University of Southern Queensland

Faculty of Engineering and Surveying

VOLTAGE CONTROL IN MICRO-GRIDS

A dissertation submitted by

Mr. ORUGANTI VARA PRASAD YADAV

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ENG8412 Research Project

towards the degree of

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ABSTRACT

It is estimated that around 400 million people have no electricity and will not have access to electrical power resources in the near future. This precludes improvements in living standards and business opportunities as without a stable and reliable electrical power source, connectivity to the global information network is not possible. Similarly without electrical power, mechanization for water supply and other agricultural business opportunities, medical resources other modern resources such as refrigeration are not possible. In such small communities, if access to the available energy is not equitable, then this can create ill-will that breaks down the traditional co-operative nature that is needed for success in rural India.

The main aim of the project is to investigate the modelling system and strategy for an Indian stand-alone village based micro-grid and its voltage stability. This is to provide the local people's electricity needs in the rural areas of that particular state. Micro-grid networks are equipped for producing sufficient energy to better the life ambitions of a small number of connected clients. The project also aims at approaching the challenge of rural electrification through the use of micro-grids within the local generation source.

The proposed DC micro-grid has been modelled and simulated using the Homer Energy Software. This Homer energy software performs the various tasks in an accurate manner by choosing the best possible alternatives and sorting out them optimally. The results showed that the renewable energy sources would be feasible option when compared with conventional energy sources for distributing the power in rural parts of India. Finally the various capital costs have been presented for achieving the best economic viability of the proposed DC micro-grid system.

Keywords: Micro-grids, Rural-electrification, Renewable energy, Distributed generation, Homer energy, India.

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CANDIDATE'S CERTIFICATION

I certify that the ideas, designs and experimental work, results, analysis and conclusions set out in this dissertation are entirely my own efforts, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

ORUGANTI VARA PRASAD YADAV

STUDENT NUMBER: 0061046980

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NOMENCLATURE AND ACRONYMS

AC	ALTERNATING CURRENT
CB	CIRCUIT BREAKER
CEA	CENTRAL ELECTRICITY AUTHORITY
COE	COST OF ENERGY
DC	DIRECT CURRENT
DG	DISTRIBUTED GENERATION
DDG	DISTRIBUTED DECENTRALIZED DISTRIBUTION
GDP	GROSS DOMESTIC PRODUCT
GW	GIGA WATTS
HV	HIGH VOLTAGE
HFAC	HIGH GREQUENCY ALTERNATING CURRENT
IEA	INDIAN ELECTRICITY AUTHORITY
IEGC	INDIA’S ELECTRICITY GRID CODE
JNNSM	JAWAHARLAL NEHRU NATURAL SOLAR MISSION
KV	KILO VOLTS
KWh	KILO WATT HOUR
LV	LOW VOLTAGE
LPG	LIQUIFIED PETROLEUM GAS
MCCB	MOLDED CASE CIRCUIT BREAKER
MG’S	MICRO-GRIDS
MNRE	MINISTRY OF NEW AND RENEWABLE ENERGY
MW	MEGA WATTS

O&M	OPERATIONAL AND MAINTAINENANCE COST
PV	PHOTO VOLTAIC ARRAYS
PLC	PROGRAMABLE LOGIC CONTROLLER
RE	RENEWABLE ENERGY
RGGVY	RAJIV GANDHI GRAMEEN VIDYUTIKARAN YOJANA
SEB	STATE ELECTRICITY BOARD
UNDP	UNITED NATIONAL DEVELOPMENT PROGRAME
WT	WIND TURBINE

CHAPTER-1

INTRODUCTION

1.1 Outline of the study

1.1.1 Chapter 1 Overview

This chapter provides the general outlook of the project by detailing its background, stating the main study objectives and outlining the problem statement. The use of micro-grids as alternatives for rural electrification is also introduced in this chapter.

1.1.2 Project Introduction

Rural electrification is one of the best alternatives for empowering the underprivileged population in India as well as in other parts of the world. The main aim of the project is to examine how micro-grids' use in rural India may be successful through the implementation of the proposed modeling system. Specifically, the modeling system and strategy will be scrutinized to ascertain whether the proposed Indian stand-alone village project is viable and has its voltage stable micro-grid based (LV is defined as less than 1KV DC).

1.1.3 Chapter 2 Overview

Chapter 2 is the literature review section of the report. This chapter covers the following areas:

- Introduction to micro-grids.
- Current status of rural electrification in India and the use of micro-grids.
- Benefits of micro-grid systems for rural households.
- Performance related issues of micro-grid systems.
- Voltage control techniques commonly used in existing micro-grid systems.
- Justification for the project.
- Summary of the background issues as indicated by various scholars.

1.1.4 Chapter 3 Overview

Chapter 3 discusses the design of the chosen micro-grid system and illustrates how it will work in order to ensure that there is voltage stability and efficiency of power supply to rural areas. Moreover, the main HOMER Energy Software testing tool has also been discussed in the chapter with particular emphasis to three main processes such as simulation, optimization and sensitivity analysis.

1.1.5 Chapter 4 Overview

Chapter 4 gives the information on how to share the load energy equally between the customers during the day time and night time by making use of the flow chart. And finally it outlines the implementation of the flow chart logic in PLC by using ZELIO software.

1.1.6 Chapter 5 Overview

Chapter 5 discusses the optimization results obtained by the HOMER energy modelling and presents the best optimal solution. It gives the information about the comparison of cost of energy versus government capital subsidy for the various biomass resources. This chapter discusses the various capital costs, monthly average electrical production and battery life involved in the proposed micro-grid design. Finally it concludes with sensitivity analysis on various parameters for the optimal system.

1.1.7 Chapter 6 Overview

Chapter 6 discusses the conclusions derived from the project and outlines the recommendations for the future scope of work.

1.2 Introduction and background of the Study

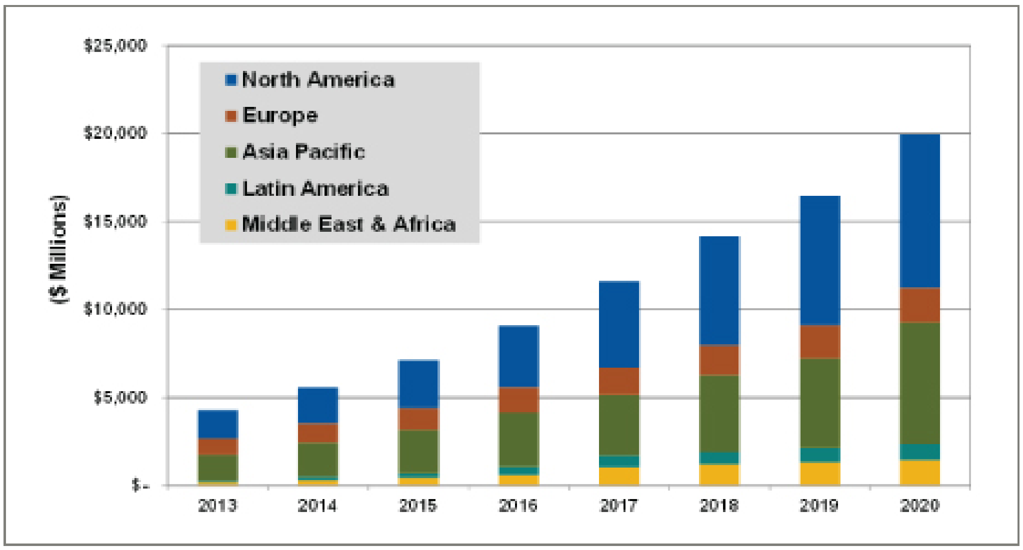
Today a large number of individuals who live in provincial and agricultural regions either have no electrical power at all, and have to depend principally on fossil fuel internal combustion engines to power generators lightning. It is estimated that around 400 million people have no electricity (IEA, 2012), and will not have access to electrical power resources in the near future. This precludes improvements in living standards and business opportunities as without a stable and reliable electrical power source, connectivity to the global information network is not possible. Similarly without electrical power, mechanization for water supply and other agricultural business opportunities, medical resources other modern resources such as refrigeration are not possible.

Where fossil fuel internal combustion engine driven remote generation is use to supply electrical power, it is becoming increasingly expensive to supply lighting and other mechanical aids to improve provincial life-style. In many parts of the developing works, micro-grid electrical supplies are now emerging. But due to the nature of these limited power supplies that are often driven from renewable energy sources, there is very wide fluctuation in the transmission of the electrical energy. Control issues on micro-grids include over low-voltage, under voltage, and equitable shared access to the available variable energy sources.

In India where micro-grid development is being implemented to supply electrical power to remote communities with no access to the current three phase HV network; this can become quite a problem, as competition for electrical energy sources by the small number of clients. MG's networks are equipped for producing sufficient energy to better the life ambitions of a small number of connected clients. In such small communities, if access to the available energy is not equitable, then this can create ill-will that breaks down the traditional co-operative nature that is needed for success in rural India.

1.2.1 Emerging of Micro-grids

The use of MG's is progressively becoming the most effective method of generating renewable energy in remote parts of the world where the use of conventional grids may not be feasible (Camblong et al., 2009). The global energy sector has exhibited tremendous growth in the 21st century. However, this growth is yet to be felt in many regions of the globe that are in the category of rural areas. As a result, the energy demand has equally grown despite the available energy resources remain almost the same. However, electricity remains one of the most important commodities for both commercial and household use.



Microgrid vendor revenue is expected to nearly triple by 2020 as concern about conventional grid vulnerability grows while the cost of energy storage and renewable energy infrastructure decline.

Figure 1.2.1 Growth of Micro-grids

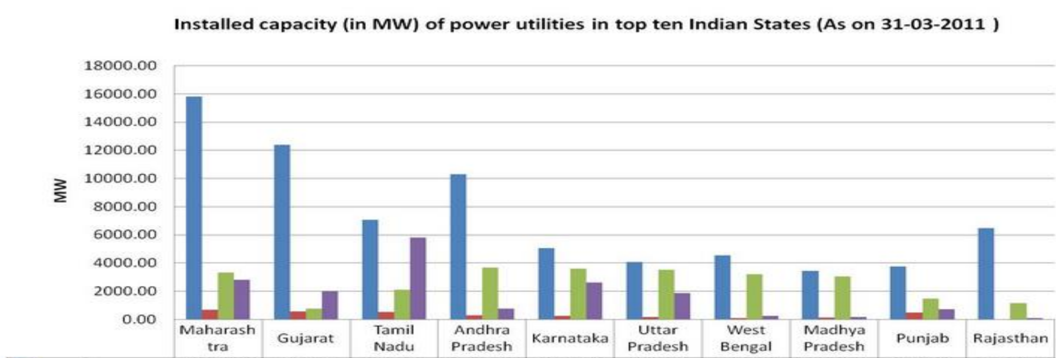
Source: (http://ensia.com/features/the-emerging-power-of-microgrids/)

From the figure1.2.1, it can be seen that micro-grids have been constantly increasing more in North-America region followed by Europe, Asia Pacific, Latin America and Africa.

However, the developing nations like India continue grappling with a problem of sufficient power distribution among its population. India, the country in focus of this project, has been one of the most affected states in terms of power deficiency in its vast rural and even urban population. Without enough power generation in the country, economic growth is likely to be affected. Therefore, the availability of electricity is one of the most important concerns for any country's socio-economic development.

1.2.2 India’s Electricity Production Capacity

It is indicated that by 2012, India had a capacity of producing about 210 GW of electric power. This is over 150 times of the capacity a company was able to produce back in the mid-90s (Chaurey & Kandpal, 2010). The country can, therefore, be said to have made important strides in the production of power to match its ever growing population, as well as commercial production demands. In fact, there has been a gradual increase in the production of electric power with the period ranging from 2011 to 2012 alone recording an 8% increase in generation of power through installed capacity. The government of India together with other energy sector enterprises has joined hands to boost the country’s generating capacity. However, the country’s generating capacity may still have to be further boosted to match current demands.



	Maharashtra	Gujarat	Tamil Nadu	Andhra Pradesh	Karnataka	Uttar Pradesh	West Bengal	Madhya Pradesh	Punjab	Rajasthan
Thermal	15813.98	12390.86	7056.62	10297.28	5075.29	4057.09	4534.01	3435.93	3774.03	6470.14
Nuclear	690.14	559.32	524.00	275.78	254.86	190.90	92.88	151.04	469.00	0.00
Hydro	3331.84	772.00	2122.20	3695.53	3599.80	3518.20	3223.67	3031.57	1456.82	1162.00
Renewable energy	2809.33	2000.47	5812.61	766.99	2616.19	1880.54	262.71	161.47	726.30	99.55

Figure1.2.2 Installed capacity of power utilities in top ten Indian States

Source: (India Census, 2011).

There are many factors associated with the growing demand of electric power in the country. First, India is among the world’s fastest growing economies. It is also worthy of mention that the country’s population only comes second to that of China. The demand generated by an ever expanding industrial sector as well as the number of households stands to outdo the supply of power in the country. As a result of an outstripped supply of power in the country, the reliability and quality of power raise a lot of concerns. This means that the country’s power supply is currently overloaded resulting in frequent outages as well as instability in voltage.

1.2.3 Power shortages and outages

In India, the shortage of power during peak hours has been estimated to be about 11%. The country's frequent power shortages have been attributed to poor repair and maintenance work within the national grid system. The Central Electricity Authority estimates daily outage levels of about 30,000 Mega Watts (MW). As a result, the country's power consumption per capital still ranks lowly at 940 kilo watt-hour (kWh) (CEA, 2014). Nevertheless, the demand for electricity in the country has continued to plummet even as inefficiencies still exist in the country's power generation and distribution system.

Moreover, power distribution companies in India still owe about 2 trillion rupees to financial institutions, which has made it difficult for them to access additional financing needed for expansion and rehabilitation of the aging national grid system (CEA, 2014). As a result, the country's electricity supply continues to be unreliable given the number of unplanned shutdowns during peak hours when actual demand levels exceed installed capacity.

Inefficiencies in the country's power distribution system have also resulted in increased tariffs. The costs of connection as well as the monthly power bills continue to rise in the country effectively locking out low income earning households mostly living in rural areas. Due to this, the transmission and distribution of power in the country have been affected in most parts of the country.

This subsection looks at how under performance in the three components may have led to insufficient and unreliable power in most parts of the country.

1.2.3.1 Generation of Power

Firstly, the generation of power in the country has been facing numerous challenges with frequent shortages of fuel. Fuel plays a crucial role for the generation of power in the country, but the instabilities in the global oil production and supply markets have been affected the stock levels in the country. The price of fuel also remains unstable given the changing supply levels. Due to the challenges associated with costs, the private sector of the country agreed for distributing the power by the use of fuel.

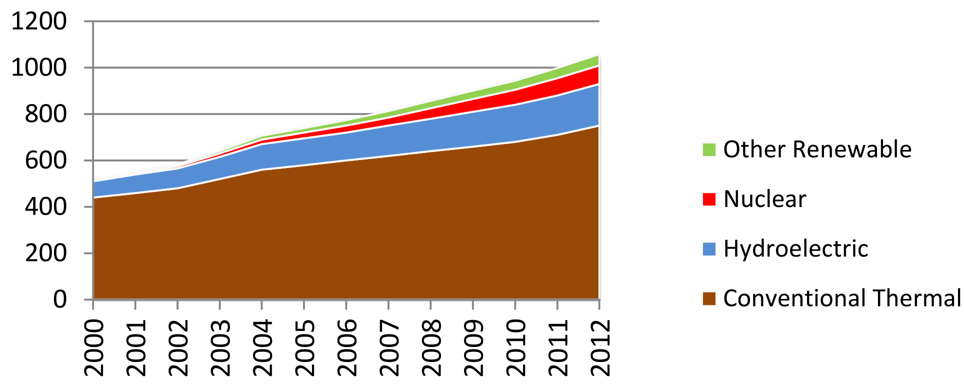


Figure 1.2.3.1 Comparison of electricity by the various energy sources

Source: **(**Author, Data obtained from *CEA Annual Report* 2012)

In 2011 – 2012, private sector participants contributed to about 58% of all electric power produced in the country. Further, within the last five years, private sector in India has contributed to about 48% of all power generated in the country. Therefore, the role of the private sector cannot be underscored.

The government must continue to engage the private sector and even encourage more participants on board to boost electric power generation capacity in the country. As per the common practice globally, India relies on four main power generation sources to feed its national grid.

1.2.3.1.1 Power Generation Sources

Considering the three main sources, thermal power generation sources account for about two-thirds of all electric power produced (CEA Annual Report 2012) in the country today which is about 57% (137,386 MW). This is followed by hydroelectric sources of power generation that contribute about 39,291MW of electricity (19%). The other categories include renewable source, which contribute about 12% (24,998 MW) of electric power and lastly, nuclear power generation contributing about 2.3% of total power supply (4780 MW).

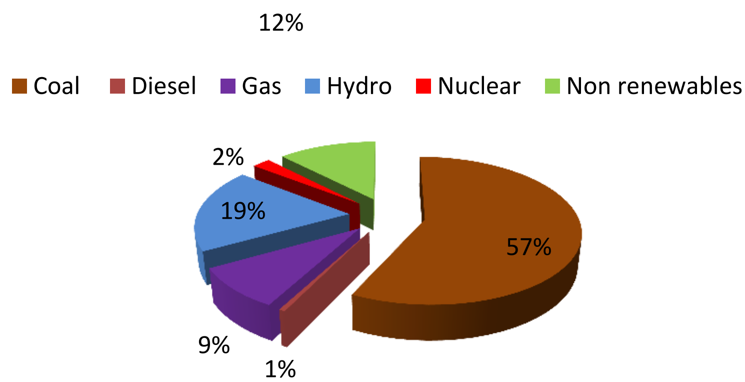


Figure 1.2.3.1.1 Power generation sources

Source: **(**Author, with data from *Monthly Reports CEA* December 2012)

The thermal sources have large capacity for generating the electricity followed by hydropower, renewable energy source and finally ended up with nuclear power as shown in the figure 1.2.3.1.1. However, the country's generation still remains unreliable if the level of supply is anything to go by. For instance, if there is an additional capacity installed within the country's power generation process, it might effect on the demand side of the load. This in turn affects the transmission of the generated power. Questions of transmission efficiency still continue to be raised in the country's energy sector. Transmission is evidently on the supply side rather than on the demand side of power generation.

1.2.3.2 Transmission

Without an effective transmission plan, the installed capacity may not be effectively utilized as the country intends to boost its power production. There have been a lot of challenges within the energy sector that hindered the engagement of other private sector participants to invest in the absorption of all power sources to the national grid. Secondly, a huge proportion of the country's thermal power is generated throgtb ugh coal plants. Coincidentally, India has a vast amount of coal deposits still unexploited. However, it is alarming to note that the country's coal industry has not matched up the demand for coal in the thermal plants due to issues of inefficiencies (Lhendup, 2008). In addition, there are policy issues as well as infrastructural development issues attached to the frequent shortages.

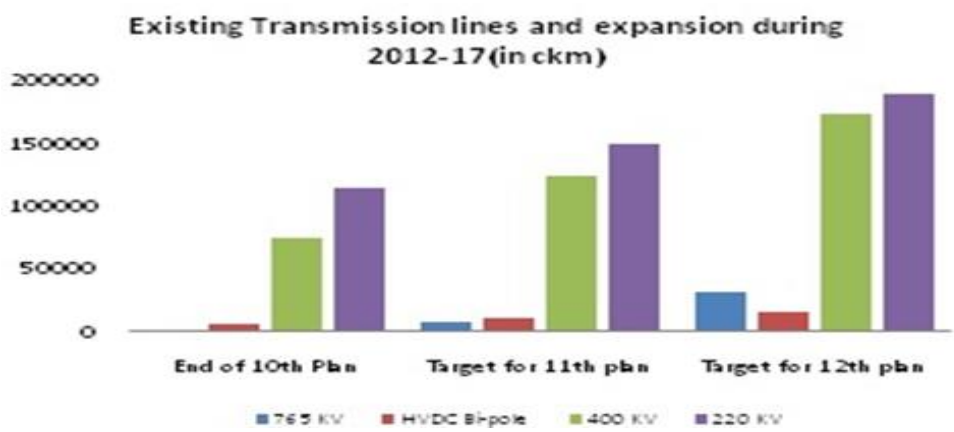


Figure 1.2.3.2 Existing Transmission lines in India

Source: **(**Author, with data from *Monthly Reports CEA* December 2012)

Aside from overreliance on coal, this commodity is largely bulky and highly non-renewable. Consequently, it raises the question of sustainability for future generations as well as other environmental management issues. Generally, the country's transmission process has been monopolized. The country's Central Transmission Utility and State Transmission Utility are the only participants charged with planning, development and implementation of supply networks. Therefore, private sector has been left to the sidelines of this important function of power supply in the country.

However, the country is beginning to relax its laws to involve the private sector in transmission of power. This has ensured the increase in competition and efficiency.

Currently, the Electricity Act of 2003 and the India's Electricity Grid Code (IEGC) regulate the power transmission component. However, there is a need for the realignment of regulation and strengthening of institutions so that the company's transmission capacity can be equally boosted. The last and important component is a distribution. Distribution of power is the most recognizable feature of all. It ensures that the end consumer is reached by the national grid. For the government and other investors in this sector, effective distribution also affects the overall revenue levels to be attained. The nature of distribution also underscores the different needs of consumers (commercial, residential or industrial).

1.2.3.3 Distribution

The commercial viabilities of the existing distribution utilities are mostly owned by the Government. Within the last five years, the unit costs of distribution have increased by over 20%. However, this apparent increase was not commensurate with an equal increase in the costs of electricity supply. The result is the ever widening gap between the costs of supply and those of electricity tariffs in the country. Therefore, investing in the country's distribution network is a financial risk.

Second, the government continues to register substantial losses within its distribution infrastructure. Losses occur to due to destruction and theft of distribution utilities. Replacing such utilities amidst rising costs of purchase has resulted in increased expenditure. Considering that the tariffs charged to consumers do not change more often, the revenue accrued from distribution has been significantly reduced. As a result, there is little investment done to ensure increased efficiency, quality and accessibility of electric power. At the same time, India continues to grapple with an ageing electricity grid.

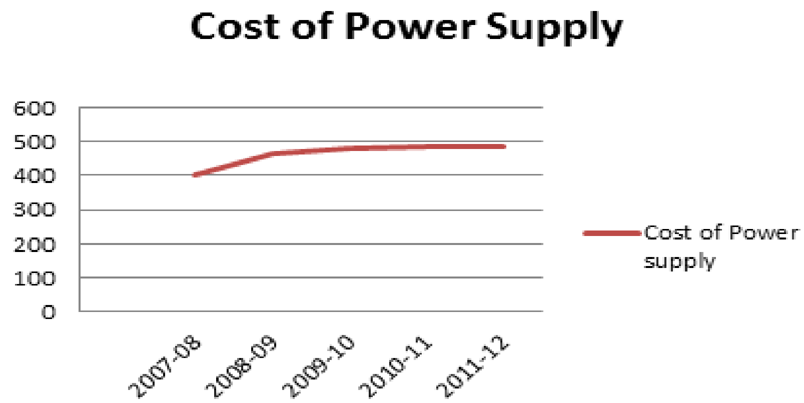


Figure 1.2.3.3 Cost of power supply (Paisa/kWh)

Source: **(**Author, with data from *Monthly Reports CEA* December 2012)

The dilapidation of the country's electricity distribution utilities was exposed in July 2012 when the country experienced a blackout that affected its 670 million consumers. This unexpected power failure obviously resulted in massive losses not only for the distribution firms, but also for the commercial and industrial consumers. As a result of power supply instability in the country, the government has been looking for other alternatives in the renewable source category. The country's major cities continue to overstretch the demand for electric power. At the same time, rural households also depend on electricity to develop into future urban areas. However, the failures discussed above do not assure rural India that they are going to have stable supplies in future. This project finds a best alternative solution for reducing the power problem in the rural parts of the country.

1.3 The problem

Having reviewed the background of this study, it is evident that India faces the challenges related to generation, transmission and distribution of electric power to its populous regions. India mainly produces the electricity by the use of fossil fuels. But this has negative impact on environment by increasing the global warming on the earth. Coal has the maximum amount of effect on the environment by releasing the carbon emission gases into the atmosphere followed by natural gas as shown in the figure 1.3.1.

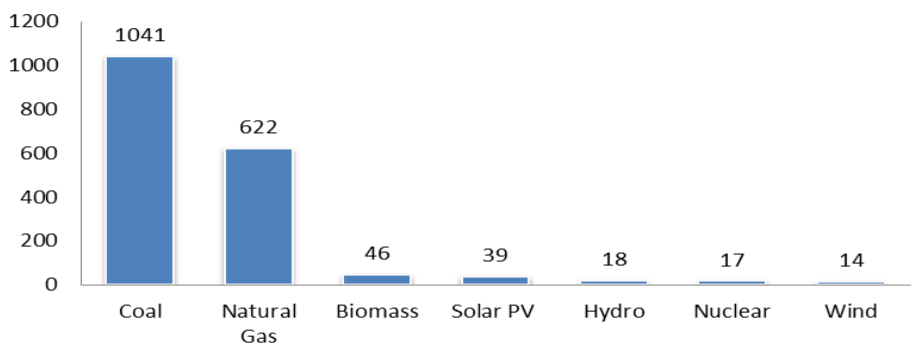


Figure 1.3 Carbon emission gases released by various resources

Source: **(**Farhan Beg, 2013**)**

Therefore, renewable energy sources play a crucial role for saving the environment globally. As the government and private sector participants in the energy sector look for solutions, there is a need for the rural population to adopt sustainable energy production and distribution methods. This study identifies the use of MG’s as an alternative to the sustenance of the country’s rural household demand for electric power. A key challenge lies in the implementation of MG’s use in remote areas where extension of the national grid may not be viable.

1.3.1 Use of Micro-grids

Micro-grids are intended to decentralize the generation and transmission of power to such isolated areas. However, it is important to investigate how this project may be implemented for the benefit of rural populations in the country. The specific interest to this study is the control of voltage for the MG's to ensure there are a maximum utilization as well as improved safety. The use of MG's in the country will certainly help to reduce the number of people who are not still connected to the national grid. Even though India has a rapidly growing population, its power supply capacity still remains low.

1.3.2 Electrification Rates

For the country to attain the growth objectives and match nations like China, sustainable actions must be taken to alleviate the country from its energy problem. In comparison to China, which has 99.4% coverage, about 66% of India's population has meaningful access to the national electricity grid. This poor coverage is further compounded on by the fact that a majority of the country's population (7 out of 10) live in rural areas. As of 2010, only half of India's rural population had access to electricity. Therefore, the gap between the demand and supply for electric power is wider for the rural populations more than the urban ones.

The main reason for the low electrification rates in India is that the traditional approach of the grid-extension is not possible. Thereby causing the poor load factors, dispersed demand and the main disrupted power supply in the country. Therefore the option of implementing the national grid to the rural areas is not an optimal solution. In most of the rural parts of India, the access of electricity is not equally provided to all the customers and even some of the house-holds were remain un-electrified. From this it is noted that the proportion of electrified households in the rural parts still remains low.

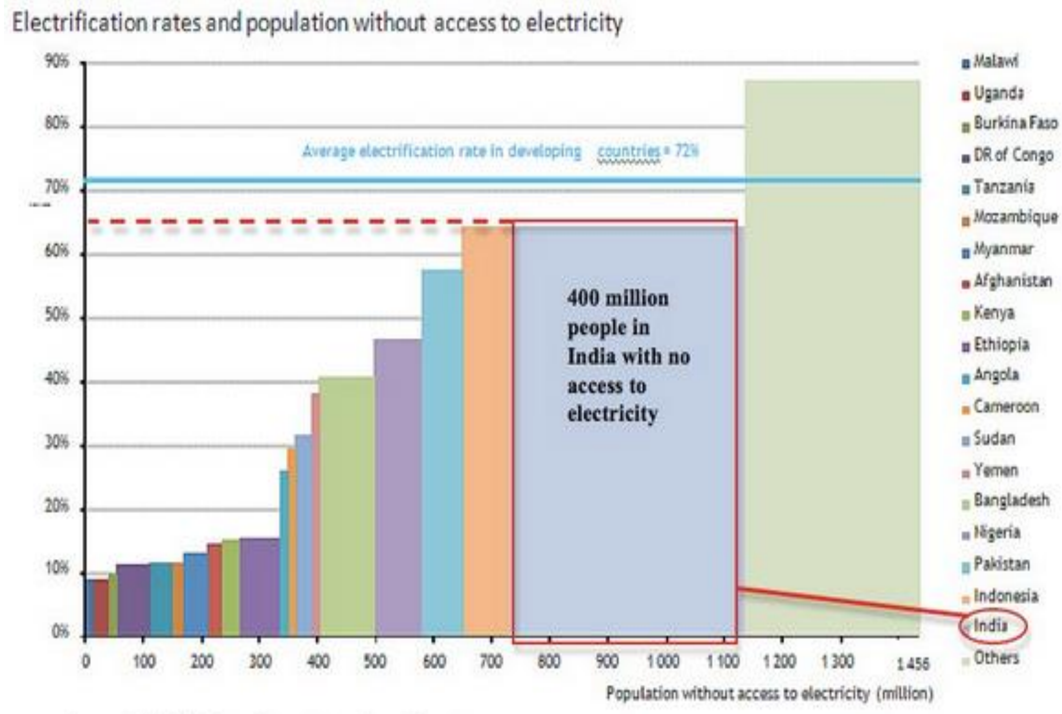


Figure 1.3.2 Status of electrification in India

Source: **(**WEO 2009; http://www.iea.org/weo/electricity.asp)

It is surprising to see that India is ranked among the least developed nations in the world in terms of its electrification rates per population as shown in the figure 1.3.3. The main reasons why India is un-developed despite of its high GDP is because of huge segment of population which consists of poor, rural and dwelling households.

Most of the house-holds in rural parts of the India utilize the source of lighting by the use of kerosene, fossil fuels, solar and the other oils. This creates a problem to the people when there is no availability of these resources.

Generally, only about 55.3% of the country's rural population has access to electricity compared to the electrification rates of about 92.7% in urban areas. More-over, 1.2 million people of the total country's population do not have access to any form of lighting.

Table 1.3.2 Source of lighting for Indian House-holds

Item No.	House list Item	Percentage		
		Total	**Rural**	**Urban**
P	**Households by main source of lighting**			
P.1	Total number of households	100%	100%	100%
P.2	Electricity	67.2%	55.3%	92.7%
P.3	Kerosene	31.4%	43.2%	6.5%
P.4	Solar	0.4%	0.5%	0.2%
P.5	Other oil	0.2%	0.2%	0.1%
P.6	Any other	0.2%	0.2%	0.2%
P.7	No lighting	0.5%	0.5%	0.3%

Source: (http://www.censusindia.gov.in/2011census)

From the table 1.3.2, the disparity in source of lighting for rural and urban populations in India is alarming. And the percentage of source of lighting to rural areas is less when compared with urban areas. Therefore, the low connectivity rates of the rural areas may be attributed for the further development to increase their rates.

1.3.3 Rural Settlements

Two major characteristics of most rural areas include dispersed settlements and unfavorable terrains. Sparsely populated areas mostly arise because of rural-urban migration trends. Therefore, it may be commercially untenable to expand the existing supply network to reach the rural areas. In addition, the rough terrain in most of these areas provides massive challenges for installation of distribution of power line in a larger scale (Illindala, Siddiqui, Venkataramanan&Marnay, 2007). Even when such lines and transmitter are installed, the costs of maintenance may be unbearable considering the demand for power in such regions. Consequently, connecting the rural population to the national grid may not provide a rational solution to the country's coverage problem.

1.3.4 Decentralized Power Systems

The ideal model of electricity generation and supply in rural areas, therefore, relies on decentralization. There is a need for strategically located generation units with localized distribution networks for the rural regions. In this way, easy access to electricity is guaranteed to every household. The costs of installation and maintenance for decentralized models are also likely to be lower; MG's provide a viable solution of the country's electricity generation and distribution problem.

As opposed to centralized power systems identifiable to the country's existing national grid, MG's enable the distributed generation. The aims of MG's are to enable the generation of electricity close to the area of utilization. In the case of rural India, MG's are to be located in rural villages to enhance accessibility.

A micro-grid largely utilizes the available renewable energy sources for the sake of generation. For instance, the solar panels mounted on rooftops may facilitate a distributed generation to one or more households. In other words, they ensure the production of electric power at the same location where the renewable energy has been harnessed.

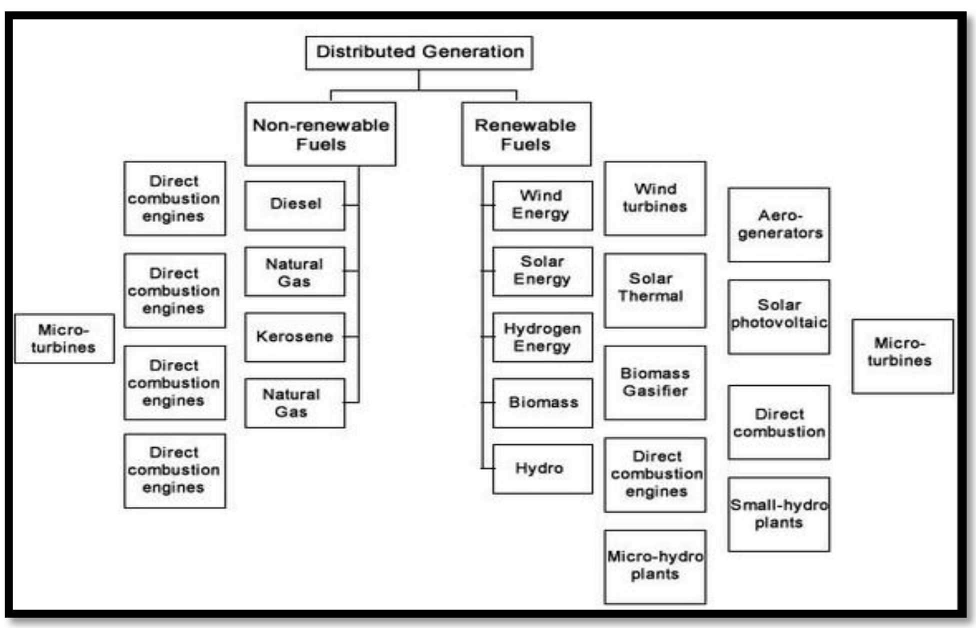


Figure 1.3.4 Sources for Distributed Generation

Source: **(**http://indiasmartgrid.org/en/technology/Pages/Distributed-Generation.aspx)

To transmit the power effectively, a micro-grid must combine the operating functions, cluster of loads and resources using the controllable unit. Referring to the figure 1.3.5, resources used are in the form of renewable or non-renewable forms. However, most MG's utilize the renewable forms of energy more than the non-renewable sources. To the utility, MG's which are connected with controllable loads produces the effective supply to the transmission network. MG's utilizes the energy fuel categories such as wind turbines, direct combustion engines and solar thermals which provide the electricity as per the demands of the local consumers.

Micro-grids provide the source of livelihood which improves reliability, reduces feeder loses and enhance sustainability through waste utilization of the energy. Therefore, distributed systems are essential because of their ability to switch from national grid systems to island operations without creating challenges for critical loads.

1.4 Research Objectives

The main objectives of the research are as follows

- To analyze AC/DC topologies and their control of energy dispatch operation
- To test whether LV residential loads can be supplied with DC and deriving their load models
- Developing operation control strategies for equitable energy dispatch between load users and investigate protection systems applicable for LV dc micro grid systems
- Model in Homer energy software with various hybrid sustainable energy supply sources, and the available output over annual period. This is to investigate energy availability versus energy demand
- To design and model a LV dc system which is used for future development of rural area
- To provide an equitable power sharing methods and how this can match voltage regulation

As the time permits

- Comparing AC micro grids and its protection requirements
- Investigate alternative customer voltage regulator based solutions

Micro-grids provide the more challenges to the solar panels in the rural populations despite the fact that they can generate more reliable and sustainable power for the households in rural population. MG's must be closely monitored to ensure that the rural populations enjoy the benefits of localized power distribution. As a result, the main aim objective of the project is to investigate how voltage control can be effectively done to make ensure that rural populations have access to quality, reliable and cost-effective sources of electricity.

1.5 Chapter Summary

Today, many households in rural areas still lack access to electricity. India still relies on an outdated national grid system. As a result, about 40% of generating power is lost during the transmission. This loss rate is one of the highest in the world. Consequently, many households in rural areas are not able to receive an adequate power supply. In addition, such inefficiencies have resulted in high costs of maintenance, transmission and distribution. Therefore, it remains economically unviable to supply most rural areas with electricity from the national grid. Extending the national grid to more rural areas will currently cost about Rs57/kWh/km. This is due to the fact that expanded connections will require additional generation of power which further compounds the cost problem.

Coal is the main raw material used in the country's thermal generation plants. The additional use of coal will contribute to extreme degradation of the environment through excessive emissions of carbon from the coal generation plants. Given that India already contributes the huge amounts of greenhouse gas emissions into the atmosphere, the expansion of national grid may not be sustainable. However, sustainable sources of power must be explored if rural households are to be uplifted. Electric power will aid the expansion of irrigation systems, small and micro enterprises and other commercial activities that all contribute to national economic growth.

In such a way, the use of MG's does provide the best alternative for lighting the villages and boosting the economic levels of rural areas. MG's will also ensure that the country reduces carbon emissions through use of ecologically friendly power generation sources like wind and solar energy. In theory, India's potential to generate solar energy is pegged at 5000trillion kWh/year (Venkataramanan & Marnay, 2008). Most of the country's rural areas have the abundant sunlight throughout the year to support a solar powered micro-grid system. The use of solar photovoltaic energy should therefore remain a priority for all stakeholders in the country energy sector. However, there are many implementation and design issues that must be addressed to make this project successful.

CHAPTER-2

LITERATURE REVIEW

2.1 Introduction

The background of this study has revealed a deplorable state of India's electric power generation, transmission and distribution. Importantly, it has highlighted the need for decentralized power systems for rural populations that have previously lacked access to affordable and reliable electricity. With an improvement in technology, the energy sector has benefited from opportunities to design, test and implement efficient generation and supply systems.

The use of MG's has also been advanced through improved control, monitoring and billing systems. Essentially, the potential MG's hold in the modern world is tremendous. Their use has been specifically encouraged among the remote and underdeveloped regions that have not been, presently connected to reliable and sustainable sources of electricity.

Micro-grids have been proposed to help and uplift the socioeconomic status of the low-income earning population who live in rural parts of India. This chapter reviews all literature relating to the operation, implementation and customization of micro-grid power systems for rural area settings. It also outlines the benefits of decentralized power generation and distribution systems in rural areas as well as the role of renewable energy sources in India.

Further, both opportunities and challenges in the implementation and use of such systems are implored. Subsequently, the information obtained from similar projects and cases will be used to strengthen the viability of this project. To begin, it is important to understand the meaning and functioning of micro-grids as elaborated in the following section.

2.2 Micro-grids

Carbon arc technology was the first business provision on the planet which was utilized by utilizing electricity for lighting. This light was made by an arc between two carbon tips which brings about giving a brilliant white light from excitation of the ionized gas pathway of the electrical arc current. The carbon tips needs to be adjusted, the correct arc gap maintained, and the tips periodically replaced. This technology was created in nineteenth century and similarly electrical engineering produced batteries and other electrical sources of energy. Dynamos were utilized for delivering power through distribution networks that developed, and these were supplied originally by both DC or AC voltage and current sources.

The first lighting network was implemented by Thomas Edison in the year 1878. He used DC to supply the power to power both lights and electrical motors. He created the first technology for a complete low-voltage DC network in the year 1882 to supply around 1200 lights in the Pearl Street, New York; serving an area about 2.6 km^2. This was in fact the first micro-grid.

Micro-grid generally refers to the source of single electrical distribution system which is interconnected through small number of distributed generators that can be power-driven by making use of renewable energy sources with different load clusters. MG's takes the concept of decentralized generation for the supply of electricity. Moreover this can produce relatively low voltage power from the localized generation systems. The sources of generation for such decentralized systems include photovoltaics (PV), micro-hydro and biomass systems which generates enough power supply to a limited number of customers.

Generally, MG's are meant to function independently from the normal national grid systems. They mainly utilize locally available resources to generate, distribute and manage local power supply and demand (Lilienthal, 2013). There are numerous forms of MG's, some of which may run autonomously or sometimes parallel to existing national grids.

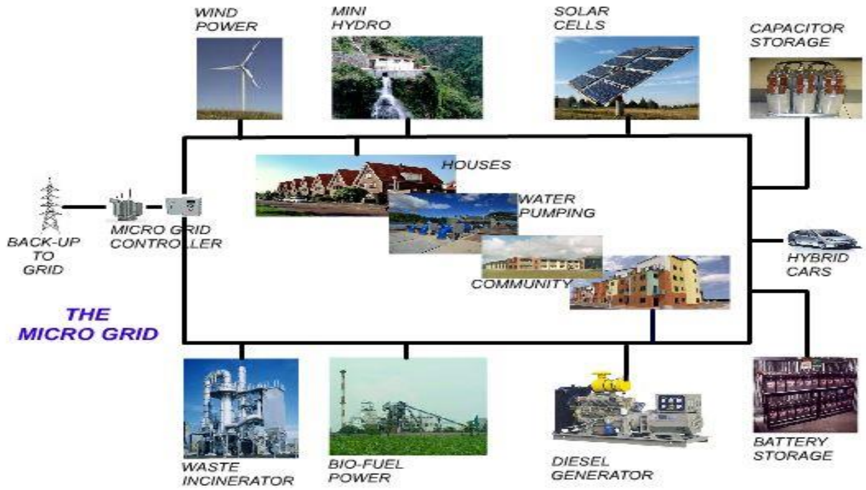


Figure 2.2 General layout of Micro-grid

Source: (www.googleimages/Microgrids)

Just like conventional grid systems, micro-grids are able to serve the power to the households, commercial institutions and community utilities. These MG's are built to enhance reliability and affordability of the electric power as the central grid may sometimes be costly, inaccessible or un-reliable.

Micro-grids can be categorized into five main areas, according to the regions or institutions they are meant to serve. They include remote systems, commercial centers and both institutional and military communities. However, there exists a different category in relation to the size of such decentralized energy distribution systems. First, there are large-grid connected ones that may serve military barracks or educational centers. The second category includes small-grid connected MG's that may have a form of backup generators that complement national grid supplies. In addition, there are small remote MG's that may serve local populations like villages. Lastly, the large one remote may serve the isolated regions or areas like islands.

2.2.1 Grid connections

In the rural parts of India, the grid connections provide the best approach for the sake of electrification to the majority of rural house-holds. The latest government RGGVY is focusing in expanding the existing grid to reach all the villages for the sake of rural electrification by the end of the year 2012 (James Cust, Anoop Singh and Karsten Neuhoff, 2007). Report studies shows that the average cost of supply is around Rs.3/kWh which proves to be significantly higher for the rural electrification. Also the cost of delivery to rural areas is three times the generation cost which is alarming.

The cost of the grid connection increases rapidly as the distance between the grid and the area increases. The cost will generally increase by Rs.1/kWh per kilometer of expansion to the villages. (James Cust, Anoop Singh and Karsten Neuhoff, 2007)

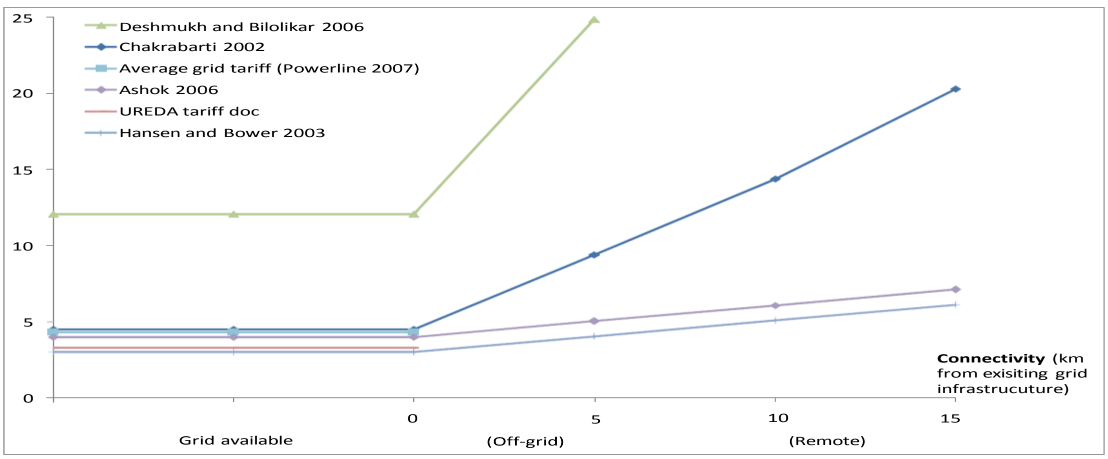


Figure 2.2.1 Cost of grid electrification between the existing grids related to the distance

Source: (James Cust, Anoop Singh and Karsten Neuhoff, 2007)

The grid tariffs for the poor house-holds ranges from Rs.0-10/month while for the domestic customers it ranges from Rs.0-130/month. These tariffs will lie in the range of cost of supply and are based on the redistributive policies and financial relief which will be notified by SEB. Hence the grid connections represent the cheapest electrification option for rural house-holds considering the per unit cost terms (James Cust, Anoop Singh and Karsten Neuhoff, 2007).

2.3 Renewable Energy Scenario in India

2.3.1 Role of Renewable energy (RE)

India is the sixth largest country in the world for generation of electricity [28] through the energy sources like thermal, hydro, nuclear and the rest by making use of renewable sources. However, renewable energy sources are preferred over the fossil fuels as they are eco-friendly to the nature. The main RE sources used in India are wind energy, solar energy, biomass and hydro energy. The total capacity generated by using RE sources [29] is about 30 GW, in which wind contributes (18.3GW), hydro (3.4GW), biomass (1.2GW) and solar (1GW).

Unlike renewable energy sources, there are non-renewable sources available for the generation of electricity. They include Oil, Coal, Gas and Hydro-power which are also responsible for the country's generation of electricity. But there is an increase in environmental concern by making use of coal as they release the carbon emission gases in to the atmosphere such that there will be increase in the level of global warming. In order to reduce these emissions, MG's uses the available sources of renewable energy for producing the electricity without any harmful effects to the global environment.

Though India has vast number of renewable energy sources, still there is no proper supply of electricity to half of the rural parts in the states. Hence MG's plays a crucial role for developing the growth of the country and more over increasing the economic benefits to the rural parts of the India. However, in this project DC micro-grid utilizes the RE sources such as wind energy, solar energy and biomass energy for the implementation of MG system to the rural areas.

2.3.1.1 Wind Energy in India

Wind power energy is the most common available renewable energy generation technology in the developing world. This program was initiated in the year 1983-84 (Farhan Beg, 2013) for the generation of power to the majority of the people in India. Most of the wind power energy arrangement will be grid connected. These cannot be connected through off-grid stand-alone generation as there will be variations in the supply generation. In 2009, India has installed the power capacity of 1,338MW out of the total capacity of 10,925MW through wind generation (Indian Renewable Energy Status Report Background for DIREC 2010). However, the installed capacity has risen up to 12,009MW in the month of June 2010 which disclosed the 70% of total installed renewable energy capacity.

Table 2.3.1.1 Wind Power Potential across nine states in India

State	Wind Power Potential(MW)
Andhra Pradesh	8,968(MW)
Gujarat	10,645(MW)
Karnataka	11,531(MW)
Kerala	1,171(MW)
Madhya Pradesh	1,019(MW)
Maharashtra	4,584(MW)
Orissa	255(MW)
Rajasthan	4,858(MW)
Tamil Nadu	5,530(MW)
Total	48,561(MW)

Source: (Indian Renewable Energy Status Report Background for DIREC 2010).

The C-WET, a state run organization has estimated the highest wind potential across the nine states which are shown in the Table2.3.1.1. This assumption was based on the percentage of availability of land area and each megawatt of wind capacity requires 12 ha of land. Therefore, the total wind potential available in India is 48,561MW with Karnataka, Gujarat, and Andhra Pradesh has the highest available wind potential followed by other states.

2.3.1.2 Solar Energy in India

India is located between the Tropic of Cancer and the Equator; due to this the annual average temperature ranges from 25 degree Celsius to 30 degree Celsius (Peter Meisen, 2006).The country has 300 sunny days per year which receives the average hourly radiation of 200MW/km^2. This clearly shows that India has the vast amount of solar potential which is used for producing the electricity. The India Energy Portal has estimated that the 12.5% of land can be used for the installation of solar energy. However, the country has underutilized the solar resource due to high capital costs.

Majority of the installed Solar PV projects were accounted for 0.5% of grid-connected renewable energy additions during the year 2009-2010. In the month of June 2010, India has installed the solar capacity of 15.2MW which is based on PV technology, while 20% of the installed capacity is being used for off-grid applications. .According to the phase 1 of JNNSM, India planned to install 500MW of grid connected solar power by the end of the year 2013 (Indian Renewable Energy Status Report Background for DIREC 2010). However, the National Action Plan was ready to launch the National Solar Mission to generate 1,000MW of power by the same year 2013.

2.3.1.3 Biomass Energy in India

Bio-energy is the traditional source of household energy in India which contributes 14% of global energy supply. India has most of the non-conventional energy sources such as wood and cow-dung which are used for the energy supply. As there is no access of electricity in rural areas, people use wood and cow-dung as fuel for the purpose of cooking and water heating. Biomass energy is obtained from the organic material which is used as the conversion process for producing the power, heat and fuel. These biomass resources produces the power through grid-connected bio-mass power plants, off-grid distributed biomass power applications and finally by using sugar mill industries. It is estimated that the biomass resources produces 500 million tons per year, out of which 120-150 million tons is used for the generation of power (Indian Renewable Energy Status Report Background for DIREC 2010).

Recently India have established 2000 gasifiers with a capacity of 22 MW through which the rural households have been electrified with biomass gasifier based generators. MNRE has estimated that the amount of biomass resources available for power generation is about 189 million tones, which roughly produces 25 GW of power through installed capacity. The generations of power capacity through various renewable energy resources are presented in the table 2.3.1.3.

Table 2.3.1.3 Generation of Power Capacity (MW) through Grid-connected renewable energy sources

Renewable energy program	**2010-11**	**Cumulative Deployment up to 31.12.10**	
	Target	Achievements up to 31.10.2010	
Wind Energy	2,000MW	1259.03MW	13065.78MW
Small Hydro Power	300 MW	203.92MW	2939.33MW
Biomass Power	455MW	143.50MW	997.10MW
Bagasse Cogeneration		216 MW	1562.03MW
Waste to power (Urban and Industrial)	17MW	7.50MW	19.00MW
		-	53.46MW
Solar Power	200MW	5.54MW	17.82MW
Total	2,972MW	1835.49MW	18654.52MW

Source: (N. K. Sharma, P. K. Tiwari and Y. R. Sood 2011)

India has achieved 18654.52 MW total capacity of power generation till 31st December 2010 which is about 10% of the total installed power generation capacity. This power capacity is shared by various sources in which wind power contributes 13,066 MW; small hydro-power contributes 2,939 MW, biomass of 2,559 MW and finally solar shares 17.8 MW as shown in the table 2.2.1.3 (N. K. Sharma, P. K. Tiwari, and Y.R. Sood 2011).

2.4 Global Status of Micro-grids

It has already been mentioned that the technological advances have led to the development of MG systems. As a result this leads to the various numerous design, control and monitoring systems which are used for the localized MG systems.

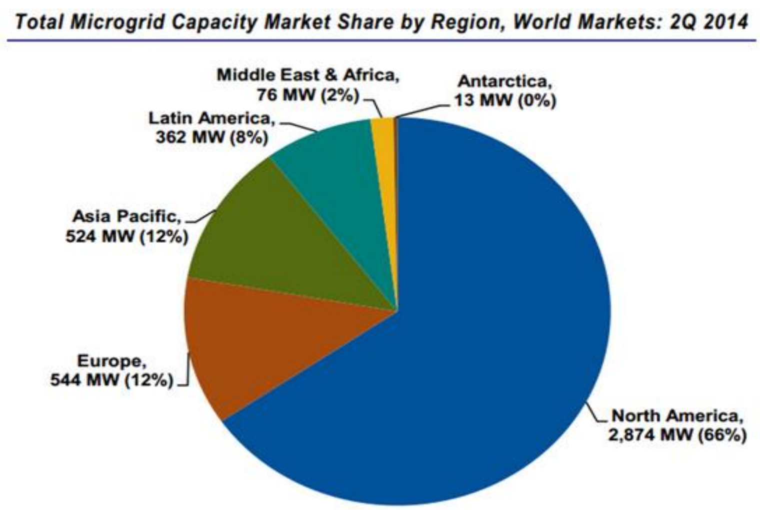


Figure 2.4: Micro-grid capacity for different regions

Source: (Navigant research, 2014)

The Navigant Research which has developed the global data base of MG systems has estimated that there is a capacity of 3793 MW which is currently in circulation. According to this source, North America is the leader in the availability of MG systems with highest installed capacity as shown in the figure 2.4.

It is also noticeable that educational institutions have also relied on the localized energy generation and transmission systems. However, compared to other sources of power generation and supply systems, the use of micro-grid still remains underutilized. And its current use all over the world is to indicate their potential in terms of today's rural communities, because rural communities are most deprived of electricity, as an energy distribution is imbalanced.

This hierarchy mostly reflects the energy systems utilized by different households in the economy according to their income levels. Rural areas are placed down in the hierarchy because they utilize traditional fuels or energy generation, and distribution systems. For rural populations in India, kerosene and wood fuel are the chief sources of energy. On the other hand, the urban population categorized under middle class or higher-class citizens are likely to use an efficient, cleaner and cheaper fuel sources like the national grid, solar or LPG.

The adoption of micro-grid systems as an alternative power supply system for rural areas is, therefore, the best means of raising poor communities within the energy access hierarchy. There are numerous reasons why they are viable for rural areas as discussed by scholars throughout the globe. The following sub-section identifies some of the key benefits micro-grid systems accord the rural populations.

2.4.1 Benefits of Rural Settings

From the onset, micro-grid systems are meant to replace the usual low quality energy generation systems in rural with efficient and higher quality ones. In rural areas of India, kerosene, wood and other readily available energy sources are usually convenient for use even though they might have long-term effects on the socio-economic and ecological development of rural households (Liu & Su, 2008). Collectively, there are a lot of benefits India may accrue as a result of improving generation and supply of energy in rural areas. Some of the major benefits of MG systems for rural areas as identified by scholars include economic development, social empowerment, health improvement and environmental sustainability. Most importantly, India will benefit economically from the increased electrification rates in the country.

2.4.1.1 Economic Benefits

MG's plays a very crucial role for the economic benefits of the country to any community or institutional area. For rural communities that have traditionally relied on other energy sources like wood and fuel, micro-grids are replaced and may be evaluated in terms of cost savings. For instance, Sovacool and Drupady (2012) illustrate high prices of other energy forms evaluated by quoting a figure of $11 per month used by Bangladesh households in purchasing kerosene. An additional $4 may be used in rural Haiti for charging of mobile phone batteries or purchase of disposable batteries monthly. In most cases, households continue to be exploited by unscrupulous dealers, who charge exorbitant prices for battery charging services.

When all these costs of acquisition are summed up, rural households are said to incur about 130 USD/kWh on average. Compared to the alternative energy sources like micro-grid generated power, these households engage in an expensive venture to get their daily supply of fuel and power. On the contrary, the long-term economic impacts for the use of micro-grid in homes, institutions and villages are tremendous. For example, a report by the UNDP (2008) estimated a 52% increase in household income for micro-grid users within a span of 10 years. Aside from increasing income, their use can also be associated with a boost to a country's national income.

Another important economic impact of micro-grid systems is in a multiplier effect especially to the agricultural sector. Most rural households depend on agriculture mainly for subsistence purposes. The introduction of MG systems will however facilitate the growth and expansion of agribusiness in rural areas. For instance, power can be tapped into large tracts of land for purposes of irrigation (Blyden & Lee, 2006). In turn, village residents are empowered to produce more fruits, vegetables and other cash crops that may be sold in the urban areas. The expansion of agriculture in India's rural regions will also contribute to its gross domestic product's growth, which is positive for the country's future economic outlook.

MG systems provide an alternative and sustainable power to individuals, communities and institutions. One of their main economic advantages is that they are able to assure consumers in reliability. Even in rural areas, commercial and industrial segments of the market benefit from such opportunity to expand their production. Therefore, a country's production is enhanced in addition to increased empowerment of the poor. This is one of the ways countries like India are willing to improve the state of their economies. On the other hand, the social benefits of using decentralized energy generation and supply systems are similarly numerous.

2.4.1.2 Social Benefits

Socially, MG systems provide stable electricity needed for the social development of the country. Education, communication, entertainment and information flows are tremendously boosted through equitable access to reliable and affordable energy sources. First, many rural schools remain largely inaccessible by the national grid. As a result, a lot of students are not able to advance their learning due to reduced hours. They are only able to study during the day while their urban counterparts have electricity to help them study at night. Reduced study time translates to poor performance in comparison to those who have abundant time. Electricity supply also determines the availability of learning channels like computers and other electronic media.

The introduction of MG systems within institutional and community levels is, therefore, essential to provide the much-needed boost to learners within rural regions. Secondly, communication and information flow can be significantly increased with the introduction of micro-grid systems in rural areas. As already mentioned, rural households depend on fewer businesses to help charge their cell phones at a price. However, not all households are able to sustain the costs of charging their cell phones monthly. They have to reduce their usage of such gadgets even though they may be the only ways of communication and access to information. Restricted communication and information access subsequently results in communities 'locked out' from the rest of the world.

MG systems also provide a cheaper power needed for the entertainment and informational purposes like watching televisions and listening to the radio. Local musicians and artists can also develop when they are able to produce and distribute their work within such channels. As a result, MG systems can be stated as channels of exposing rural and remote regions to other lifestyles and social dynamics. They are great contributors to the social development of communities. Compared to the traditional sources of energy, micro-grids also provide the opportunities for villages and rural households to improve their health.

2.4.1.3 Health Benefits

The health of any given population is considered as one of the greatest concerns for their government. MG systems provide an opportunity for rural households to shift from the use of non-renewal and unclean sources of energy to sustainable and clean ones. Kerosene use is quite rampant in rural areas because it is available for families who need to light up their homes at night. However, the health side effects that come with prolonged use of Kerosene can be expensive to many households in such regions who are already grappling with other diseases. Kerosene is likely to result in shelter fires, respiratory complications and poisoning in cases where children accidentally ingest them.

In addition, the use of this energy source has been linked to other diseases like tuberculosis and cataracts. Women are also exposed to these illnesses during the time of delivery since the insufficient light provided by lamps may prevent midwives from effectively performing delivery procedures (Mills, 2012). In rural India, there are even unfrequented risks associated with insufficient lighting at night. For instance, a survey carried out in the Ganges river delta indicated that the numbers of snakebites and tiger attacks were significantly reduced with the introduction of both domestic and public lighting systems.

The implementation of DG also contributes in raising the living standards of populations through enabling the possible processes like food and drug preservation. Local hospitals are able to carry out their duty effectively by storing the drugs and other materials in refrigerators. Households are able to preserve their food and hence prevent cases of food poisoning. Lastly, MG systems utilize the renewable sources of energy that are not only healthy for the rural populations, but also to their environments.

2.4.1.4 Ecological Benefits

A huge proportion of India's national grid is supplied by power from thermal generators. These generators utilize either coal or diesel as their main sources of energy. Given that the two sources are non-renewable, the burden to the environment has been tremendous. However, the adoption of micro-grid power systems in rural areas will help the government and communities in their efforts to look for efficient and sustainable power. As already noted by many experts in the energy sector, the expansion of the national grid in order to accommodate rural electrification efforts will require an increased generation and utilization of coal deposits. This will only serve to increase carbon emissions in the atmosphere, contrary to the conservation efforts being put in the country and globally.

MG's mainly utilize renewable energy sources like solar, wind, biomass and micro-hydro. Effective use of such systems, therefore, contributes a lot in environmental conservation efforts in rural areas. In the rural areas, they also help in reducing pressure on natural resources like forests. Most households in such areas also depend on firewood for cooking. All economic, social and ecological benefits of micro-grids establishment and use generally depend on decentralized energy systems. The following section, therefore, reviews all performance issues as highlighted by various scholars.

2.5 Micro-grids Performance

In their critical review-based study, Schnitzer et al., (2014) identify the reliability and economic viability as the two most important indicators of the performance of micro-grid systems. First, they state that a reliability component of performance can be further grouped into energy service and schedule. Therefore, MG system must satisfy the two conditions throughout its expected lifetime. In terms of energy service reliability, MG system is expected to produce the output levels originally planned for the given number of consumers. In case of electricity for rural households, any micro-grid is expected to meet the demands of all connected households irrespective of the load differentials.

However, most MG systems may not be able to provide energy to all the customers regardless the demand or load levels. As a result, the system should be designed to control the energy level in that demand if supply is balanced. Voltage regulation, therefore, is a part of finding the right balance for the micro-grid system deployed for a given community or institution. A good example is the regulation of use; if households are able to use certain electrical appliances like energy saving bulbs or are limited to a given daily kW of power so that the energy can be shared equally among the users.

It is also important to note that there might be other external factors to affect the performance of micro-grid systems. For instance, weather patterns, natural calamities and energy resource fluctuations may hinder the generation of power within the system. Therefore, the design of any system should take into account such factors. On the other hand, a micro-grid with a reliable schedule can readily fulfill its original planned schedule. Since MG's may not operate full time as they usually have schedules set both for day and night operations. Performance in this case is evaluated through the ability of a MG to supply the needed power within its set schedules without failure.

On the other hand, a financially viable micro-grid should be able to balance its revenue stream to its operational expenditure. Since MG's may or may not run solely on the tariffs collected from its customers, issues like government subsidy and other external funding are important for performance. Consequently, the financial viability indicates whether a given micro-grid may be operated within a planned period and is able to generate directly or indirectly to fund its operations through the given resources.

There are other factors to consider as well for the MG's performance. They include affordability, availability, service coverage, and environmental impacts. As a performance component, availability is assessed through the given time such that the micro-grid may supply energy to the connected households. On the other hand, affordability indicates the rate at which a given power system's rates can be easily settled by users. For effective performance, a micro-grid system should be able to utilize the cheapest available source of energy for the area served.

In terms of environmental performance, MG’s are expected to record the minimal pollution effects on the environment. They are supposed to use a renewable energy or other energy alternatives that do not contribute to environmental pollution. Micro-grid is also an empowerment tool for the villages. Thus, it should have the ability to support the income generation activities. For instance, if there exists the small and micro-enterprises in the area being served, they must grow in a direct relation to its existence.

Another perspective of performance is the viability for design and operational abilities of any given micro-grid. Customer's use, operations and maintenance factors, as well as program design, are the main components of operational ability of MG systems.

2.5.1 Cost Recovery

Firstly, micro-grid operations must have a model for cost recovery. All costs of design, setup and operations must be returned within a given period. Sufficient tariff collection is an on-going concern for many micro-grids operating on a business model. There are two main issues associated with tariffs.

On one hand, tariffs should not be too low to support funding of operations. On the other hand, tariffs are also not expected to be higher for rural households, who mostly look for cheaper alternatives in the long-run. Power from micro-grid systems should be charged at lower rates than the prevailing rates of other sources to remain competitive in the markets. Secondly, theft is also an issue that might affect cost recovery for any micro-grid. Theft may be witnessed in two main ways. The first is the theft of supply through illegal connections within the grid system. The second way is vandalism targeted to existing infrastructure like the generation plant and the distribution lines.

When more electricity is being used in the system than what is actually being paid for, there is a negative pressure on cost recovery. This might greatly affect the performance of the whole system.

2.5.1.1 Operations and Maintenance

In an ideal micro-grid system, the costs of operations and maintenance are actually transferred to the end consumer. As a result, recovery of initial costs is important for achieving sustainability within the system. The system needs to collect enough tariffs to pay off its initial capital costs and remain viable enough to offset other costs associated with O&M. In cases where cost recovery is hindered or is lower, operations and maintenance of the micro-grid may be greatly affected.

For other micro-grid models, government subsidy may play an important role in financing O&M as the system adjusts towards the recovery of all costs. The sources of finance during the initial stages of operation, therefore, may be an important factor of performance given that it boosts the levels of operations and maintenance. However, there are the factors not related to the sources of financing, which might have an impact on O&M. They include a contractor performance and training levels of the users or communities being served.

In most cases, MG's would require independent suppliers who agree to contracts for supply and installation, as well as the implementation of the system. In some cases, the contractor may be incompetent. The contractor may not be keen on maintaining the system regularly through replacement of the parts worn out, replenishing of the needed resources or overhaul of the system parts that have become a hindrance to performance. When the proper functioning of O&M is neglected by the contractor, financing performance of the micro-grid will be negatively affected in the long run. Poor O&M may eventually affect the reliability of the whole system through frequent downtimes needed for upgrades.

Rural communities certainly need an adequate training on the use of power supplied by the micro-grid system. This is one of the efforts meant to ensure sustainability in the whole system. The consumers are expected to take the necessary precautions in their homes to ensure that they do not hinder the flow of supply through damage of circulation components. For instance, when there is a short circuit within the system, it may affect some users when there is need for temporary micro-grid system shutdown.

Therefore, all parties involved in training communities may affect operations and maintenance in many ways. Firstly, they determine what has been passed to the final consumer on usage habits and precautions. Secondly, the content of their sensitization is likely to influence the rates of responsibility within the system among the different users. For instance, well-informed users are responsible enough to use the power supplied wisely as well as pay the required tariffs as required to ensure continuity of the system.

2.5.1.2 Customer Usage

Load limits and rate of growth are the two most important usage factors that must be taken into consideration. In recognition that the supplier plays an important role in operations and maintenance of every micro-grid, consumers must also reciprocate through responsible usage. As a component of performance, customer usage determines the rate of O&M by choosing to obey or disregard load limits set within the system. Load limits are assigned to every consumer within the system in order to ensure that the total peak level is sustained. Since micro-grids generate limited power, it must be equally distributed to the available consumers through assigned load limits at peak periods (Kirubi et al., 2009).

Load limit for usage is common for solar PV installations that have batteries that can store power for given durations. However, systems that utilize other sources of energy like biomass, diesel or micro-hydro may not be heavily affected by customer load. Operational performance is highly affected when customers exceed their load limits. When the system continuously experiences overloads, there is frequent ware of the supply lines, which may lead to blackouts. Eventually, the supplier will have to cope with high rates of O&M, which influences performance of these micro-grids.

On the other hand, the rate of unmet demand in the system also poses great performance challenges on micro-grids. Under normal functioning, MG’s are able to serve existing customers through optimized load capabilities. However, as the number of consumer’s increases, there are two alternatives for meeting new demands. Firstly, the supplier may decide to expand existing capacity through additional installations that boost power generation.

For instance, the supplier may increase the number of solar PV and their battery storage capacities. On the other hand, the supplier might decide to intervene on the demand side by lowering load limits per household or consumer.

The decision made at this stage is important for performance. In case if load limits continue to be limited whilst the demand side grows, the whole system can be overburdened. This leads to increased unreliability of the micro-grid system, which may be occasioned by blackouts. Performance of the system also influences demand. For instance, a system that matches the demand of customers encourages more people to have the access of electricity while unreliability of the demand forces the consumers from dis-connecting the load. Despite the challenges of operations mentioned in this section, many scholars have identified good initiatives to overcome them.

2.5.2 Performance Best Practice

To enhance quality in the management of MG's there are a lot of effective approaches identified by different scholars. Generally, micro-grid performance best practice covers three major components that include operations, planning, and maintenance. They are classified into strategic planning, social issues and operation as discussed below.

Strategic planning is concerned with the technical design of MG's and how such designs are likely to determine performance levels. As a result, the strategic planning component mainly looks at all the information available within the operational environment in order to determine the ideal design for a chosen system. As part of best practice, therefore; the designers of any micro-grid element should not only consider their technical functioning elements, but also look at how they are able to be integrated within given socioeconomic contexts. In the case of rural communities, the design of micro-grid systems should be able to reflect the characteristics of such populations socially and economically. For instance, if most consumers engage in more activities in the afternoon hours more than at other times, the design should take care of the load schedule for this usage period.

Design should also have cultural elements to ensure that local communities identify with the system. The second element of performance is operations, which include technical, financial and commercial considerations. The success of the operation highly relies on the responsible use by customers within a grid system and their promptness to pay tariffs. Tariffs are the main sources of income for micro-grids. As such, best practice requires that the system has an effective billing and collection system. However, affordability also plays an important role in the performance of MG's.

The technical aspects of operation entail effective demand side management (DSM) as outlined by (Harper, 2013). The author outlines five main DSM strategies that include use of energy efficient appliances, limited business hours, restricted household use, price incentives and the involvement of communities in the micro-grid management systems. As a result, there are different technological models which are proposed for the DSM strategies. Examples include load limiters, smart controllers (for optimized load reduction), prepaid meters and other advanced metering systems.

Lastly, the social aspects of performance mostly concern community management as well as participation. For any success to be realized, communities must be involved in the management of the system, especially with regards to the demand side. Training and sensitization of communities are two best practice approaches identified by the literature. Through training and sensitization campaigns, households are able to understand issues dealing with safety, responsible usage, prompt payments and effective feedback to the management of micro-grids in cases of outages or challenges.

The community may also be involved in the planning process through surveys and feedback channeling systems. From the survey information analyzed, the operators of a given system may develop even more community-oriented design as part of performance best practice. Of all the issues identified above, design components are the most critical for performance of any micro-grid system. An ideal design for a MG system should not only ensure maximum generation and transmission, but also ensure that there is an effective distribution and balancing of load capacities within existing consumption points. Scientific literature has also outlined the different control designs adopted by different operators as discussed in the following section.

2.6 Voltage Control Models

Many authors have examined the different control topologies available for micro-grid systems. Firstly, it is recognized that the introduction of varied electronic interfaces have led the emergence of many control management challenges. MG's utilizes the new forms of electronic interfaces and therefore require well-designed control management utilities. To allow large clusters of micro-grid power generators to facilitate distributed generation, it is therefore important that designers create controllable power electronic interfaces (ESMAP, 2000). These interfaces are important because they allow micro-generators to support both island and satellite power grid modes.

As a result, electronic interface are required to exhibit certain characteristics. Firstly, they are expected to provide fixed power as well as localized voltage capabilities. Secondly, they are expected to enable distributed generation (DG) through fast load monitoring as well as storage capabilities. Lastly, they are also expected to integrate "frequency droop" techniques to ensure that load sharing among local consumers can be possible even in the absence of communication. As a result, there are proposals by some designers that low-bandwidth data communication models should be utilized as per each DG. However, this model is only achievable through the integration of two control techniques. They include the droop control method as well as average power control. These techniques work differently but for the benefit of the model.

The average control method basically has a slow update rate. It is therefore used to supplement the other control technique by overcoming sensitivity voltage as well as current analysis errors. The droop systems are generally meant to ensure harmonic load sharing among the different consumers. As a result, this model is able to achieve adaptive control, which is not reliant on effective communication between DG systems. On the other hand, the quality of power adversely influences the success of any micro-grid system. As a result, power quality control is an essential part of micro-grid design as stated by different authors (ESMAP, 2000).

Through their efforts to ensure that different micro-grid models have effective power quality control capabilities, different filtering methods have been proposed by designers. Designers in the energy sector as well as many authors propose the use of single-phase high-frequency AC (HFAC) micro-grid. This system is able to facilitate the integration of various renewable energy sources within the distributed generation (DG) system. However, better performance of DG systems is attained through power flow control between grid and micro-grid systems. This capability can be enabled through a bidirectional control model as proposed by authors. Through this model, amount of power to be supplied as well as feedback power during off peak hours may be specified or controlled.

An effective micro-grid control model must also take into account the issue of reliability. Reliability is usually affected by constant load changes, DG location and DG output alterations. Consequently, authors propose that there is structured frequency isolation between the micro-grid and the utility. This is because the interconnection of many DGs on one hand and the loads on the other within a particular region may require safe operational practices. In other words, any form of voltage fluctuation in the utility side may adversely affect load voltages as well as power frequency on the micro-grid side. As a result, isolation is one of the major control management approaches that may be deployed for micro-grid systems that act as supplements to utility systems.

Another issue of great concern related to voltage control among different authors is the stability of load sharing. Stability issues mainly arise in micro-grid systems because of the process of converting DC power to AC. This is because the conversion process may either slow or faster depending on load demands. Generally, a modular structure for controllers is discussed. The best structure is one that is flexible enough to meet the demands of different AC systems. A P-I regulator, which has the ability to determine set points for flux and generator angle, is proposed by designers (ESMAP, 2000). However, there are other advanced stability control techniques that may be used. These control methods are mostly based on frequency droop and voltage (Sovacool, 2012).

Droop models have also been investigated through many studies as part of MG voltage control topology. There are three major types of droop models that include the angled and frequency droops. Overall, a controller model having a modified voltage angled loop is preferred to enhance sharing between interconnected converters in the micro-grid system. The control efficiency capability voltage loop accords the system is that it influences close loop elements without having any impacts on the regulation of power frequency. The frequency droop controller has generally higher frequency instability within the micro-grid system in comparison to the angled droop. However, both angled and frequency droop controllers are meant to attained equal stability margins with the DG system.

Another important part of control is the property of micro-grid systems to enhance protection. Protective devices for LV DC micro-grid systems can be in the form of power circuit breakers, fuses, and molded circuit breakers (MCCB) and isolated-case CB. In most cases, these models are applicable for AC- DC topologies even though they can also be used for DC applications. First, fuses generally have heat-absorbent materials as well as fuse links enclosed in ceramic cartridges. In cases where voltage exceeds the set limits, the fuse contributes to control through the melting action of the fuse link. Melting of the fuse link is likely to result in the formation of an arc, which regulates voltage since the system's voltage should be equal to the arc voltage for transmission to be possible (Hatziargyriou et al., 2007).

Molded-case CBs generally have contactors, quenching chambers as well as tripping devices. When tripping occurs in the MCCB system, the contacts separate leading to the formation of an arc. The arc is then forced to an adjacent quenching chamber that consists of multiple metal plates. These metal plates are responsible for replicating the arc into smaller arc elements, which then leads to increase of total arc voltage and therefore a reduction in arc temperatures.

Within the micro-grid, it is, therefore, important for a combination of control approaches to be utilized as already discussed. In the supply side, protective devices should be selectively deployed to ensure that each consumer has specified load capabilities. The whole supply system should also be capable of stability through prevention of tripping and other problems associated with overloaded circuits.

The use of circuit breakers and fuses is, therefore, an important component of voltage control within MG‘s. However, these protections merely complement other control measures already discussed in this section.

For rural settings, the utilization of autonomous systems will be important for control as well as for safe use purposes. Electronic circuits are important to complex micro-grid systems (Katiraei et al., 2007). However, there are proposals for voltage control to be effected at the converter level. Control by converters takes place when flow between DC input source and the system generated DC is harmonized (Hafez & Bhattacharya, 2012). In cases where battery storage is not available, multiple input systems are proposed (ESMAP, 2000).

For instance, a micro-grid system may be composed of wind turbine, solar PV cells, solid oxide fuel cell generators, DC and AC loads. In this case, a three-phase grid control utility is designed to ensure that there is constant supply of voltage as per consumer load requirements. For combined systems distributed generation systems that utilize Energy Control Management Software given priority by designers (Pogaku, Prodanovic & Green, 2007).

2.7 Project Justification

Given that India’s electricity generation and supply still remains unreliable as discussed in this chapter, it is inevitable that remote rural villages will continue to have limited or no access to power. However, the introduction of micro-grid systems to enable small power generation will bring hope to rural populations who have given up on state owned national grid systems.

It is also important that chosen micro-grid system designs are reliable, affordable and accessible to all households within rural India. Despite the availability of different control models for MG systems, any chosen model should be based on stability, reliability, and safety. At the same time, usage is an important performance issue for MG systems. Particularly, it is important to look at topologies that effectively manage loads within different users.

Such load management systems should cater for usage either during the day or at night. For instance, the limited energy generation may require that commercial activities be supplied with power during the day while households utilize the system at night.

In order to ensure the proper and responsible usage that in turn promotes reliability in the whole system, a voltage control topology must be designed and tested according to the objectives of this project. By looking at the most suitable voltage control topology strategy to be deployed in rural India, this project also adds to the limited resources available on micro-grid system control approaches. It also identifies loopholes available in existing models, which will be useful in the development of sustainable models in future.

2.8 Summary

With an improvement in technology, the energy sector has benefited from opportunities to design, test and implement efficient generation and supply systems. The use of micro-grids has also been advanced through improved control, monitoring and billing systems. In effect, the potential MG's hold in the modern world is tremendous. Their use has been specifically encouraged for remote and underdeveloped regions that have not presently been connected to reliable and sustainable sources of electricity.

In rural areas of India, Kerosene, wood and other readily available energy sources are usually convenient to use even though they might have long-term effects on the socioeconomic and ecological development of rural households. Collectively, there are many benefits Indian households may accrue as a result of improving generation and supply of energy in rural areas. Some of the major benefits of MG's for rural areas as identified by scholars include economic development, social empowerment, health improvement and environmental sustainability (Zhanghua & Qian, 2008).

There are two most important performance indicators for micro-grids. First, is the reliability component of performance and the other grouped into energy service reliability and schedule reliability. Any micro-grid, therefore, must satisfy the two conditions throughout its expected lifetime. In terms of energy service reliability, a micro-grid is expected to produce the output levels originally planned for the given number of consumers. In case of electricity for rural households, any MG is, therefore, expected to meet the demands of all connected households irrespective of the load differentials.

In the literature review undertaken, there is only one author who uses similar micro-grid topography, but used different simulation methods for the dynamic load studies. This author also has not carried out a financial analysis of the cost of electricity, nor sensitivity study to find an optimal possible configuration for the micro-grid. This project will investigate and quantify such optimization and sensitivity studies to better understand the financial viability of micro-grids, not just potential technical solutions.

CHAPTER-3

RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

This chapter outlines the tools, procedures and techniques for the implementation of the proposed DC micro-grid system. Most importantly, this study uses an experimental setup that is modeled using Homer Energy software. From the literature review, one of the most challenging components of MG's is the harmonization of load capacity to serve all consumers. Voltage control in micro-grids is one of the components that should be closely monitored to ensure that rural populations enjoy the benefits of localized power distribution.

As a result, this paper investigates how voltage control may be effectively done to ensure that rural populations have access to quality, reliable and cost-effective source of electricity. MG systems are used to enable the generation of electricity close to the area of utilization. For the case of rural India, micro-grid systems must be located in rural villages to enhance accessibility. Micro-grid systems largely utilize available renewable energy sources for the production of electricity. Within the project's objectives and aims, an appropriate model was developed and manipulated to come up with the best voltage control topology for the proposed system.

3.2 Project Design

The project design follows an experimental set up tested to come up with the most suitable voltage control model. This study was particularly modeled for a low voltage DC micro-grid protection. Given the demands of different households, load profiles were developed. As discussed in the literature review, micro-grid control systems are based on the regulation of interconnected resource loads for equitable distribution of power.

The LV system relies on a DC-DC micro-grid distribution topology. After design, the DC-DC micro-grid distribution network is afterwards connected to DC-AC inverter at the customer's end. To this end, it is able to produce AC power from low DC voltage through the battery. Through different upgrade points, the whole system has the ability of delivering maximum power to consumers during the day in set intervals to each of the households connected.

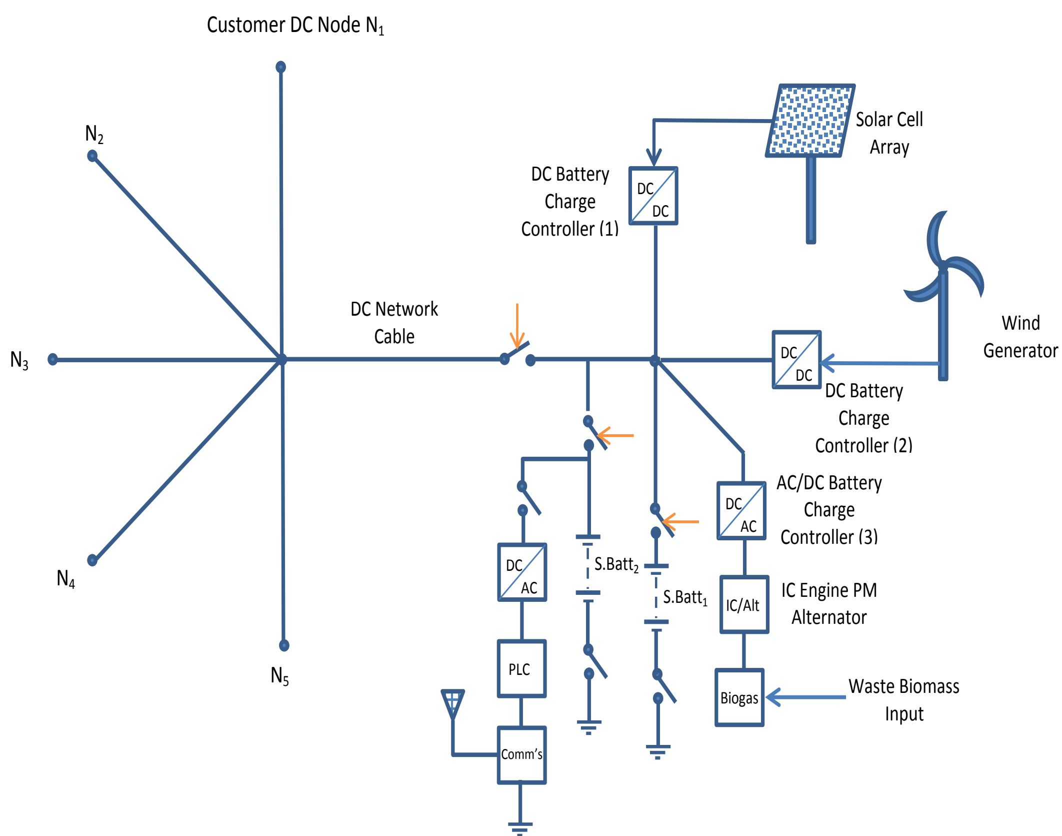


Figure 3.2 Proposed DC Micro-grid Outline (Note**:** In the figure1 the arrow marks indicates communications controlled relay-switch)

The chosen design for this project was a DC cluster micro-grid with an integrated remote controlled slave consumer unit as shown in the figure 3.2. In this design, frequency of AC signal, which is directed over the DC signal acts as a communication channel. Moreover, a low-bandwidth communication based strategies have been designed for secondary control of the DC micro-grid. This has enabled the enhancement of load current sharing accuracy and the regulation of DC output within the MG system.

According to the design, the DC micro-grid system is composed of distributed energy resources (DER) and energy storage equipment (ESS), which has the function of supplying voltage loads through a common DC bus. DER's used in conventional micro-grid systems can be of various categories. For the proposed design MG utilizes the RE sources such as photovoltaic arrays (PV), wind turbine (WT), fuel cells (FC), bio-mass and other thermal generators. These sources are selected based on cost and availability criteria given that the system implementation took part in remote parts of rural India. For instance, solar LV systems are mostly affordable and, therefore, can be easily acquired by community-based investment groups.

Secondly, the LV systems also support the project's main objective of providing sustainable electricity. The LV DC micro-grid system is connected to a battery which is used as a storage resource. During the process, it gets charged and is, therefore, used for producing the power especially at night, as well as on cloudy days when there is insufficient sunlight. Therefore PV supply is chosen as it has the advantage of providing uninterrupted power to all households.

With the three sources of energy identified, there is reliability of generation and supply at regular intervals of time. Alternative sources of generation also allow the DC micro-grid system to deal with capacity changes such as increased load or node connectivity demands by new consumers. They are connected to the system through the centralized DC inverter. The DC inverter also has a battery. The purpose of the battery is to facilitate storage for continued supply.

After the design and integration of all resources within the system, voltage control was the main element investigated by this study. Voltage control is deployed locally for every DER within the DC micro-grid in order to effectively regulate transmission to the bus. Loop strategies are employed within the system because supply should be done according to load limits per household. In addition secondary control is employed to take care of the challenges caused by differences in distance between the power generation and consumption points.

The following section discusses the implementation of proposed LV DC micro-grid system through Homer Energy Software, which is considered as the main design tool for the project.

3.3 METHODOLOGY

3.3.1 Introduction to HOMER ENERGY

HOMER ENERGY is a software application developed by the U.S National Renewable Energy Laboratory especially for designing the micro power systems and for the comparison of power generation technologies. HOMER is used to model the proposed MG design with various features like life cycle costs, installation of the system as well as the operation and maintenance thorough out the project cycle. The software was utilized in the project for three main reasons which include simulation, optimization and sensitivity analysis. As a result, the methodology followed a three-phase procedure. Simulation process involves the evaluation of a micro-grid system ability to cope with load demands of consumers as well as remaining financially viable within the project life cycle.

On the other hand, optimization refers to the process of employing different micro-grid design and configuration features through the simulation process to enable the researcher arrive at a suitable design. The suitable design for this project was intended to be sustainable for rural communities in terms of cost-effectiveness as well as quality transmission of electricity. Lastly, sensitivity analysis goes further to perform a number of optimizations so that effects of changes in resource, financing and demand capacity are able to be gauged.

3.3.2 Load schedule considered for the proposed micro-grid

Table3.3.2 represents a potential typical load schedule for the customers for 2hrs interval during the day time that either the sustainable energy sources supply, or is partly supplied by the battery that is attached to these resources.

Total energy demands for such a system would be 17.5 kW-hr during the five by two hour intervals during daylight hours.

Table 3.3.2a Typical Load Schedule considered during the day time

Load Type 1: Shared 2 hours for each of the five customers for day in the morning hours			
	(Power)		Energy Usage
Description	Load	Period of Use	Sub-total of demand
Daylight Hours - Agricultural and Domestic Load	kW	(Hrs.)	(kW-hr)
Pumping water	0.85	1.5	1.275
Washing	0.9	0.5	0.45
Milling	0.55	1	0.55
Chaff make	0.55	1	0.55
Dairy – cheese making	1	0.5	0.5
Total energy usage per 2 hour interval (kW-hr)			3.325
Maximum demand if all loads co-incident at any time during the 2 hours periods		3.325kW	Kw

Table 3.3.2b represents the load schedule for customers during the night time for each 1hr interval. Similarly the night time load would be 23.5 kW-hr over a total of 5 hours in the evening period, before the central controller would turn power off during 11 p.m. to 7 a.m.

Table 3.3.2b Coincidental Night Schedule

		Power (kW)	(Hrs.)	(kW-hr)	Hourly Demand	
Time Period	Load Type shared by the five customers during night tie for each five days	Load	Time	Energ y		
5:00 - 6:00	Lighting	0.1	1	0.1		
	Entertainment	0.45	1	0.45		
	Fan	0.3	1	0.3		
	Ancillary Load (Laptop, modem)	0.1	0	0	0.85	
6:00 - 7:00	Lighting	0.1	1	0.1		
	Entertainment	0.45	1	0.45		
	Fan	0.3	1	0.3		
	Ancillary Load (Laptop, modem)	0.1	0	0	0.85	
7:00 - 8:00	Lighting	0.1	1	0.1		
	Entertainment	0.45	1	0.45		
	Fan	0.3	1	0.3		
	Ancillary Load (Laptop, modem)	0.1	1	0.1	0.95	
8:00 - 9:00	Lighting	0.1	1	0.1		
	Entertainment	0.45	1	0.45		
	Fan	0.3	1	0.3		
	Ancillary Load (Laptop, modem)	0.1	0	0	0.85	
9:00 - 10:00	Lighting	0.1	1	0.1		
	Entertainment	0.45	1	0.45		
	Fan	0.3	1	0.3		
	Ancillary Load (Laptop, modem)	0.1	0	0	0.85	
10:00 - 11:00	Lighting	0.1	1	0.1		
	Entertainment	0.45	0	0		
	Fan	0.3	1	0.3		
	Ancillary Load (Laptop, modem)	0.1	0	0	0.4	
				4.75	Max Evening Power Demand	
	Total co-incident Energy demand (kW-hr)at night for all five customers			23.75	0.95	k W

The three-stage modeling process in HOMER was, therefore, meant to come up with the most suitable DC micro-grid design for rural India. The data schedule for each day is loaded into the software so that it shows the average utilization of power per day or per month.

The following sub-sections provide a detail of how the three stages were performed in HOMER.

3.3.3 Implementation of HOMER Simulation Interface

The purpose of HOMER simulation process is to assess long-term operational capabilities for the proposed DC micro-grid design. Figure 3.3.1 outlines the resources employed for the simulation process in the HOMER interface.

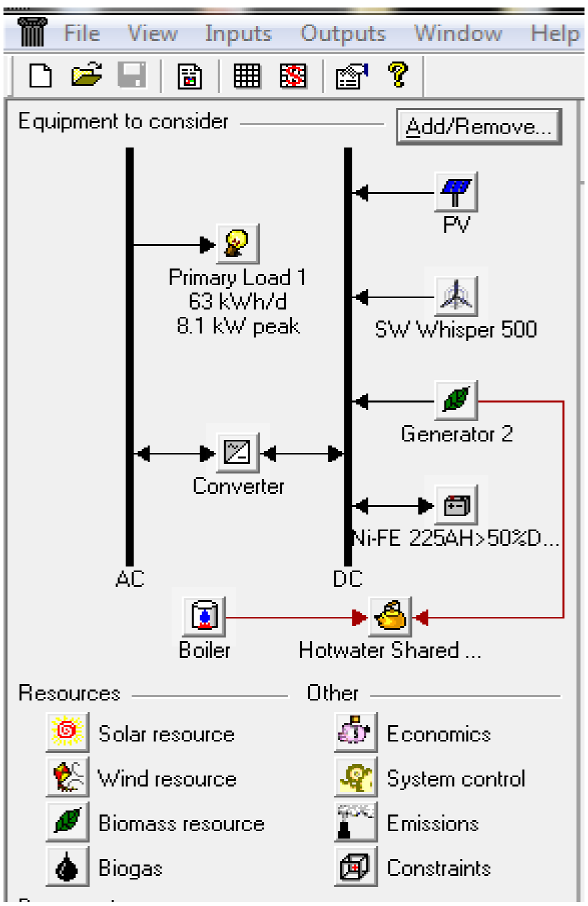


Figure 3.3.3 Equipment considered for the HOMER interface

The simulation process has two purposes. First it determines the system to be feasible if it can satisfy the demands set by the user such as electric and thermal load to be served equally. Secondly, it considers the life cost of the system which is used for comparing the economics of the various system configurations. Assessment of the proposed micro-grid design was done through a 2-hour simulation series for one year. Basically, HOMER goes through the process by calculating renewable power capacity and compares this capacity to the corresponding consumer loads. In the process, the system determines instances where surplus power may be available and how it may be utilized. In the same way, the model determines instances where generated power may be less than the actual demand by consumers and how additional power may be generated. After a year's assessment has been made, the system determines whether the specified design has met the desired performance goals within the provided resource requirements.

The various lists of system component sizes, capital costs, replacement and O&M costs considered in the HOMER analysis is presented in the table 3.3.3.

Table 3.3.3 Details of the Capital, Replacement and O&M Costs considered in the proposed scheme for the equipment's employed

Component detail	**Capital cost ($)**	**Replacement cost($)**	**O&M cost ($/yr)**
Solar PV system (1-10KW)	1500	1600	0
Wind turbine(3KW DC)	700	700	50
Battery(13.3V,2.99KWH)	2200	800	100
Converter(1-10KW)	1000	1200	20
Generator(30KW)	38000	40000	0.5

3.3.4 Model Inputs to the HOMER

3.3.4.1 Load Input

The load profile was developed for the five customers according to their daily household activities as shown in the figure 3.3.4.1.

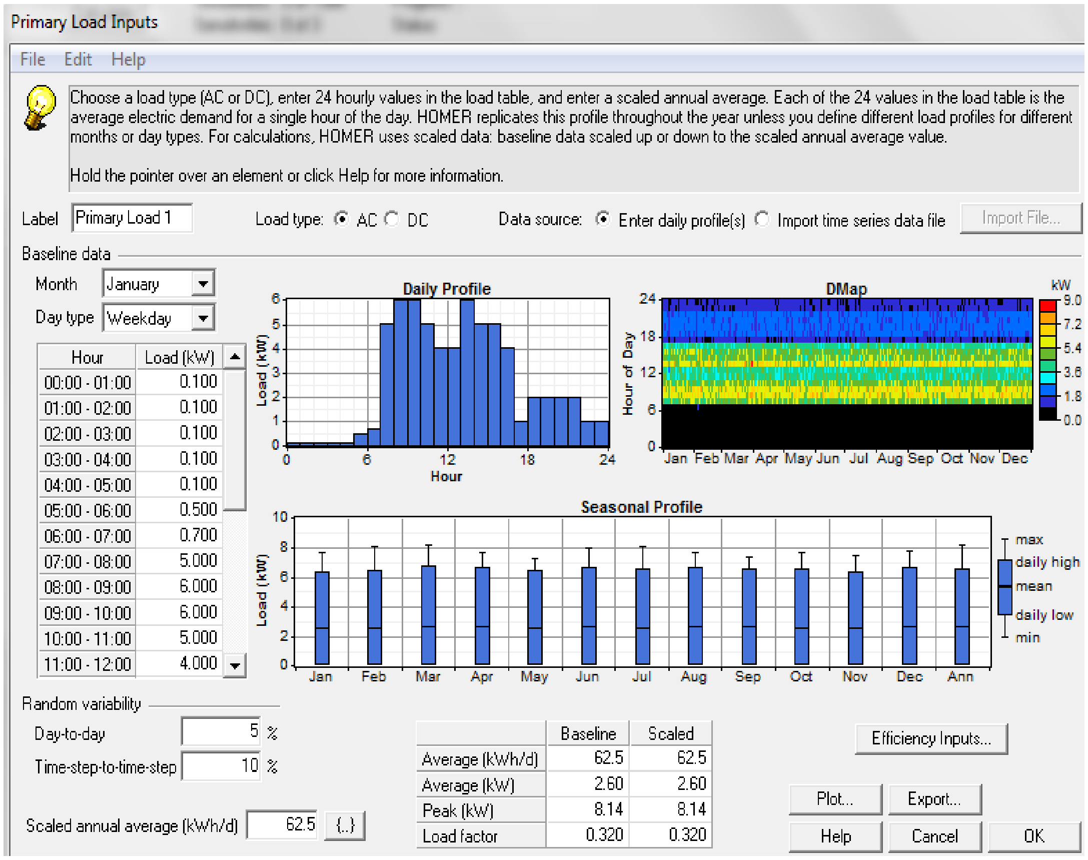


Figure 3.3.4.1 Load Input

3.3.4.2 Photovoltaic Solar Input

PV system converts the solar radiation into DC electricity. In the physical implementation of the system, this will require a solar charge controller. These PV panels were specified with the capital cost as $1500/kW and replacement cost as $1600/kW as mentioned in the table 3.3.2. Therefore little maintenance is required for the batteries on the PV system.

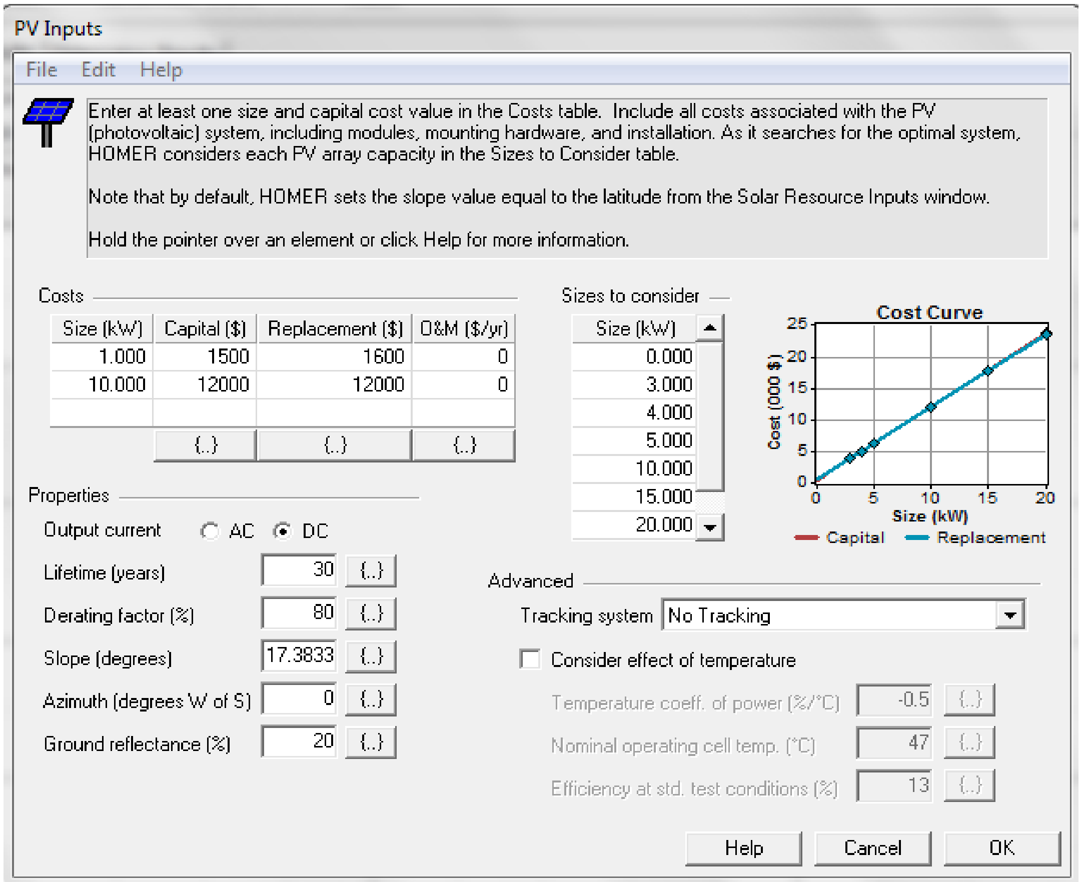


Figure 3.3.4.2 Photovoltaic Solar Input

Each PV panel is associated with 80% of derating factor for the production of electricity. The life span of the PV array considered in this project is 30 years. The latitude size of the chosen location is 17.23 degrees north, and the longitude is 78.29 degrees east as shown in the figure3.3.4.2.

3.3.4.3 Wind System Input

SW Whisper 500 was chosen as the wind turbine for the simulation and it has the rated capacity of 3kW DC as shown in the figure 3.3.4.3.

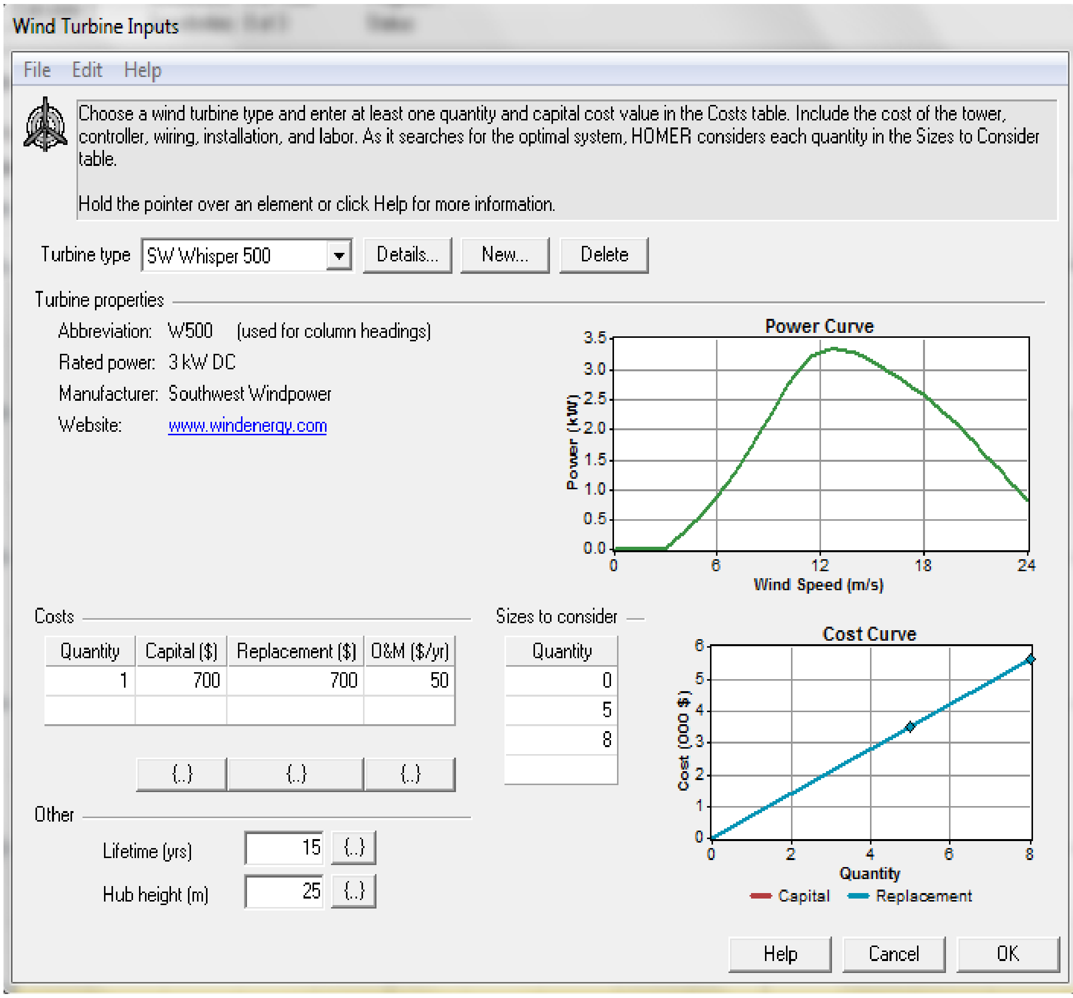


Figure 3.3.4.3 Wind Turbine Input

3.3.4.4 Generator Input

The size of the generator considered as 30kW and the generators were not allowed for operating at less than 30% capacity. This produces the enough power to the customers under the load strategy at all time.

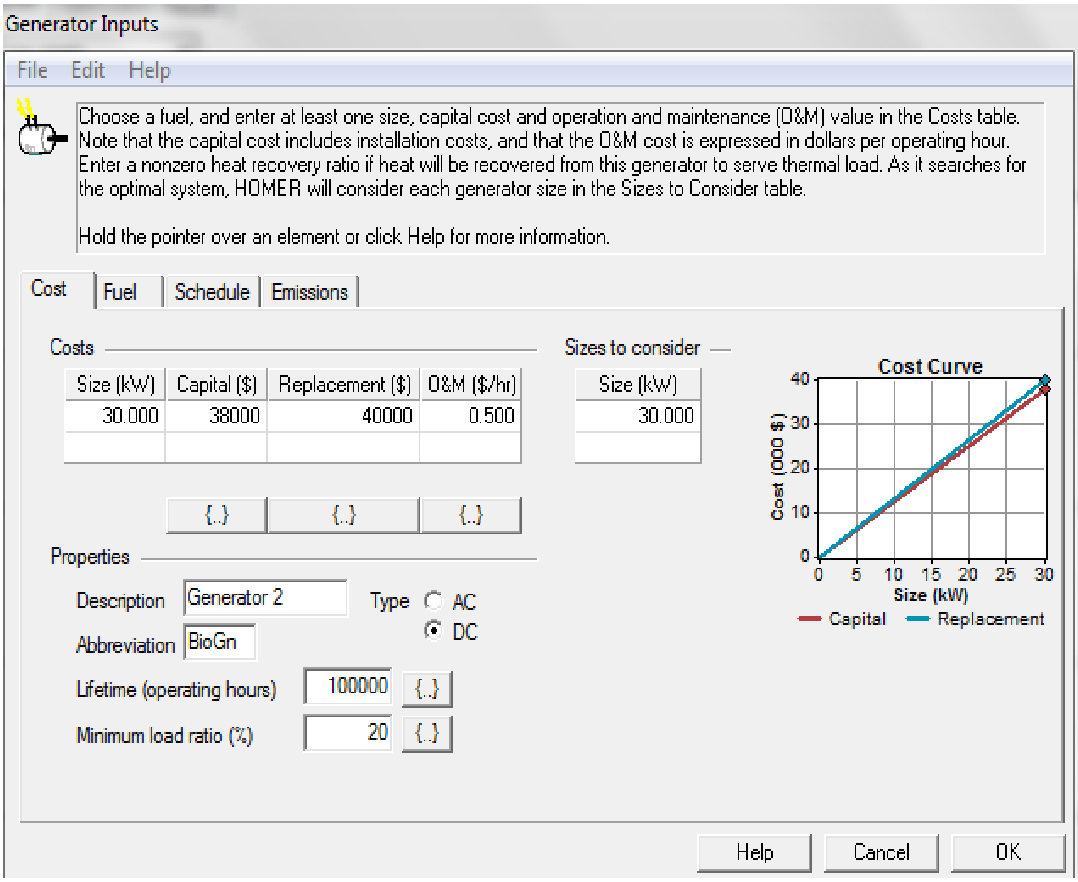


Figure 3.3.4.4 Generator input

3.3.4.5 Batteries

The HOMER model is capable of testing different types of battery. Nickel-iron Edison battery (Ni-Fe 225AH) is chosen for the proposed scheme as it has the very long life compared to other types of batteries.

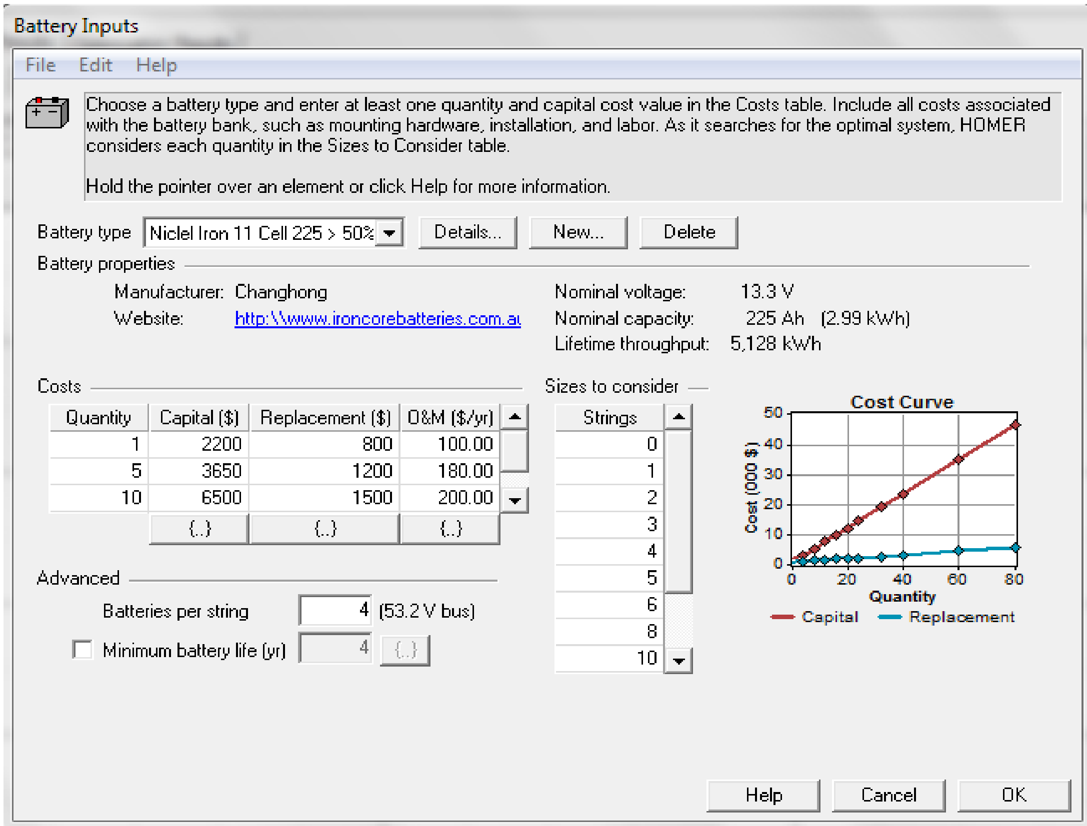


Figure 3.3.4.5 Batteries Input

3.3.4.6 Converters

It is a device used for converting electric power from either DC to AC (Inversion) or from AC to DC (rectification). In this model it would function only as an inverter. The size of the converter considered for the simulation purposes are in the range from 1-10kW.

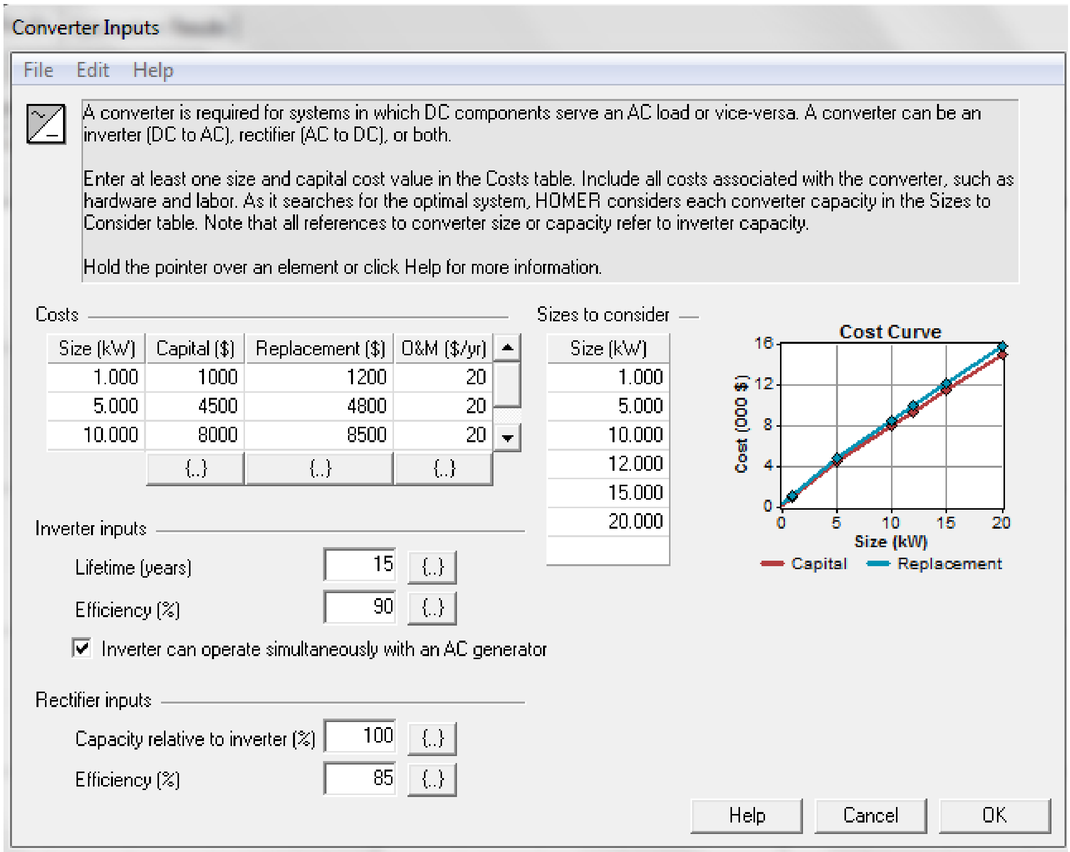


Figure 3.3.4.6 Converter Input

In addition, HOMER energy software also provides output on costs, power demand trends and the likely effects on the environment as per each resource used. As a result, the simulation process was used to determine design modifications needed for the DC micro-grid set up. Subsequently, the optimization process was performed which is discussed in the section 3.3.5.

3.3.5 Optimization

The goal of optimization is to determine the correct system components like sizes, quantity of each component and a power dispatch strategy, which meets the basic requirements of the micro grid. In this process, HOMER simulates the different system configurations and discards the ones which are infeasible and presents the best system configuration according to the total net present cost. The best system configuration is the one which satisfies the user specific assumptions at the lowest net present cost.

Homer performs the optimization process (Alexis R. Harvey. 2012) based on the following decision variables which include:

- ✓ Size of PV array
- ✓ Number of wind turbines
- ✓ Presence of hydro system
- ✓ Generator size
- ✓ Number of batteries
- ✓ Size of the ac-dc converter
- ✓ Size of the electrolyzer
- ✓ Size of the hydrogen storage tank
- ✓ Dispatch strategy

3.3.6 Sensitivity Analysis

In this process the HOMER will perform the multiple optimizations for assumptions of input to measure the effects or changes in the model inputs. Sensitivity analysis helps in assessing the effects of changes in the variables so that designer can know the fuel price and average wind speed, and from such a study of this comes the financial analysis and optimal model for the cost of the electricity that would possible be fully or partially recovered from the customers. Through this analysis, it also reveals how the outputs will vary according to the change in inputs.

3.4 Safety and Risk Analysis

In this design if we choose the Input DC voltage that is within normal international extra low voltage standard. So a 48 V nominal system would fulfill this requirement. This limits any possibility of electrical shock on the DC system. The DC system would be protected from overload either by a DC circuit breaker, and possibly HRC fuses. The DC-AC inverter converts the DC voltage to AC voltage such that it produces the normal 230V power to the customers which in turn will run normal home appliances such as lighting, fans, TVs, other electronic entertainment systems, and possibly a computer. The inverters chosen would have electrical isolation through an inbuilt transformer, and protective function for overvoltage, overload (i.e. over current). So isolation would always exist between AC and DC, and sufficient and correctly rated cut-out switches would exist on either side of the inverter, so replacement can safely take place in the event of failure, example due to lighting strike. These general protection requirements are the risks associated with the design of low voltage dc micro grid.

For this purpose the ratings of DC voltage are specified in the range 48V nominal, with droop maybe to 32V when the battery would have end of discharge protection and disconnect. The DC/AC inverter, as do standard such inverters for remote area application, would be able to handle this voltage drop, as a well as an overvoltage of 56 Volts. And even in the design there is a DC-AC inverter so that the harm can be avoided as it utilizes the battery operating voltage of 48V.

The conductor size must be correctly checked so that the voltage loss occurrence will be minimized, and conductor sag due to heating under high current conditions does not occur. Therefore the length of the conductor is chosen less than 1km for this low voltage dc micro grid. (Note for such DC micro-grids, DC is normally limited to a maximum distance of about 2 km).

CHAPTER-4

DISPATCH OF ENERGY BETWEEN THE CUSTOMERS

4.1 Introduction

DC micro-grids have high efficiency, reliability as they ensure equal load sharing of energy to the customers and always maintain the low voltage regulation of the system. The proposed micro-grid design for the load sharing of energy between the customers is outlined in the figure 4.1.

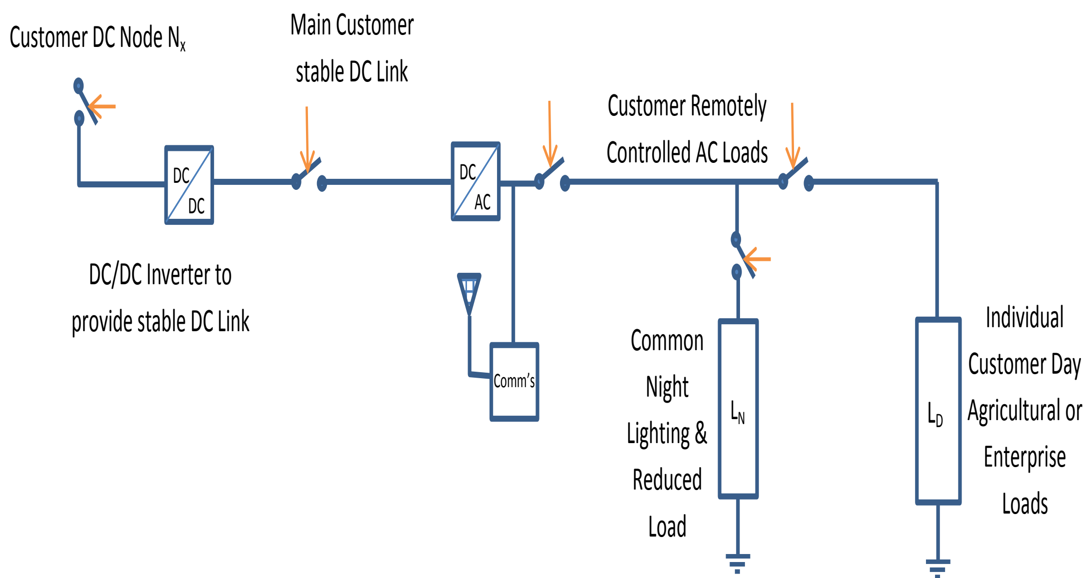


Figure 4.1 Customer Node Inverter and Load arrangement for DC Micro-grid (The arrow marks indicates communications controlled relay-switch**)**

Referring to the figure 4.1, when the input voltage of 48v is supplied to the main switch then the Inverter converts the dc voltage to ac voltage so that the power is distributed to the customers during the day time for 2hrs. And during the night times the power is supplied through batteries with a low load so that the customers can utilize the power for TV, Fans, etc.

The remote controlled customer slave unit is also included such that it access the time being utilized by each customer for 2hrs during the day time and from 5pm-11pm in the night times. From this it analyses in such a way that the every customer can utilize the power during day times and night times according to their requirements.

Here comes the research question how to share the energy equitably between the customers during the day time and night time which is discussed in the next section 4.2.

4.1.1 Flow Chart Logic for equitability dispatch of energy between the customers

The energy must be shared equally by all customers with in the specified load. If the particular customer in the house-hold utilizes the extra energy than the required limit, then it will affect the other customers who could not be able to utilize the energy with in the given limit. In such small communities, if access to the available energy is not equitable, then this can create ill-will that breaks down the traditional co-operative nature that is needed for success in rural India. Hence it is necessary for a micro-grid to deliver the power equally to all the customers with in their specified limit.

The below figures 4.1.1a to 4.1.1c represents the flow chart logic for equitability load sharing of energy between the customers.

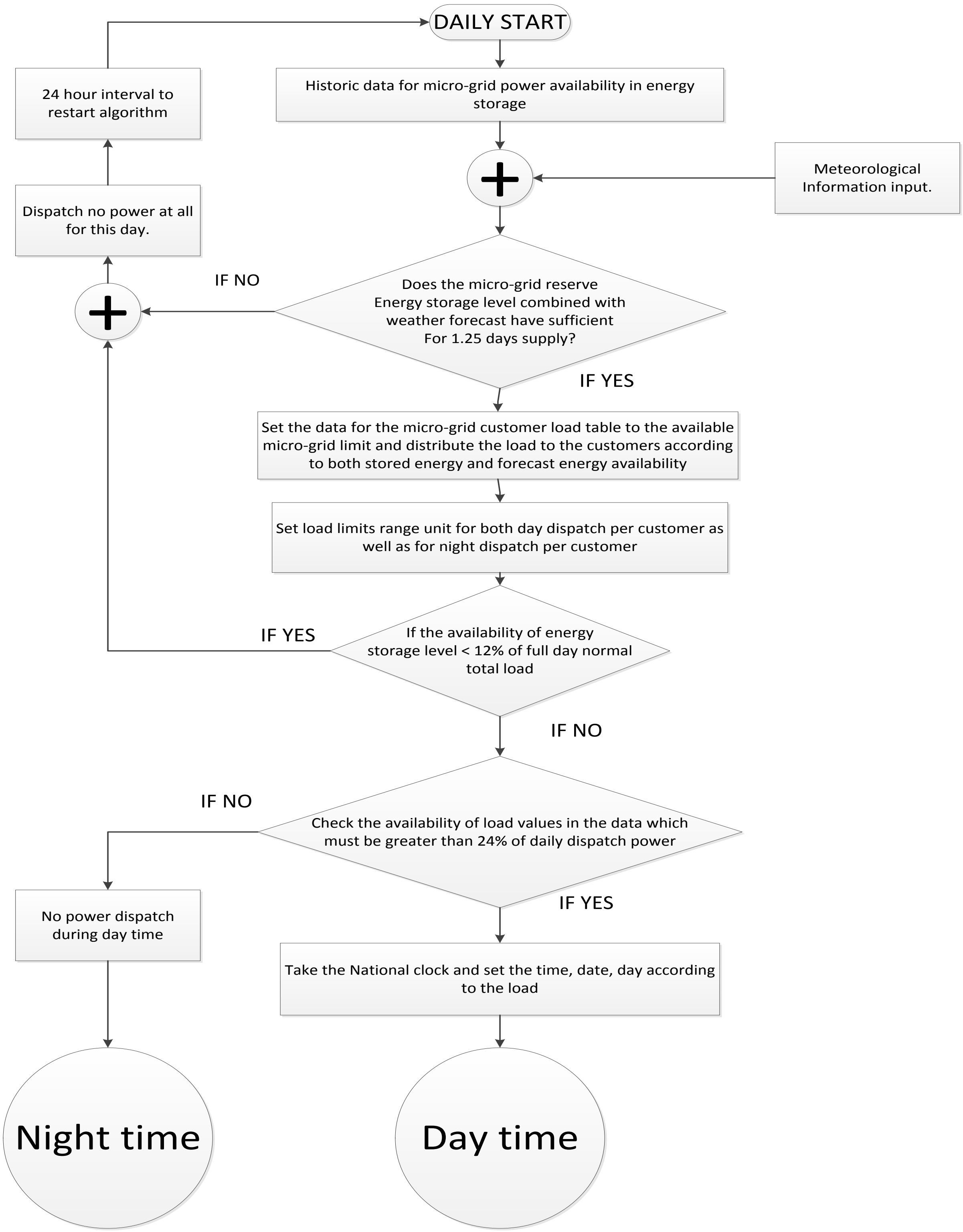


Figure 4.1.1a Flow chart for load sharing of energy between the customers

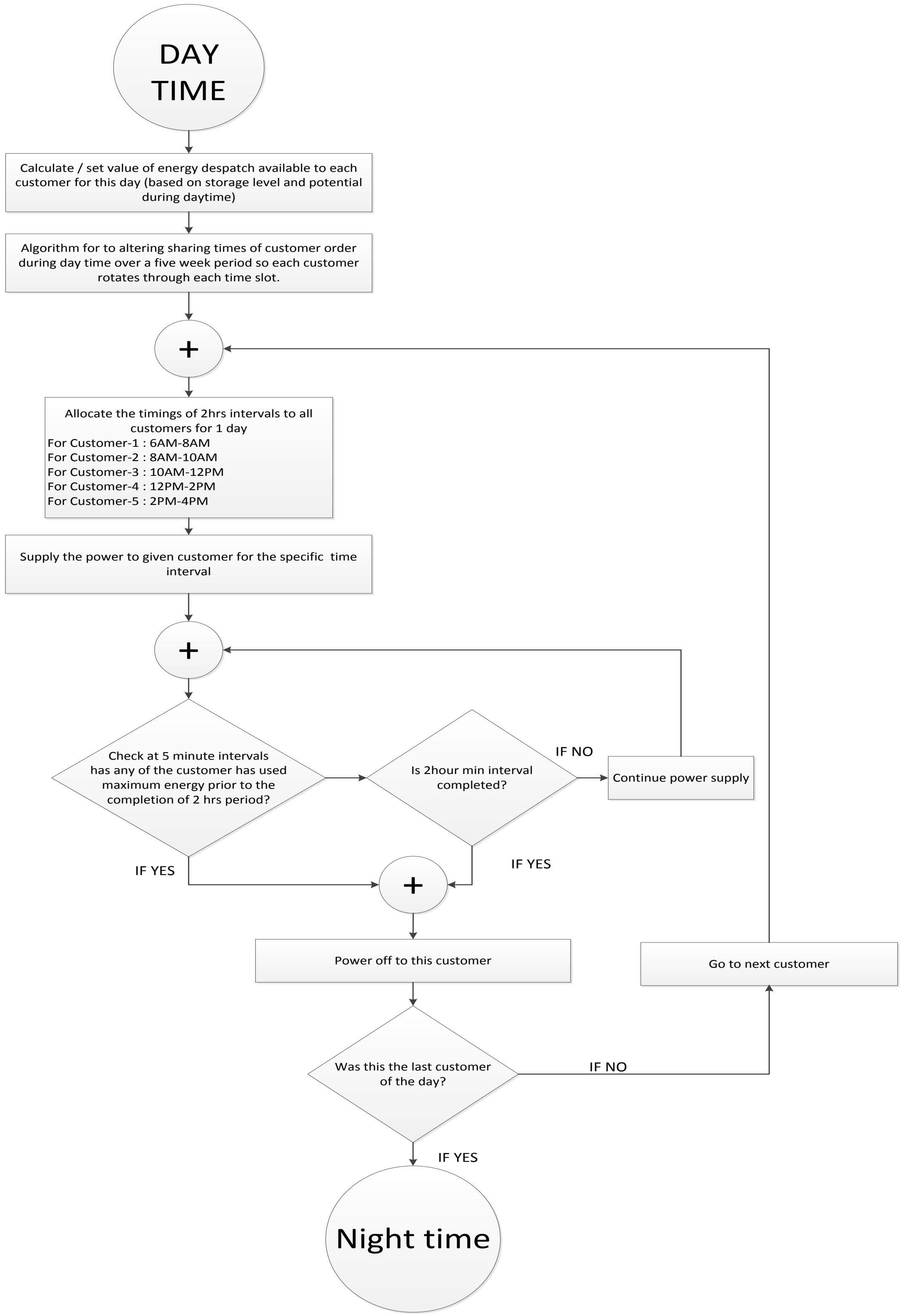


Figure 4.1.1b Flow chart for load sharing of energy between the customers during the day time

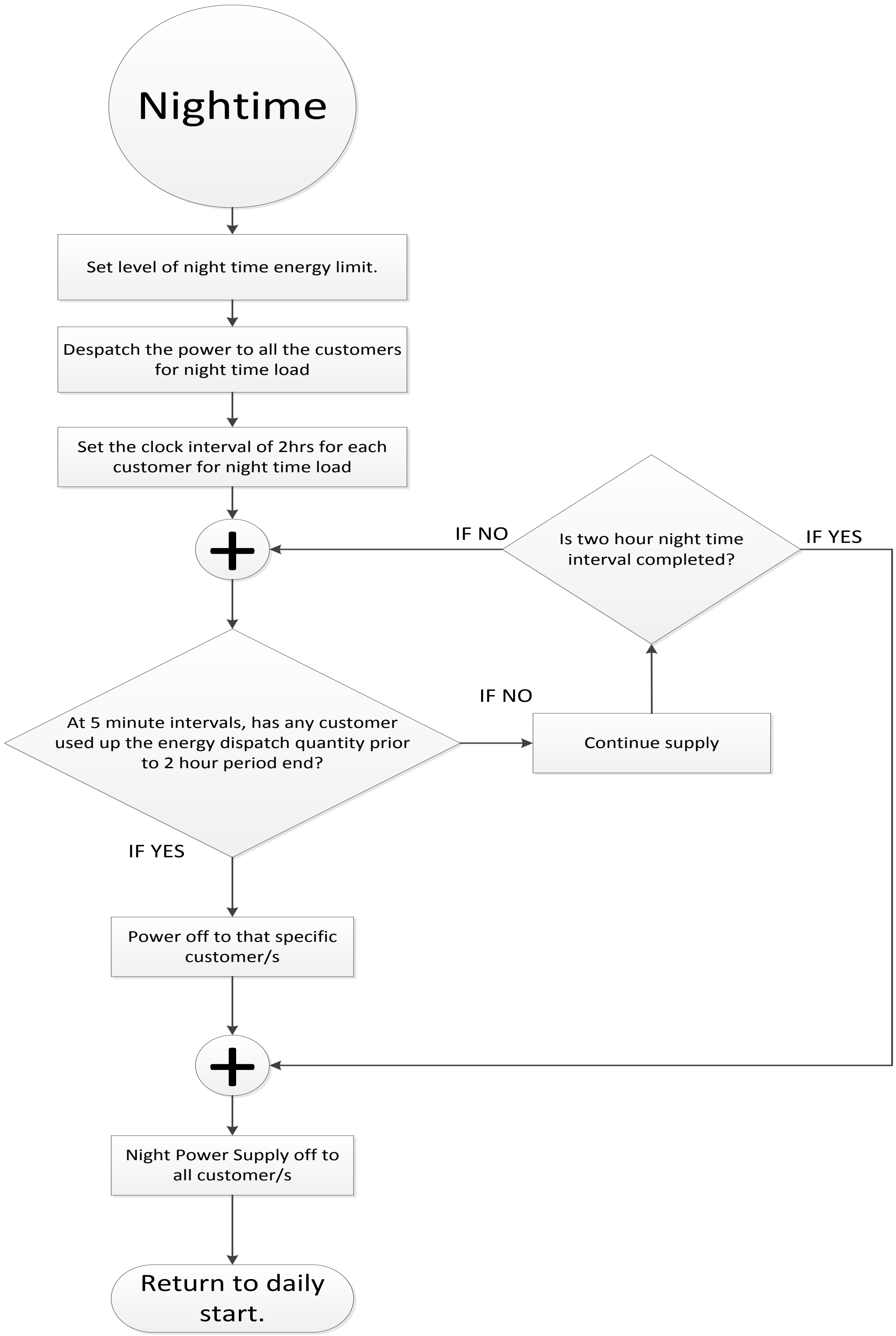


Figure 4.1.1c Flow chart for load sharing of energy between the customers during the night time

The above flow chart logic is implemented in PLC programming with the help of Zelio software which is discussed in the following section.

4.2 Implementation of Flow chart logic in PLC Programming by using Zelio Software

PLC is the programmable logic controller which reads the input data and executes the program task and finally it updates the output data based on the task set out by the program. Basically it is designed for handling the multiple analog and digital inputs and outputs.

For this project, the information about the total load supplied to the customers needs to be taken from the meteorological department and is considered as the integer value or input data for the PLC. These inputs are used for monitoring the load consumed by the each customer. After setting the input values, the logic is then implemented in zelio software which is used to set the load data to each customer with in the specified limits during the day time and night time.

4.2.1 Introduction to Zelio Software

Zelio Software is especially used for the programming the logic either through ladder networks or by using functional blocks. However, in this project the program is implemented by using functional blocks as it has capability of having multiple inputs to the logic and capable of producing the multiple outputs or single out put based on the requirements of the program.

Some of the standard specifications set out by the Schneider Electric for the Zelio software are: (Source: www.schneider-electric.com)

- Compact range: 3 monobloc models with 10, 12 or 20 I/O and versions available with or without display and buttons.
- Modular range: 2 bases with 10 or 26 I/O that can be extended using:
- Modbus or Ethernet communication extension modules

- 6, 10 or 14 discrete I/O and 4 analog I/O extension modules. Extreme compactness: up to 26 I/O.
- Supply voltage of bases: 12 V DC, 24 V DC, 24 V AC, 100... 240 V AC.
- Large back-lit LCD display: 4 lines of 18 characters and 1 line of icons, contextual navigation using 6 buttons.

This software utilizes SR3B262BD as a CPU module and the specifications for the CPU module are presented in Appendix D

.

4.2.2 Input Parameters used in the programming

The figure 4.2.2 represents the filtered analog inputs which will calculate the load consumed by the each customer. And it compares the calculated value with the load set value and delivers the power to the specified customer depending on the calculated value.

Input	No	Symbol	Function	Lock	Parameters	Comment
IB	B00		Filtered analog input	–	Electrical connection at input : 0 - 10 V Cut-off frequency : 0.04 Hz	Power Consumed Customer - C1
IC	B01		Filtered analog input	–	Electrical connection at input : 0 - 10 V Cut-off frequency : 0.04 Hz	Power Consumed Customer - C2
ID	B09		Filtered analog input	–	Electrical connection at input : 0 - 10 V Cut-off frequency : 0.04 Hz	Power Consumed Customer - C3
IE	B10		Filtered analog input	–	Electrical connection at input : 0 - 10 V Cut-off frequency : 0.04 Hz	Power Consumed Customer - C4
IF	B11		Filtered analog input	–	Electrical connection at input : 0 - 10 V Cut-off frequency : 0.04 Hz	Power Consumed Customer - C5

Figure 4.2.2 Physical Inputs used in the PLC

4.2.3 Physical Outputs

The physical outputs are connected to the external relay to switch on/off the actual isolators for distributing the load to the customers. The load delivered to the customer will be in the specified limit.

Output	No	Symbol	Function	Comment
Q1	B54	OUT	Discrete output	Customer - C1
Q2	B55	OUT	Discrete output	Customer - C2
Q3	B56	OUT	Discrete output	Customer - C3
Q4	B57	OUT	Discrete output	Customer - C4
Q5	B61	OUT	Discrete output	Customer - C5

Figure 4.2.3 Digital outputs for each customer

And the load schedule assumed for all the customers in a day is specified in the table 4.2.3

Table 4.2.3 Load limit for each customer in a day

<table>
<tr><td colspan="2">For Customer</td><td colspan="2">Energy allocated (MW)</td></tr>
<tr><td colspan="2">1</td><td colspan="2">15MW</td></tr>
<tr><td colspan="2">2</td><td colspan="2">10MW</td></tr>
<tr><td colspan="2">3</td><td colspan="2">15MW</td></tr>
<tr><td colspan="2">4</td><td colspan="2">5MW</td></tr>
<tr><td colspan="2">5</td><td colspan="2">5MW</td></tr>
<tr><td>Total number of customers</td><td>5</td><td>Total energy available (MW)</td><td>50MW</td></tr>
</table>

4.2.4 Configurations used in programming

The following functions are used in the program to accomplish load sharing between the customers C1, C2, C3, C4, and C5.

B03: Input Integer used to get the total value of load on day time.

B04: It is a numerical constant used to manipulate 1.25% of total load.

B05: It is a numerical constant value which is used in the percentage Calculation.

B07: It is comparator instruction which compares the 1.25% of total load and if this value is greater than the 1.25%, the output of the comparator will be switched ON.

B08: Input register used to get the historical data from the stored energy value.

B12: Input registers used to get the meteorological data.

B13: Numerical constant used in calculation of 12 % of full load.

B14: Numerical constant used in calculation of 24% of full Load to enable day dispatch of the load.

B41, B42, B43, B44 B45, B46, B47 and B48: These are Mul/Div Instruction which decides the percentage of load sharing between each customer's during day and night Time.

B21: AND gate used to enable the day dispatch of the Load.

B70: AND gate used to enable the night dispatch of the Load.

For more details about the other configurations, refer the Appendix D section.

4.2.5 TIME PROGRAMMER (Daily, Weekly and Yearly Programmer)

This timer is used in the programming especially to handle the hours between the customers for the load sharing of energy. This timer is especially used to decide the duration of load to be dispatched to the particular customer. Each 2hrs of load sharing between the customers are rotated and the timer will automatically switch to the next customer.

B62 — Daily, weekly and yearly programmer

Number	Change to	Daily	Day(s)	Week(s)
00	ON	06:00	MON,TUE,WEDS,THURS,FRI,SAT,SUN	1,2,3,4,5
01	OFF	08:00	MON,TUE,WEDS,THURS,FRI,SAT,SUN	1,2,3,4,5

B70 — Daily, weekly and yearly programmer

Number	Change to	Daily	Day(s)	Week(s)
00	ON	18:00	MON,TUE,WEDS,THURS,FRI,SAT,SUN	1,2,3,4,5
01	OFF	20:00	MON,TUE,WEDS,THURS,FRI,SAT,SUN	1,2,3,4,5

B82 — Daily, weekly and yearly programmer

Number	Change to	Daily	Day(s)	Week(s)
00	ON	08:00	MON,TUE,WEDS,THURS,FRI,SAT,SUN	1,2,3,4,5
01	OFF	10:00	MON,TUE,WEDS,THURS,FRI,SAT,SUN	1,2,3,4,5

Figure 4.2.5a Daily, weekly and yearly programmer

B86	Daily, weekly and yearly programmer			
Number	Change to	Daily	Day(s)	Week(s)
00	ON	20:00	MON,TUE,WEDS,THURS,FRI,SAT,SUN	1,2,3,4,5
01	OFF	22:00	MON,TUE,WEDS,THURS,FRI,SAT,SUN	1,2,3,4,5

B90	Daily, weekly and yearly programmer			
Number	Change to	Daily	Day(s)	Week(s)
00	ON	10:00	MON,TUE,WEDS,THURS,FRI,SAT,SUN	1,2,3,4,5
01	OFF	12:00	MON,TUE,WEDS,THURS,FRI,SAT,SUN	1,2,3,4,5

B94	Daily, weekly and yearly programmer			
Number	Change to	Daily	Day(s)	Week(s)
00	ON	22:00	MON,TUE,WEDS,THURS,FRI,SAT,SUN	1,2,3,4,5
01	OFF	00:00	MON,TUE,WEDS,THURS,FRI,SAT,SUN	1,2,3,4,5

B98	Daily, weekly and yearly programmer			
Number	Change to	Daily	Day(s)	Week(s)
00	ON	12:00	MON,TUE,WEDS,THURS,FRI,SAT,SUN	1,2,3,4,5
01	OFF	14:00	MON,TUE,WEDS,THURS,FRI,SAT,SUN	1,2,3,4,5

B102	Daily, weekly and yearly programmer			
Number	Change to	Daily	Day(s)	Week(s)
00	ON	00:00	MON,TUE,WEDS,THURS,FRI,SAT,SUN	1,2,3,4,5
01	OFF	02:00	MON,TUE,WEDS,THURS,FRI,SAT,SUN	1,2,3,4,5

B106	Daily, weekly and yearly programmer			
Number	Change to	Daily	Day(s)	Week(s)
00	ON	14:00	MON,TUE,WEDS,THURS,FRI,SAT,SUN	1,2,3,4,5
01	OFF	16:00	MON,TUE,WEDS,THURS,FRI,SAT,SUN	1,2,3,4,5

B110	Daily, weekly and yearly programmer			
Number	Change to	Daily	Day(s)	Week(s)
00	ON	02:00	MON,TUE,WEDS,THURS,FRI,SAT,SUN	1,2,3,4,5
01	OFF	04:00	MON,TUE,WEDS,THURS,FRI,SAT,SUN	1,2,3,4,5

Figure 4.2.5b Daily, weekly and yearly programmer

Refer the Appendix D section for the main PLC program which is implemented by using Zelio software.

4.3 Summary

From this section, initially the flow chart logic was developed for load sharing of energy equally between the customers. Later this was implemented in PLC programming by the use of Zelio software. The main advantage of using PLC's is that it can monitor and set the load schedule to each customer with in their specified period of time. If any of the customers uses the excess load, then the PLC will automatically set the timer such that the power will turned off to that particular customer and it will switch to another customer. Hence, the energy will be shared equally among the customers by setting the certain conditions to the energy limit.

CHAPTER-5

RESULTS AND DISCUSSIONS

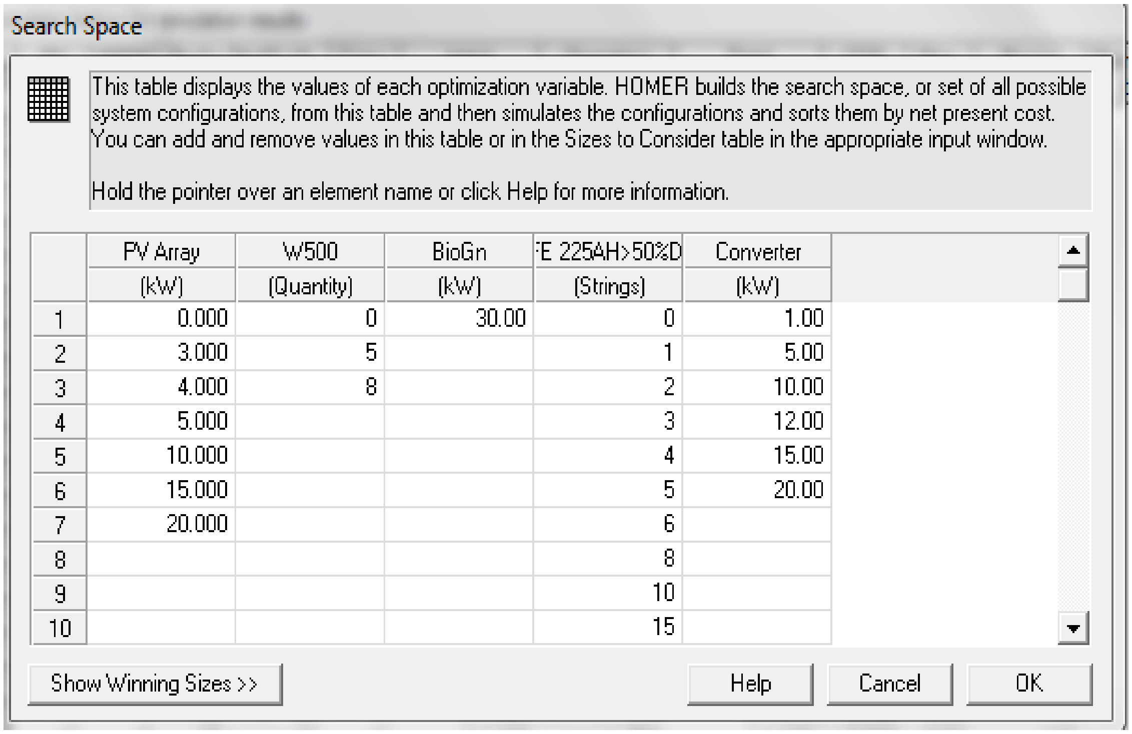
5.1 Introduction

HOMER simulates and optimizes the different system configurations which are specified through the combination of component inputs. It performs the hourly based simulations and produces the best feasible systems of different combinations which are ranked on the basis of net present cost (NPC). Solar energy, wind turbine and biomass energy were considered as the energy sources for the purpose of the simulation. In addition to this, batteries and generator are also included in order to make sure that there is continuous supply of electricity with in the specified load. In this case, there were total of 1260 feasible systems obtained after the thousands of simulations performed by the HOMER.

This part of the section describes about the optimization results and the comparison of cost of electricity and the investments made by the government for the installation of the proposed DC micro-grid system in the rural areas. Other results such as comparison of total net present cost, cost of energy, O&M costs versus various biomass resources have been presented. HOMER also presents the life cycle of the battery as well as the monthly electric production for the change in the biomass resources. Finally this chapter concludes with the sensitivity analysis for the optimal systems obtained by the optimization process.

5.2 Optimization Results

In this process, HOMER simulates the different systems in the search space and presents the best feasible systems in an order according to the total net present cost.

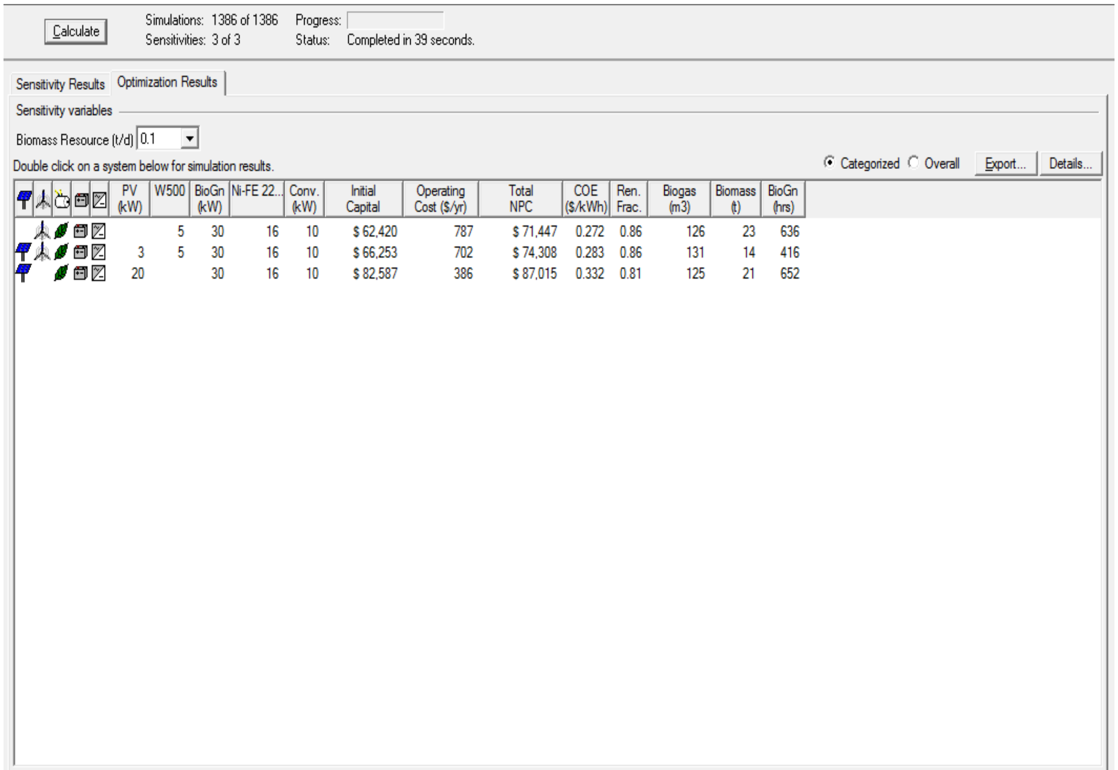


	PV Array (kW)	W500 (Quantity)	BioGn (kW)	E 225AH>50%D (Strings)	Converter (kW)
1	0.000	0	30.00	0	1.00
2	3.000	5		1	5.00
3	4.000	8		2	10.00
4	5.000			3	12.00
5	10.000			4	15.00
6	15.000			5	20.00
7	20.000			6	
8				8	
9				10	
10				15	

Figure5.2a: Search space for each optimization variable

After running the hourly simulations of different s ystems, HOMER produced the best optimization results for the various cases considered which are shown in the following figures.

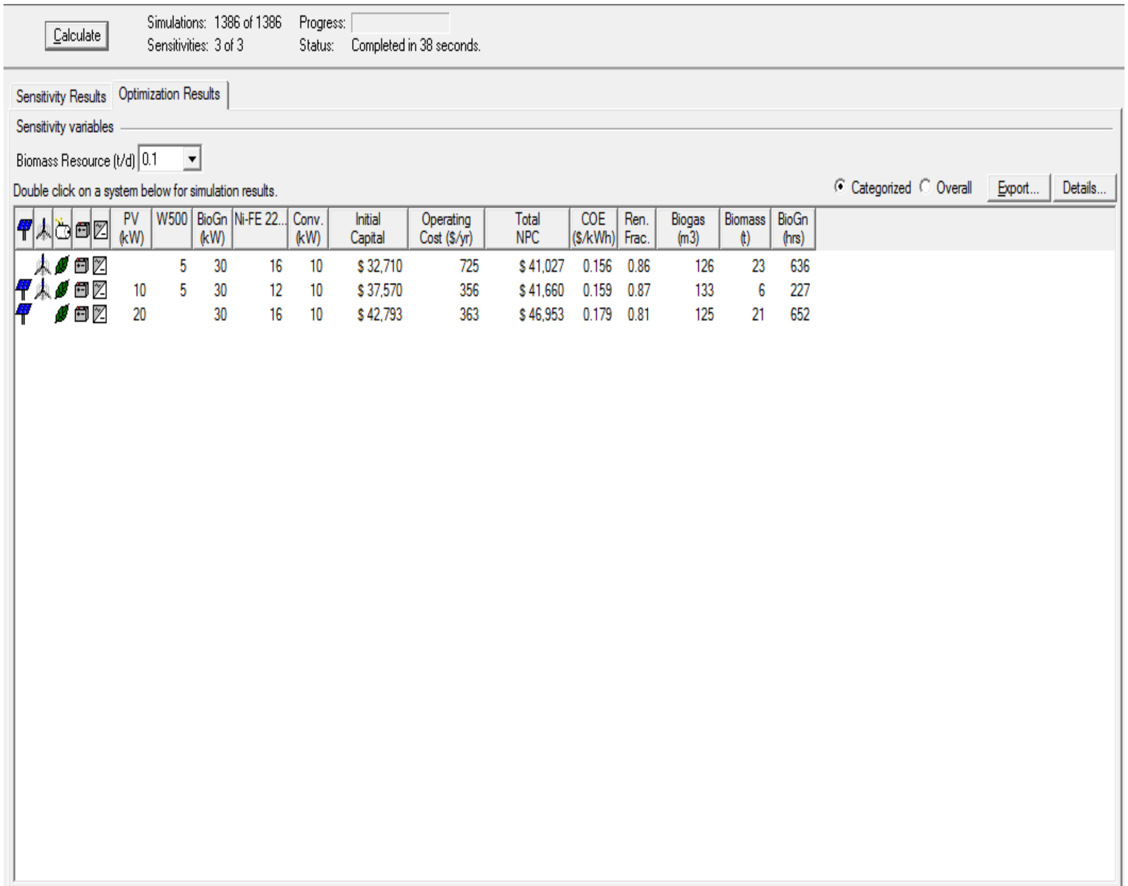
Case 1: Full Capital Costs 0% variability for day to day with 0% random variability for Time-steps. (Biomass resource = 0.1t/d)



PV (kW)	W500	BioGn (kW)	Ni-FE 22...	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Biogas (m3)	Biomass (t)	BioGn (hrs)
	5	30	16	10	$ 62,420	787	$ 71,447	0.272	0.86	126	23	636
3	5	30	16	10	$ 66,253	702	$ 74,308	0.283	0.86	131	14	416
20		30	16	10	$ 82,587	386	$ 87,015	0.332	0.81	125	21	652

Figure5.2b: Optimization results for full Capital Costs 0% variability for day to day with 0% random variability for Time-steps. (Biomass resource = 0.1t/d)

Case 2: Half subsidised Capital Costs 0% variability for day to day with 0% random variability for Time-steps. (Biomass resource = 0.1t/d)


Calculate | Simulations: 1386 of 1386 | Sensitivities: 3 of 3 | Progress: | Status: Completed in 38 seconds.

Sensitivity Results | Optimization Results

Sensitivity variables

Biomass Resource (t/d) 0.1

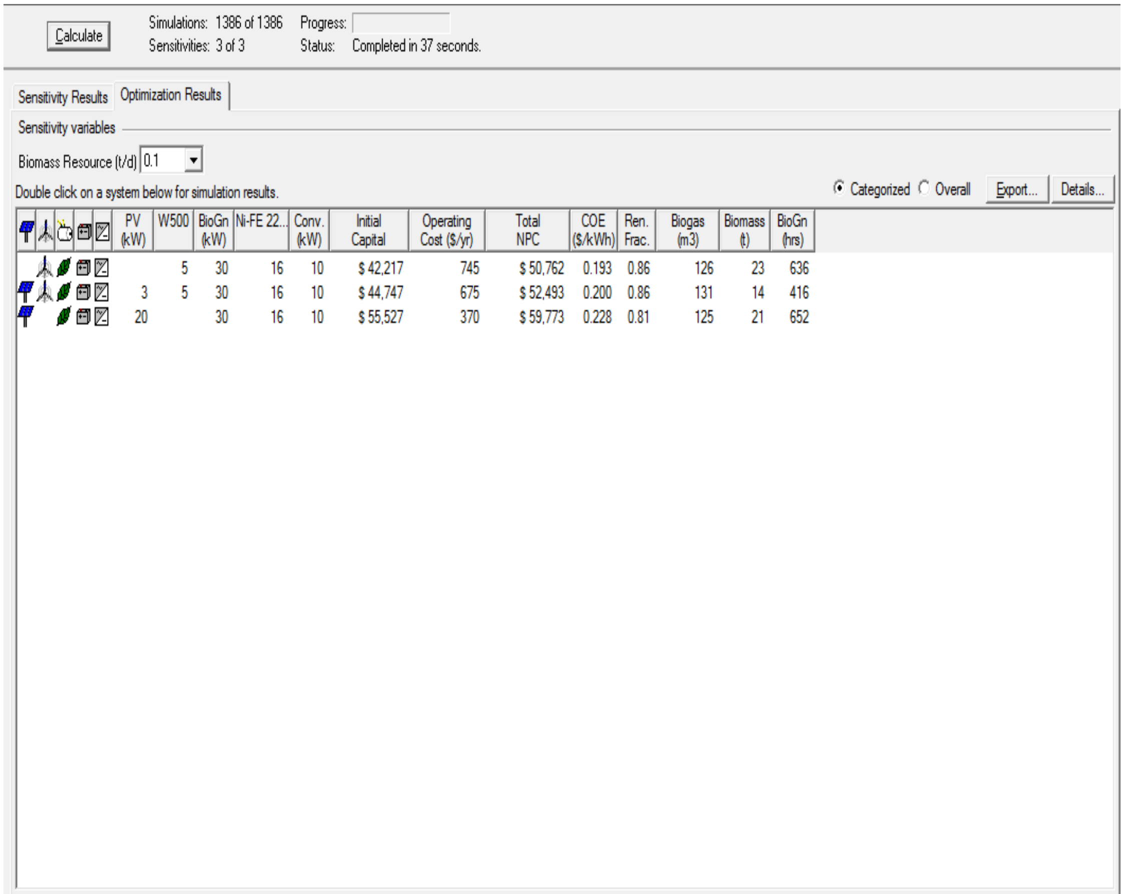
Double click on a system below for simulation results.

Categorized | Overall | Export... | Details...

PV (kW)	W500	BioGn (kW)	Ni-FE 22...	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Biogas (m3)	Biomass (t)	BioGn (hrs)
	5	30	16	10	$ 32,710	725	$ 41,027	0.156	0.86	126	23	636
10	5	30	12	10	$ 37,570	356	$ 41,660	0.159	0.87	133	6	227
20		30	16	10	$ 42,793	363	$ 46,953	0.179	0.81	125	21	652

Figure5.2c: Optimization results for half subsidised Capital Costs 0% variability for day to day with 0% random variability for Time-steps. (Biomass resource = 0.1t/d)

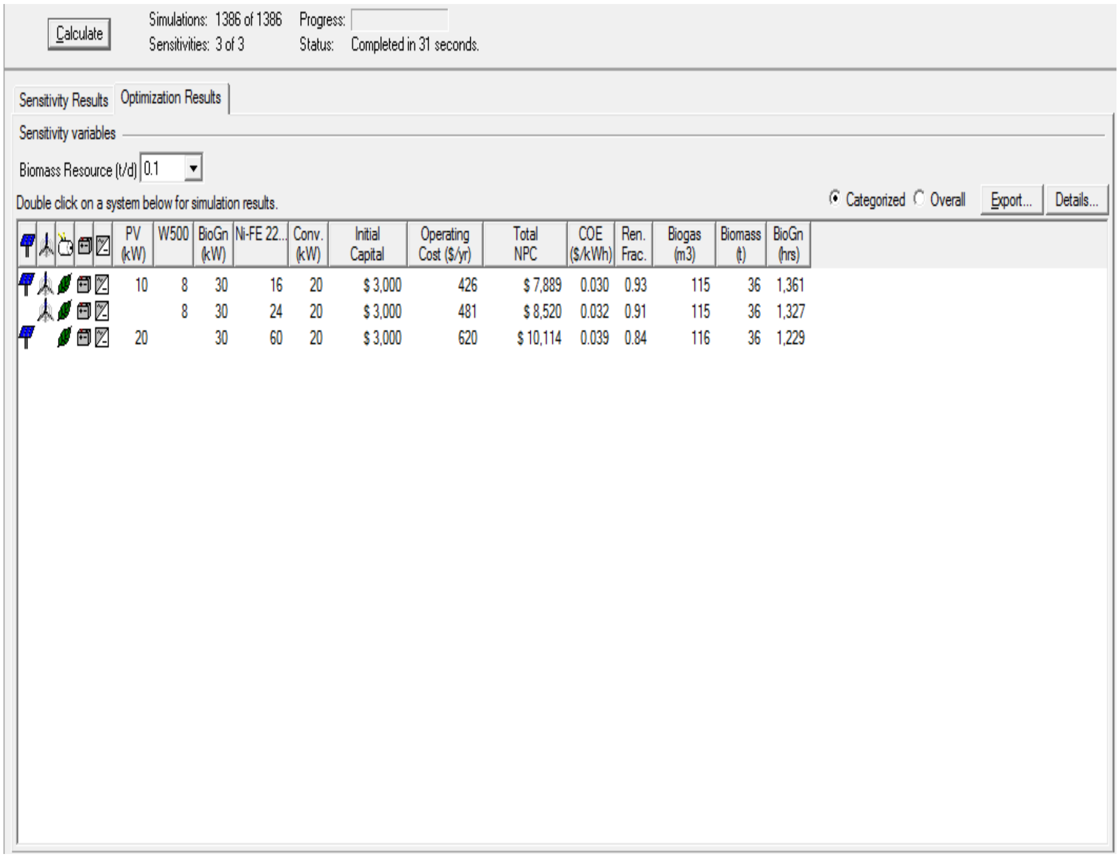
Case3: 66% subsidised Capital Costs 0% variability for day to day with 0% random variability for Time-steps. (Biomass resource= 0.1t/d)



PV (kW)	W500	BioGn (kW)	Ni-FE 22...	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Biogas (m3)	Biomass (t)	BioGn (hrs)
	5	30	16	10	$ 42,217	745	$ 50,762	0.193	0.86	126	23	636
3	5	30	16	10	$ 44,747	675	$ 52,493	0.200	0.86	131	14	416
20		30	16	10	$ 55,527	370	$ 59,773	0.228	0.81	125	21	652

Figure5.2d: Optimization results for 66% subsidised Capital Costs for day to day with 0% variability and 0% random variability for Time-steps. (Biomass resource= 0.1t/d)

Case4: Fully Government subsidised Capital Costs 0% variability for day to day with 0% random variability for Time-steps. (Biomass resource = 0.1t/d)



PV (kW)	W500	BioGn (kW)	Ni-FE 22...	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Biogas (m3)	Biomass (t)	BioGn (hrs)
10	8	30	16	20	$ 3,000	426	$ 7,889	0.030	0.93	115	36	1,361
	8	30	24	20	$ 3,000	481	$ 8,520	0.032	0.91	115	36	1,327
20		30	60	20	$ 3,000	620	$ 10,114	0.039	0.84	116	36	1,229

Figure 5.2e: Optimization results for fully Government subsidised Capital Costs 0% variability for day to day with 0% random variability for Time-steps. (Biomass resource = 0.1t/d)

For the optimization results for different cases refer to the Appendix B section.

5.2.1 Discussions for optimization results

The various numbers of values are entered for each decision variable in the search space as shown in the figure5.2a. This search space has 1260 different system configurations as there are 7 PV panels, 3 wind turbines, 10 battery strings and 6 converters which are multiplied to each other. After this HOMER simulates the system configurations and presents the best possible optimal system according to the NPC (net present cost) as shown in the figures 5.2b to 5.2e.

From the obtained optimized results, the first four columns indicates the components considered for the simulation, the next four columns indicate the size of each component and lastly the five columns indicate the results obtained by the process of simulation such as initial capital cost, operating cost, total net present cost, COE (cost of energy), annual fuel consumption and finally the number of hours generator operates in an year.

The first row of the optimization results indicates that the system has low net present cost compared to the other rows which means that this is the best optimal system. For example considering the figure 5.2b, the optimal system contains 5 wind turbines, 30 biogas generators, 16 batteries and 10 converters with the total net present cost of $71,447. Similarly the second ranked system contains the same components except the fact that 3 PV panels were included and the total NPC is $74,308. Likewise, the third ranked system contains the same components neglecting the wind turbine and adding extra 17 PV panels to the original system which in turn contains 20 PV panels and the total NPC for this system is $87,015.

5.3 Comparison of Government Capital Subsidy and Cost of Energy (COE) for Various Biomass Resources

5.3.1 Introduction

HOMER operates the system so as to reduce the total net present cost and presents the best system configuration. This section describes the comparison of cost of electricity produced for the investments made by the government according to the day to day variability and time steps for the various biomass resources considered.

The graphs were plotted between the government capital subsidy and the cost of electricity for the variation in the biomass resources which are presented in the following section.

5.3.1.1 Government capital cost versus Cost of Energy for the biomass resource 0.1t/d

Table 5.3.1.1 Results showing various costs for the biomass resource 0.1t/d

	day to day	Time steps	t/d	$/kWh	$/yr	$/yr
Government input (%R)	Variability	Random variability	Biomass resource	COE	Total Capital Cost	Total NPC
0	0	0	0.1	0.272	62420	71447
0	0	0	0.1	0.283	66253	74308
0	0	0	0.1	0.332	82587	87015
50	0	0	0.1	0.156	32710	41027
50	0	0	0.1	0.159	37570	41660
50	0	0	0.1	0.179	42793	46953
66	0	0	0.1	0.193	42217	50762
66	0	0	0.1	0.2	44747	52493
66	0	0	0.1	0.228	55527	59773
100	0	0	0.1	0.03	3000	7889
100	0	0	0.1	0.032	3000	8520
100	0	0	0.1	0.039	3000	10114

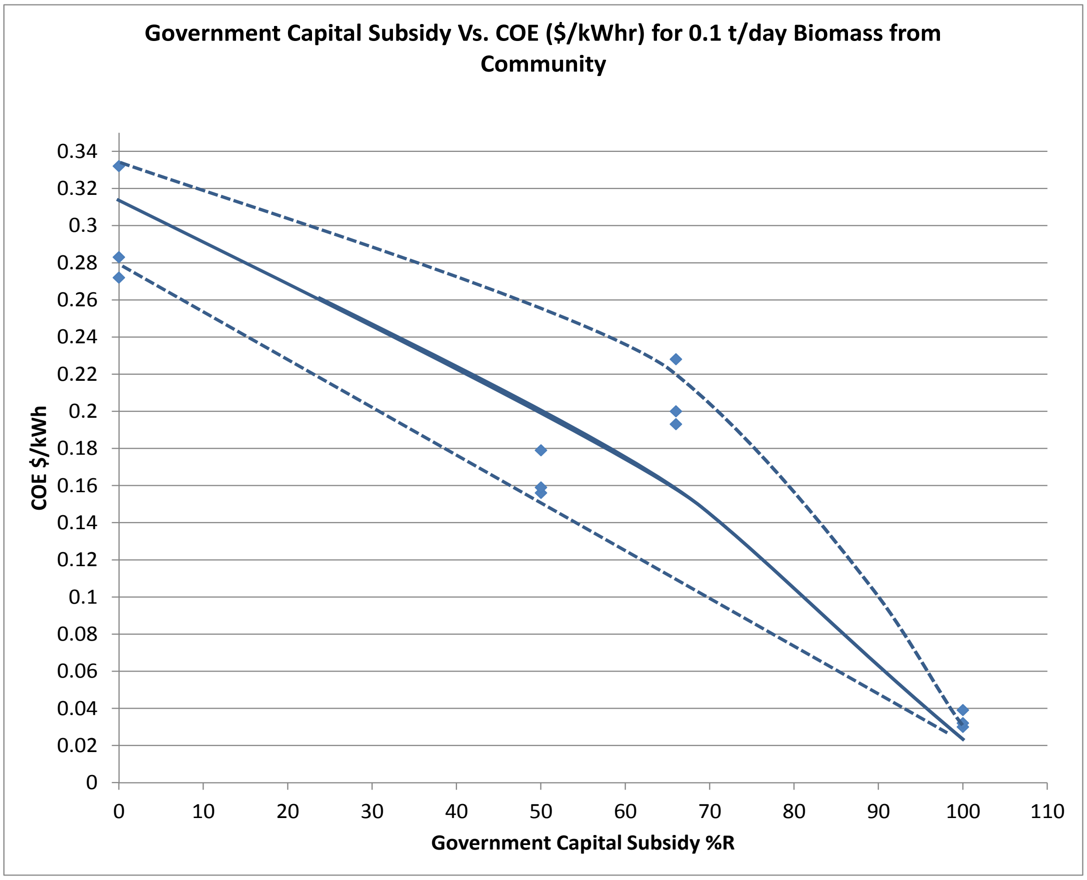


Figure 5.3.1.1: Comparison of Government Capital Subsidy versus COE for 0.1t/d biomass resource

Note: (1USD = 61.78 INR as of today's date and all the costs were assumed in $/kWhr)

5.3.1.2 Government capital cost versus Cost of Energy (COE) for the biomass resource 0.2t/d

Table 5.3.1.2 Results showing various costs for the biomass resource 0.2t/d

	day to day	Time steps	t/d	$/kWh	$/yr	$/yr
Government input (%R)	Variability	Random variability	Biomass resource	COE	Total Capital Cost	Total NPC
0	0	0	0.2	0.272	63973	71377
0	0	0	0.2	0.276	62240	72384
0	0	0	0.2	0.331	70920	86880
50	0	0	0.2	0.154	33487	40339
50	0	0	0.2	0.16	32620	41917
50	0	0	0.2	0.191	38737	50220
66	0	0	0.2	0.192	43242	50271
66	0	0	0.2	0.197	42098	51666
66	0	0	0.2	0.236	50172	61983
100	0	0	0.2	0.013	3000	3463
100	0	0	0.2	0.022	3000	5644
100	0	0	0.2	0.03	3000	7893

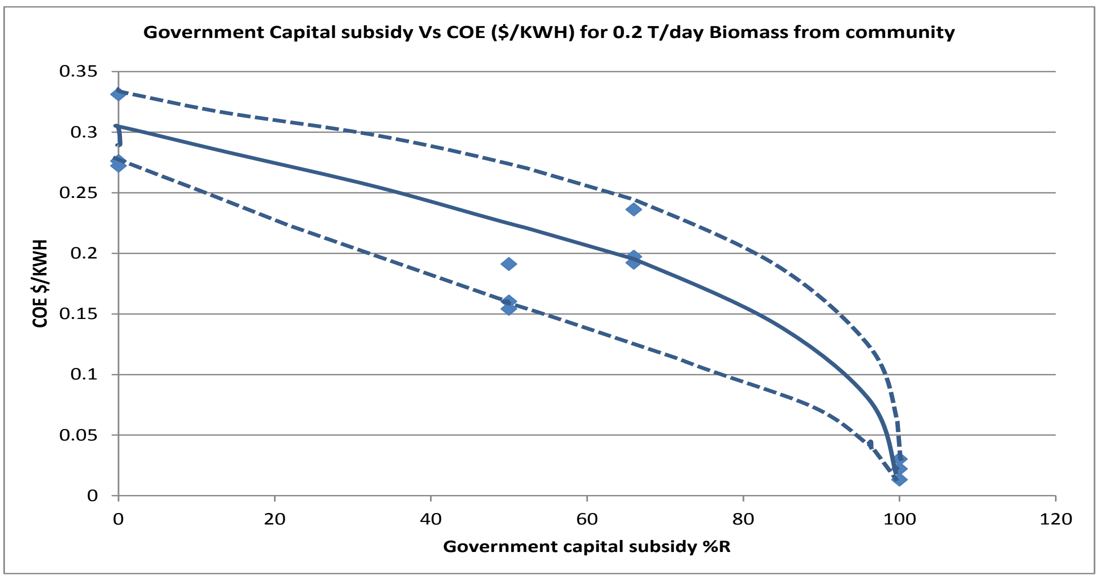


Figure 5.3.1.2: Comparison of Government Capital Subsidy versus COE for 0.2t/d biomass resource

Note: (1USD = 61.78 INR as of today's date and all the costs were assumed in $/kWhr)

5.3.1.3 Government capital cost versus Cost of Electricity for the biomass resource 0.3t/d

Table 5.3.1.3 Results showing various costs for the biomass resource 0.3t/d

	day to day	Time steps	t/d	$/kWh	$/yr	$/yr
Government input (%R)	variability	Random variability	Biomass resource	COE	Total Capital Cost	Total NPC
0	0	0	0.3	0.275	57,860	72,251
0	0	0	0.3	0.282	61,693	73,954
0	0	0	0.3	0.325	60,473	85,356
50	0	0	0.3	0.165	31,570	43,376
50	0	0	0.3	0.167	32,930	43,730
50	0	0	0.3	0.195	41,017	51,097
66	0	0	0.3	0.201	40,712	52,767
66	0	0	0.3	0.204	41,738	53,501
66	0	0	0.3	0.241	53,182	63,377
100	0	0	0.3	0.018	3,000	4,746
100	0	0	0.3	0.021	3,000	5,601
100	0	0	0.3	0.025	3,000	6,567

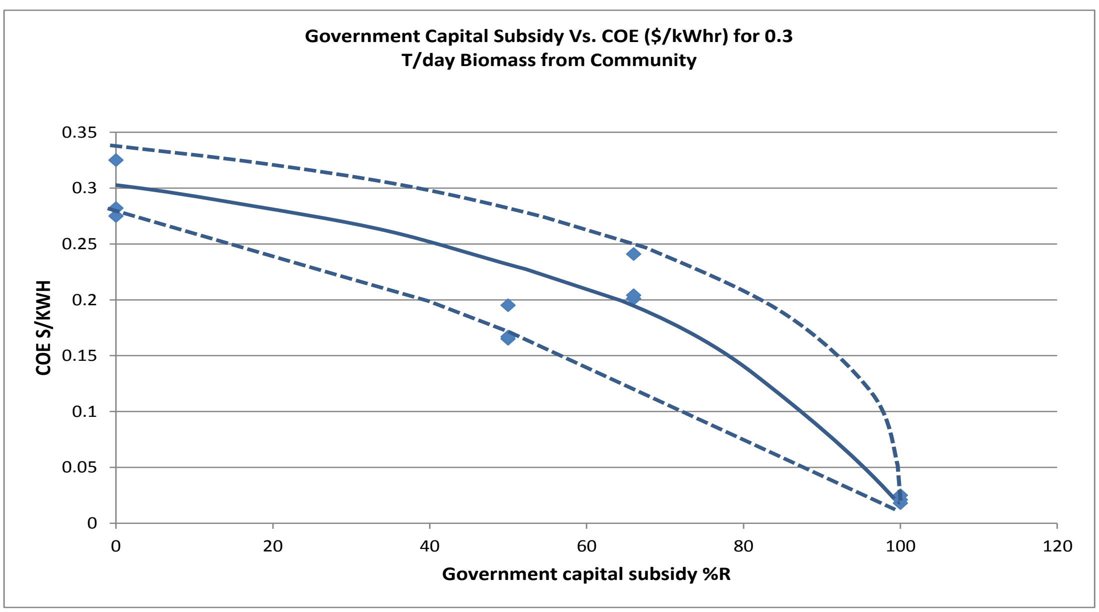


Figure5.3.1.3: Comparison of Government Capital Subsidy versus COE for 0.3t/d biomass resource

Note: (1USD = 61.78 INR as of today's date and all the costs were assumed in $/kWhr)

5.3.2 Discussion of results for comparison of government capital subsidy versus cost of energy (COE)

For the optimal solution of the proposed model, the comparisons of COE versus Government capital subsidy were plotted for three different biomass resources. From the figures 5.3.2 to 5.3.4, it was observed that if the government does not subsidies the tariff for the electricity then the average cost of energy required by the customers for paying the electricity was found to be $0.3 cents/kWhr for all the cases. If the government wishes to subsidies half of the tariff, then COE was found to be $0.22 cents/kWhr and similarly if they wish to subsidies the whole tariff for the electricity the COE was found to be $0.03 cents/kWhr for all the three biomass resources considered. This clearly shows that irrespective of the production of various biomass resources, the average cost of energy almost remains same for all the three cases and more over the COE varies accordingly with the change in the subsidization of the government for paying the electricity. For the three biomass resources considered, it was observed that the cost of energy reduces as the government wishes to contribute the more percentage of subsidizing the tariff. Hence the people who live in rural areas will totally depend on the contribution of government subsidy for paying the tariff.

5.4 Cost Summary Analysis of Various Resources

HOMER has simulated and ranked the various systems according to the total net present cost. Hence it is necessary to check the capital costs, replacement costs, O&M costs for the different sources employed in the proposed micro-grid design.

The graphs were obtained by considering the all resources which include PV array, wind turbine, biogas generator, batteries and converters for the various biomass resources employed.

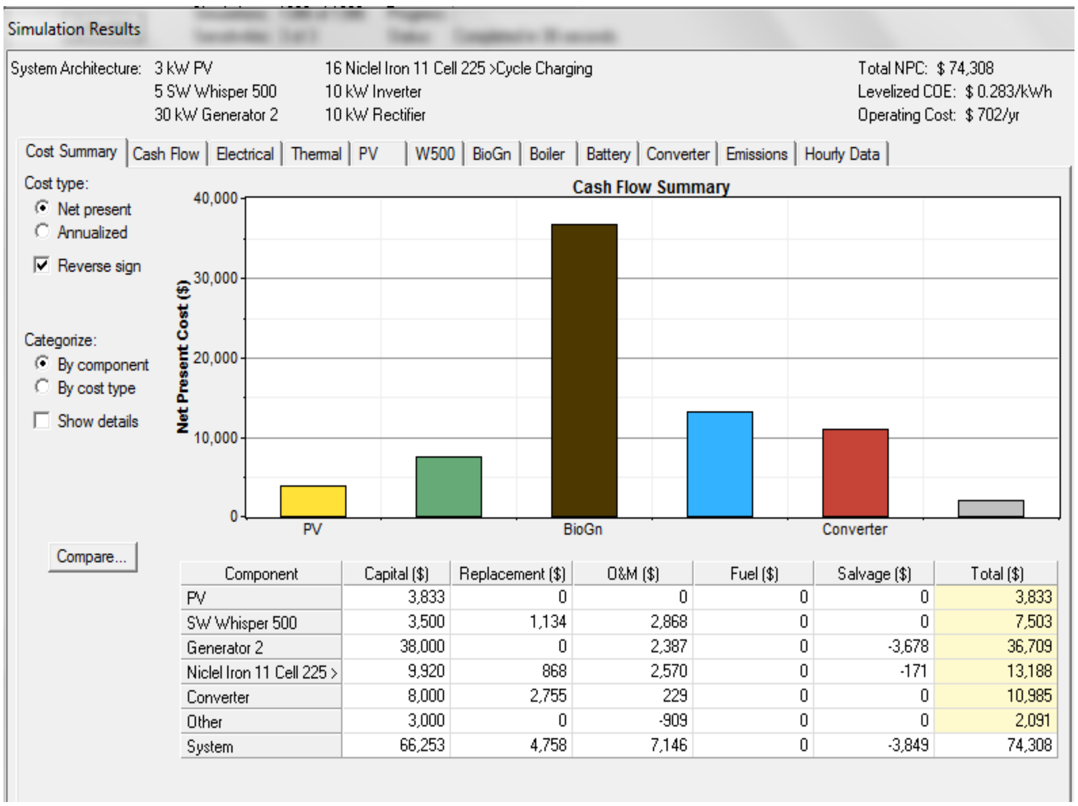
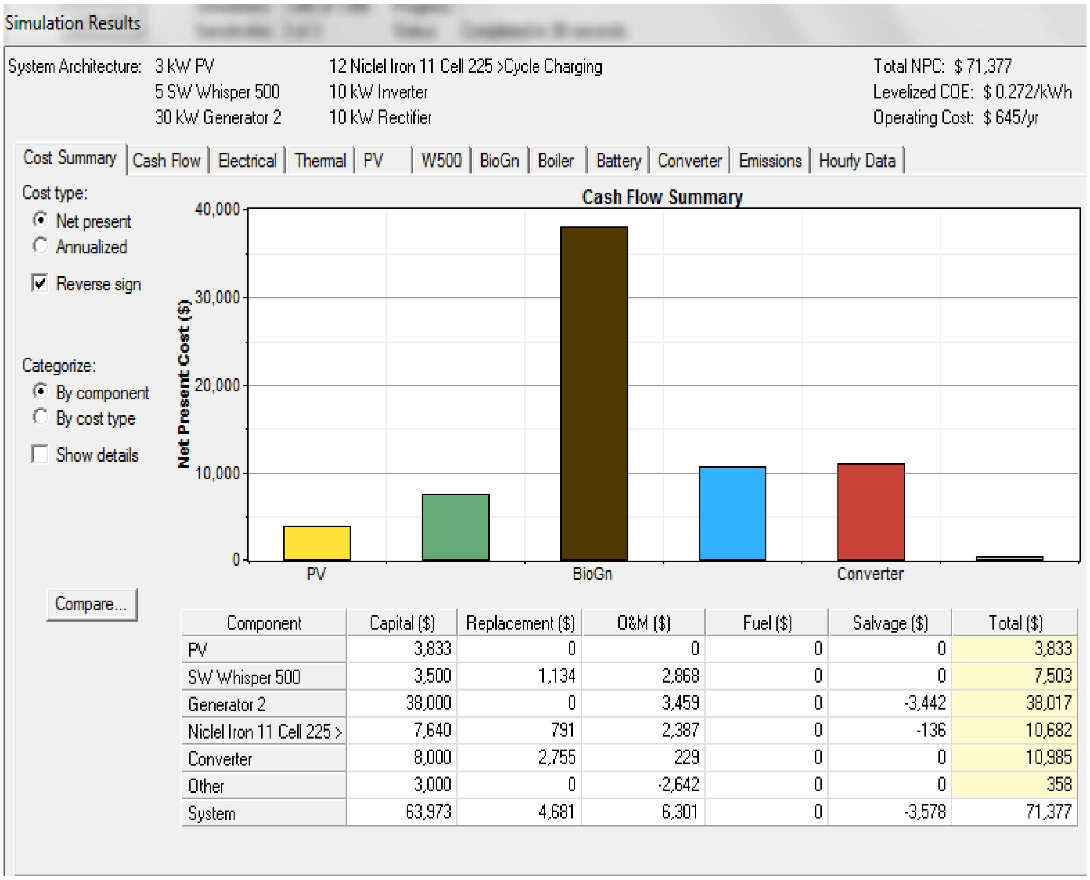
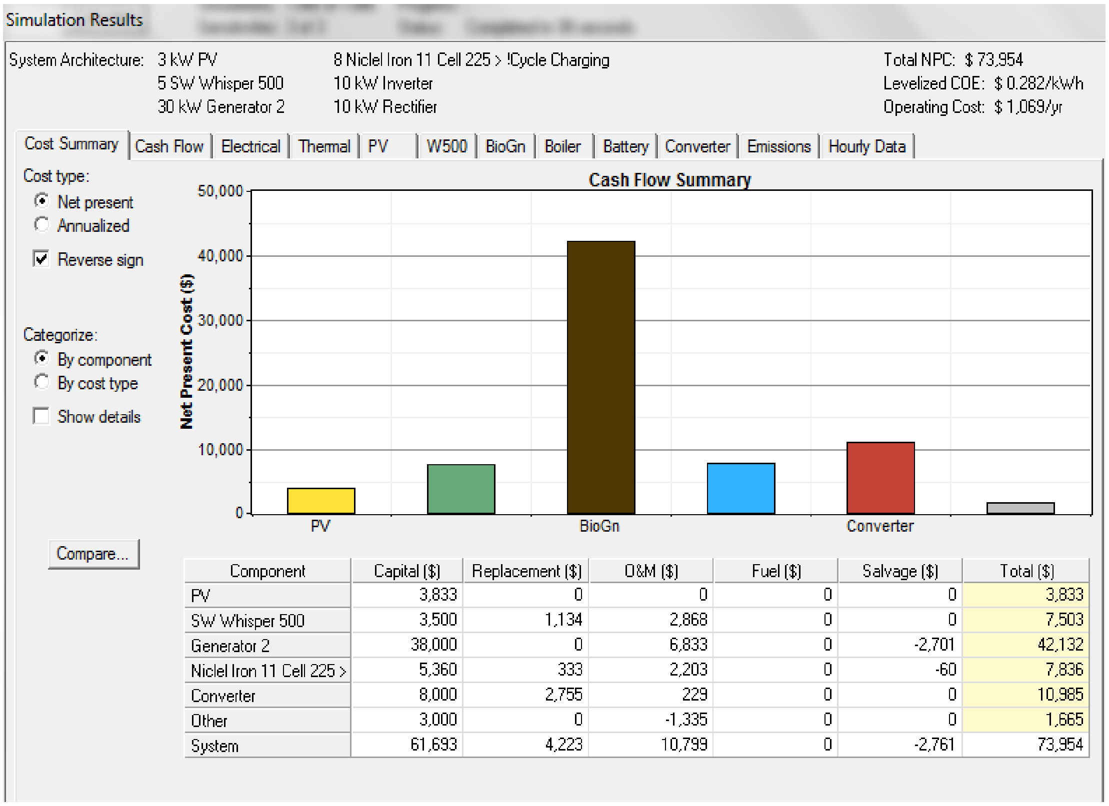


Figure 5.4a Cost summary for the all resources by considering the biomass resource as 0.1t/d



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	3,833	0	0	0	0	3,833
SW Whisper 500	3,500	1,134	2,868	0	0	7,503
Generator 2	38,000	0	3,459	0	-3,442	38,017
Niclel Iron 11 Cell 225 >	7,640	791	2,387	0	-136	10,682
Converter	8,000	2,755	229	0	0	10,985
Other	3,000	0	-2,642	0	0	358
System	63,973	4,681	6,301	0	-3,578	71,377

Figure 5.4b Cost summary for the all resources by considering the biomass resource as 0.2t/d



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	3,833	0	0	0	0	3,833
SW Whisper 500	3,500	1,134	2,868	0	0	7,503
Generator 2	38,000	0	6,833	0	-2,701	42,132
Niclel Iron 11 Cell 225 >	5,360	333	2,203	0	-60	7,836
Converter	8,000	2,755	229	0	0	10,985
Other	3,000	0	-1,335	0	0	1,665
System	61,693	4,223	10,799	0	-2,761	73,954

Figure 5.4c Cost summary for the all resources by considering the biomass resource as 0.3t/d

5.4.1 Discussion of results

The cost summary of various resources has been presented for the different biomass resources which are shown in the figures 5.4a to 5.4c.

Case1: For biomass resource 0.1t/d (tone/day)

By observing the figure 5.4a, the HOMER has considered 3kW PV panels, 5 SW whisper 500, 30kW biogas generator, 16 Nickel Iron batteries, 10kW each inverter and converter. For this equipment, the total net present cost was found to be $74,308 and the cost of energy (COE) was $0.283/kWh and finally the operating cost was $702/yr which is shown in the figure 5.4a.

Case2: For biomass resource 0.2t/d (tone/day)

Similarly by considering the figure 5.4b, the HOMER has considered all the resources with 3kW PV, 5 SW whisper 500, 30kW biogas generator, 12 Nickel iron batteries, 10kW each inverter and converter. The total net present cost was found to be $71,377 and the cost of energy (COE) was $0.272/kWh and the operating cost was $645/yr which is shown in the figure 5.4b.

Case3: For biomass resource 0.3t/d (tone/day)

Finally for the biomass resource 0.3t/d, the cost summaries for all the resources are shown in the figure 5.4c. HOMER considered the 3kW PV, 5 SW whisper 500, 30kW biogas generators, 8 Nickel iron batteries and 10kW each inverter and converter. The total NPC for this case was found to be $73,954 and the cost of energy was $0.282/kWh and finally the operating cost was found to be $1,069/yr.

5.4.1.1 Interpretation of results

By considering all the three cases, the total NPC was found to be higher for the biomass resources 0.1t/d and 0.3t/d. Similarly the cost of energy and the operating cost were significantly higher for the biomass resources 0.1t/d and 0.3t/d. However the best system will be considered by the HOMER which has the low total net present cost compared to other systems. In this case, the system has produced the lowest net present cost when the biomass releases 0.2tones/day as shown in the figures 5.4.1.1a to 5.4.1.1c

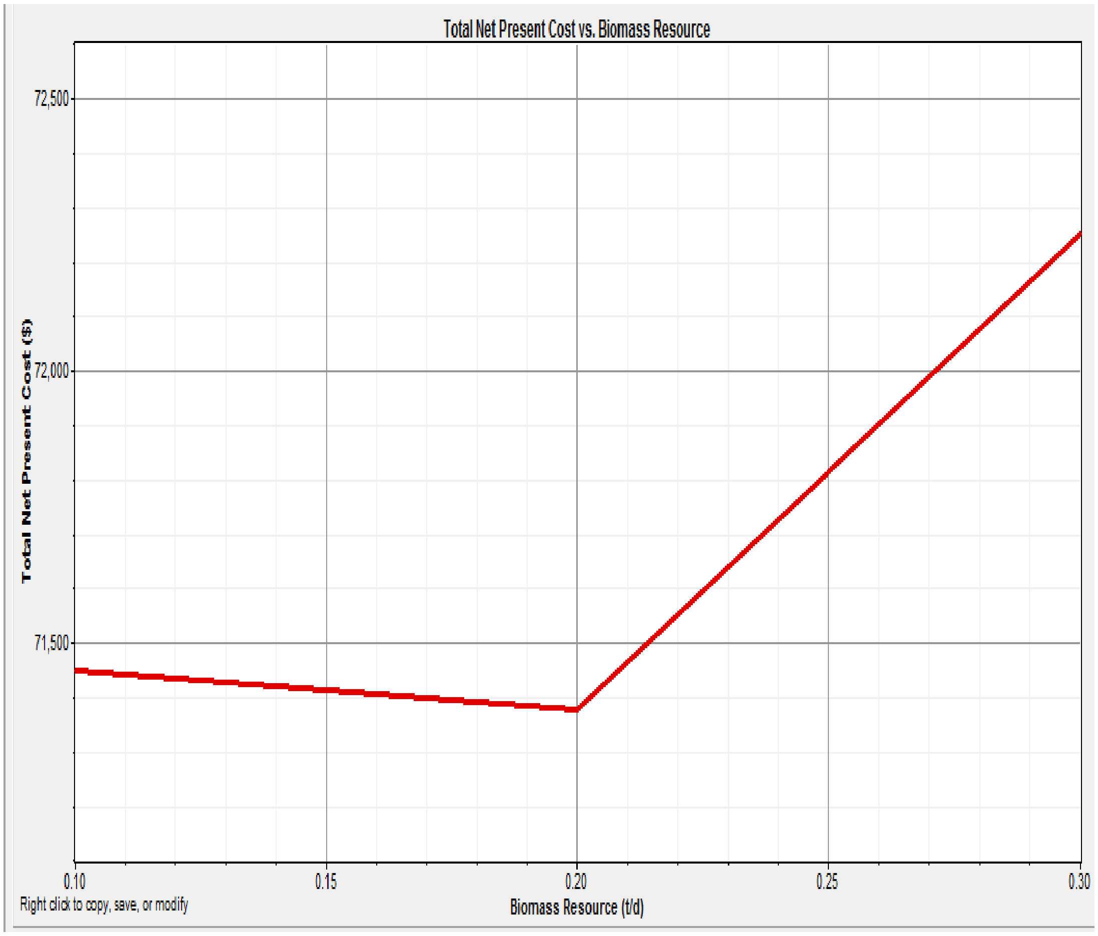


Figure 5.4.1.1a Total Net Present Cost ($) versus Biomass resources (t/d)

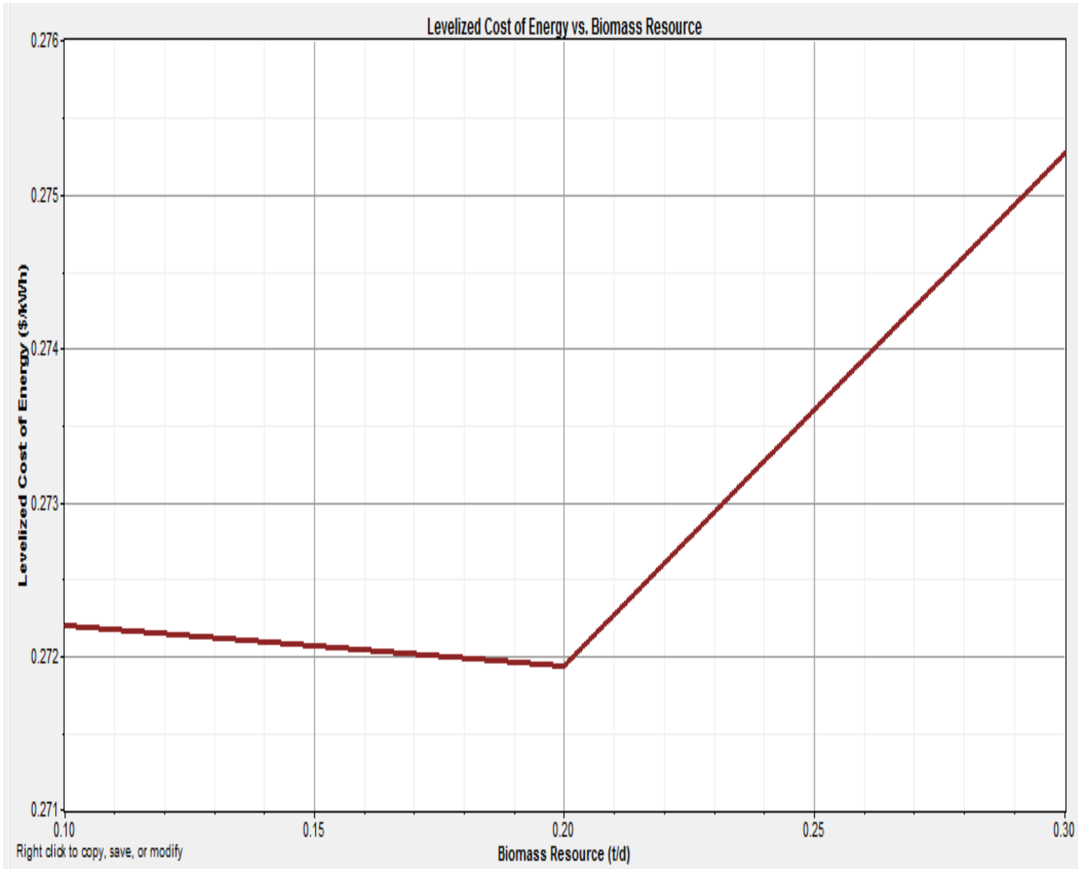


Figure 5.4.1.1b Cost of Energy ($/kWh) versus Biomass resources (t/d)

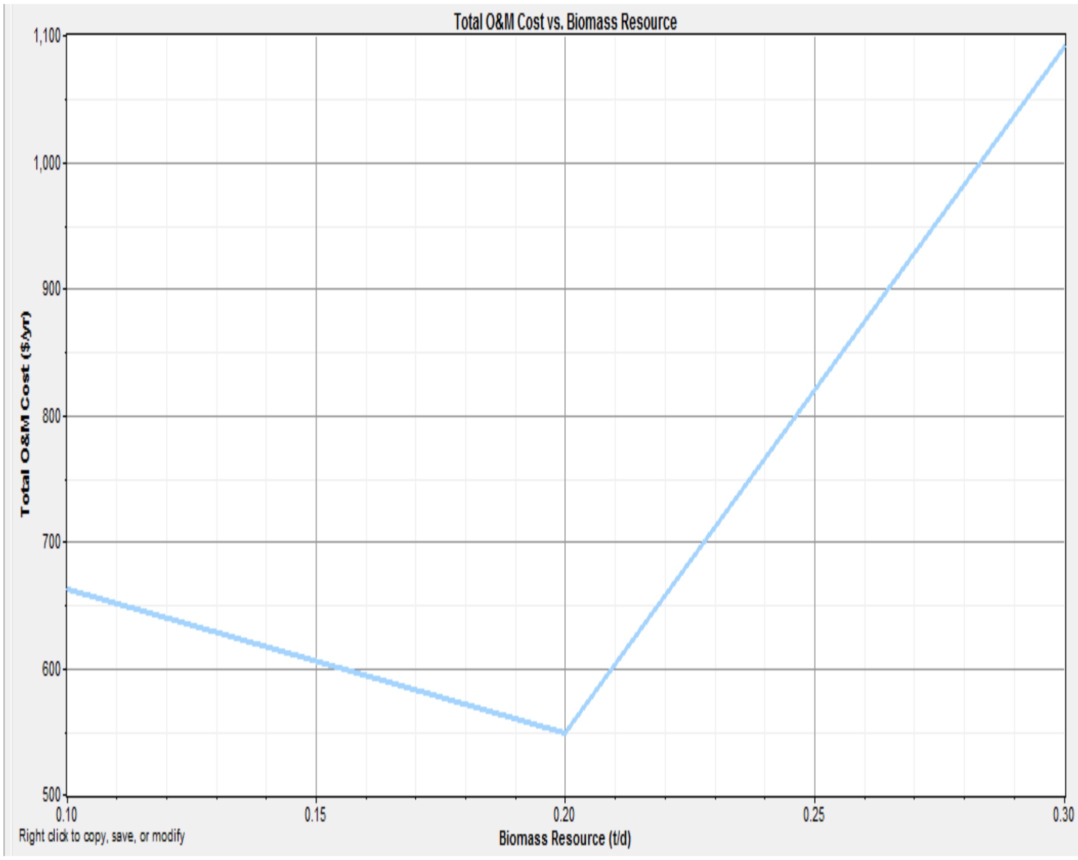


Figure 5.4.1.1c Total O&M Cost ($/yr) versus Biomass resources (t/d)

From the figures 5.4.1.1a to 5.4.1.1c, it is noted that the total net present cost (NPC), cost of energy (COE) and the O&M costs were found to be lowest when the biomass resource is 0.2tone/day (t/d).

To summarize the results, the net present cost, cost of energy and operating cost for the biomass resources 0.1t/d, 0.2t/d and 0.3t/d are presented in the table 5.4.1.1.

Table 5.4.1.1 Cost summary for various biomass resources

Biomass resource (t/d)	Total Net Present Cost ($)	Cost of Energy $/kWh (COE)	Operating Cost ($/yr)
0.1(t/d)	$74,308	$0.283/kWh	$702/yr
0.2 (t/d)	$71,377	$0.272/kWh	$645/yr
0.3 (t/d)	$73,954	$0.282/kWh	$1069/yr

5.5 Analysis of Battery life

For the proposed scheme, Nickel iron battery was chosen for the storage of excess electricity which is generated by the biogas generator. The function of the battery is that it needs to generate the stored energy of power during the night times. Hence the life cycle of the battery plays an important factor for installation of micro-grid to the rural areas.

In this section the expected life cycle of the Nickel iron battery for the different biomass resources has been presented.

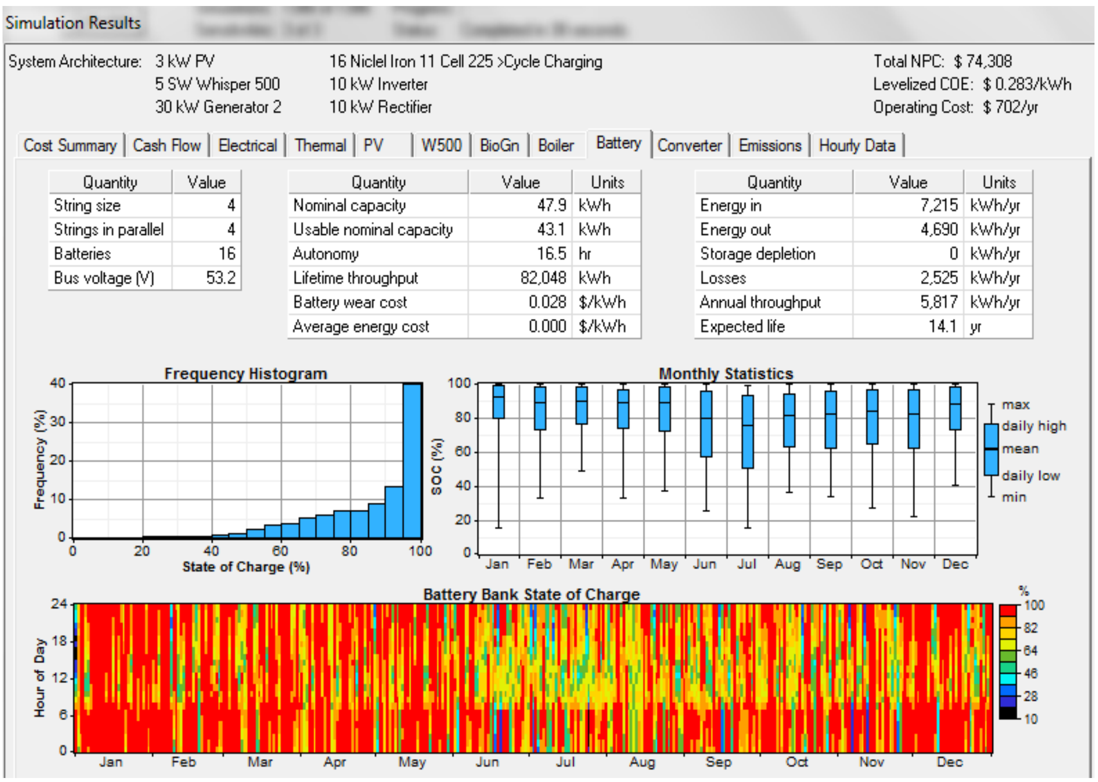


Figure 5.5a Nickel Iron Battery Life for the biomass resource 0.1t/d

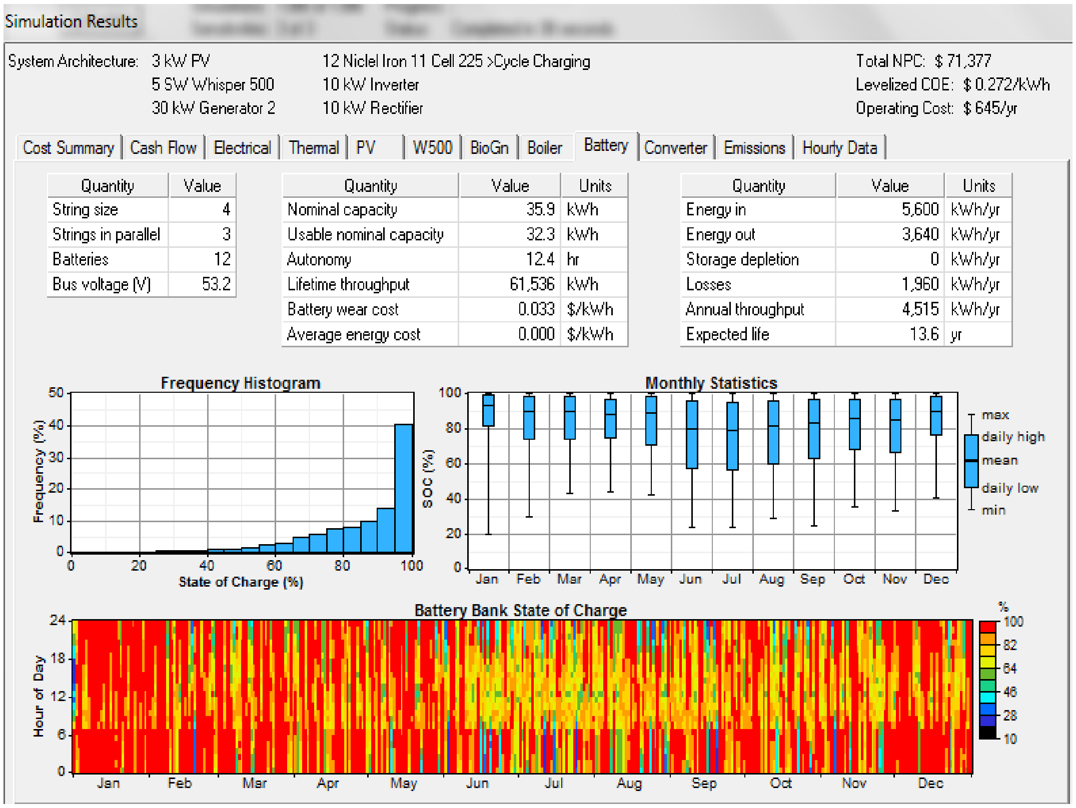


Figure 5.5b Nickel Iron Battery Life for the biomass resource 0.2t/d

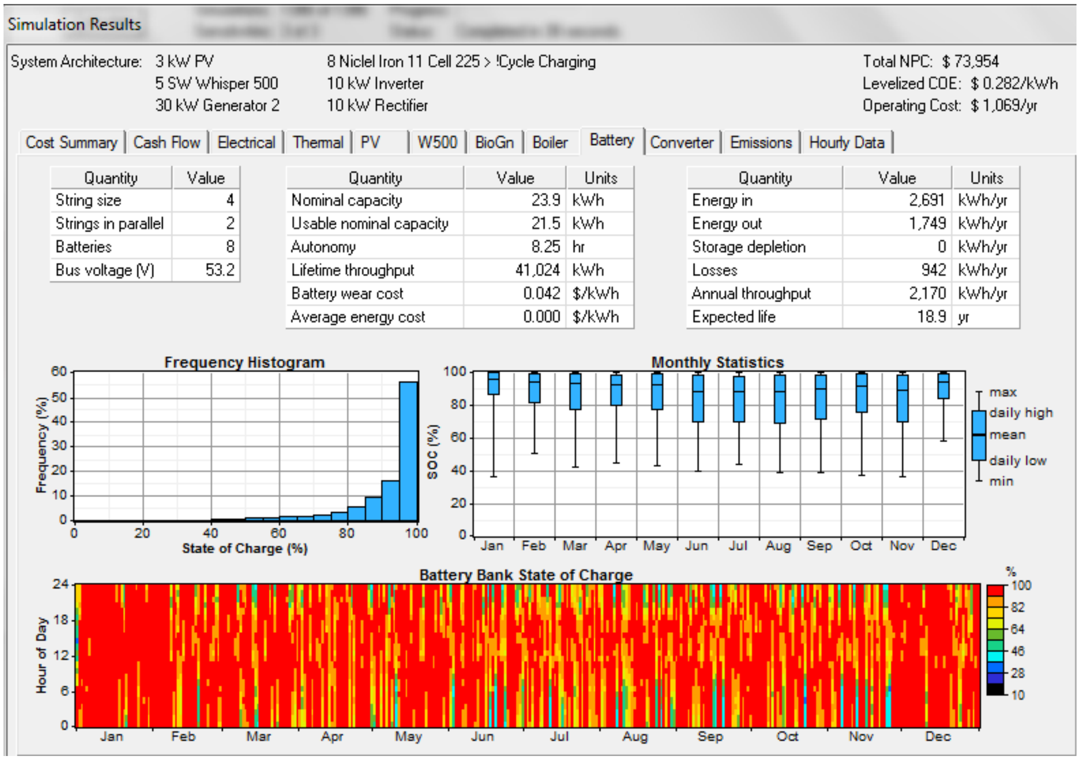


Figure 5.5c Nickel Iron Battery Life for the biomass resource 0.3t/d

5.5.1 Discussions for life cycle of the Nickel iron battery

The life cycle of any battery generally depends on the various parameters such as load, temperature and the capacity of charging and dis-charging pattern. Hence the life cycle of the battery can be increased by optimizing the operating conditions.

From the figures 5.5a to 5.5c, it is noticed that the expected life cycle of the nickel iron battery was higher for the biomass resource 0.3t/d which is 18.9 years. To summarize the comparisons of battery life for the three different biomass resources, the following graph was obtained after the simulation which is shown in the figure 5.5.1.

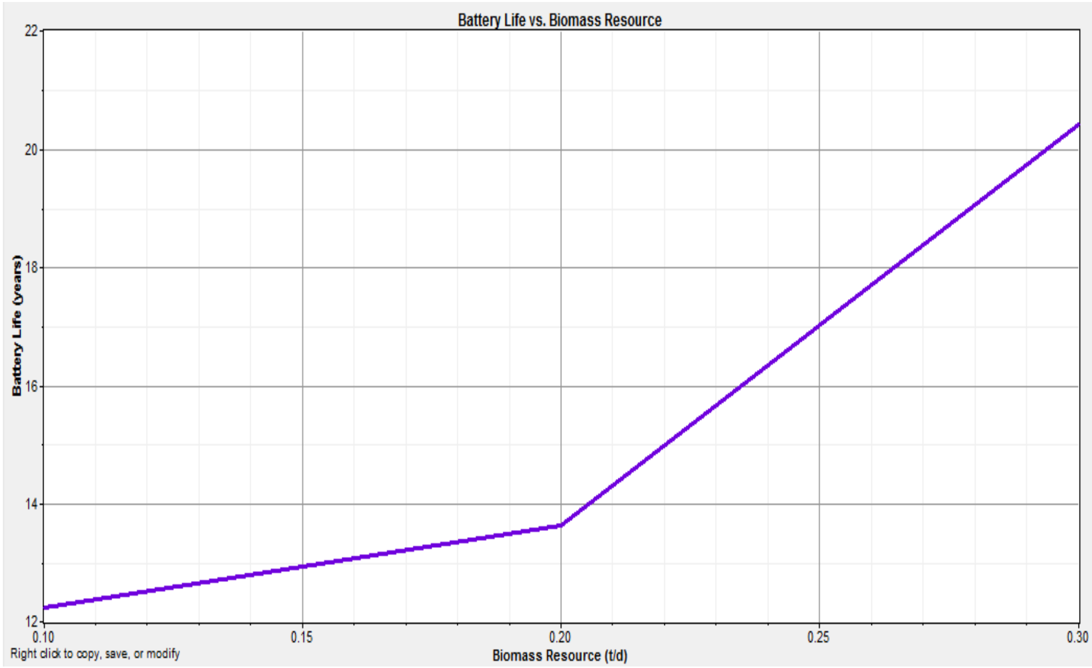


Figure 5.5.1 Comparison of battery life for various biomass resources

Hence from the figure 5.5.1, it is clearly noted that the life of the nickel iron battery increases when the biomass resources change from 0.1t/d to 0.3t/d.

5.6 Analysis of Monthly Electrical Production

The HOMER has simulated the different system configurations by considering the energy sources such as PV array, wind turbine and biomass energy. For the purpose of simulation, biomass resource is considered as the sensitivity variable. The monthly electrical production was compared for the various biomass resources as shown in the following figures.

For Biomass resource 0.1t/d

In this case, the HOMER has considered the resources such as wind turbine and generator for the production of electricity.

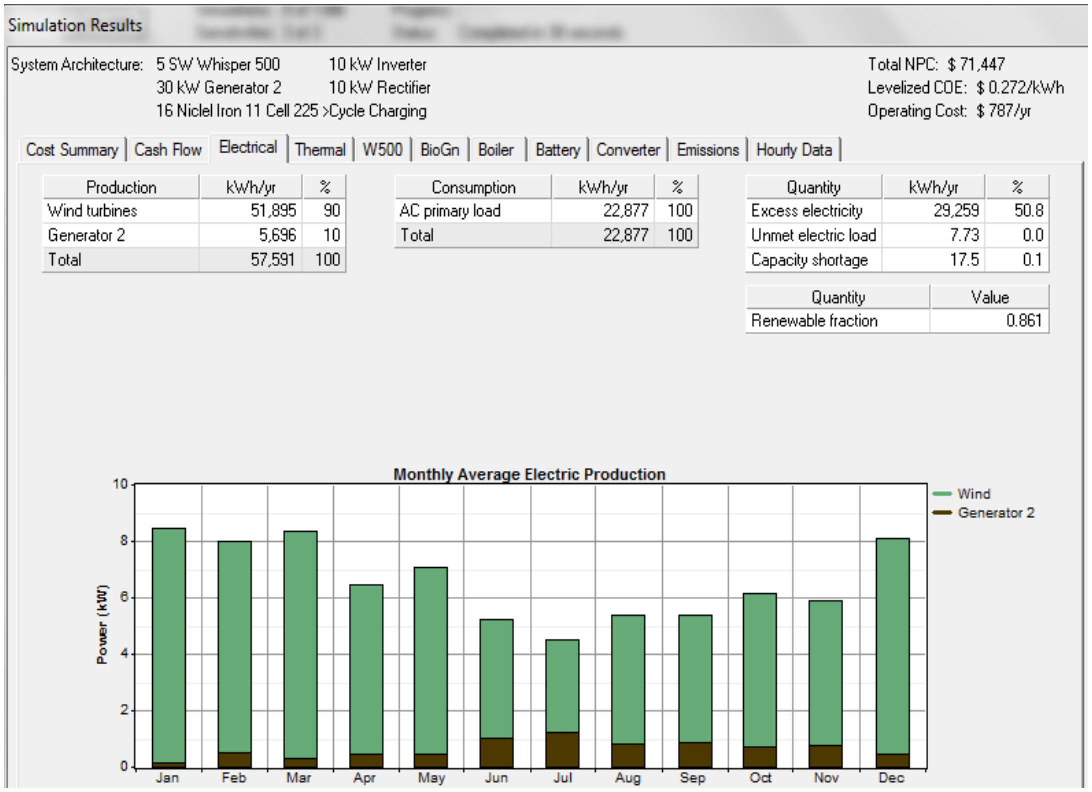


Figure 5.6a Monthly Electric Production by considering the resources as wind turbine and generator

From the figure 5.6a, it is clearly seen that most of the electric production was through the source of wind turbine which produces 51,895kWH/yr and the generator contributes only 10% of the total electric production.

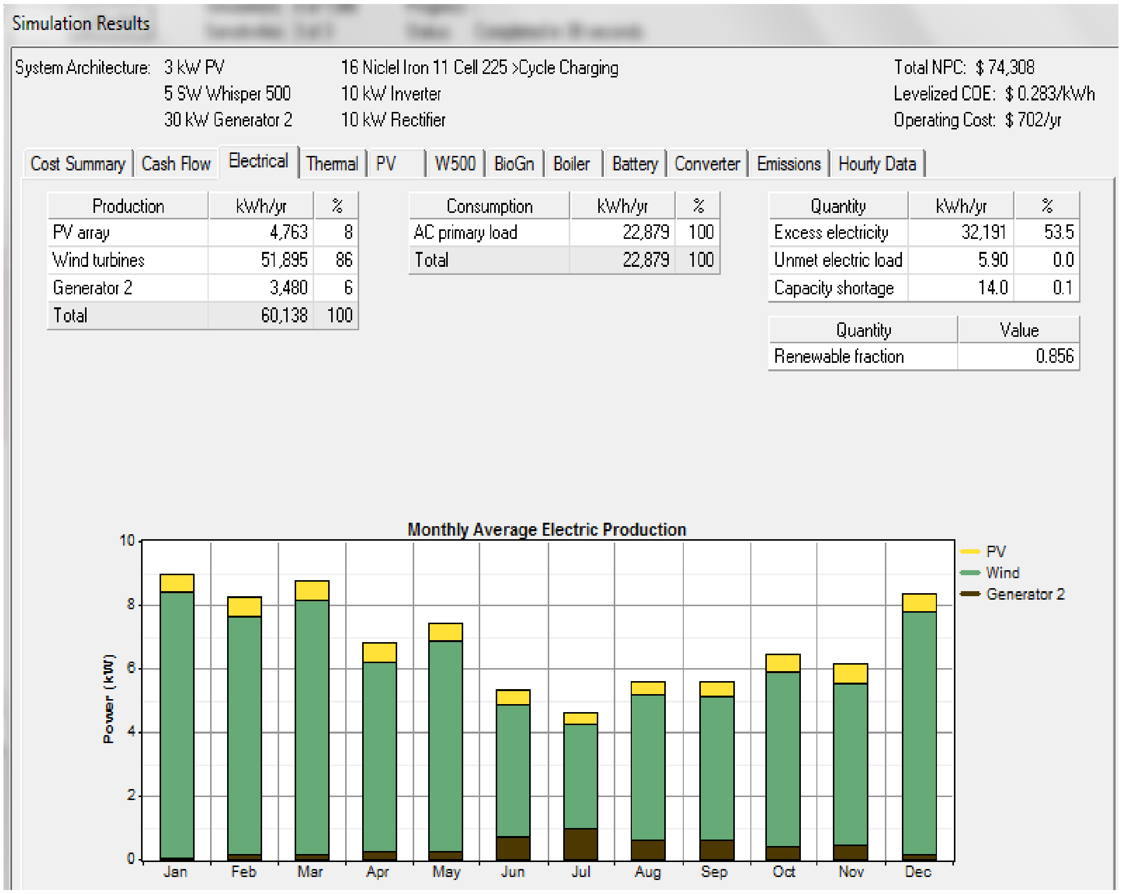


Figure 5.6b Monthly Electric Production by considering the all sources

In this case, the HOMER ranks the system components for the production of electricity in the following order wind turbine, PV array and generator. However, most of the contribution for the production of electricity was through wind turbine.

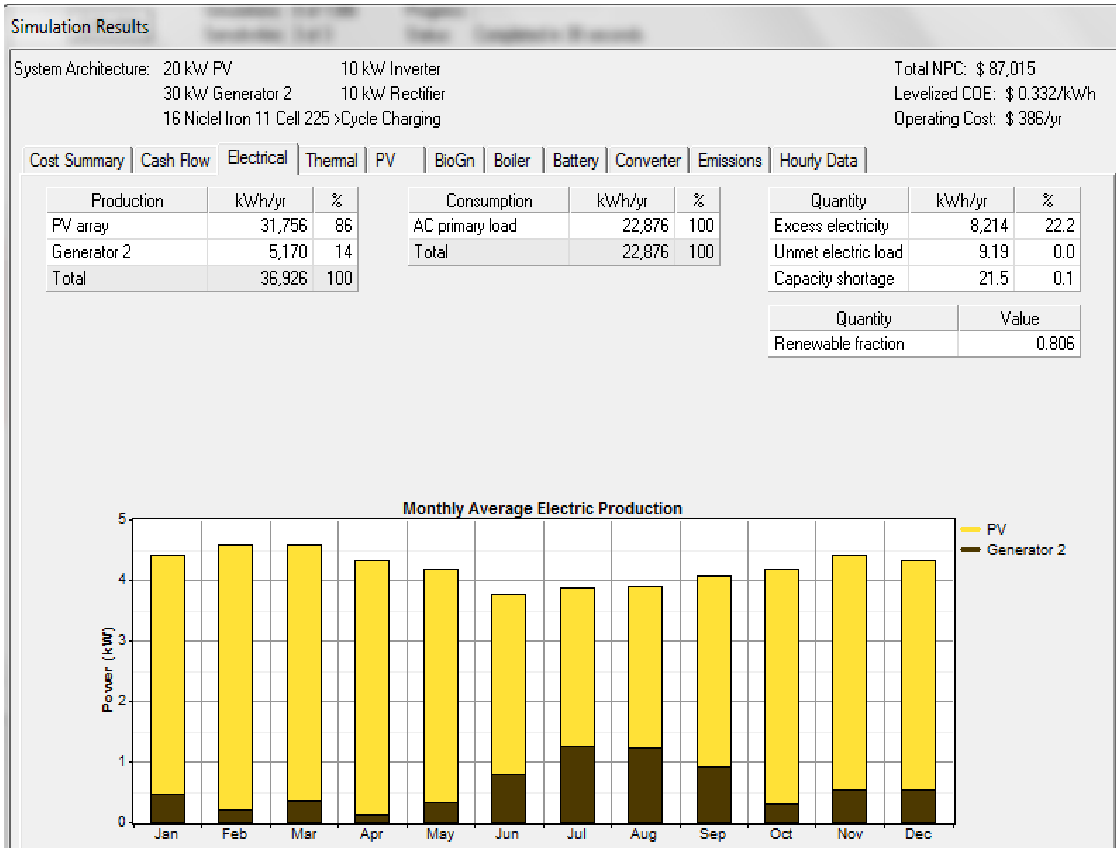


Figure 5.6c Monthly Electric Production by considering PV array and generator as sources

In this case, most of the electric production was produced through PV array source and the rest by the generator source.

5.6.1 Interpretation of results

From the figures 5.6a to 5.6c, it is observed that most of the electric production was produced through wind turbine. But, the main disadvantage is that the system has produced excess electricity which means that the energy is wasted.

Table 5.6.1 Comparison of excess electricity produced by considering the various resources

Biomass resource (t/d)	Sources considered	Excess electricity produced (%)
0.1	5SW Whisper500 and 30kW Generator	50.8%
0.1	3kW PV, 5SW Whisper500 and 30kW Generator	53.5%
0.1	20kW PV and 30kW Generator	22.2%

Although HOMER has indicated that the combination of wind turbine and generator produces more electricity than the other combinations, but it has the disadvantage of producing the excess electricity than needed. Hence, HOMER considers the combination of PV array and generator as the best one for the production of electricity to the rural areas.

5.7 Sensitivity Analysis results

HOMER has presented the best optimal system by considering the input parameters as global solar with radiation of 5.17264kWh/m^2/d, wind speed5.76m/s, and the diesel price as \$0/m^3. Sensitivity analysis refers to process of changing the input variables and to check the effect of the input variables on the optimal system presented by the HOMER. Therefore, analysis has been conducted on the optimal system for studying the various effects of the system.

This section presents the various parameters affected with the change in the sensitive variables for the optimal system.

5.7.1 Comparison of Total Net Present Cost (NPC) for various biomass resources with change in wind speed

Case 1: Biomass Resource 0.1t/d

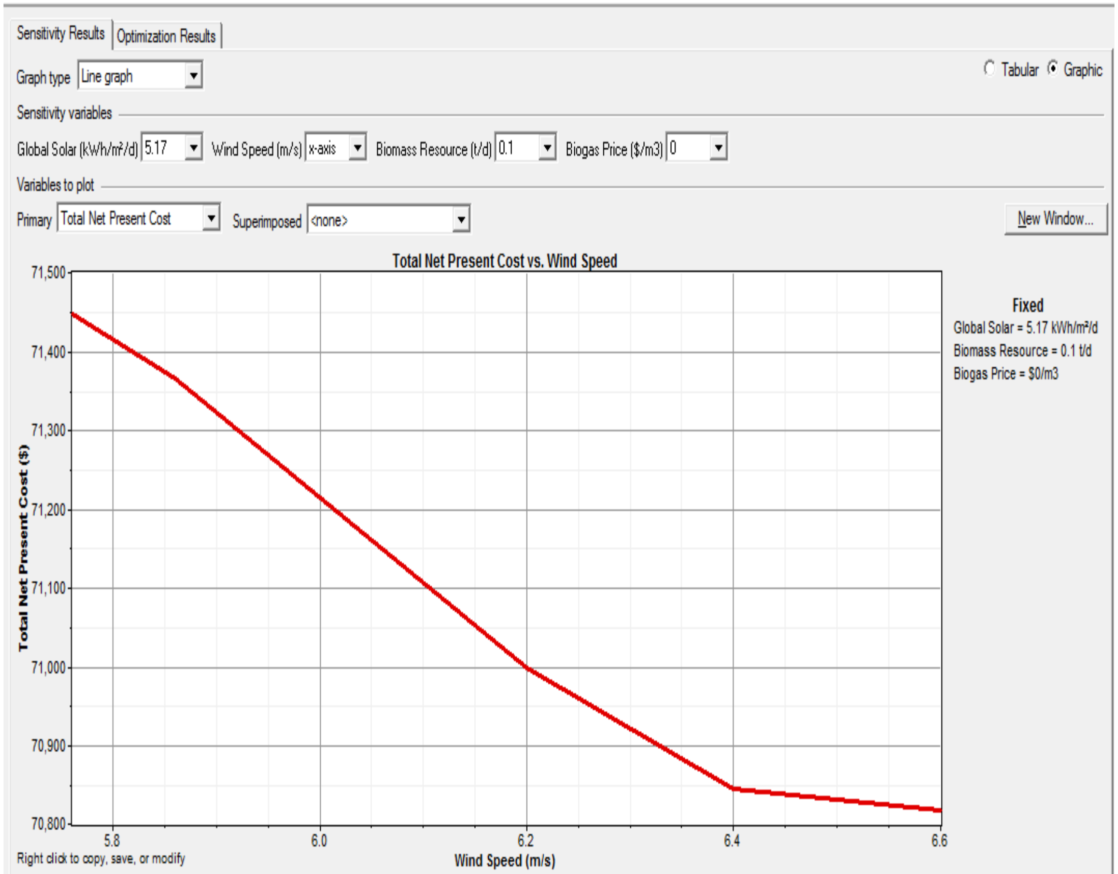


Figure 5.7.1a Total Net Present Cost ($) versus Wind speed (m/s)

Case 2: For Biomass Resource 0.2t/d

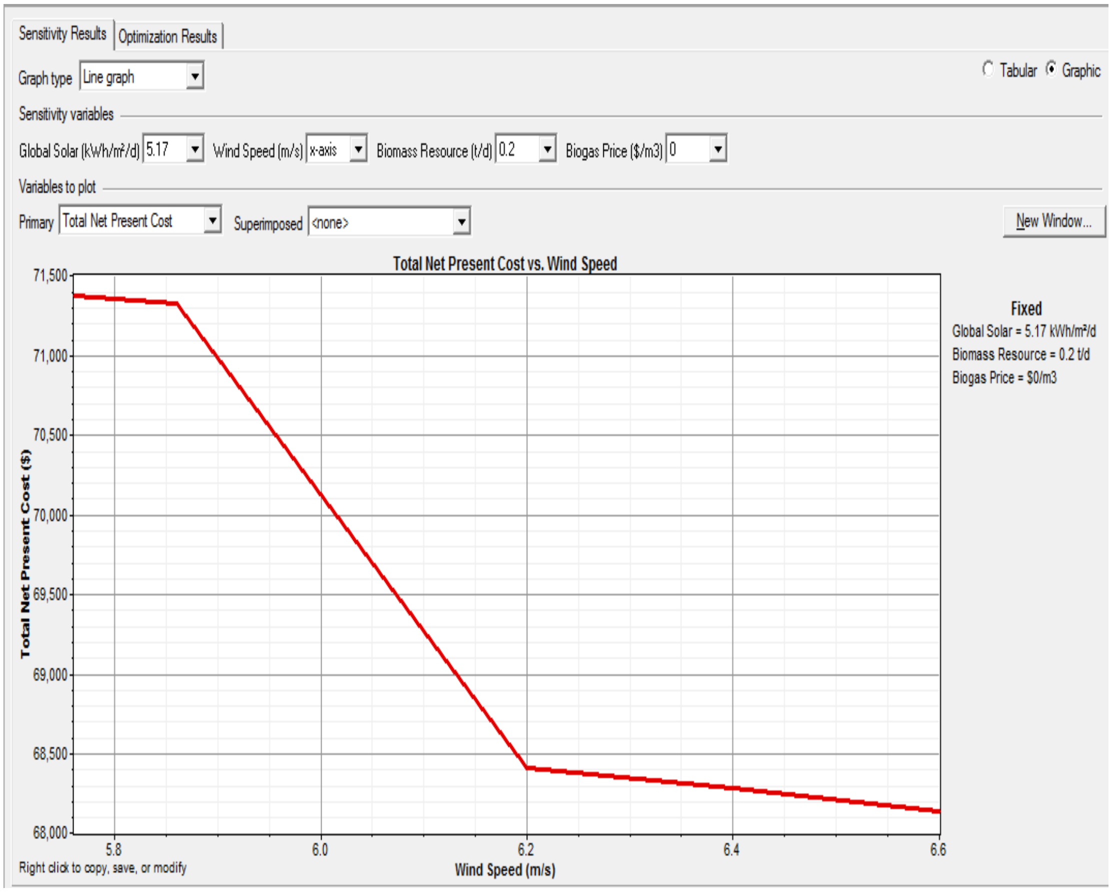


Figure 5.7.1b Total Net Present Cost ($) versus Wind speed (m/s)

Case 3: For Biomass Resource 0.3t/d

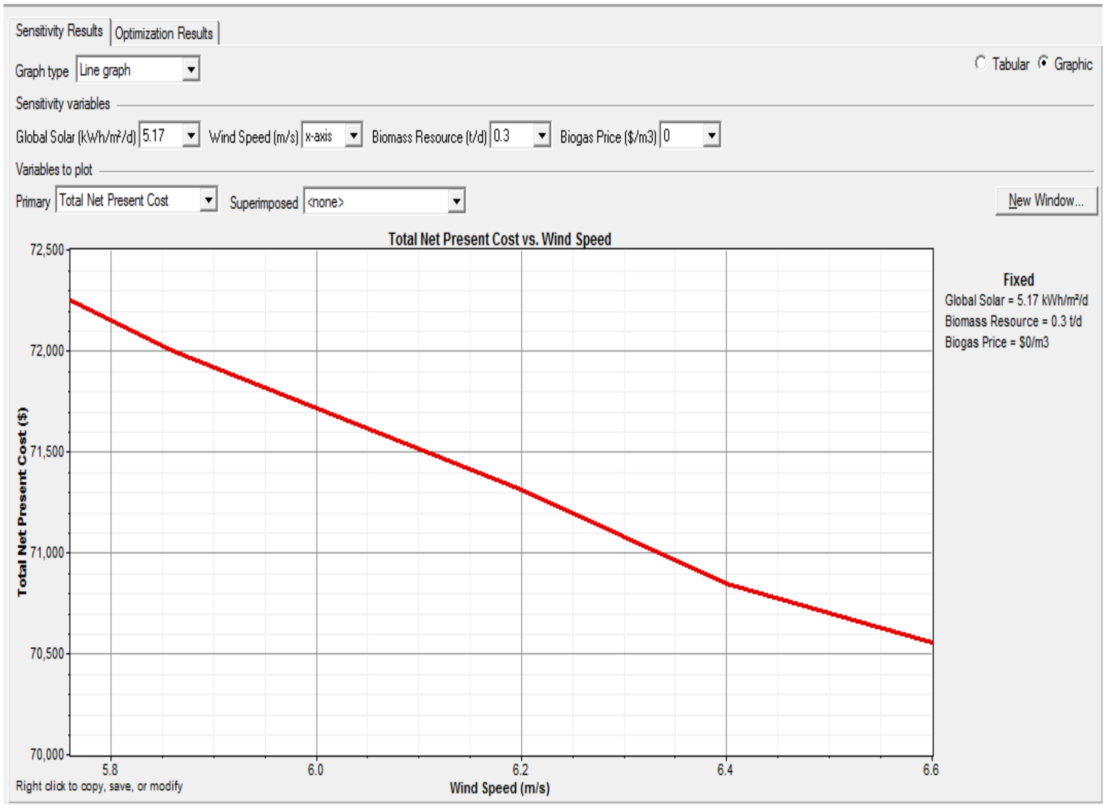


Figure 5.7.1c Total Net Present Cost ($) versus Wind speed (m/s)

5.7.1.1 Discussion of results

From the figures 5.7.1a to 5.7.1c, it has been observed that as the wind speed increases from 5.76m/s to 6.6m/s there is reduction in the total net present cost which is shown in the table 5.7.2.

Table 5.7.2 summarizes the results for the total net present cost varying with wind speed for different biomass resources considered.

Table 5.7.2 Total Net Present Cost versus Wind Speed versus wind speed for different biomass resources

Biomass Resource (t/d)	Wind Speed (m/s)	Total Net Present Cost ($)
0.1t/d	5.76m/s	$71,450
	6.0m/s	$71,220
	6.6m/s	$70,900
0.2t/d	5.76m/s	$71,400
	6.0m/s	$70,100
	6.6m/s	$68,180
0.3t/d	5.76m/s	$72,250
	6.0m/s	$71,700
	6.6m/s	$70,550

However the total reduction in NPC is found to be lower when the biomass resource is 0.2t/d. Hence the system is said to be more feasible for the biomass resource 0.2t/d.

5.7.3 Comparison of Cost of Energy for various biomass resources with change in the speed of wind direction

The cost of energy must be as low as possible especially for the people who live in rural households. Hence, Homer performs the sensitivity analysis for the optimal system obtained by the process of optimization.

The graphs for the cost of energy and the speed of wind direction are presented in the figures 5.7.3a to 5.7.3c for the various biomass resources.

Case1: For Biomass Resource 0.1t/d

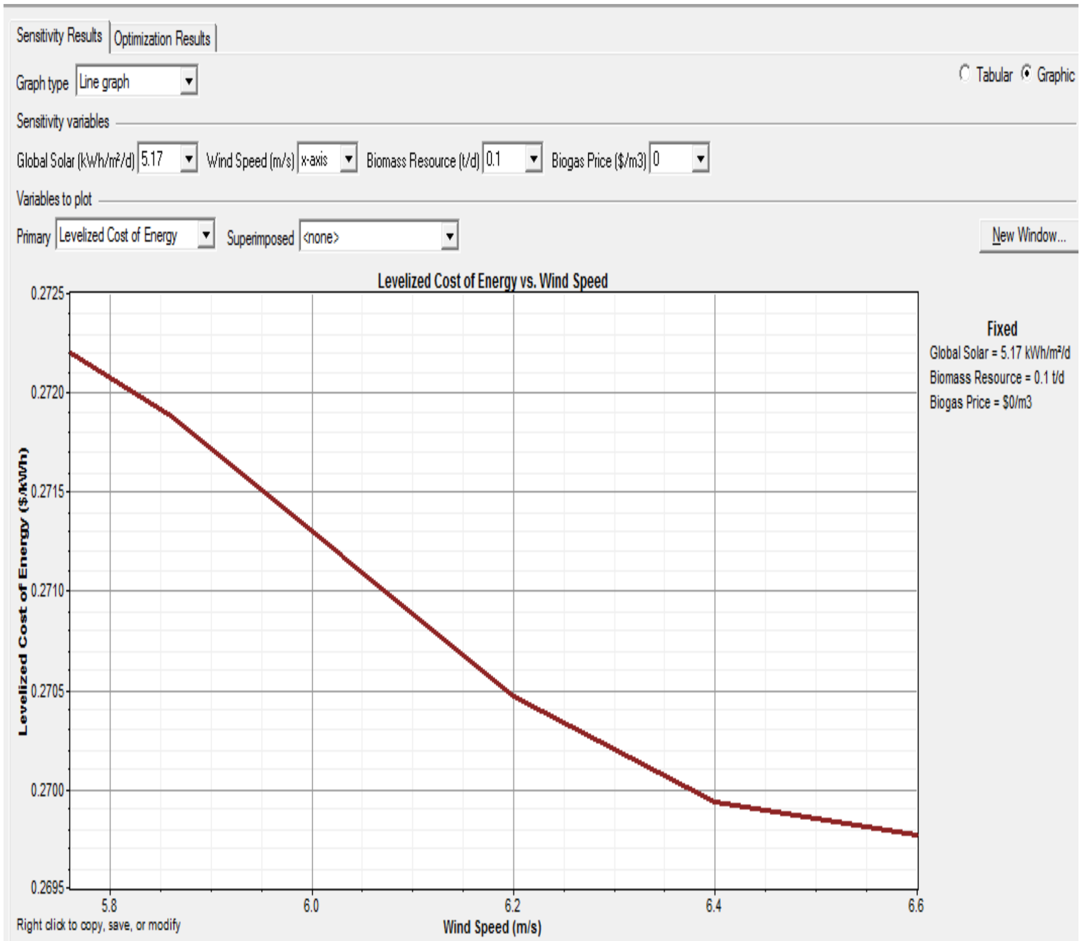


Figure 5.7.3a Cost of Energy versus Wind speed for biomass resource 0.1t/d

Case2: For Biomass Resource 0.2t/d

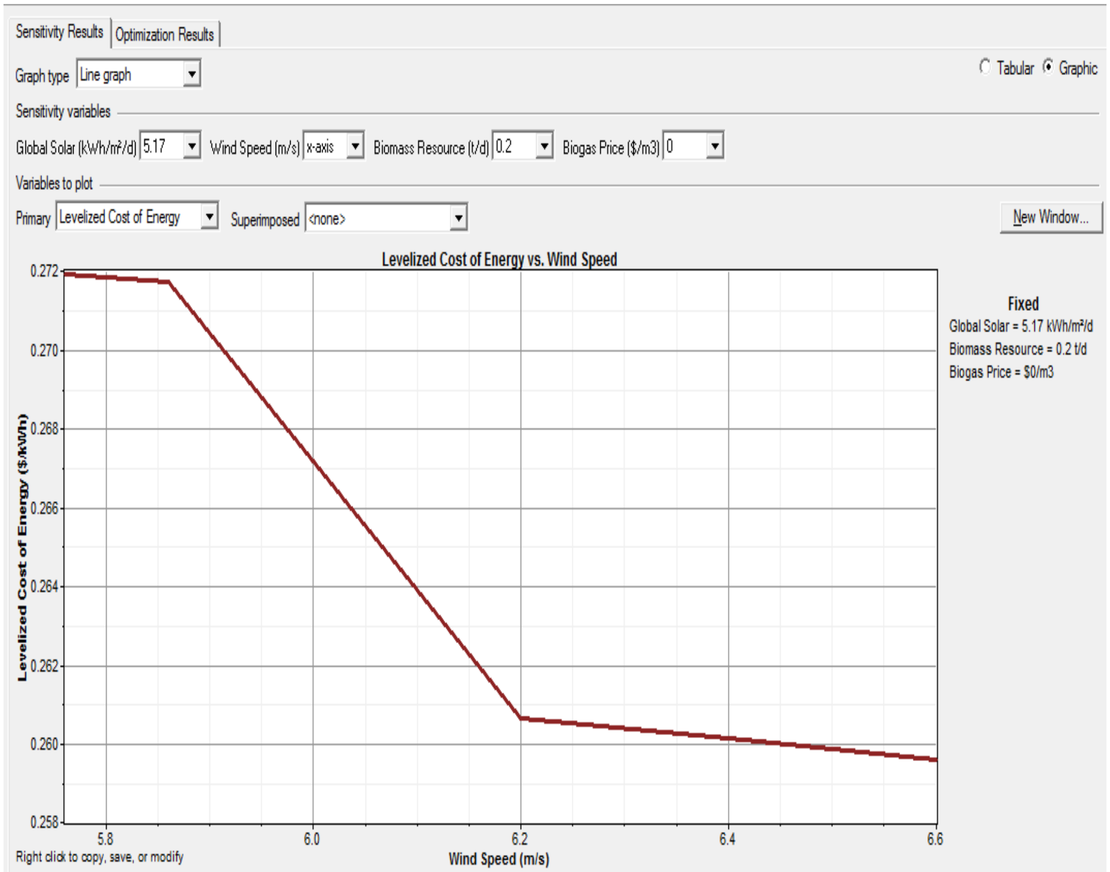


Figure 5.7.3b Cost of Energy versus Wind speed for biomass resource 0.2t/d

Case3: For Biomass Resource 0.3t/d

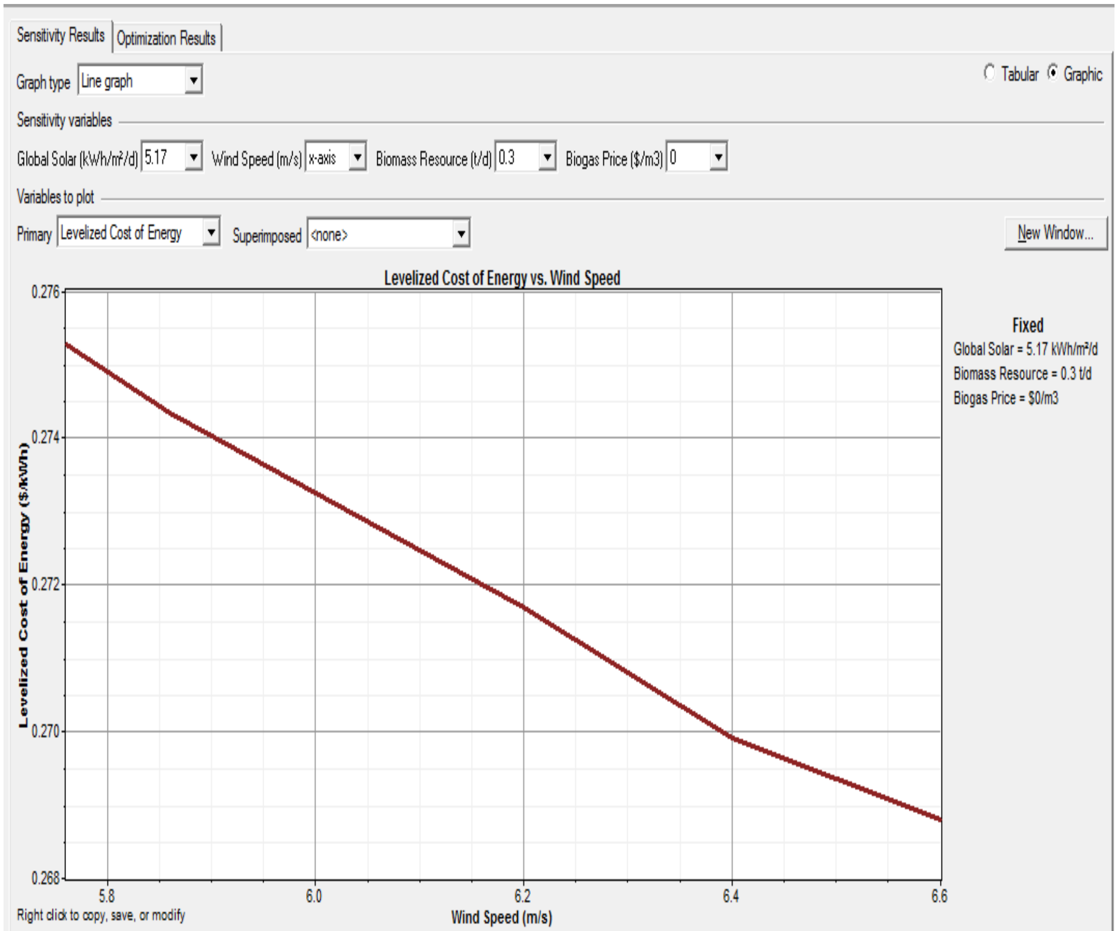


Figure 5.7.3c Cost of Energy versus Wind speed for biomass resource 0.3t/d

5.7.3.1 Discussion of results

From the figures 5.7.3a to 5.7.3c, it is well noticed that the slope of the graph reduces when there is an increase in the speed of wind direction. This means that the cost of energy will be cheaper as the speed of the wind direction increases.

Table 5.7.3.1 summarizes the results for the cost of energy varying with wind speed for different biomass resources considered.

Table 5.7.3.1 Comparison of Cost of Energy versus wind speed for different biomass resources

Biomass Resource (t/d)	Wind Speed (m/s)	Cost of Energy ($/kWh)
0.1t/d	5.76m/s	$0.2722/kWh
	6.0m/s	$0.2713/kWh
	6.6m/s	$0.2698/kWh
0.2t/d	5.76m/s	$0.2719/kWh
	6.0m/s	$0.2671/kWh
	6.6m/s	$0.2588/kWh
0.3t/d	5.76m/s	$0.2741/kWh
	6.0m/s	$0.2734/kWh
	6.6m/s	$0.2690/kWh

By analyzing the table 5.7.3.1, the cost of energy is becoming lower with the increase in the wind speed when the biomass resources change from 0.1t/d to 0.3t/d. But it can also be noticed that the cost of energy has the lowest values for the biomass resource 0.2t/d compared with 0.1t/d and 0.3t/d. Hence the system is said to be more feasible when the chosen biomass resource is 0.2t/d.

Chapter 6

Conclusions and Future Scope of Work

6.1 Conclusions

The main objective of the project was to design a high-performance low voltage DC micro-grid model to be utilized in rural parts of India. This was to increase future electrification rates in rural areas, which have shown great disparities when compared to urban areas. The proposed DC micro-grid design was developed and modelled by using HOMER Energy Software through a three-staged process involving simulation, optimization, and sensitivity analysis.

The results from the sensitivity analysis process may lead to a lot of inferences being made with regards to the design and control of DC micro-grid systems relying on wind, solar and biomass resources. First, continuous supply of power relies on abundance of sunlight for the PV cell array (annual average of 5.17kWh/m2 per day), adequate wind speed (annual average of 5.76 meters per second) and availability of biomass (capacity of 0.1 t/ day). And through the simulation results, the best optimal system was obtained for the biomass resource 0.2t/d with low net present cost of $71,400 compared to the other biomass resources.

For the optimal solution of the proposed model, the comparisons of COE versus government capital subsidy have been presented. For the three biomass resources considered, it was observed that the cost of energy reduces as the government wishes to contribute the more percentage of subsidizing the tariff. Hence the people who live in rural areas will totally depend on the contribution of government subsidy for paying the tariff. And flow chart was developed for load sharing of energy between the customers during the day time and night time. Further this logic was implemented in PLC programming for monitoring the load dispatch of energy to the customers. Hence the micro-grid is setup in such a way that the power is delivered equally to all the customers through-out the day.

Micro-grid will only remain a feasible option for rural electrification to the users, generating companies and the larger Indian economy if the selected rural areas are densely populated. This is because the cost requirements for setting up and operating the micro-grid system can only be marinated through consumer tariff payments even in the presence of government subsidy. As a result, the role of the government and other private investors in the country's rural electrification program is to provide both facilitations, as well as financing of the project.

6.2 Future Scope of Work

Many studies have been based on the importance, design and performance of micro-grid systems. However, there are still gaps with regards to the control of voltage generated by such systems, especially on the part of consumers. Many incidences that occur pose great risk to the end consumer more than the operators of the DC micro-grid power station. As a result, there is need for studies to be conducted on control issues for implementing the best micro-grid design for the rural households by making use of automated controllers.

Secondly, the use of Homer Energy software has made it possible to assess future performance of DC micro-grid systems. This has meant that designers of such systems are able to make adjustments to their systems even without conducting field tests. However, the problem with simulation results is that they make use of available information with regards to wind speed, solar radiation intensity or availability of biomass resources, which may be adversely affected by uncertainties in the external environment depending upon the chosen area of operation.

As a result, researcher should also focus on how results of modeling systems like HOMER may be integrated into locally based conditions. This is because DC micro-grid systems mainly utilize solar and wind energy, which are highly dependent on climatic conditions. Since climatic conditions are constantly changing, such systems should have real-time resource availability adjustments that may help designers to alter future cost and performance implications. In this way, sustainability of power supply for rural areas will be achieved.

6.3 Recommendations

The development of hybrid micro-grid systems will not only be able to utilize renewable energy sources, but it also needs to be supplemented by the national grid which is important for power supply reliability in rural areas. In this project, the proposed micro-grid design has the capabilities to operate in grid connection as well as in islanded mode. Other recommendations for this project include:

- The development of standardized LV DC micro-grid systems that should be capable of addressing the voltage levels for the various component requirements
- Improvement of protection systems must be taken into the consideration, as there will be formation of arc systems especially when the system is in computation.
- The development of micro-grid systems needs to include local energy sources for the integration of sustainability issues.

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Appendix A- Project Specification

University of Southern Queensland

(See ENG8411/8412 Masters dissertation Introductory Book Section 9.2 for examples pages 67-68)

ENG8411/8412 Research Project
PROJECT SPECIFICATIONS

FOR: ORUGANTI VARA PRASAD YADAV

TOPIC: VOLATAGE CONTROL IN MICROGRIDS

SUPERVISOR/S: ANDREAS HELWIG

ENROLMENT: ENG8411 – S1, 2014
ENG8412 – S2, 2014

PROJECT AIM: The main aim of the project is to investigate the modelling system and strategy for an Indian standalone village based micro grid and its voltage stability(LV is defined as less than 1KV dc).

SPONSORSHIP:
(If applicable)

PROGRAMME: Issue A, 25th March 2014

1. To analyse AC/DC Topologies and their control of energy dispatch operation
2. To test whether LV residential loads can be supplied with DC and deriving their load models
3. Developing operation control strategies for equitable energy dispatch between load uses and investigate protection systems applicable for LV dc micro grid systems
4. Model in Homer Energy software various hybrid sustainable energy supply sources, and the available output over annual period. This is to investigate energy availability versus energy demand
5. To design and model a LV dc system which is used for future development of rural area
6. To provide an equitable power sharing method/s and how this can match voltage regulation

As time permits:

7. Compare AC micro grids and its protection requirements
8. Investigate alternative customer voltage regulator based solutions

AGREED 28/03/14 (Student) 28/03/2014 (Supervisor/s)

ENG8111/12 PROJECT PROPOSAL FORM VALID AT: 28 MARCH 2014 ISSUED 11/09/12

Appendix B-Resources Considered for the HOMER

B.1 Solar resource

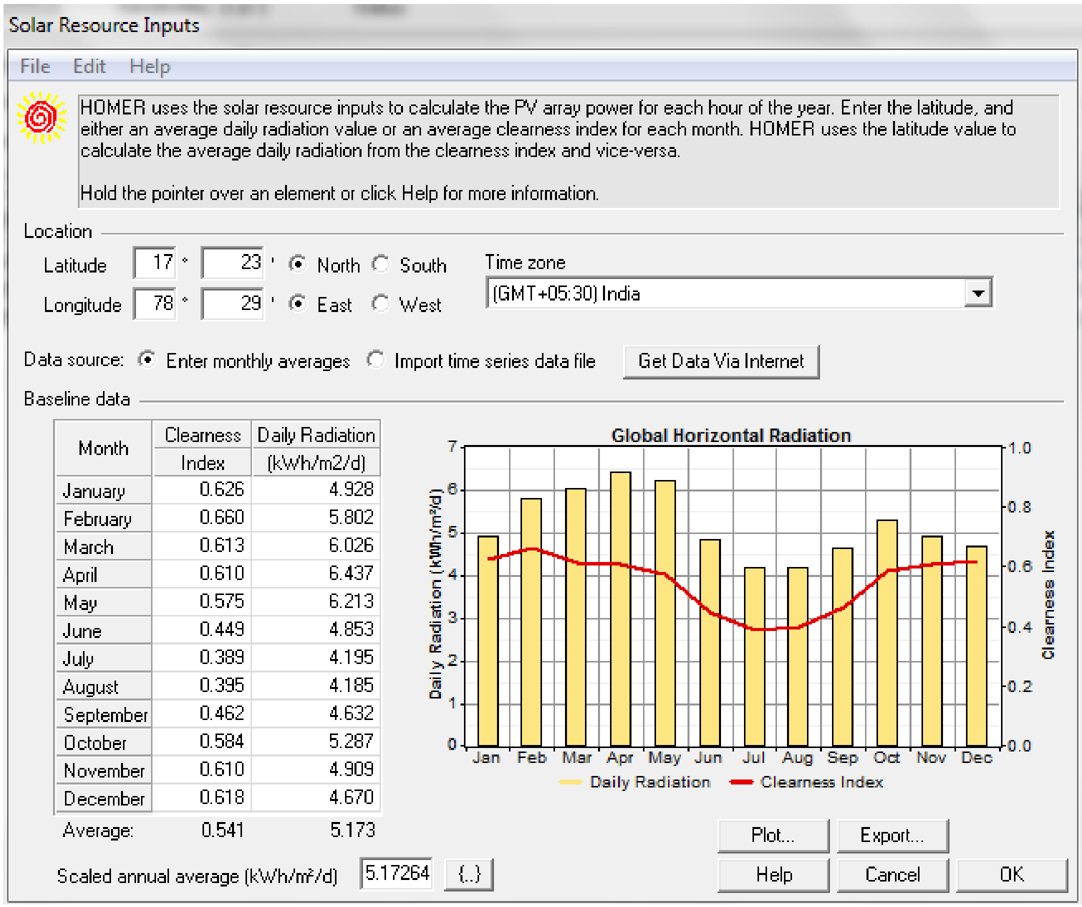


Figure B.1: Solar resource input

B.2 Wind resource

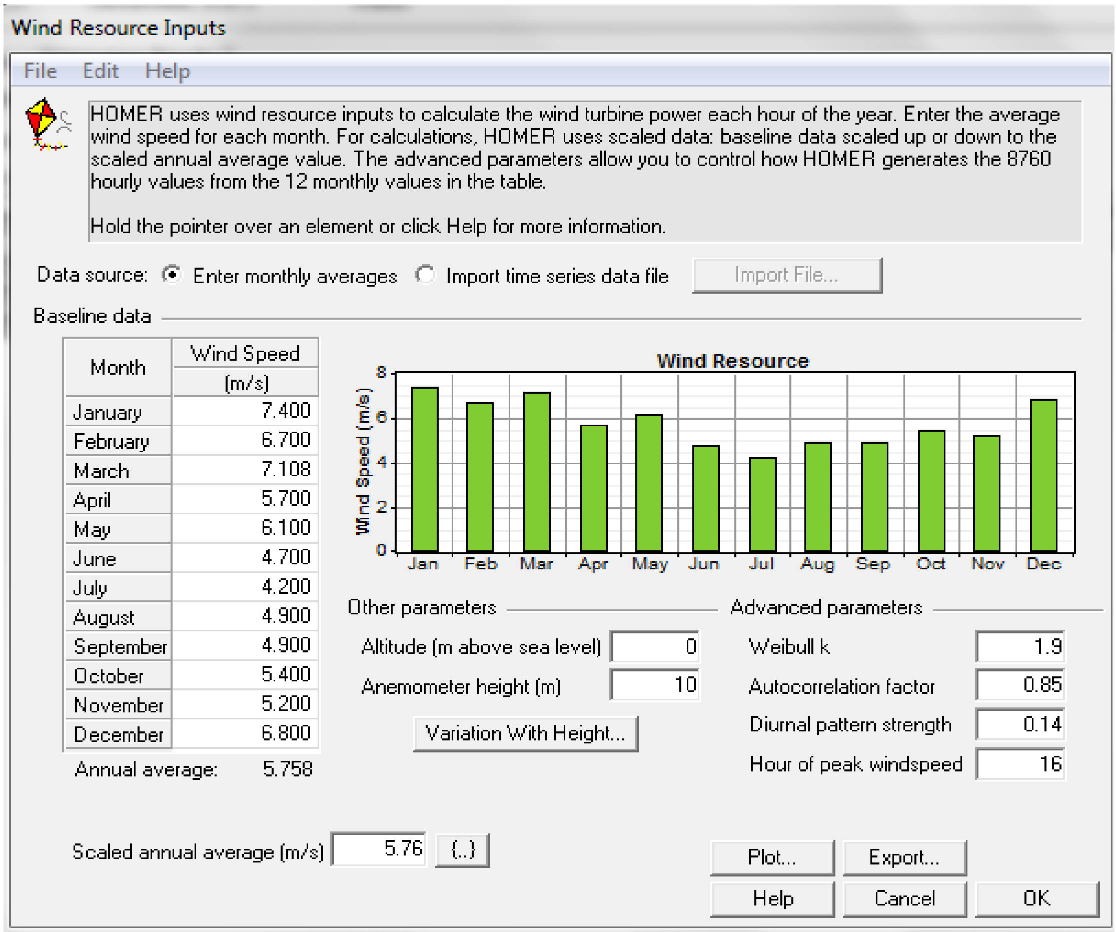


Figure B.2: Wind resource input

B.3 Biomass resource

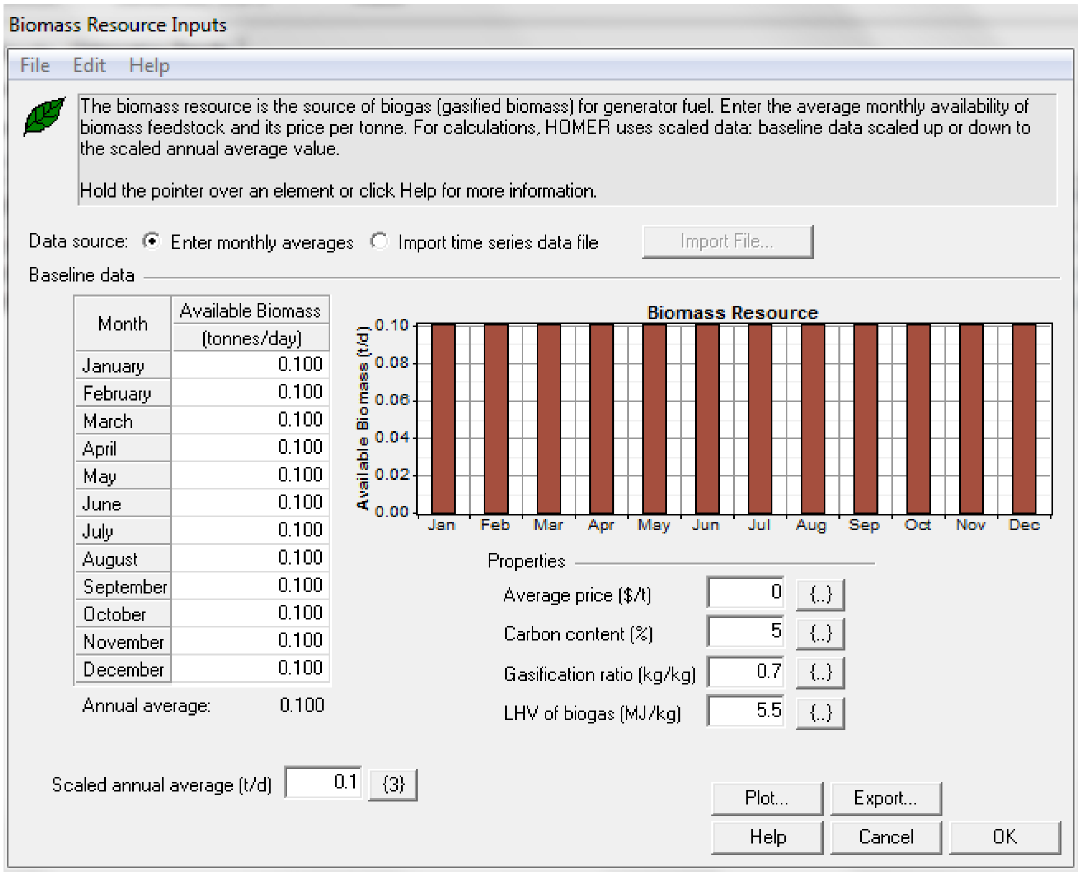


Figure B.3: Biomass resource input

Appendix C- Optimization Results

The following are the optimization results obtained by the HOMER after simulating the different system configurations. It presents the optimal systems in the order based on the total net present costs.

C.1: Full Capital Costs 0% variability for day to day with 0% random variability for Time-steps. (Biomass resource = 0.2t/d)

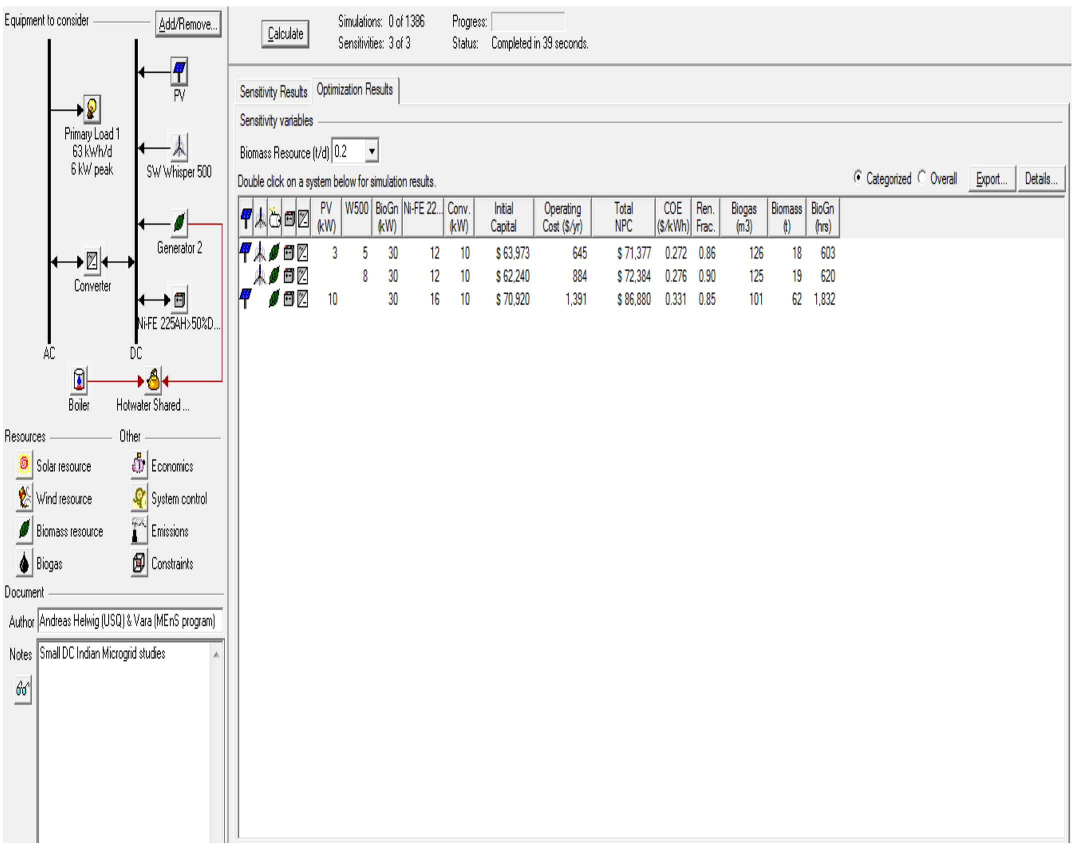


Figure C.1: Optimization results for Full Capital Costs 0% variability for day to day with 0% random variability for Time-steps. (Biomass resource = 0.2t/d)

C.2: Full Capital Costs 0% variability for day to day with 0% random variability for Time-steps. (Biomass resource = 0.3t/d)

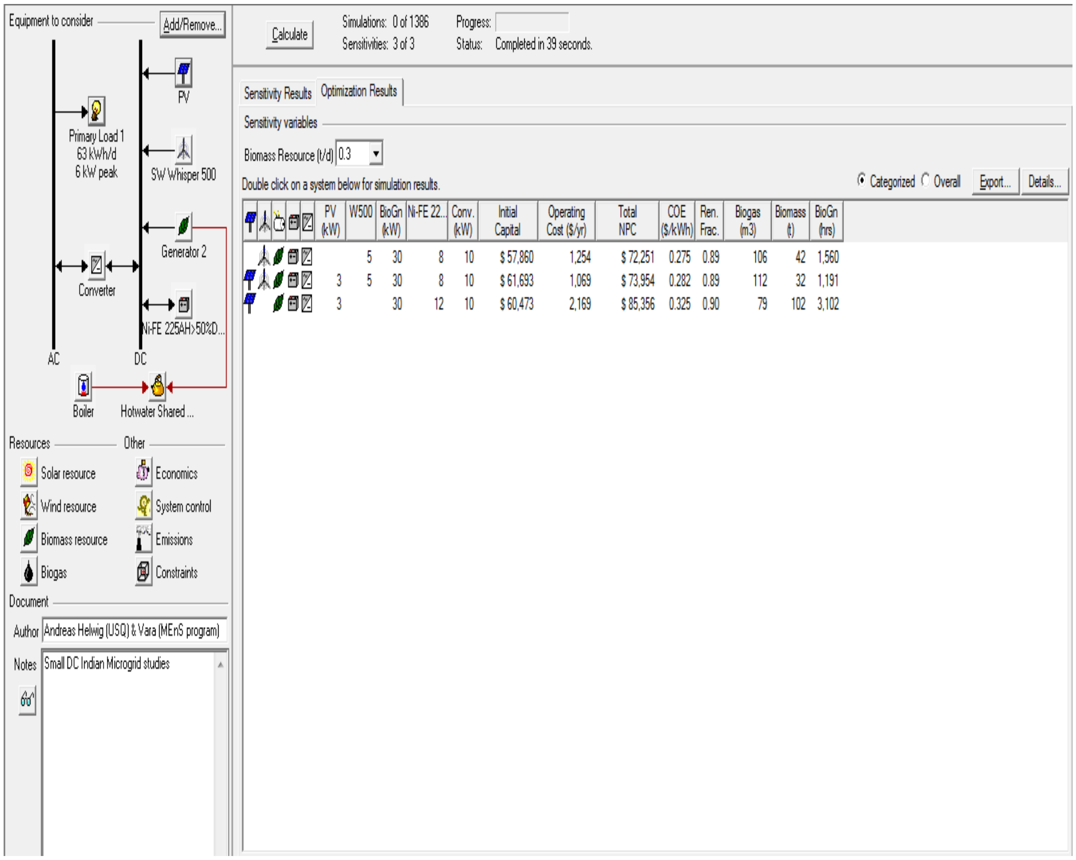


Figure C.2: Optimization results for Full Capital Costs 0% variability for day to day with 0% random variability for Time-steps. (Biomass resource = 0.3t/d)

C.3 Full Capital Costs 5% variability for day to day with 10% random variability for Time-steps. (Biomass resource = 0.1t/d)

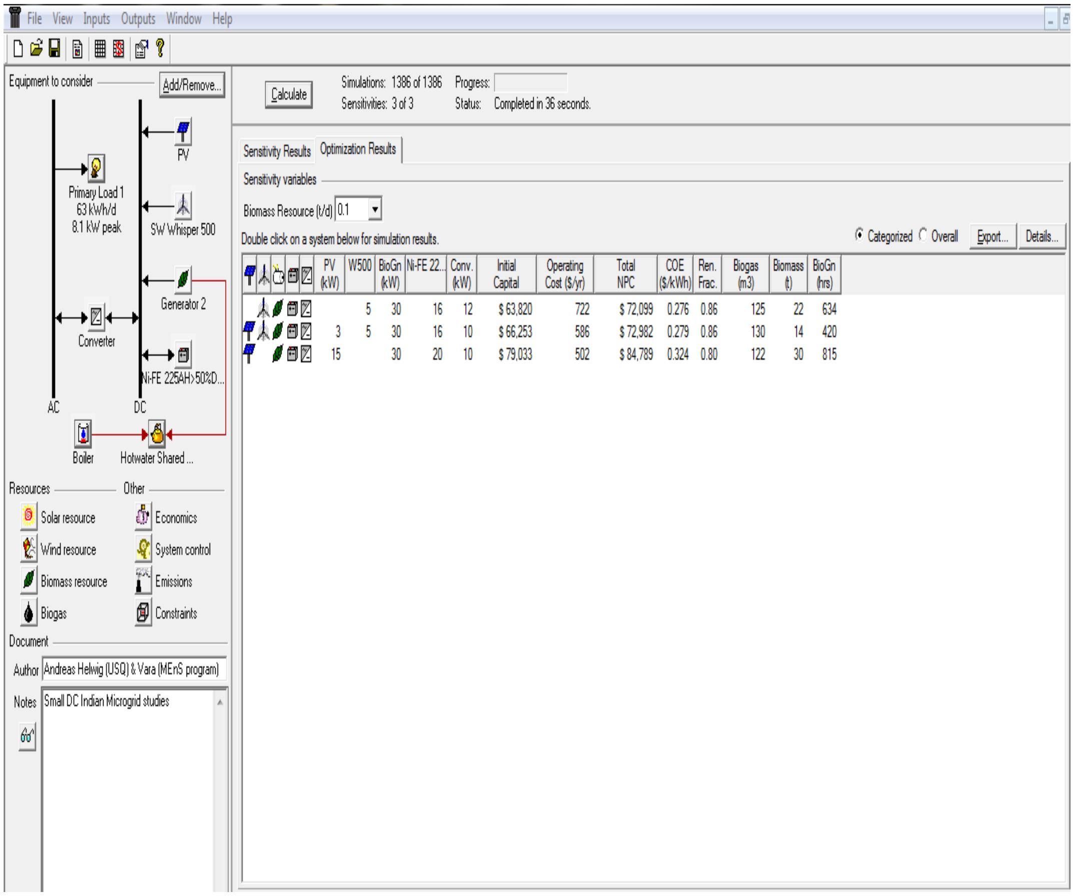


Figure C.3: Optimization results for Full Capital Costs 5% variability for day to day with 10% random variability for Time-steps. (Biomass resource = 0.1t/d)

C.4 Full Capital Costs 5% variability for day to day with 10% random variability for Time-steps. (Biomass resource = 0.2t/d)

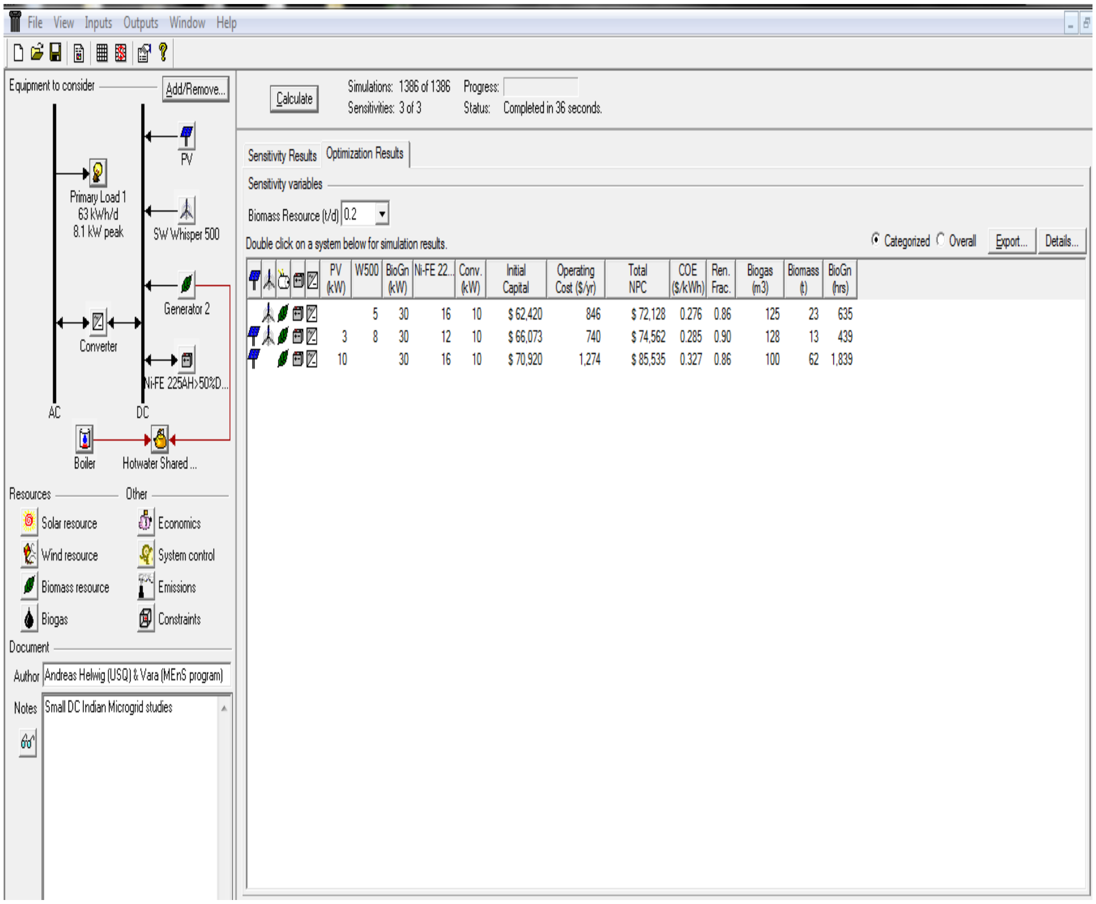


Figure C.4: Optimization results for Full Capital Costs 5% variability for day to day with 10% random variability for Time-steps. (Biomass resource = 0.2t/d)

C.5 Full Capital Costs 5% variability for day to day with 10% random variability for Time-steps. (Biomass resource = 0.3t/d)

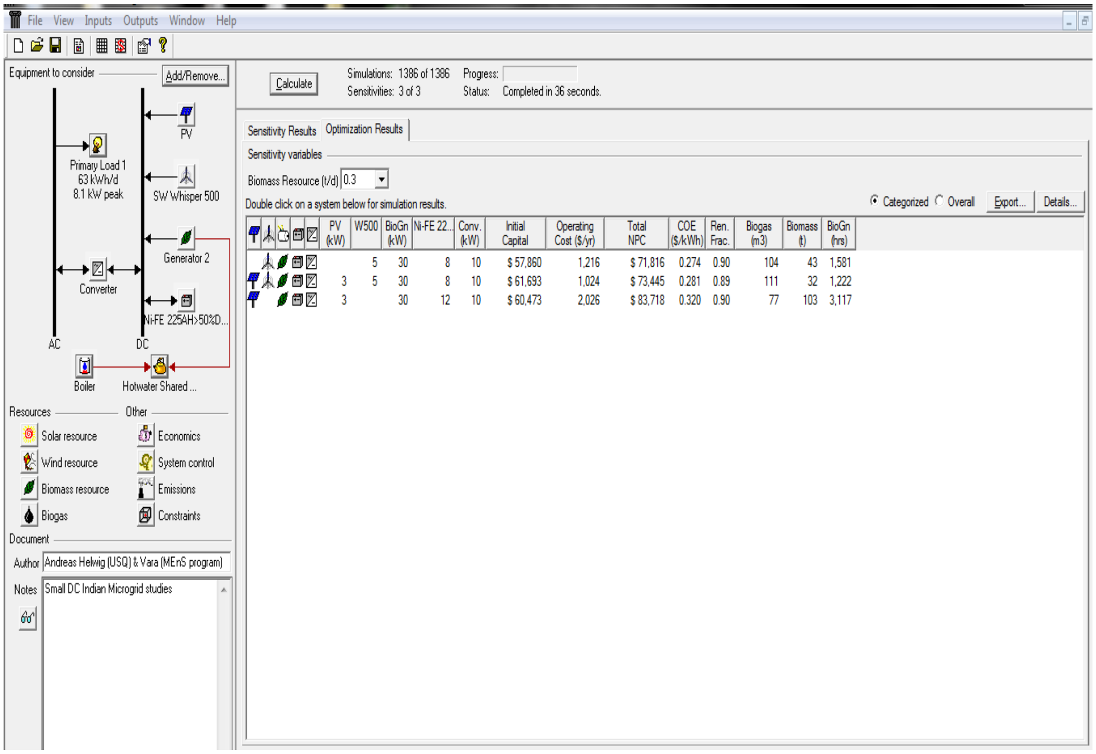


Figure C.5: Optimization results for full Capital Costs 5% variability for day to day with 10% random variability for Time-steps. (Biomass resource = 0.3t/d)

C.6 Half Capital Costs 0% variability for day to day with 0% random variability for Time-steps. (Biomass resource = 0.2t/d)

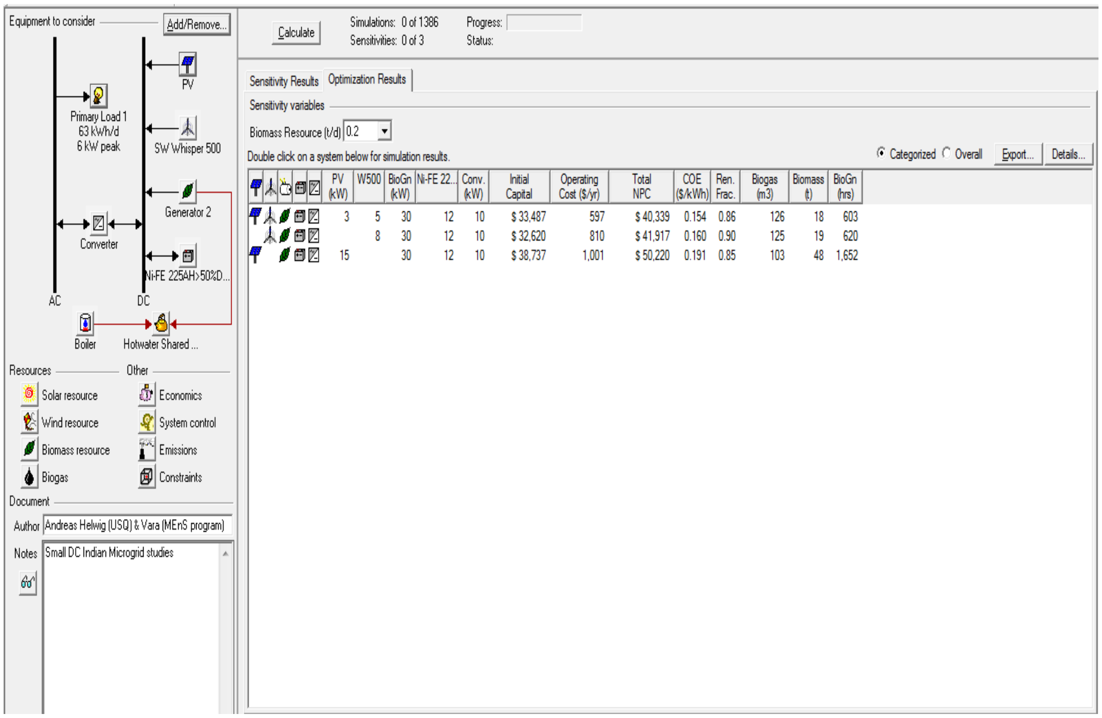


Figure C.6: Optimization results for half subsidized Capital Costs 0% variability for day to day with 0% random variability for Time-steps. (Biomass resource = 0.2t/d)

C.7: Half subsidized Capital Costs 0% variability for day to day with 0% random variability for Time-steps. (Biomass resource = 0.3t/d)

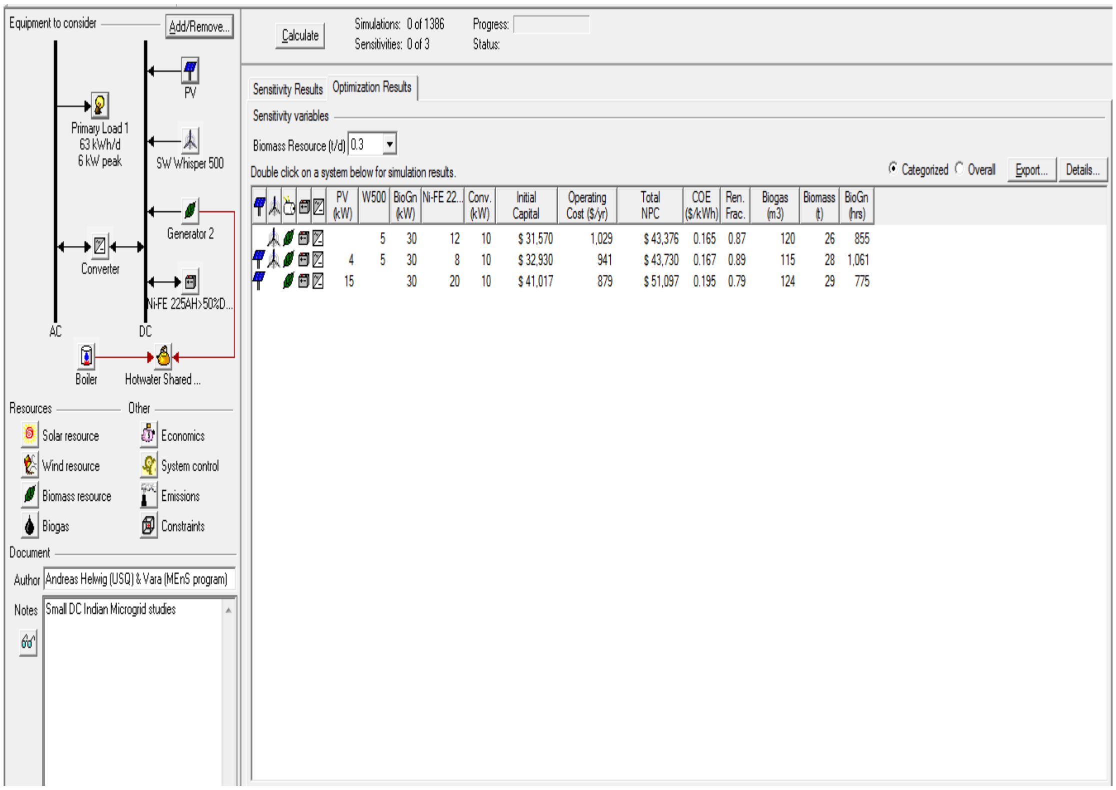
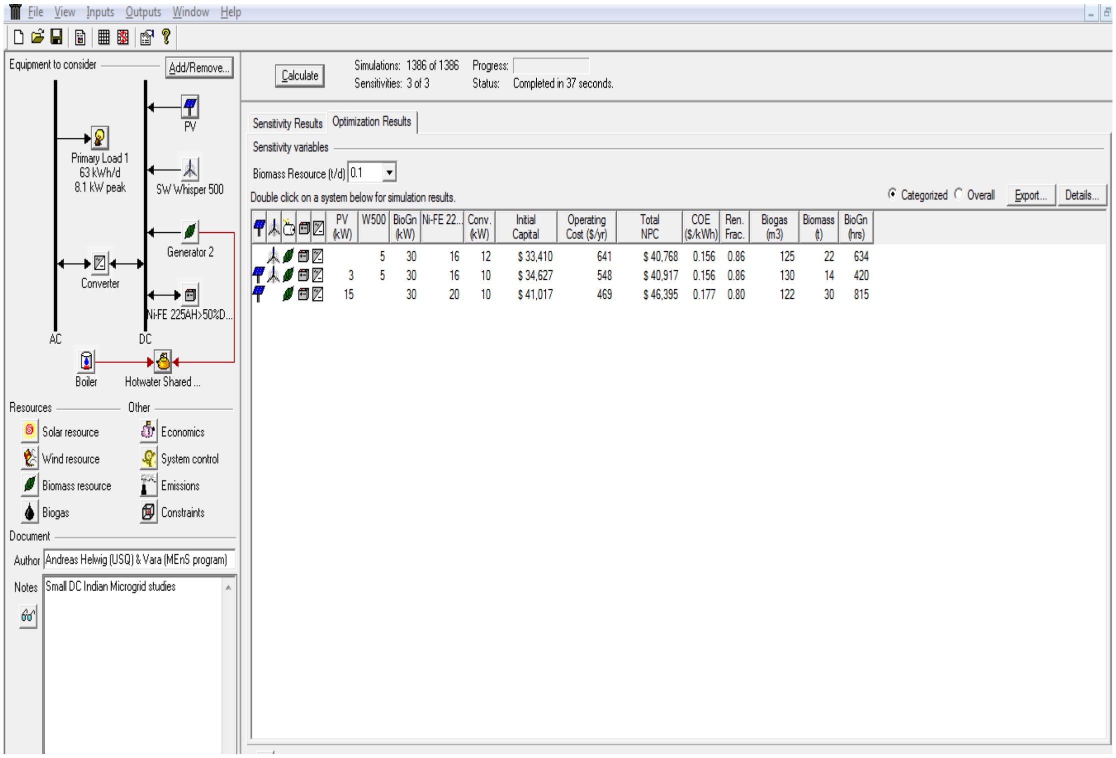


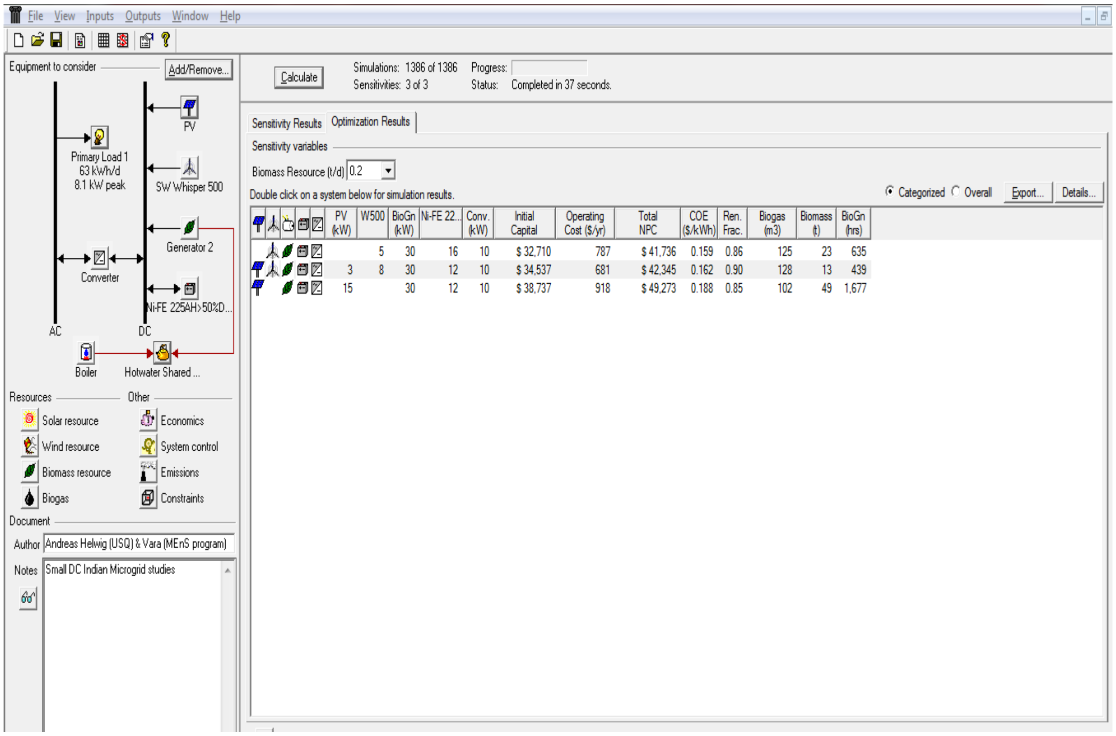
Figure C.7: Optimization results for half subsidized Capital Costs 0% variability for day to day with 0% random variability for Time-steps. (Biomass resource = 0.3t/d)

C.8: Half subsidized Capital Costs 5% variability for day to day with 10% random variability for Time-steps. (Biomass resource = 0.1t/d)



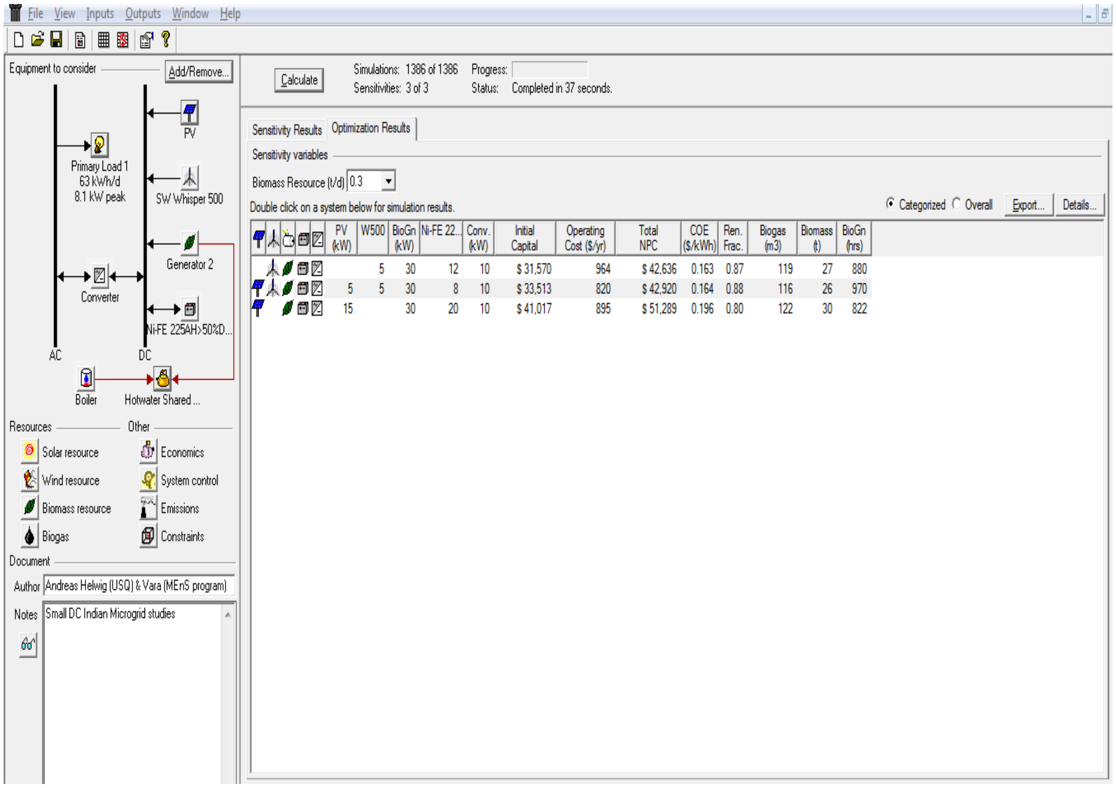
FigureC.8: Optimization result for half subsidized Capital Costs 5% variability for day to day with 10% random variability for Time-steps. (Biomass resource = 0.1t/d)

C.9: Half subsidized Capital Costs 5% variability for day to day with 10% random variability for Time-steps. (Biomass resource = 0.2t/d)



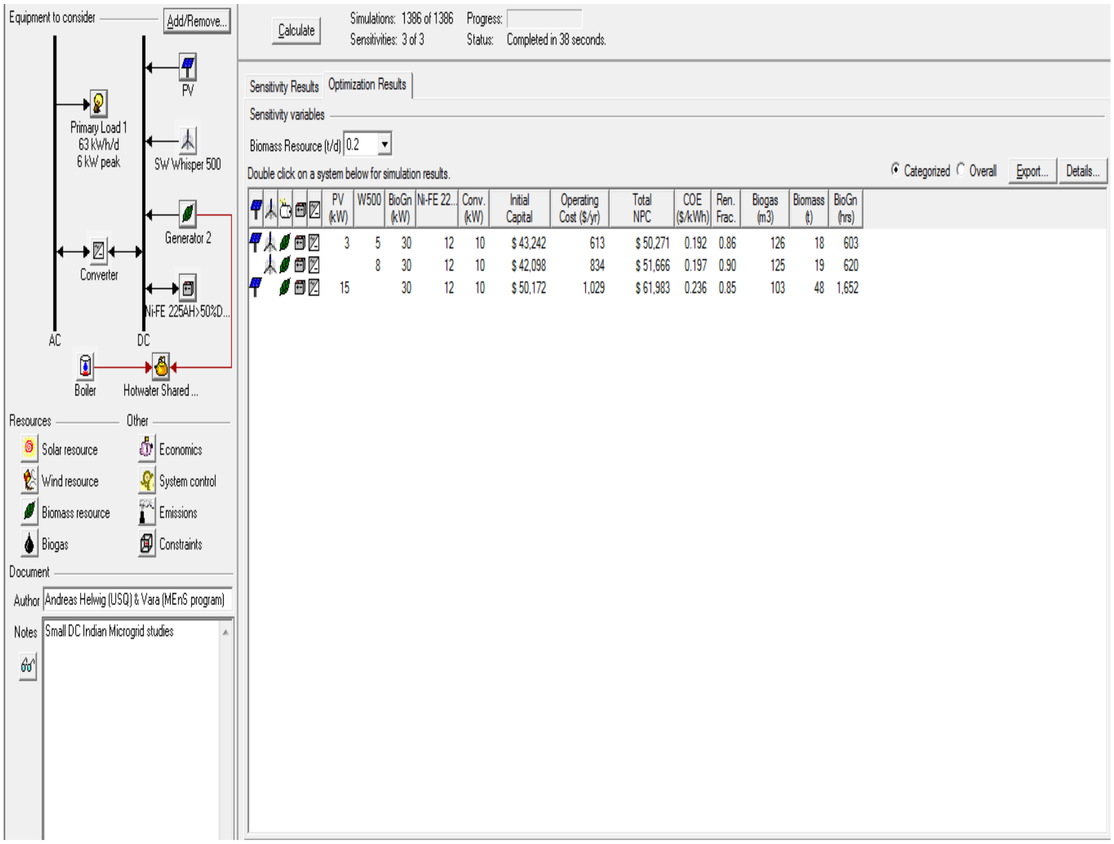
FigureC.9: Optimization result for half subsidized Capital Costs 5% variability for day to day with 10% random variability for Time-steps. (Biomass resource = 0.2t/d)

C.10: Half subsidized Capital Costs 5% variability for day to day with 10% random variability for Time-steps. (Biomass resource = 0.3t/d)



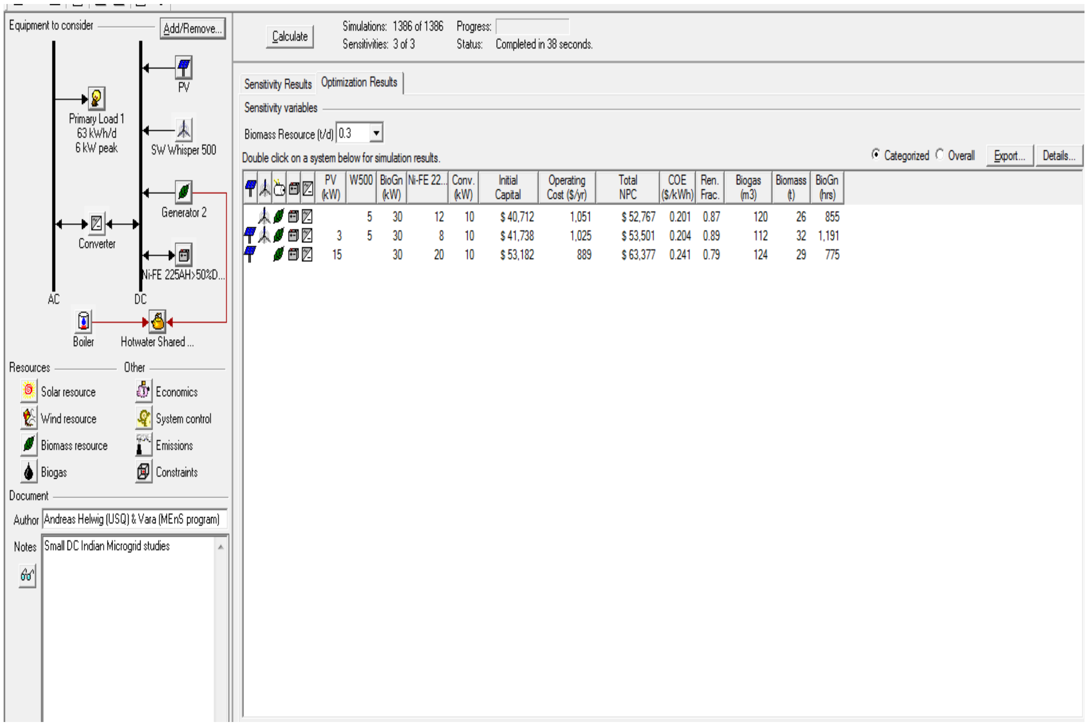
FigureC.10: Optimization result for half subsidized Capital Costs 5% variability for day to day with 10% random variability for Time-steps. (Biomass resource = 0.3t/d)

C.11: 66% Subsidized Capital Costs 0% variability for day to day with 0% random variability for Time-steps. (Biomass resource = 0.2t/d)



FigureC.11: Optimization result for 66% subsidized Capital Costs 0% variability for day to day with 0% random variability for Time-steps. (Biomass resource= 0.2t/d)

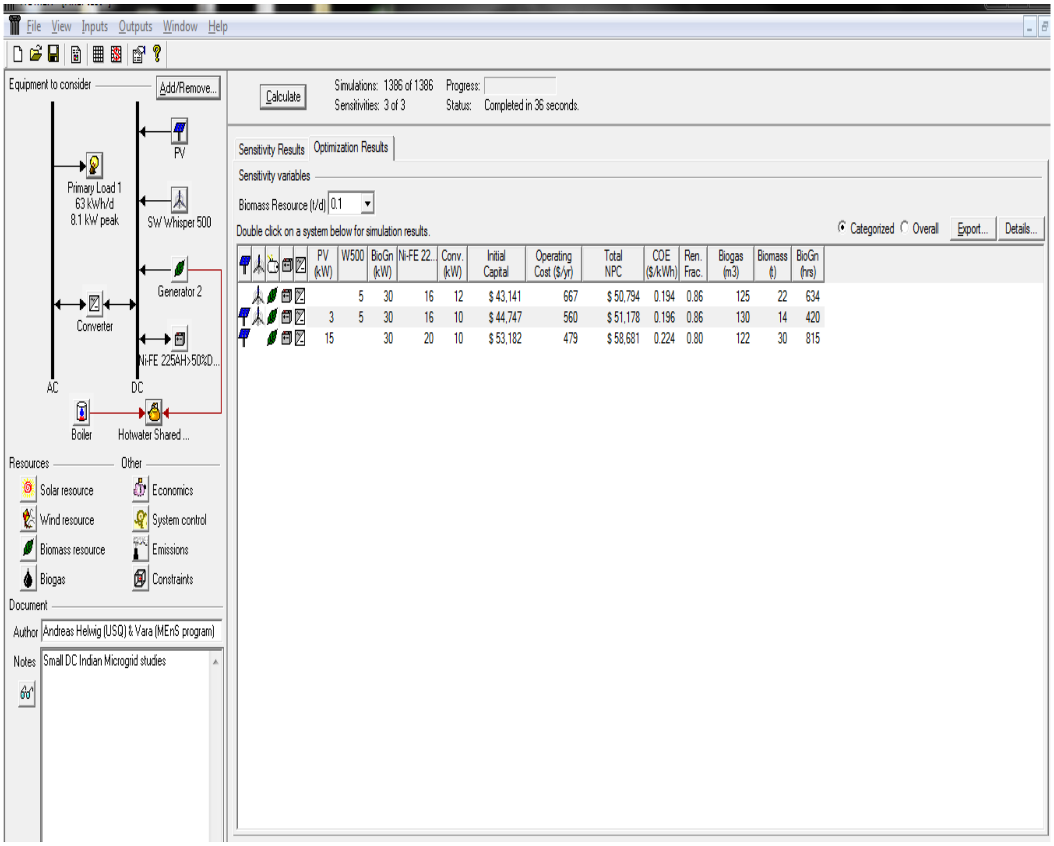
C.12: 66% Subsidized Capital Costs 0% variability for day to day with 0% random variability for Time-steps. (Biomass resource = 0.3t/d)



PV (kW)	W500	BioGn (kW)	Ni-FE 22...	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Biogas (m3)	Biomass (t)	BioGn (hrs)
	5	30	12	10	$ 40,712	1,051	$ 52,767	0.201	0.87	120	26	855
3	5	30	8	10	$ 41,738	1,025	$ 53,501	0.204	0.89	112	32	1,191
15		30	20	10	$ 53,182	889	$ 63,377	0.241	0.79	124	29	775

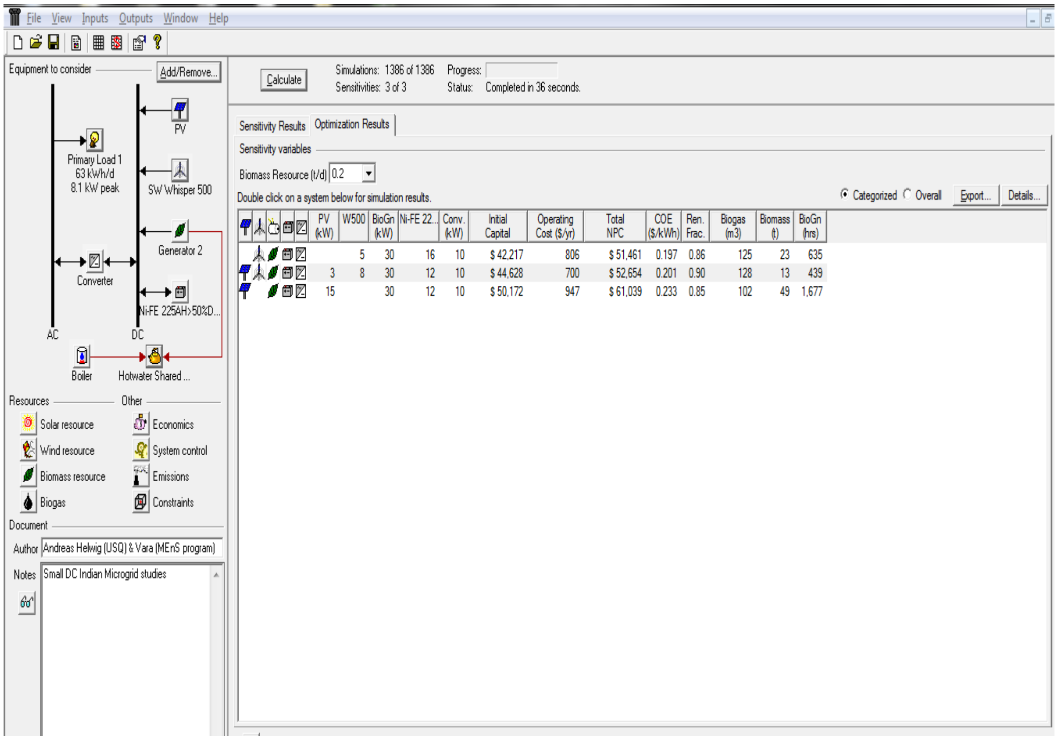
FigureC.12: Optimization result for 66% subsidized Capital Costs 0% variability for day to day with 0% random variability for Time-steps. (Biomass resource= 0.3t/d)

C.13: 66% Subsidized Capital Costs 5% variability for day to day with 10% random variability for Time-steps. (Biomass resource = 0.1t/d)



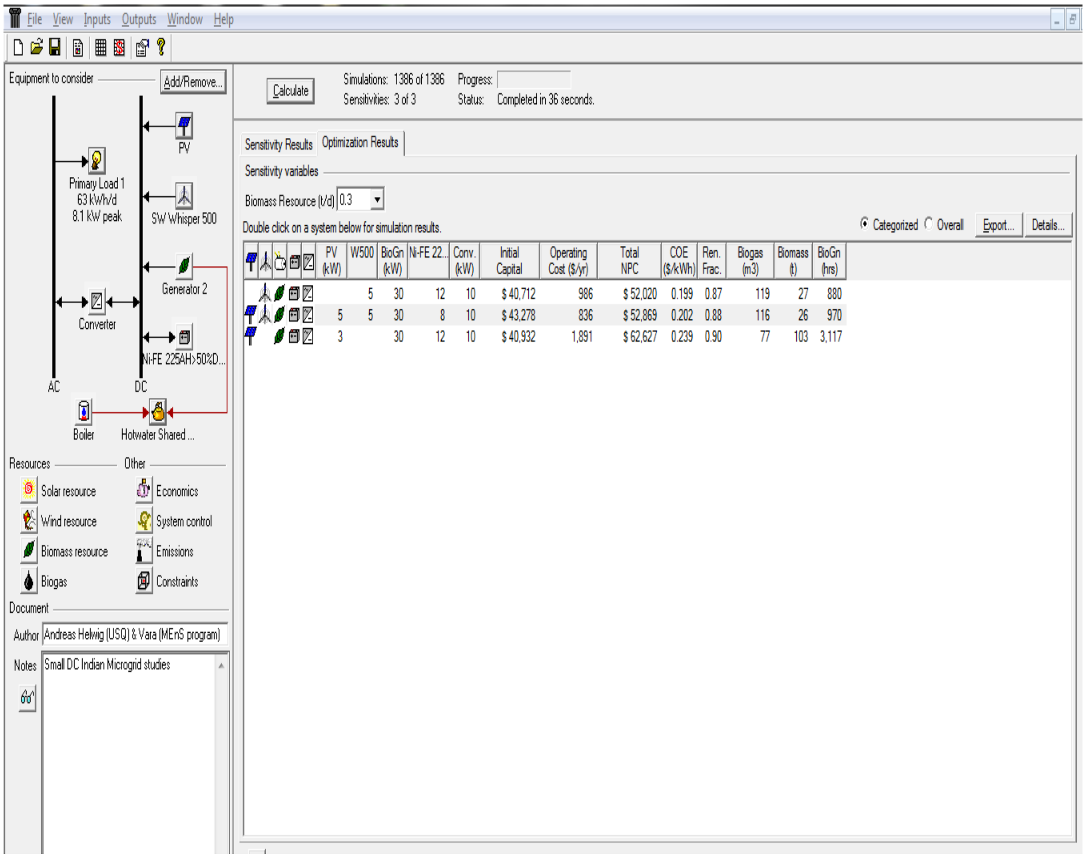
FigureC.13: Optimization result for 66% subsidized Capital Costs 5% variability for day to day with 10% random variability for Time-steps. (Biomass resource= 0.1t/d)

C.14: 66% Subsidized Capital Costs 5% variability for day to day with 10% random variability for Time-steps. (Biomass resource = 0.2t/d)



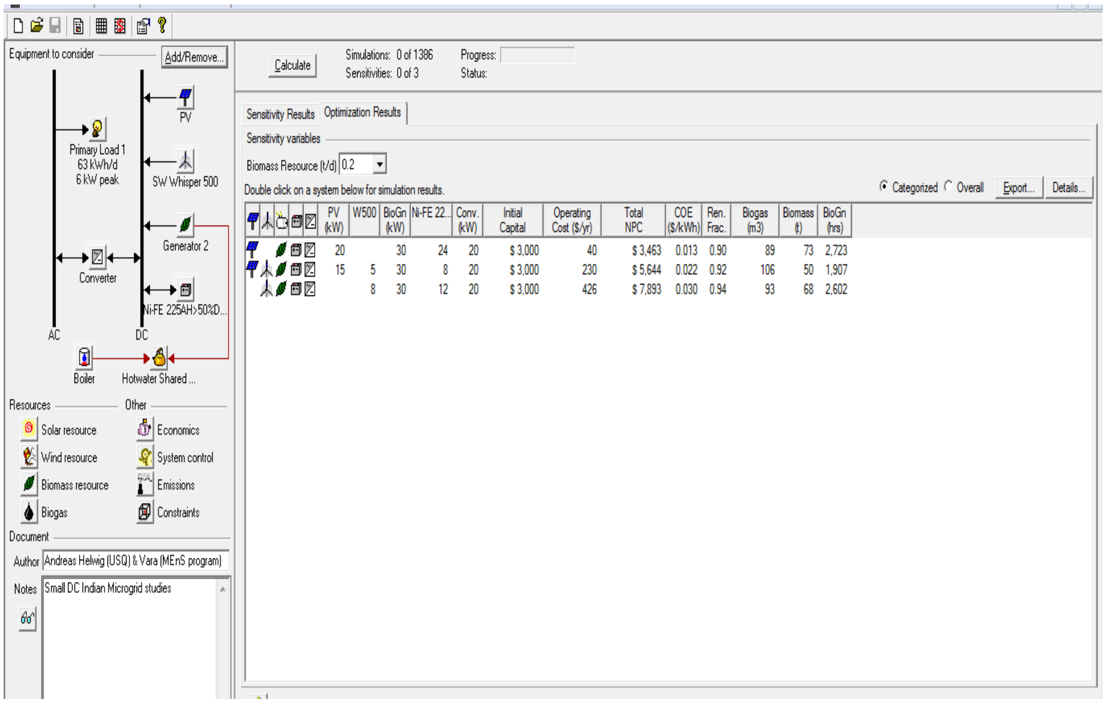
FigureC.14: Optimization result for 66% subsidized Capital Costs 5% variability for day to day with 10% random variability for Time-steps. (Biomass resource= 0.2t/d)

C.15: 66% Subsidized Capital Costs 5% variability for day to day with 10% random variability for Time-steps. (Biomass resource = 0.3t/d)



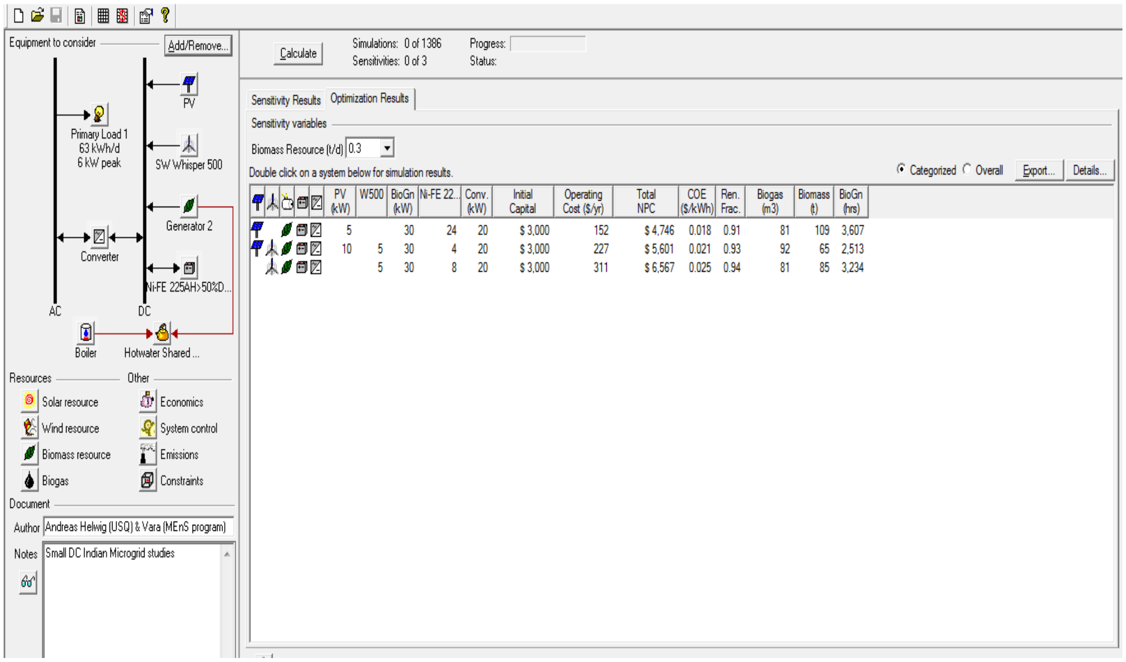
FigureC.15: Optimization result for 66% subsidized Capital Costs 5% variability for day to day with 10% random variability for Time-steps. (Biomass resource= 0.3t/d)

C.16: Fully Government subsidized Capital Costs 0% variability for day to day with 0% random variability for Time-steps. (Biomass resource = 0.2t/d)



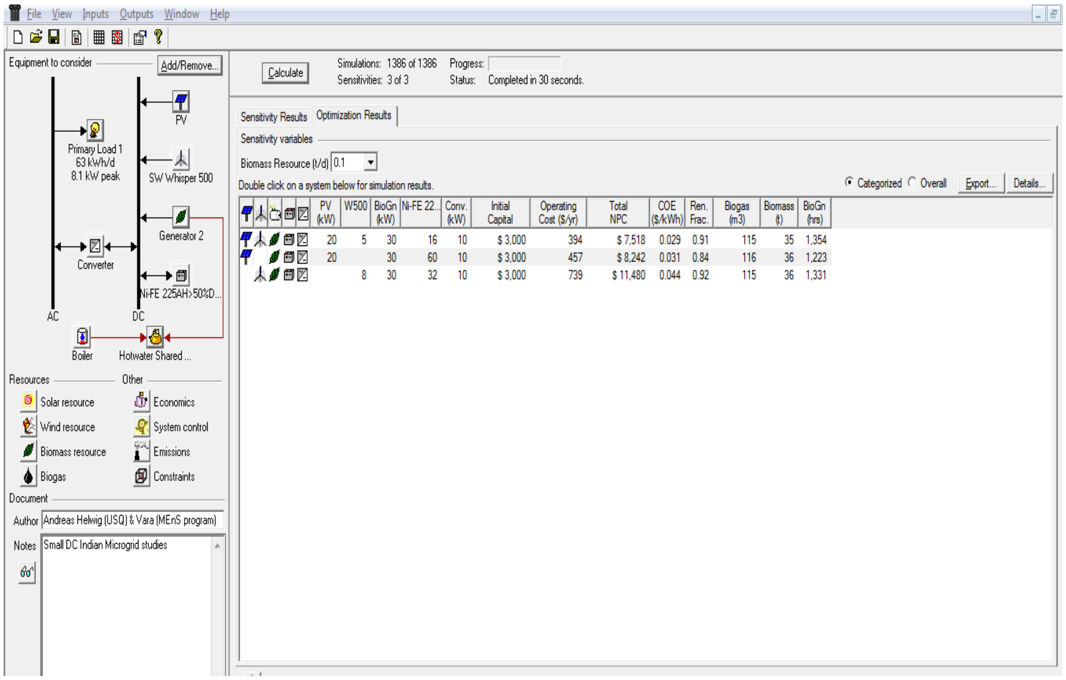
FigureC.16: Optimization result for fully Government subsidized Capital Costs 0% variability for day to day with 0% random variability for Time-steps. (Biomass resource = 0.2t/d)

C.17: Fully Government subsidized Capital Costs 0% variability for day to day with 0% random variability for Time-steps. (Biomass resource = 0.3t/d)



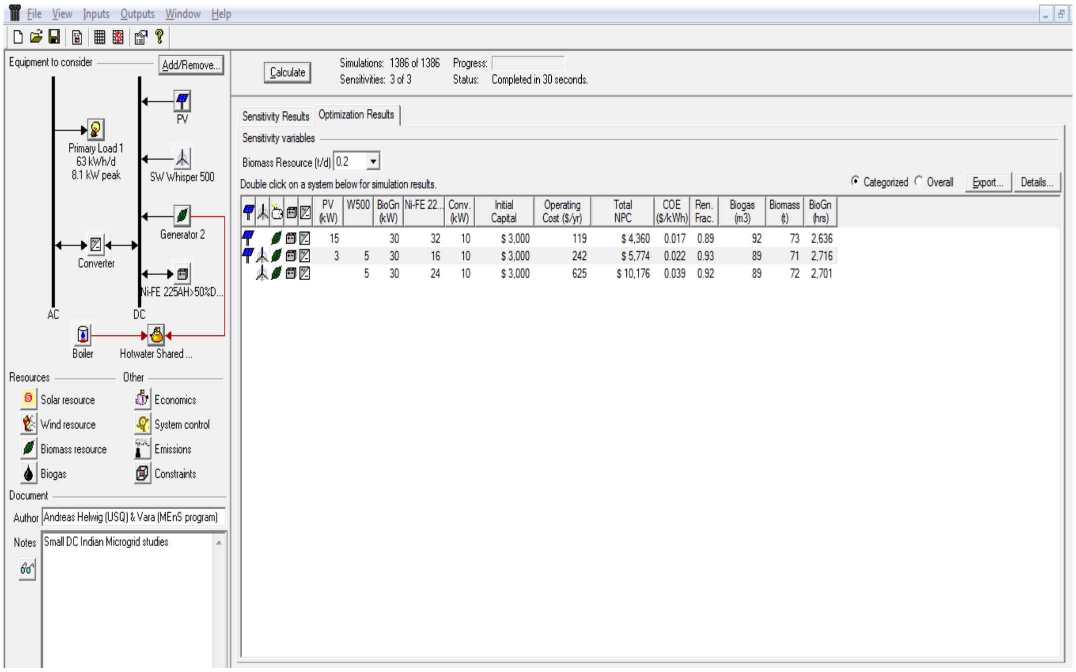
FigureC.17: Optimization result for fully Government subsidized Capital Costs 0% variability for day to day with 0% random variability for Time-steps. (Biomass resource = 0.3t/d)

C.18: Fully Government subsidized Capital Costs 5% variability for day to day with 10% random variability for Time-steps. (Biomass resource = 0.1t/d)



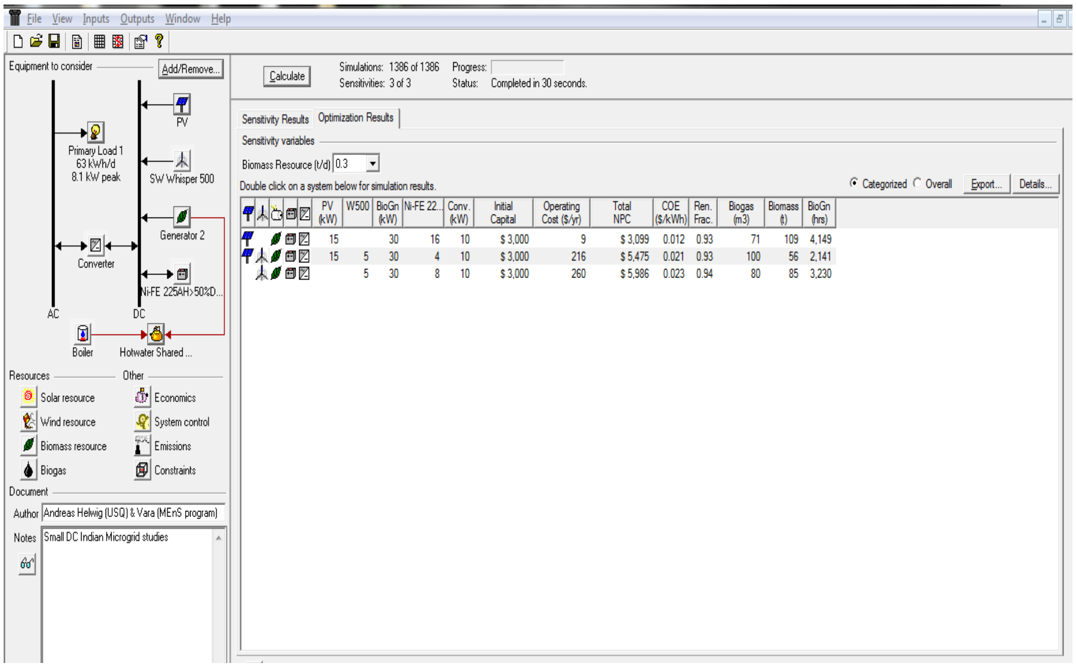
FigureC.18: Optimization result for Fully Government subsidized Capital Costs 5% variability for day to day with 10% random variability for Time-steps. (Biomass resource = 0.1t/d)

C.19: Fully Government subsidized Capital Costs 5% variability for day to day with 10% random variability for Time-steps. (Biomass resource = 0.2t/d)



FigureC.19: Optimization result for Fully Government subsidized Capital Costs 5% variability for day to day with 10% random variability for Time-steps. (Biomass resource = 0.2t/d)

C.20: Fully Government subsidized Capital Costs 5% variability for day to day with 10% random variability for Time-steps. (Biomass resource = 0.3t/d)



FigureC.20: Optimization result for Fully Government subsidized Capital Costs 5% variability for day to day with 10% random variability for Time-steps. (Biomass resource = 0.3t/d)

Appendix D- PLC PROGRAMMING USING ZELIO SOFTWARE

D.1 SR3B262BD CPU MODULE

Figure D.1: SR3B262BD CPU Module

The standard specifications specified by the Schneider Electric for the SR3B262BD is presented below. (Source: www.schneider-electric.com)

Specifications of the module:

- Number or control scheme lines : 120 with ladder programming/<= 200 with FBD programming
- Cycle time: 6...90 millisecond
- [Us] rated supply voltage : 24 V DC
- Supply voltage limits : 19.2...30 V
- Supply current : 70 mA (without extension) / 180 mA (with extensions)
- Power dissipation in W :5 W without extension
- Discrete input number :16 conforming to EN/IEC 61131-2 type 1
- Discrete input type : Resistive
- Discrete input voltage : 24 V DC
- Discrete input current : 4 mA
- Counting frequency : 1 kHz for discrete input

- Analogue input number : 6
- Analogue input type : Common mode
- Analogue input range : 0...10 V/0...24 V
- Analogue input resolution : 8 bits
- Number of outputs : 10 transistor output(s)
- Output voltage : 24 V (transistor output)
- Output voltage limits : 19.2...30 V DC (transistor output)
- Overload protection : With, transistor output
- Short-circuit protection : With transistor output
- Overvoltage protection : With, transistor output
- IP degree of protection : IP40 (front panel) conforming to IEC 60529/ IP20 (terminal block) conforming to IEC 60529
- Ambient air temperature for operation : -4...131 °F (-20...55 °C) conforming to IEC 60068-2-1 and IEC 60068-2-2 / -4...104 °F (-20...40 °C) in non-ventilated enclosure conforming to IEC 60068-2-1 and IEC 60068-2-2
- Ambient air temperature for storage : -40...158 °F (-40...70 °C)
- Operating altitude : 6561.68 ft (2000 m)
- Altitude transport : <= 10000 ft (3048 m)
- Relative humidity: 95 % without condensation or dripping water.

D.2 Configurations used in the programming

No	Symbol	Function	Lock	Latching	Parameters	Comment
B03		Input integer	---	---	No parameters	Total Load On Day Supply
B04		Numerical constant	No	---	Value of the constant : 125	125%
B05		Numerical constant	No	---	Value of the constant : 100	100 %
B07		Comparison of 2 values	---	---	VALEUR 1 VALEUR 2	1.25 comparison
B08		Input integer	---	---	No parameters	Historic Data
B12		Input integer	---	---	No parameters	Meteorological Data
B13		Numerical constant	No	---	Value of the constant : 12	12%
B14		Numerical constant	No	---	Value of the constant : 24	24%
No	Symbol	Function	Lock	Latching	Parameters	Comment
B40		MUL/DIV	---	---	No parameters	C1 - Night
B41		MUL/DIV	---	---	No parameters	C2 - Day
B42		MUL/DIV	---	---	No parameters	C2 - Night

Figure D.2a Configurations used in the programming

B43		MUL/DIV	---	---	No parameters	C3 - Day
B44		MUL/DIV	---	---	No parameters	C3 - Night
B45		MUL/DIV	---	---	No parameters	C4 - Day
B46		MUL/DIV	---	---	No parameters	C4 - Night
B47		MUL/DIV	---	---	No parameters	C5 - Day
B48		MUL/DIV	---	---	No parameters	C5 - Night
B62		Daily, weekly and yearly programmer	No	---	See details below	
B67		Comparison of 2 values	---	---	VALEUR 1 – VALEUR 2	
B69		Cyclic timing	No	No	On time : 0H 0M 1S Off time : 0H 0M 5S Function Li - Continuous flashing	
B70		Daily, weekly and yearly programmer	No	---	See details below	
B71		Logic AND	---	---	No parameters	Night Enable
B82		Daily, weekly and yearly programmer	No	---	See details below	
B83		Comparison of 2 values	---	---	VALEUR 1 – VALEUR 2	
B85		Cyclic timing	No	No	On time : 0H 0M 1S Off time : 0H 0M 5S Function Li - Continuous flashing	
B86		Daily, weekly and yearly programmer	No	---	See details below	
B90		Daily, weekly and yearly programmer	No	---	See details below	
B91		Comparison of 2 values	---	---	VALEUR 1 – VALEUR 2	
No	Symbol	Function	Lock	Latching	Parameters	Comment
B93		Cyclic timing	No	No	On time : 0H 0M 1S Off time : 0H 0M 5S Function Li - Continuous flashing	
B94		Daily, weekly and yearly programmer	No	---	See details below	
B98		Daily, weekly and yearly programmer	No	---	See details below	
B99		Comparison of 2 values	---	---	VALEUR 1 – VALEUR 2	

Figure D.2b Configurations used in the programming

D.3 Zelio Logic Program for load sharing of energy between the customers

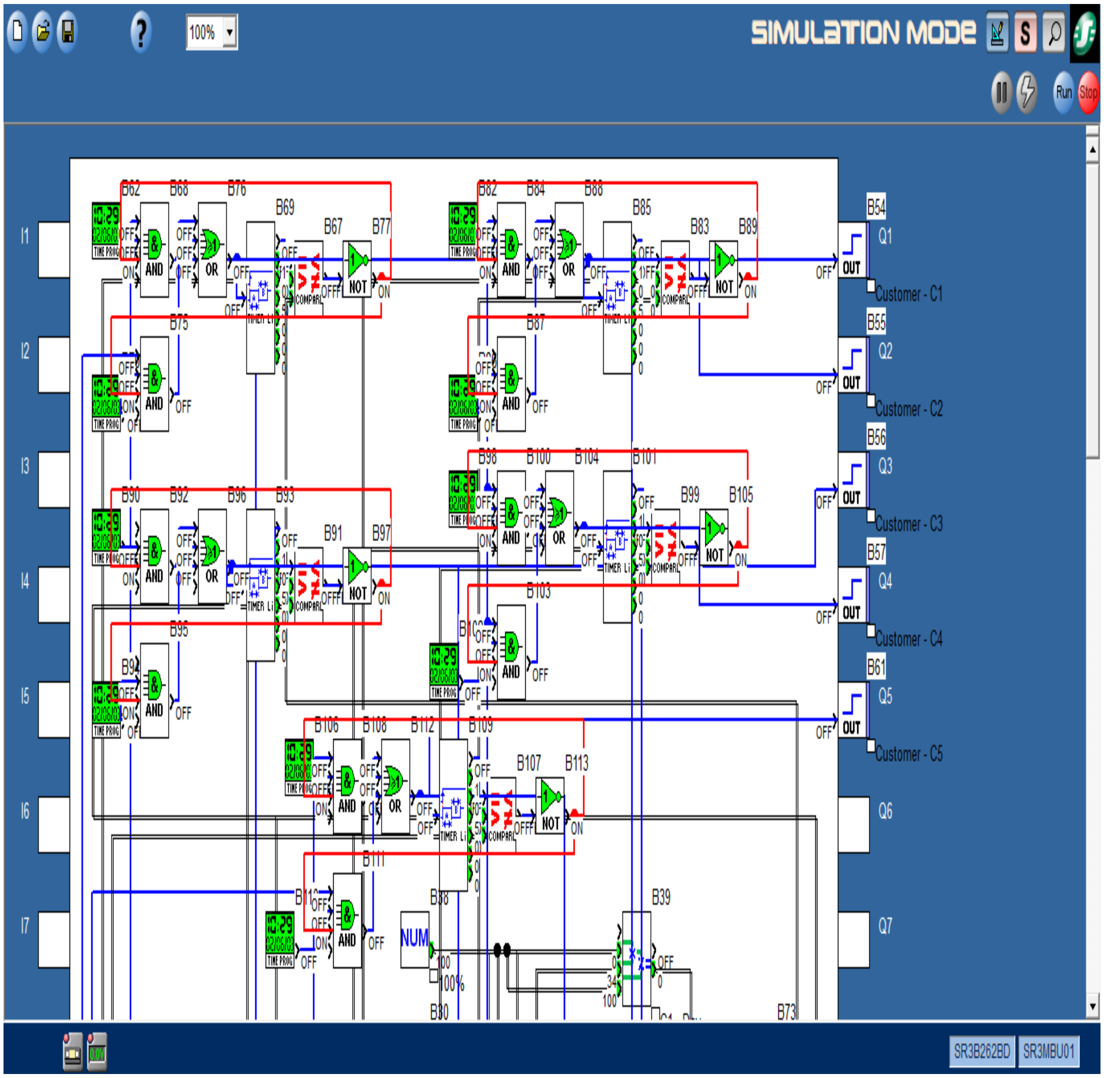


Figure D.3a: Zelio logic for the load sharing of energy between the customers

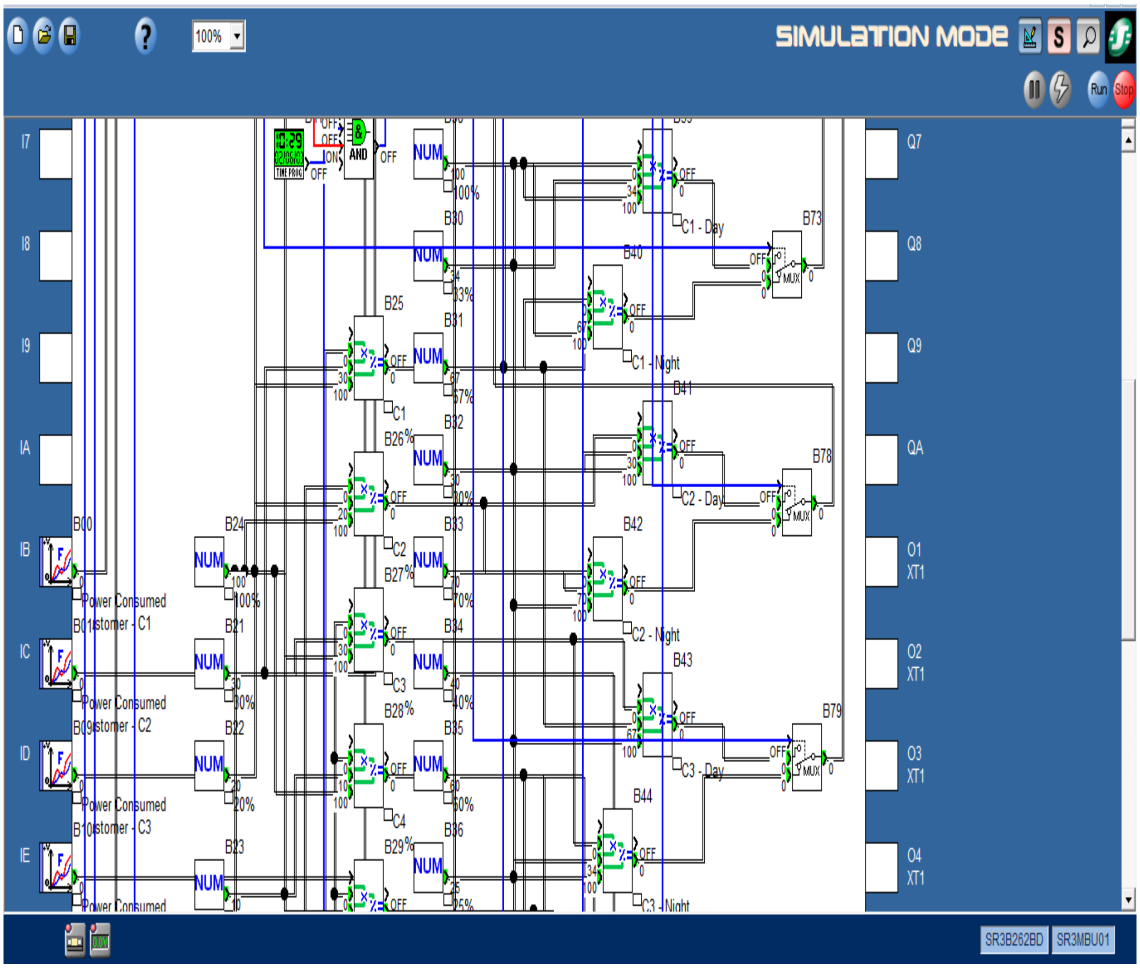


Figure D.3b: Zelio logic for the load sharing of energy between the customers

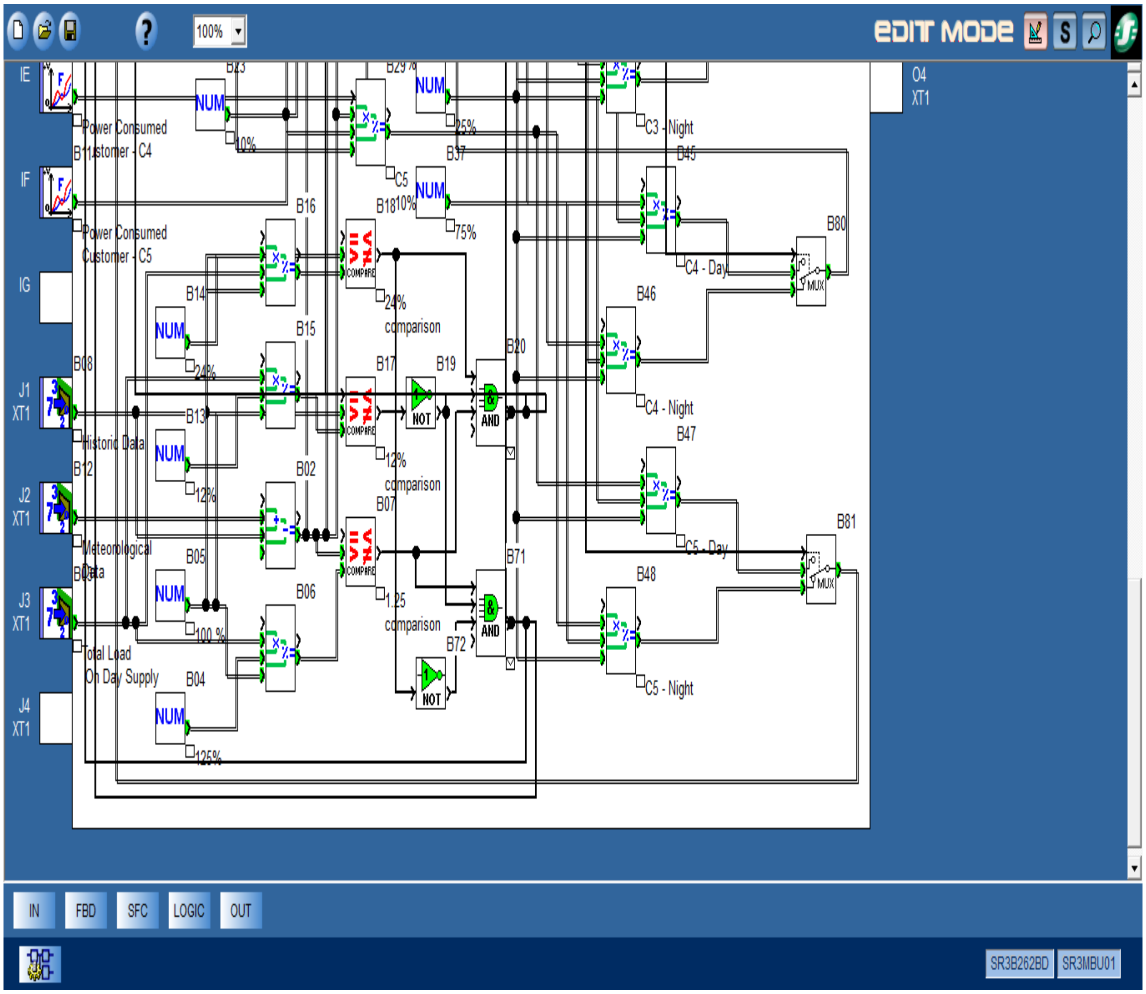


Figure D.3c: Zelio logic for the load sharing of energy between the customers

After setting up the functional blocks in the logic, press the simulation button as well as the run button as shown in the figures D.3a to D.3c. Then the program will execute and turns into the red color indicating that the load is delivered to the particular customer during the given period of time. In the J1-XTI port, the load value is entered to the input depending upon the requirements of the energy needed by the customers. For example if we choose to enter 50MW of energy, then this value is divided between the customers during the day time and night time. Hence the load sharing of energy can be monitored by using the PLC such that it reduces the human error in dispatching the energy.