b-h} - (Efficiency of Biomass to heat energy conversion)

$\eta_{b-m} = \eta_{b-h} \times \eta_{h-m}$ (Total efficiency of conversion to mechanical energy Using Dual Fuel Mode Diesel Generating Set)

$\eta_{b-e} = \eta_{b-h} \times \eta_{h-m} \times \eta_{m-e}$ (Total efficiency of conversion to electrical energy)

For Biomass(BES)

η_{bes-m} Efficiency of Biomass (BES) to mechanical output Using Engine

$\eta_{bes-e} = \eta_{bes-m} \times \eta_{e-m}$ Efficiency of Biomass (BES) to electricity :

For Wind

η_{w-m} - (Efficiency of wind to mechanical energy conversion)

$\eta_{w-e} = \eta_{w-m} \times \eta_{m-e}$ (Total efficiency of conversion to electrical energy)

$\eta_{w-h} = \eta_{w-m} \times \eta_{m-e} \times \eta_{e-h}$ (Total efficiency of conversion to heat energy)

For Solar

η_{pv-e} - (Efficiency of PV cells to electrical energy conversion)

$\eta_{pv-m} = \eta_{pv-e} \times \eta_{e-m}$ (Total efficiency of conversion to mechanical energy)

$\eta_{pv-h} = \eta_{pv-e} \times \eta_{e-h}$ (Total efficiency of conversion to heat energy)

Using above mentioned approach the efficiency at every stage of conversions for all the available resources is determined. The efficiency of hydro to mechanical is assumed to be 70% considering some of the energy would be lost in civil structures works like channel, penstock, etc. and turbines. The best turbines can have hydraulic efficiencies in the range 80 to over 90% (higher than most other prime movers), although this will reduce with size. Micro hydro systems tend to be in the range 60 to 80% efficient [44]. The efficiency of generator to convert mechanical shaft output power to electricity is assumed 95% for all the resources. Similarly the conversion of electricity to heat is 70% which is the conversion efficiency associated with the electric hot plate [53]. The conversion of solar PV energy from electricity to cooking is quite illogical when the other rational method of using solar concentrator (Cooker) is available, so its value is taken zero for computational purpose. Similarly, BES is suitable for electricity generation and/or obtaining rotating shaft power. Its use as heat for cooking is taken as 40% as it can be used by directly in improved stoves.

The efficiencies of conversion of biogas to heat for cooking and solar PV to electricity are available in the literature while the efficiency of wind energy conversion is assumed.

For Hydro

Efficiency of hydro to mechanical energy conversion[(a)] : $\eta_{hy-m} = 65\%^a$

Efficiency of mechanical energy to electricity[(a)] : $\eta_{m-e} = 95\%^b$

Efficiency of electricity to heat for cooking[53] : $\eta_{e-h} = 70\%$

For Biogas(BGS)

Efficiency of Biogas energy to heat (for cooking) [45] : $\eta_{bgs-h} = 45\%$

Efficiency of Biogas to mechanical output using generator[(a)]: $\eta_{h-m} = 38\%$

Efficiency of Biogas to electricity [48] : $\eta_{bgs-e} = 35.2\%$

For Biomass(BES)

Efficiency of Biomass (BES) to mechanical output Using Engine[(a)] : $\eta_{bes-m} = 38\%$

Efficiency of Biomass (BES) to electricity [48] : $\eta_{bes-e} = 35.2\%$

For Wind

Efficiency of Wind to mechanical energy conversion[(a)] : $\eta_{w-m} = 35\%$

Efficiency of mechanical to electrical[(a)] : $\eta_{m-e} = 95\%$

Efficiency of electrical to heat for cooking[45] : $\eta_{e-h} = 70\%$

For Solar

Efficiency of Solar to electrical energy conversion [1] : $\eta_{pv-e} = 12\%$

Efficiency of Solar to Mechanical energy[(a)] : $\eta_{pv-m} = 10\%$

(a) Assumed

While the conversion efficiency of various resources to meet various demands as determined above has been presented in table 4.1.

Table 4.1: The Efficiencies of various conversion systems

Needs / Resources	Mechanical	Electrical	Heat
Hydro (MHP)	0.65	0.60	0.42
Biomass (BGS)	0.38	0.35	0.45
Biomass (BES)	0.38	0.35	0.40
Wind	0.35	0.33	0.23
Solar (PV)	0.10	0.12	

4.3 SIZING OF SHP

The general formula for any hydro system's power output is given in equation 4.1 [43].

$$P = \eta \times \rho \times g \times Q \times H \qquad 4.1$$

where P is the mechanical power produced at the turbine shaft (Watts), 'η'' is the hydraulic efficiency of the power plant including the losses in civil structures, turbines and generator, ρ is the density of water (kg/m^3), g is the acceleration due to gravity (m/s^2), Q is the volume flow rate passing through the turbine (m^3/s), and H is the gross head (m).

The head available at a site can be measured using altimeter or other survey techniques. It is the value of discharge that has crucial impact on the optimal sizing of hydro power plant due to the fact that its availability changes with time. Besides the output power has to be matched with the availability of load, which is again ever changing. The determination of optimal capacity of small hydro plant of run off river is very useful in obtaining optimal energy value. To determine optimal installation capacity of SHPs all technical, economic and reliability indices are to be considered in a trade off relations. It is observed that with the increase in the number of generation units or capacity more investment will be needed and shall be reflected in higher tariff cost if it could not be utilized fully. This will, however, improve the reliability index but reduces plant load factor [55].

The remote areas which are not connected with grid require reliable power. Hence, the generation capacity can be fixed at lowest available discharge which would be available 100% throughout the year. Base on that the total capacity of MHP estimated to be 21kW.

The standard sizes Pelton micro hydro turbines available are presented in table 4.2

Table 4.2: The Standard Pelton Micro Hydro Turbines Available in India[58]

	Runner Dia. (mm)	**Runner Dia. (mm)**	**Runner Dia. (mm)**	**Runner Dia. (mm)**	**Runner Dia. (mm)**
	225	275	350	425	450
Head (m)	**Turbine Output (kW)**				
40	17	26	41	61	68
50	23	35	57	86	96
60	31	48	75		
70	40	62	94		
80	47	73			
90	56	87			

It is evident that a wide range of standard turbines are available in India but these standard turbines are available for various combinations of head and runner diamater. It can be seen that turbines available for 70 to 90 meter heads have capacities ranging from 47 to 80 kW and none of the standard turbine is suitable. the choice of turbine suitable for particular head and discharge is limited.

The turbine required for the site is of 21 kW capacity suitable for 85 meter head and 0.04 m^3/sec discharge. However the turbine for the site can be manufactured to suit the site and a twenty (20) kW turbine is considered for the village. The energy 122640 kW can be generated with it at 0.7 plant load factor.

4.4 SIZE OF BIOMASS Plant

4.4.1 Biomass Gasifiers

The biomass from forest to the tune of 149325 kg/day as assessed in chapter-3 will provide energy 149324 kWh/day[1]. To utilize biomass for electricity generation for six hours a day due to technological & operational limitation and load profile in use of engine continuously the Producer gas generator of size 45 kW electrical output is estimated and used for assessment of cost of energy.

The commonly used small capacity diesel engines in India are of ratings 3 kW, 5kW, 7.5 kW, 12.5kW, 16 kW, 24 kW and 48 kW. The producer gas can be used as a duel fuel mode in any of the Diesel generator by incorporating appropriate size of gasifier. The capacities of readily available gasifiers are shown in table 4.4. Some of the manufacturers have standardized their 100% producer gas engine as shown in table 4.3. The standard ratings of gasifiers available are shown in table 4.4.

It can be seen that 45 kW producer gas generator is not readily available. Either lower capacity 32 kW set or of higher capacity 80 kW set can be selected. But opting for lower capacity set will entail unsatisfied customers while the higher size will lead to loss of power. Both the choices are uneconomical. It would be more appropriate to have a 10 kW and one 32 kW hundred percent producer gas engine. This will have the flexibility in operation and meeting peak load and/or adverse load profile. The output will however can remain same by way of adjusting the time of use minimally as compared to the adjustment of time required had 80 kW generator is selected

Table 4.3 :Capacities of 100% Producer Gas Generator Available in India

Rated Woody Mass Consumption (kg/hr)	Electrical Output (kW)
15	10
50	32
120	80
180	120
240	160
340	240
480	320
600	400

Table 4.4 :Capacities of Gasifiers For Thermal Application Available in India

Rated Woody Mass Consumption (kg/hr)	Thermal Application (kWe)
20	20
50	50
75	75
120	120
180	180
270	270
360	360
480	480
600	600

4.4.2 Biogas Digestor

The sizing of biogas plant is based on the output of dung yield as determined in Chapter-3. A biogas digester for capacity of utilizing cattle dung 1 kg/day is designed and presented in table 3.5. The density of mix is assumed 1090kg/m3 after mixing of water in the ratio of 1:1. The retention period is taken 55 days on higher side due to higher altitude of the region of study. The Gas yield per kg of wet dung is taken 0.036 m^3 /kg [11] and Calorific value of biogas is 4700 kcal/m^3 [28]

Table 4.5 : Sizing of Biogas Digester for unit capacity

1	mass of wet dung	kg/day	m	1
2	1 kg of wet dung yield 0.036m3 of gas so m kg would yield	M3	m x 0.036	0.036
3	Energy Output	kWh/day	(mx0.036x 4700)/860=	0.1967
4	Add water in equal quantity		2xm	2
5	Density of mix	Kg/m3	ρ	1090[a]
6	Volume of mix	M3	2xm/ρ	0.002
7	Volume of digestor	M3	2xmxRd/ρ	0.10[a]
8	Additional volume for storage 60% of vol of digester	M3	0.6 x2xmxRd/ρ	0.06
9	Total Volume of Digester in m3	M3	(7)+(8)	0.16
10	So 1 m3 of digestor can produce	kWh/day	(3)/(9)	1.22
11	Or 1 kWh energy require volume of digester equal to CF_{kWh-m3}	M3/day	(9)/(3)	0.821

[a] Assumed, ρ=1090kg/m3 and Retention days,Rd=55 days

It can be seen that one m^3 of biogas digester can yield 1.22 kWh/day of energy and one kg of cattle dung give up 0.1967 kWh of energy. Based on the above calculation to utilize the full available potential of cattle dung of 5375 kg/day the total aggregate capacity of Biogas digester required for the village under study is 860 m^3. It will produce biogas 193 m^3/day which can yield energy 1057 kWh/day (385994 kWh/year).

The standard sizes of biogas digesters have been designed in wide range of capacities starting from 1,2 and 3 m^3 family size digester to 85 m^3 of community size plant. As the cattle dung is available in large quantity it will require very large number of biogas digester if family size digesters are selected. This will require large space and will be expensive. It is therefore proposed to have a numbers of large community size biogas digesters of total capacity of 860 m^3 for the village.

The standard sizes of biogas plants commonly used to utilize above potential are shown in Table 4.6. As it is evident that biogas digester are designed for large number of unit sizes starting from 1m3 to 85 m3 the required size of 860m3 can be achieved in multiple units of small sizes without any difficulty. It is proposed to have 10 numbers of 85 m^3 biogas digester and five 2 m^3 digester to the houses that lies in extremes of the village.

Table 4.6: Standard Sizes of Biogas Plants [1]

Category	Size of Digester / Plants (m^3)
Family size	1-10
Medium	10-30
Community size	30-85

4.5 SIZING OF SOLAR PV SYSTEM

As discussed earlier, a stand alone SPV system consists of a PV array, storage battery and electronic interface. The sizing of SPV system is to find the number and capacity of solar modules including batteries needed to reliably meet the load of a given area throughout the year as per the availability of solar insolation. The total capacity of the system can be determined by applying the concept of peak sun discussed inchapter-3 and the size can be determined by knowing how much resources are required to be satisfied in a cost effective and efficient way [36]. The equation 4.2 can be used for size determination.

$$SPV_R = P_{cap} \times \frac{H_{daily-av}}{H_{peak-sun}} (kWh/day)$$

$$E_{pv} = \eta_{PV} \times SPV_R \qquad 4.2$$

SPV_R Solar power resources

Under the present study to evaluate the unit cost of energy for the resources 5.012 kWh/m^2/day as determined in para 3.4.3 the capacity of panel is taken 1 kW assuming 12 % efficiency considered to evaluate the unit cost of energy[1].

The standard sizes of Solar PV panels available in India are from 5 W to 165W having 36 cells and output voltage of 12 volts. These panels can be configured in parallel and series to attain higher capacity. Due to its availability in lower unit sizes there is a flexibility in configuring bigger size.

4.5.1 Sizing Of Battery

The battery bank is sized to operate the loads during a sequence of below average insolation days, called the days of autonomy. In the design, days of autonomy is taken depending on the level of reliability required, which is normally two to three days. In battery sizing some other factors like maximum depth of discharge, temperature correction, rated battery capacity and battery life is considered. In this design depth of discharge is taken to be 65%. Temperature correction to account for decrease in battery efficiency at low temperature is taken 0.9. So the Required battery capacity in Ampere-hour (Ah) is given by expression 4.3 [39]

$$B_{rc} = \frac{E_{PV(Ah)} \times D_S}{(DOD)_{\max} \times \eta_T} \qquad 4.3$$

where,

D_s – is battery autonomy or storage days;(DOD)*max*- maximum battery depth of discharge; η_T - temperature correction factor and B_{rc} - Required storage capacity

For one (1) kW solar PV panel and peak sun of 5.012 hrs the energy required to store per day is 0.601 kWh or 0.05 Ah/day for a 12 V battery assuming 85 % efficiency. So for days of autonomy to be two the size of 12 V 30batteries required to be 1.42 Ah.

4.6 SIZING OF WIND TURBINE

Wind Turbine Average Power Output is the power produced at each wind speed multiplied by the fraction of the time that wind speed experienced.

Wind turbine relating power and wind speed is given by equation 4.4

$$P_w = \frac{1}{2} \times \eta \times C_p \times \rho \times A \times (v^3) \quad 4.4$$

As the wind potential in the study area is limited, therefore, the small capacity systems can be used to tap wind potential. In order to determine unit cost of the system a 3 meter long rotor diameter having efficiency is considered. At an average speed of 3 m/sec a 0 .5 kW wind turbine will yield 810 kWh/year assuming wind to be available 6 hours a day for 300 days in a year at load factor of 0.9..

The standard turbines available in India are of capacities 225 kW, 250 kW, 300 kW, 400 kW, 600 kW, 750 kW, 800 kW, 1000 kW and 1500 kW. In small capacities the turbines are designed as per site requirements..

4.7 COST OF ENERGY

It is essential to evaluate cost of energy of each of the energy conversion system to establish its viability. To evaluate project economically there are various techniques: like net present value method, internal rate of return method, return on investment, benefit cost ratio method and pay back period method. Out of these the Net present value methods are most commonly used. The Net Present Value Criterion (NPV) examines the cash flow of a project over a given period of time period and resolves them to one equivalent present date cash flow through the use of various economic factors. One mostly used such economic factor is capital recovery factor. The CRF resolves the cost of equipment in a series of annual cost taking into consideration the discount or interest rate and is given by expression 4.5 [16]

$$CRF = \frac{r(1+r)^n}{(1+r)^n - 1} \quad 4.5$$

Where "*r*" is the discount rate and "*n*" is the period of evaluation in years.

The Capital cost, Annual maintenance cost, fuel cost and replacement cost are taken into account to determine the cost of energy. As the fuel component in case of IRES does not exist only the annual capital cost or amortization cost and maintenance cost is considered. The same can be represented in a modified version of economic method 4.6a and 4.6b [42]

$$C_{an} = \sum_i \left[\frac{r(1+r)^n \times C_i \times S_i}{((1+r)^n - 1)} + m \times AEG_i \right] \quad 4.6a$$

$$COE = \frac{C_{an}}{AEG} \quad 4.6b$$

C_{an} , Amortization Cost in Rs; C_i, Capital cost of components per unit capacity; Si is the capacity or size of the energy conversion system, n, Life of the component in year; COE Cost of energy; m_i is the maintenance cost per unit energy generation and Annual energy generation *(AEG)* is given by equation 4.7 and unit cost of generation by equation 4.8. ('k' is the load factor)

$$AEG_i = \sum_i^m (k \times \eta_i \times w_i) \quad 4.7$$

$$COE_i = CRF \times \frac{C_i \times S_i}{AEG_i} + m_i \quad 4.8$$

For simplicity and to give a conservative estimate interest rates are quoted net of inflation at 7% (Discount rate 10% and General inflation 3%) [42] The life of Micro hydro unit, Biogas digester, Wind energy system and Solar PV is assumed to be 20 years. The capital recovery factor for all the components will therefore is as follows:

$$CRF = \frac{r(1+r)^n}{((1+r)^n - 1)} = 0.09439$$

The capital cost of Micro hydel, Producer gas (BES), Wind, Solar PV and D.G.Set units are taken Rs. 90/W, Rs 20/W Rs 125/W and Rs. 200/W , respectively. While the operating cost of Micro hydel, Producer gas (BES), Wind and Solar PV units are Rs.0.15/kWh, Rs.0.2/kWh Rs.0.1/kWh and Rs. 0.05/kWh, respectively[52. The per cubic meter cost of biogas digester is Rs. 4500 [63] and the operation cost is assumed to be Rs. 0.15 /kWh. The costs of energy from various sources as calculated above have been presented on table 4.7.

Table 4.7: Cost of Energy from Various Renewable Sources

ITEM	Unit	Resource				
		HYDRO	BES	BGS	WIND	SPV
System rating	KW and *m^3	20	42	860*	0.5	1
Ann. Energy generated,(AEG)	kWh/Year	149011	44423	347394	810	1352
Amortization period	Years	20	20	20	20	20
Capital Recovery Factor	CRF	0.09439	0.09439	0.09439	0.09439	0.09439
Cost per unit capacity	Rs/kW or **Rs/m^3	90000	20000	4500**	125000	200000
Annual Maintenance Cost,(m_i)	Rs/kWh	0.15	0.2	0.15	0.1	0.05
Cost of Energy (COE)	(Rs/kWh)	1.30	2.00	1.20	7.40	14

The unit cost of energy for MHP is 1.30 Rs/kWh, for Biomass energy system Rs.2.00 Rs./kWh, BGS is 1.20 Rs/kWh, Wind is 7.40 Rs./kWh and Solar PV is 14 Rs/kWh.

CHAPTER-5

OPTIMISATION OF RENEWABLE ENERGY CONVERSION SYSTEM

5.1 GENERAL

The harnessing of renewable energy is presented. The methodology is evolved to utilize the available renewable resources in a cost effective manner. In this regard the objective along with the resource and demand constraints are formulated mathematically which are then solved using appropriate method.

5.2 OBJECTIVE AND DESIGN

The aim is to satisfy all energy needs of remote villages in cost effective, reliable and appropriate manner by a stand-alone renewable energy conversion system/ systems utilizing the locally available energy resources. The renewable energy resources available are:

i Biomass

ii Hydro energy

iii Wind energy

iv Solar energy

The main energy needs of the villagers are:

i Medium grade heat energy for cooking

ii Rotating mechanical shaft energy

iii Electricity at 240 Volts

There are variety of resources and variety of demand. The following two approaches can be applied to achieve the above stated objective:

- Maximization of the investment efficiency. This case suits to the design problem for the area where the resources are in abundance and economic feasibility is the prime consideration.
- Maximization of the amount of energy annually produced from the available resources. This case suits to design problems for the area where the resources are meager and the objective is to exploit the highest possible energy potential of the area in order to cover the local demand.

Both the approaches have been adopted to achieve above stated objective. The cost minimization can be achieved by optimizing cost based objective function considering demand and resource constraints. For optimization of efficiency the critical issue is to resolve the resource need combination problem and matching of quality of energy resource to the quality of the energy need. The demand can be met either by converting all form of energies to a single form (say electricity) and then reconvert to the utilizable form of energy for end use. But there will be loss of energy in each of the conversion and result in suboptimal utilization of precious resources. The utilization of resources can be done in a manner that demand of energy for each of the tasks is met by the resources which has the lower cost and higher conversion efficiency. For that the efficiency calculation for each of the energy conversion has been assessed, which is incorporated in the objective equation.

5.3 OBJECTIVE FUNCTION

For the formulation of objective function η_{i-j} is expressed as the conversion efficiency of ith resources to satisfy jth energy needs; w_{i-j} is the ith resources to satisfy jth energy needs and is in kWh. C_{i-j} is the cost of ith resource in meeting jth task. The objective function to maximize the overall efficiency is shown in equation 4.1.

$$Maximize(Z_1) = \sum_{i=1}^{m}\sum_{j=1}^{n}\left[\left(\eta_{i-j} \times w_{i-j}\right)\right] \qquad 4.1$$

While the objective function to maximize the cost is given in equation 4.2

$$Minimize(Z_2) = \sum_{i=1}^{m}\sum_{j=1}^{n}\left[\left(C_{i-j} \times w_{i-j}\right)\right] \qquad 4.2$$

m and *n* are the number of resources and energy needs respectively.

Resource Constraints: The total energy supplied by each of the resources for various energy needs cannot be more than that of its availability. Hence, the sum of a resource is less than or equal to its maximum availability. This can be represented mathematically as expression 4.3

$$R_{i,\max} \geq \sum_{j=1}^{n} w_{i-j} \qquad 4.3$$

For, $i=1,2....m$

Demand Constraints: The sum of the product of energies supplied by various resources and its conversion efficiency for a given energy needs must be equal to the total requirement of the energy for that particular task. It can be mathematically represented as expression 4.4

$$L_j = \sum_{i=1}^{m} \left(\eta_{i-j} \times w_{i-j}\right) \qquad 4.4$$

For j=1,2.....n; L_j, is the load or energy needs of "j^{th}" task;

Non Negativity Constraints: All the resources must be equal or greater than zero. Mathematically it can be represented as equation 4.5.

$$w_{i-j} \geq 0 \qquad 4.5$$

For i =1,2,3.....m. and j =1,2,3.....n.

5.4 OPTIMIZATION EQUATIONS

The resources available and load demand as ascertained in Chapter-2 is utilized to arrive at the optimal configuration of the integrated renewable energy system (IRES). The wind energy conversion system is not used because of non availability of wind regime in the area. In the village under study the forest residue and waste is found to be the main source of fulfilling cooking need of the villagers and use of traditional *chulha* is prevalent. The use of wood is putting undue pressure in the forest which will increase with the growing population and demand of energy. With this view the forest waste and residue is considered one fourth of its present use. Thus four renewable sources of energy are available – Micro Hydro Power, Biogas, Biomass (Fuel wood for direct use or Through BES) and Solar PV. The energy requirements to be fulfilled are also three – Electricity, Mechanical and Heat (Cooking needs). The equation of optimization of efficiency is follows :

Maximize:

$$Z_1 = 0.60MHP_E + 0.65MHP_M + 0.42MHP_H + 0.35BGS_E + 0.38BGS_M + 0.45BGS_H$$
$$+0.35BES_E + 0.38BES_M + 0.45BES_H + 0.12SPV_E + 0.1SPV_M$$

The equation of cost minimization is as follows:

Minimize:

$Z_2 = 1.30MHP_E + 1.30MHP_M + 1.30MHP_H + 2.50BGS_E + 2.50BGS_M + 1.10BGS_H$
$2.50BES_E + 2.50BES_M + 0.5BES_H + 14SPV_E + 14SPV_M$

The cost of BGS for electricity and mechanical energy conversion is taken as calculated for BES system due to the requirement of similar system of conversion. Similarly for biomass to heat energy for cooking energy conversion the cost of wood collection is assumed to be Rs. 0.5 per kWh as the cook stove will act as conversion system.

Demand constraints:

$0.60MHP_E+0.35BGS_E+0.35BES_E+0.12SPV_E=124203$ kWh/year

$0.50MHP_H+0.45BGS_H+0.35BES_H=227431$ kWh/year

$0.65MHP_M+0.38BGS_M+0.38BES_M+0.10SPV_M = 9600$ kWh/year

Resource Constraints:

$MHP_E+MHP_M+MHP_H \leq 248353$kWh/year

$BGS_E+BGS_M+BGS_H \leq 347395$kWh/year

$BES_E+BES_M+BES_H \leq 126926$kWh/year

$SPV_E+SPV_M+SPV_H \leq 100000$kWh/year

The resource constraints have been arrived at by assuming the load factor for hydro 0.85 and biomass energy system is taken 0.85. For biogas it is assumed to be 0.9. There is no constraint in the quantum of solar insolation that can be harnessed as far as quantity is concerned. The numbers of solar panels are required to be increased as per the insolation available. Hence the solar energy resource is assumed to be 100000 kWh/day for the optimization purpose.

Non- negativity constraints:

$MHP_E \geq 0$; $MHP_M \geq 0$; $MHP_H \geq 0$

$BGS_E \geq 0$; $BGS_M \geq 0$; $BGS_H \geq 0$

$SPV_E \geq 0$; $SPV_M \geq 0$; $SPV_H \geq 0$

The above equations are linear and can be solved by linear programming. Besides, there are two objective functions with conflicting goals which can be solved by applying goal programming [21]. Initially the efficiency of various conversions as estimated earlier in the chapter-3 and cost of energy in as determined in chapter-4 are incorporated to form objective equations. This is then solved using "TORA Software".

On solving the above linear equations using "TORA SOFTWARE" the results of resource used for satisfying various energy needs are presented in table 4.1.

Table 5.1: The Results of Allocation of Resources as Per Optimization

	Resources Allocated for			Total Resources
	Lighting	***Heat (For Cooking)***	***Mechanical***	
Resources	***(kWh/year)***	***(kWh/year)***	***(kWh/year)***	***(kWh/year)***
HYDRO (MHP)	185172	48411	14770	248354
BIOGAS (BGS)	0	347395	0	347395
BIOMASS (BES)	0	126926	0	126926
SOLAR (SPV)	109164	0	0	109164
			TOTAL	831839

The electricity of the village is met by the MHP and SPV, Mechanical needs (rotating shaft energy) will be met by MHP and the MHP, BES and BGS will cater to the cooking load. The result of optimization prefers hydro and biogas due to their higher efficiencies and lower cost. Solar PV is chosen to the extent of only unfulfilled energy needs that could not be satisfied by the Hydro and biogas. The propose system can provide power to entire village with the renewable energy resources available locally. The optimized allocation of various resources for needs are as follows:

The output of hydro for electricity, MHP_E =185172 *kWh/year*

The use of hydro for Cooking, MHP_H =48411 *kWh/year*

The use of hydro for Mechanical energy needs, MHP_M =14770*kWh/year*

The use of Biomass for Cooking energy needs, BGS_H =347395*kWh/year*

The use of Biomass for Cooking energy needs, BES_H =126926*kWh/year*

The use of Solar PV Energy for electricity, SPV_E =109164 *kWh/year*

From the optimization it is emerged that electricity requirement can be met by MHP (111103 kWh/year) and solar PV (13100 kWh/year). The cooking energy need will be met by Biogas (156327 kWh/year), Biomass i.e fuel wood (50770 kWh/year) and MHP (20332 kWh/year). The mechanical energy requirement of the village can be met by MHP completely. Based on the assessment a SPV panel of 8.0 kW is required.

5.5 Cost of Energy

The unit generating cost of the electricity, Cooking energy and rotating shaft energy have been assessed based on equation as discussed in para 4.7. The costs are presented in table 5.1.

Table 5.1: Cost of Energy

Sl No.	Item	Cost
1	Electricity	2.64
2	Heat (Cooking Energy)	1.00
3	Mechanical (Rotating Shaft Energy)	1.30

CHAPTER-6

CONCLUSIONS

To study the use of Renewable energy resources for energy needs of rural area a remote village *Ramani* in *Chamoli* district of *Uttaranchal* has been selected village. The resources available locally and various energy requirements have been assessed. An attempt has been made to satisfy all the energy needs of the villagers from the available resources in most efficient and cost effective manner. A generalized optimization model for finding optimal combination of Integrated Renewable Energy System is developed to harness the renewable energy in remote area considering cost minimization and efficiency maximization. As a result of study following conclusions have emerged:

1 The hydro power potential in the village is estimated to be 149011 kWh/year, biogas potential to be 347394 kWh/year and the biomass (BES) potential has been assessed to be 44423 kWh/year. The Solar energy potential of 162 kWh/year from a one kW solar panel.

2 The demand of energy for lighting is 124203 kWh/year, for cooking 227431 kWh/year and for grain grinding 9600 kWh/year.

3 Based on the assessment done in this study the unit cost of energy for micro hydro (MHP) is 1.30 Rs./kWh, for Biomass conversion system (BES) is 2.00 Rs./kWh, for Biogas conversion system (BGS) 1.20 Rs./kWh, for wind is 7.40 Rs./kWh and for Solar PV 14 Rs./kWh.

4 In the concluding combination the ratings of various renewable energy systems is 20 kW for Micro Hydro Power, 860 m^3 for Biogas Digester. A SPV panel of 8.0 kW is required.

5 The model developed for the village has an optimized cost of energy is Rs.2.64 per kWh for electricity, for cooking 1.00 Rs/kWh and for rotating shaft Rs.1.30 per kWh.

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