

# **OPTIMAL RURAL MICROGRID SYSTEM USING HOMER**

*Thesis submitted in partial fulfillment of the requirements for the award of the degree  
of*

**MASTER OF ENGINEERING**  
in  
**POWER SYSTEMS & ELECTRIC DRIVES**

Submitted by

**Gerry**  
**(Roll No. 801141013)**

Under the supervision of

**Ms. Sonia**  
**Lecturer, EIED**



**JULY-2013**

**ELECTRICAL & INSTRUMENTATION ENGINEERING DEPARTMENT**  
**THAPAR UNIVERSITY**  
*(Established under section 3 of UGC act 1956)*  
**PATIALA-147004**

## CERTIFICATE

I hereby certify that work which is being presented in the Thesis entitled "**Optimal Rural Microgrid System using HOMER**" in partial fulfilment of the requirement for the award of degree of Master of Engineering in **Power Systems and Electric Drives** submitted in Electrical & Instrumentation Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under supervision of **Ms. Sonia**, Lecturer, EIED, Thapar University.

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



**Gerry**

(Roll No. 801141013)

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

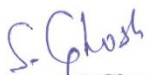


**Ms. Sonia**

**Lecturer, EIED**

Thapar University, Patiala

Countersigned by :



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



**Dr. S.K. Mohapatra**  
**Dean of Academic Affairs**  
Thapar University, Patiala

## Acknowledgement

First and foremost, I thank God, the Almighty for his strength and blessings to carry out this work.

I am feeling greatly obliged by **Dr. Smarajit Ghosh**, Professor & Head, Electrical and Instrumentation Engineering Department and **Ms. Manbir Kaur**, Associate Prof. & P.G. Coordinator, Electrical and Instrumentation Engineering Department, Thapar University for providing their generous help and inspiring guidance throughout this work.

I wish to express my deep gratitude to my guide **Ms. Sonia**, Lecturer, Department of Electrical and Instrumentation Engineering, Thapar University, Patiala, for her guidance, meticulous effort and inspiring encouragement which able me to enrich my knowledge and reproduce it in present form. There are no enough words to describe the debt I owe to my guide, for having created a stimulating atmosphere of academic excellence, the basic element of any long lasting endeavour.

I am also thankful to the entire faculty and staff members of Electrical and Instrumentation Engineering Department, for their direct and indirect help and cooperation.



Date : 12-07-2013

Place: Thapar University

(Gerry)

Roll No. 801141013

## **Abstract**

Energy is central to nearly every major challenge and opportunity the world faces today. Access to energy for all is essential for creating jobs, developing economies, increasing incomes, food production, security or climate change. Approximately one and a half billion people around the world, still lack access to electricity and the majority of them live in developing nations. Countries like India still face a severe energy crunch, with millions of rural inhabitant's still lacking access to secure and assured electricity, making this a development priority. The energy shortage is most acute among India's rural poor and in states such as Punjab, where more than 80% of the population still live in the rural areas; the majority of them still rely on conventional and traditional fuels for their energy needs. As governments and the energy sector seek to provide more modern and reliable energy services to these communities, there is a growing gap in the ever increasing demand and the shrinking supply of energy from conventional sources, as these are fast depleting.

To facilitate energy access and a clean energy transition, a new approach has to be thought about. However, microgrid could be a useful concept for accelerating current rural electrification efforts, support renewable energy integration into energy systems, and create a reliable electricity system. In this thesis the optimal cost analysis of hybrid renewable energy system is done using Hybrid Optimization Model for Electric Renewable (HOMER). The HOMER energy modeling software is a powerful tool for designing and analyzing hybrid power systems, which contain a combination of conventional generators, wind turbines, solar photovoltaic's, hydropower, batteries, fuel cells, biomass and other inputs. It is currently used all over the world by tens of thousands of people. In this thesis real time optimal cost analysis is done based on the load profile, solar radiation and wind speed which was collected from village Jhalkari in District Patiala, Punjab in India for both grid-tied and off-grid system. A comparison is shown based on per unit cost of electricity production, operating cost found by simulation results. Moreover, the optimization of system is obtained by varying the sensitivity variables like solar radiation, wind speed etc. Cash flow summary of the hybrid renewable energy system is obtained which will be useful for the optimal cost allocation of each individual component present in the system.

# TABLE OF CONTENTS

S.No.	CONTENTS	PAGE NO.
	<i>Certificate</i>	<b>i</b>
	<i>Acknowledgement</i>	<b>ii</b>
	<i>Abstract</i>	<b>iii</b>
	<i>Table of Content</i>	<b>iv</b>
	<i>List of figures</i>	<b>vii</b>
	<i>List of Tables</i>	<b>ix</b>
	<i>List of abbreviations</i>	<b>x</b>
	<b>CHAPTER 1 INTRODUCTION</b>	<b>1-12</b>
1.1	Overview of Microgrid	1
1.2.	Historical Perspective	3
1.3	Literature review	4
1.4	Role of Renewable Energy in India	8
1.5	Current Scenario of Renewable Energy	9
1.6	Objective of Thesis Work	12
1.7	Organisation of Thesis	12
	<b>CHAPTER 2 MICROGRID ARCHITECTURE</b>	<b>13-32</b>
2.1	Overview	13
2.2	Microgrid Service area	13
2.3	Microgrid configuration	15
2.3.1	DC Coupled Microgrid	15
2.3.2	AC Coupled Microgrid	16
2.3.3	AC and DC Coupled Microgrid	17
2.4	Modes of Microgrid	17
2.5	Power Generation Equipment for Microgrid	19
2.6	Renewable Energy Technologies	20
2.6.1	Photovoltaic Array	21
2.6.2	Wind Energy Conversion System	22
2.6.2.1	Wind turbine operation system	23

2.6.2.1.1 Constant speed wind turbine	23
2.6.2.1.2 Variable speed wind turbine	24
2.6.3 Hydro Power	26
2.6.4 Biomass Energy	28
2.6.5 Reformed Biogas Fuel cell	30
2.7 Distributed Storage Technologies	31
<b>CHAPTER 3 HYBRID MICROGRID SYSTEM</b>	<b>33-45</b>
3.1 Microgrid vision	33
3.2 Evolution of Energy Modernisation	34
3.3 Microgrid Energy Management	37
3.3.1 Microsource Controller	37
3.3.2 Control Function for Microsource Controller	38
3.3.2.1 Active and Reactive control	38
3.3.2.2 Voltage Control	39
3.3.2.3 Storage Requirement for Fast Load Tacking	40
3.3.2.4 Load Sharing through P-f Control	40
3.3.3 Central Controller	41
3.3.3.1 Energy Management Module	42
3.3.3.2 Protection Co-ordination Module	43
3.4 Control strategy for switching operation	43
<b>CHAPTER 4 MODELLING OF HYBRID RENEWABLE ENERGY SYSTEM</b>	<b>46-52</b>
4.1 Design overview	46
4.2 Benchmark HOMER Design Schematic	46
4.3 Assessment of Renewable Energy Resources	48
4.3.1 Solar Irradiance and PV array	48
4.3.2 Wind Speed and Wind Turbine	49
4.3.3 Hydro Resources and Micro Hydro Turbine	50
4.3.4 Biomass Resources and Biomass Generator	50
4.3.5 Reformed Biogas Fuel Cell	51
4.4 Converters	51
4.5 Batteries	51
4.6 Assessment of System Demand	52
<b>CHAPTER 5 OPTIMIZATION OF MICROGRID USING HOMER</b>	<b>53-68</b>
5.1 General	53

5.2 Technical Terminology	54
5.3 Optimal Generation Mix	55
5.3.1 Off-grid / Islanding Mode of Power Generation	55
5.3.1.1 Simulation	56
5.3.1.2 Detail Contribution of DERs	56
5.3.1.3 Cost Summary	57
5.3.1.3 Emission Rate	58
5.3.2 Grid Connected Power Generation	58
5.3.2.1 Simulation	59
5.3.2.2 Detail Contribution of DERs	59
5.3.2.3 Cost Summary	60
5.3.2.4 Emission Rate	60
5.3.2.5 Grid Exchange	61
5.4 Comparison Study	62
5.5 Analysis of Grid Connected System	63
5.4.1 Analysis of PV array	63
5.4.2 Analysis of Hydro generator	64
5.4.3 Analysis of Biogas generator	64
5.4.4 Analysis of Converters	65
5.4.4 Evaluation of Energy Production	65
<b>CHAPTER 6 CONCLUSIONS &amp; FUTURE SCOPE</b>	<b>69</b>
6.1 Conclusion	69
6.2 Future work	69
<b>APPENDIX</b>	<b>70</b>
<b>REFERENCES</b>	<b>71-73</b>

## LIST OF FIGURES

<b>S.No.</b>	<b>TITLE</b>	<b>PAGE NO.</b>
Figure 1.1	Architecture of Microgrid	2
Figure 1.2	India energy challenge	11
Figure 2.1	Microgrids on a Radial Distribution System	14
Figure 2.2	DC Coupled Configuration	16
Figure 2.3	AC Coupled Configuration	16
Figure 2.4	AC and DC Coupled Microgrid	17
Figure 2.5	Evolution of global cumulative installed capacity, 2000-2011	22
Figure 2.6	Variable speed pitch-regulated wind turbine	25
Figure 2.7	Indian commutative wind installation (MW)	26
Figure 2.8	World hydropower Technical resources potential	27
Figure 2.9	Share of global installed biomass capacity in 2011	29
Figure 2.10	Reformed Biogas Fuel Cell	31
Figure 2.11	Annual fuel cell usage	31
Figure 3.1	Process overview of supply system design	34
Figure 3.2	Microgrid technology evolution ranges from strategic energy efficiency	35
Figure 3.3	Microgrid architecture and controllers	37
Figure 3.4	Basic scheme for typical Microsource controller	39
Figure 3.5	Droop characteristics for V-Q droop controllers	40
Figure 3.6	Active power versus frequency droop characteristics	41
Figure 4.1	Simulation model	47
Figure 4.2	Global horizontal radiation of study area	48
Figure 4.3	Monthly average wind speed	49
Figure 4.4	Monthly average stream flow	50
Figure 4.5	Monthly average biomass availability	51
Figure 4.6	AC load Profile	52
Figure 5.1	Flow chat for optimization	53
Figure 5.2	Cost optimization using HOMER for islanding mode	56
Figure 5.3	Percentage wise contribution of DERs in islanding mode	56
Figure 5.4	Monthly average electricity production	57

Figure 5.5	Net present cost of islanding mode	58
Figure 5.6	Cost optimization using HOMER for grid-connected system	59
Figure 5.7	Contribution of DERs in grid connected system	59
Figure 5.8	Monthly average electricity production	60
Figure 5.9	Cost summary in grid connected system	60
Figure 5.10	Photovoltaic Output (kW) at hours of day vs. months of year	64
Figure 5.11	Hydro generator output (kW) at hours of day vs. months of year	64
Figure 5.12	Biogas generator output (kW) at hours of day vs. months of year	65
Figure 5.13	Inverter output (kW) at hours of day vs. months of year	65
Figure 5.14	Power production by different DERs in a month	66
Figure 5.15	Power production by different DERs in a day	66
Figure 5.16	Total electrical load served daily profile	67
Figure 5.17	Grid sale and purchase with power vs. month of January	67
Figure 5.18	Total load and load served with power vs. month of January	68
Figure 5.19	Monthly average of excess of electricity production	68

## LIST OF TABLES

S.No.	Name of Tables	Page No.
4.1	Cost detail of Reformer, Hydrogen Tank, Fuel Cell	51
4.2	Battery Constraints	52
5.1	Emission Rate of Pollutant in Off-Grid Connected system	58
5.2	Emission Rate of Pollutant in Grid Connected system	61
5.3	Grid Power Exchange	61
5.4	Comparison of cost of both systems	62
5.5	Comparison Electricity Transaction of both the systems	62
5.6	Emission Rate of both the systems	63

## LIST OF ABBREVIATIONS

DERs	Distributed Energy Resources
SCB	Section Circuit Breaker
DG	Distributed Generation
RE	Renewable Energy
MPPT	Maximum Power Point Tracking
WECS	Wind Energy Conversion System
TSR	Tip Speed Ratio
RBFC	Reformed Biogas Fuel Cell
CHP	Combined Heat and Power
CC	Central Controller
LC	Load Controller
MCs	Microsource controllers
UPS	Uninterrupted Power Supply
EMM	Energy Manager Module
PCM	Protection Co-ordination Module
AC	Alternation Current
DC	Direct Current
NPC	Net Present Cost
COE	Cost of Electricity
O&M	Operation and Maintenance



# CHAPTER 1

## INTRODUCTION

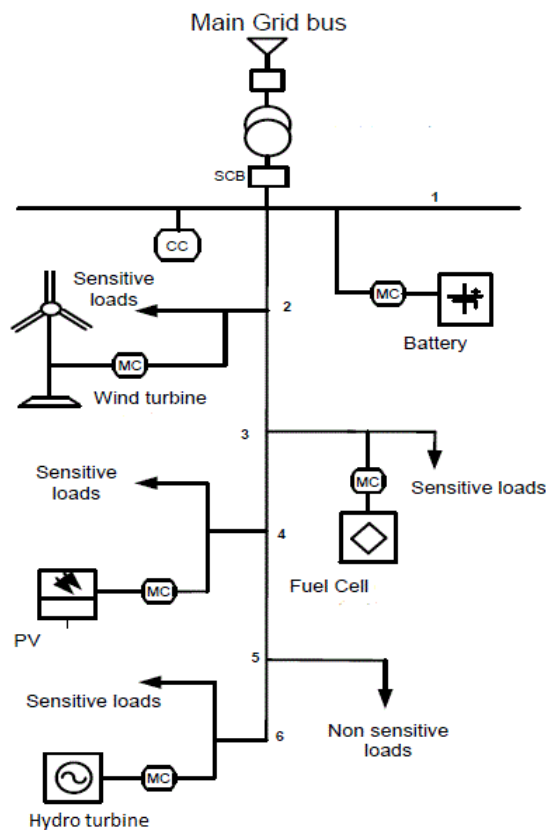
### 1.1 Overview of Microgrid

A microgrid is a small power system composed of one or more distributed generation units that can be operated independently or connected to utility. The microgrid is a small-scale, flexible, reliable source of electricity. It is connected to both local generating system units and utility grid to prevent from outages. Microgrid may range in size from a tiny residential load to small city.

As energy generation and distribution companies are competing in the market place, we have seen an increasing interest in renewable or non-conventional energy sources. In addition to this competition, companies are seeing demands from customers for higher quality and cleaner electricity. As we know that the world's coal stocks are reducing and new legislation are made for the use of greener energy solutions, we are led to seek new alternate sources of energy generation. One solution which is currently attracting attention are microgrid systems which is comprised of distributed energy resources (DERs) such as solar cells, wind turbines, micro-turbines, biogas turbine, fuel cells and storage batteries. There are several reasons why microgrids are increasingly used. First, because they use alternate energy resources, which are more environmentally friendly with lower carbon footprints and improve the reliability and power quality. Further, they have smaller financial commitments and require fewer technical skills to operate as they rely more on automation. Finally, it is the only option if new or upgraded transmission infrastructure cannot be developed in a timely or cost effective fashion. Alternatively, it can provide high quality, uninterrupted power supply as needed by many companies who use highly sensitive equipment.

The on-site generation sources give ability to isolate the microgrid from a larger network and provide highly reliable electric power. By-product heat from generation sources such as micro turbines could be used for local process heating or space heating, allowing flexible trade off between the needs for heat and electric power. Microgrids were proposed in the wake of the 30 and 31 July 2012 blackout in India. This outage affected over 620 million people, about 9% of the world population or half of India's population spread across 22 states in Northern, Eastern, and Northeast India.

Modern microgrid is an integrated energy system consisting of interconnected loads and distributed energy resources which can operate in parallel with the grid or in an intentional island mode. In the microgrid, alternative energy sources such as renewable can be integrated with local consumptions and are more efficient and initiate less environmental issues. This, in turn, enables performance optimization and enhances the supply reliability. As microgrid is near the load which will make less transmission loss, this makes microgrid even more effective. Finally, micro grids can be modified according to the needs of the site which it will be servicing. Fig 1.1 represents Architecture of the microgrid. The developed microgrid consists of six buses and composed of a battery connected to bus 1, a 10kW rated Wind Electric Generation System located at bus 2, a Solid Oxide Fuel Cell connected to the bus 3, a PV array connected to the bus 4 and a Hydro generation system connected to the bus 6. In the microgrid simulation model, inverters play a vital role by interfacing microsourses with the AC power side. There is a section circuit breaker (SCB), which is used to achieve a smooth transition between grid-connected to islanding mode and vice versa [1].



**Fig 1.1: Architecture of Microgrid**

## 1.2 Historical Perspective

The concept of the microgrid, which is receiving much attention today, is not a new idea. In fact, Thomas Edison's first power plant constructed in 1882 (the Manhattan Pearl Street Station) was essentially a microgrid since a centralized grid had not yet been established. By 1886, Edison's firm had installed fifty-eight direct current (DC) microgrids. In fact, as late as 1918 about half of the customers in the country (in most towns and small cities) were still receiving their power from small-scale isolated power systems with generation plants. The areas served were less than a few kilometers, and the power systems in individual towns were not interconnected with each other. Therefore each town operated as an independent island mode. Many early microgrids were not particularly reliable because only one power plant supplied all of the energy. If that plant failed, then the whole system was down. Early power system engineers considered interconnecting some of the systems to improve reliability. The idea was that if one town's power was out due to a problem at the plant, then the adjacent town would be available to pick up the load. It was also discovered that by interconnecting isolated systems, a greater diversity of load was obtained, which led to improved load factor and more economical operation of the generation plants. But, it is easy to connect different microgrid as they were operating at various frequencies ranging from 25Hz to 100Hz. Methods of synchronization, protection, and control of remote plants were also still in their infancy then, so this was a barrier to interconnection as well. Between 1910 and 1920, various technological innovations and other factors set in motion the movement away from the early microgrids and follow towards a system based upon increasingly large-scale central-station plants. Early microgrids were phased-out during 1910-1950 era due to government policy and performance advantages of bulk power system.

During the last three decades of the twentieth century, various factors have increased interest in the use of distributed generation and in perhaps returning to the more widespread use of microgrid. Due to technical improvements in distributed generation (DG) technologies during the 1980s and 1990s, the need for increasing reliability/power quality in power systems, deregulation of the power industry and an increasingly constrained T&D system have promoted distributed generation.

### 1.3 Literature Review

**J. Zhenhua** *et.al* [2] has presented the Integration of wind turbines and photovoltaic systems with grid leads to grid instability. One of the solutions to this problem can be achieved by the implementation of microgrid. Even though there are several advantages associated with microgrid operation, there are high transmission line losses. In a microgrid there are several units which can be utilized in a house or country. In a house renewable energy resources and storage devices are connected to DC bus with different converter topology from which DC loads can get power supply. Inverters are implemented for power transfer between AC and DC buses. Common and sensitive loads are connected to AC bus having different coupling points. During fault in the utility grid microgrid operates in islanded mode. If in any case renewable source can't supply enough power and state of charge of storage devices are low microgrid disconnects common loads and supply power to the sensitive loads.

**F. Katiraei** *et.al* [3] has given the microgrid concept which lowers the cost and improves the reliability of small scale distributed generators. The main purpose of this concept is to accelerate the recognition of the advantage offered by small scale distributed generators like ability to supply waste heat during the time of need. From a grid point of view, microgrid is an attractive option as it recognizes that the nation's distribution system is extensive, old and will change very slowly. This concept permits high penetration of distribution generation without requiring redesign of the distribution system itself.

**P. Piagi** *et.al* [4] has purposed the microgrid concept acts as solution to the problem of integrating large amount of micro generation without interrupting the utility network's operation. The microgrid or distribution network subsystem will create less trouble to the utility network than the conventional micro generation if there is proper and intelligent coordination of micro generation and loads. In case of disturbances on the main network, microgrid could potentially disconnect and continue to operate individually, which helps in improving power quality to the consumer.

**H. Akagi** *et.al* [5] has presented the work on renewable power plants are implemented in rural areas which are far away from the main grid network and there is possibility of weak transmission line connection. The microgrid concept provides an effective solution for such

weak systems. The operation can be smoothened by the hybrid generation technologies while minimizing the disturbances due to intermittent nature of energy from PV and wind generation. Also there is possibility of power exchange with the main grid when excess/shortage occurs in the microgrid.

**Xianjun Zhang** *et.al* [6] has described the work in which of a combined cooling, heating, and power (CCHP) microgrid model was built to improve system efficiency of energy utilization and lessen environmental problems caused by animal wastes based on multi-objective optimization. The final goal is to maximize energy output from distributed energy resources (DERs) and meanwhile minimize daily system operating cost. Extra electricity generated beyond the load demand could be used to charge battery storage.

**H. Kanchev** *et.al* [7] has presented the essential element in the new era of smart power, several approaches have been reported in the literature in relation to microgrids intelligent energy management applicable within the smart grid system .

**Shuai Lu** *et.al* [8] has investigated the control strategies for distributed energy resources (DERs), including diesel generators, energy storage and demand response (DR), to achieve high penetration of wind energy in a rural microgrid. In such a system, it could be both economical and environmentally friendly to harness wind power and displace the consumption of fossil fuels. Detailed dynamic models of DERs and household loads are built to simulate the microgrid is also represented.

**M. Rezwan Khan** *et.al* [9] has analyzed the technical and economic benefit of DC microgrid in comparison to the usual AC microgrid considering the socio economic condition of rural Bangladesh. Results show that the cost of energy can be significantly lower in the case of a DC grid.

**M. Barnes** *et.al* [10] has summarized and highlighted the operating principles and key conclusions of research and field trials to-date of microgrid. An overview is given on demonstration projects for microgrid which have been, and are being, constructed. The range of hardware and control options for microgrid operation is reviewed.

**Bo Dong** *et.al* [11] has focused on control strategies of microgrid which consists of wind turbines, photovoltaic panels, batteries and super-capacitors with Hybrid DC and AC Buses. The different control strategies for grid-connected and islanded operation are described which can keep power balanced and AC/DC bus stable. Simulation and experimental results are shown to verify the proposed control method.

**C.V. Dobariya** *et.al* [12] has followed the centred around the encountered and foreseen issues, enabling technologies and economics for encouraging the deployment of microgrids in India. It also presents state-of-the-art issues and feasible solutions associated with the deployment of microgrid technologies leading to the conceptualization of efficient and smart microgrids. The role of enabling technologies, automation and communication for sustainable development of microgrids is also explained.

**R. Kuwahata** *et.al* [13] demonstrated a case study in the state of Bihar in India. Results from the case study allow the costs of electrification by microgrids to be compared with those of extending the grid, and minimum distances from the grid where microgrid systems would be financially preferable to be determined. Taking into consideration the additional benefits offered by microgrid systems such as the ability to provide a highly reliable electricity supply, reduce transmission losses, expand the grid with smart features and facilitate the integration of renewable energies, it presents a convincing alternative to existing electrification strategies in developing countries.

**T. E. Del Carpio Huayllas** *et.al* [14] has presented the current status and state-of-the-art of microgrid systems as well as the barriers that are being encountered for their integration to the network. The expectation about the microgrid performance, issues related to the microgrid standards, autonomous operation, control strategies, regulatory barriers as well as its protection and islanding operation, among other aspects, were discussed. Some examples of practical installations worldwide will also be presented.

**J. A. P. Lopes** *et.al* [15] has demonstrated Large-scale integration of distributed energy resources in low voltage distribution grids will have a serious impact on power system operation. The development of the microgrid concept is presented as a solution to overcome some of the negative impacts of massive microgeneration deployment. It has paved the way for an active network management approach within the smart grid paradigm. The microgrid

concept is able to address the integration of geographically dispersed energy resources, thus avoiding significant technical problems that may affect the security of operation.

**Md. Moniruzzaman** *et al.* [16] have done a techno-economic analysis of only renewable based hybrid systems have been done with a well connected grid system. A comparison is shown based on per unit cost of electricity production, operating cost found by simulation results and traditional fossil fuel based energy sources.

**Ahmad Rohani** *et al.* [17] have designed the aspects of a hybrid power system that will target to remotely located village. The main power of the hybrid system comes from the photovoltaic panels and wind generators, while the fuel cell and batteries are used as backup units. HOMER is a design model that determines the optimal architecture and control strategy of the hybrid system. The simulation result indicate that the proposed hybrid system would be feasible solution for the distributed generation of the electrical power for standalone applications at remote location.

**M.M. Bin Othman** *et al.* [18] has discussed the optimization of the renewable energy hybrid system based on the sizing and operational strategy of generating system. The optimization software HOMER is used for sensitivity analysis to obtain the optimal configuration of hybrid renewable energy based on different combinations of generating system.

**P. Sunderan** *et al.* [19] has determined the technical and economical feasibility of a PV-natural gas hybrid power system to supply electricity and energy for a university in Malaysia. The simulation in HOMER was performed for a 2MW PV generator together with 8.4MW gas generator. With the inclusion of PV, the amount of natural gas burned in the hybrid system was reduced and this in turn reduced the amount of environmentally polluting gases emitted into the atmosphere by 7.2% as compared to a gas only system. Hence, it is suggested that a PV hybrid power system should be implemented as it a cleaner and more economical method of power generation.

**M. Anwari** *et al.* [20] has analyzed the potential implementation of renewable hybrid wind/diesel energy system in Pemanggil Island, Malaysia. The suitability of utilizing hybrid wind/diesel energy system over standalone diesel system was discussed mainly based on

different wind irradiances and diesel prices. It has also placed a main emphasis on fuel savings and reduction in carbon emissions by using different hybrid systems.

**D. K. Yadav** *et al.* [21] has presented technical design and the economic viability of hybrid wind-diesel power supply systems to meet the load requirements compared to traditional diesel supply systems.

**U. Sureshkumar** *et al.* [22] has performed real time optimal cost analysis of Hybrid energy system is done based on the load profile, solar radiation and wind speed that was collected from Mandapam in Ramanathapuram District, Tamil Nadu in India. The simulation of a hybrid energy system composed of PV together with WG, and battery storage has performed and a power management strategy has designed and simulated.

**M. I. M. Rashid** *et al.* [23] has analyzed the economic feasibility of 1MW PV system for a small industrial area in Rembia-Krubong Malacca is examined by using the HOMER software simulation. Several optimizations depending on the few sensitivity factors will be simulated and the best optimized system will be proposed as the feasible system.

**M.M. Hasan** *et al.* [24] has highlighted the benefit of introducing solar PV both in grid and non grid areas to reduce the pressure on the existing grid network and to save money from the government exchequer in terms of laying transmission and distribution networks. The cost of energy has been calculated for households using solar PV in the grid and non grid areas. Cost calculation has been made through Homer simulation assuming a moderate load for rural households.

#### **1.4 Role of Renewable Energy in India**

Ensuring energy access to all is a key catalyst for economic and human growth. However, extreme poverty inhibits people from gaining access to essential energy services, resulting in a vicious cycle. Lack of access to energy (energy poverty) and its impact on human welfare, including health of women and children, education and income, continues to be a significant cause of poverty in developing countries. Energy access is, therefore, an essential part of any vision of inclusive growth.

In India, inspite of several policy initiatives undertaken by the Government of India in the recent past, with significant progress in extending the national grid and the scaling up of decentralized distributed generation models using renewable energy resources. Expanding energy access to poor families and communities is a complex development challenge, particularly in rural areas. Recent estimates reveal that almost 400 million people in the country lack access to electricity and a significant proportion relies on firewood, animal dung, and agricultural residues for cooking and heating. Although the grid has been extended to a large part of the country, even in electrified villages, electricity supply is erratic and unreliable. The annual per capita consumption of electricity in rural areas is about 100kWh (kilowatt hour) against the national average of 734kWh, the latter itself being far lower than the world average.

At the same time, India has considerable experience and is home to several innovations and successful examples of providing energy access through renewable sources of energy to the remotest areas of the country [12]. These also have a scale-up potential in other parts of the world. It has also been well established that the cost of decentralized renewable energy decreases in comparison to conventional grid-powered electricity; the farther away from the grid the electricity is used. However, the challenges before us are to ensure that this access happens rapidly, while ensuring that the sustainability-related constraints are taken into account. Renewable energy technologies can permit local control of the energy resources and power generating systems, are suitable for smaller applications and can offer a viable means of providing electricity and clean fuel to the presently un-served people, besides, creating employment and entrepreneurship opportunities, mostly in remote and rural areas. However, this requires tremendous innovation in technology choices, supportive policy frameworks, and mobilization of additional public and private financial resources.

### **1.5 Current scenario of Renewable energy**

Energy security is important for India, which is largely dependent on fossil fuel imports to foster its economic growth. According to the World Energy Outlook report, India will become the third largest net importer of oil before 2025 after the United States and China. This will not be sustainable in the long run given the high volatility of international crude oil prices. Coal imports are also likely to increase from 12 percent in 2005 to 28 percent in 2030. Hence, India's energy planning must focus on harnessing renewable energy production in the

long run to achieve energy security and also meet global climate change objectives [14].

In order to exploit the full potential of renewable energy India must ensure the following. First, the renewable energy sector is still developing and hence involves high upfront and operating costs. At present, the renewable energy market in India is growing at 15% per year. In order to increase the renewable power generation to 200 gigawatts in 2030 from the present capacity of 8 gigawatts, India will require an estimated 200 USD billion capital investment. The burden of higher power generation costs will be transferred to the end users making it a less attractive alternative energy option. Large scale investments in technology and research and development are therefore required to lower energy generation costs and make it affordable in the long run.

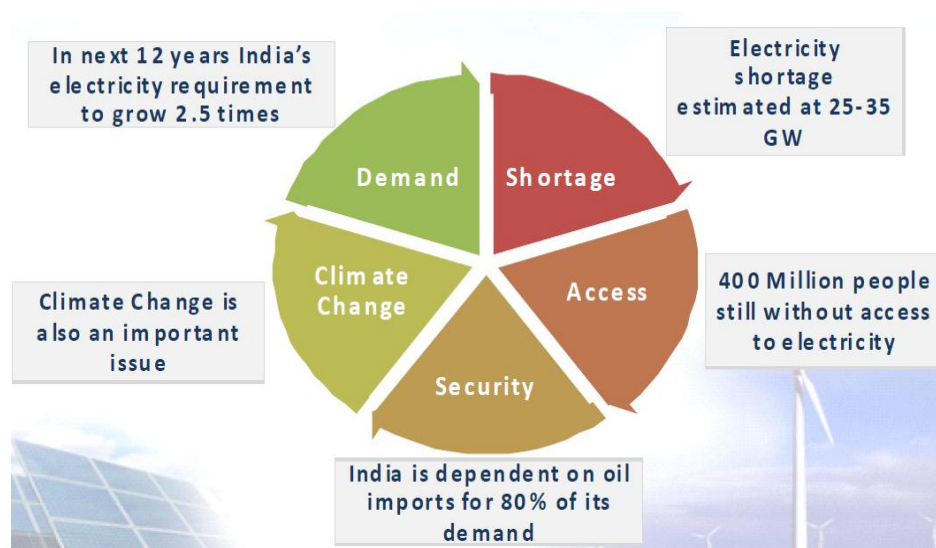
Second, energy security cannot be achieved by just providing renewable energy at affordable costs. It will also require decentralisation of energy production to all parts of the country. This can be achieved by participation of local institutions in the production and distribution of energy supply. A decentralised supply of energy will ensure gradual increase in the number of energy consumers across all sectors in rural areas. Energy self sufficiency will result in greater economic development in the long run through increased employment opportunities and higher standards of living in rural areas.

Third, renewable energy can be profitably developed only with the help of private sector participation since there are limitations on how much the public sector can spend. The government must offer policy incentives in the initial stages of energy production to encourage large scale investments from the private sector. For instance, India has the fifth largest installed capacity of commercial wind power in the world. It generates 1.6 percent of the country's power. This was primarily achieved by adoption of market oriented strategies and policy support provided by the government which encouraged private industry and investor participation. A progressive policy based on monetary and fiscal incentives must be initiated to attract not just domestic investors but also foreign players.

Having said this, it is important to note that any form of energy will be sustainable only if it is used in an efficient manner. Renewable energy sector is poised to expand in the long run. However, coal will continue to remain the dominant source of power in the next 20 to 30 years in spite of the contribution made by renewable forms of energy to India's energy mix.

Hence, it becomes imperative to scale up the performance of existing conventional sources of energy through cleaner and efficient technology.

India plans to develop at least nine coal-fired Ultra Mega Power Projects, which is aimed at providing electricity to all villages by 2012. These power plants are likely to emit large quantities of green house gases without the adoption of clean energy technologies. China, for instance, has built more efficient coal power plants that are not only less polluting but also have lesser output costs. India must exploit new avenues in emerging technologies that will reduce coal consumption, produce larger power output and enhance environmental sustainability. India also needs to strengthen its regulatory system, restructure its existing institutions and cut energy losses in order to bridge the existing gap between energy demand and supply.



**Fig 1.2: India energy challenge**

The real challenge faced by India is to expand its renewable energy sector without slowing down the progress of its economic sectors as shown in Fig 1.2. India will need to maximise the utilisation of renewable energy in order to insulate it from any future supply disruption and price shocks of fossil fuels. For this, India's energy security policy must undertake a dominant shift towards diversification of renewable energy options.

At the basic level, development of any form of energy will be sustainable only if it is clean, affordable and accessible. Therefore, expanding different sources of renewable energy is definitely a viable energy security option for India in the long run.

## **1.6 Objective of thesis work**

The objective of thesis work is summarized as follows:

- Planning to set up a microgrid in the remote village Jhalkari in Patiala district, Punjab in India. The survey and analysis of the area is done for feasibility of different distributed energy resources (DERs).
- Simulation and Optimization of grid connected and off-grid system using HOMER.
- The comparison study of both the systems is done based on per unit cost of electricity production, capital cost, operating cost found by simulation results and find out the best suitable distributed energy resources for specified area.
- The performance and economical analysis is done. Further, environment impacts of both the systems are also studied.

## **1.7 Organisation of thesis**

A brief outline of all the chapters that follow is presented next.

### **Chapter II: Microgrid Architecture**

A review of the microgrid architecture including configuration, forms, types and modes are presented. Also it discusses the various renewable energy sources and technologies with their current status and potential in India.

### **Chapter III: Hybrid Microgrid system**

This chapter introduces the design procedure for optimal energy management. It also draws the light of vision on evolution to modernization in microgrid system. It discusses the control strategic of Hybrid microgrid.

### **Chapter IV: Modeling of Hybrid Renewable Energy System**

In this chapter Simulation Model is obtained using HOMER and the assessment of renewable energy resources are done for the Jhalkari site.

### **Chapter V: Comparison and Analysis Remarks**

In this chapter cost and efficiency optimization of Hybrid microgrid in rural village is presented both for islanding and grid connected system. The simulation results are obtained using HOMER. Further, the comparison and analysis of result is done.

### **Chapter VI: Conclusion and Future Scope**

This chapter draws the conclusion and outlines the scope and areas for further work

## CHAPTER 2

### MICROGRID ARCHITECTURE

#### 2.1 Overview

There are many possible configurations for microgrids, ranging from very small systems serving a single customer site up to very large systems that serve thousands of customers. This chapter investigates possible architectures for microgrids and discusses some of the factors that must be considered in the design of such systems.

A microgrid may take on many forms:

- Peak Electrical Load: 1 kW up to 100 MW
- Number of Customers Served: 1 to 50,000
- Type of customers: residential, commercial, or industrial
- Area served: from one house up to 10 square kilometers
- Part Time Microgrid - may be configured to switch between “islanded” and “non-islanded” operating modes based on the state of the bulk supply
- Full time Microgrid - always operates independently of the bulk supply
- AC or DC, Low voltage or high voltage architectures may be used
- Radial or networked designs with one or more generators

With regard to the above characteristics, there is no one particular system design that can be universally applied to all microgrids. The variety of loads to be served, intended applications, generation technologies to be applied and environments in which these system will be located indicate that microgrid designs will be very diverse.

#### 2.2 Microgrid Service Areas

Microgrids may be applied in a broad range of sizes and configuration as shown in Fig 2.1. There are microgrid “subsets” that could be derived on a typical radial distribution system. These microgrid subsets include a single customer, a group of customers, an entire feeder, or a complete substation with multiple feeders. A large substation could have up to 100MW of

capacity, eight or more feeders, and could be serving more than 10,000 customers. When islanded, such stations would represent the high end of the microgrid size range.

Microgrids employed on radial circuits are not the only possibility. Microgrids may be employed within looped or networked architectures. In fact, for reasons of reliability and control flexibility, if a system were designed from scratch and were intended for high reliability, it would likely employ a looped or network architecture. This would allow redundant power flow paths between generation sources and loads, and improved voltage regulation.

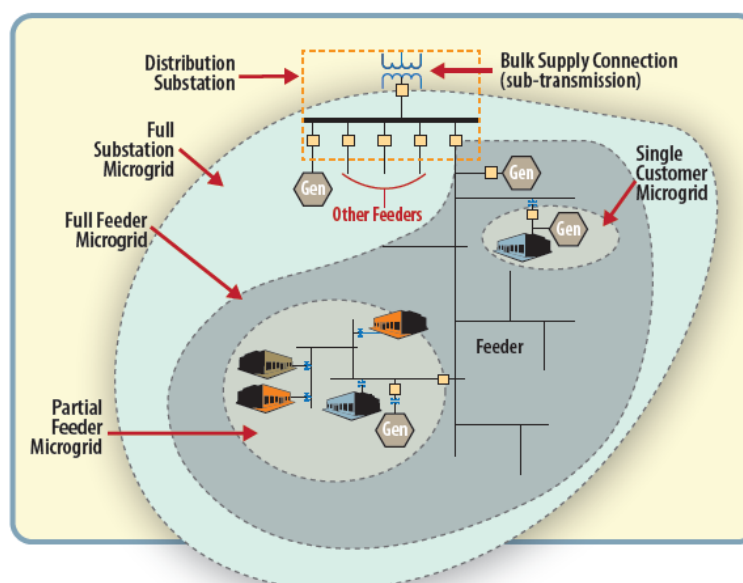


Figure 2.1: Microgrids on a Radial Distribution System

**Single Facility Microgrids:** These Microgrids include installations such as industrial and commercial buildings, residential buildings, and hospitals, with loads typically under 2MW. These systems typically have low inertia and require backup generation for off-grid operation. Microgrids for these applications will be designed to have improved power availability and quality, and a subset of them, such as hospitals, will require a seamless transition between grid-connected and island operation.

**Multiple Facility Microgrids:** This category includes microgrids spanning multiple buildings or structures, with loads typically ranging between 2 and 5MW. Examples include campuses (medical, academic, municipal, etc), military bases, industrial and commercial complexes, and building residential developments. As with single facility Microgrids, the

design of multiple facility Microgrids will be driven by the need for high availability as well as improved power quality.

**Feeder Microgrids:** The feeder microgrid will manage the generation and/or load of all entities within a distribution feeder – which can encompass 5-10MW. These microgrids may incorporate smaller microgrids – single or multiple facilities – within them. The appeal of these microgrids is the potential to realize regional improvements in availability, offered by the ability of the microgrid to separate from the bulk grid during grid disturbances and service its internal loads. Utilities, municipal utilities and coops are seen as future owners/operators of these microgrids.

**Substation Microgrids:** The substation microgrid will manage the generation and/or load of all entities connected to a distribution substation – which can encompass 5-10MW. It will likely include some generation directly at the substation, as well as distributed generation and microgrids included at the feeder and facility level. The appeal is again the potential to realize improvements in availability, offered by the ability of the microgrid to separate from the bulk grid during disturbances and service its internal loads.

All of these microgrid categories will benefit from the ability to control the dynamic exchange of power between the microgrid and the bulk grid over the interconnecting tie line(s).

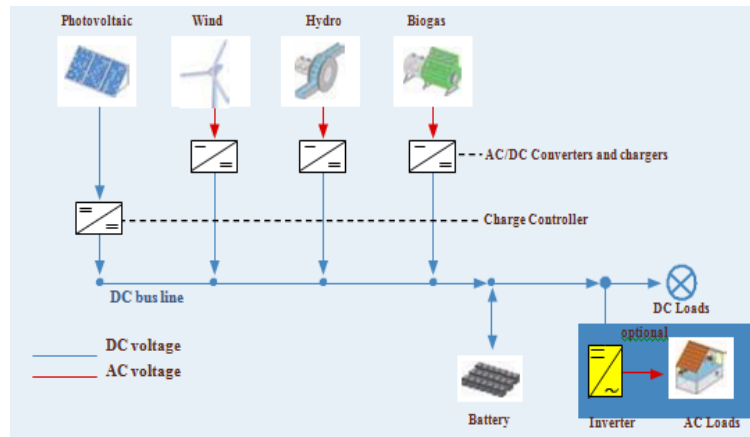
## **2.3 Microgrid Configurations**

Different microgrid configurations have been presented in various researches [2], [5], [11]. They are generally, divided into 3 types: DC coupled, AC coupled and AC and DC coupled configurations.

### **2.3.1 DC Coupled Microgrid**

In a DC coupled configuration, all energy sources are linked together on the DC side before being connected to the AC side (loads and/or grid) via inverters. Nowadays, DC coupled configurations are used mostly for smaller hybrid systems upto a certain size (a few kW), depending on various external parameters. Solar home systems are a simple form of a standalone DC coupled microgrid configuration, where only PV generators are used to provide energy to consumers, such as houses or small first aid stations at the scale of a village. In the Fig 2.2 shown below, represents all distributed energy sources such as PV

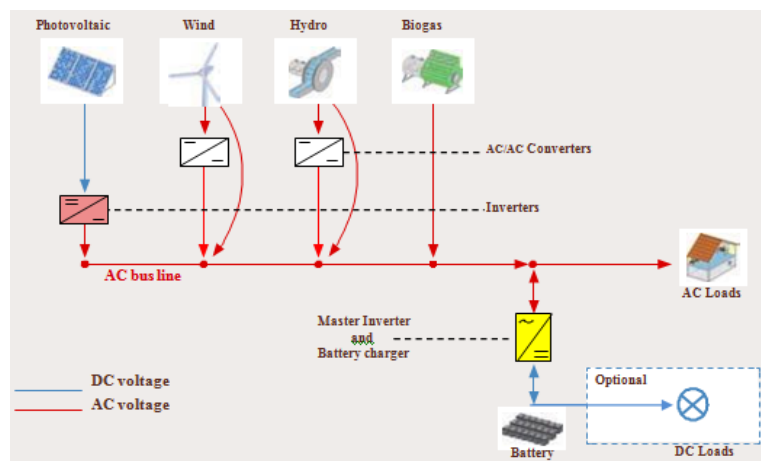
array, Hydro, Wind and Biogas generator are connected to DC bus line, which is coupled to battery and DC load [5]. To supply electricity to AC load the energy has to be converted by the use of converter as shown in Fig 2.2. The power range for a DC coupled configuration is extremely broad and can be used cost effectively for various off-grid applications.



**Fig 2.2: DC Coupled Configuration**

### 2.3.2 AC Microgrid

In AC Coupled configuration is used for the large size then implemented in DC coupled configuration. More flexible systems with modularly structured components are achieved by coupling all consumers and generators on the AC side. In this, DERs which produce electricity in DC form such as photovoltaic array has to convert the energy in AC form by the use of Inverters and then connected to AC bus line. All the other DERs which produce electricity in AC form will be directly connected to AC bus line. From this AC bus line electricity is provided to AC load and it is coupled to DC load and battery after the electricity is converted in DC form as presented in Fig 2.3.



**Fig 2.3: AC Coupled Configuration**

### 2.3.3 AC and DC Coupled Microgrid

As mentioned earlier, DC coupling is the natural solution in small systems, but in large systems, AC coupling is advantageous. In the wide range in between, it is also possible to combine AC and DC coupled in one system, namely, an AC and DC coupled configuration [2]. This technology has emerged due to the need to supply (medium power) AC loads by DC power sources and to charge the battery on the DC-side also via combustion generators, such as diesel gensets, as illustrated in Fig 2.4. Such a configuration is used to supply remote or rural consumers who have larger energy demands. In this there are two different buses AC and DC bus are present, which will connect to different DERs according to their power production in their respected form. The exchange of power takes place through them by the use of converter as shown in Fig 2.4.

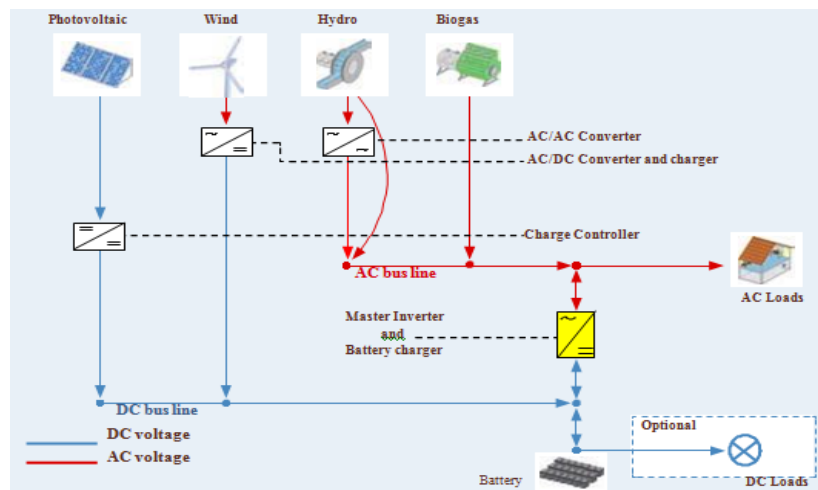


Fig 2.4: AC and DC Coupled Microgrid

### 2.4 Modes of Microgrid

With the growing demand, rising fossil-fuel prices and international pressure to reduce greenhouse gas emission, developing nation are facing two pressing issues that need to be addressed in parallel: increasing energy access to pull people out of poverty, while integrating as much renewable as possible. Rural electrification program are considered an important part of the strategy to achieve universal electrification in developing countries. These programs provide access to electricity services either by extending the central grid, or building off-grid generation capacity [25]. Since the ultimate goal is to provide reliable electricity service at affordable cost, the cheaper of the two options is usually the one that is implemented.

### **Grid connected (anti-islanding mode)**

For a village that is not yet electrified, connecting to grid is seen as the preferred option; because it means that it will be integrated directly into the central grid and can access cheap power supply (due to economies of scale). However, in many developing countries there isn't enough central grid supply [4] to cover all demand, and small rural connections are often cut off in favour of maintaining supply to cities and industries (resulting in frequent blackouts). Another issues is that the central grid operators often do not know exactly how much power is consumed where in the system, due to lack of metering equipment and rampant energy thefts. This makes it difficult to control the power quality such as maintaining voltage and frequency within standard operating limits. Furthermore in some cases, even if extending the grid is the cheaper option, rural community may not be able to afford the interconnection cost.

### **Off grid (islanding mode)**

Under these circumstances, the option of building off-grid supply system such as solar home systems and microgrids may be better than extending the grid. This is because it can provide reliable electricity supply at a relative low cost. Power can be sourced from local renewable resources and due to short distance between the generator and consumers, there are very less electricity losses in the system. Furthermore, such a system can be installed and setup for operation in a relatively short length of time. The negative aspects of these systems are that they are typically design for a particular consumption profile; therefore require an additional equipment to cater for increase in demand. Also, once an off-grid supply system is provided, the village is often neglected in further electrification consideration because from the central system's point of view its work is done on electrifying that village.

Although in principle rural electrification program lead to universal electrification, in reality, there are obstacles that need to be overcome until the desired level of electricity service can be available to all. These obstacles are created by the limits imposed by the imperfect system, such as inadequacies of the central grid infrastructure and operation capability, high initial cost of project and lack of foresight in system design that is adopted. These act to create a gap between the extending the grid and building off-grid system. For an un-electrified rural village, gaining access to electricity service provided by the central grid can be the cheapest solution. However, often the supply reliability and quality is compromised because of

rampant supply shortages and electricity theft. On the other hand, home energy systems and off-grid distribution system can provide more reliable service. These options are particularly suitable for village that are remote from the grid or where the grid supply is limited. Once an off-grid solution is implemented however, often it is dropped from the priority list to extend grid service, therefore creating a gap that prevent reliable universal electrification with grid expansion to be achieved.

## **2.5 Power Generation Equipment for Microgrid**

The generation technologies that may be used for typical microgrid systems include:

- Internal combustion engines (10 kW to 10 MW)
- Mini to small-size combustion turbines (0.5 to 50 MW)
- Microturbines (20 to 500 kW)
- Fuel cells (1 kW-10 MW)
- Photovoltaic systems (5 W to 5 MW)
- Wind turbines (30 W to 10 MW)

The size ranges shown adjacent to each technology are suggested as the most likely implementation of the above technologies given the current status of these generation technologies. However, application of units larger or smaller than indicated is also possible.

Because microgrid generation is located at or near loads, it must be suitable for use in load environments and must be placed where it can operate without causing problems with noise, emissions, aesthetics, and other site-related issues. Ideal microgrid generation technologies will have the following characteristics:

- Modular design (scalable from 1 kW up to 100 MW)
- Low capital cost
- Low operation and maintenance cost
- Suitable for residential, commercial, and industrial permitting constraints
- Low emissions
- High efficiency over broad range of loading conditions (at least 40%)

- Usable waste heat (higher exhaust temperature is usually better)
- High power quality (low harmonics, good voltage and frequency regulation)
- Good load-following characteristics (for large load steps and transient motor starts)
- Rapid start up (from cold start and standby conditions)
- Good energy density (high power/weight and high power relative to footprint area required.
- High reliability and dispatch ability
- Resistant to damage by power system voltage and current anomalies (surges, voltage unbalances, and so on)
- Operate on fuel that can be easily delivered or transported to the site
- A mature technology with excellent support infrastructure

None of the available distributed generation technologies meet all of the ideal characteristics above. For example, fuel cells get high marks for emissions, modularity, and their ability to be integrated into residential/commercial sites with minimal siting concerns. However, they currently suffer from high capital cost and still are considered an early commercial and/or developing technology that needs further technical improvement. On the other hand, internal combustion engines are very mature, have excellent support infrastructure, and have low capital cost, but they are not ideal for some applications due to noise and emissions issues.

## **2.6 Renewable Energy Technologies (RETs)**

Renewable energy power plants have been developed in the past several decades. DERs are used in microgrid to mean utilization of small generators that are located in the distribution system or on sites to supply electricity. Integration of various DG technologies with a grid named microgrid is an important pathway to a clean, reliable, secure, and efficient energy system for developed economies with established levels of quality and reliability of electrical service. Numerous promising and load management technologies are under development or are entering early commercialization stages, and the DERs technologies have the destiny to shape microgrids.

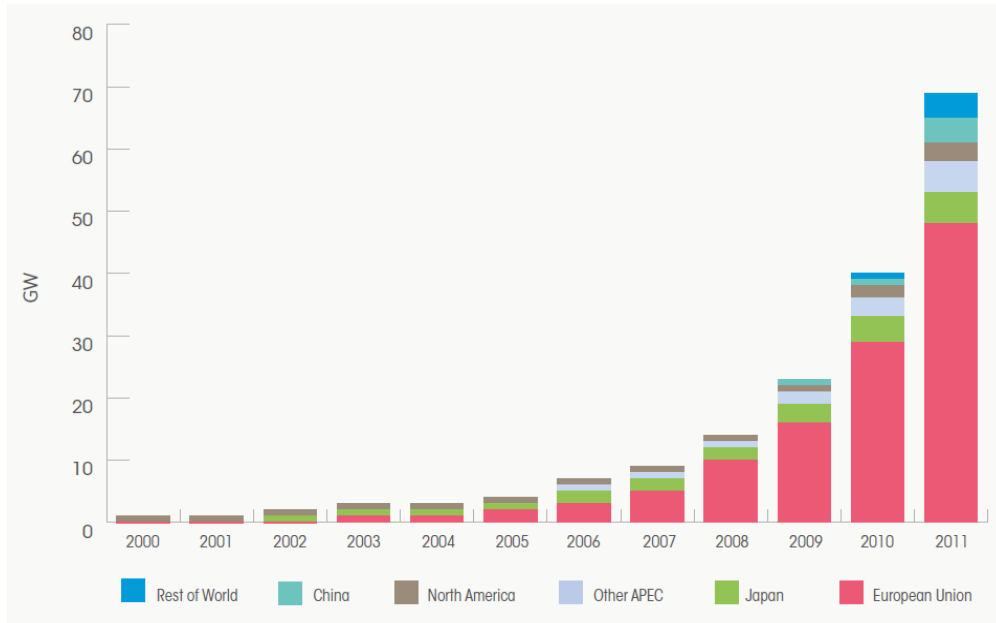
### 2.6.1 Photovoltaic Array

Solar PV generation involves the generation of electricity from free and inexhaustible solar energy. The major advantages of a PV system are (i) sustainable nature of solar energy as fuel, (ii) minimum environmental impact, (iii) drastic reduction in customers' electricity bills due to free availability of sunlight, (iv) long functional lifetime of over 30 years with minimum maintenance and (v) silent operation. Owing to these benefits, today PV systems are recognized by governments, environmental organizations and commercial organizations as a technology with the potential to supply a significant part of the world's energy needs in a sustainable and renewable manner. Moreover, due to the extensive improvement in inverter technologies, PV generation is now being preferred and deployed worldwide as DERs for augmentation of local generation at distribution voltage level. Though PV cells can be effectively used as a DER in a microgrid, yet they suffer from the disadvantages of high installation cost and low energy efficiency. It has been studied that small PV installations are more cost-effective than larger ones, which indicates the effectiveness of feeding PV generation directly into customer circuits at low voltage distribution networks. However, the nature of PV generation being DC, suitable power converter circuits are to be employed for converting DC power into AC at the specified frequency level. Hence, they can be potential contributors to a microgrid.

Solar energy reaches the PV cell in two components, direct and diffuse. The direct component is about 85% and comes through direct radiation. The diffuse component is about 15% and comes through scattered diffusion in the atmosphere. A PV cell behaves as a photodiode. Light energy incident on the cell surface in the form of photons generates electron-hole pairs as current carriers at the p-n junction. Thus, photocurrent produced by a PV cell is directly related to its surface area, incident irradiance and ambient temperature. Generated voltage is limited by the forward voltage drop across the p-n junction. As the voltage and the current output of a single cell are very small, a large number of cells are arranged in series-parallel combination to produce PV arrays or modules of higher voltage and power rating. Most PV modules are equipped with MPPT systems that maximize the power output from the modules by shifting the operating point depending on the solar irradiance.

PV is one of the fastest growing renewable energy technologies today and is projected to play a major role in global electricity production in the future [7]. Driven by attractive policy incentives (e.g. feed-in tariffs and tax breaks), the global installed PV capacity has multiplied

by a factor of 37 in ten years from 1.8GW in 2000 to 67.4GW at the end of 2011, a growth rate of 44% per year Fig 2.5. New capacity installed in 2011 was 27.7GW, two-thirds more than the new capacity added in 2010. Assuming an average capacity factor of 0.2 would imply that solar PV in 2011 produced 118TWh of electrical power.



**Fig 2.5: Evolution of global cumulative installed capacity, 2000-2011**

## 2.6.2 Wind Energy Conversion Systems

WECS convert wind energy into electrical energy. The principal component of WECS is the wind turbine. This is coupled to the generator through a multiple-ratio gearbox. Usually induction generators are used in WECS. The main parts of a wind turbine are the tower, the rotor and the nacelle. The nacelle accommodates the transmission mechanisms and the generator. Rotor may have two or more blades. Wind turbine captures the kinetic energy of wind flow through rotor blades and transfers the energy to the induction generator side through the gearbox. The generator shaft is driven by the wind turbine to generate electric power. The function of the gearbox is to transform the slower rotational speeds of the wind turbine to higher rotational speeds on the induction generator side. Output voltage and frequency is maintained within specified range, by using supervisory metering, control and protection techniques [8]. Wind turbines may have horizontal axis configuration or vertical axis configuration. The average commercial turbine size of WECS was 300kW until the mid

1990s, but recently machines of larger capacity, up to 5MW, have been developed and installed.

The output power of a wind turbine is determined by several factors such as wind velocity, size and shape of the turbine. The power developed is given by

$$P = \frac{1}{2} C_p \rho V^3 A$$

where P is power (W),  $C_p$  power coefficient,  $\rho$  air density ( $\text{kg/m}^3$ ), V wind velocity (m/s) and A swept area of rotor blades ( $\text{m}^2$ ).

Power coefficient  $C_p$  gives a measure of the amount of energy extracted by the turbine rotor. Its value varies with rotor design and the tip speed ratio. TSR is the relative speed of the rotor and the wind and has a maximum practical value of about 0.4. The torque output often suffers from dynamic variations due to fluctuations in wind speed caused by tower shadow, wind shear and turbulence. These variations lead to a dynamic perturbation in the output power and hence a flicker in the generated voltage. In a constant speed wind turbine, power variation and voltage flicker do pose a problem in the network. On the contrary, variable speed wind turbine systems provide much smoother output power and more stable bus voltage with lower losses. However, a major problem of WECS is that due to the intermittent nature of generation and energy consumption in the generating plant itself, the declared net capacity is lesser than the nameplate capacity.

### **2.6.2.1 Wind turbine operating systems**

Depending on controllability, wind turbine operating systems are classified as

- (1) Constant speed wind turbines and
- (2) variable speed wind turbines.

#### **2.6.2.1.1 Constant speed wind turbines**

These operate at almost constant speed as predetermined by the generator design and gearbox ratio. The control schemes are always aimed at maximising either energy capture by controlling the rotor torque or the power output at high winds by regulating the pitch angle. According to the control strategy, constant speed wind turbines are again subdivided into (i) stall-regulated turbines and (ii) pitch regulated turbines. Constant speed stall-regulated turbines have no options for any control input. Here, the turbine blades are designed with a fixed pitch to operate near the optimal TSR for a given wind speed. When wind speed

increases, the angle of attack also increases. Consequently an increasingly large portion of the blade starting at the blade root enters the stall region. This results in the reduced rotor efficiency and limitation of the power output. Another variation of this concept is to operate the wind turbine at two distinct constant operating speeds by either changing the number of poles of the induction generator or changing the gear ratio. The main advantage of stall regulation is its simplicity. However, the main disadvantage is that these wind turbines are not able to capture wind energy in an efficient manner at wind speeds other than the design speed. Constant speed pitch-regulated turbines typically use pitch regulation for starting up. After start-up, power can be controlled only above the rated wind speed of the turbine.

Constant speed wind turbine operating systems have the following advantages:

- (1) They have a simple, robust construction and are electrically efficient.
- (2) They are highly reliable due to fewer parts.
- (3) No current harmonics are generated as there is no frequency conversion.
- (4) They have a lower capital cost as compared to variable speed wind turbines.

However, they have the following disadvantages as compared to variable speed turbines:

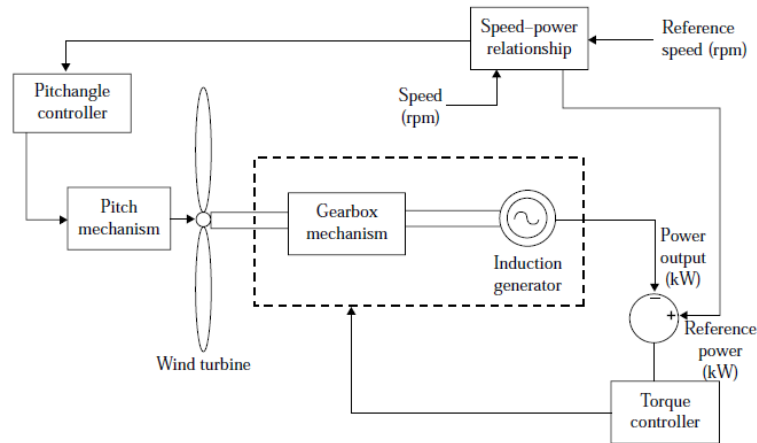
- (1) They are aerodynamically less efficient.
- (2) They are prone to mechanical stress and are noisier.

#### **2.6.2.1.2 Variable speed wind turbine system**

A typical variable speed pitch-regulated wind turbine system is shown in Fig 2.6. It has two methods for controlling the turbine operation, viz. speed changes and blade pitch changes. The control strategies usually employed are (i) power optimization strategy and (ii) power limitation strategy. Power optimisation strategy is employed when the wind speed is below the rated value. This strategy optimises the energy capture by maintaining a constant speed corresponding to the optimum TSR. If, however, speed is changed due to load variation, the generator may be overloaded for wind speeds above nominal value. To avoid this, methods like generator torque control are used to control the speed. Power limitation strategy is used for wind speeds above the rated value. This strategy limits the output power to the rated value by changing the blade pitch to reduce the aerodynamic efficiency.

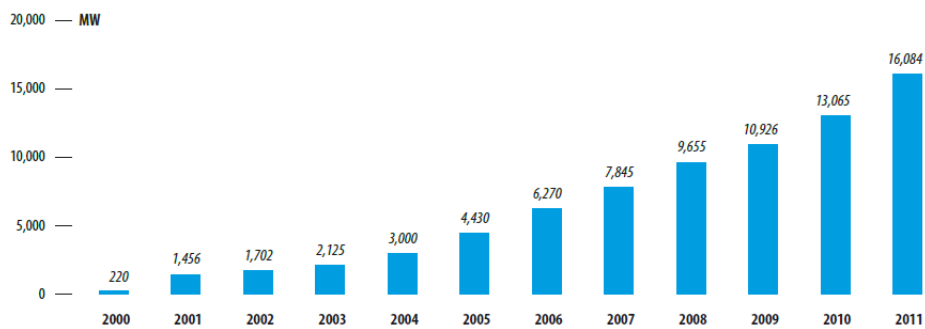
Variable speed wind turbine systems have the following advantages:

- (1) They have high energy capture capacity and are subjected to less mechanical stress.
- (2) They are aerodynamically efficient and have low transient torque.



**Fig 2.6: Variable speed pitch-regulated wind turbine**

The wind power industry has experienced an average growth rate of 27% per year between 2000 and 2011, and wind power capacity has doubled on average every three years. A total of 83 countries now use wind power on a commercial basis and 52 countries increased their total wind power capacity in 2010 (REN21, 2011). India had another record year of new wind energy installations between January and December 2011, installing more than 3GW of new capacity for the first time to reach a total of 16,084MW. As of March 2012, renewable energy accounted for 12.2 percent of total installed capacity, up from 2 percent in 1995. Wind power accounts for about 70 percent of this installed capacity. By the end of August 2012, wind power installations in India had reached 17.9GW. Under the New Policies Scenario of the World Energy Outlook (2011), total power capacity in India would reach 779GW in 2035. To reach 779GW in 2035, capacity must grow at a CAGR of 5.9 percent, or over 20 GW per year from 2009 through 2035. The largest addition per year up to now was nearly 18 GW during fiscal year 2011-2012; this scale of expansion could pose a challenge for the government [IEA, 2012] without a significant role for renewable. During fiscal year 2011-2012 wind energy alone delivered over 3GW to India's new installed capacity, accounting for over 16.5 percent of total new installed capacity as shown in Fig 2.7.



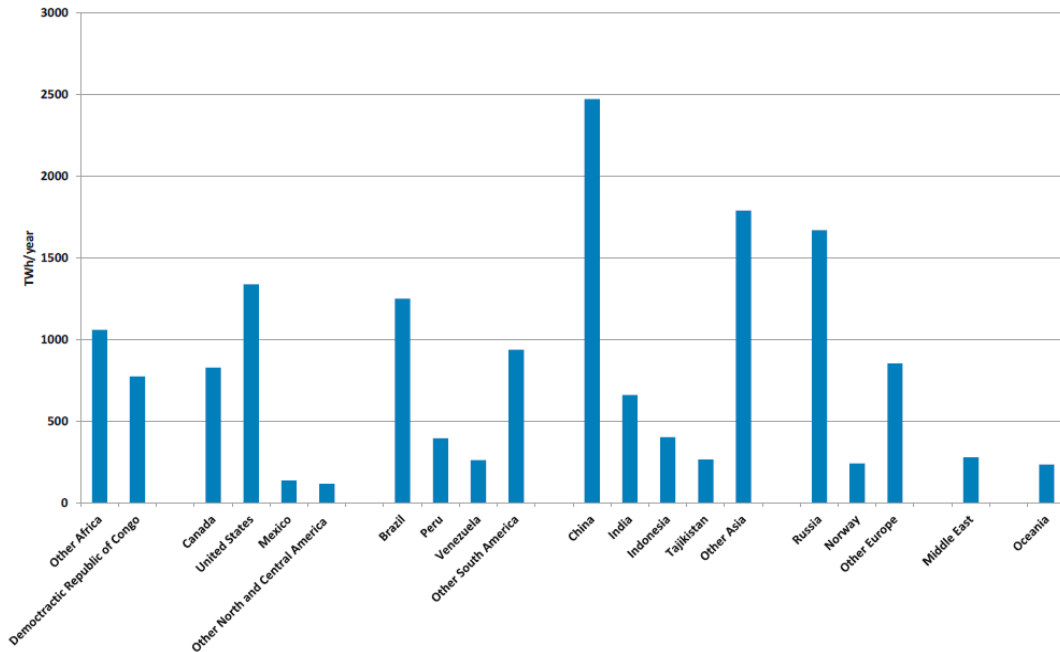
**Fig 2.7: Indian commutative wind installation (MW) (Source-GWEC 2012)**

### **2.6.3 Hydro Power:**

Hydropower is a renewable energy source based on the natural water cycle. Hydropower is the most mature, reliable and cost-effective renewable power generation technology. Hydropower schemes often have significant flexibility in their design and can be designed to meet base-load demands with relatively high capacity factors, or have higher installed capacities and a lower capacity factor, but meet a much larger share of peak demand. Hydropower is the largest renewable energy source, and it produces around 16 % of the world’s electricity and over four-fifths of the world’s renewable electricity. Currently, more than 25 countries in the world depend on hydropower for 90 % of their electricity supply. Hydropower can serve as a power source for both large, centralized and small, isolated grids. Small hydropower can be a cost-competitive option for rural electrification for remote communities in developed and developing countries and can displace a significant proportion of diesel-fired generation. In developing countries, another advantage of hydropower technology is that it can have important multiplier effects by providing both energy and water supply services (e.g. flood control and irrigation), thus bringing social and economic benefits.

Hydropower transforms the potential energy of a mass of water flowing in a river or stream with a certain vertical fall (termed the “head”). The potential annual power generation of a hydropower project is proportional to the head and flow of water. Hydropower plants use a relatively simple concept to convert the energy potential of the flowing water to turn a turbine, which, in turn, provides the mechanical energy required to drive a generator and produce electricity.

It is clear that the hydropower resource is very large, with many parts of the world being fortunate enough to have large resource potentials Fig 2.8. Virtually all regions have some hydropower resources although these resources are sometimes concentrated in a small number of countries and are not always located adjacent to demand centres.



**Fig 2.8: World hydropower Technical resource potential (Source-WEC, 2011)**

Hydropower plants can be constructed in a variety of sizes and with different characteristics. In addition to the importance of the head and flow rate, hydropower schemes can be put into the following categories:

- *Run-of-river* hydropower projects have no, or very little, storage capacity behind the dam and generation is dependent on the timing and size of river flows.
- *Reservoir* (storage) hydropower schemes have the ability to store water behind the dam in a reservoir in order to de-couple generation from hydro inflows. Reservoir capacities can be small or very large, depending on the characteristics of the site and the economics of dam construction.
- *Pumped storage* hydropower schemes use off-peak electricity to pump water from a reservoir located after the tailrace to the top of the reservoir, so that the pumped

storage plant can generate at peak times and provide grid stability and flexibility services.

These three types of hydropower plants are the most common and can be developed across a broad spectrum of size and capacity from the very small to very large, depending on the hydrology and topography of the watershed. They can be grid-connected or form part of an isolated local network.

#### **2.6.4 Biomass Energy:**

Biomass power is power obtained from the energy in plants and plant-derived materials, such as food crops, grassy and woody plants, residues from agriculture or forestry, and the organic component of municipal and industrial wastes. Biomass power provides two valuable services: it is the most important source of renewable energy in India and it is an important part of our waste management infrastructure. In the future, farms cultivating high-yielding energy crops (such as trees and grasses) will significantly expand our supply of biomass. These energy crops, coupled with high-efficiency conversion technologies, can supplement our consumption of fossil fuels and help us respond to global climate change concerns.

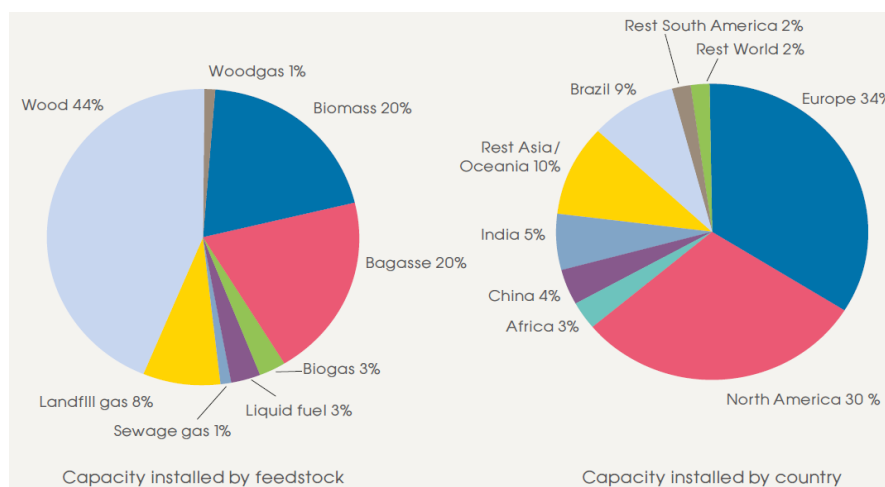
Wood has been used for energy longer than any other biomass source and today is still the largest biomass energy resource. The largest source of energy from wood is pulping liquor or "black liquor," a waste product from processes of the pulp, paper, and paperboard industry. Biomass energy can also be derived from waste and from alcohol fuels. Waste energy is the second-largest source of biomass energy. The main contributors of waste energy are municipal solid waste, manufacturing waste, and landfill gas.

Biomass can be used for direct heating (such as burning wood in a fireplace or wood stove), for generating electricity, or can be converted directly into liquid fuels to meet transportation energy needs. Electricity generated from biomass is also called Bio-power. Bio-power facilities use many different technologies; the most common is burning of wood or other biomass feedstock to produce steam which then is used to drive turbines and produce electricity. Some generators use a mix of biomass and fossil fuels to generate electricity, while others burn methane, a product of the natural decay of organic materials. In the United States, the pulp and paper industries are major producers of bio-power, using residues from paper production to produce electricity for industrial plant use.

Biomass power is close to a carbon-neutral electric power generation option — biomass absorbs carbon dioxide from the atmosphere during its growth and then emits an equal amount of carbon dioxide when it is processed to generate electricity. Thus, biomass fuels "recycle" atmospheric carbon, and may reduce global warming impacts. Bio-power facilities produce fewer other pollutants than equivalent fossil fuel power facilities.

While biomass is a renewable energy resource, it can have both negative and positive environmental impacts. It may reduce emissions and pollutants, but factory farming of biomass crops can reduce biodiversity and negatively impact wildlife habitat. Municipal solid waste may contain toxins which could cause pollution if it is used as a biomass feedstock. As with other renewable resources, use of appropriate technology will promote the most positive environmental impacts.

In 2010 the global installed capacity of biomass power generation plants was between 54GW and 62GW (Platts, 2011) [26]. The capacities installed by feedstock and globally installed by different countries/region are shown in Fig 2.9.



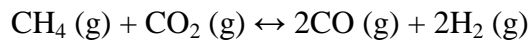
**Fig 2.9: Share of global installed biomass capacity in 2011 by feedstock and country/region (Source-PLATTS, 2011)**

Despite the large biomass resources in developing and emerging economies, the relative contribution of biomass is small. Around 84% of total installed biomass power generation today is based on combustion with steam turbines for power generation, with around half of this capacity also producing heat (combined heat and power) for industry or the residential and service sectors.

### 2.6.5 Reformed Biogas Fuel Cells:

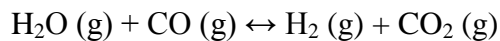
Fuel cells are often compared to batteries. Both convert the energy produced by a chemical reaction into usable electric power. However, the fuel cell will produce electricity as long as fuel (hydrogen) is supplied, never losing its charge. Hydrogen is an ideal fuel in many respects. It has the simplest atomic element with single proton and electron. It is also the most plentiful element in the universe [27]. Despite its simplicity and abundance, hydrogen doesn't occur naturally as a gas on the Earth - it's always combined with other elements such as oxygen and carbon. Hydrogen is also found in many organic compounds, notably the hydrocarbons that make up many of our fuels, such as gasoline, natural gas, methanol, biogas and propane. Hydrogen can be separated from hydrocarbons through the application of heat a process known as reforming. A fuel cell combines hydrogen and oxygen to produce electricity, heat, and water. We are using biogas as hydrocarbon fuel to generate hydrogen and that hydrogen is used in fuel cell to generate electricity is known as Reformed Biogas Fuel Cell (RBFC) as shown in Fig 2.10. Biogas contains 80 percent of methane which is comprised of carbon, hydrogen and oxygen. Its chemical formula is CH<sub>3</sub>OH.

In Reforming: The fundamental step at this stage is the catalytic conversion of the CH<sub>4</sub>/CO<sub>2</sub> stream into H<sub>2</sub> and CO through following reaction.

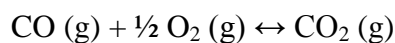


CO purification: This stage involves two processes, WGS and COPROX, aimed at the almost total removal of CO from the stream feeding the cell (Zhang et al, 2004), since CO could poison the cell. The main reactions taking place during these processes are as follows:

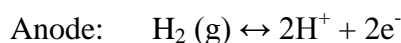
WGS: Water-gas displacement producing additional H<sub>2</sub>.

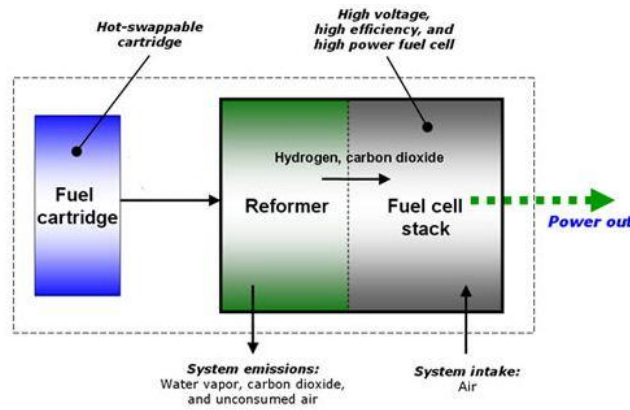
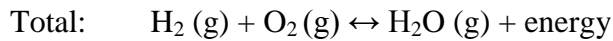
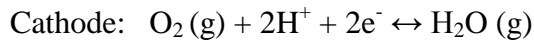


COPROX: CO preferential oxidation through air injection



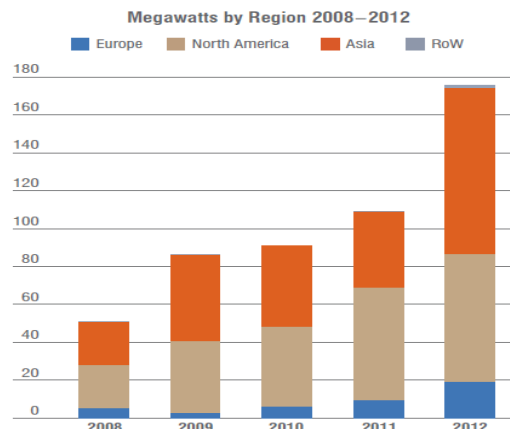
Fuel cell: The gas exiting from the fuel processor is made up of a mixture of H<sub>2</sub> and CO<sub>2</sub>. This gas stream is fed into the fuel cell system.





**Fig 2.10: Reformed Biogas Fuel Cell**

Continued growth in annual fuel cell system shipments was seen worldwide in 2011, increasing 39% compared to 2010 to reach a new high of 24,600 units. So far 2012 has seen that momentum maintained and expectations are for full-year system shipments to more than triple relative to 2011, reaching 78,200. In megawatt terms, 2011 grew 20% versus the previous year to exceed 100MW for the first time and it is seen 61% growth in megawatts for 2012, totaling 175.8MW as shown in Fig 2.11.



**Fig 2.11: Annual fuel cell usage (Source - Fuel cell today, 2012)**

## 2.7 Distributed Storage Technologies

Storage is important in the microgrid both because peak loads are expensive to serve with purchased power and microgrid generation sources may not be able to respond to load changes as needed. Load changes are usually caused by short-lived events, such as fast

transients resulting from starting of motors or turning on/off of equipment, or from slower changes that exceed the ramping capability of generation available at any given time. Storage systems can be designed to switch into operation in sub-cycle time frames, so they are ideal for tracking fast load changes or immediately providing back-up if utility power is lost.

**Batteries:** Batteries are the traditional method of storing electrical energy; there is considerable operational experience with battery systems. Lead-acid batteries, available in almost any size, are used in many applications that require back-up power. Batteries using other chemistries are now also available commercially, for example the flow batteries. Recent improvements have increased energy storage density and extended battery lifetimes.

**Flywheels:** These systems now incorporate composite rotors, magnetic bearings, and advanced power electronics. Flywheels store energy in high-speed (up to 100,000-rpm) rotating wheel-like rotors or disks connected to motor/generators. The amount of power stored in the flywheel is proportional to the square of the rotational speed. The energy stored in flywheels can be discharged at high power (kW) for a short time or at a slower rate for a longer period.

**Superconducting Magnetic Energy Storage:** Superconductors allow the passage of electrical current without losses. Electrical energy is stored as a circulating current in a superconducting coil of wire. This circulating current establishes a magnetic field in which the energy is stored. Power electronic interfaces charge and discharge the superconducting coil. Super capacitors are very-high-capacity electrolytic devices that store energy in the form of electrostatic charge. They are composed of two electrodes with a very thin separator. Energy storage capacity increases as the surface area of the electrodes increases.

## CHAPTER 3

### HYBRID MICROGRID SYSTEM

#### 3.1 The Microgrid Vision

A microgrid includes generation, distribution system, consumption and storage, and manages them with advanced monitoring, control and automation systems. The critical first step of pursuing a microgrid solution is a permanent reduction in consumption (electricity, water and gas). This will give the consumer near-term cost savings driven by measured and verifiable conservation measures. A fully-developed microgrid has the capability of automatically disconnecting and operating independently or with the main grid. Microgrids will have approximately 80 percent of their on-site power generation be from renewable technologies integrated with thermal energy storage and electric battery storage.

Microgrids can offer reliable and cost competitive electricity services. The microgrid approach is “smart” because it can facilitate the integration of renewable energies, thereby contributing to national RE targets. In addition it can reduce transmission losses by having generation close to demand. Being built from modular distributed generation units, it can adequately adjust to demand growth. It can operate both in island mode and grid-connected mode, making operation flexible and can also offer grid support features. The process involved in the supply system design is present in Fig 3.1.

#### **Step 1: Renewable resource assessment**

The first step to this approach is to make an assessment of the resources available in the area. In the case study area, these are biomass, hydro, wind, fuel cell and solar PV power. While there are no detailed wind measurements available, there are indications that in some areas wind turbines could operate economically as well.

#### **Step 2: Demand projections**

The second step is to assess the level of electrical demand that will need to be serviced. Once there is access to electricity services, demand will almost always grow, accompanying economic growth. As the proposed electrification approach starts on a per village basis, a set of village demand profiles is generated based on hypothetical household demand profiles. The village demand profiles also contain assumptions about non-household loads such as a

school, health stations or public lighting. The village-based electricity supply system forms the smallest individual unit of a supply system. Therefore the matching set of generation assets is also determined on a per-village basis.

### Step 3: Define optimal generation mix

The third step in this approach is to design a system which can serve the demand using the resources available in the most economic manner. At this point it is of utmost importance that the system design uses standard components and is kept modular so that it can be replicated easily for expansion across the entire state. In designing such a system, an appropriate generation mix needs to be developed, which can meet demand 99% of the time at the lowest production cost. This can be determined using production simulation software such as HOMER 2.2, which calculates the optimal generation capacities based on a number of inputs about the installation and operation costs of different types of generation technologies in India.

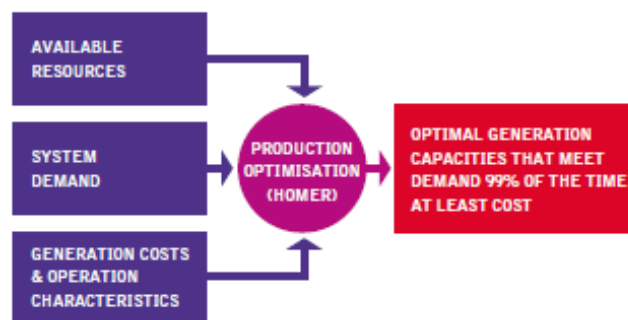
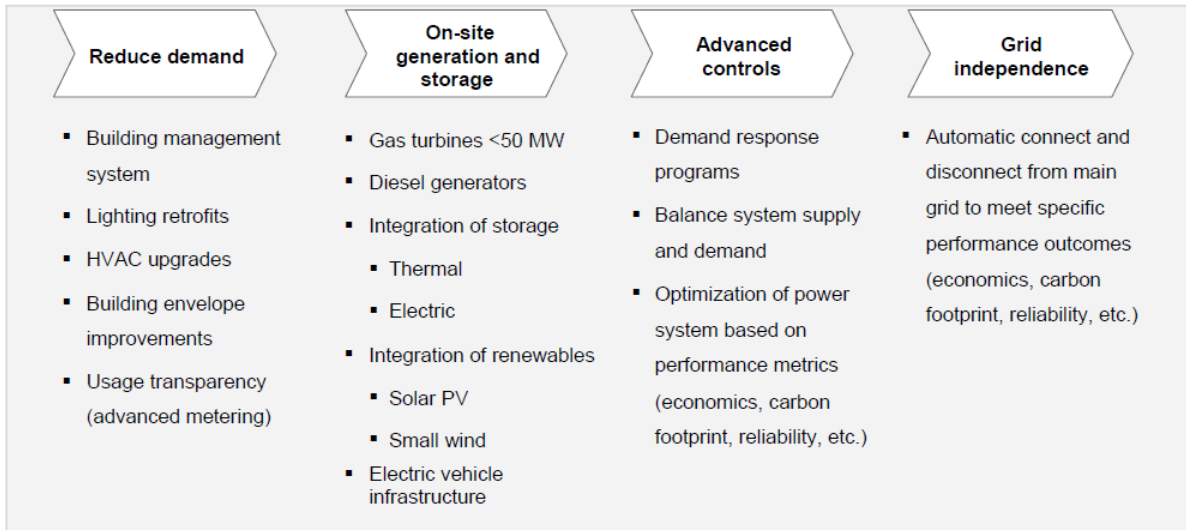


Fig 3.1: Process overview of supply system design

### 3.2 Evolution of Energy Modernization

Implementing a microgrid solution will involve four phases: demand reduction, on-site generation and storage, advanced controls and automatic grid independence Fig 3.2. Each phase is not completely distinct, nor must they be implemented in sequence, there are areas of overlap. Generally, a customer that follows this path will have the lowest lifecycle cost. More mature and economic technologies will be implemented first [15], and newer technologies, which may not yet have very favorable cost/benefit ratios, will be implemented later.



**Fig 3.2: Microgrid technology evolution ranges from strategic energy efficiency**

### **Demand Reduction**

Reducing an installation’s electricity, natural gas and water consumption requires a change in customer behavior combined with the implementation of conservation measures. Some examples of widely commercialized solutions include programmable thermostats, occupancy sensors, efficient lighting, building envelope improvements, chiller and boiler upgrades/retrofits, building management systems and advanced metering. The cost savings that result from conservation measures can be leveraged to fund advanced on-site generation and storage solutions. While electricity conservation is the primary focus of this phase, water conservation will improve project payback.

### **On-site generation and storage**

Implementation and integration of on-site generation (renewable and conventional) and storage solutions is the next level of microgrid development. The goal is to deploy power generation that is cleaner (lower GHG) and more efficient for the end user than what is generated by the main grid. Renewable, on-site electricity generation options include solar photovoltaic and small wind turbines. Given the relatively low cost of natural gas and efficiency of modern CHP solutions, end users can deploy small gas turbines (under 50MW) to provide an economically viable generation capability. To lower the total carbon footprint, locally produced biomass or methane from landfills can be used as fuel for the turbines instead of natural gas. Storage of energy, whether thermal or electric, may be high- or low-tech. Batteries, flywheels, compressed air and pumped hydroelectric storage are among the more high-tech (and higher cost) options. Relatively low-tech storage solutions include

chilled water or ice storage. Electric vehicles offer another alternative for energy storage. Although experts are split on the feasibility and business case of using electric vehicles as storage, what is universally accepted is the attraction of recharging vehicles at night – when the demand for electricity and the cost of electricity is lowest.

### **Advanced controls**

Control systems such as distribution supervisory control and data acquisition (SCADA), building management and demand response are all parts of an intelligent microgrid network. As the percentage of on-site renewable generation approaches around 20 percent of the total power supply, the control and optimization of the power system becomes a significant challenge. Centralized transparency into all devices, from the power generation assets to the devices that consume electricity, enables proactive management of the power system. With automated monitoring and controls, power system supply and demand can be optimized and balanced in real time and faults can be quickly detected, isolated and repaired. Advanced controls allow systems to operate based on performance metrics such as economics, carbon footprint or reliability. Advanced demand response systems enable automatic peak load shedding and participation in the energy markets (where allowed by local regulations) – a key revenue generating opportunity. In addition, storage assets can be automatically deployed to sustain mission critical loads. The key challenge is the integration of the disparate systems to optimize the total system.

### **Grid independence**

A fully evolved microgrid is the culmination of the previous three phases and the ability to operate independently from the main grid for an extended period of time. Automated controls know when, how and why to be grid independent, or connected to the main grid. Grid independence can be accomplished in two ways. First, if the microgrid has internal combustion engines with reactive power compensation within the system to provide voltage and frequency regulation, the power system can connect or disconnect via relays, switches and breakers – this is the more developed method and commercially available today. Alternatively, the microgrid generation and storage assets can connect to the main grid via a series of inverters, allowing for more advanced control of power in both directions between the main grid and the microgrid.

### 3.3 Microgrid Energy Management

Microgrids require wide-range control to ensure system security, optimal operation, emission reduction and seamless transfer from one operating mode to the other without violating system constraints and regulatory requirements [4]. This control is achieved through a Central Controller (CC), Load Controller (LC) and the dedicated Microsource Controllers (MCs) connected to the microsourses and the storage devices as shown in Fig 3.3.

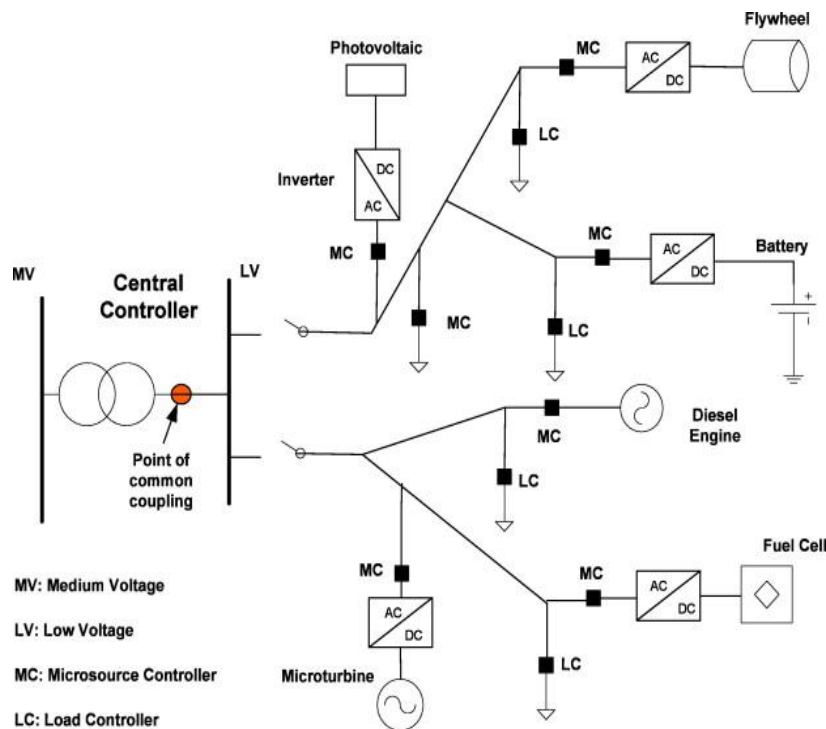


Fig 3.3: Microgrid architecture and controllers

#### 3.3.1 Microsource controller

The microsourses and storage devices in a Microgrid are fitted with MCs that execute smooth and flexible operation of these devices to meet customer and utility requirements. MCs may operate with or without any intervention of the CC. MC functioning depends greatly on the power electronic interfaces provided in the microsourses and storage devices. MCs ensure (i) new microsourses can be added to the system without modification in the existing Microgrid configuration, (ii) Microgrid can connect/disconnect itself to/from the utility in a rapid and seamless fashion [11], (iii) active and reactive power can be independently controlled, (iv) voltage sag and system imbalances can be corrected, (v) faults can be handled without the

loss of stability and (vi) Microgrid can meet the requirements of load dynamics of the power utility. The key features of an MC design are as follows:

- (1) There is no scope for interaction among the microsources without the intervention from CC. This enables each MC to respond effectively to the system changes without requiring data from any other MC or data source.
- (2) Though the MC is designed to communicate with the CC and acts as per its directives, it would be able to override those CC directives that are deemed unacceptable for its microsource.

### **3.3.2 Control functions for microsource controller**

The built-in control features of the MCs are as follows:

- (1) Active and reactive power control
- (2) Voltage control
- (3) Storage requirement for fast load tracking
- (4) Load sharing through P-f control.

They should ensure that the microsources rapidly pick up their share of load when the Microgrid disconnects itself from the utility. MCs should also enable the seamless transition of the Microgrid from grid-connected to stand-alone mode and vice versa with minimum disturbance to both the systems.

#### **3.3.2.1 Active and reactive power control**

The microsources may be (i) DC sources like solar PV, fuel cells and storage battery or (ii) AC sources like micro turbines and wind turbines. For the first category, DC power is directly converted into P-f (50/60 Hz) AC while for the second one, the AC output at non-standard frequencies is first rectified to DC and then reconverted into power frequency AC through converters. In both the cases, DC/AC conversion takes place through a voltage source inverter that forms the principal component of the power electronic converter. Fig 3.4 shows the basic scheme for a typical MC consisting of the microsource and the power electronic converter. The voltage source inverter in the converter system controls both magnitude ( $V$ ) and phase angle ( $\delta_1$ ) of the output voltage ( $V \angle \delta_1$ ) at converter terminal (Bus-1). The microsource supplies controlled power to the Microgrid bus (Bus-2) at a voltage of  $E \angle \delta_2$  through an inductor of reactance  $X$ . Normally,  $V \angle \delta_1$  leads  $E \angle \delta_2$  by the power angle  $\delta$ ,

where  $\delta = \delta_1 - \delta_2$ . The active power flow (P) is controlled by controlling  $\delta$ , whereas reactive power (Q) is controlled by controlling V. The controls are based on feedback loops of output power P and microgrid bus voltage magnitude E, which are related as per the following equation:

$$P = \frac{3VE}{2X} \sin \delta$$

$$Q = \frac{3VE}{2X} (V - E \cos \delta)$$

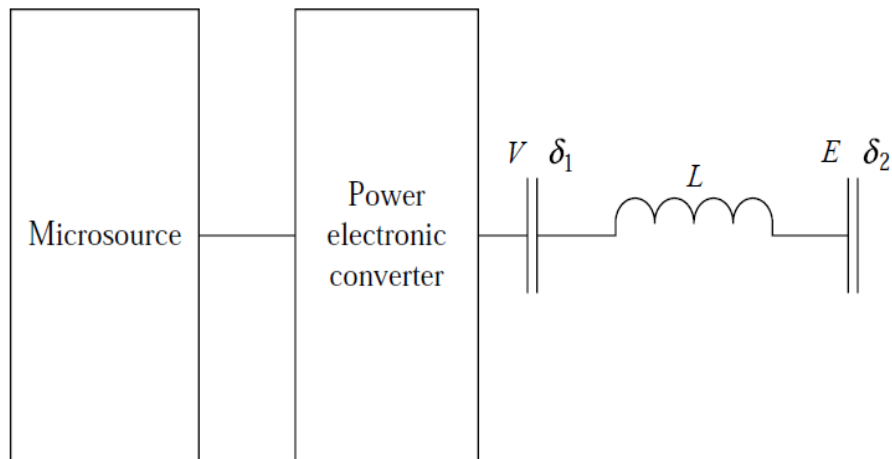
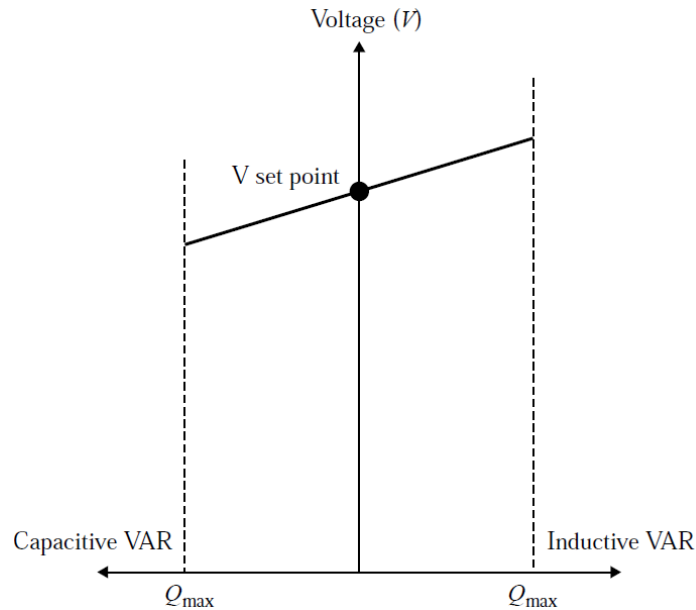


Fig 3.4: Basic scheme for typical Microsource controller

### 3.3.2.2 Voltage control

Apart from active and reactive power control, voltage control at the Microgrid bus is also needed for overall stability and reliability of microgrids. Microgrids with a large number of microsources may suffer from reactive power oscillations without proper voltage control. Similar to that for large synchronous generators, voltage control function of MC addresses the issue of alleviating large circulating reactive currents amongst microsources. For utility, this circulating current is normally restricted by the large impedance between generators, whereas in case of Microgrids, the problem becomes quite prominent as the feeders are mostly radial with small impedance between the sources. Sometimes, these circulating currents may also exceed the rated currents of the microsources even with small differences in their voltage set points. The circulating currents can be controlled by using voltage–reactive power (V-Q) droop controllers with droop characteristics as shown in Fig 3.5.



**Fig 3.5: Droop characteristics for V-Q droop controllers**

The function of the controller is to increase the local voltage set point when the microsource reactive currents become predominantly inductive and to decrease the set point when the current becomes capacitive. The reactive power limits is set by VA rating (VAR; S) of the inverter and active power (P) output of the microsource as per the following relation:

$$Q_{\max} = \sqrt{S^2 + P^2}$$

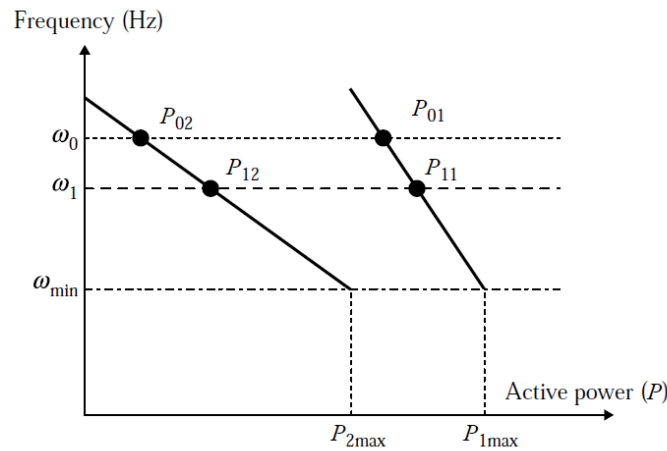
### 3.3.2.3 Storage requirement for fast load tracking

For grid-connected Microgrids, the initial power balance during connection of new loads is taken care of by the large inertia of utility generators. However, for standalone operation, the Microgrid needs to ensure initial power balance through its storage devices, which effectively provide the system inertia for the Microgrid. The DC storage devices are connected to the DC bus of the microsource, whereas AC storage devices are connected directly to the Microgrid bus. The MC ensures proper utilisation of the storage devices for fast load tracking.

### 3.3.2.4 Load sharing through P-f control

Microgrid controllers ensure smooth and automatic change over from grid-connected mode to stand-alone mode and vice versa as per necessity. This is similar to the operation of uninterruptible power supply (UPS) systems. During transition to standalone mode, the MC of each microsource exerts local P-f control to change the operating point so as to achieve local power balance at the new loading. The controller does this autonomously after proper load

tracking without waiting for any command from the CC or neighboring MCs. Fig 3.6 shows the drooping P-f characteristic used by the MCs for P-f control.



**Fig 3.6: Active power versus frequency droop characteristics**

During grid-connected mode, Microgrid loads are supplied both from the main utility grid and the microsources, depending on customer needs. When utility supply is interrupted due to any contingency, the Microgrid seamlessly switches over to the stand-alone mode. During change over, the voltage phase angles of the microsources also change, leading to obvious drop in their power output. Hence, local frequency also changes, in which case each microsource quickly picks up its share of load without any new power dispatch schedule from the CC. For example, it is assumed that two microsources operate at a common minimum frequency with their maximum capacities  $P_{1max}$  and  $P_{2max}$ . In grid-connected mode they operate at a base frequency delivering powers  $P_{01}$  and  $P_{02}$  respectively. With the change in load demand, the microsources operate at different frequencies causing a change in relative power angles, and the frequency of operation drifts to a lower common value with different proportions of load sharing. This occurs as per the droops of the P-f characteristics as shown in Fig 3.6. Since droop regulation decreases the Microgrid frequency, the MC needs to incorporate a control function to restore the operation to the rated frequency with proper load sharing.

### 3.3.3 Central Controller

The main interface between this control level and microgrid, is the central controller (CC). The MCC is responsible of the optimization of its operation according to the cost supply price, the microgrid controllable components and the expected loads. To manage the microgrid components, the MCC also must coordinate local controllers associated with each

component. To carry out these objectives, the MCC has two main functional modules which are EMM (Energy Management Module) and PCM (Protection Co-ordination Module).

### **3.3.3.1 Energy Manager Module (EMM)**

The EMM incorporates various control functions for controlling the energy optimal operation of the Microgrid. This section discusses a simple EMM that incorporates the basic priority control functions needed for satisfactory functioning of the Microgrid. The number of control functions can always be increased to achieve finer and more sophisticated control, though adding to design complexity. Basic microsource control functions are Voltage control, Power factor control, Prime mover speed control and Frequency regulation. In order to keep the Microgrid control simple, the number of control functions in the EMM is limited to only the basic minimum. This minimises the number of feedback signals required by EMM from MCs for sending out necessary commands to the microsourses. The operating strategy for EMM is briefly discussed in the following two sections.

#### **Grid-connected operation**

In grid-connected mode, EMM control signals are restricted to the active power and local voltage set points for microsourses. The local voltage and power factor control exerted by the MCs make the Microgrid appear to the utility grid as a controllable load operating at unity power factor. Thus, the EMM does not exert any additional voltage control that may interfere with the functioning of voltage regulators and shunt capacitors of the utility or with the MCs in the Microgrid itself. If the distribution feeder in Microgrid gets lightly loaded and there is some voltage rise, it is arrested by utility controllers. However, the EMM dictates the voltage control of microsourses only for certain critical Microgrid buses.

#### **Stand-alone operation**

In stand-alone mode also, the main function of the EMM is to provide the active power and voltage set points for MCs. Frequency and reactive power flow are controlled by the MCs autonomously through P-f and Q-V droop characteristics. The EMM does not communicate any command signal for control of phase angle and frequency to the MCs. But it continuously monitors the Microgrid frequency and implements rapid load shedding through MCs in case the frequency is not restored within a preset time for ensuring system stability. For stand-alone operation, these control functions respond rapidly to obtain load-generation balance as

fast as possible. This is because, in terms of generation capacity, the isolated Microgrid is not as stable as the grid-connected Microgrid.

### **3.3.3.2 Protection Co-ordination Module (PCM)**

PCM supervises the overall protection for the Microgrid. Protection philosophy for Microgrid is different from conventional distribution networks though both are radial systems. This is because of the following differences:

- (1) Microgrids contain both generators and loads resulting in bidirectional power flow through the protective devices in a radial system.
- (2) Passive distribution network turns into an active one due to the presence of microsources.
- (3) Microgrids undergo a considerable change in its short-circuit capacity when it changes from grid-connected mode to stand-alone mode. This has profound effect on conventional overcurrent relays that operate on short-circuit current sensing.

A key feature of PCM is its ability to distinguish between the protection requirements for the two operating modes and address the contingencies accordingly. Basic protection requirements for the two modes are briefly discussed in the next section with respect to some possible occurrences. Typical microgrid configuration as shown in Fig 3.3 is considered. However, additional protection features may be incorporated in PCM, depending on the customer-specific requirements.

## **3.4 Control Strategy for Switching Operation**

The critical feature that makes a microgrid unique is the ability to switch from grid-connected mode to island mode and vice-versa. The aim is to suggest system design that achieves this goal at moderate initial investment costs. There are several reasons for a microgrid to switch from grid-connected to island operation mode. For example if there is blackout on central grid induced by a fault, if the region is subjected to rotating blackout due to insufficient supply or if the quality of supply is undesirable for the application in the microgrid.

In connecting and disconnecting a microgrid to and from the grid, however, there are a number of significant technical challenges. These are related to maintaining stable operation during and after the switching event and require a sophisticated control strategy involving

monitoring, communication and coordination between generators and system operation. Depending on the quality of service required by the load in the microgrid, the regulations stipulated in the grid code for operation practices and number of grid support features desired, several different designs could be developed.

**The simple solution:** For application in development countries as a tool to improve energy access however, rather than designing such a complicated and expensive system. It may be sufficient to restrict the switching from grid-connected mode to island mode in the case of supply from the central grid being unavailable for a prolonged period of time (e.g. due to rotating power cuts) and the transition from island mode to grid-connected mode when the grid supply is back.

Such transition would be handled by manual switching upon confirmation that there will be a prolonged blackout and that the central grid is ready to receive the microgrid connection back again. If there were a controller, this transition would be aided with the boosting of local generation to match local load before the microgrid is disconnected, and preparing the voltage, frequency and phase of the island system to be in synchronization with the grid when re-connecting to the grid. However, without a controller, the manual switching would be accompanied by a brief blackout of the microgrid, following by a black start operation. Synchronous generator such as biomass system fed by biomass gasifier (like the husk power system), as well as some modern solar PV inverters and wind power converter can support system black start, therefore make this solution possible by choosing the right type component. This system is not exactly the most elegant solution. Without a microgrid controller which can coordinate the output of local generation and load, such a switching event would constitute a brief blackout of the microgrid system each time the microgrid is switching to and from grid connected mode to island mode. However, it removes the need for a complicated and expensive control scheme, therefore could be an economically accessible solution which still provides a more reliable supply compared to a system which relies solely on the grid supply, and a cheaper supply compared to a system which does not have the option to access grid supply.

**Advanced solution:** As the economic capacity develops and power system operation capabilities as well as regulations accommodate for it, more sophisticated control strategies may be implemented. This would attempt to make the transitions between grid-connected and

island mode smoother, by implementing a control scheme that can coordinate the output of the distributed generation with the local demand.

Such a full-fledged system would require a number of different component, costing approximately 5 million INR (100,000 USD) for one microgrid. It should be noted that this price estimated is only indicative; real price in actual project implement may differ significantly.

## CHAPTER 4

### MODELING OF HYBRID RENEWABLE ENERGY SYSTEM

#### 4.1 Design Overview

Hybrid power systems for remote applications are catching momentum due to their potential to significantly reduce fossil fuel consumption. Power sources in a hybrid power system can be coupled through a DC bus or through an AC bus. This section evaluates optimal off-grid and grid connected energy system configurations that can power the community center, utilizing the load curve data discussed further. Hybrid Optimization Model for Electric Renewable (HOMER), analytical software engineered by the National Renewable Energy Laboratory (NREL), is the tool used in this analysis. This software calculates which system configurations provide the best option, in terms of cost, for supplying electricity to the remote village Jhalkari which is located at longitude 30.320 and latitude 76.395. The remote village Jhalkari consist of 600 people with 120 houses and 250 cattle's. This village is mainly depended on agricultural activities. HOMER ranks optimal system configurations according to their net present cost (NPC) of renewable resources. Sensitivity analyses were also conducted to determine the impact of variations in natural resources, economic, or load conditions on the system, such as unanticipated attenuation of solar radiance, wind speed or increased electricity consumption; this helps to determine which system configurations are robust and adaptable to unanticipated variances in model assumptions.

#### 4.2 Benchmark HOMER Design Schematic

This hybrid energy system, which incorporates the use of renewable, consists of four primary functions: power production, energy consumption, storage and sell of excess electricity to grid. Power production relies on a PV array, wind-turbine, biomass, hydro-turbine and fuel cell. Energy consumption is dictated by a power versus time load curve. Energy storage is achieved with the use of a battery bank and converter. Utilizing HOMER, the benchmark simulation is comprised of loads AC as shown in Fig 4.1. The PV array and Fuel Cell produce DC power that can be fed directly into the DC bus without AC conversion, whereas hydro-turbine, wind-turbine and biomass generator is connected to AC bus. To AC bus is also connected to grid system in order to sell the excess of electricity at the off peak hours. Meeting AC energy load requirement necessitates that this energy be converted from DC to

AC. The converter allows for energy transformation from DC to AC, or vice versa. Given that neither the PV array nor fuel cell produces AC energy, the converter should transform just enough energy to AC to meet this load requirement in order to minimize conversion losses.

### Benchmark Simulation

Simulation modeling is the process of creating and analyzing a digital prototype of a physical model to predict its performance in the real world without actually making it. The benchmark simulation attempts to faithfully represent reality, although the lack of available site specific data often proves a challenge. In compensation, alternative simulations and sensitivity analysis were conducted to elucidate shortcomings in the benchmark model. Overall, the results of these tests indicate model robustness and its ability to work in actual conditions successful.

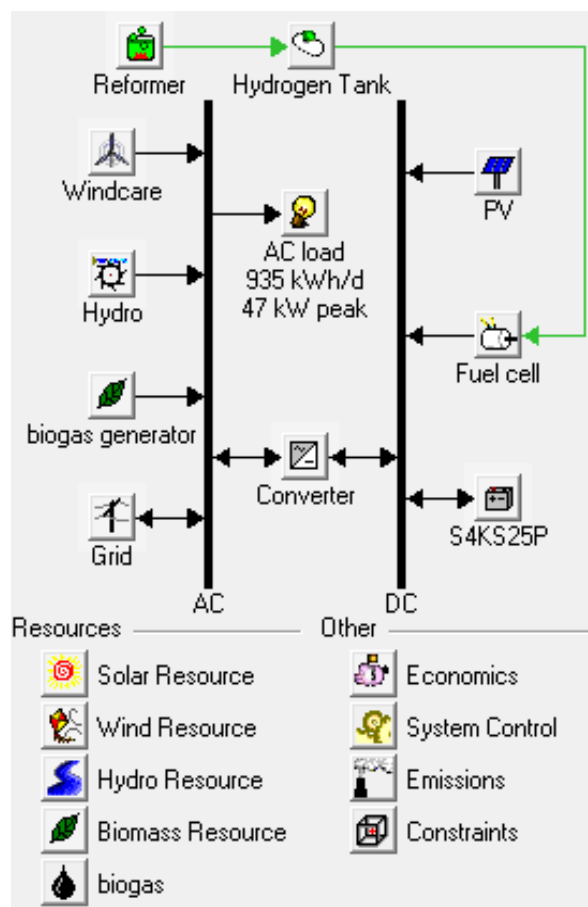


Fig 4.1: Simulation Model

### 4.3 Assessment of Renewable Energy Resources

The economically exploitable renewable energy resources in study area are Solar, Wind, Hydro, Biomass.

#### 4.3.1 Solar Irradiance and PV Array

Solar irradiation is the measure incident of total amount of solar radiation transmitted to the surface of the Earth's atmosphere in a given unit of time. We can simply say that solar irradiation is the amount energy transmitted from the sun to Earth's outer atmosphere. This measurement is normally done in square units per units of time. Solar radiation for this study area was obtained from the NASA Surface Meteorology and Solar Energy website. An average solar radiation of 5.22kWh/m<sup>2</sup>/day and a clearness index of 0.608 were identified for the study area. The clearness index is a measure of the clearness of the atmosphere. It is the fraction of the solar radiation that is transmitted through the atmosphere to strike the surface of the Earth. It is a dimensionless number between 0 and 1, defined as the surface radiation divided by the extraterrestrial radiation. The clearness index has a high value under clear, sunny conditions, and a low value under cloudy conditions. Fig 4.2 shows the average monthly solar radiation and clearness index for the study area.

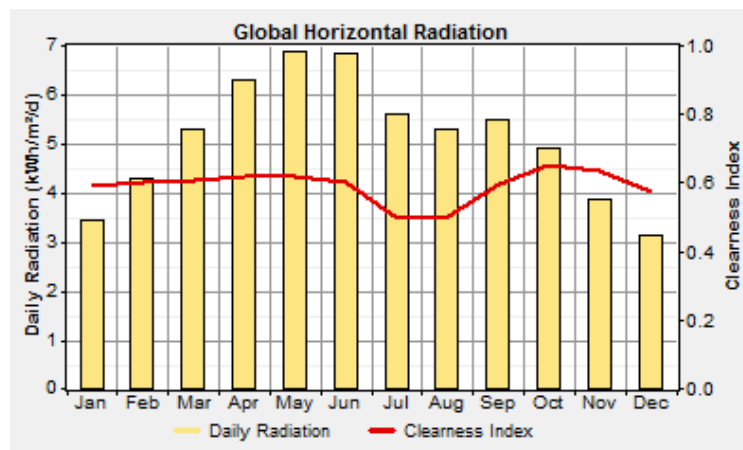


Fig 4.2: Global horizontal radiation of study area (Source: NASA Solar Energy Data)

The PV array modeled in HOMER gives DC output in direct proportion to incident solar irradiation. The installation cost of PV array is taken 175,000INR/kW (3242USD/kW) [28] and replacement cost is 170,000INR/kW (3149USD/kW). O&M cost is practically zero and

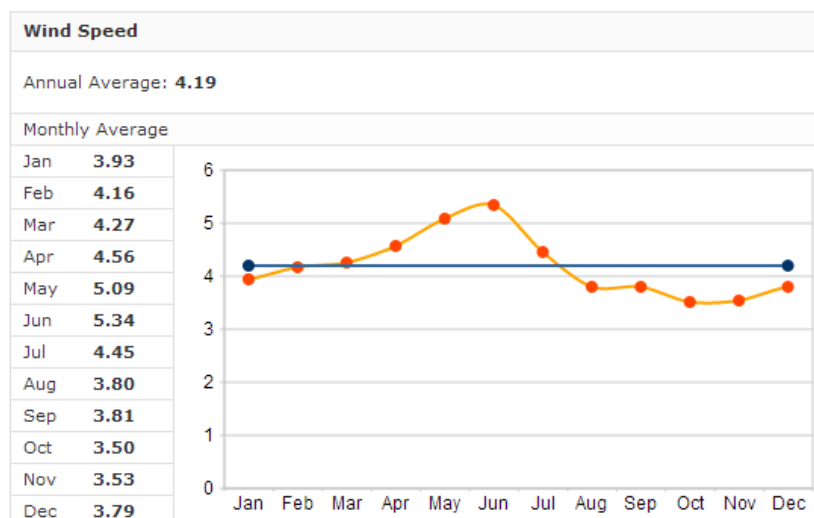
its lifetime is 30 years. A derating factor of 80% is applied to each panel to account for the degrading factors caused by temperature, soiling, tilt, shading etc.

### 4.3.2 Wind Speed and Wind Turbine

Wind turbines harness the wind to generate electricity. Wind turns the turbine blades, which spin a shaft, which connects to the generator and makes electricity. A local transformer is then used to step up the electrical voltage, so that the electricity can then be sent through transmission and distribution lines to homes, businesses and other users. The power (i.e. energy per second) in the wind hitting a wind turbine with a certain swept area is given by:

$$\text{Power} = 0.5 \times \text{Swept Area} \times \text{Air Density} \times \text{Velocity}^3$$

where Power is given in Watts (i.e. joules/second), the Swept area in square metres, the Air density in kilograms per cubic metre, and the Velocity in metres per second. Wind resources are determined using the NREL (National Renewable Energy Laboratory) database considering the wind direction at 10 meters above the surface of the earth. The database provides average wind speed is 4.19 m/s. The manufacturer Windcare turbine is used, which gives the output of 10 KW AC. The installation cost of wind turbine is taken 1,684,540INR (31,770USD) [29] and replacement cost is 1,521,520INR (28,000USD). Operation and maintenance (O&M) cost is \$65/year and its lifetime is 30 years. Fig 4.3 represents monthly average wind speed.



**Fig 4.3: Monthly average wind speed (Source: NASA Wind Data)**

### 4.3.3 Hydro Resource and Micro Hydro Turbine

In the study area, the stream has an annual average flow of 935 L/s. With design flow of 1100L/s (1.1 m<sup>3</sup>/s), 3m head and 65% efficiency, it is determined that a run-of-river type micro hydro plant of 2x20kW rated capacity can be installed. The capital cost for the installation of micro hydro is taken as 288,220INR (5340USD) [30] with replacement cost of 280,000INR (5187USD) and operation and maintenance (O&M) cost of 250USD per year. The electrical power generated by micro hydropower generator is given by:

$$\text{(Power) } P = \eta \rho g h Q$$

Where  $\rho$  is the density of the water (10<sup>3</sup> Kg/m<sup>3</sup>),  $h$  is the head of water,  $g$  is the gravitational constant (10 m/sec<sup>2</sup>),  $Q$  is the volume of water flowing per second (the flow rate in m<sup>3</sup>/second) and  $\eta$  is the efficiency of the turbine. Fig 4.4 represents monthly average stream flow given in appendix A.1.

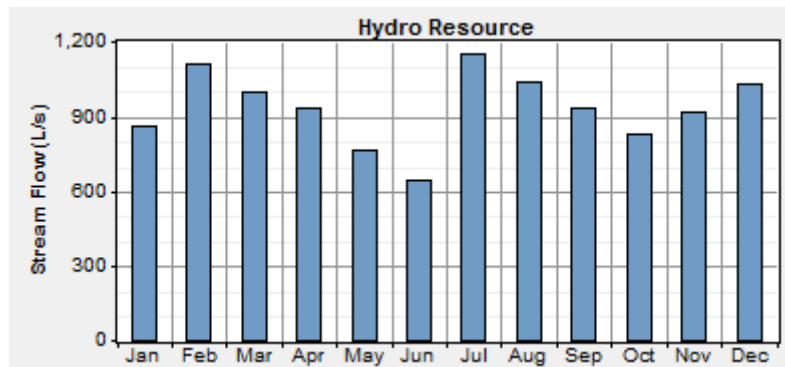


Fig 4.4: Monthly average stream flow

### 4.3.4 Biomass Resource and Biomass Generator

Biomass is a versatile source of energy. Biomass includes all plant life (trees, agricultural plants, bush, grass, algae, etc.), agricultural residues (crop and agro-processing), and wastes (municipal waste, animal and human wastes). Biomass undergoes anaerobic fermentation to produce biogas. Biogas is used as fuel to generate power from engine-generator set. The average biomass available in study area is 3.9tonnes per day and monthly available average biomass resource is shown in Fig 4.5. The capital cost of biogas powered generator is 54,340INR/kW (1000USD/kW) with replacement cost of 46,189INR/kW (850USD/kW) and O&M cost of 0.5USD/hour [31].

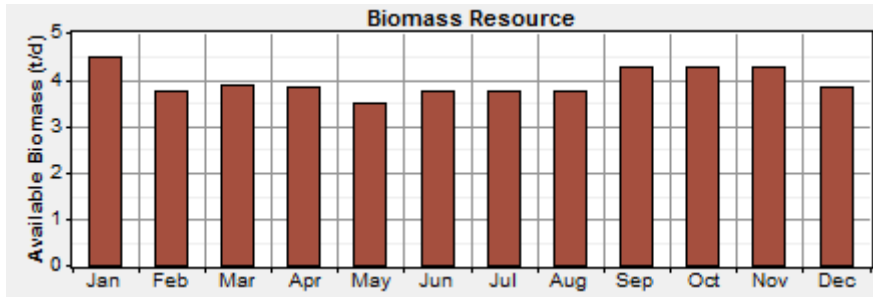


Fig 4.5: Monthly average biomass availability

#### 4.2.5 Reformed Biogas Fuel Cell (RBFC)

Reformer is used to produce hydrogen from hydrocarbon fuel such as natural gas, methane, propane, auto gas, diesel etc and the produced hydrogen is stored in hydrogen tank which is used by fuel cell to generate DC electricity. The cost details of reformer, hydrogen tank and fuel cell is given in table 4.1. Biogas is used as the hydrocarbon fuel, as it is cheap, readily available and renewable resource. The cost of biogas is assumed to be purchased at \$0.3/m<sup>3</sup> [17].

Table 4.1: Cost details of Reformer, Hydrogen Tank and Fuel Cell

Costs	Reformer	Hydrogen Tank	Fuel Cell
Capital Cost	\$2000/(kg/hr)	\$1300/kg of H <sub>2</sub>	\$3000/kW
Replacement Cost	\$2000/(kg/hr)	\$1200/kg of H <sub>2</sub>	\$2700/kW
O & M Cost	\$15/yr	\$10/yr	\$0.020/hr

#### 4.4 Converters

A converter is a device that converts DC power to sinusoidal AC power in inversion process and from AC to DC power in rectification process. The bidirectional converter costs 800USD/kW [18], has replacement cost of 750USD/kW and O&M cost of 15USD/yr for a lifetime of 30 years. The inverter and rectifier efficiencies are assumed to be 85% and 90% respectively.

#### 4.5 Battery

A battery is a device consisting of one or more electrochemical cells that convert stored chemical energy into electrical energy. This project utilized 216 Ah (amp hour), deep cycle

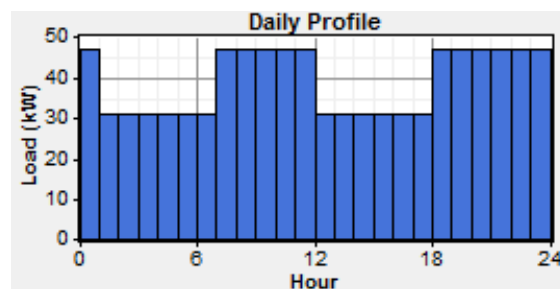
DC batteries. The HOMER software provides a number of preloaded batteries available for modeling purposes. From these choices, a Surette Battery 4KS-25P vented lead-acid, tubular-plated, deep cycle battery was decided upon as an appropriate surrogate for modeling. Capital Cost for batteries is 66887.46INR (1,236USD) [32], replacement cost is 60,610INR (1,120USD), whereas O&M cost is \$15/yr reported by the RESPRO. A detailed listing of this battery’s specifications is provided below in table 4.2.

**Table 4.2: Battery Constraints (Source NREL, 2012)**

Nominal capacity:	1900 Ah
Nominal voltage:	4 V
Round trip efficiency:	80 %
Min. state of charge:	40 %
Float life:	12 yrs
Lifetime throughput:	10,569 kWh
Suggested value:	10,494 kWh
Max. charge rate:	1 A/Ah
Max. charge current:	67.5 A

#### 4.6 Assessment of System Demand

An electricity load curve for has been generated for the remote village Jhalhari for activities such as lighting, cooling, communication and other household appliances etc. for each household. A school, health care center, public lightening and community center are the major power consumers. Basically, it is a small village which is mostly dependent on agriculture activities. The AC load Profile has an annual average of 662kWh/day and an annual peak of 85kW. The load curve is generated by taking the reading from the log sheet of the feeder, which is made available from the respective electricity board. There are six villages on the same feeder these are Naulakker, Balpur, Sarana, Dhotonda, Rajinder Nagar and Jhalhari. Fig 4.6 exhibits the load profile of the Jhalkari village given in appendix A.2. The random variability is added to load data, so day to day variability is kept at 20% and 15% time-step-to-time-step variability.



**Fig 4.6: AC load Profile**

## CHAPTER 5

### OPTIMIZATION OF MICROGRID USING HOMER

#### 5.1 General

Optimization of renewable energy hybrid system looks into the process of selecting the best components and its sizing with appropriate operation strategy to provide cheap efficient, reliable and cost effective. The techno economic analysis usually looks at the best possible combination from available resources for lowest net present cost. This thesis discusses the optimization of the hybrid system in context of minimizing the excess energy and cost of energy using HOMER. The hybrid system consisting of solar, wind, hydro, biomass, fuel cell and battery as back-up is connected to grid system for the basis of assessment. The system configuration of the hybrid is derived based on a theoretical domestic load at a remote location and local solar radiation, wind flow and water flow rate data. The demand loads are used in the simulation using HOMER to find the optimum combination and sizing of components [22].

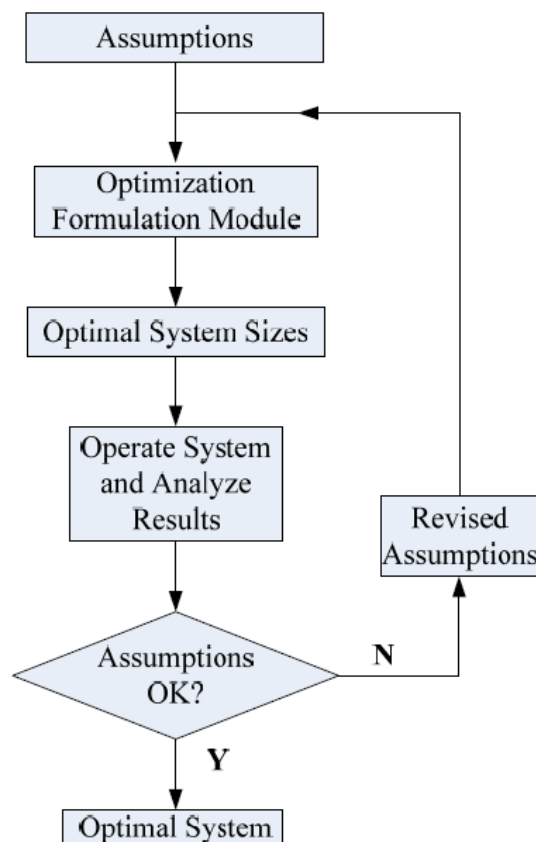


Fig 5.1: Flow chat for optimization

The analysis and design of microgrid systems can be challenging, due to the large number of design options and the uncertainty in key parameters, such as load size and future fuel price. The block diagram algorithm for designing an optimized hybrid renewable energy system is shown in Fig. 5.1. In this first of all assumption are made then optimal formulation is done based on the objective of minimum cost. If tuning is needed the new data will be fed back into the optimization formulation module to have a new set of optimal sizes [21]. In this way the optimization is performed.

## 5.2 Technical Terminology

**Total Net Present Cost ( $C_{NPC}$ ):** The total net present cost of a system is the present value of all the costs that it incurs over its lifetime, minus the present value of all the revenue that it earns over its lifetime. Costs include capital costs, replacement costs, O&M costs, fuel costs, emissions penalties, and the costs of buying power from the grid. Revenues include salvage value and grid sales revenue.

**Total annualized cost ( $C_{ann,tot}$ ):** The total annualized cost of a component is the cost that, if it were to occur equally in every year of the project lifetime, would give the same net present cost as the actual cash flow sequence associated with that component. It is calculated by annualized cost by first calculating the net present cost, then multiplying it by the capital recovery factor, as in the following equation:

$$C_{ann,tot} = CRF(i, R_{proj}) \cdot C_{NPC}$$

$i$  = annual real interest rate

$R_{proj}$  = Project life time

CRF = function returning capital recovery factor

**Levelised cost of electricity generation:** the levelized cost of electricity generation is defined as the average cost per kWh of useful electrical energy produced by the system. The approach used in the analysis renewable energy resources is based on a discounted cash flow discounting financial flows (DCF) analysis (annual, quarterly or monthly) to a common basis, taking into consideration the time value of money. Given the capital intensive nature of most renewable power generation technologies and the fact that fuel costs are low, or often zero,

the weighted average cost of capital (WACC), often also referred to as the discount rate, used to evaluate the project has a critical impact on the LCOE. The formula used for calculating the LCOE of renewable energy technologies is:

$$\text{LCOE} = \frac{\sum_{t=1}^n \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^n \frac{E_t}{(1+r)^t}}$$

Where:

LCOE = the average lifetime levelised cost of electricity generation;

$I_t$  = investment expenditures in the year  $t$ ;

$M_t$  = operations and maintenance expenditures in the year  $t$ ;

$F_t$  = fuel expenditures in the year  $t$ ;

$E_t$  = electricity generation in the year  $t$ ;

$r$  = discount rate; and

$n$  = economic life of the system.

### **5.3 Optimal Generation Mix**

The concept of microgrid can be applied for all those villages which are not connected to grid or to those villages which have the access of electrical utility. The advantage of access of utility is that we can buy at the time of shortage of supply or supply the excess of electricity to grid at off-peak hours to make the operating cost lower. Thus to have better view, this thesis will explain both the simulation results one after the other.

#### **5.3.1 Off-grid / Islanding Mode of Power Generation**

Off-grid applications are major Indian renewable energy priorities. Such applications not only replace fossil fuels but also make significant contribution to reduction in their consumption. As such, the strength and potential of renewable energy lies in its ability to generate power in decentralized and distributed mode which has the advantages of production at consumption points and does away with land and environmental related concerns and problems.

### 5.3.1.1 Simulation Result

Simulation of DERs in HOMER for cost optimization provides results in terms of optimal energy system, which is based on total net present cost ( $C_{NPC}$ ) and cost of electricity. Several simulations were performed for different sizes of PV array, biogas generator, wind turbines, hydro, fuel cell, converters and battery banks. Combination of the equipment depends on the optimization parameters and sensitivity variable. HOMER identifies the lists of all possible combinations for optimal results are shown in Fig 5.2, following:

	PV (kW)	XLS	Hydro (kW)	bio (kW)	FC (kW)	S4KS25P	Conv. (kW)	Reformer (kg/hr)	H2 Tank (kg)	Initial Capital	Operating Cost (\$/yr)	Total NPC	COE (\$/kWh)	Ren. Frac.	biogas (L)	Biomass (t)	bio (hrs)	FC (hrs)
	20		20.0	35		10	20			\$ 133,540	17,250	\$ 354,051	0.081	1.00		715	6,994	
	20	1	20.0	35		10	20			\$ 164,540	16,283	\$ 372,686	0.085	1.00		659	6,610	
	20		20.0	35	5	10	20	5		\$ 153,540	17,192	\$ 373,306	0.086	1.00		715	6,994	0
	20	1	20.0	35	5	10	20	5		\$ 184,540	16,224	\$ 391,941	0.090	1.00		659	6,610	0

Fig 5.2: Cost optimization using HOMER for islanding mode

The result on the topmost of is taken as the most optimal result as it has minimum initial cost, operating cost and cost of energy. The optimal configuration of DERs obtained from HOMER consists of 20kW of PV array, 20kW rated micro hydropower plant, 35kW biogas powered generator system, 10 numbers of Surrerte S4KS25P battery banks of 1900Ah nominal capacity and 20kW bidirectional converter. Simulation result also provided the costs of optimal DERs for given configuration. The total net present cost for DERs over the project lifetime is 354,051USD. The capital cost, operating cost and levelized cost of energy for DERs is around 133,540USD, 17,250USD per year and 0.081USD/kWh respectively.

### 5.3.1.2 Details of contribution of DERs

Component	Production	Fraction
	(kWh/yr)	
PV array	33,322	10%
Hydro turbine	156,685	45%
biogas generator	160,400	46%
Total	350,407	100%

Load	Consumption	Fraction
	(kWh/yr)	
AC primary load	341,253	100%
Total	341,253	100%

Quantity	Value	Units
Excess electricity	1,094	kWh/yr
Unmet load	0.000538	kWh/yr
Capacity shortage	0.00	kWh/yr
Renewable fraction	1.000	

Fig 5.3: Percentage wise contribution of DERs in islanding mode

As it is clearly shown in Fig 5.3 that PV array contributes 10 percent, hydro turbine contributes 45 percentage which is second highest renewable energy in use and biogas is the highest used renewable energy which is 46 percentage. The AC primary load 341,253kWh/year. In this off-grid or islanding mode as the excess of electricity produced is 1,094kWh/year which is 1.5 percentage of electricity produced. Excess electricity is surplus electrical energy that must be dumped because it cannot be used to serve a load or charge the batteries. Excess electricity occurs when there is a surplus of power being produced (either by a renewable source or by the generator when its minimum output exceeds the load) and the batteries are unable to absorb it all. The monthly average electricity production is shown in Fig 5.4.

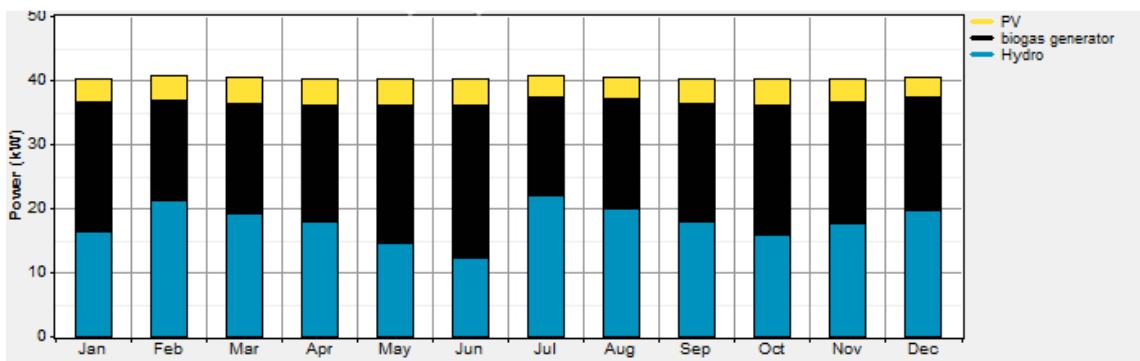
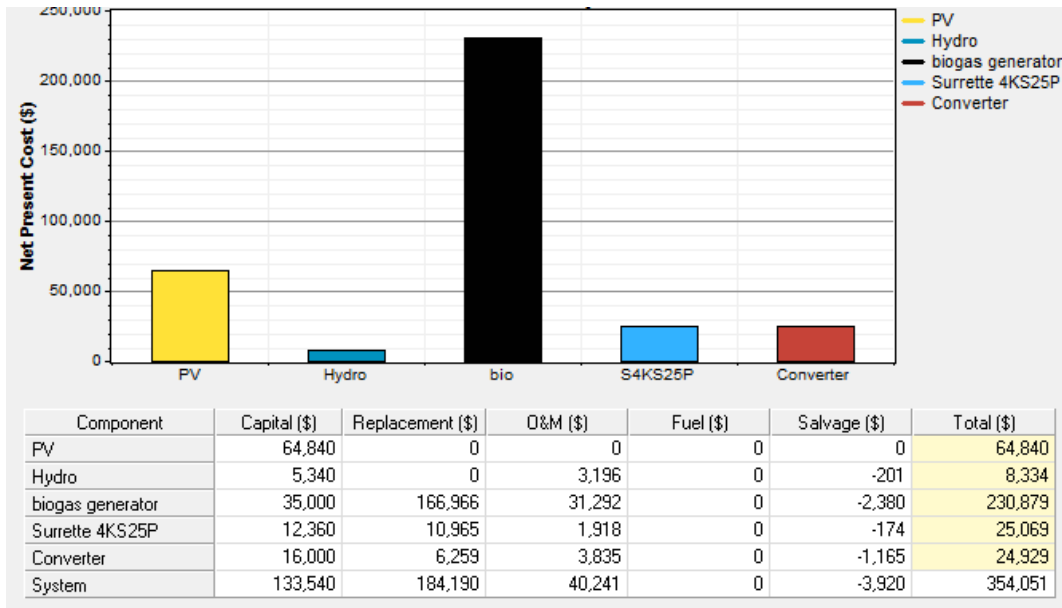


Fig 5.4: Monthly average electricity production

### 5.3.1.3 Cost summary

The cost summary helps to know the capital cost, replacement cost, O&M cost, fuel cost, salvage cost involved by each component in the system. In this PV array has a capital cost of 64,840USD, which its total cost as there is no replacement, fuel, salvage cost involved. The main point to be note here is that that cost evolved in the system is more because it is not connected to grid, so it should be sufficient to cater the peak load. As to cater the peak load it has to produce extra energy and this energy will be in use at the peak load time and for the rest time the extra energy is used to store energy in batteries and if system is connected to grid then some of extra energy can be purchased for grid at peak hours and access energy at off-peak hour can be sold to grid. This will help in lowering the capital and operation cost. Similarly, the part by part contribution of each component is shown in Fig 5.5.



**Fig 5.5: Net Present Cost of Islanding Mode**

### 5.3.1.4 Emission Rate

Renewable energy describes the energy we can harness from the sun, the wind and the oceans or from renewable organic matter or ‘biomass’. Increasing our use of renewable energy sources can help us cut emissions of carbon dioxide, the main cause of climate change. However, we need to balance this benefit against the potential impact of each renewable technology on the local environment. The different types of pollutant and their emission kg per year are shown in the table 5.1.

**Table 5.1: Emission Rate of Pollutant in Off-Grid Connected System**

Pollutant	Emissions (kg/yr)
Carbon dioxide	54.5
Carbon monoxide	5.62
Unburned hydrocarbons	0.623
Particulate matter	0.424
Sulfur dioxide	0
Nitrogen oxides	50.2

### 5.3.2 Grid connected power generation

Grid connected power systems are power systems energized by DERs which are connected to the utility grid. Thus it continues to power a location even though power from the electric utility is no longer present. The main advantage is that we can take the electrical supply at the

time of shortage of supply and deliver the extra power to grid at off-peak hours. By this, operating cost of whole system will drop significantly.

### 5.3.2.1 Simulation Result

	PV (kW)	XLS	Hydro (kW)	bio (kW)	FC (kW)	Conv. (kW)	Reformer (kg/hr)	H2 Tank (kg)	Grid (kW)	Initial Capital	Operating Cost (\$/yr)	Total NPC	COE (\$/kWh)	Ren. Frac.	biogas (L)	Biomass (\$)	bio (hrs)	FC (hrs)
	15		20.0	30		20			10	\$ 99,970	12,469	\$ 259,371	0.048	0.99		940	8,123	
	15	1	20.0	30		20			10	\$ 130,970	11,383	\$ 276,484	0.050	1.00		908	7,844	
	15		20.0	30	5	20	5		10	\$ 119,970	12,411	\$ 278,626	0.051	0.99		940	8,123	0
	15	1	20.0	30	5	20	5		10	\$ 150,970	11,325	\$ 295,739	0.053	1.00		908	7,844	0

Fig 5.6: Cost optimization using HOMER for grid connected system

The optimal configuration of DERs obtained from HOMER consists of 15kW of PV array, 20kW rated micro hydropower plant, 30kW biogas powered generator system, 20kW bidirectional converter and from grid 10kW of power is taken to supply load. Simulation result also provided the costs of optimal DERs for given configuration. The total net present cost for DERs over the project lifetime is 259,371USD. The capital cost, operating cost and levelized cost of energy for DERs is around 99,970USD, 12,469USD per year and 0.048USD/kWh respectively.

### 5.3.2.2 Detail of contribution of DERs

Component	Production	Fraction
	(kWh/yr)	
PV array	24,992	6%
Hydro turbine	156,685	37%
biogas generator	243,690	57%
Grid purchases	3,382	1%
Total	428,749	100%

Load	Consumption	Fraction
	(kWh/yr)	
AC primary load	341,253	80%
Grid sales	84,958	20%
Total	426,211	100%

Quantity	Value	Units
Excess electricity	0.00105	kWh/yr
Unmet load	0.000280	kWh/yr
Capacity shortage	0.00	kWh/yr
Renewable fraction	0.992	

Fig 5.7: Contribution of DERs in grid connected system

As it is clearly shown in Fig 5.7 that PV array contributes 6 percent, hydro turbine contributes 37 percent which is second highest renewable energy in use and biogas is the highest used renewable energy which is 57 percent. The AC primary load 341,253kWh/year and grid sales are 84,958kWh/year. In this grid connected mode as the excess of electricity produced is 0.00105kWh/year which is zero percent. The monthly average electricity production is shown in Fig 5.8.

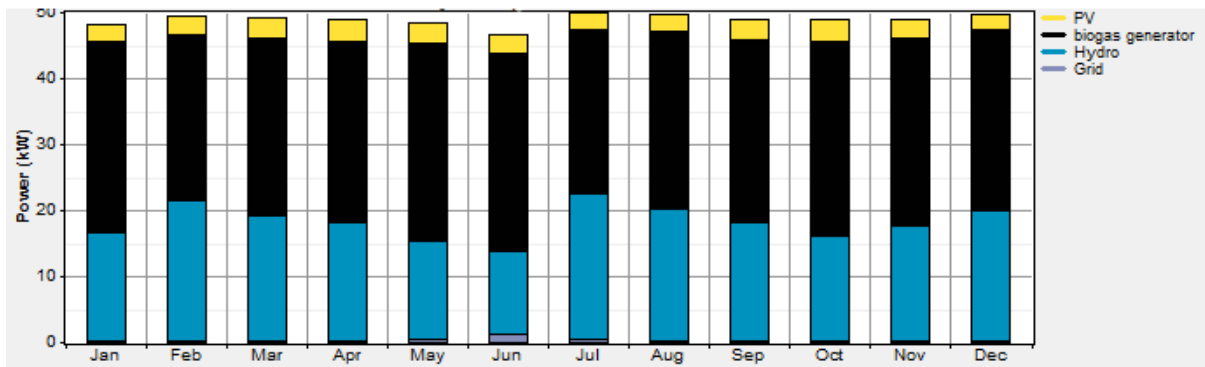


Fig 5.8: Monthly average electricity production

### 5.3.2.3 Cost summary

The cost summary helps to know the capital cost, replacement cost, O&M cost, fuel cost, salvage cost involved by each component in the system. In this PV array has a capital cost of 64,840USD, which its total cost as there is no replacement, fuel, salvage cost involved. Similarly, the part by part contribution of each component is shown in Fig 5.9.

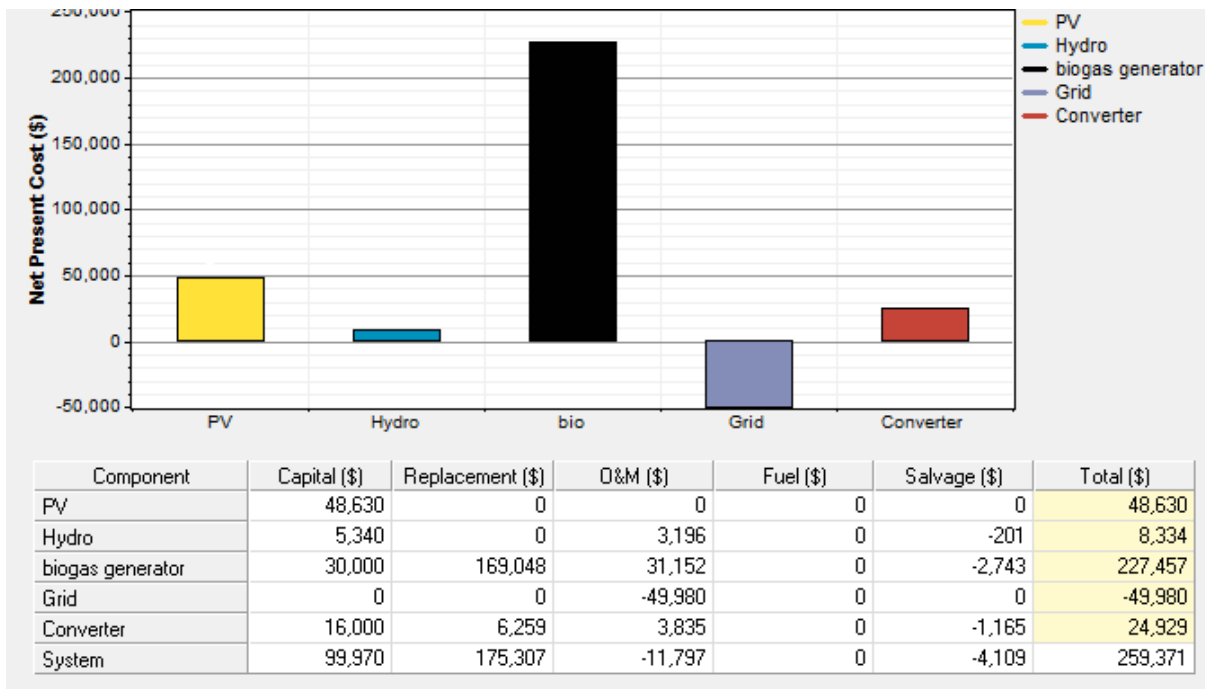


Fig 5.9: Cost summary in grid connected system

### 5.3.2.4 Emission Rate

Emission rate is the amount of pollution released to the atmosphere per unit weight during combustion. However, renewable energy has received much attention by environmental

policymakers because renewable energy technologies have significantly lower emissions than traditional power generation technologies. In this the grid connected system emission of carbon dioxide other gases are taken out on yearly basis in the table 5.2.

**Table 5.2: Emission Rate of Pollutant in Grid Connected System**

Pollutant	Emissions (kg/yr)
Carbon dioxide	-3.56
Carbon monoxide	2.27
Unburned hydrocarbons	0.251
Particulate matter	0.171
Sulfur dioxide	0
Nitrogen oxides	20.2

### 5.3.2.5 Grid exchange

Grid exchange gives the summary of electricity transaction month wise as shown in table 5.3. In this energy purchased, energy sold, peak demand, energy charges in each month are represented. It is observed that as June, July and August have peak demand, so in this season energy is purchase form grid and in October, November, December and January access of energy is sold to grid, which will lower the operating cost. It is seen that annual energy purchased is 3,382kWh and annual energy sold 84,958kWh. So, annual net purchase 81,576kWh. In this the cost of buying power from the main grid is 5.2INR/kWh (0.1 USD/kWh) and the price at which supply is given to main grid is 2.6INR/kWh (0.050 USD/kWh). With this the annual charges of electricity sold to grid is 3,910 USD.

**Table 5.3: Grid Power Exchange**

Month	Energy	Energy	Net	Peak	Energy	Demand
	Purchased	Sold	Purchases	Demand	Charge	Charge
	(kWh)	(kWh)	(kWh)	(kW)	(\$)	(\$)
Jan	142	6,682	-6,541	4	-320	0
Feb	247	6,942	-6,694	6	-322	0
Mar	183	7,378	-7,195	5	-351	0
Apr	189	6,949	-6,760	5	-329	0
May	440	6,806	-6,366	2	-296	0
Jun	1,004	5,375	-4,372	4	-168	0
Jul	367	8,012	-7,645	6	-364	0
Aug	190	7,836	-7,646	5	-373	0
Sep	145	6,928	-6,783	5	-332	0
Oct	221	7,148	-6,927	4	-335	0
Nov	101	7,031	-6,930	4	-341	0
Dec	152	7,869	-7,717	5	-378	0
Annual	3,382	84,958	-81,576	6	-3,910	0

## 5.4 Comparison Study

As simulation of both off-grid system and grid connected system is done. Now the comparative analysis of both off-grid system and grid connected system is done. For easy evaluation of results are shown in the tabular form. The table 5.4 shows the comparison of both systems in terms of Initial Capital Cost, Operating Cost, Net Present Cost and Cost of Electricity.

**Table 5.4: Comparison of Cost of both systems**

<b>Content</b>	<b>Off-Grid System</b>	<b>Grid Connected System</b>
Initial Capital Cost	133,540 USD	99,970 USD
Operating Cost	17,250(USD/yr)	12,459(USD/yr)
Net Present Cost	354,051 USD	259,371 USD
Cost of Electricity	0.081(USD/kWh)	0.048(USD/kWh)

Now, the comparison of both systems in terms of AC Primary Load, Grid Sales and Excess Electricity are done in the table 5.5. it is observed that in off-grid system grid sale nil, so there is excess of electricity in the system which can be utilized whereas there is no excess electricity in the grid connected system as all the excess electricity is sold to grid.

**Table 5.5: Comparison of Electricity transaction of both systems**

<b>Content</b>	<b>Off-Grid System</b>	<b>Grid Connected System</b>
AC Primary Load	341,253(kWh/yr)	341,253(kWh/yr)
Grid Sales	0 (kWh/yr)	84,958(kWh/yr)
Excess Electricity	1,094(kWh/yr)	0.00105(kWh/yr)

As HOMER has the enhanced feature of estimating the air emission from the off-grid connected and grid connected system. Now the comparison of both the system is done by taking in consideration various pollutant emission in atmosphere per year in table 5.6. These pollutants are harmful to environment as well as to living beings and causes the hazardous diseases. As we are using the renewable energy resources which are pollution free still the comparison is made in both the systems in order to make the pollutants to negligible extend.

**Table 5.6: Emission Rate of both systems**

<b>Emissions</b>	<b>Off-grid system</b>	<b>Grid connected system</b>
Carbon dioxide	54.5(kg/yr)	-3.56(kg/yr)
Carbon monoxide	5.62(kg/yr)	2.27(kg/yr)
Unburned hydrocarbons	0.623(kg/yr)	0.251(kg/yr)
Particulate matter	0.424(kg/yr)	0.171(kg/yr)
Sulfure dioxide	0(kg/yr)	0(kg/yr)
Nitrogen oxide	50.2(kg/yr)	20.2(kg/yr)

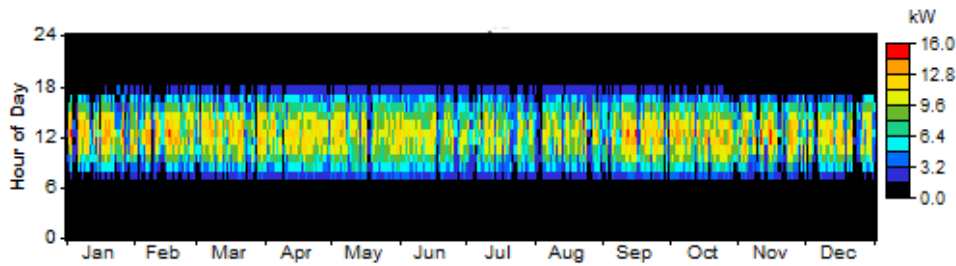
From the above comparisons, it is being concluded that the grid connected system have lower initial cost, cost of electricity and emission of pollutant. The biggest advantage of grid connected system is that we can purchase and sale the electricity to grid whenever it is needed. Also in grid connected system there is no need of battery as the grid is connected for the backup in the case of failure of supply from microgrid system.

## **5.5 Analysis of Grid Connected System**

In this grid connected system analysis of the results is done which will include analysis of each renewable source of energy PV array, hydro generator and biomass generator. Therefore, rated capacity, mean output, capacity factor, levelised cost, hour of operation and penetration of each renewable energy source discussed.

### **5.5.1 Analysis of PV array**

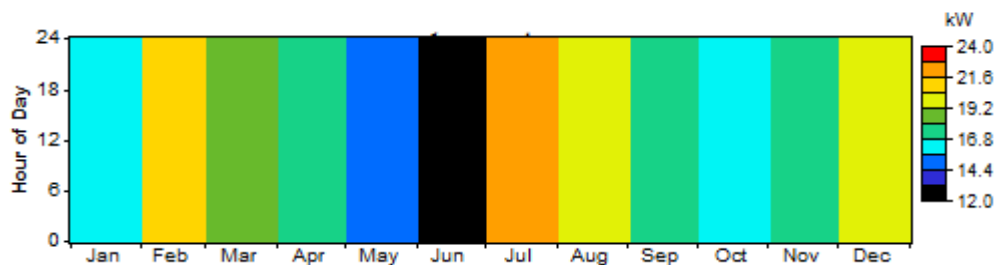
PV array has the rated capacity of 15kW and mean output of 2.9kW or 68.5kWh/day with capacity factor of 19 percent. The capacity factor is the average power output of the PV array (in kW) divided by its rated power. The total production of electricity by photovoltaic array is 24,992kWh/year. The PV penetration is 7.32 percent with the levelized cost of 0.152USD/kWh. The PV penetration is the average power output of the PV array divided by the average primary load. The total hour for the operation is 4,374hr/year. The Fig 5.10 shown below gives the view of photovoltaic output at hours of day vs. months of year. In this the side scale colour depicts the PV array usage in kilowatts.



**Figure 5.10: Photovoltaic Output (kW) at Hours of Day vs. Months of Year**

### 5.5.2 Analysis of Hydro generator

Hydro generator has nominal capacity of 20kW and mean output of 17.9kW with the capacity factor of 89.6 percent. The capacity factor is the average power output of the hydro turbine divided by its nominal capacity. The total production of electricity by hydro generator is 156,685kWh/year. The hydro penetration is 45.9 percent with the levelized cost of 0.00416 USD/kWh. The hydro penetration is the average power output of the hydro turbine divided by the average primary load. The minimum output is 12.3kW and maximum output is 22kW. The total hour for the operation is 8,760hr/year. The Fig 5.11 shown below gives the view of hydro output at hours of day vs. months of year. In this the side scale colour depicts the quantity of hydro energy usage in kilowatts.

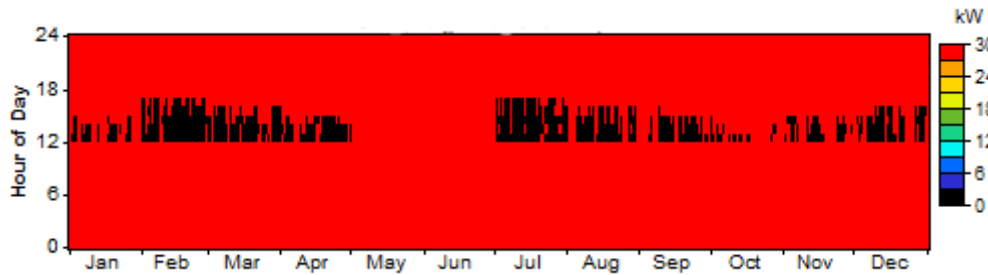


**Figure 5.11: Hydro generator output (kW) at Hours of Day vs. Months of Year**

### 5.5.3 Analysis of Biogas generator

Biogas generator has the electrical production of 243,690kW/year and mean output of 30kW with capacity factor of 92.7 percent. The capacity factor is the average power output of the biogas generator (in kW) divided by its rated power. The total production of electricity by photovoltaic array is 243,690kWh/year. The total hour for the operation is 8,123hr/year. The total number of starts in a year is 231starts/year. The maximum and minimum output is 30kW each. The feedstock consumption is 940 tonnes/year and specific fuel consumption is 2700kg/kWh. Thus fuel energy input is 1,005,221kWh/year and mean electrical efficiency of

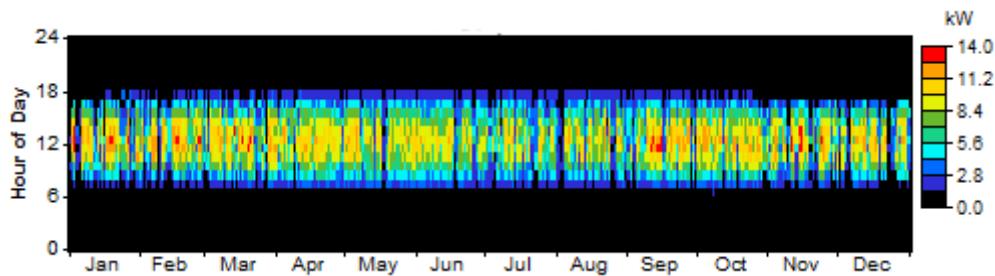
24.2 percent. The Fig 5.12 shown below gives the view of biogas generator output at hours of day vs. months of year. In this the side scale colour depicts the biogas generator usage in kilowatts.



**Figure 5.12: Biogas generator output (kW) at Hours of Day vs. Months of Year**

### 5.5.4 Analysis of Converters

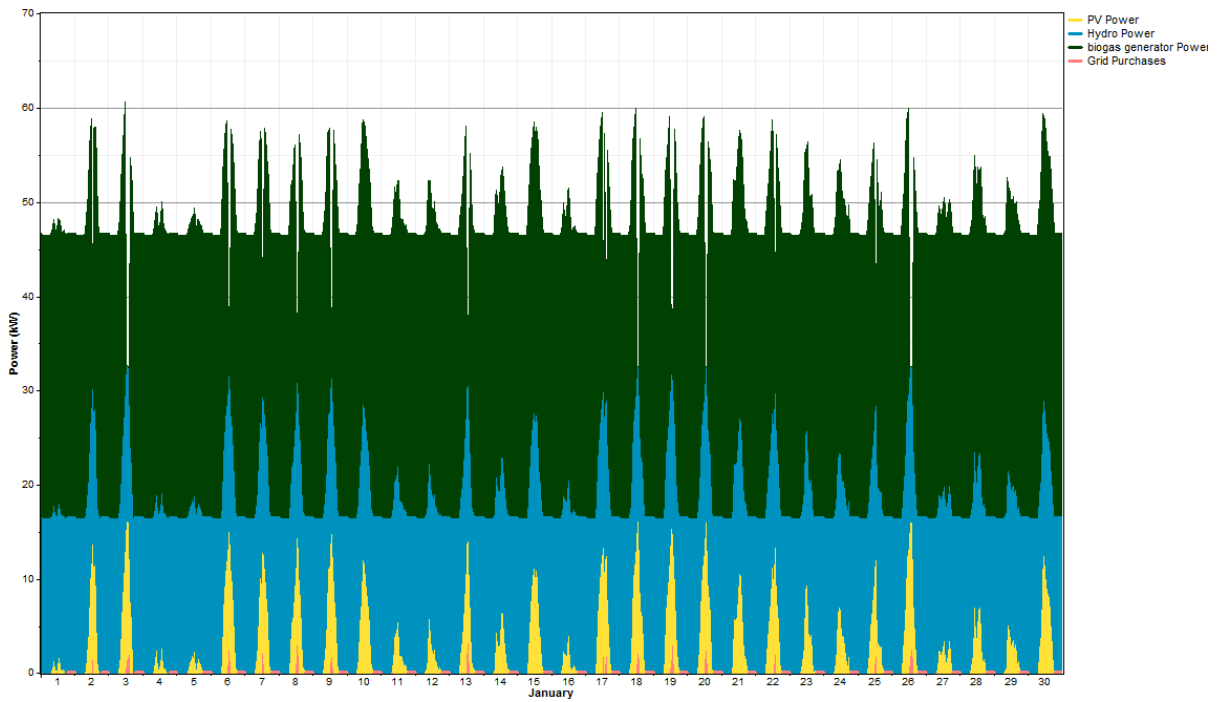
As we have seen that there is ac load so only inverter is need to convert the direct current into alternation current and there is no need of rectifier. On the DC busbar PV array is connected, power produced by it has to be converted into AC power for this we need inverter. The converter taken has the capacity of 20kW and the mean output of 2.6kW with the capacity factor of 12.8 percent. The energy taken in and out is 24,992 and 22,492kWh/year. The hour of operation is 4,374hr/year. The Fig 5.13 shown below gives the view of inverter output power at hours of day vs. months of year.



**Figure 5.13: Inverter output (kW) at Hours of Day vs. Months of Year**

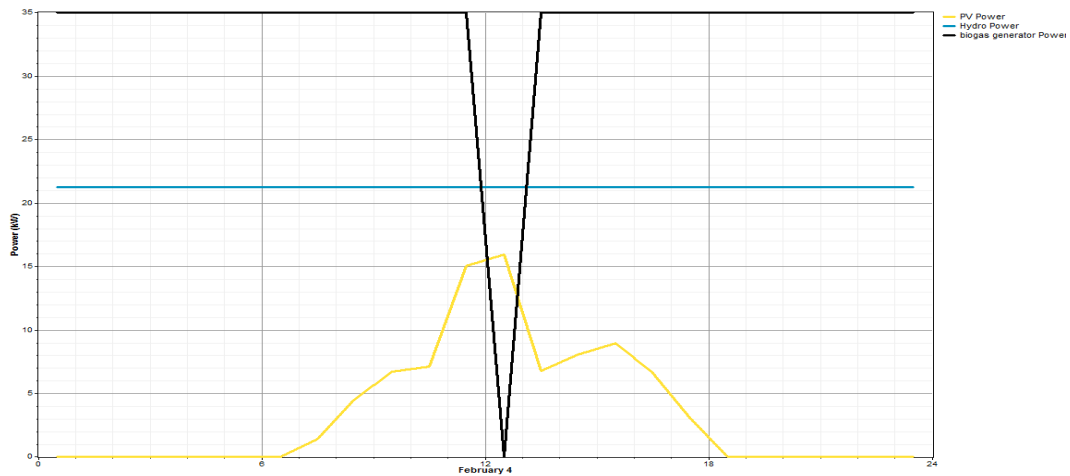
### 5.6 Evaluation of Energy Production

In this section the overall view on the contribution of different renewable and grid purchase in the grid connected system for a month is shown in the Fig 5.14. it is seen that PV has the small contribution in the production and major production of electricity is done by the hydro and biomass generator. It is seen that a very small quantity of grid supply is purchase for the peak loads.



**Fig 5.14: Power production by different DERs in a month**

Now the simulation for one day is done as shown below in the Fig 5.17.

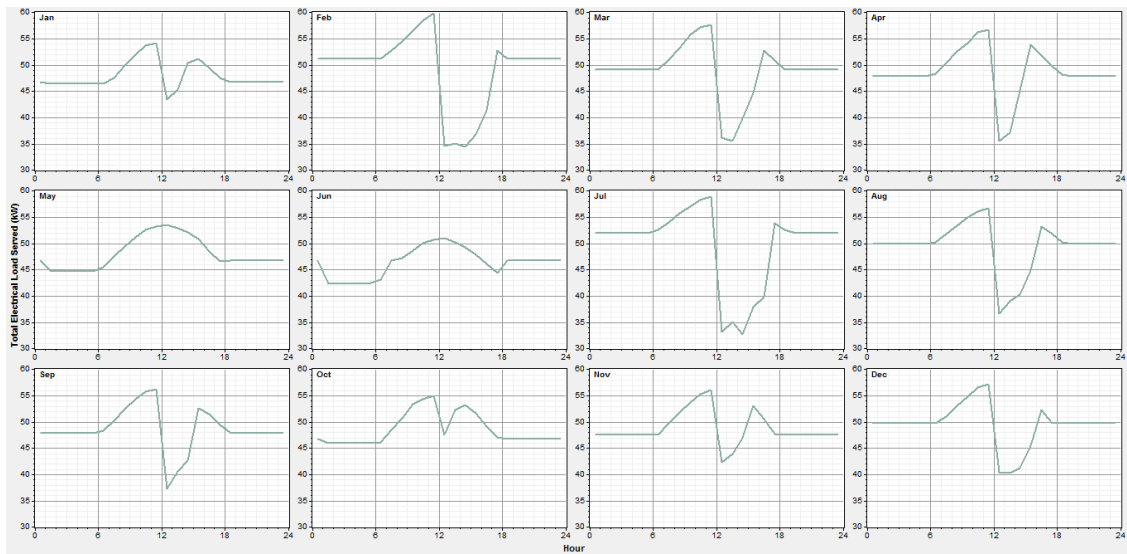


**Fig 5.15: Power production by different DERs in a day**

The total electrical load served daily profile is shown in the Fig 5.16. In this each month daily electrical load is shown. This will give the real idea of the daily need of electricity served in each month by the renewable sources of energy and some of electricity is purchased by the grid to cater the peak load. The total electrical load served is the total amount of energy that went towards serving the primary loads during the year, plus the amount of energy sold to the grid. The total electrical load served using the following equation:

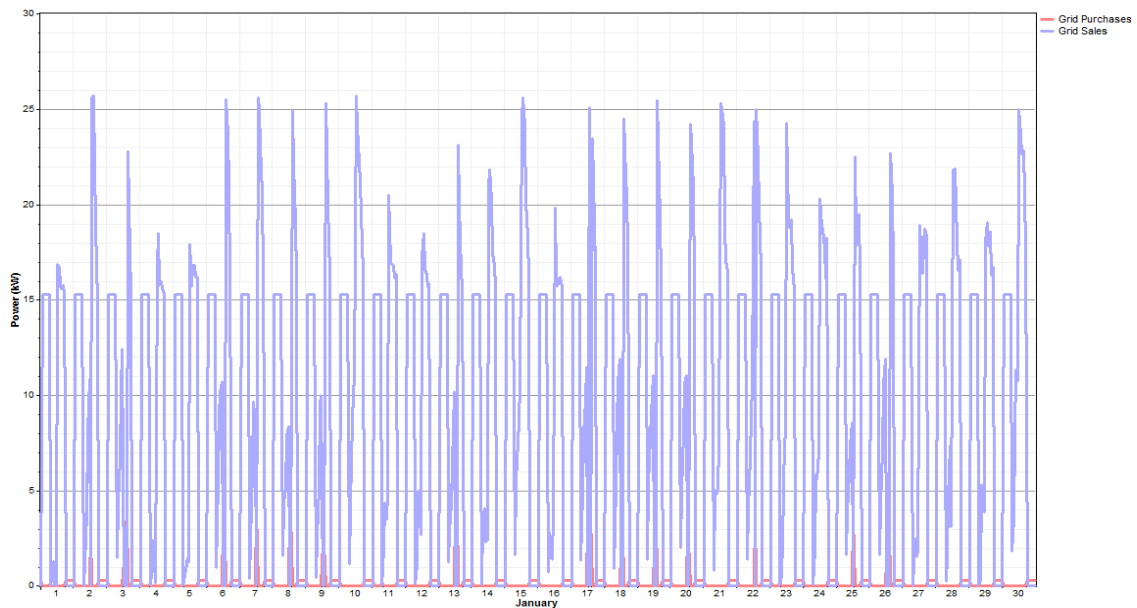
$$E_{\text{served}} = E_{\text{served, AC prim}} + E_{\text{grid sale}}$$

Where  $E_{\text{served, AC prim}}$  is AC primary load served and  $E_{\text{grid sale}}$  is energy sold to grid.



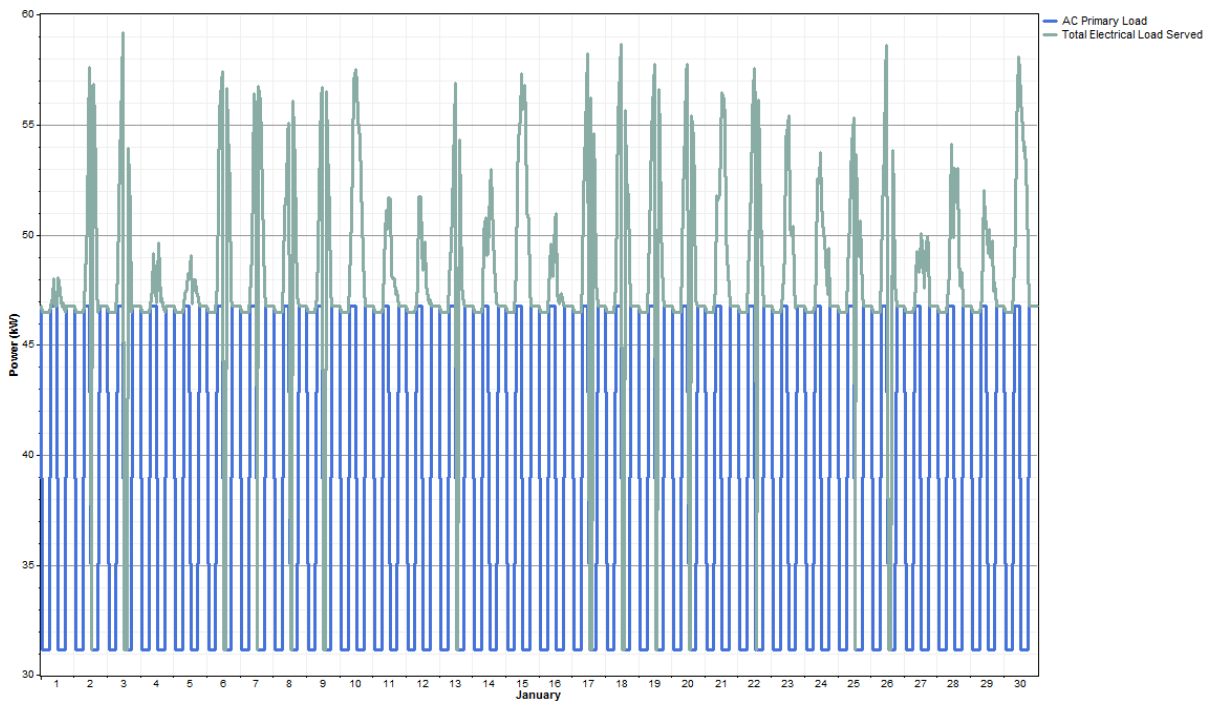
**Fig 5.16: Total electrical load served daily profile**

The Fig 5.17 shows the total electricity purchased from the grid and the electricity sold to grid. This is represented in the graph of power vs. month of January. It will give the real view that the electricity is purchased in January month is 4kW at the peak hours and the electricity sold to grid is 25kW. The total units sold to grid are 6,682kWh and energy purchased is 142kWh. Ultimately, the grid will supply to grid at peak hour hence need of storage devices such as batteries are avoid which will bring the cost down. The excess of electricity is sold to grid which will bring down the cost.

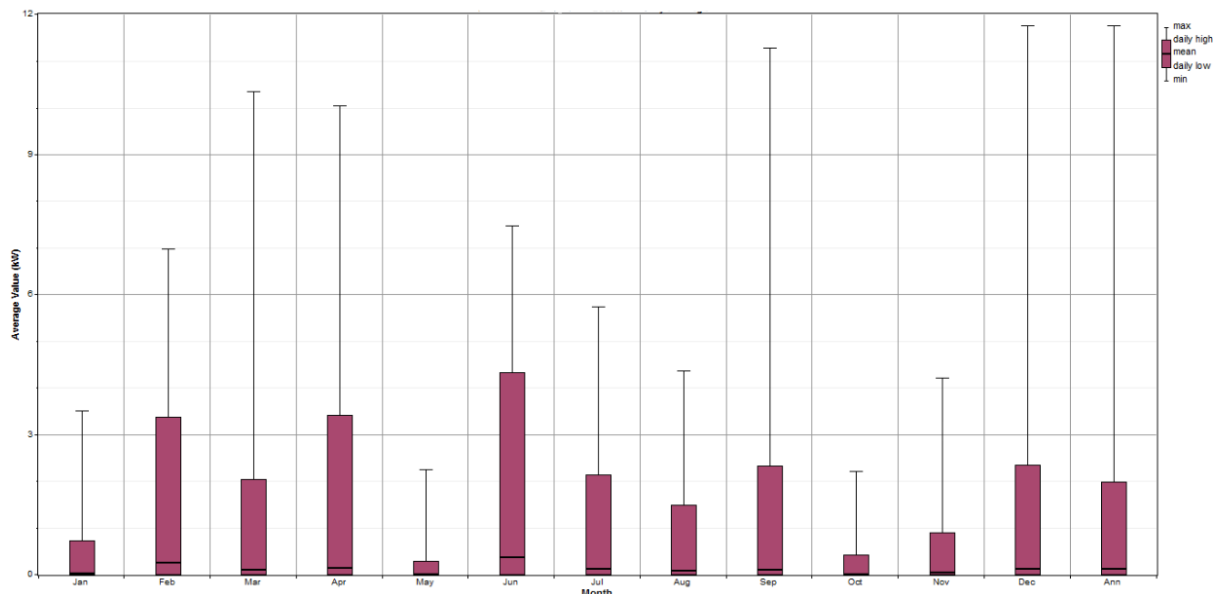


**Fig 5.17: Grid sale and purchase with power vs. month of January**

As the grid connected system is capable of catering the total load, the graph given below shows the AC load and the total electrical load served. This is shown in the power vs. month of January. Similarly, we can get the graph for each and every graph. As we can see in the Fig 5.18 shows that system is well capable to cater the total load as electricity produce is more than needed, this excess of electricity is sold to grid. Whereas in the Fig 5.19 depicts the monthly average of excess of electricity production.



**Fig 5.18: Total load and load served with power vs. month of January**



**Fig 5.19: Monthly average of excess electricity production**

## CHAPTER 6

### CONCLUSION & FUTURE SCOPE

#### 6.1 Conclusion

The key outcome of the thesis is that optimal energy system will be tuned for the hybrid renewable energy resources. In this thesis the study conducted is in two types of simulations (off-grid and grid connected) and results are discussed. The optimal sustainable generation systems for village Jhalkari were proposed, which is located at 30° 320'N latitude and 76° 395' E longitude. The village has a population of 600 with 120 scattered households and 250 cattle including bovine, poultries, swine etc. The study area has adequate sunshine, low to moderate wind speeds, falling water and abundant biomass year round. The results suggested that grid-tied systems are much more cost effective and feasible when compared to off-grid systems. This is primarily due to the high cost incurred due to use of battery storage in off-grid systems for backup power in case of emergencies or fault in the primary systems. It is recommended that a continuous improvement method be used to modify these systems from grid-tied to completely isolated off-grid system over time. The another reason is that the extra electrical energy produced is sold to grid and when there is need of electrical energy then it is purchased from grid to supply the peak load. Even though several researchers and practitioners lobby for innovative approaches, our analysis indicates that grid-tied systems are economically feasible at this point of time. Given, the result of our analysis we would also recommend that grid connected growth in energy sector is essentially more economical and profitable when compared to off-grid connected system.

#### 6.2 Future Scope

The presented work can be extended in other following related areas:

- Modeling and optimization can be done for larger areas like city or town taking in consideration AC, DC and Thermal load with the various combinations of DERs can be performed.
- Optimization and Modeling can be by using new software like iHOGA, TRNSYS 17, PVSYST 5, RETScreen Plus, MATLAB optimization toolbox and genetic algorithm can be done in future. DERs can be employing with sensors and intelligent control.

## APPENDIX

**TABLE A.1**  
**AVERAGE STREAM FLOW FOR EACH MONTH**

Month	Stream Flow (L/s)
January	861
February	1,110
March	999
April	936
May	768
June	645
July	1,151
August	1,040
September	935
October	833
November	920
December	1,033

**TABLE A.2**  
**24 HOUR VALUES OF LOAD TABLE**

Hour	Load (kW)
00:00-01:00	46.750
01:00-02:00	31.160
02:00-03:00	31.160
03:00-04:00	31.160
04:00-05:00	31.160
05:00-06:00	31.160
06:00-07:00	31.160
07:00-08:00	46.750
08:00-09:00	46.750
09:00-10:00	46.750
10:00-11:00	46.750
11:00-12:00	46.750
12:00-13:00	31.160
13:00-14:00	31.160
14:00-15:00	31.160
15:00-16:00	31.160
16:00-17:00	31.160
17:00-18:00	31.160
18:00-19:00	46.750
19:00-20:00	46.750
20:00-21:00	46.750
21:00-22:00	46.750
22:00-23:00	46.750
23:00-00:00	46.750

## REFERENCES

- [1]. Robert H. Lasseter and Paolo Piagi, "Microgrid: A conceptual solution", IEEE, *Power Electronics Specialists Conference*, vol 6, pp 4285-4290, June 2004.
- [2]. Jiang Zhenhua, and Yu Xunwei, "Hybrid DC and AC-Linked Microgrids: Towards Integration of Distributed Energy Resources", IEEE, *Energy 2030 Conference*, pp 1-8, Nov 2008.
- [3]. F. Katiraei and M. R. Iravani, "Power management strategies for a microgrid with multiple distributed generation units", IEEE, *Transaction on Power Systems*, vol 21, pp 1821-1831, Nov 2006.
- [4]. P. Piagi and R. Lasseter, "Autonomous control of microgrids", IEEE, *Power Engineering Society General Meeting*, pp 1-8, June 2006.
- [5]. H. Akagi, Y. Ito and Z. Yang, "DC microgrid based distribution power generation system", IEEE, *Power Electronics and Motion Control Conference*, vol 3, pp 1740-1745, Aug 2004.
- [6]. Xianjun Zhang, Ratnesh Sharma, Yanyi He "Optimal energy management of a rural microgrid system using multi-objective optimization", IEEE, *Innovative Smart Grid Technologies*, pp 1-8, Jan 2011.
- [7]. H. Kanchev, D. Lu, F. Colas, V. Lazarov and B. Francois, "Energy management and operational planning of a microgrid with a pv-based active generator for smart grid applications", IEEE, *Transaction on Industrial Electronics*, vol 58 , pp 4583-4592, Oct 2011.
- [8]. Shuai Lu, Marcelo A. Elizondo, Nader Samaan, Karanjit Kalsi, Ruisheng Diao, Yu Zhang, "Control strategies for distributed energy resources to maximize the use of wind power in rural microgrids", IEEE, *Power and Energy Society General Meeting*, pp. 1-8, July 2011.
- [9]. M. Rezwan Khan, "A stand alone DC microgrid for electricity supply in rural Bangladesh", IEEE, *International Conference of Renewable Energy Technology*, pp 1-4, Jan 2012.
- [10]. M. Barnes, J. Kondoh, H. Asano, and J. Oyarzabal, "Real-World MicroGrids- an Overview", IEEE, *International Conference of Systems Engineering*, pp.1-8, May 2007.
- [11]. Bo Dong, Yongdong Li, ZhixueZheng, Lie Xu "Control strategies of microgrid with hybrid DC and AC buses", IEEE, *Conference of Power Electronics and Applications*, pp 1-8, 2011.

- [12]. C.V. Dobariya, V.S.K.M. Balijepalli, S.A. Khaparde, "Deployment of MicroGrids in India", IEEE, *Power and Energy Society General Meeting*, pp 1-7, July 2010
- [13]. R. Kuwahata, N. Martensen, T. Ackermann, S. Teske, "The role of microgrids in accelerating energy access", IEEE, *International Conference of Innovative Smart Grid Technologies*, pp 1-9, Oct. 2012.
- [14]. T. E. Del Carpio Huayllas, D.S. Ramos, R.L. Vasquez-Arnez, "Microgrid systems: Current status and challenges", IEEE, *Transmission and Distribution Conference and Exposition: Latin America*, pp 7-12, Nov. 2010
- [15]. J. A. P. Lopes, A. G. Madureira and C. C. L. M. Moreira, "A view of microgrids", *WIREs Energy Environment*, vol. 2, pp. 86–103, Dec. 2012
- [16]. M. Moniruzzaman, S. Hasan, "Cost analysis of PV/Wind/diesel/grid connected hybrid systems", *International Conference on Informatics, Electronics & Vision*, pp.727-730, May 2012.
- [17]. A. Rohani, K. Mazlumi, H. Kord, "Modeling of a hybrid power system for economic analysis and environmental impact in HOMER", IEEE, *Iranian Conference on Electrical Engineering*, pp 819-823, May 2010.
- [18]. M.M. Bin Othman, N.A.B.A. Razak, I. Musirin, "Optimal sizing and operational strategy of hybrid renewable energy system using homer", IEEE, *International Conference on Power Engineering and Optimization*, pp 495-501, June 2010.
- [19]. P. Sunderan, B. Singh, N.M. Mohamed, N.S. Husain, "Techno-economic analysis of an off-grid photovoltaic natural gas power system for a university", *International Symposium & Exhibition in Sustainable Energy & Environment*, pp 129-135, June 2011.
- [20]. M. Anwari, M.I.M. Rashid, H.T.M. Muhyiddin, A.R.M. Ali, "An evaluation of hybrid wind/diesel energy potential in Pemanggil Island Malaysia", IEEE, *International Conference on Power Engineering and Renewable Energy*, pp 1-5, July 2012.
- [21]. D.K. Yadav, S.P. Girimaji, T.S. Bhatti, "Optimal hybrid power system design using HOMER", IEEE, *International Conference on Power Electronics*, pp 1-6, Dec. 2012.
- [22]. U. Sureshkumar, P.S. Manoharan, A.P.S. Ramalakshmi, "Economic cost analysis of hybrid renewable energy system using HOMER", IEEE, *International Conference on Advances in Engineering, Science and Management*, pp 94-99, March 2012.
- [23]. M.I.M. Rashid, M. Anwari, H.I. Hui, T.W. Yee, C.K. Wee, "Photovoltaic power system simulation for small industry area", IEEE, *International Conference on Electrical, Control and Computer Engineering*, pp 263-268, June 2011.

- [24]. M.M. Hasan, M.F. Khan, "A comparative study on installation of solar PV system for grid and non grid rural areas of Bangladesh", IEEE, *International Conference on Developments in Renewable Energy Technology*, pp 1-5, Jan. 2012.
- [25]. Jie Zhang, Peng Wu, Jie Hong, "Control strategy of microgrid inverter operation in Grid-connected and Grid-disconnected modes", *International Conference on Electric Information and Control Engineering*, pp 1257-1260, April 2011.
- [26]. Platts, World Electric Power Plants Database, Platts, New York, NY, 2011.
- [27]. Markku Rissanen, J. Schlabbach, Lars Strupeit, "Simulation for Technical and Economic Analysis of a Hybrid-Fuel-Cell System", *International Conference on Power Engineering, Energy and Electrical Drives*, pp 353-358, April 2007.
- [28]. Government of India: Ministry of New and Renewable Energy, "Revised capital subsidy and Benchmark cost of SPV system", 3 March 2013 [Online]. Available: [http://www.mnre.gov.in/filemanager/userfiles/revised\\_capital\\_subsidy\\_and\\_benchmark\\_costofthe\\_spv\\_system.pdf](http://www.mnre.gov.in/filemanager/userfiles/revised_capital_subsidy_and_benchmark_costofthe_spv_system.pdf)
- [29]. Windcare India, small wind turbine, Coimbatore, Tamil Nadu: Windcare India.
- [30]. Alternate Hydro Energy Centre, Model Detailed Project Report, "Micro Hydro Electric based Power Plant (2x50 kW)", *Ministry of New and Renewable Energy, Government of India, New Delhi, 2007*
- [31]. M.R. Nouni, S.C. Mullick and T.C. Kandpal, "Biomass gasifier projects for decentralized power supply in India: A financial evaluation", *Energy Policy*, vol 35, issue 2, pp 1373-1385, 2007.
- [32]. Rolls Battery Engineering limited [online] Available: <http://www.rollsbattery.com>, 3 March. 2013

## **PUBLICATIONS**

1. Gerry and Sonia, "Optimal Rural Microgrid Energy Management using HOMER," *International Journal of Innovations in Engineering and Technology*, vol.2, Issue.1, pp. 113-118, ISSN: 2319-1058, Feb. 2013.
2. Gerry and Sonia, "Rural Microgrid Optimization for Grid Connected System using Homer", *National Conference on Electrical System & Energy Technology*, NIT-Hamirpur, June 2013