THE REPUBLIC OF TURKEY
BAHCESEHIR UNIVERSITY

SIZE OPTIMIZATION OF SOLAR AND WIND HYBRID SYSTEM

Master Thesis

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INDUSTRIAL ENGINEERING

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Thesis Supervisor: Prof. Dr. MEHMET BARIŞ ÖZERDEM

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I dedicate my thesis to my beloved parents and to my wife Sevcan Çelebi Yousaf**,** my foundation of motivation and strength, who have devoted their years supporting my study, that make me feel loved, proud and fortunate.

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ABSTRACT

SIZE OPTIMIZATION OF SOLAR AND WIND HYBRID SYSTEM

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Industrial Engineering

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The oil price instability, the growing ratio of global warming, and the finishing reserves of oil and gas have made it unavoidable to look for some other energy resources. Numerous countries are going toward the option of clean and less harmful renewable energy. Furthermore, solar photovoltaic (PV)–Wind/battery hybrid power production system technology is developing energy substitute since it acquires prospects for industrialized and emerging countries.

The objective of the study is size optimization of hybrid energy system in order to replace typical grid connected system with renewable energy resources consists of PV panels, wind turbines, batteries and generator to meet the energy consumption of a normal house. The thesis is going to consider three scenarios which are grid-tied, off-grid and load-shedding/power cut hours. The conventional grid connected system is providing energy at an average cost of $0.12/kWh and overall Net Present Cost of that system is more than $6000 for the projected lifetime span of 25 years. The aim is to design an optimal hybrid system with renewable energy resources with better and less price and rate of returns with lesser payback time than already existing energy system. The selected location for this study is a city of Islamabad in Pakistan with Latitude 33.5 and longitude 73.5. For analysis, there are two sensitivity variables are used for comparison which are wind speed and diesel fuel prices for diesel generator.

Keywords: Solar, Wind, Hybrıd System, On/Off Grid, Homer.

ÖZET

GÜNEŞ VE RÜZGAR HIBRIT SISTEMI BOYUTU OPTIMIZASYONU

Khurram Yousaf

Endüstri Mühendisliği

Tez Danışmanı: Prof. Dr. Mehmet Barış Özerdem

Haziran 2015, 137 Sayfa

Petrol fiyatlarındaki istikrarsızlık, küresel ısınmanın artan kaygıları, petrol ve gaz kaynaklarının tükenmesi yenilenebilir kaynak arama fikrini kaçınılmaz hale getirdi. Sayısız ülke petrolden elde edıen enerji yerine, temiz ve daha az zararlı olan yenilebilir enerji kaynaklarına yöneldi. Dahası, gelişmiş ve gelişmekte olan ülkerler için, zorluklarla başa çıkılması ve fırsatlar akımından güneş fotovoltaik (PV) –rüzgar / pil hibrid güç üretim sistemi yükselen bir enerji alternatifidir.

Bu çalışmanın amacı, nomal bir evin tüketimini karşılamak için, PV paneller, rüzgar türbinleri, piller ve jeneratör olan hibrid enerji sistemlerinin kullanımını ilgi çekici bir hale getirip, insanları teşvik etmektir. Tez üç farklı senaryoyu göz önüne alıyor; Şebekeye bağlı, şebekesiz ve elektrik kesintisi. Konvansiyonel şebeke bağlantılı sistemin ortalama maliyeti \$0.12/kWh ve 25 yıllık bir projede şimdiki net maliyet \$6000'dan daha fazladır. Amacımız, daha verimli ve daha ucuz yenilebilir hibrid enerji kaynakları tasarlamak ve zaten mevcut olan enerji sisteminden daha kısa zamanda geri ödeme sağlamaktır. Bu çalışma için seçilen yerleşke 33.5 enleminde ve 73.5 boylamında olan Islamabad Pakistan'dadır. Analiz edildiğinde, iki hassasiyet değiskenin kullanıldığı karşılaştırmalardan birincisi rüzgar hızı ve ikincisi dizel jeneratör için dizel yakıt fiyatlarıdır.

Anahtar Kelimeler: Rüzgar, Fotovoltaik, Hibrid, On/Off Grid, Homer.

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LIST OF ABREVIATIONS

AC	:	Alternating current
COE	:	Costs Of Energy
CO_2	:	Carbon monoxide
DC	:	Direct current
DOD	:	Depth of discharge
HOMER	:	Hybrid Optimization Model for Electric Renewable
KWh	:	kilo Watt hour
MPPT	:	Maximum Power Point Tracking
NPC	:	Net present cost
NREL	:	National Renewable Energy Laboratory
O&M	:	Operation and maintenances
PV	:	Photovoltaic
PDF	:	Probability density function

RER : Renewable energy resources

1. INTRODUCTION

1.1 WHAT IS ENERGY?

Energy is significant to everybody. Any activity and human activity is obligatory energy. Energy is playing an essential role for human life. Energy can appear in a lot of different forms like mechanical energy, chemical energy, radiant energy, thermal energy and it also can use to transform into different forms such as movement, heating and vibration. In 20th century, oil and gas had played an essential role as energy resources in the world. Oil and gas form leading resources of energy currently. All this resources are non-renewable resources and it will exhaust out in the future years. Scientists had discovered out this matter and looking for the avoidance method. Anticipation method had supported out from the scientists that are using renewable sources as spare for the non-renewable resources.

1.2 RENEWABLE ENERGY RESOURCE

There are a lot of types of renewable energy resources presently develop such as solar energy, wind energy, thermal energy and many others. These renewable energy sources are not fully develop when the price of petroleum is little. The scarcity of non-renewable resources effected the market and price of petroleum timid. People are returning back to renewable energy resources. Renewable energy is infinite and clean for atmosphere. For instance, solar energy can generate electricity when sunny days while wind energy can generate electricity when windy weather condition. Although renewable energy sources are produce less energy compare with energy yield from petroleum, it helps to protect environment and dropping the shortage of non-renewable sources.

1.3 HYBRID SYSTEMS

The Hybrid PV and Wind Electricity System is well suitable for the conditions where sun light and wind have seasonal shifts, for example, in summer the sun light is abundant but windless, while in winter wind resource increased that can complement the solar resource. The dependability of the stand-alone hybrid PV-wind system in generating energy has been proven by earlier research. From last 20 years the renewable energies especially solar and wind energies are more preferable as compared with conventional energy system. These substitute energy resources are clean, green, free in their obtainability and renewable. But high capital cost, predominantly for photovoltaic, made its growth a sluggish. The best method to endeavour to cut the cost of these systems is by making use of hybrid designs that uses both wind and photovoltaic.

1.4 STRUCTURE OF THESIS

To make it simply, the thesis is written into few fractions which are divided into following parts:

First part is discussing the background and geography of the country, potential of renewable resources in the country, i.e. wind and solar energy potentials in the country.

Second Part will show the study of the wind energy potentials. It is comprises of study for the resources of wind energy, the energy generated by wind turbine, calculations with formulas, method to select and design wind turbine.

Third Part carries basic hypothetical related research into solar energy. In this part, consultation are made regarding the sun as a source of energy, study of solar radiation from sunshine and ıts data and other solar related details are discussed.

Fourth part would cover a brief introduction to batteries, inverters and control charger and drop some light on general workings of these components.

In Fifth part, the thesis will illustrate the findings of three different scenarios which has been taken into account for the size optimization of hybrid system. This part will also show the results, graphs, tables and other data for selected optimal hybrid designs according to their NPC, COE, Initial cost, and renewable energy resources saturation in the hybrid system and characteristics of converters and batteries.

The last part of this Thesis would propose the conclusion of the study done on optimal hybrid sizes and give some recommendations for further work in advancements. Later this study would give the bibliography and Appendix for more concerned data. The household consumer profile has also been mentioned briefly.

2. LITRERATURE REVIEW

2.1 BACKGROUND AND GEOGRAPGHY OF LOCATION

Pakistan is situated in continent of Asia between 23.30 degree and 36.45 degree latitude (North) and 61 degree and 75.45 degree longitude (East). Pakistan is a geographic and cultural wonderland. Situated at the cross-roads in Asia geographically Pakistan has the benefit of a very exceptional landscape. Pakistan occupies a position of great geostrategic significance, touched by Iran on the west, Afghanistan on the northwest, China on the northeast, India on the east, and the Arabian Sea on the south. The total land area is estimated at 803,940 square kilometres.

Figure 2.1: Map of Pakistan

Source: Wikipedia

2.2 PREVIOUS STUDIES ON HYBRID SYSTEMS

For many economic and environmental reasons and to decline the reliance on typical conventional energy systems, numerous countries in the world are devoting intrest in alternative and renewable energy to protect themselves from unseen circumstances. Relatively great research, explanation and development are needed for this reason. It is also potential to integrate RERs with usual power systems to lessen the cost of energy (COE). Wind and photovoltaic (PV) systems are one of the most promising technologies nowadays but they offer many challenges to steadiness and consistency of the system due to their irregular and fluctuating nature. Various forecasting procedures and calculation models play an imperative role in handling these uncertainties [2]. It is crucial to consider the dynamics and intermittency of RERs while designing systems for their broad use [3]. One of the main factors that make these systems more cost effective is reduced fuel cost together with O&M cost.

Adequate research has been done on applications and role of renewable technology in industrial countries but it is still in its initial stages of adoption in Pakistan. Payyad and Moubayed [4] discussed different configurations of PV panels, wind turbines and diesel generator to supply the load of a typical house. The optimal solution was obtained on the basis of lowest NPC and lowest COE. Mahmud et al. [5] projected a hybrid system for a remote island having electricity requirement of 53 kWh/day. Different simulations were performed in HOMER and PV/Wind/Diesel/Battery system was found most feasible. Razak et al. [6] discussed the optimal sizing and operational strategy of hybrid energy system on the basis of total NPC. Zhang and Ma [7] did technical and economic analysis on PV/Wind system and concluded that wind speed has a huge impact on system cost. Koussa et al. [8] studied that when PV, wind and diesel systems are used together, reliability of the system is enhanced and size of the battery storage is also minimized because there is very small dependence on one system. Simic and Mikulicic [9] presented the influence of wind turbine power curve on COE for a small off grid hybrid system. Many researchers have worked on the optimal design of PV/Wind/Diesel hybrid system in HOMER but none of the literature deals specifically with the issue of using hybrid energy system for load shedding periods. This thesis provide also a comprehensive study analysis of issue mentioned earlier along with the total load needs of the site under concern. The main objective is to determine the most cost effective system configuration that can meet the consumer demand. Different case studies are simulated in HOMER and compared with existing system.

2.3 POTENTIAL OF RERs IN PAKISTAN

As a result of huge country population of about 180 million and a quickly developing economy, energy needs are potentially enormous and short fall of energy is growing sharply. The country is facing serious forthcoming energy lack as its economy and population grow while global fossil fuel prices keep on rising day by day. Load shedding in the country has affected every sector of life inadequately. According to an assessment, it costs 2.5 billion $/year to country's economy which is an average 2percent drop to its gross domestic product (GDP) [10]. In addition, it has also caused unemployment to around 400,000 people per annum [11]. Therefore it is necessary to utilize the available RERs to meet the required demand of consumers.

Pakistan's major energy supply mix consists of fossil fuels like wood, coal, oil, gas etc which contribute to 65percent of the total supply [12]. The country is blessed with abundant wind and solar resources. One study shows that the overall wind potential in Pakistan is about 346,000 MW [13]. But this opportunity is available only in certain coastal areas of the country and transmitting this power to other cities is a huge task. Therefore, use of wind energy is limited to the remote consumers only [10]. Solar insolation levels are also very high in Pakistan and average daily surface radiation in most of the areas is above 5 $kWh/m^2/day$ [14]. Another problem is the social acceptance of these energy systems as compared to other countries in the region like Malaysia, India and China. Recently, India has injected about 1100 MW of renewable energy to their power systems [15]. Moreover, the energy planners are concerned about the capital cost of this system [16]. Therefore, proper incentives are needed to promote RERs and if these resources are properly utilized, they can greatly affect the total generation.

2.4 ENERGY GROWTH OF PAKISTAN

2.4.1 Economy

Pakistan's economy is growing intensively for energy requirements and the energy supplies are coming into country from the mean of imports It can be seen from the growth of population, the energy demand is also growing very fast. The duration of last 10 years shows the rise of 4.95 percent in energy demand per annum, whereas the the population has been increasing with the rate of 2.26 percent [17]. Special attention has been paid by the policy makers to minimize the demand at peak hours like in morning and in evening. This kind of policies will help the country to reduce the amount of investments and will decrease the marginal cost of energy [18].

2.4.2 Demand Supply Gap

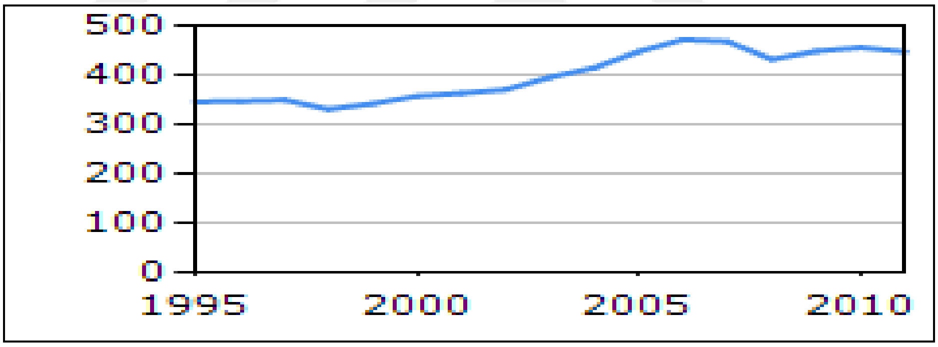
The electricity demand of Pakistan is increasing with the compound rate of growth at the rate of 7.9 percent during the period of 2005 to 2010[19]. Electric used per capita in

Pakistan is around 469kWh/capita which is a very tiny amount of energy used in industrialized countries [20]. The electricity demand in Pakistan goes at peak value of 21835MW whereas the generated capacity is fluctuating between the values of 17523MW and 14640MW seasonally.

Hence the supply- demand gap is also changing with the seasonal shifts with the values between 3500-4310 MW. Presently, the supply demad gap is being controlled by some load-shedding (Power cut) to main the flow of electricity in the country. There is a load shedding of around 6 to 8 hours in big cities and in rural areas this load shedding is exceeding 12 hours per day.

Export sector often failed to accomplish the target and pledge resulting loss of international clients and good will. Overall the load shedding has shaped a negative influence on the economy of Pakistan. Figure 2.1 shows the energy consumption graph from 1995-2010.

Figure 2.2: Electric power consumption (kWh per capita)



Source: The World Bank Group

2.4.3 Energy Consumption of Household in Pakistan

24 million houses comprises residential sector of Pakistan and it is consuming around 20 percent of total energy in the country. 70 percent houses can access to the blessing of electricity in the country. National sector consume 42.15 percent of total electricity generated [17]. The survey from CRCP shows that the lighting and space cooling are two major electrical end using categories amongst household in Pakistan. Bulbs and tube lights are generally used for lighting, whereas fans, air coolers and air conditioners are used for space cooling. These two basic end uses account for two third of the total household electricity consumption [22]. Table 2.1 specify fuels consumed by the end user in residential sector [22].

Table 2.1: Fuel Utilization in Housing Sector of Pakistan

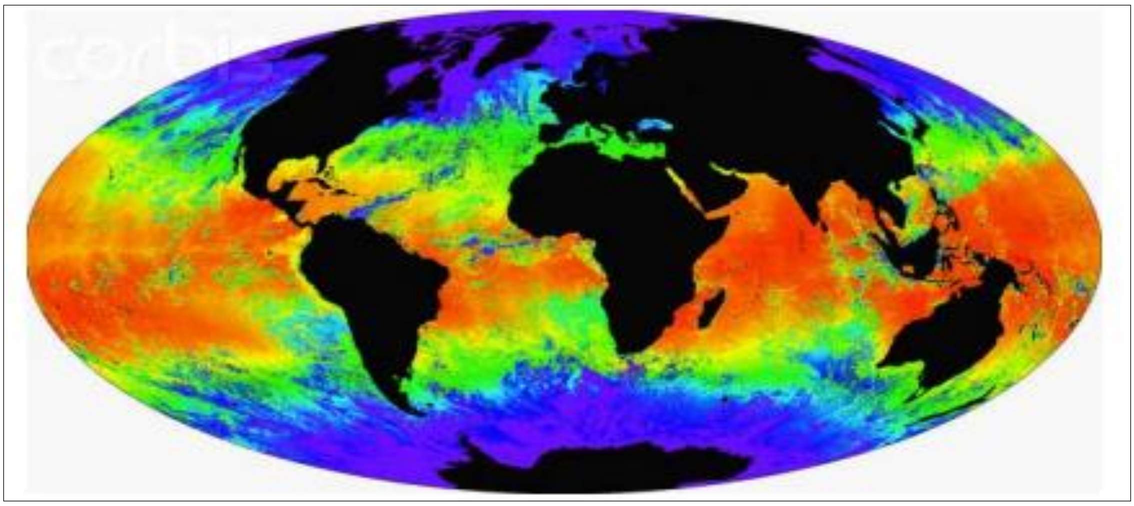
End Use	Oil	Natural Gas	Electricity
Lighting			●
Cooking	●	●	
Space heating		●	●
Water heating		●	
Other appliances		●	●

Source: Estimation of Pakistan energy growth

3. THEORY OF WIND ENERGY

3.1 SOURCE OF ENERGY

Figure 3.1: NASA satellite temperature image of globe



Source: Green Energy

The vicinity around equator is heated further by the sun as compared to the remaining part of world. The deep colours, red, orange and yellow specify the hot areas in the infra-red image (NASA satellite, 1984).

Consequently the difference between temperature and pressure, and also the Coriolis Effect, there are diverse global wind patterns at different latitudes. Trade winds, prevailing westerlies, and polar easterlies are some of the types that can be mentioned in this regard. (Danish wind, 2008).

3.2 HISTORY OF WIND ENERGY

Since many years the wind energy is being used by numerous civilizations on earth. Firstly, it was used in ships to sail it from one place to another by the wing movements.

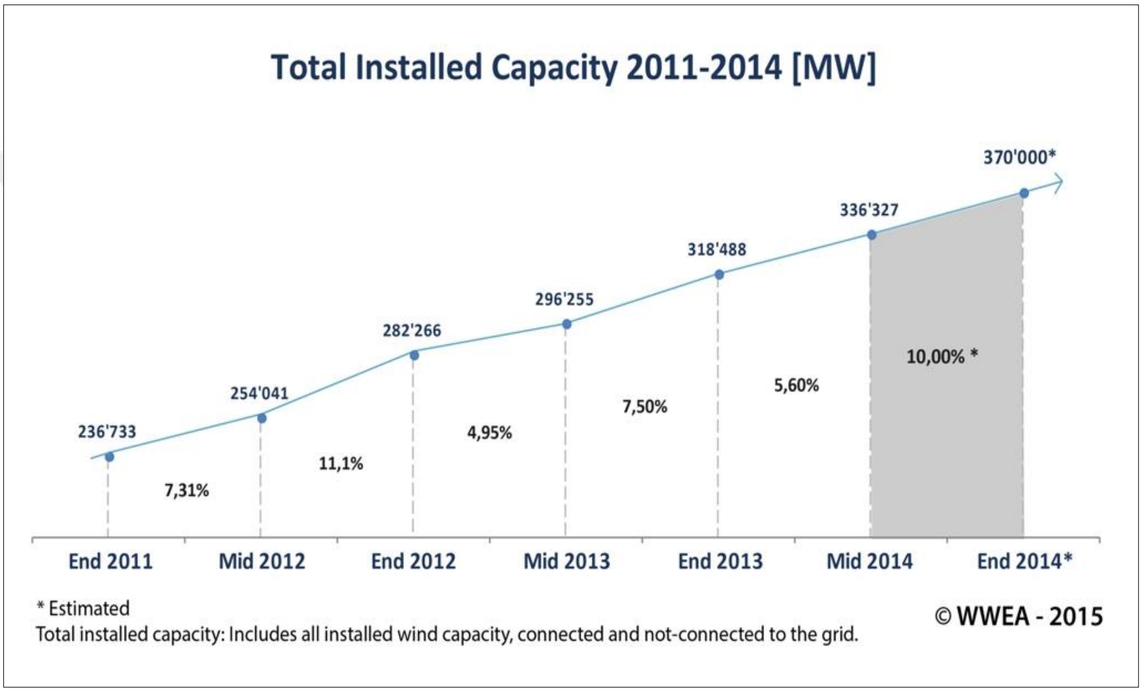
Other several human populations used this energy for transportation and other goods. This energy was used by the Europeans for the crushing of grains and to pump water in 1700s to 1800s. First ever wind turbine was installed in U.S. in 1890 for the purpose of electric generation (Patel, 2006).

On the other hand, there was not so much interest was taken into the use of wind energy other than the charging of batteries and small usage. After sometime these usage of wind energy was replaced also by the grid availability in the area. The increase in oil and gas rates in 1973 made countries to go back toward the usage of renewable energy resources

Nowadays, even greater wind turbines are being built for example 5MW. The fastest growing renewable resources are wind energy in the sector of business (Gipe, 2004). Small wind turbines are becoming attractive option for providing electricity to farms and residential areas.

Universal capacity reached 370,000 MW, Figure 3.2[World Wind Energy 2015] shows the total installed in the last few years.

Figure 3.2: Total installed capacity of Wind Energy

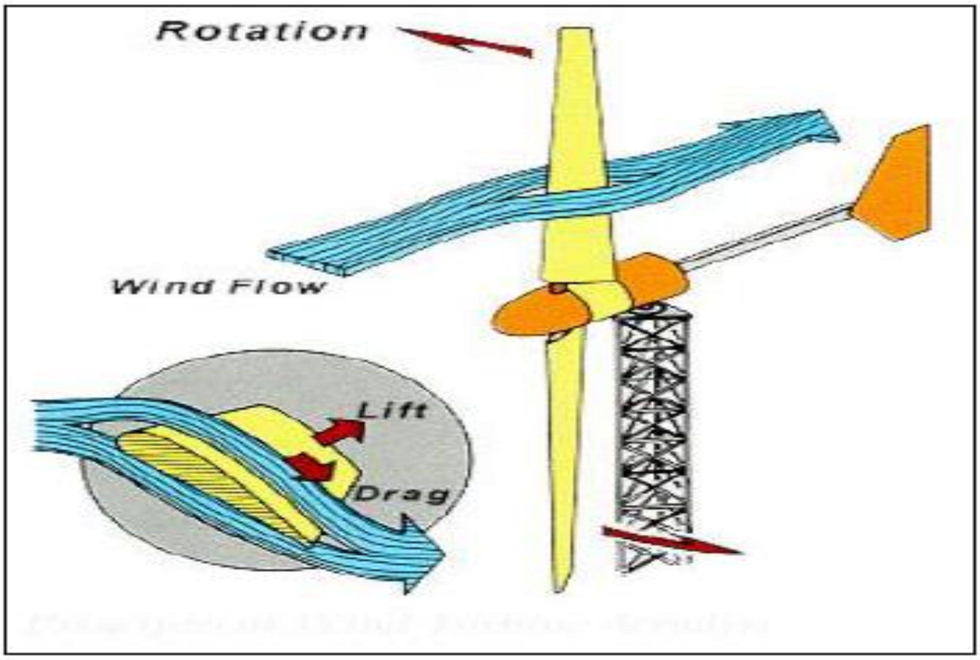


Source: WWEA-2015

3.3 CONVERSION SYSTEM OF WIND ENERGY

The rough earth's territories get unevenly heated by the sun's rays. Because of this effect it makes some region of the world hotter than the other places. The hot air in the warmer regions converts less dense and light and thus rises up. This upwardly movement of the hot air creates a vacuum which is immediately filled up by cold air from the neighbouring cooler territories. The movement of this air is known as wind and the energy generated by it is normally said to be kinetic or it also known as motion energy. Figure 3.3 shows the basic Principe of wind energy conversion system.

Figure 3.3: Basic Principle of Wind Energy Conversion System



Source: PEOCO

3.4 ENERGY AND POWER OF WIND TURBINE

The power obtainable in the wind, Pw, is directly proportional to density of air which is ρ, wind speed v^3, and the swept area by blade is πr^2, where r is the radius of blade, it is shown in equation (3.1). The performance coefficient of turbine, represents the efficiency of the turbine in converting the power in the wind to mechanical power (turbine power), PT, as shown in equation (3.2). A function of the tip-speed ratio, λ, where λ is the ratio of blade linear tip velocity and wind speed, summarized by equations (3.3) and (3.4), where ω is the turbine angular velocity.

$$Pw = \frac{1}{2} Cp\, \rho \pi r^2 v^3 \quad \textbf{(3.1)}$$

$$PT = CpPw \quad \textbf{(3.2)}$$

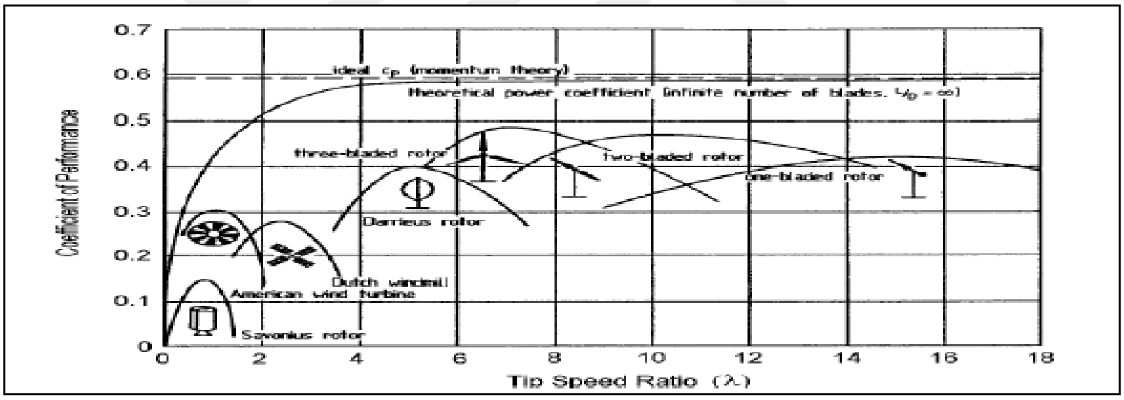
$$Cp = f(\lambda) \quad \textbf{(3.3)}$$

$$\lambda = \frac{\omega r}{v} \quad \textbf{(3.4)}$$

3.4.1 Performance Coefficient (Cp)

The Cp typically has a maximum value of 40–45percent, the theoretical peak value of Cp is 59percent, known as Betz‟ limit, after its discovery by Albert Betz in 1919 [23]. The turbine Coefficient of performance is a function of tip speed ratio. Therefore for any wind speed Coefficient of performance vs. tip-speed ratio (TSR) specifications permits a turbine's power characteristic to be forecast. A contrast of various wind turbines and their respective Cp characteristics are shown in Figure 3.4 [24]. The figure shows that turbines with great solidity (total blade area) reach their peak Cp at low values of λ. In comparison, small solidity turbines, such as the two and three-bladed turbines, have a higher peak Cp, which occurs for higher TSR values, and therefore yield low starting torque.

Figure 3.4: Comparison of Various Turbines Coefficient of Performance vs. Tip-Speed Ratio



Source: Micro and Small Enterprises.

High optimal TSR turbines are more problematic to start in low wind speeds, due to their low starting torque, and have the potential to create surplus acoustic noise. The starting difficulty can be resolved by primarily driving the turbine up to operational speed. [25].

3.4.2 Region of Turbine Operations

Modern small-scale and large-scale wind turbines use variable-speed operation, due to the benefits compared to constant-speed operation, such as greater energy yield (about 10percent), reduced noise and reduced mechanical stress [26, 27, 28]. More energy is accessible from a variable-speed turbine as the turbine, and thus power, is maximized by adjusting its speed in accordingly with the speed of wind. Turbines operate using maximum power point tracking (MPPT) below rated wind speed, generally 12m/s. The closure speed is usually 25m/s (double the rated) and the turbine is stationary for security motives at this speed of wind.

3.4.3 Area of Rotor Swept

The power output of wind turbine is linked with the area grasped by the wind turbine's rotor. More power would be achievable as the area of swept increases. the area is t is given in equation 3.5 below for the horizontal axis turbine,:

$$A = \pi r^2 \qquad \textbf{(3.5)}$$

Where r is the blade radius. The association among the rotor's diameter and the energy capture is important to design a wind turbine.

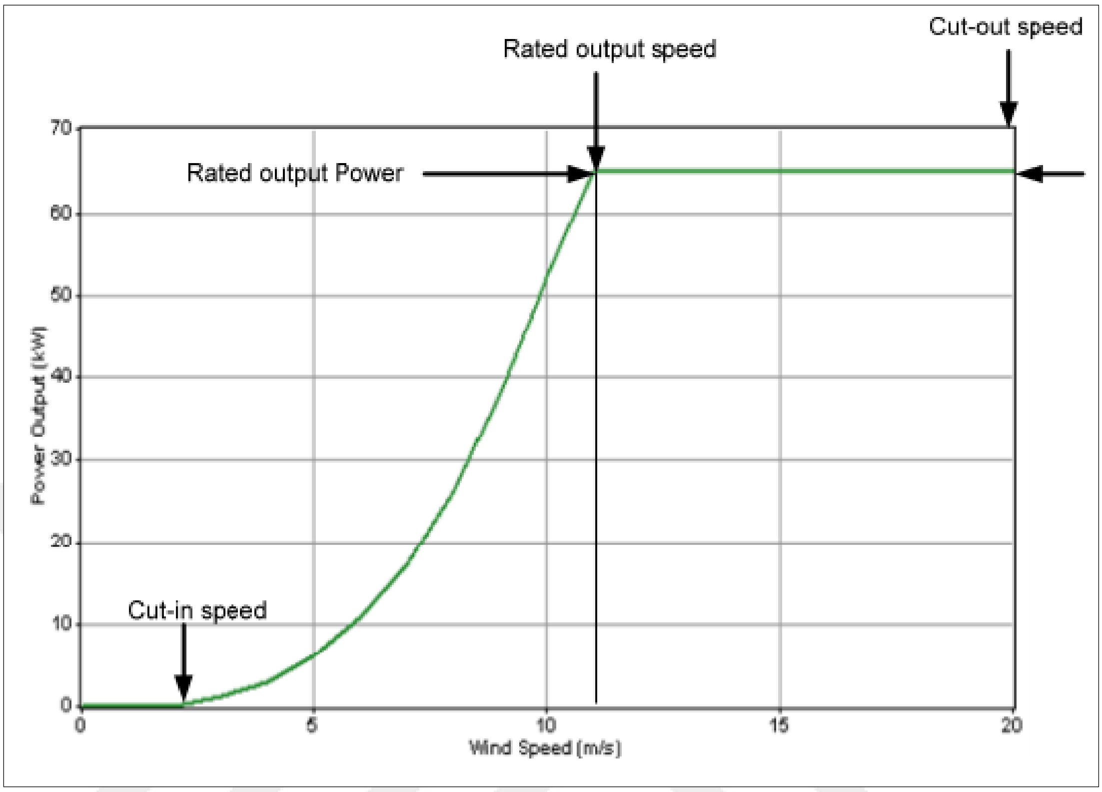
3.5 WIND TURBINE CHARACTERISTICS

There are three significant points at which much consideration is paid for the speeds and the resultant turbine output powers for every wind turbine. These are the following:

1. Cut-in speed,
2. Rated output speed
3. Cut-out speed.

Figure 3.5 shows characteristics below:

Figure 3.5: Power output of a typical 65kw Wind Turbines with steady wind speed characteristics



Source: Wind Energy Systems

3.5.1 Cut-in Speed

The speed at which the turbine first starts to rotate is known as the cut-in speed and is typically between 2 and 4 meters per second (Wind Power Program).

3.5.2 Rated Output Wind Speed

This limit to the produce output is known as the rated power output and the wind speed at which it is reached is known as the rated output wind speed. However, typically this speed is between 12 and 17 m/s (Wind Power Program).

3.5.3 Cut-out speed

A braking system is working to take the rotor to a stoppage position. This is known as the cut-out speed and is usually about 25 m/s (Wind Power Program).

3.6 DIFFERENT TYPES OF WIND TURBINES

Kinetic energy is converted into mechanical energy by the wind turbine. Then mechanical energy is converted into electricity, the machine used to do that is known as a wind generator (Gipe, 2004).

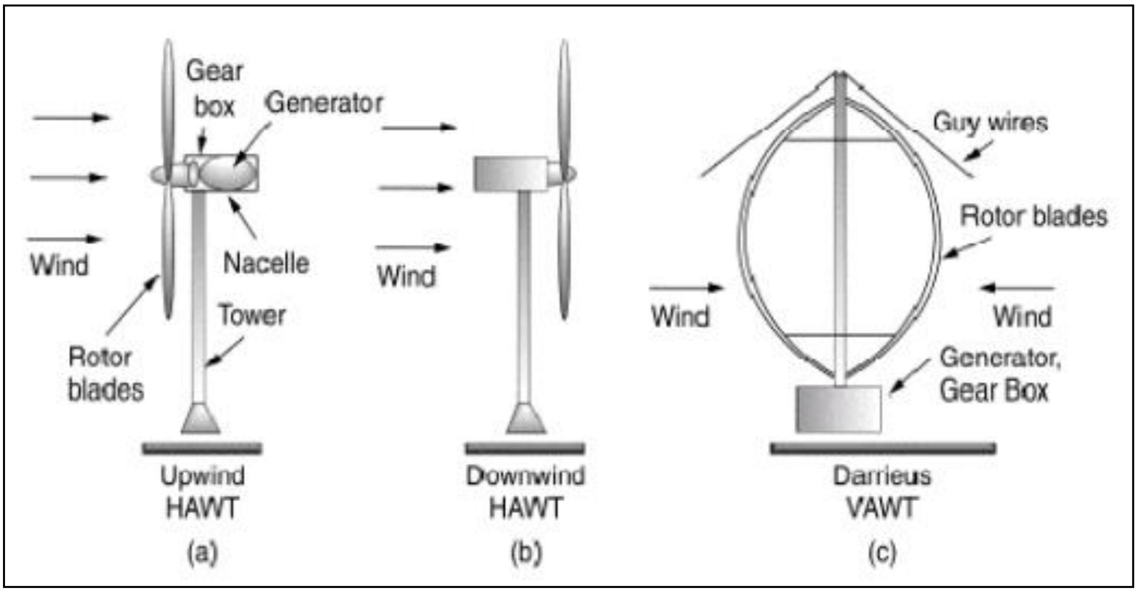
3.6.1 Hawt & Vawt

There are numeral different wind turbine types available presently. The horizontal axis turbine HAWT is by far the most corporate type of turbine. Another kind of turbine is the vertical axis, VAWT arrangement that uses drag and lift as the driving forces; the horizontal also uses drag and lift, but in other proportions.

The advantages with upwind turbines are that the tower does not act as an obstacle for the VAWT´s are not as commercial and economically competitive as the HAWT´s. Some of the VAWT types suffer from low efficiency due to design difficulties as well as the problem with operation close to the ground. Parts of the vertical turbines will therefore receive low quality winds causing power losses (Boyle, 1996).

The commonly used turbines nowadays are HAWT. Figure 3.6 shows types wind turbines:

Figure 3.6: a. Upwind machine b. down wind machines c. Vertical axis wind turbines VAWT allow wind from every direction

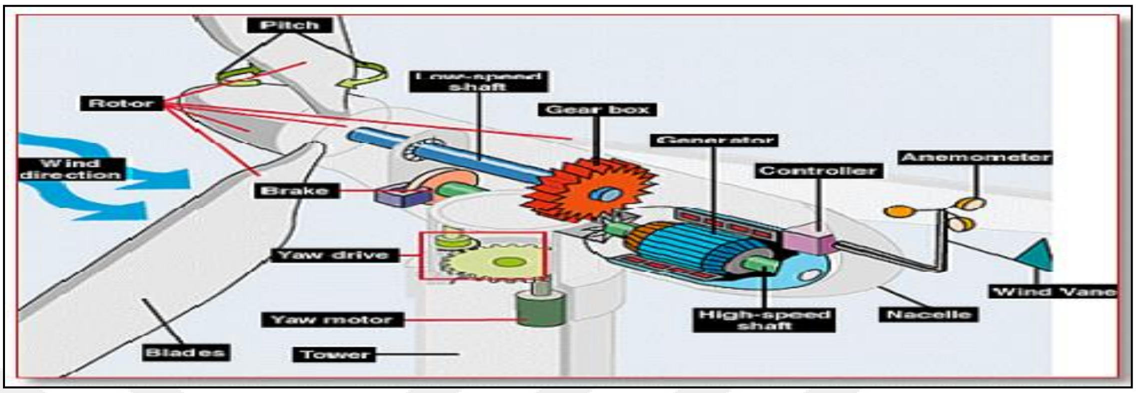


Source: Masters, 2004.

3.6.2 Components of Wind Turbine

The most common turbine type is the horizontal axis wind turbine. A cut-view given in Figure 3.7.

Figure 3.7: Cut-view of a wind turbine



Source: DOE/NREL

a. Anemometer

It is measuring the wind speed and them it is transmitting this speed to the controller.

b. Blades

Two or three blades are used mostly by wing turbines for the electric production. Wind driving over the blades then causes the blades to lift and rotate around the axis of turbine.

c. Brake

To stop the rotating blades a brake is used mechanically, electrically or by the mean of hydraulics in the case of emergency stop.

d. Gear box

It connects the high speed moving shaft with low speed moving shaft and this way its increasing the speed from 30 to 60 rpm to almost around 1000 to 1800 rpm. This is the rotational speed needed by the generator to generate electricity (NREL).

e. Generator

It usually an off-the-shelf induction generator, that produces 60/50-cycle AC electricity.

f. Nacelle

The nacelle is attached on the top of the tower and covers the gear box and other components including low- and high-speed shafts, generator, controller, and brake.

g. Rotor

The rotor of wind turbine is the combination of blades and hub together.

Tower

Towers of wind turbines are prepared from tubular steel, concrete, or steel frame. Higher tower will produce higher outputs because the speed of wind is more at more heights.

3.7 BASIC WORKINGS OF TURBINES

The blade, using aerodynamic lift, capture energy from wind in order to turn the shaft. In small wind turbines the shaft usually drives the generator directly. The generator converts the mechanical energy into electricity. The shaft power causes coils to spin past alternate poles of magnets allowing electric current to flow. If a permanent magnet device is being used the opposite occur: current flow as magnets spin past coil windings. In addition, in large wind turbines the shaft connected to the generator via a gearbox those steps up the rotational speed for the generator.

In off-grid application it is tough to possess the frequency of the subsequent current continuous, as it depends on wind speed which is tremendously inconstant. Subsequently the current is typically rectified to give DC.

3.7.1 Efficiency of Wind Turbines

German aerodynamicist Albert Betz has proposed that the maximum power that can be extracted from any wind turbine would not exceed than 59 percent. This is also known as Betz law [Betz, 1966]. But in reality, nowadays the wind turbines are providing less than the value described by Betz limit. The efficiency of any winf turbine is affected by a lot of different factors which are rotor of turbine, transmission losses, generation losses etc. Normally, the efficiency of turbine rotors are between 40 to 50 percent. The efficiencies from generator and gearbox is muc higher which are closelt to be around 80 to 90 percent respectively. Wind speed is also effecting the efficiency of wind turbines.

3.8 FACTOR INVOLVES IN DESIGNING A WIND TURBINE

In designing a wind turbines, many factors should be take into account like performance of dynamics, the power, the strength, and the weaknesses like fatigues of the materials used and other assemblies. Following criteria should be follow to design a wind turbine:

a. Endure high wind loads; optimal strength and firmness

b. Yielding to accommodate load of shades

c. To manage the loads by means of mechanically or electrically

The most significant design variables are:

a. Blade numbers

b. Control Power system

c. Types of generators

The most frequently used wind turbine designs are using Three-bladed horizontal-axis for on-grid wind turbines. Steadiness is the most important purpose for this. Turbines with even quantity of blades give steadiness difficulties (Danish wind, 2008).

There are further factors which can cause an immense effect on the in designing a wind turbine which comprises of the wind speed and its power density at a particular height. Figure 3.8 shows the table of different wind speed at different heights with their power density values.

Figure 3.8: Wind class group by wind speed and power density

Class	10 m (33 ft)		30 m (98 ft)		50 m (164 ft)	
	Wind power density (W/m^2)	Speed m/s (mph)	Wind power density (W/m^2)	Speed m/s (mph)	Wind power density (W/m^2)	Speed m/s (mph)
1	0 - 100	0 - 4.4 (0 - 9.8)	0 - 160	0 - 5.1 (0 - 11.4)	0 - 200	0 - 5.6 (0 - 12.5)
2	100 - 150	4.4 - 5.1 (9.8 - 11.5)	160 - 240	5.1 - 5.9 (11.4 - 13.2)	200 - 300	5.6 - 6.4 (12.5 - 14.3)
3	150 - 200	5.1 - 5.6 (11.5 - 12.5)	240 - 320	5.9 - 6.5 (13.2 - 14.6)	300 - 400	6.4 - 7.0 (14.3 - 15.7)
4	200 - 250	5.6 - 6.0 (12.5 - 13.4)	320 - 400	6.5 - 7.0 (14.6 - 15.7)	400 - 500	7.0 - 7.5 (15.7 - 16.8)
5	250 - 300	6.0 - 6.4 (13.4 - 14.3)	400 - 480	7.0 - 7.4 (15.7 - 16.6)	500 - 600	7.5 - 8.0 (16.8 - 17.9)
6	300 - 400	6.4 - 7.0 (14.3 - 15.7)	480 - 640	7.4 - 8.2 (16.6 - 18.3)	600 - 800	8.0 - 8.8 (17.9 - 19.7)
7	400 - 1000	7.0 - 9.4 (15.7 - 21.1)	640 - 1600	8.2 - 11.0 (18.3 - 24.7)	800 - 2000	8.8 - 11.9 (19.7 - 26.6)

Source: Wikipedia, 2010.

3.8.1 Method for Selecting Wind Turbines

A method known as decision matrix is used. It is a methods used to rank the multi dimension option of an option set. Therefore to select form different manufacturers different criteria is used. The main criteria used here to evaluate and select from this manufacturers are Cost of the system includes maintenance, shipping and tower costs, Tower height, Cut in speed, Rated speed, Power output, Survival wind speed. By giving weight factor, range from 0 to 1 for each. For cost it is given 0.3 it means much of picking depends on the cost of wind turbine supplied by manufacturers and 0.1 weight factor for each criterion is given.

3.8.2 Calculation of Cost of Wind Turbine

The overall prices of wind turbines are in the range of $1,500 – $3,000 per kW installed. Systems up to 1kW will cost around $1500 whereas larger systems in the region of 2.5kW to 10kW would cost between $10,000 up to $25,000 installed. And the initial capital cost of wind turbine includes cost of different components and activities necessary. These are the cost of wind turbines (rotor and generator), tower, foundation, installations, and shipping costs. To determine these costs other than the cost of turbine the technique suggested by National Renewable Energy Laboratory is used for this study. These costs are given in the following Table 3.1:

Table 3.1: Parameters of calculating cost of Wind Turbine

No	Parameters	factor of Cost
1	Rotor	$1,500 – $3,000 per kW
2	Tower	15percent of the turbine cost
3	Foundation	303.24 x [hub height x rotor swept area]$^{0.4037}$ in dollar
4	Installation	$40 per kW
5	Assembly	1.965 x (hub height x rotor diameter)$^{1.1736}$ in dollar

Source: NREL, USA

3.9 DATA ANALYSIS FOR WIND SPEED

3.9.1 Probability Density Function (PDF)

The probability that the speed of wind has a specific value can be defined interlink of a probability density function. It is experienced that the speed of is more expected to be close to the mean value than from it, and there is approximately as probable to be under the mean as above it [29]. A type of PDF known as Weibull distribution is used. The Weibull distribution function is given by equation 3.2 below.

$$P(u) = \frac{k}{c}\left(\frac{u}{c}\right)^{k-1} e^{\left(\frac{-u}{c}\right)^{k}} \qquad \textbf{(3.9)}$$

Where: $P\ u$ is the frequency or probability of occurrence of wind speed u C is the Weibull scale parameter with unit equal to the wind speed unit K is unit less, Weibull shape parameter The Weibull k value, or Weibull shape factor, is a constraint that reflects the breadth of a distribution of wind speeds. Further values are shown in table 3.2.

Table 3.2: Values for Shape Factor

Types of wind	**Shape factor (k)**
Inland Winds	1.5 to 2.5
Coastal Winds	2.5 to 3.5
Trade Winds	3 to 4

Source: Weibull factor studies

3.9.2 Height Variations

Idyllically, the measurement of wind speed is at the particular area and specific height of hub of the wind turbine. Accurately, this kind of precision is not usually possible to measure the speed of wind. The speed of wind is firstly measured at different heights, because most turbine towers are taller than normal met towers. Secondly, the met towers are having some specific kind of necessities than turbines, so they might not be suitable to be in the same area as other tower. In reality, the data will need some amount of extrapolation to do this kind of measurements.

In wind energy studies of variation of wind speed with height two models are used to form the vertical profile these are logarithmic law and power law [29].

a. Logarithmic profile

It has origin from bindery layer flow in fluid mechanical and in atmospheric study.

b. Power law profile

It is a model used by many energy scholars, represent the power law for vertical wind speed profile as flollows:

$$\frac{U(z)}{U(z_r)} = \left(\frac{z}{z_r}\right)^{\alpha} \quad \textbf{(3.10)}$$

Where,

(z) wind speed at height z

(zr) Wind speed at reference height zr

α is power law exponent

In power law model determining α is very unique because it has been found that α various with elevation, time of the day, season of the nature of the terrain, wind speed and temperature.

There are different techniques proposed by many researchers to determine the values, these are [31]

1. Correlation of velocity and height which is proposed by Justus 1978 as

$$\alpha \cong \frac{0.37 - 0.88\ln(U_{ref})}{1 - 0.088\ln(\frac{z_{ref}}{10})} \quad \textbf{(3.11)}$$

2. Correlation depend on surface roughness by Counihas 1975 as

$$\alpha=0.096\log10zo+0.016(\log10zo)2+0.024 \quad \textbf{(3.12)}$$

For 0.01m <zo <10m,

where, zo , represents surface roughness and it have specific value for different surface as shown in the following Table 3.3:

Table 3.3: Different Value of Roughness Factor

No	Description	zo
1	Very smooth, ice or mud	0.01

2	Clam open sea	0.20
3	Blow sea	0.5
4	Snow surface	3.0
5	Lawn grass	8.0
6	Rough pasture	10.0
7	Fallow filed	30.0
8	crop	50
9	Few tree	100
10	Many tree few building	250

Source: Wiley, 2002.

Meanwhile the power law is frequently used for height forecast of wind profiles, with the exponent n occasionally taken as reliant on surface surroundings or on atmospheric firmness for steadiness between the wind speed profiles and the height difference of the Weibull wind speed probability distributions, it is essential only that the exponent n vary as $n = a + b \ \ell n \ V1$ where a and b are constants whose values depend on the reference height.

4. THEORY OF SOLAR ENERGY

4.1 INTRODUCTION

Photovoltaic (PV) solar cells made of semiconductors materials generates electrical power, the unit of measurement is Watts or Kilowatts, when they are enlighten by photons. Many PV have been in uninterrupted outdoor operation on Earth or in space for over 30 years (A. Luque, 2003).

The sun emits energy outwardly at the temperature of 5760K approximately. The electromagnetic radiations are known as the sunshine or as we know it with the name of solar energy. The earth distance from ths sun is around 150 million km and the total area of it is around 510 million km^2 and 21 percent of which is land.

Furthermore, the solar radiations arriving at the surface of earth are varies hourly or monthly basis because of the angle of sun with earth. The variation in hourly period is because of the movement of earth from east to west and the monthly variations are produced due to the presence of clouds and both daily and monthly deviation is caused by the position of sun.

Pakistan is one of the emerging countries which do not have the properly recorded solar radiations data available at hand like other developed countries, only sunshine interval data is accessible from different sources. On the other hand, the data can be calculated by bunch of equations using the data regarding with the sunshine hours and other available resources from local atmospheric conditions centre.

4.2 HISTORY

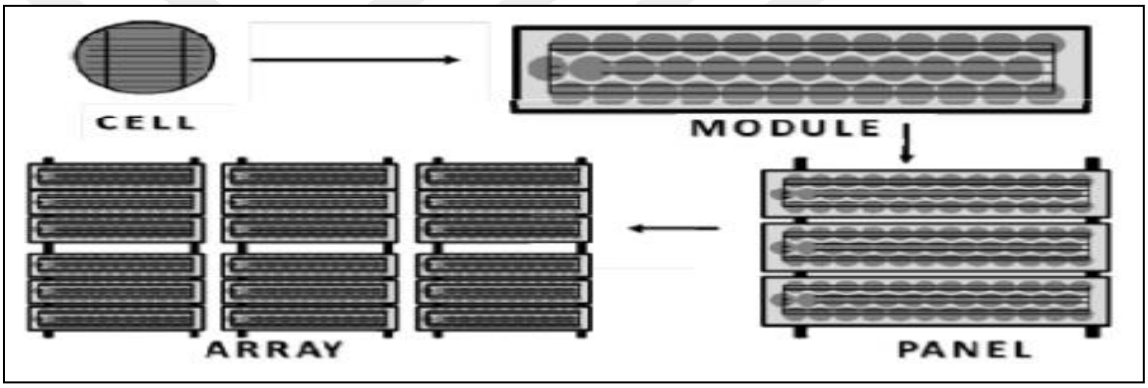
The history of PV starts from a very long time firstly recorded in 1839 by the frech physicist names as Alexander Edmond Becquerel, who shown the experimental effects of an electrolyte cell fabricated of two different electrodes. When the cells are wide-open to bare light, there is an electricity generation because of this phenomenon and in 1954 Bell Labs designed the first ever solar cell (USDE, 2004).

After the designing of solar cell, the technology is adopted by U.S. space programs for the generation of power. In the meantime, for earth orbiting satellites this technology was rapidly developed and widely used to create electricity for it. Nowadays, this solar energy technology is spreading all over the world, especially in remote areas where the grid extension is very difficult (Patel, 2006).

4.3 PPHOTOVOLTAIC (PV)

The PV cells are being used from a long time. These cells are normally seen on the calculators. These small cells are then made into big solar module and after that its is arranged in a way to make a solar panel and then solar panels are arranged in a order to make an array. Normally, 36 cells are used in a module by the industry for large power fabrication. These cells are usually wired into a parallel order to amplify current and can be wired into series to increase voltage. Figure 4.1 how a cell can be converted into an array:

Figure 4.1: Construction of a PV Array



Source: Patel, 2006

4.4 PV ELECTRICITY

PV panel convert to sunlight to DC electricity. The PV generated electricity is soundless, low maintenance and there is no need of fuel or oil supply. However, PV energy is available when enough irradiance is accessible. PV panel is available in wide variety of rating up to 100Wp.In some cases, panel up to 300Wp each are fabricated. There is also AC PV panels by including an inverter into the panel set-up to allow easy and modular AC bus link.

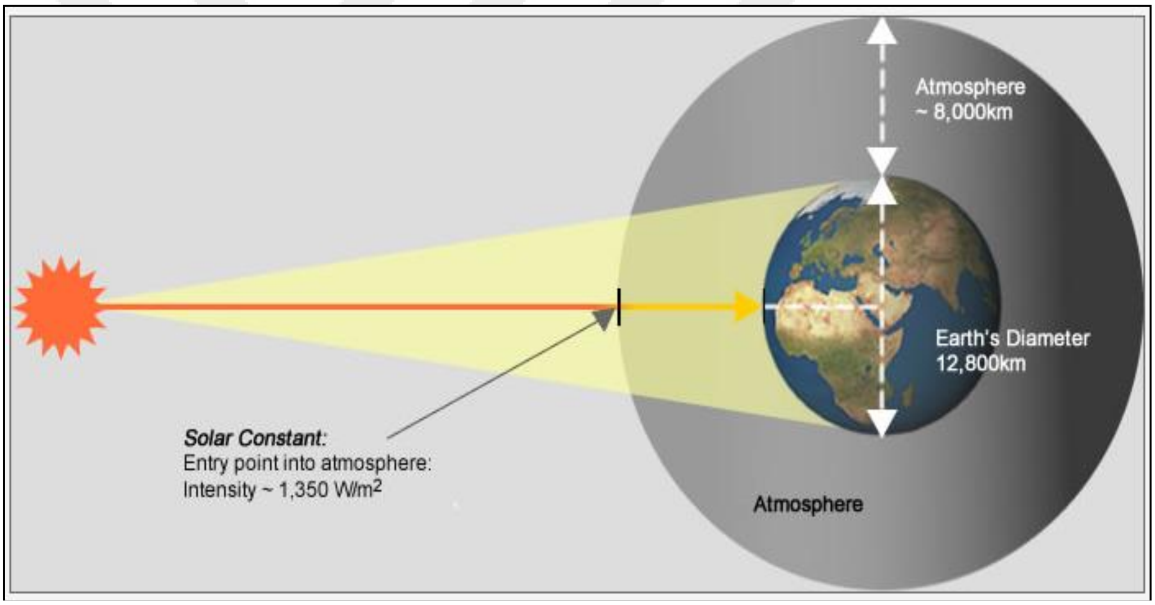
A lean economy scale can often be noted for the different panel sizes up to 100Wp, conversely after that the size cost will rise linearly with size. The main drawback of PV is its great capital costs although it is hopeful that the panel costs might fall in the future. PV can be implemented for small power necessities in areas remote from the existing grid.

4.4.1 Solar Resource

Solar radiation that arrives at the earth's surface in a continuous line is known as direct, while sunlight dispersed by clouds, dust, humidity and pollution is known as diffused. The summation of the direct and diffuse sunlight is known as global-horizontal insolation. Concentrating solar technologies, which use mirrors and lenses to concentrate sunlight, depend on direct radiation, while PV cells and other solar technologies can work with diffused radiation.

Solar radiation offers an enormous amount of energy to the earth. The earth surface is getting amount of energy almost equals to 10,000 times of global energy spending per annum. This amount ranges about 1,700kWh/m^2 yearly (Patel, 2006).

Figure 4.2: Solar energy for earth



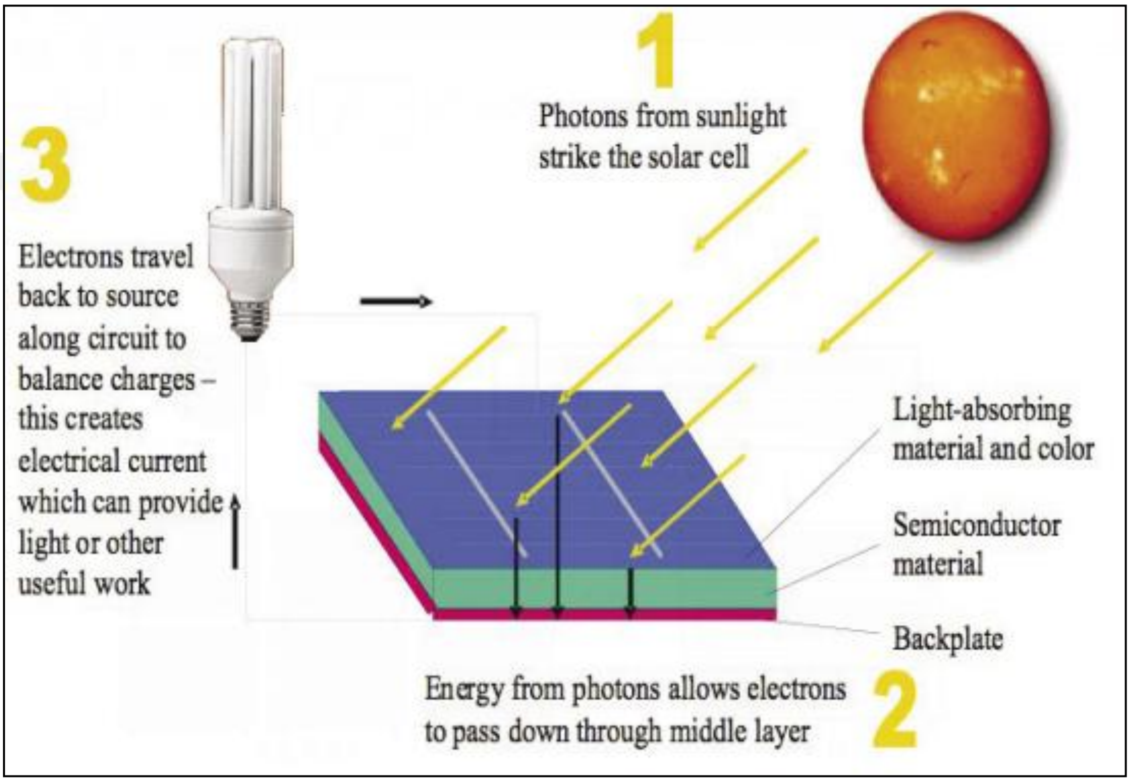
Source: Green Rhino Energy Ltd.

The potency of solar irradiation directly outside the earth's atmosphere on a horizontal surface is nearly constant at approximately the rate of 1,350 W/m2, the so-known as Solar Constant. This entry point into the atmosphere is known as Air Mass.

4.5 BASIC PRINCIPLE OF PV

PV cells transform sunlight straight into electricity by taking advantage of the photoelectric effect. Cells are built from semiconductor materials coated with light-absorbing equipment. When photons in sunlight strike the top layer of a PV cell, they deliver adequate energy to knock electrons throughout the semiconductor to the underneath layer, causing a parting of electric charges on the top and base of the solar cell. Linking the underneath layer to the top with a conductor decide an electrical circuit and allows the electrons to flood back to the top, generating an electric current and permitting the cycle to repeat with more sunlight (Clean Energy Associates). Figure 4.3 demonstrates how photovoltaic cells work.

Figure 4.3: How Photovoltaic Cells Work



Source: Clean Energy Associates

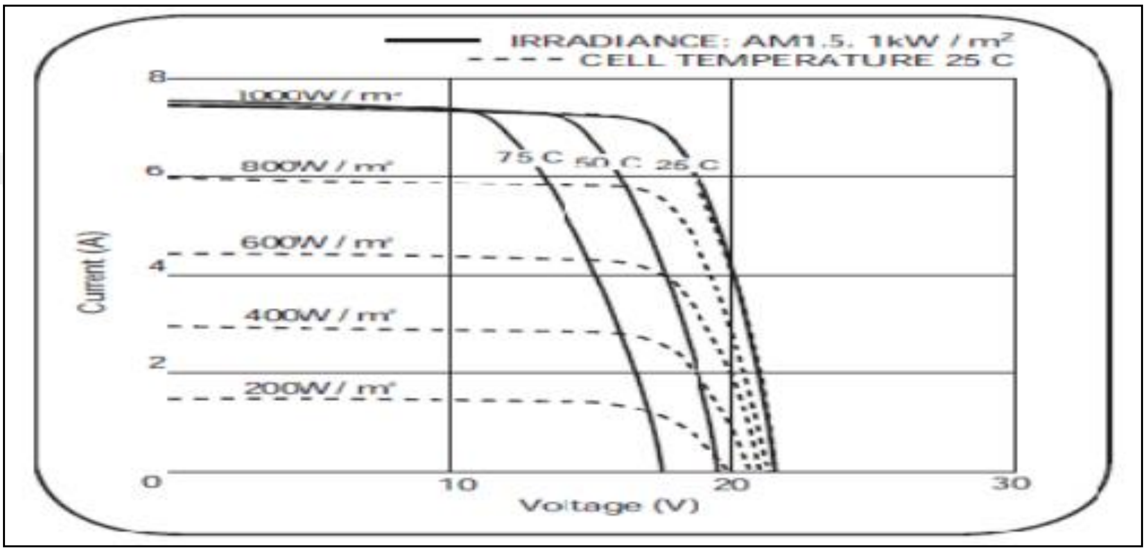
4.5.1 Power Characteristics of Solar Module

PV panels have a precise voltage-current relationship, which is portrayed in an IV-curve in the figure 4.4. The maximum power point (MPP) operation is where the extreme panel output power is obtained with a given irradiation and temperature.

Manufactures typically offer I-V curves speciation at diverse levels of irradiance maintaining other variables such as temperature and wind speed constant figure 4.4. PV panel generates at invariable irradiation levels roughly constant current from short circuit current to just beforehand the current value near the open circuit voltage. If the irradiance rises, the PV panel output escalates straightly. The extreme power point voltage stays nearly unaltered by the level of irradiance, and open circuit voltage changes only a little bit (Jimenez-98).

An I-V curve as exemplify in figures 4.4 is simply all of a module's probable operating points, (I-V combinations) at a given cell temperature and light strength. Increases in cell temperature boost current slightly, but drastically reduce voltage. Maximum power is derived at the lap of the curve.

Figure 4.4: I-V curves showing the effect of solar isolation and temperatures on PV panel performance



Source: Kyocera, 2009

4.5.2 Types of PV cells

There are presently five commercial production technologies for PV cells which are described briefly as follows:

a. Single Crystalline Silicon

This is the more lavish production procedure, but it's also the most capable sunlight conversion technology obtainable. Cells efficiency averages between 11 percent and 16 percent.

b. Polycrystalline Silicon

This has a somewhat lower conversion efficiency compared to single crystalline and developed costs are also lesser. Cells yield averages between 10 percent and 13 percent. But Kyocera's sophisticated cell processing technology and automated production amenities have formed multi-crystalline solar cells with efficiencies of over 16.5 percent.

c. String Ribbon

This is a modification of polycrystalline silicon make. There is a smaller quantity of work in its fabrication as a result costs are even lesser. Cells efficiency averages 8 percent to 10 percent.

d. Thin Film

Thin film solar cells are the substitute for silicon cells. Cells efficiency averages 6 percent to 8 percent.

e. Amorphous

This is made when the silicon material is vaporized and placed on the glass or stainless steel. It is inexpensive type of cell as compared with others. Cells efficiency is an average around 4 percent to 7 percent. Cells efficiency declines with raise in temperature (Antony et al. 2007).

4.5.2.1 Types of Array

Solar panel array type depends on the axis of rotary motion. There are three types which are following:

a. Fixed
b. one axis Sun-tracking
c. two axis Sun-tracking

When solar panels follow the sun they make supplementary electricity with further better performance and with superior efficiencies.

4.5.2.2 Derate factor

The Derate factor is the loss of power efficiency as a result of all the factors that concern a perfect system. This comprises factors such as the DC to AC Derate factor, age, shading, sun tracking, etc.

4.6 PV INSTALLATION

The tilt angle of a PV array can be optimize in a number of various system purposes, for example maximizing yearly, summer or winter energy generation. Using changeable fixed mounts and changing the title angle at times through the year can provide additional increase energy production (Jimenez-98).

For best year round power output with the least amount of maintenance, solar array should be facing true south at a tilt angle equivalent to your latitude regarding the horizontal place, a good rule of thumb is:

a. Latitude minus 15° in the summer
b. Latitude in the spring/fall
c. Latitude plus 15° in the winter

When the PV modules are installed in parallel they can be separated into isolated sets to fine-tune the battery charging current. Though, this is only possible for big systems, because one PV module is not working correctly any more can take out a whole string, PV panels need to be kept unpolluted, free overshadowing, and electrical connections need intermittent check for loose connections and erosion.

4.7 POTENTIAL OF SOLAR ENERGY FOR ISLAMABAD, PAKISTAN

Pakistan is country with a very high rate of insolation available. This country is receiving solar energy around 7 – 8 hours on an average level per day. There are around 3000 to 3300 hours of sunshine in one year. For the operation of PV panels, this country is having a great weather conditions. But there is a difficulty of available global solar radiation on a horizontal surface as in Pakistan there are only few metrological station are recording data.

4.8 METHODS OF PREDICTION

In the current work the H/ H_o, the monthly global solar radiation falling on a horizontal surface at specific location and the monthly mean daily radiation on horizontal surface in the absence of atmosphere is given by the following expression [31,32].

$$H/H_o = a + b\,(n/N) \quad \textbf{(4.1)}$$

Where n is the monthly mean daily no. of sunshine hour and N is the day length at particular location and a and b are the atmospheric determined regression constant. n/N is also known as the potential percentage of sunshine hour.

The regression constant a and b have been gotten from the relationship given as [33] and also confirmed by Frere et.al method (Fere et.al 1980) as given below:

$$a = -0.110 + 0.235\cos\Phi + 0.323(n/N) \quad \textbf{(4.2)}$$

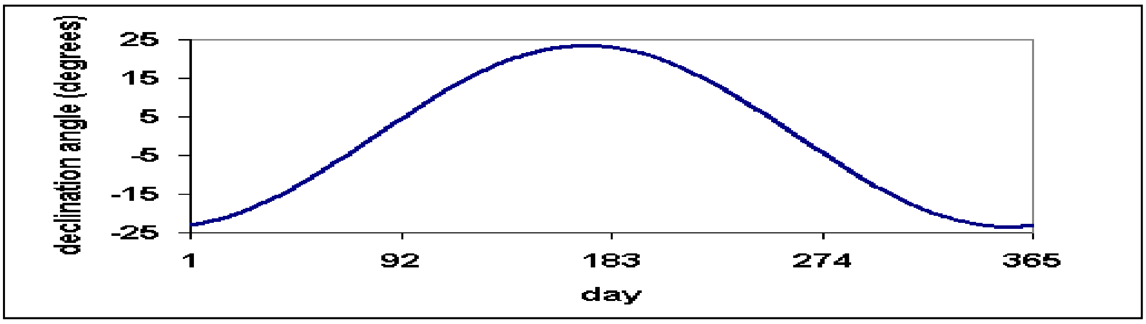
$$b = 1.449 - 0.553\cos\Phi - 0.694(n/N) \quad \textbf{(4.3)}$$

The value H may be described by following expression:

$$H = 24/\pi\, I_{sc}\,([1+0.033\cos(360n/365)]\,[\cos\Phi\cos\delta\sin\omega s + 2\pi\omega s/360\,\sin\Phi\sin\delta] \quad \textbf{(4.4)}$$

Where I_{sc} is the solar constant, Φ is the latitude of the area, δ is the solar declination and ωs is the sunset hour angle Solar declination (d, rad) is the angle between the equatorial plane and the straight line joining the centres of the earth and the sun. When the sun is directly above at any location during solar noon, the latitude of that location gives the declination. The maximum declination is on summer solstice (June 22nd, 23.45°=0.4093 rad), the minimum on winter solstice (December 21st, -23.45°=-0.4093), and is equal to 0 during two equinoxes (March 21st and September 22nd).

Figure 4.5: Declination angle throughout the year



Source: Wikipedia

The declination of the sun, δ(d) (rad), varies daily and is calculated from the following expression which is:

$$\delta d = 23.45 \sin[360 \times 248+n/365] \qquad \textbf{(4.5)}$$

A daylight time factor (ωs) is calculated to analyse the solar day length for any latitude located between the polar circles, based on equations stated by Spitters et al. (1986):

$$\text{Cos } \omega s = -\tan\Phi \tan\delta \qquad \textbf{(4.6)}$$

4.8.1 Prediction of diffuse solar radiation

The diffuse solar radiation H_d can be projected by an experiential formula which relates the diffuse solar radiation component H to the daily total radiation H. The equations which is generally used are given below in equations 4.7 and 4.8:

$$H / H_d = 1.00-1.13\, K_T \text{ (Page,Jk)} \qquad \textbf{(4.7)}$$

$$H / H_d = 1.390-4.027\, K_T + 5.53(K_T)\, 2- 3.108(K_T)^3 \text{ (Liu \& Jorden)} \qquad \textbf{(4.8)}$$

Where H_d is the monthly mean of daily diffuse solar radiation and $K_T = H/H_o$ is the clearness index.

5. BATTERIES, CHARGE CONTROLLERS AND INVERTERS

5.1 INTRODUCTION

Electrical energy in electrochemical form is stored in a device which has Direct current storage; this devise is known as battery. The stored amount of energy is then managed by the use of an inverter or controller attached to it.

5.1.1 Batteries

The conversion efficiency of batteries is not perfect. The energy is lost in the form of heat throughout charging or recharging and the energy stored is also released in the chemical reaction.

Batteries are divided in two groups.

1. Primary batteries which are only converting the chemical energy into electrical energy and they are not chargeable.
2. These types of batteries are rechargeable and they are being used in hybrid systems.

The internal component of a typical electrochemical cell has positive and negative electrodes plates with insulating separators and a chemical electrolyte in between. The cells store electrochemical energy at a low electrical potential, usually a few volts (A. Luque, 2003).

5.1.2 Types of Batteries

Different kinds of batteries are available nowadays:

1. Lead-acid
2. Nickel cadmium
3. Nickel-metal
4. Lithium-ion
5. Lithium-polymer
6. Zinc air

5.1.3 Battery Electricity

Battery is an electro-chemical device that is store energy in chemical form. They are used to excess energy in the later use. Most batteries used in the hybrid are of the depth of the lead – acid types. The lead-acid battery widely used and, although complex. Its major limitation is that it must be operated within strict boundaries as it is susceptible to damage under a certain condition- such as overcharging, undercharging and remaining for long periods a low state of charge (Jimens- 98), (Slabbert, Seeling and Hochmuse-97). Battery cost can form a minor part of the system initial costs, but adverse condition, battery maintenance and replacement can become a significance portion of system lifecycle cost and can prove to be expensive a long run. If the operating condition is favourable, however, these batteries can last up till 15 years in an autonomous.

5.2 BASIC WORKING PRINCIPLE

Batteries comprise of one or more 2V-cells wired in series. Each cell consists of plates that immersed in an electrolyte. Electricity is produced when there is a chemical reaction occurs between the plate and electrolyte. This reaction of battery is inverted when the battery is in a state of charging.

The maximum DOD is determined by the thickness of plates in the battery. Outside this thickness the battery will start to suffer damage. There are two types of batteries which are following:

1. Shallow cycle batteries, such as car batteries, have thin plates and are design to yield a great current for small time span. These kind of batteries should not be a deeper discharge than 10-20 percent depth of discharge after which the battery ruined easily (Jimenez-98).
2. Deep cycle batteries have dense, often cylindrical plates and can be often be discharged until the value of 70 percent-80 percent. However, this types of battery cannot be quickly charged and discharge (Jimenez-98).

5.3 STORAGE CAPACITY

The energy that can be taken from its full state of charge is the amount of energy which is known as the capacity of a battery. The capacity of a battery would be lower if the discharging current is higher.

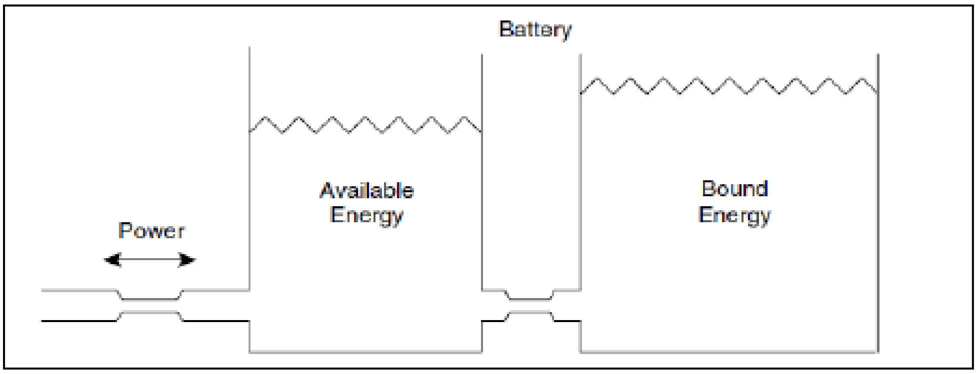
The storage capacity of the battery is generally is given in ampere-Hours or after the with multiplication the battery's nominal voltage in kWh. The value for the storage capacity depends on its operation, age and treatment. When there is a low rate of discharging and charging then the capacity would be increased. Most battery manufacturer gives the storage capacity for a given discharge time, usually 20 or 100 hours.

5.4 MODELLING OF A BATTERY

Kinetic Battery Model is used to describe the modelling of battery to explain the amount of energy which can be captured by at each time step by the bank of batteries. This model of battery depends on the system of two tanks. The first tank is having the energy which is available to transform it into DC and the other tank is having the bound energy, which is not yet available to the system and is chemically stored (Maxwell and McGowan, 1993).

This type of battery assumes that it is not be affected by the external factors like temperature throughout its lifetime. The essential properties of these kind of batteries are including the voltage (nominal), its curve of capacity, curve of lifetime, minimum SOC, and efficiency of its round trip. Figure 5.1 shows the basic model of kinetic battery concept.

Figure 5.1: Kinetic battery model concepts

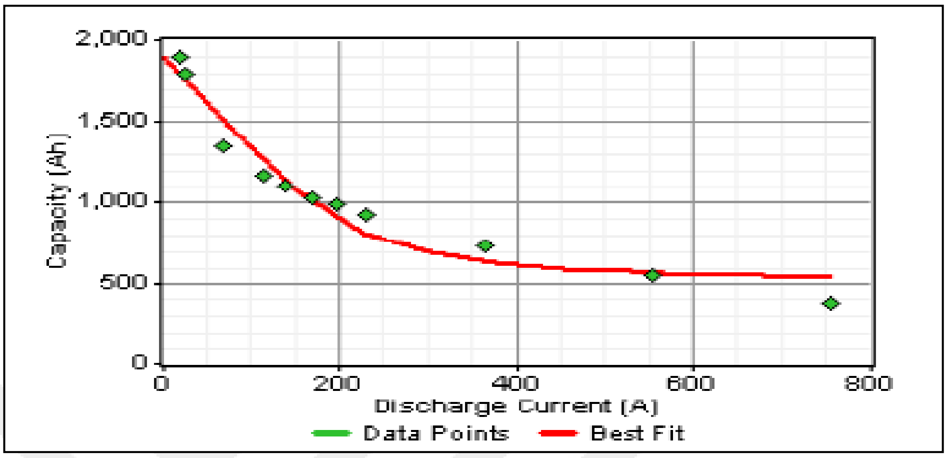


Source: Battery Powers

The conversion rate of available energy and bound energy rely on the difference in height between the two tanks (Paul Gilman and Peter Lilienthal).

The figures 5.2 and 5.3 show the different related curves of battery.

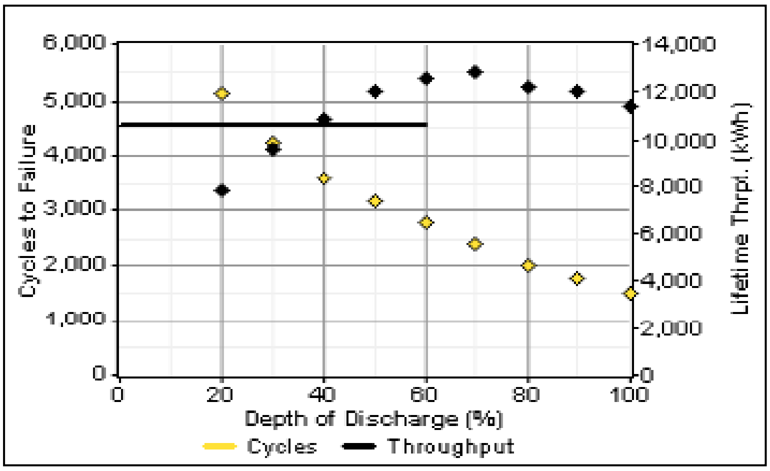
Figure 5.2: Capacity curve for deep-cycle battery model



Source: Surrette4KS25P

Figure 5.2 displays a lifetime curve typical of a deep-cycle lead–acid battery. The number of cycles goes to failure (points), drops abruptly with rising the depth of discharge. The lifetime throughput curve, shown in Figure 5.3 as black dots, characteristically demonstrates a much weaker reliance on the cycle depth (Paul Gilman and Peter Lilienthal).

Figure 5.3: Lifetime curve for deep-cycle battery model



Source: Surrette4KS25P

The higher the DOD, the lower will be the cycles and the lifetime of the batteries (can be seen from Figure 5.3).

5.5 PERFORMANCE OF A BATTERY

The renewable energy is constantly alternating that is why there is a need to store it. This stored electricity is then used when there is a load requirement in the system and there is not much electricity is available at that time from other components. The battery performance is mostly categorized by the SOC [34]. The charging and discharging and self-discharge efficiency are both ignored in the model formula of battery.

Alternatively, the charging and discharging efficiency can be approximated by multiplying an empirical coefficient (larger than 1) of the PL(t). The state of charge at the moment t can be obtained using the following equation:

$$SOC(t) = SOC(t-1) + \frac{N_{wind} \cdot P_{wind}(t) + N_{PV} \cdot P_S(t) - P_L(t)}{V_b C_b} \quad \textbf{(5.1)}$$

Where PL(t) is the electric power demand at moment t, Vb is the battery voltage, Cb is the capacity of battery bank, Nwind denote the number of WT, and NPV is the number of PV.

If Nwind _ Pwind(t) + NPV _ PS(t) > PL(t), the power generated by both the PV arrays and the wind turbines exceeds the load, hence the battery will be charging.

If Nwind _ Pwind(t) + NPV _ PS(t) < PL(t), the power generated by both the PV arrays and the wind turbines is insufficient to supply the load, hence the battery will be discharging.

5.6 REGULATORS OF BATTERY

Battery regulators are used to control the process of the batteries used in an off-grid hybrid system and thus protect them from poor condition. The key functions are top of charge regulation to avoid overcharging and load disconnection to stop excessive discharging. Moreover they may show the status of the system and may also give a boost charge from time to time to avoid the stratification of the battery. Regulators measure the level of voltage to an approximated state of charge but this may vary with charge and discharge currents, temperature compensation and ampere hour counting determined state of charge more precisely. Set points are selected to take full advantage of battery life time.

5.7 BATTERY IN HYBRID SYSTEM

Battery operation in a hybrid system as opposed to a single-source application may result in certain advantages with respect to battery lifetime optimization. This can be attributed to the fact that there is often more sophisticated control installed in a hybrid system due to the interaction of many components. This requires better regulation of components and will results in better treatment the battery. Moreover, there are more energy sources available resulting in the battery not being utilized to as high a degree as in single-source systems. Batteries are costly and can often be sized smaller in hybrid system than in a single-source system.

5.8 CHARGE CONTROLLERS FOR PV

Charge controllers are used to regulate the voltage exist in the hybrid system. These controllers are used for PV panels. The main role of these controllers is to stop over charging of batteries attached to the hybrid system by the PV arrays. Batteries voltage is constantly checked by a charge controller. The charge controller will cut the charging current supplying to the battery by the PV array system (A. Luque, 2003). The efficiencies of these controllers are around 95 – 98 percent.

When many charge controllers are used simultaneously then it is important to split the PV array system into sub-array system. Every of these sub arrays systems are then connected to the bank of batteries.There are five different types of PV controllers which are listed as follows:

1. Shunt controller
2. Single-stage series controllers
3. Diversion controller
4. Pulse width modulation (PWM) controller
5. Maximum power point tracking controllers (MPPT).

5.8.2 General working principles

Maximum power trackers are high- frequency DC-DC converters used to force the output of PV arrays to their maximum instantaneous power. They can improve the efficiency. They can couple to the battery regulators, directly to DC water pumps or to AC water pumps via an inverter. Best result are achieved with direct DC pumps coupling where the potentially the biggest operating mismatch occur. Smaller improvements are realized with battery coupling as the natural battery/array operating point is usually close to the array MPP (Jimenez-98), (Slabbert, Seeling-Hochmuth-97).

5.9 INVERTERS

The device which is converting direct current (DC) into alternative current (AC) is known as inverter. This device is used with the sources such as batteries, solar modules, wind turbine and PV panels. With the placement of inverter with the renewable energy hybrid system, then the equipment in the households which are operated on AC can be used. Frequency rate of 50Hz or 60 Hz is yield with a sine wave waveform of AC.

The efficiency of converting the direct current to alternative current of many inverters nowadays is around 90 percent or higher than this value up to 95 percent.

5.9.1 Basic Working Principle of an Inverter

The harmonic distortion of inverters is an important issue specifically when the powering components like refrigerators and computer and is an indication as to what degree the inverter output wave form is non-sinusoidal. Inverter output wave form can be square wave or it can be modified sine wave.

Square wave and quasi-wave inverters will present distortion as compared with a 50Hz sine wave, but less costly than sine wave inverters (Jimenez-98). They can suitable power resistive load such as resistance heaters or incandescent lights.

Modified sine wave inverters yield a staircase square wave that is more likely to be almost a sine wave. They can supply most electronic devices and motors. Though, some sensitivity electronic may need sine wave inverters. These inverters can produce utility grid power but cost than the other types of inverters (Jimenez-98).

6. HOMER ENERGY SIMULATION SOFTWARE

6.1 INTRODUCTION

HOMER stands for Hybrid Optimization Model for Electric Renewables. This program is copy right software of Midwest Research Institute (MRI) and it is offered by the National Renewable Energy Laboratory (NREL) for the use of U.S. Department of Energy (DOE)

This program is available on its website on internet without any charges. This software also comes with the readily available data and information about resources and components used in it for example wind turbines, generators, batteries, etc.

6.2 HOMER DESIGNS OF SYSTEMS

The software is very handy with numerous designs for system like on-grid, off-grid and with other back up devices. In this program, the renewable technologies are having following designs:

1. Power sources
2. Storage
3. Loads

1. Power sources consist of following:

a. Photovoltaic (PV)
b. Wind turbine
c. Hydro power
d. Generators (diesel, bio-gas, or coal-fired; electric utility grid etc.)

2. Batteries are included in the storage type.
3. In loads group, there are two types common used in software:

a. Primary loads.
b. Deferrable loads.

HOMER is an smart software which can detect the proper timings of energy supplied to the components and software can resolve the times at what time the batteries should be charged and at what time the generator should be operated

6.3 DISPATCH STRATEGY

Homer is using a strategy called Dispatched Strategy which is nothing but there are some certain types of rules which this program is following to operate the generator and the control of battery is handled when there is lack of energy provide by the renewable components. There are two kinds of dispatch strategy which has been used by the software itself;

1. **load following**
2. **Cycle charging.**

1. This strategy is supplying the deferrable load in following two conditions given below:

a. If storage tank is vacant
b. If system yields surplus electricity.

2. In this strategy of this software, when there is an excess amount of electricity produce by the components in the system then the generator will supply energy of the deferrable load. If the storage tank is vacant, then the deferrable load is reflected as primary load and then components will only provide energy to this load as a primary load.

6.4 SENSITIVITY ANALYSIS

Homer is giving the option of including sensitivity analysis which is helping in the calculation and projecting the economic and technical possibilities of the components included in the hybrid system. This software is providing the stability calculations on the basis of per 60 minutes periods (hourly for 8760 hours). It is comparing the load of electric of each hour with the system's capability to provide energy for that particular hour.

When the software is using this function for analysis, then there should be different sizes considered for every component used in the system to meet the load requirement. As the search space of different sizes and other inputs is increased then the processing time of this software is also increased. The time of computation would be dependent on the number of sizes are compared in the search space. The simulation results then areprepared with the best optimal solution on the top of the list according to its Net Present Cost.

7. METHEDOLOGY AND HYBRID SYSTEM DESIGNS RESULTS

7.1 HYBRID ENERGY SYSTEMS

The best economical solution for the electrical demands of remote rural areas where it is very hard to provide electricity with the grid stations and the extension for grid station is very expensive, is hybrid energy system. These hybrid systems include a combination of one or more than a few renewable energy sources for instance solar photovoltaic, battery and wind energy with back up of generator or grid.

A constant flow of continuous power is provided by this kind of hybrid system. Hybrid systems contains of grouping of wind turbine and photovoltaic modules, offer greater reliability than any one of them alone.

Wind and solar hybrid systems also allow the use of smaller, inexpensive components than would otherwise be required if the system is only depending on only one power resource. This can significantly lower the price of a remote power system. The use of renewable energy resources gives a incredible potential for many applications and particularly off-grid standalone systems. In this perspective, one of the most promising applications of renewable energy technology is the setting up of hybrid energy systems in distant areas, where the grid extension is expensive and the cost of fuel increases considerably with the remoteness of the site (green, 2010).

Regardless of advancements in the field of hybrid systems in refining dependability and dropping the total size of it, the initial cost is still not less. Improvements in energy capability allow users to meet their energy requirements from smaller, cheap power systems than once was feasible.

7.1.1 Hybrid System Optimization Modelling Methodology

To design an optimum hybrid system, first of all there is a need of answering the following questions, “What and which kind of components does it make logic to comprise in the design of a hybrid system?”, “The number of equipments required and of what size each component should be used to get the best possible solution?” and “What will be the entire costs concerned in the design to get optimal design?” The huge figure and types of technology options and the variation in technology expenses and accessibility of energy resources make this assessment difficult.

In designing an optimized hybrid system involves careful deliberation of dozens of variables

Including following kinds of variables to handle:

1. Electric load profile
2. Solar resource available at the location
3. Wind resource available at the location
4. Types and characteristics of batteries
5. Types and characteristics of solar modules
6. Types and characteristic of generators
7. Types and characteristic of wind turbines (power curve)
8. Fuel prices (Diesel, gasoline)
9. Initial expenses, Operating & maintenance and replacement costs of all components of the system.

7.2 ENERGY CONSUMPTION

Energy consumption is the electrical power your loads consume in a period of time. It is measured in kWh. Loads are usually the largest single influence on the size and cost of a PV and wind turbine system. In order to reduce the cost of the PV and wind turbine system it is necessary to use more efficient, lower demand appliance and to eliminate, partially or completely, the use of other loads.

7.2.1 Load Distribution

The type of Appliances and their electric load of an average middle class house in Pakistan are as following in the Table 7.1 given below:

Table7.1: Variety of Appliances and their electric load in a house

Load electric Name	Specification	Power Consumption	Quantity	Daily Working Hours	Daily Electric Consumption
Illumination	Energy-saving Lamp	11W	8	6	528W
Computer	LCD	150W	2	8	1000W

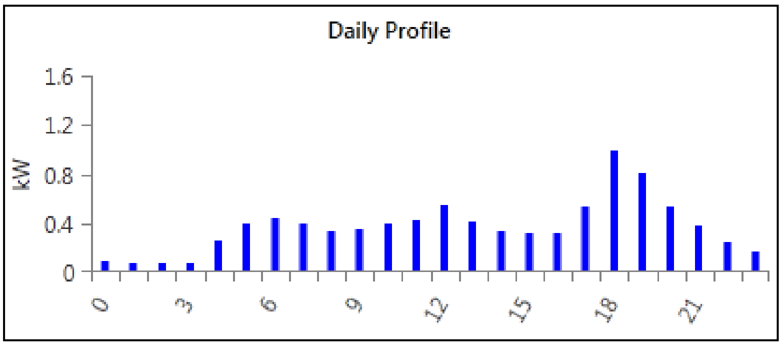
Refrigerator	150L	100W	1	24	800W
Washing Machine		550W	1	1	550W
Microwave		1000W	1	2	2000W
Air conditioning	1.5P	1200W	1	4	4800W
Satelite antenna	21"LCD	50W	1	6	300W
Color TV		150W	1		900
Pumps		400W	1	2	800
Total		3838W			11.278KW

Table7.2: Average scaled electric load profile

Metric	**Baseline**	**Scaled**
Average (kWh/day)	11.27	11.27
Average (kW)	0.47	0.47
Peak (kW)	2.39	2.39
Load Factor	0.2	0.2

It is assumed for electric load profile of an average middle class house in Pakistan is same throughout the year since there is no proper recorded data is available in any data base. The primary electrical load is shown in Figure 7.1 given below:

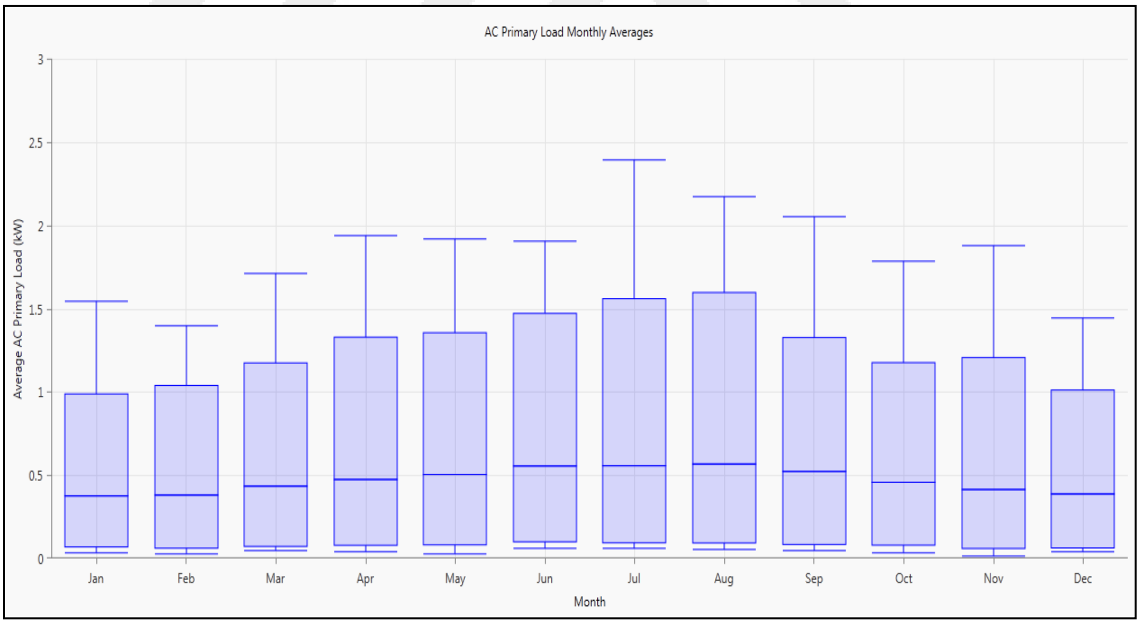
Figure 7.1: Daily profile of electric load



From the figure 7.1 it can be seen that, the peak load of daily profile was observed at around 18:00h until 21:00h. The highest demand present between 18:00h and 20:00h PM and while relatively smaller load requirements are found between 00:00h and 6:00h .The daily energy utilization of electricity is comparatively lower in most of the time during 24 h apart from around the time between 18:00h to 20:00h.

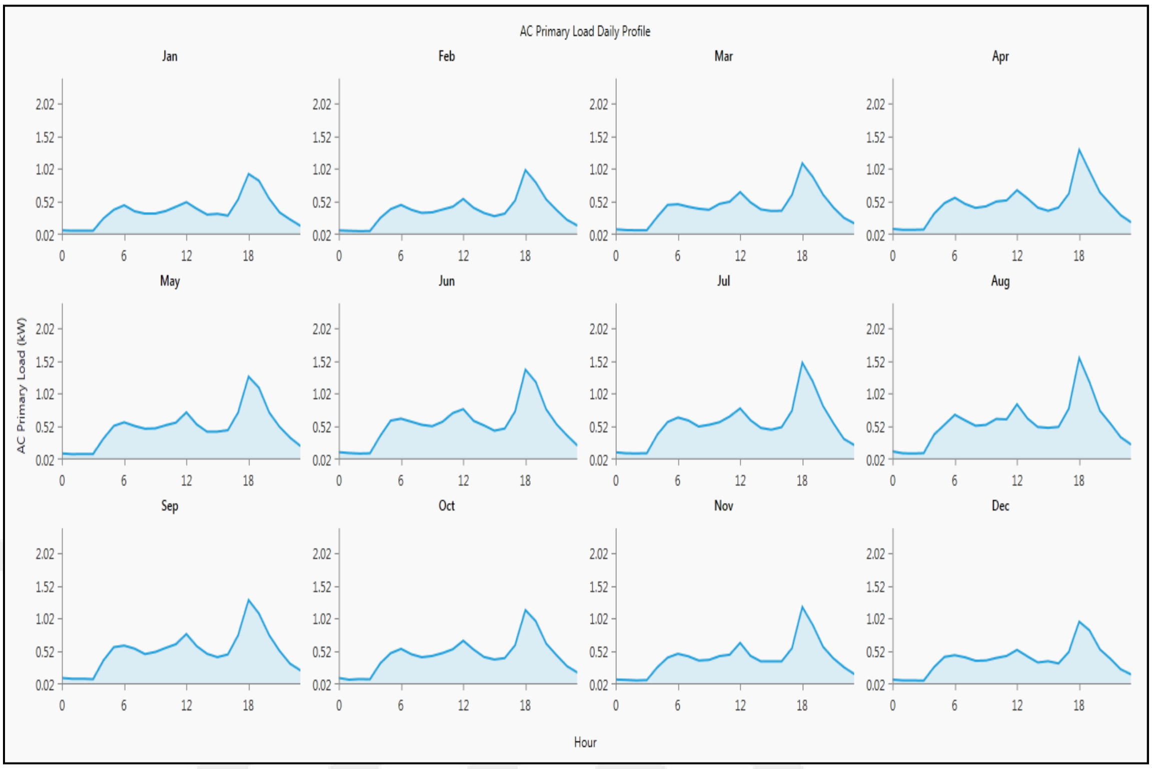
Figure describes the monthly average variation of load present all around the year. The maximum load of 2.39 kW which is also the peak load of our annual profile can be seen during the month of July. The load is highest in this month because of the hot temperature outside and mostly people are using more Air Conditioning systems in this month as compared to other months. The lower loads can be observed in the months from December to February because the temperature is cold in these months and heating systems in Pakistan are used on natural gas equipments and that is why electric consumption is low. The mean of other months are almost similar in load demands.

Figure 7.2: Monthly average variation of load around the year



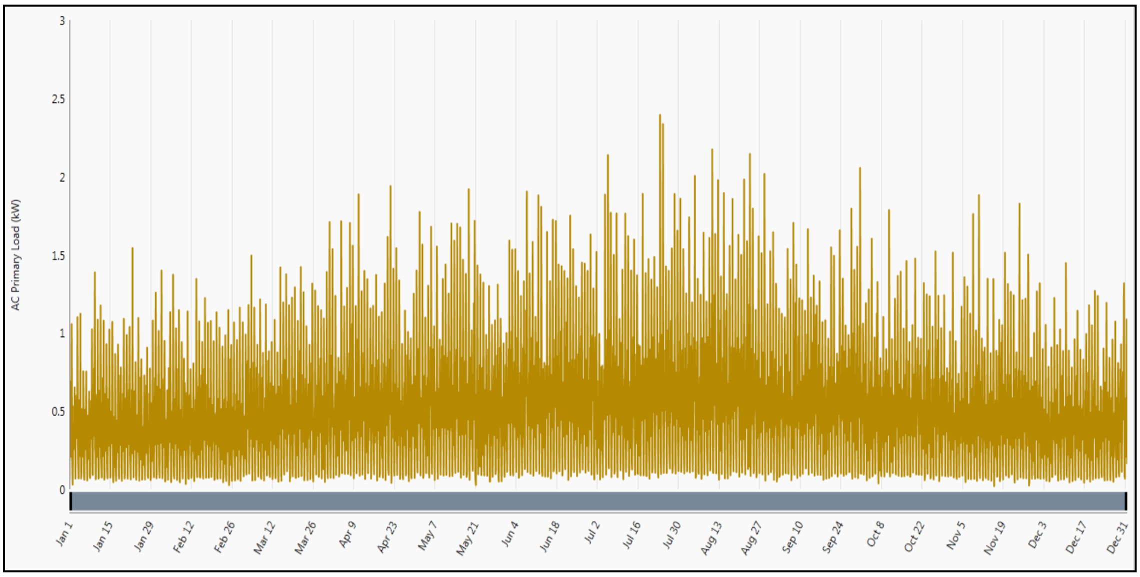
In figure 7.2, the daily profile of electric load according to the months in the year is shown. As described above, it can be seen that the peak daily electric demand is around 18:00h and the load is greater in summers as compared to the cold months in the year.

Figure 7.3: Daily profile of electric load according to the months



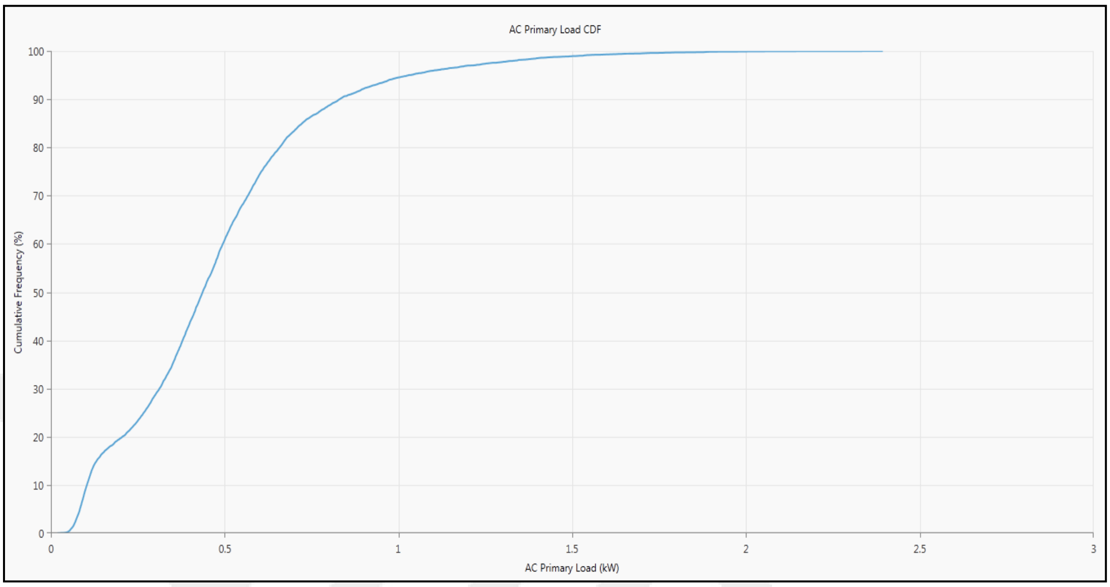
From the figure 7.3, it is clear that the highest consumption has been occurred in the last weeks of month July and the lowest demands can be observed during December until February. The mean of electric consumption throughout the year is not so different but slight diversity can be seen during the year.

Figure 7.4: Average variation of load around the year



Cumulative distribution function can be seen in the figure 7.5 given below. It is clear that the cumulative frequency is maximum during the peak hours.

Figure 7.5: CDF of AC primary load



7.3 ENERGY RESOURCES FOR HYBRID SYSTEM

The setting up of renewable energy system utterly depends on the resources available for the given site. The resources include wind speeds, average daily surface solar insolation and their well-timed variation. The meteorological data of wind speed and solar insolation is taken from NASA surface meteorology and solar energy website.

7.3.1 PV Solar Energy Resource at the Site

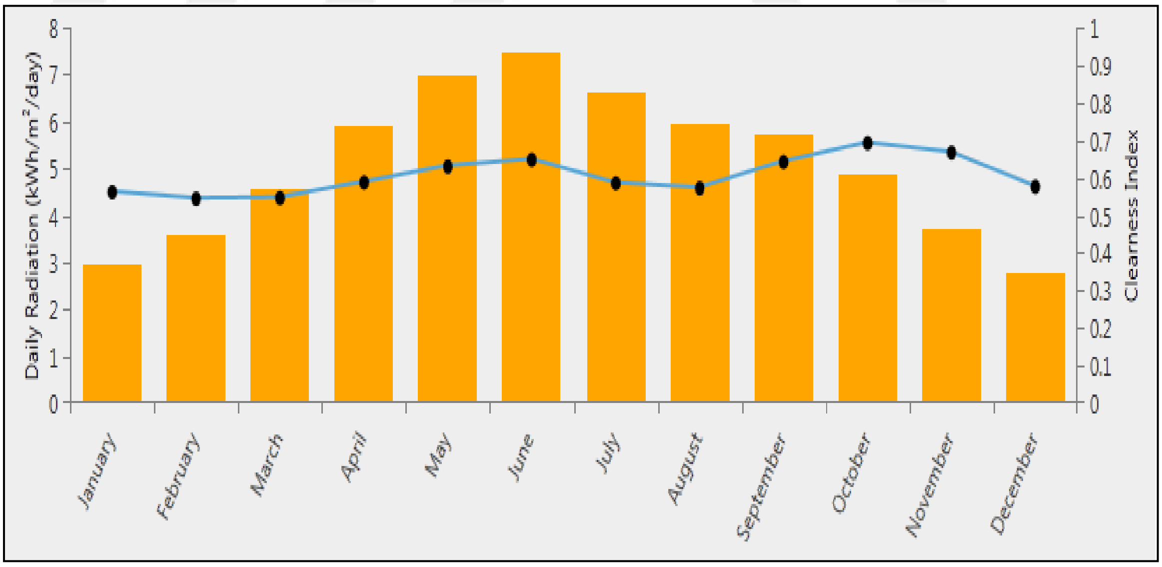
Monthly solar radiations and clear index for the selected site are shown in Table 7.3. There are three essential of solar radiation reaching on the ground: global radiation, diffused radiation and direct radiation. Global and diffused radiations are usually measured while the direct component is estimated.

The solar radiation data, monthly daylight hours and No sun/Black days profile has been downloaded from NASA Surface meteorology and Solar Energy database. These global horizontal radiations are monthly average values over 22 year period (July 1983 – June 2005) at Latitude 34, Longitude 73.5.

Table 7.3: Monthly average solar global horizontal irradiance

Month	Clear Index	Daily Radiation ($kWh/m^2/day$)
January	0.561	2.950
February	0.544	3.570
March	0.546	4.550
April	0.587	5.880
May	0.629	6.990
June	0.648	7.460
July	0.585	6.600
August	0.572	5.940
September	0.641	5.700
October	0.691	4.890
November	0.667	3.690
December	0.576	2.790

Figure 7.6: Average monthly and daily solar radiation and clear index profile



The average daily solar radiation for the selected site is 5.1 $kWh/m^2/day$ and average clearness index is 0.604. These insolation levels are at peak from April to July and lowest for the months of November and December.

Table 7.4: Monthly Daylight hours

Month	Day Light Hours
January	10.25
February	11.05
March	11.98
April	12.98
May	13.85
June	14.30
July	14.08
August	13.37
September	12.40
October	11.40
November	10.50
December	10.03

From the table 7.4 above it can be seen that the longest daylight hours are from May to August and lower daylight is observed in the month of December at the selected site.

In table 7.5, maximum numbers of No-Sun or Black days are presented. As seen in the table of clear index, it is also seen here that the number of no-sun days are higher in the month of February and July.

Table 7.5: Monthly No-sun hours

Month	No-Sun Hours
January	4.56
February	6.19
March	5.97
April	5.56
May	3.55
June	4.26
July	7.06
August	4.87

September	4.80
October	5.39
November	4.32
December	5.00

Figure 7.7: Average variation of Global solar around the year

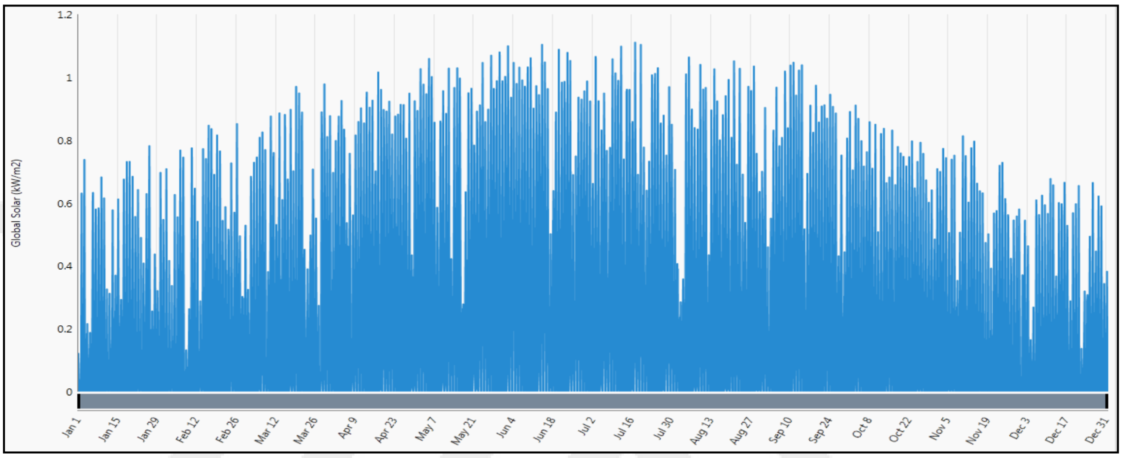


Figure 7.8: Monthly average variation of Global solar around the year

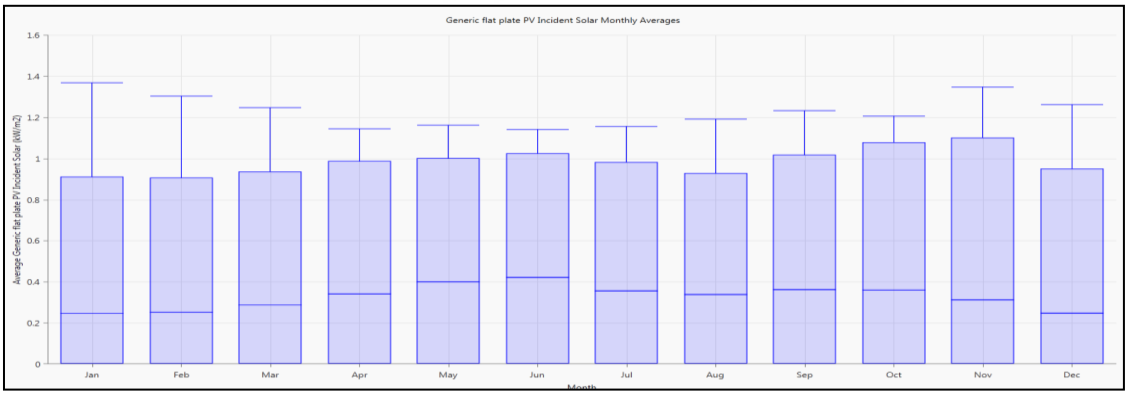


Figure 7.9: Daily profile of Global solar to the months

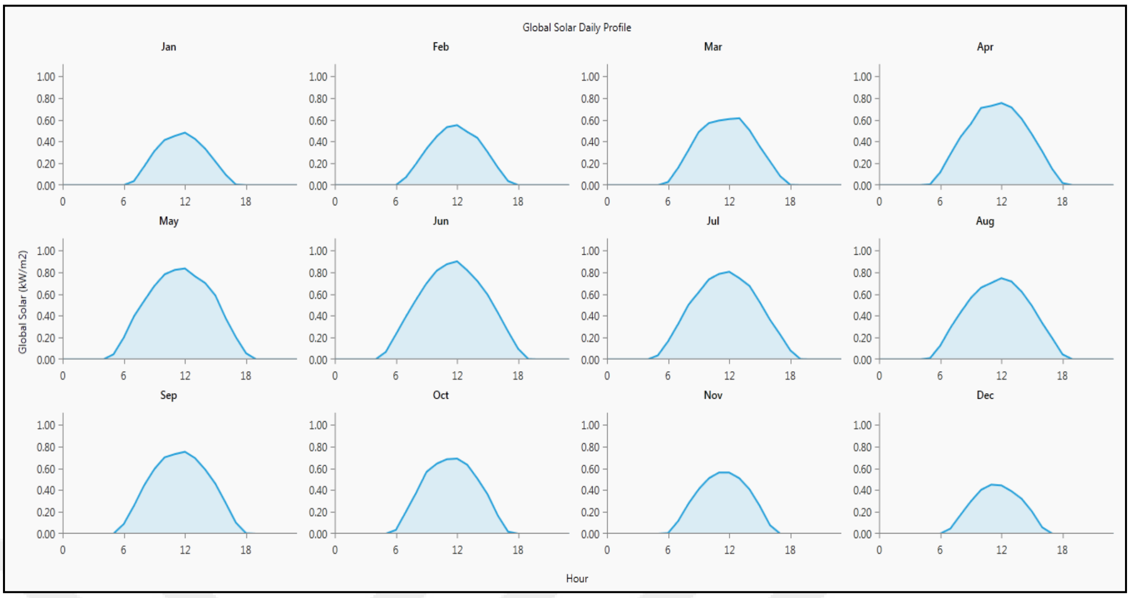
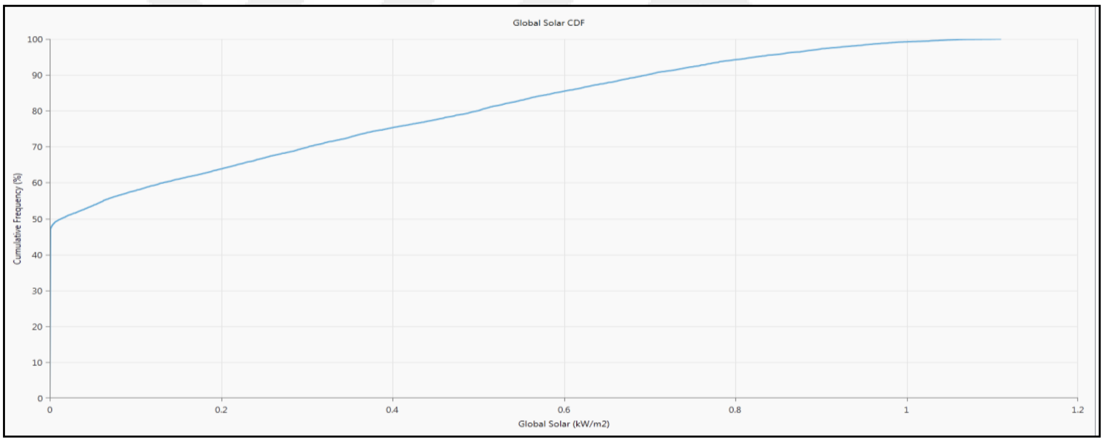


Figure 7.10: CDF of Global solar



7.3.2 Wind Energy Resource at the Site

The, monthly and annual wind speed profile has been downloaded from NASA Surface meteorology and Solar Energy database. These monthly average values have been recorded over 10 year period (July 1983 – June 1993) at Latitude 34, Longitude 73.5 at the height of 50m and 10m above the earth surface for terrain similar to airports.

Table 7.6: Monthly and Annual Wind speeds at 50m and 10m

Month	Wind speed 50m(m/s)	Wind speed 10m(m/s)
January	6.00	4.20
February	5.94	4.24
March	6.32	4.61
April	6.87	5.03
May	6.21	4.61
June	5.89	4.44
July	5.78	4.13
August	5.79	4.04
September	6.28	4.30
October	7.29	4.98
November	7.03	4.93
December	6.24	4.43
Annual	**6.30**	**4.50**

The monthly wind speed variations are shown in Table 7.6 above and from these values the average wind speed for the area at the height of 50m and 10m respectively is found to be 6.30m/s and 4.50m/s. Figures 7.11, 7.12, 7.13 and 7.14 shows diagrams and graphs of wind speeds.

Figure 7.11: Average variation of Global Wind speed around the year

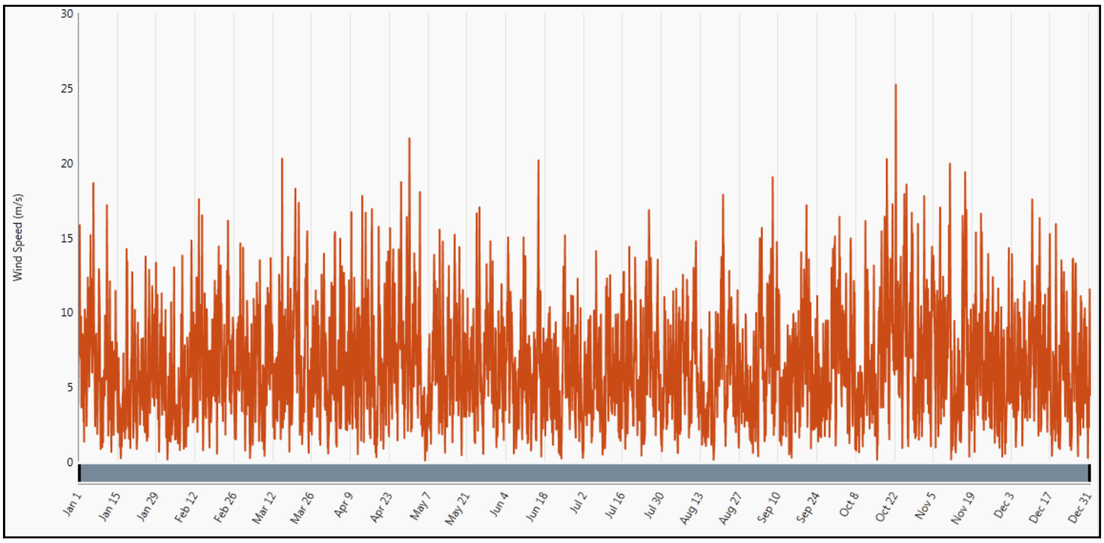


Figure 7.12: Monthly average wind speed around the year

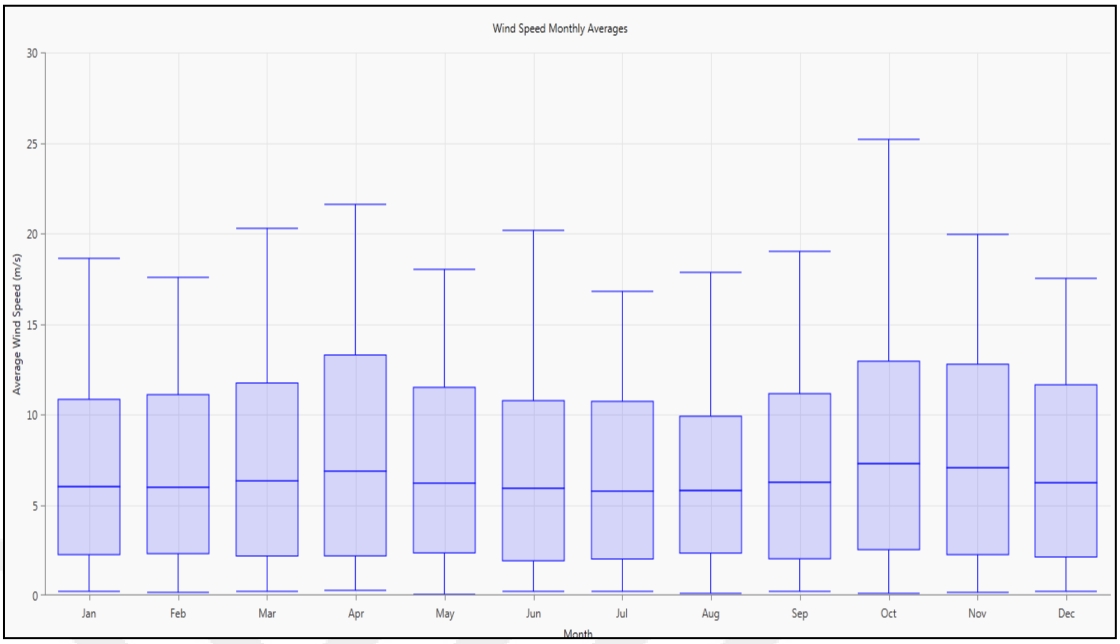


Figure 7.13: Daily profile of Wind speed to the months

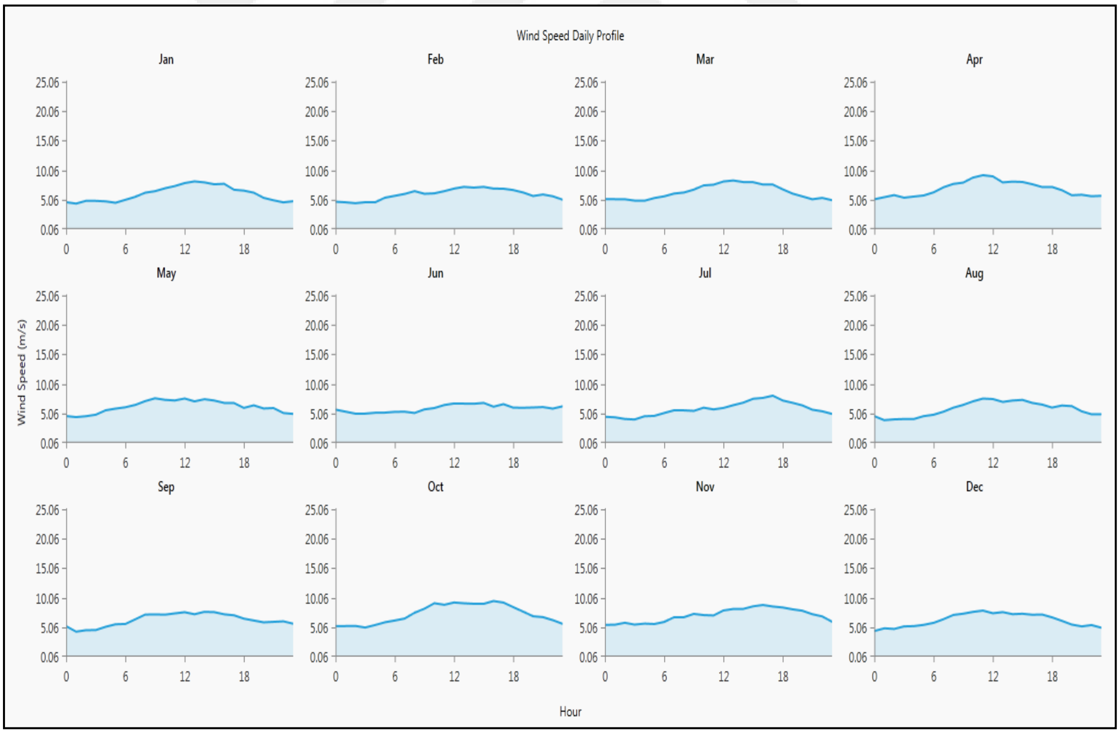
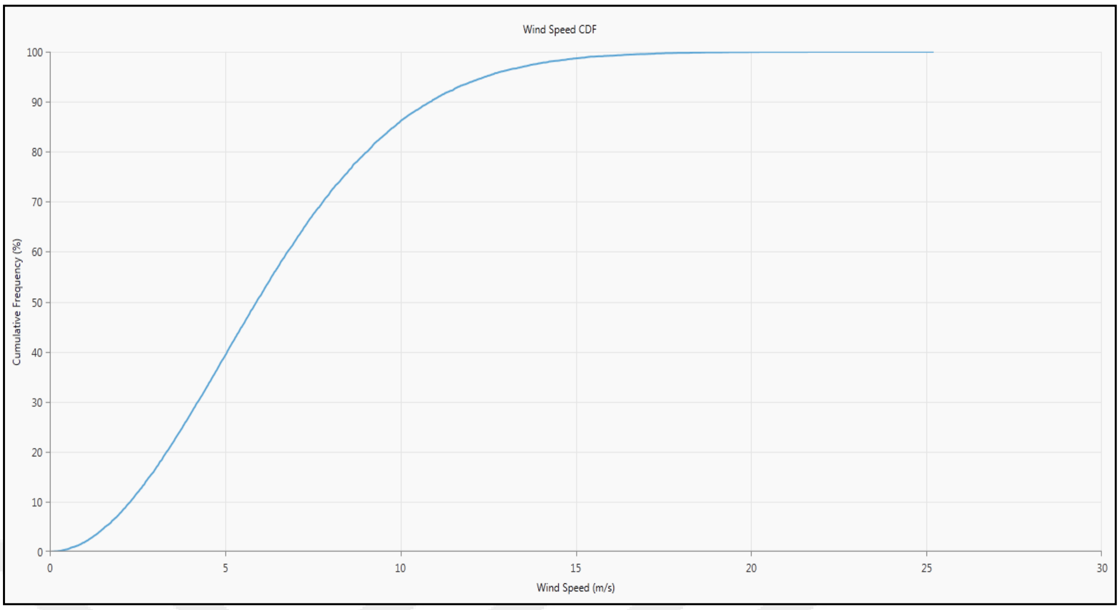


Figure7.14: CDF of Wind speed



7.4 ECNOMIC EVALUATION OF HYBRID SYSTEM

7.4.1 Annual Real Interest Rate

The annual real interest rate is one of the HOMER's inputs which are also known as the real interest rate. It is the discount rate used to change between one-time costs and annualized costs. It is found in the Economic Inputs window. The annual real interest rate is connected to the nominal interest rate by the equation given below (HOMER):

$$i_R = \frac{i_N - f}{1 + f} \qquad \textbf{(7.1)}$$

In this equation 7.1, i_R is the real interest rate, i_N is the nominal interest rate (the rate at which you could get a loan), and f is the annual inflation rate.

In this thesis, the homer calculates the real interest rate of 5.88 percent given 8 percent discounted rate and 2percent expected inflation rate.

7.4.2 Cost of Energy

HOMER defines the cost of energy (COE) as the average cost/kWh of useful electrical energy formed by the system. To calculate the COE, HOMER splits the annualized cost of generating electricity (the total annualized cost minus the cost of serving the thermal load) by the total valuable electric energy manufacture. The equation for the COE is as follows (HOMER):

$$COE = \frac{C_{ann,tot}}{E_{prim,AC} + E_{def}} \qquad \textbf{(7.2)}$$

The annualized cost of a component is equivalent to its annual operating cost plus its capital and replacement costs annualized over the project period. The annualized cost of each component is equivalent to the sum of its: annualized capital cost, annualized replacement cost, annual O&M cost and annual fuel cost (if applicable) (NREL, HOMER user manual).

It calculates the annualized capital cost of each component by means of the given equation below:

$$C_{acap} = C_{cap} \cdot CRF(i, R_{proj}) \qquad \textbf{(7.3)}$$

7.4.3 Net Present Cost (NPC)

The present value of the cost of installing and operating the system over the period of the project. Project lifetime in this study is measured over a period of 25 years. The net present cost is calculated regarding to the following equation 7.3 (HOMER):

$$C_{NPC} = \frac{C_{ann,tot}}{CRF(i, R_{proj})} \qquad \textbf{(7.4)}$$

The capital recovery factor is a ratio used to calculate the present value of an annuity (a series of equal annual cash flows). The equation for the capital recovery factor is shown below:

$$CRF(i,N) = \frac{i(1+i)^N}{(1+i)^N - 1} \qquad \textbf{(7.5)}$$

Assumed project lifetime in this thesis is 25 years.

7.4.4 System Cost Values that used in Simulations

The costs and expenses used in HOMER energy software for simulation determination are given in the table below. In this software there are other expenses which are not included and are neglected are as follows:

1. Personnel outgoings
2. transport cost
3. ground rent or price
4. tax and other cost

Table 7.7: Costs of different components for simulation in HOMER

Component		Capital Cost ($)	Replacement Cost ($)	Operating & Maintenance Cost ($)
Wind turbine	1kW 0.5kW 0.3kW	1500 750 350	1500 750 350	30 15 7
PV Modules	1kW	1000	1000	10
Batteries	1Trojan LP16 1kW LeadAcid	500 300	500 300	15 10
Converter (Inverter + Rectifier + Charge controller)	1kW	300	300	0

Diesel Generator	1 kW	500	500	0.03($/hour)

Table 7.7 Costs of different components for simulation in HOMER, **e**ven though, in ideal working circumstances; PV panels, batteries, inverters and charge regulators are economical. Operating and maintenance costs are imprecise in actual working condition.

Costs of hybrid system include: components initial costs, components replacement costs, system maintenance costs, fuel and/or operation costs, and salvage costs or salvage revenues. HOMER performs these energy balance calculations for every system configuration that the software users specify.

HOMER then decide whether every configuration is feasible, i.e., whether it can meet up the electric demand under the conditions that the user provide in the software, and make an estimation of the cost of installing and operating the system over the lifetime of the project. The system cost calculations depends on the costs such as capital, replacement, operation and maintenance, fuel, and interest. After simulating all of the possible system configurations, HOMER demonstrates a list of configurations, classified by net present cost (lifecycle cost).The total net present cost of a system is the present value of all the costs that it acquire over its lifetime, minus the present value of all the revenue that it produce over its lifetime. Costs include capital costs, replacement costs, O&M costs, fuel costs, emissions penalties, and the costs of buying power from the grid. Revenues include salvage value and grid sales revenue.

7.5 RESULTS AND DISCUSION:

7.5.1 Types of Scenarios:

In this thesis, there are three different types of scenarios are discussed for the sake of designing an optimal and best hybrid system for a house. The scenarios which are considered in this study are as follows:

I. Grid-Tied/Connected Hybrid System
II. Off Grid/Stand alone Hybrid System
III. For load-shedding/Power Cut hours Hybrid system

a. **Search Space and Sensitivity Input for HOMER**

To get the "optimal hybrid system design" determined by HOMER depends on the input assumption statement. Key assumptions of two different types, for search space and sensitivity analysis are reviewed in the table given below, and followed by a more detailed discussion in later paragraphs:

I. Grid-Tied/Connected Hybrid System

These sizes were iteratively determined to be sufficiently broad that HOMER did not indicate that the "search space" of any particular item was probably too small, while at the same time trying to reduce the number of feasible options in order to keep the computational necessities, and thus model run time, at a convenient level. The sizes considered for every component, for the grid-tied hybrid system, the search space for different components and sensitivity inputs are shown in the table 7.8 and 7.9 below:

Table 7.8: Sizes considered for components for Grid-Tied HOMER model run

Converter Capacity (kW)	Grid Purchase Capacity (kW)	1kWh LA Strings (#)	PV Capacity (kW)	1 kW Wind Turbine Quantity (#)	0.5 kW Wind Turbine Quantity (#)
0.00	10,000.00	0.00	0.00	0.00	0.00
0.50		1.00	0.50	1.00	1.00
0.60		2.00	0.60	2.00	2.00
0.70			0.70		
0.80			0.80		
0.90			1.00		
1.00			1.50		
1.50			1.80		
			2.00		

Table 7.9: Sensitivity input for Grid-Tied HOMER model run

Electric Load Scaled Average (kWh/day)	Wind Scaled (m/s)

11.269	6.303
15.000	4.000
	5.000

II. Off Grid/Stand alone Hybrid System

The sizes considered for every component, for the off-grid hybrid system, the search space for different components and sensitivity inputs are shown in the table 7.10 and 7.11:

Table 7.10: Sizes considered for components for Off-Grid HOMER model run

Converter Capacity (kW)	1kWh LA Strings (#)	Generator Capacity (kW)	PV Capacity (kW)	0.5 kW Wind Turbine Quantity (#)	0.3 kW Wind Turbine Quantity (#)
0.00	0.00	0.00	0.00	0.00	0.00
0.50	1.00	1.00	1.00	1.00	1.00
1.00	2.00	1.50	1.20	2.00	2.00
1.50	3.00	2.00	1.30		3.00
2.00	4.00		1.40		4.00
2.50			1.50		
3.00			1.80		
			2.00		
			2.50		

Table 7.11: Sensitivity input for Off-Grid HOMER model run

Diesel Fuel Price ($/L)	Electric Load Scaled Average (kWh/day)	Wind Scaled (m/s)
0.820	11.269	6.303
0.900	15.000	4.000
		5.000

III. For Load-shedding/Power Cut hours Hybrid system

The sizes considered for every component, for the Load shedding/Power cut hours hybrid system, the search space for different components and sensitivity inputs are shown in the table 7.12 and 7.13:

Table 7.12: Sizes considered for components for Load-shedding hours model run

Converter Capacity (kW)	Trojan L16P Strings (#)	Generator Capacity (kW)	PV Capacity (kW)	0.3 kW Wind Turbine Quantity (#)	0.5 kW Wind Turbine Quantity (#)
0.00	0.00	0.00	0.00	0.00	0.00
0.60	1.00	1.00	0.50	1.00	1.00
0.70	2.00	1.50	0.60	2.00	
0.80	3.00		0.70	3.00	
0.90			0.80		
1.00			1.00		
1.10					
1.20					

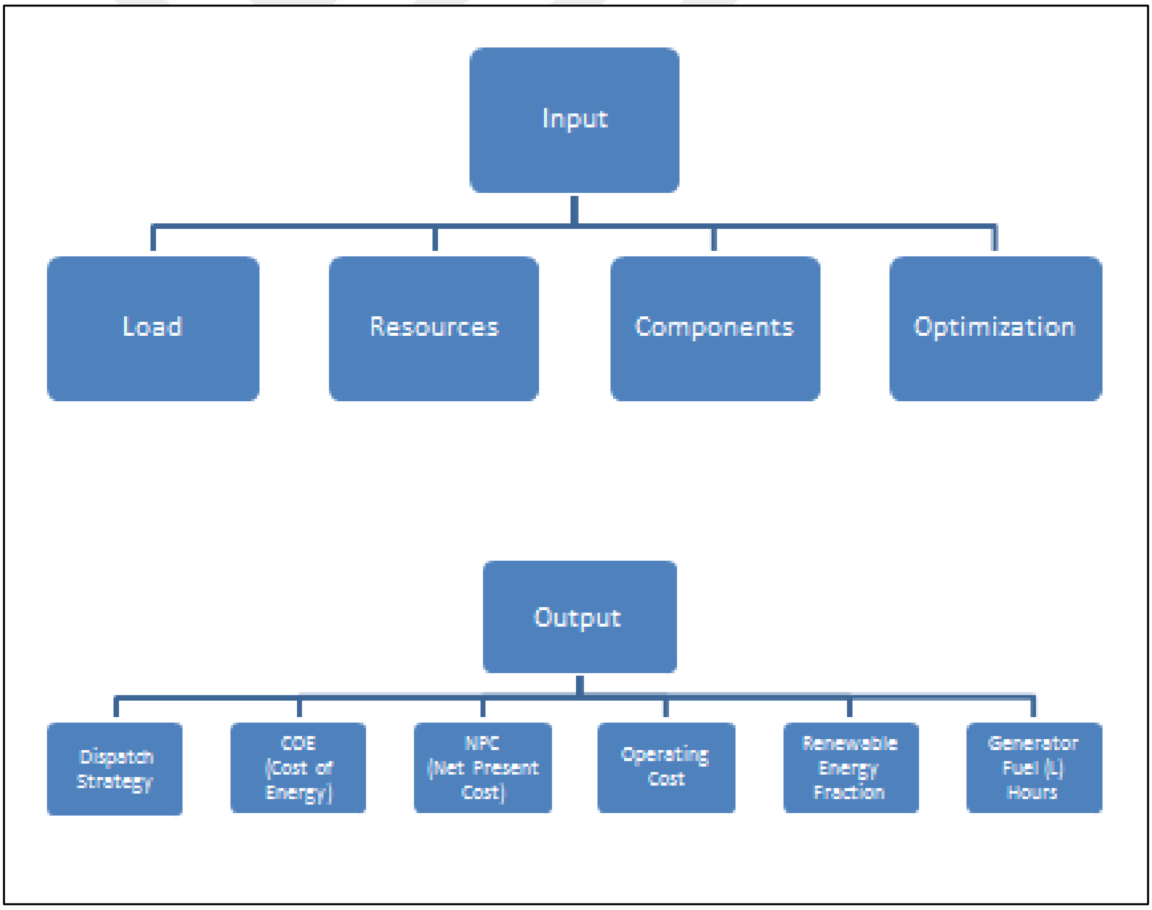
Table 7.13: Sensitivity input for Load-shedding hours HOMER model run

Diesel Fuel Price ($/L)	Electric Load Scaled Average (kWh/day)	Wind Scaled (m/s)
0.820	2.76	6.303
0.900	4.000	4.000

Flow diagram of Input and output of HOMER simulation:

Figure 7.15 shows the flow diagram of HOMER energy software from its input components to output.

Figure 7.15: Flow diagram of HOMER Simulation Results



7.5.2 Existing System

Currently, it is assumed that the house is connected to an electric grid system and it is fully dependent on this grid supply for its electric demand.

The existing system is having following characteristic for a demand of 11.27 kWh/day, from a local grid system on an average rate of electricity for $0.12.

Average electric rate has been chosen because in Pakistan there are different categories of electrical tariffs provided by the grid station for instance, first 50 kWh are provided on the rate of $0.08 and the other 100 kWh are provided with the rate of $0.12 and if the requirement increased from this level then the tariff rate is going up to $0.14/kWh.
In this study, the projected lifetime is taken 25 years.

7.5.2.1 Results of grid connected system

The detailed cost of grid connected system has been mentioned in Appendix.
Grid connected system has following costs showed in table 7.14:

Table 7.14: System total expenses

Total Net Present Cost **(NPC)**	$6,318
Cost of Energy **(COE/kWh)**	$0.120
Operating Cost **(per annum)**	$494
Grid Purchase **(kWh/year)**	4,113
Initial Capital	$0

The net present cost of grid connected system yearly and over 25 years is shown in the following figures 7.16 and 7.17 and figure 7.18 shows the monthly grid purchases during the year.

Figure 7.16: Yearly cost of Grid connected system

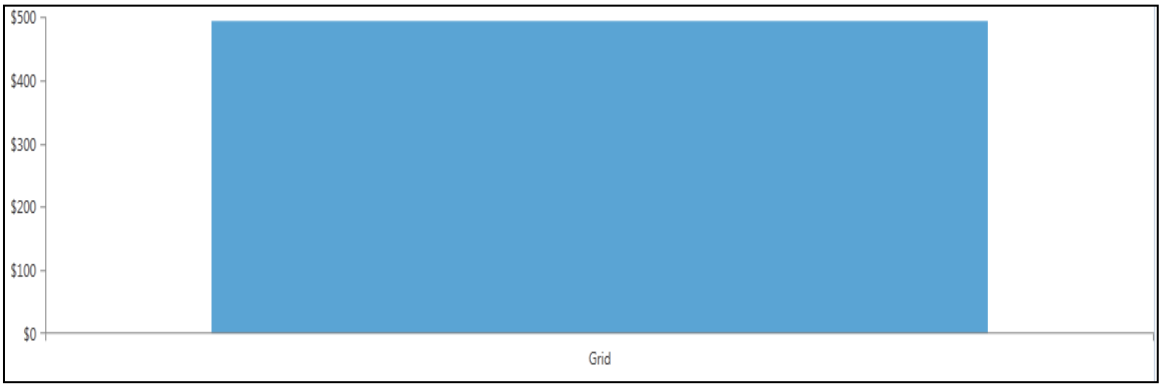


Figure 7.17: Net Present Cost of Grid connected system

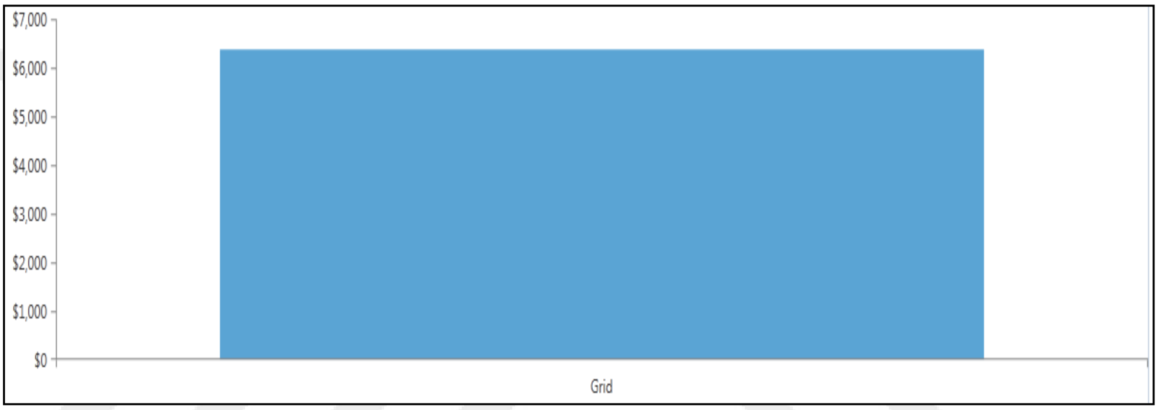
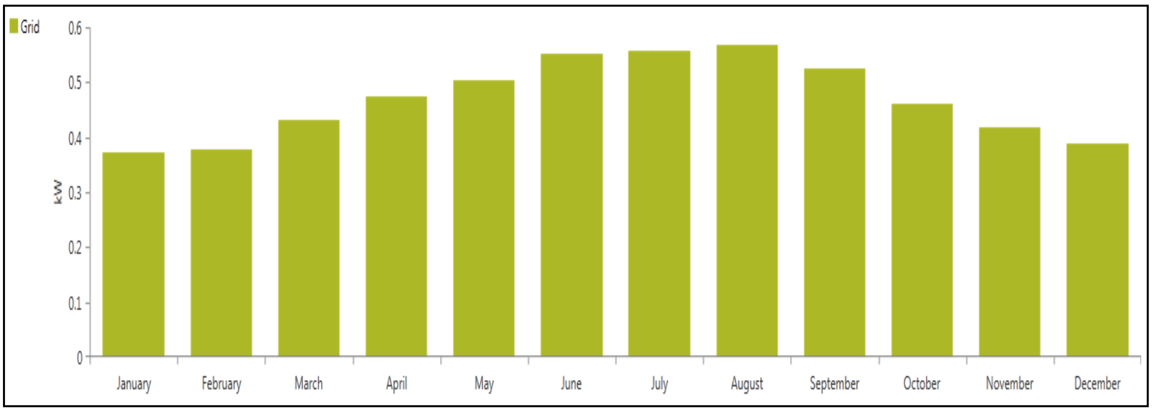


Figure 7.18: Monthly Purchases of Grid connected system



7.6 HOMER SIMULATION RESULTS FOR OPTIMAL HYBRID SYSTEM

HOMER simulation software presents the results in terms of “optimal systems” and the sensitivity analysis. This software, the optimized results are presented categorically for a particular set of sensitivity parameters like wind speed, different electric loads and fuel price in the present case. The simulation results for optimization and sensitivity are discussed in the approaching paragraphs.

7.6.1 Grid Tied Hybrid System

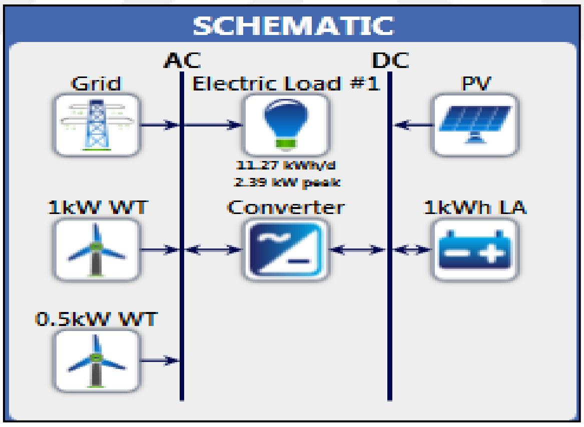
7.6.1.1 Schematic

For grid-tied hybrid system, the components that have been used for an optimization purpose are following:

1. Photovoltaic PV
2. 1 kW Wind Turbine
3. 0.5 kW Wind Turbine
4. Converter
5. 1 kWh Lead Acid Battery

The search space is already mentioned above in the table above. The schematic of grid-tied system is shown in the figure.

Figure 7.19: Schematic of grid-tied system



7.6.1.2 Simulation Results

From figure, the best optimal result of grid-tied are displayed. In this thesis, for grid-tied hybrid systems, there are 2 different kinds of sensitivity analysis has been completed with 5 categories, 2 inputs are from Electric loads and 3 inputs of wind speed are compared to get more detailed analysis which are as follows:

a. Electric Load

The real value of 11.27 kWh/day has been compared with the load until 15 kWh/day. But in this thesis we will only discuss about the basic load of 11.27kWh/day for the purpose of simplicity.

b. Wind Speed

The annual average of the area with the speeds at the height of 10m and 50m has been evaluated to get more close to the design of best optimal solution.

The HOMER energy software simulates 8,760 hours (one year) of operation and thousands of different system configurations. The system with the overall smallest amount of net present cost, according to the given sensitivity inputs, is the one top on the list.

The first two columns of the HOMER results table shows Sensitivity inputs, in this case they are Electrical load and wind scaled average. The other following columns with graphic icons representing which components are present there in the optimized system. The remaining columns show the optimized capacity of each component, in this case they are, grid capacity, dispatch strategy, the total net present cost, the cost of energy (in $ per kWh), the initial capital cost and renewable energy fraction. The optimization result for grid-tied hybrid system has been shown in the following figure 7.20.

Figure 7.20: Overall optimization results table for Grid-Tied showing system configurations sorted by total Net Present Cost

Sensitivity		Architecture							Cost				System
Electric Load #1 Scaled Average (kWh/d)	Wind Scaled Average (m/s)	PV (kW)	1kW WT	0.5kW WT	1kWh LA	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)
11.27	4.00	1.0				10,000	1	CC	$0.094	$5,338	$322	$1,180	42
11.27	5.00	0.7		1		10,000	1	CC	$0.085	$5,207	$279	$1,600	57
11.27	6.30	0.6		1		10,000	1	CC	$0.070	$4,613	$241	$1,500	66
15.00	4.00	1.0				10,000	1	CC	$0.098	$7,140	$459	$1,210	34
15.00	5.00	1.0		1		10,000	1	CC	$0.087	$6,877	$380	$1,960	54
15.00	6.30	0.7		1		10,000	1	CC	$0.077	$6,146	$352	$1,600	57

7.6.1.3 Categorical simulation results

7.6.1.3.1 At 4m/s with 11.27 kWh/day load

The optimal designs of this hybrid system are shown in the figure 7.21 below. Detailed categorical results for this system have been given in Appendix A.

Figure 7.21: Overall optimization results

Architecture							Cost					System
PV (kW)	1kW WT	0.5kW WT	1kWh LA	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)		Ren Frac (%)
1.0				10,000	1	CC	$0.094	$5,338	$322	$1,180		42
0.7		1		10,000	1	CC	$0.098	$5,687	$316	$1,600		47
1.0			1	10,000	1	CC	$0.106	$5,996	$349	$1,480		42
0.7		1	1	10,000	1	CC	$0.110	$6,345	$344	$1,900		47
		1		10,000		CC	$0.118	$6,350	$433	$750		18
				10,000		CC	$0.120	$6,381	$494	$0		0

7.6.1.3.1.1 Best optimal Design

In the figure above, it is clearly seen that the best optimal solution is to have a design of renewable component of 1kW PV panel with a converter of 0.6kW attached together with grid which can produce 42percent of renewable fraction.

From the figure, it can be seen that the best possible optimal solution at the wind speed of 4m/s with the electric load of 11.27 kWh/day is having following results mentioned in table 7.15:

Table 7.15: System total expenses of best optimal design

Total Net Present Cost **(NPC)**	$5,338
Cost of Energy **(COE/kWh)**	$0.094
Operating Cost **(per annum)**	$322
Initial Capital	$1,800

Renewable Fraction **(percent)**	42
Grid Purchase **(kWh/year)**	2,557
Grid Sales **(kWh/year)**	260
Excess Electricity (kWh/year)	187.8
Salvage NPC	$14.37

Figure 7.22: Monthly average electrical production for optimal design

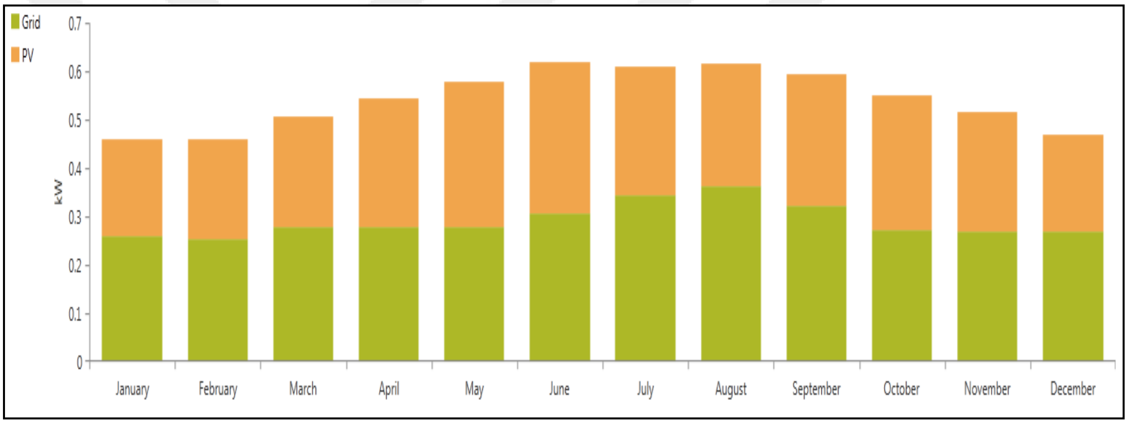


Figure 7.22 illustrate that the monthly production of renewable resource PV is around 42percent and the grid is producing other 58percent of total electric load. Figure shows that the grid purchases increased in the months of June, Jule and August because the electric demand is greater in those months. The mean values and maximum production of PV and grid purchases can be seen in the figures given below:

Figure 7.23: Monthly PV production for optimal design

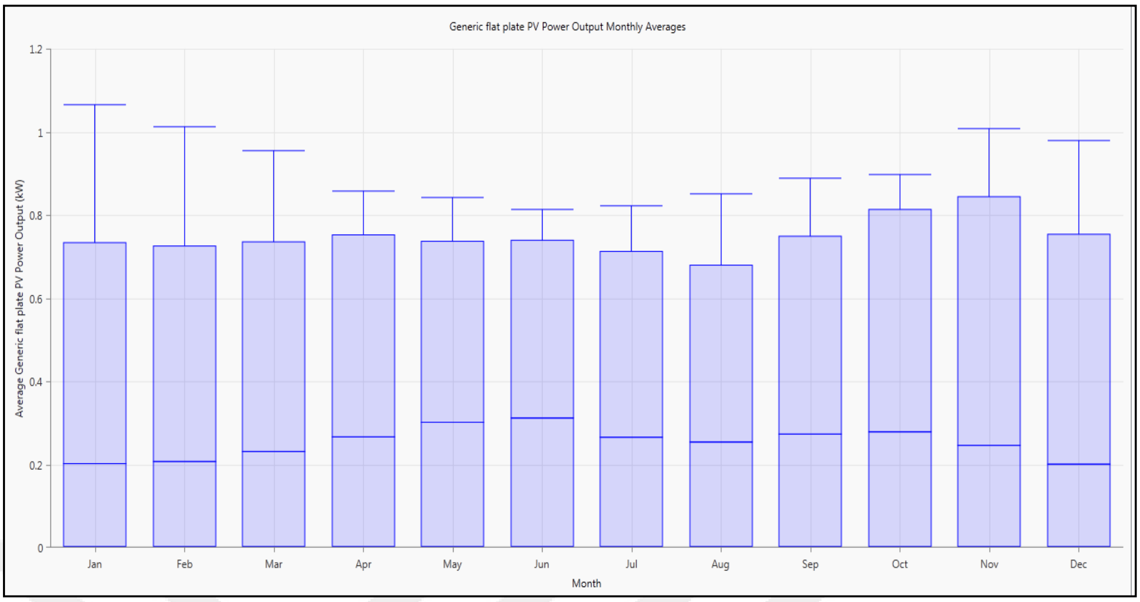
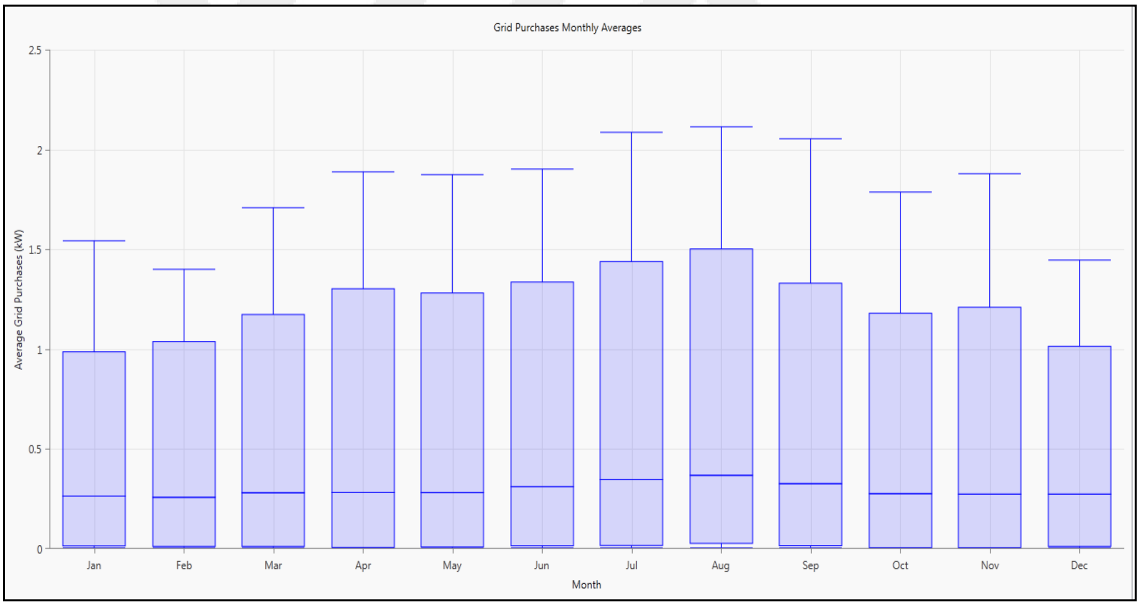


Figure 7.24: Monthly Grid purchases for optimal design



7.6.1.3.1.2 Comparison of Optimal design with Existing system

The detailed cost of tables is shown in Appendix. The optimal design compared with the current existing system and the cost analysis is shown below in table 7.16 and 7.17:

Table 7.16: Comparison of Existing and Current System

	PV (kW)	Converter (kW)	Grid (kW)	NPC ($)	Initial Capital ($)
Existing System			10000	6,381	0
Current System	1	0.6	10000	5,338	1180

Table 7.17: Rate of Returns and Payback Periods

Metric	Value
Present worth	$1,043
Annual Worth ($/year)	$98
Return on investment (percent)	14.6
Internal rate of return (percent)	14.2
Simple payback (year)	6.67
Discounted payback (year)	8.84

Figure 7.25: Graph of Nominal Comparison of systems

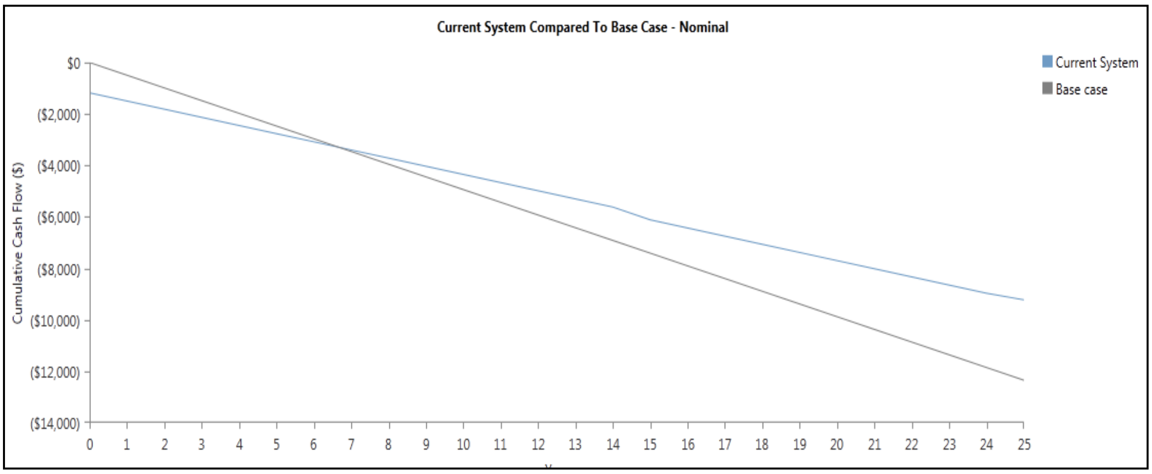
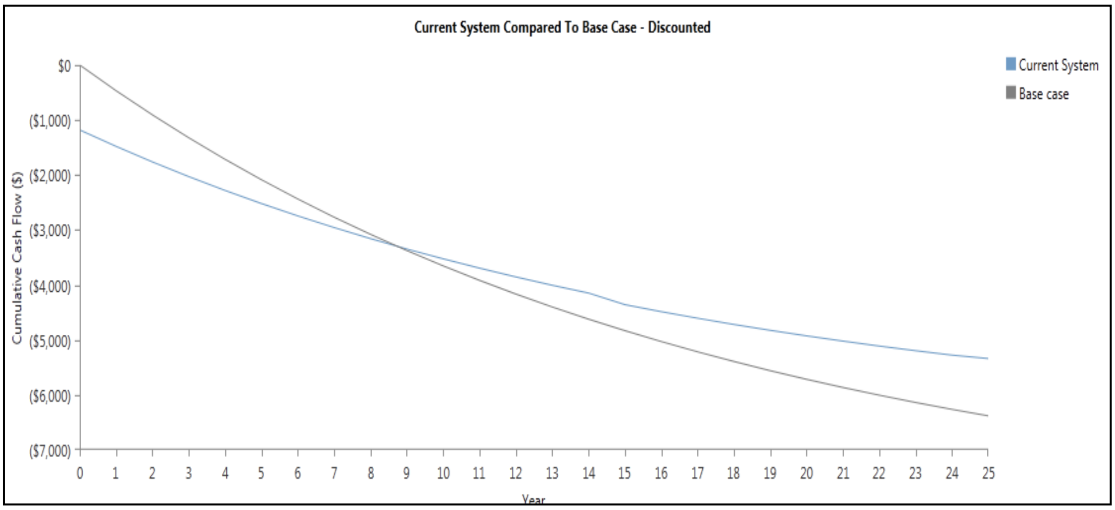


Figure 7.26: Graph of Discounted Comparison of systems



From the comparison graphs showed above in figure 7.25 and Figure 7.26 of the existing and current optimal system, it is clearly visible that the optimal hybrid system is much better than the existing system of grid connected in all the ways of costs.

7.6.1.3.2 At 6.30 m/s with 11.27 kWh/day load

The optimal designs of this hybrid system are shown in the figure 7.27 below. Detailed categorical results for this system have been given in Appendix.

Figure 7.27: Overall optimization results

Architecture							Cost					System
PV (kW)	1kW WT	0.5kW WT	1kWh LA	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)		Ren Frac (%)
0.6		1		10,000	1	CC	$0.070	$4,613	$241	$1,500		66
		1		10,000		CC	$0.080	$4,739	$309	$750		48
0.6		1	1	10,000	1	CC	$0.080	$5,272	$269	$1,800		66
1.0				10,000	1	CC	$0.094	$5,338	$322	$1,180		42
0.5	1			10,000	1	CC	$0.072	$5,343	$247	$2,150		72
	1			10,000		CC	$0.079	$5,377	$300	$1,500		60
		1	1	10,000	1	CC	$0.095	$5,599	$340	$1,200		48
	1	1		10,000		CC	$0.063	$5,615	$260	$2,250		77
0.5	1	1		10,000	1	CC	$0.060	$5,809	$225	$2,900		84
1.0			1	10,000	1	CC	$0.106	$5,996	$349	$1,480		42
0.5	1		1	10,000	1	CC	$0.081	$6,002	$275	$2,450		72
	1		1	10,000	1	CC	$0.092	$6,237	$332	$1,950		60
				10,000		CC	$0.120	$6,381	$494	$0		0

7.6.1.3.2.1 Best optimal Design

In the figure above, it is clearly seen that the best optimal solution is to have a design of renewable component of 0.6kW PV panel with a converter of 0.5kW attached together with grid which can produce 66percent of renewable fraction and 1 wind turbine of 0.5kW. From the figure, it can be seen that the best possible optimal solution at the wind speed of 6.30m/s with the electric load of 11.27 kWh/day is having following results mentioned in table 7.18:

Table 7.18: System total expenses of best optimal design

Total Net Present Cost **(NPC)**	$4,613
Cost of Energy **(COE/kWh)**	$0.070
Operating Cost **(per annum)**	$241
Initial Capital	$1,500
Renewable Fraction **(percent)**	66
Grid Purchase **(kWh/year)**	1,731
Grid Sales **(kWh/year)**	1,006
Excess Electricity **(kWh/year)**	2.4
Salvage NPC	$146.73

Figure 7.28: Monthly average electrical production for optimal design

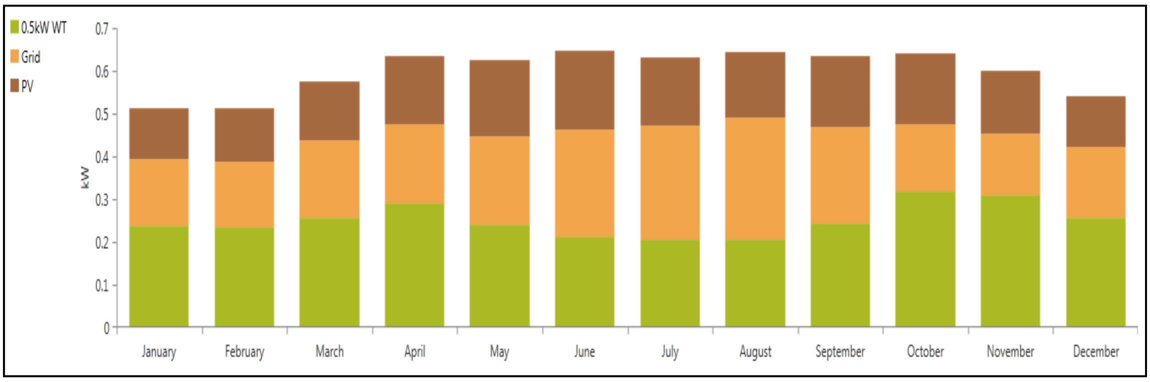


Figure 7.28 illustrate that the monthly production of renewable resource PV is around 25percent and the grid is producing other 34percent of total electric load and 0.5kW wind turbine is producing 41percent for the demand which gives the total renewable fraction of 66percent.

Figure shows that the grid purchases increased in the months of June, Jule and August because the electric demand is greater in those months and only renewable resources can provide optimal solution at higher percentage of electric production of 84percent as we can see in the figure above in optimization result but it would be more expensive than the this optimal hybrid system.

The mean values and maximum production of PV and grid purchases can be seen in the figures 7.29, 7,30 and 7.31 given below:

Figure 7.29: Monthly PV production for optimal design

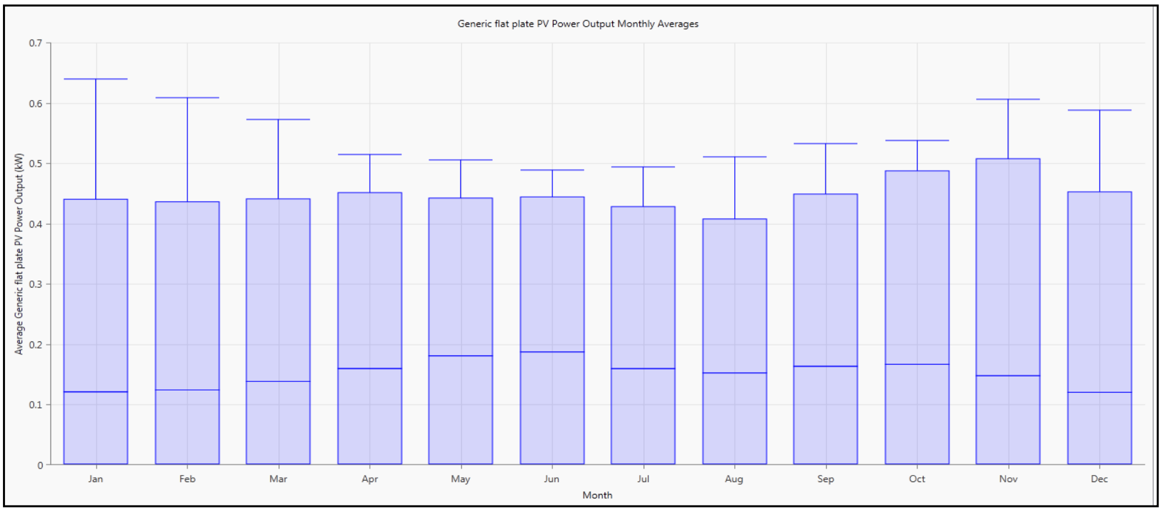


Figure 7.30: Monthly Grid purchases for optimal design

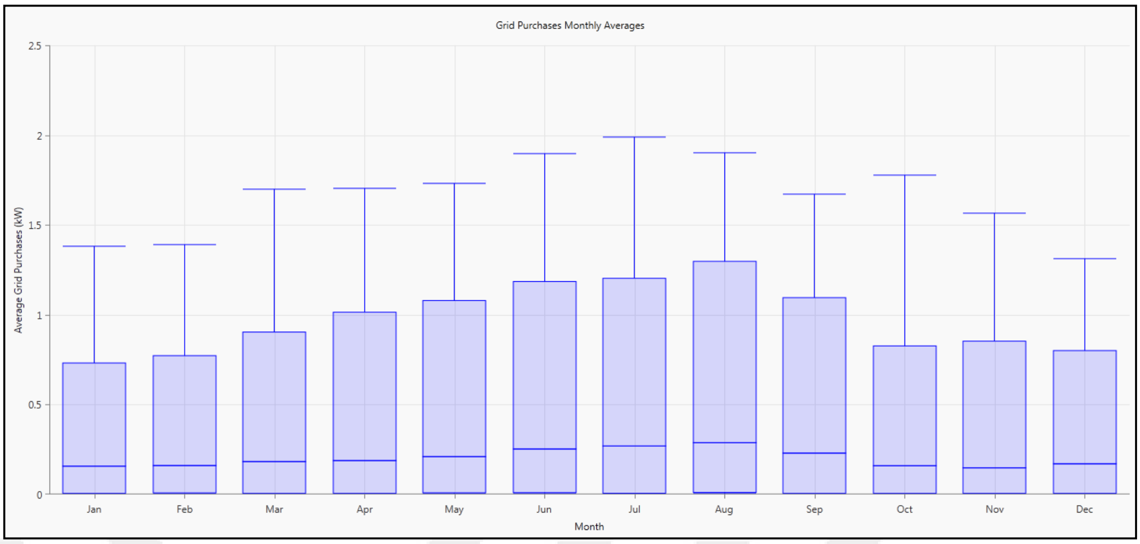
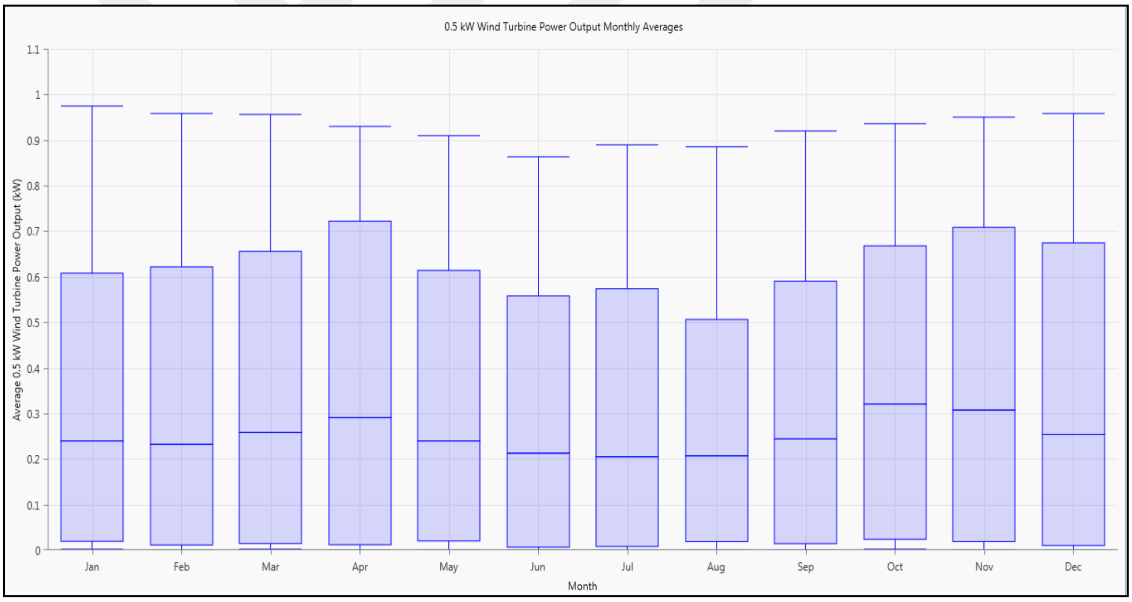


Figure 7.31: Monthly 0.5kW Wind Turbine production for optimal design



7.6.1.3.2.2 Comparison of optimal design with existing system

The detailed cost of tables is shown in Appendix. The optimal design compared with the current existing system and the cost analysis is shown below in table 7.19 and 7.20:

Table 7.19: Comparison of Existing and Current System

	PV (kW)	Converter (kW)	Grid (kW)	NPC ($)	Initial Capital ($)
Existing System			10000	6,381	0
Current System	0.6	0.5	10000	4,613	1500

Table 7.20: Rate of Returns and Payback Periods

Metric	Value
Present worth	$1,767
Annual Worth ($/year)	$166
Return on investment (percent)	16.9
Internal rate of return (percent)	16.9
Simple payback (year)	5.66
Discounted payback (year)	7.09

Figure 7.32: Graph of Nominal Comparison of systems

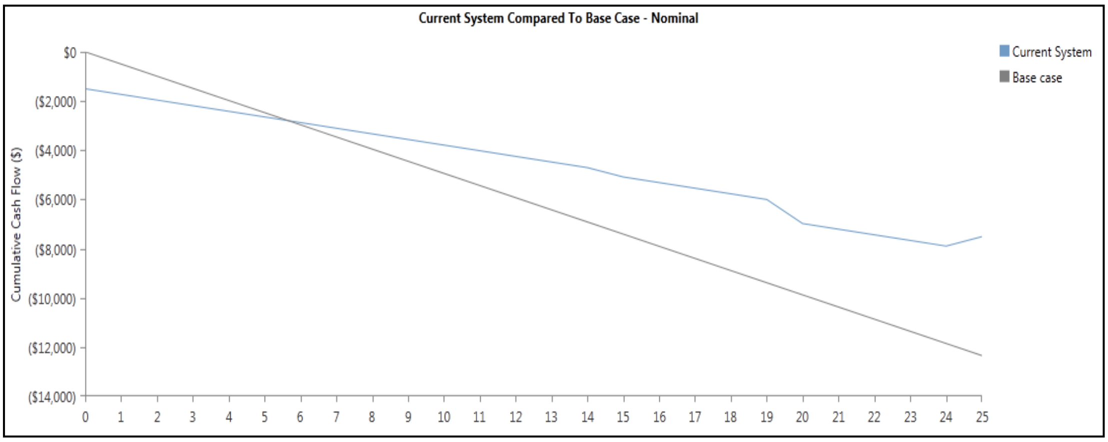
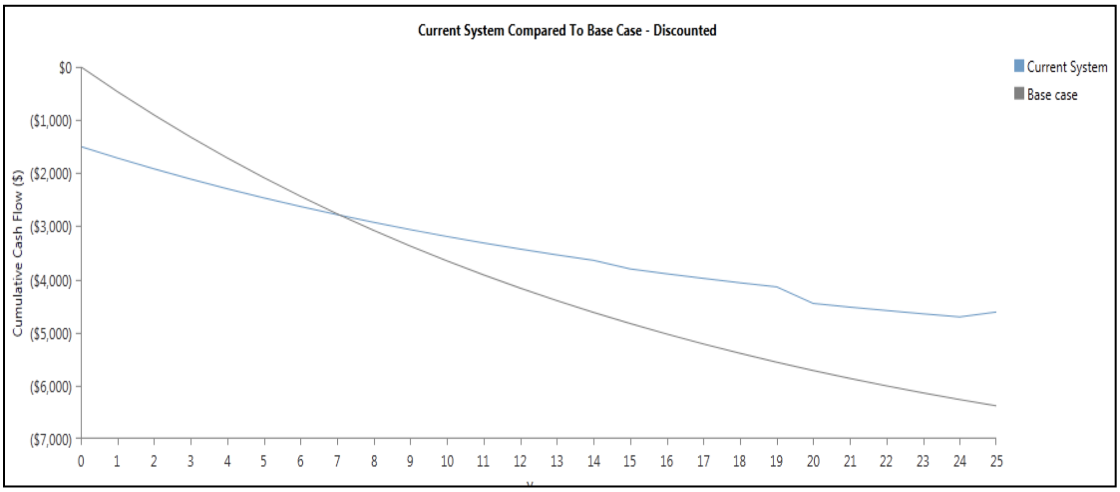


Figure 7.32: Graph of Discounted Comparison of systems



From the comparison graphs showed above in figures 7.31 and 7.32 of the existing and current optimal system, it is clearly visible that the optimal hybrid system is much better than the existing system of grid connected in all the ways of costs.

7.6.2 Off Grid Hybrid Systems

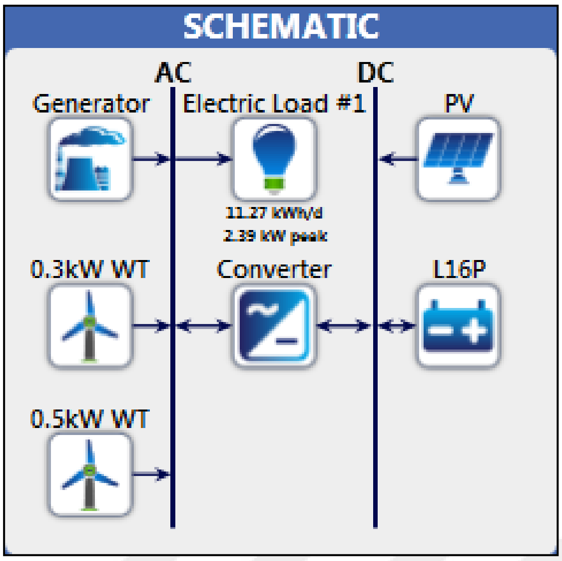
7.6.2.1 Schematic

For off-grid hybrid system, the components that have been used for an optimization purpose are following:

1. Photovoltaic PV
2. Generator
3. 0.3 kW Wind Turbine
4. 0.5 kW Wind Turbine
5. Converter
6. Trojan Lead Acid Battery

The search space is already mentioned above in the table above. The schematic of off-grid system is shown in the figure 7.33.

Figure 7.33: Schematic of off-grid system



7.6.2.2 Simulation Results

From figure, the best optimal result of off-grid is displayed. In this thesis, for off-grid hybrid systems, there are 3 different kinds of sensitivity analysis has been completed with 6 categories, 2 inputs are from Electric loads, 2 inputs of wind speed and 2 inputs are from diesel fuel price are compared to get more detailed analysis which are as follows:

a. Electric Load

The real value of 11.27 kWh/day has been compared with the load until 15 kWh/day. But in this thesis we will only discuss about the basic load of 11.27kWh/day for the purpose of simplicity.

b. Wind Speed

The annual average of the area with the speeds at the height of 10m and 50m has been evaluated to get more close to the design of best optimal solution.

c. Diesel Fuel Price

The current diesel fuel price at the rate of $0.82 is taken together with increased assumed price of $0.90 to get an idea of inflation for an optimal design. But in this thesis only hybrid systems are discussed with current price of $0.82.

The HOMER energy software simulates 8,760 hours (one year) of operation and thousands of different system configurations. The system with the overall smallest amount of net present cost, according to the given sensitivity inputs, is the one top on the list.

The first three columns of the HOMER results table shows Sensitivity inputs, in this case they are Diesel fuel price, Electrical load and Wind scaled average. The other following columns with graphic icons representing which components are present there in the optimized system. The remaining columns show the optimized capacity of each component, in this case they are, grid capacity, dispatch strategy, the total net present cost, the cost of energy (in $ per kWh), the initial capital cost and renewable energy fraction. The optimization result for off-grid hybrid system has been shown in the following figure 7.44.

Figure 7.34: Overall optimization results table for Off-Grid showing system configurations sorted by total Net Present Cost

Sensitivity			Architecture								Cost				System	Generator	
Diesel Fuel Price ($/L)	Electric Load #1 Scaled Average (kWh/d)	Wind Scaled Aver. (m/s)	PV (kW)	0.3kW W	0.5kW WT	Generato (kW)	L16P	Converter (kW)	Dispat	COE ($)	NPC ($)	Operating ($)	Initial capital ($)	Ren Frac (%)	Fuel (L)	Hours
0.82	11.27	4.00	1.8		2	1	2	2	LF	$0.297	$15,772	$814	$5,250	69	474	2,222
0.82	11.27	6.30	1.0		3	1	2	1	LF	$0.216	$11,492	$498	$5,050	83	260	1,242
0.82	15.00	4.00	2.5		2	1	4	2	LF	$0.294	$20,827	$1,062	$7,100	67	642	2,689
0.82	15.00	6.30	2.5		3	1	2	2	LF	$0.216	$15,300	$654	$6,850	82	356	1,537
0.90	11.27	4.00	1.8		3	1	2	2	LF	$0.309	$16,425	$806	$6,000	73	408	1,879
0.90	11.27	6.30	1.0		3	1	2	1	LF	$0.222	$11,793	$522	$5,050	84	242	1,124
0.90	15.00	4.00	2.5		3	1	4	2	LF	$0.304	$21,505	$1,056	$7,850	71	568	2,319
0.90	15.00	6.30	1.5		3	1	4	2	LF	$0.223	$15,775	$702	$6,700	82	360	1,501

7.6.2.3 Categorical simulation results

7.6.2.3.1 At 4m/s with 11.27 kWh/day load at $0.82 Diesel Fuel Price

The optimal designs of this hybrid system are shown in the figure 7.35 below. Detailed categorical results for this system have been given in Appendix B.

Figure 7.35: Overall optimization results

Architecture							Cost				System	Generator	
PV (kW)	0.3kW WT	0.5kW WT	Generator (kW)	L16P	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	Fuel (L)	Hours
1.8		2	1	2	2	LF	$0.297	$15,772	$814	$5,250	69	474	2,222
2.0	1	2	1	2	1	LF	$0.298	$15,835	$788	$5,650	70	452	2,118
2.5	2		1	2	2	LF	$0.316	$16,810	$902	$5,150	63	556	2,568
3.0			1	2	2	LF	$0.321	$17,042	$935	$4,950	61	592	2,714
		4	1	2	1	CC	$0.400	$21,286	$1,275	$4,800	38	946	4,577
	1	4	1	2	1	CC	$0.402	$21,363	$1,254	$5,150	40	918	4,450
	2		1	2	1	CC	$0.483	$25,678	$1,793	$2,500	4	1,457	6,931
			1	2	2	CC	$0.498	$26,486	$1,898	$1,950	0	1,570	7,170

7.6.2.3.2 Best optimal Design

In the figure above, it is clearly seen that the best optimal solution is to have a design of renewable component of 1.8kW PV panel with a converter of 1.5kW attached together with 2 win turbines of 0.5kW and 1 generator of 1kW with 2 batteries of 6V connected in 1 string with a bus of 12V which can produce 69percent of renewable fraction. From the figure, it can be seen that the best possible optimal solution at the wind speed of 4m/s with the electric load of 11.27 kWh/day at the rate of $0.82 diesel fuel price is having following results mentioned in table 7.21:

Table 7.21: System total expenses of best optimal design

Total Net Present Cost **(NPC)**	$15,772
Cost of Energy **(COE/kWh)**	$0.297
Operating Cost **(per annum)**	$814
Initial Capital	$5,250

Renewable Fraction **(percent)**	69
Generator **(kWh/year)**	1,284
0.5 Wind Turbine **(kWh/year)**	1,522
PV Panel **(kWh/year)**	3,970
Excess Electricity (kWh/year)	2,384
Salvage NPC	$349

Figure 7.36: Monthly average electrical production for optimal design

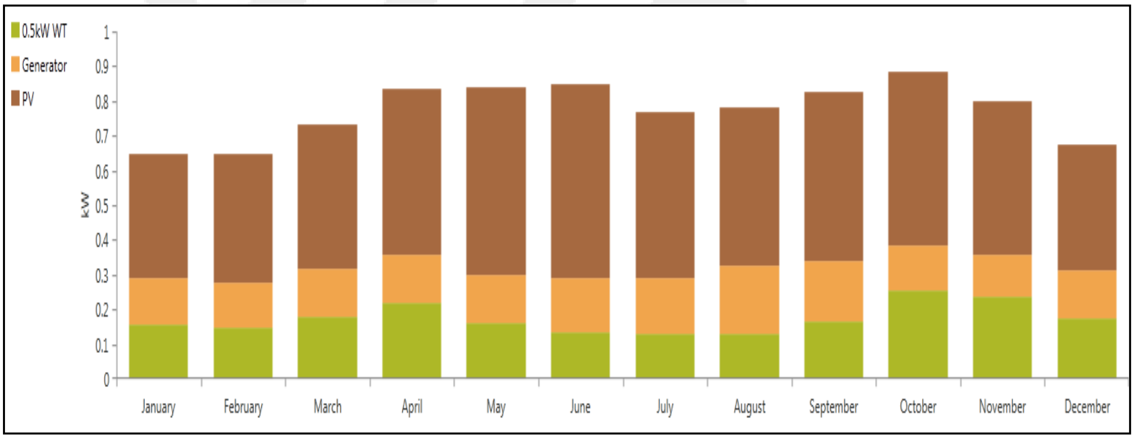


Figure 7.36 illustrate that the monthly production of renewable resource PV is the highest with the production of 58.59percent in total electricity of 6,775kWh/year and after that 0.5kW wind turbine produce 22.46percent of total load and generator is only providing 18.95percent with only 2,222 hours of operation and consumed 474 Liters of diesel per year. Total renewable fraction of this hybrid system is around 69percent together with PV and Wind turbine.

The mean values and maximum production of PV, Wind turbine and generator can be seen in the figures 7.37, 7.38 and 7.39 given below:

Figure 7.37: Monthly PV production for optimal design

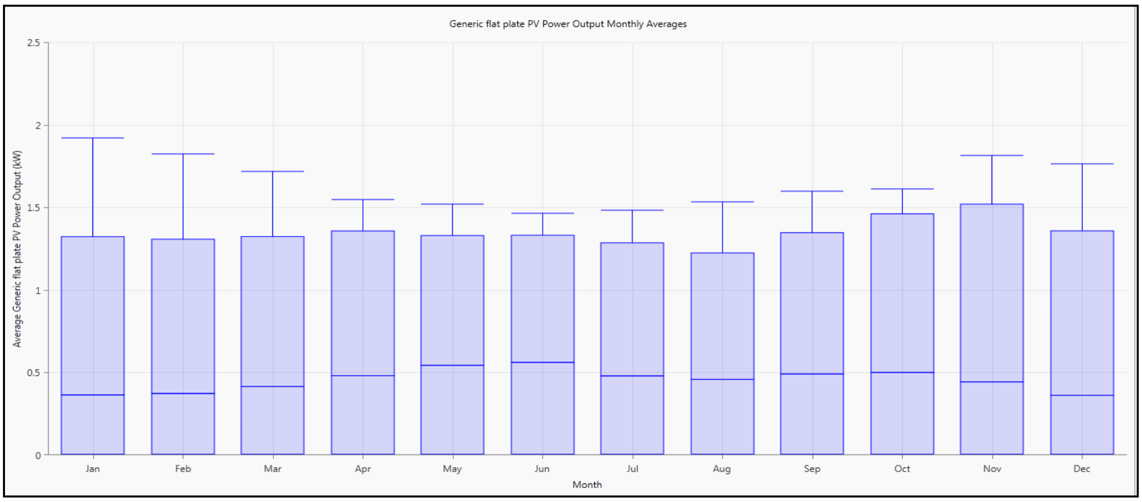


Figure 7.38: Monthly 0.5kW Wind Turbine production for optimal design

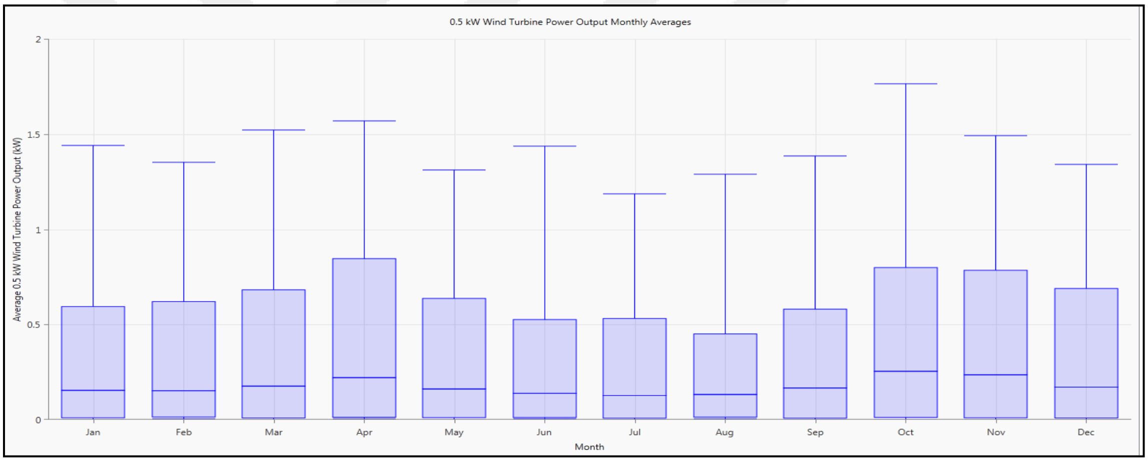
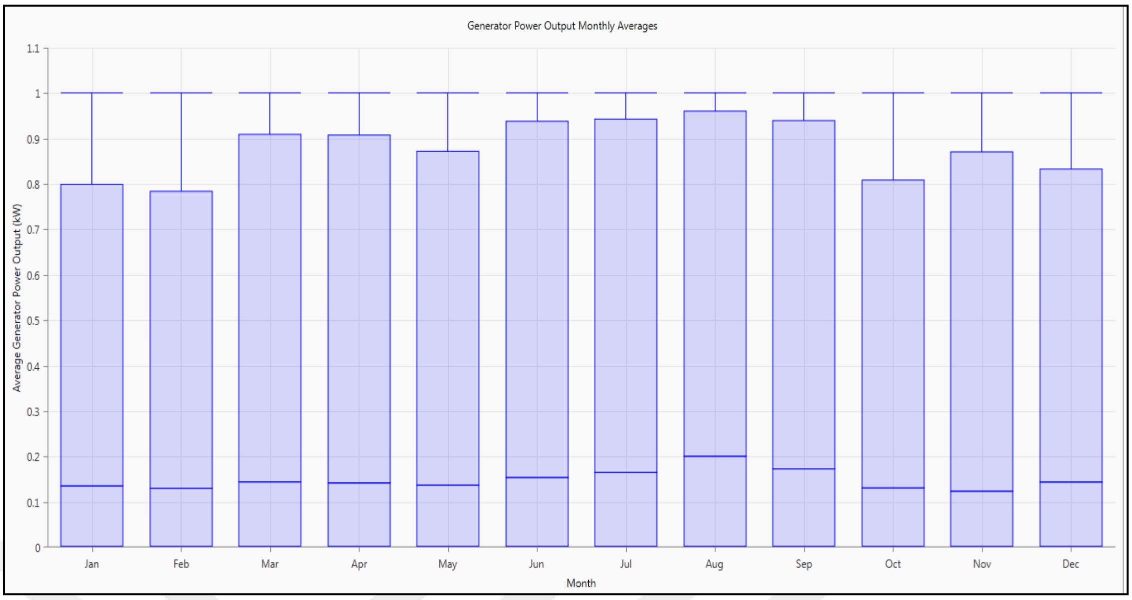


Figure 7.39: Monthly 1kW Generator production for optimal design



The figures 7.37, 7.38 and 7.39, shown above, shows that the mean production of PV panels is greater than those productions of 0.5kW wind turbine and generator. With the dispatch strategy of load following for generator, it is clear that the generator is not operating the load a lot until it is really important to provide electricity for the primary load. Renewable resources are more active in this hybrid system, which makes it the best optimal solution.

7.6.2.3.3 Comparison of Optimal design with Generator-Battery system

The detailed cost of tables is shown in Appendix. The optimal design compared with the current Generator-Battery system and the cost analysis is shown below in table 7.22 and 7.23:

Table 7.22: Comparison of Generator-Battery and Current System

	PV (kW)	0.5kW Wind Turbine	Converter (kW)	Trojan Battery	Generator 1 (kW)	NPC ($)	Initial Capital ($)

Generator-Battery System (Base System)			1.5	2	1	26,486	1,950
Current System	1.8	2	1.5	2	1	15,771	5,250

Table 7.23: Rate of Returns and Payback Periods

Metric	Value
Present worth	$10,712
Annual Worth ($/year)	$1,003
Return on investment (percent)	32.8
Internal rate of return (percent)	33.0
Simple payback (year)	2.87
Discounted payback (year)	3.23

Figure 7.40: Graph of Nominal Comparison of systems

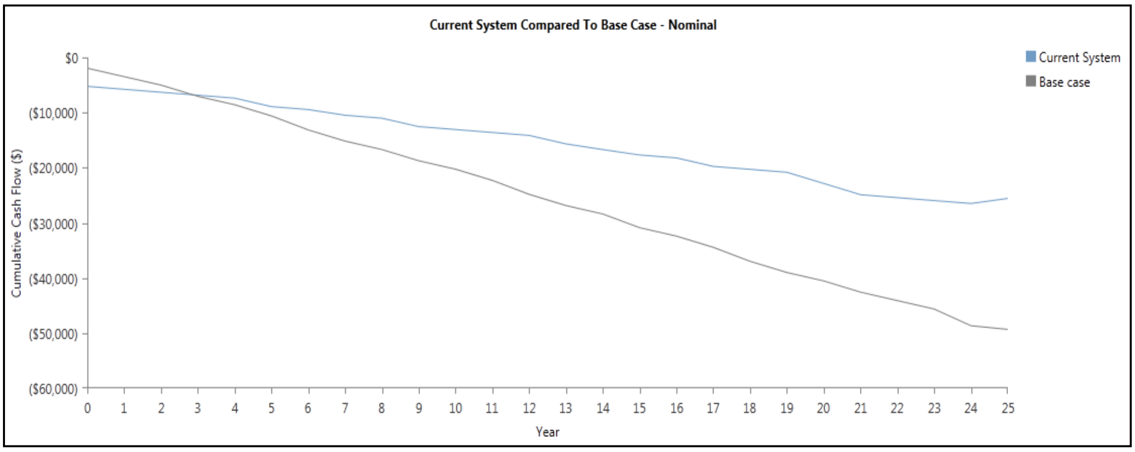
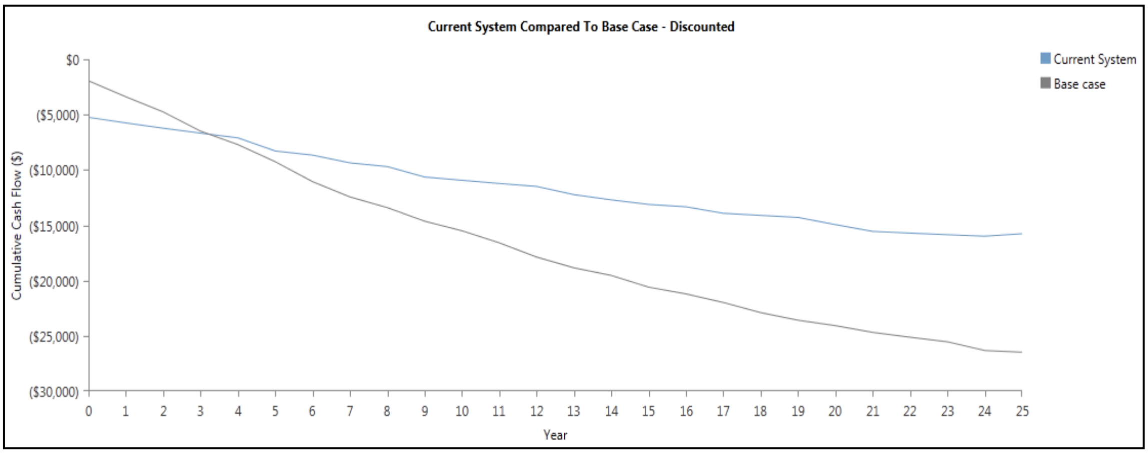


Figure 7.41: Graph of Discounted Comparison of systems



From the comparison graphs in figures 7.39, 7.40,= and 7.41 of the Generator-Battery and current optimal system, it is clearly visible that the optimal hybrid system is much better than the existing system of grid connected in all the ways of costs.

7.6.2.3.2 At 6.30m/s with 11.27 kWh/day load at $0.82 Diesel Fuel Price:

The optimal designs of this hybrid system are shown in the figure below. Detailed categorical results for this system have been given in Appendix.

Figure 7.42: Overall optimization results

Architecture								Cost				System	Generator	
⚠	PV (kW)	0.3kW WT	0.5kW WT	Generator (kW)	L16P	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	Fuel (L)	Hours
	1.0		3	1	2	1	LF	$0.216	$11,492	$498	$5,050	83	260	1,242
	1.2	1	2	1	2	1	LF	$0.220	$11,679	$528	$4,850	82	280	1,321
			3	1	2	1	CC	$0.260	$13,805	$755	$4,050	65	534	2,555
		1	3	1	2	1	CC	$0.262	$13,937	$738	$4,400	66	513	2,481
	1.8	2		1	2	2	LF	$0.288	$15,303	$840	$4,450	66	516	2,431
	2.0	1	4		6	2	CC	$0.295	$15,695	$522	$8,950	100		
	1.8		3		8	2	CC	$0.296	$15,734	$548	$8,650	100		
	3.0			1	2	2	LF	$0.321	$17,042	$935	$4,950	61	592	2,714
⚠	2.0		4	2		1	CC	$0.423	$22,515	$1,254	$6,300	53	887	3,524
⚠	2.0	1	4	2		1	CC	$0.427	$22,708	$1,242	$6,650	54	869	3,457
		2		1	2	1	CC	$0.437	$23,248	$1,605	$2,500	16	1,282	6,218
⚠			4	2			CC	$0.497	$26,441	$1,736	$4,000	33	1,271	5,042
				1	2	2	CC	$0.498	$26,486	$1,898	$1,950	0	1,570	7,170

7.6.2.3.2.1 Best optimal Design

In the figure above, it is clearly seen that the best optimal solution is to have a design of renewable component of 1 kW PV panel with a converter of 1kW attached together with

3 wind turbines of 0.5kW and 1 generator of 1kW with 2 batteries of 6V connected in 1 string with a bus of 12V which can produce 83percent of renewable fraction. From the figure, it can be seen that the best possible optimal solution at the wind speed of 4m/s with the electric load of 11.27 kWh/day at the rate of $0.82 diesel fuel price is having following results mentioned in table 7.24:

Table 7.24: System total expenses of best optimal design

Total Net Present Cost **(NPC)**	$11,492
Cost of Energy **(COE/kWh)**	$0.216
Operating Cost **(per annum)**	$498
Initial Capital	$5,050
Renewable Fraction **(percent)**	83
Generator **(kWh/year)**	700
0.5 Wind Turbine **(kWh/year)**	6,599
PV Panel **(kWh/year)**	2,205
Excess Electricity (kWh/year)	5,235
Salvage NPC	$591

Figure 7.43: Monthly average electrical production for optimal design

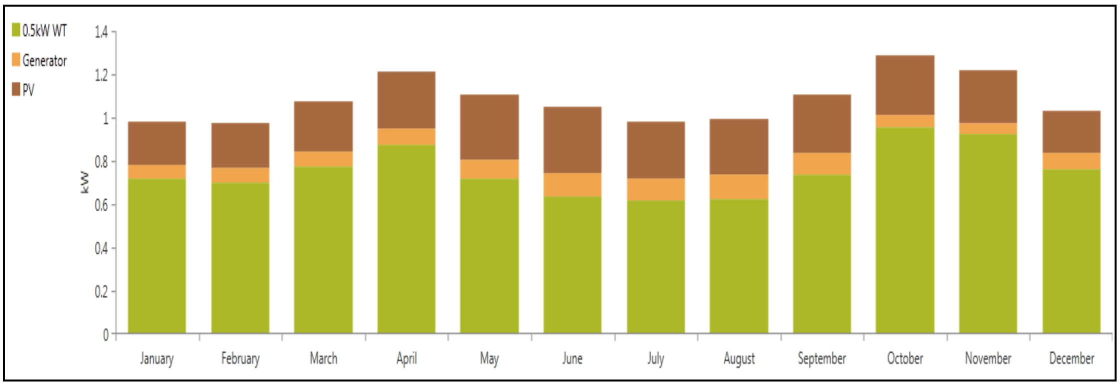


Figure 7.43 illustrate that the monthly production of renewable resource PV is producing 23.2percent in total electricity of 9,505kWh/year and after that 0.5kW wind turbine produce 69.43percent of total load and generator is only providing 7.37percent with only 1,242 hours of operation and consumed 260 Liters of diesel per year. Total renewable fraction of this hybrid system is around 83percent together with PV and Wind turbine.

The mean values and maximum production of PV, Wind turbine and generator can be seen in the figures 7.44, 7.45 and 7.46 given below:

Figure 7.44: Monthly PV production for optimal design

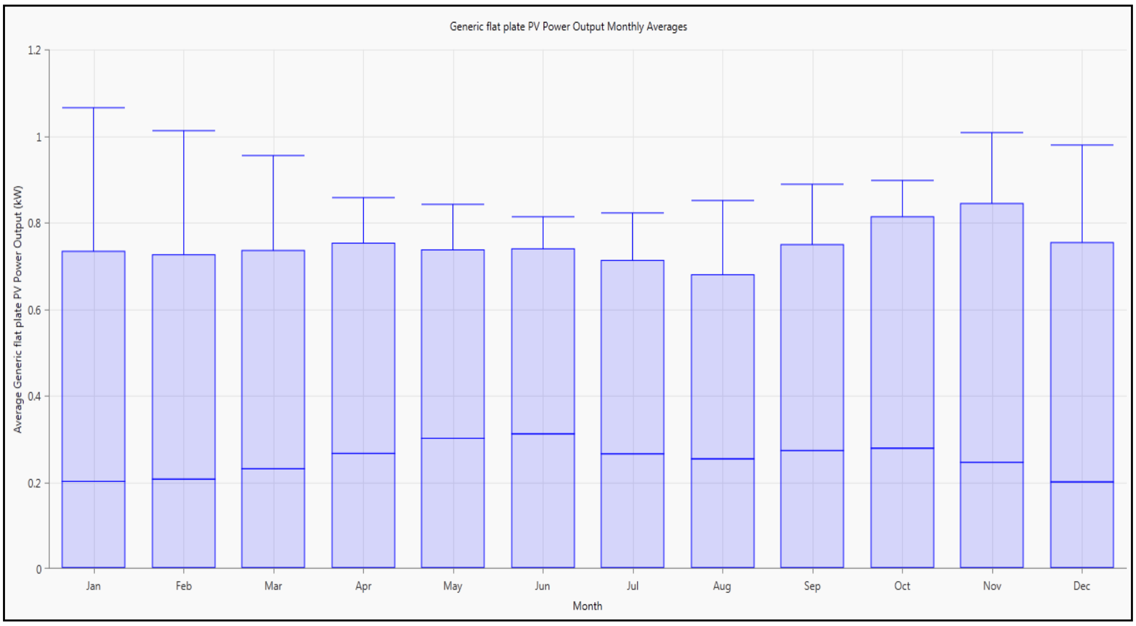


Figure 7.45: Monthly 0.5kW Wind Turbine production for optimal design

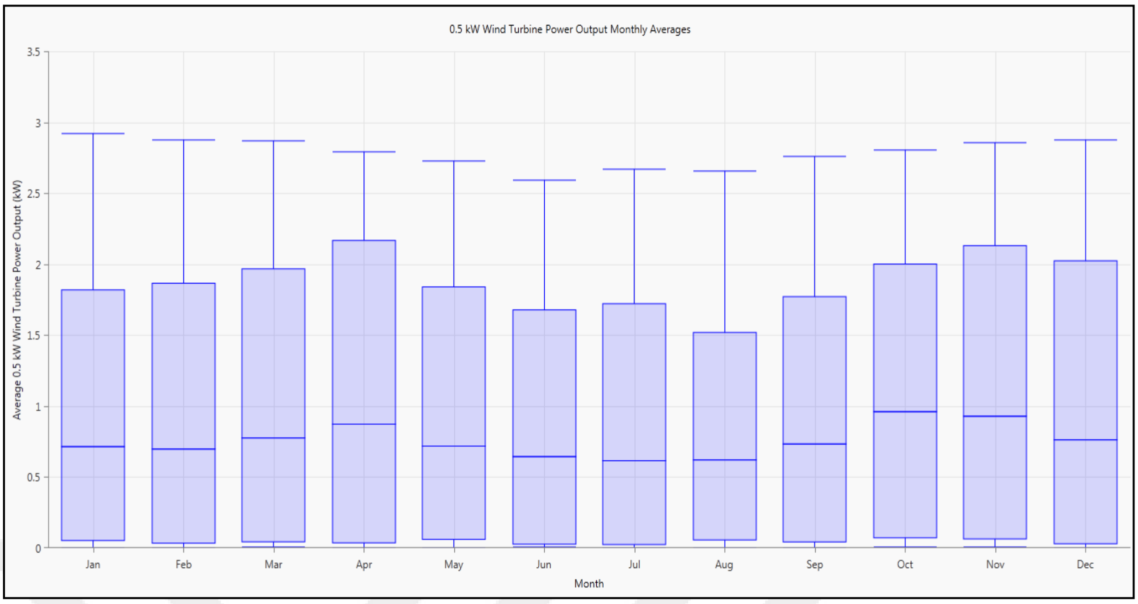
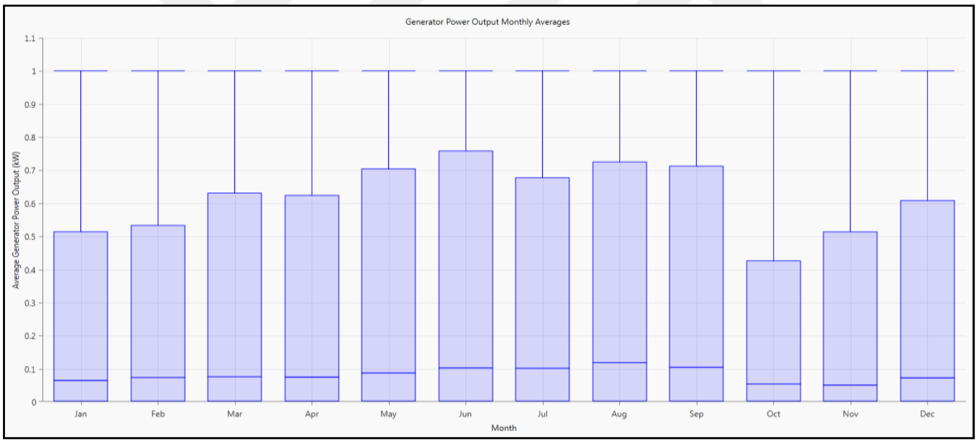


Figure 7.46: Monthly 1kW Generator production for optimal design



The figures 7.44, 7.45 and 7.46 shown above, shows that the mean production of 0.5kW wind turbine is greater because of the wind speed and its producing at the rate of more than 0.5kW on mean and the lowest part in this hybrid system is from generator which can save a lot of cost because its production is costly. With the dispatch strategy of load following for generator, it is clear that the generator is not operating the load a lot until it is really important to provide electricity for the primary load. Renewable resources are more active in this hybrid system, which makes it the best optimal solution.

7.6.2.3.2.2 Comparison of Optimal design with Generator-Battery system

The detailed cost of tables is shown in Appendix. The optimal design compared with the current Generator-Battery system and the cost analysis is shown below in table 7.25 and 7.26:

Table 7.25: Comparison of Generator-Battery and Current System

	PV (kW)	0.5kW Wind Turbine	Converter (kW)	Trojan Battery	Generator 1 (kW)	NPC ($)	Initial Capital ($)
Generator-Battery System (Base System)			1.5	2	1	26,486	1,950
Current System	1	3	1	2	1	11,492	5,050

Table 7.26: Rate of Returns and Payback Periods

Metric	Value
Present worth	$14,992
Annual Worth ($/year)	$1,404
Return on investment (percent)	45.1
Internal rate of return (percent)	43.7
Simple payback (year)	2.42
Discounted payback (year)	2.62

Figure 7.47: Graph of Nominal Comparison of systems

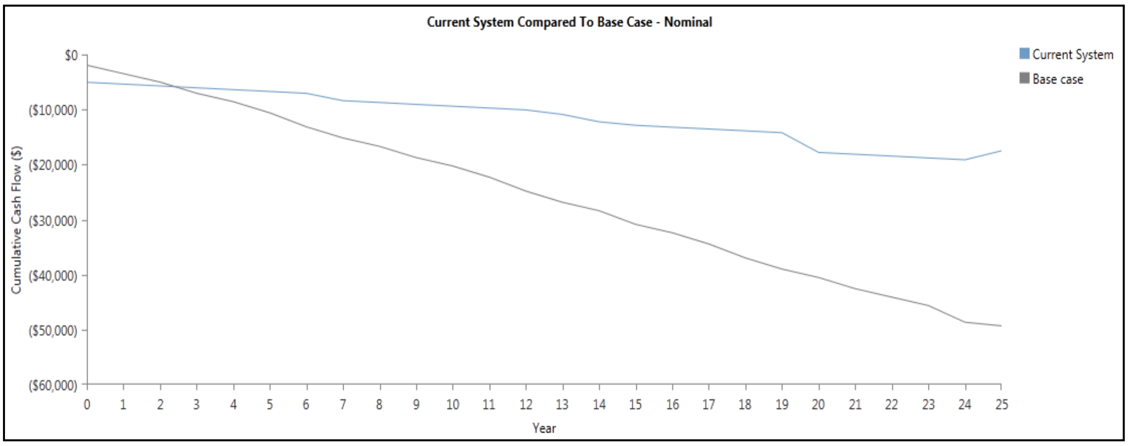
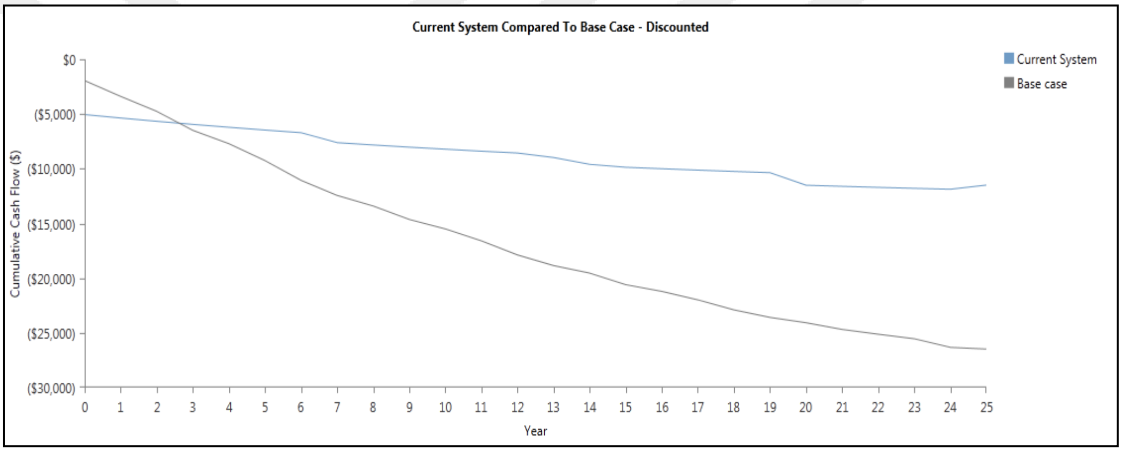


Figure 7.48: Graph of Discounted Comparison of systems



From the comparison graphs in figures 7.47 and 7.48 of the Generator-Battery and current optimal system, it is clearly visible that the optimal hybrid system is much better than the existing system of grid connected in all the ways of costs.

7.6.2.4 100percent Renewable Hybrid Energy system

At 6.30m/s with 11.27 kWh/day load at $0.82 Diesel Fuel Price, there is an option of completely renewable energy dependent hybrid system with 100percent renewable energy penetration factor.

This system consists of following components showed in table 7.27 and has following cost showed in table 7.28:

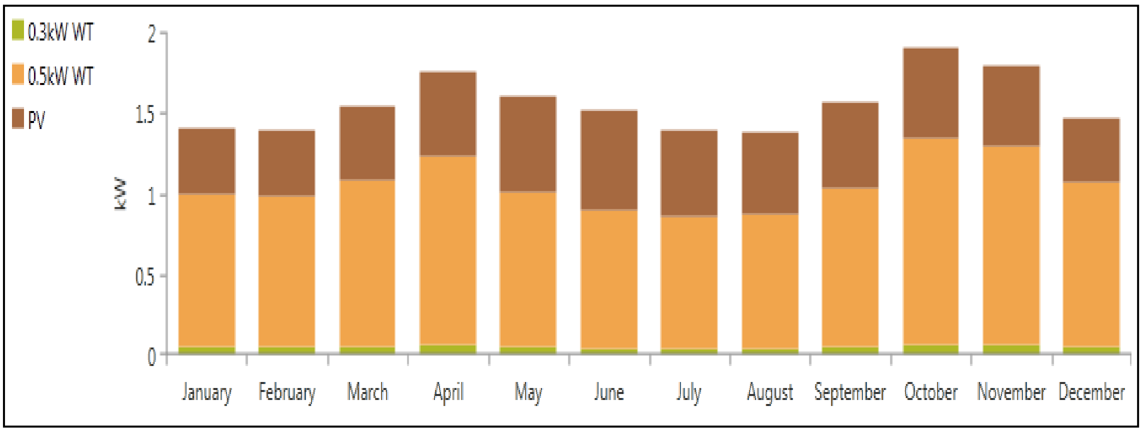
Table 7.27: 100percent renewable system configurations

System Components	PV (kW)	0.5kW Wind Turbine	0.3kW Wind Turbine	Converter (kW)	Trojan Battery
100 percent Renewable Hybrid SystemSystem	2	4	1	2	6

Table 7.28: System total expenses of 100percent Renewable Hybrid design

Total Net Present Cost **(NPC)**	$15,695
Cost of Energy **(COE/kWh)**	$0.295
Operating Cost **(per annum)**	$522
Initial Capital	$5,250
Renewable Fraction **(percent)**	100
0.3 Wind Turbine **(kWh/year)**	434
0.5 Wind Turbine **(kWh/year)**	8,799
PV Panel **(kWh/year)**	4,411
Excess Electricity (kWh/year)	9,154
Salvage NPC	$1,035

Figure 7.49: Monthly average electrical production for optimal design



This figure 7.49 explains the electrical participation of the system. 0.5kW wind turbine clearly is making the most energy for this system and the other 0.3kW wind turbine is only contributing small amount of energy toward the system and PV panel is participating around 32percent in the total system. But this system is making more than enough energy for the total demand which is around 64percent. This system also has 2.4kWh/year of unmet load and the capacity shortage is around 4.1kWh/year.

7.6.2.4.1 Comparison of Optimal design with Generator-Battery system

The detailed cost of tables is shown in Appendix. The optimal design compared with the current Generator-Battery system and the cost analysis is shown below:

Table 7.29: Comparison of Generator-Battery and Current System

	PV (kW)	0.3kW Wind Turbine	0.5kW Wind Turbine	Converter (kW)	Trojan Battery	NPC ($)	Initial Capital ($)
Generator-Battery System (Base System)		1		1.5	2	26,486	1,950
Current System	2	1	4	2	6	15,695	8,950

Table 7.30: Rate of Returns and Payback Periods

Metric	Value
Present worth	$10,789
Annual Worth ($/year)	$1,011
Return on investment (percent)	19.6
Internal rate of return (percent)	20.4
Simple payback (year)	4.58
Discounted payback (year)	5.26

Figure 7.50: Graph of Nominal Comparison of systems

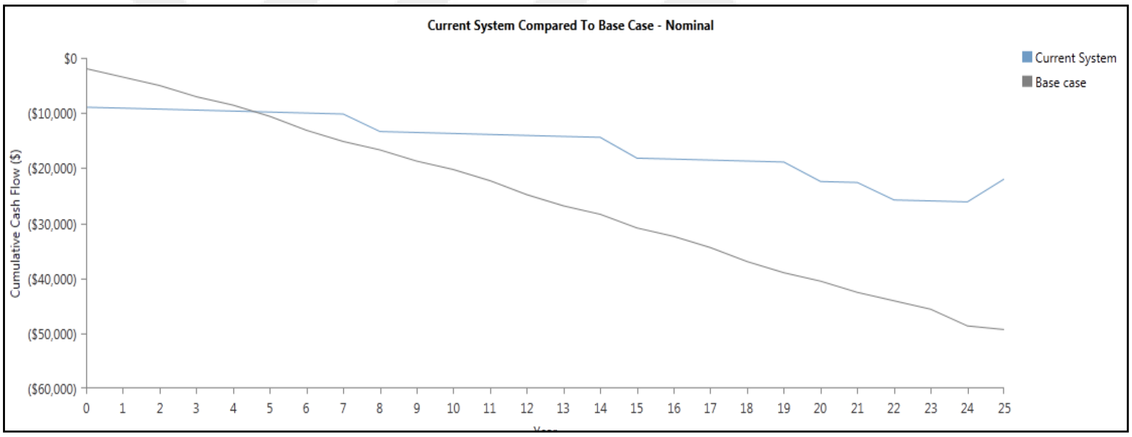
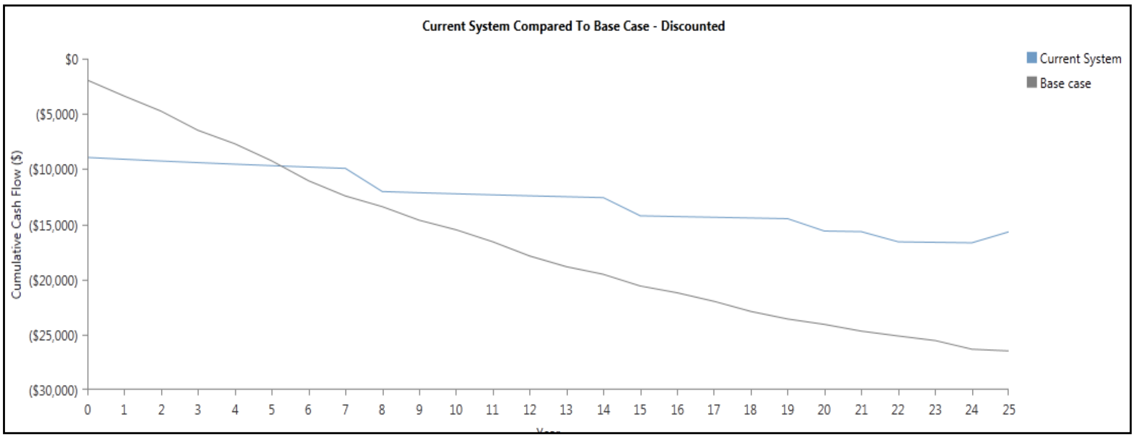


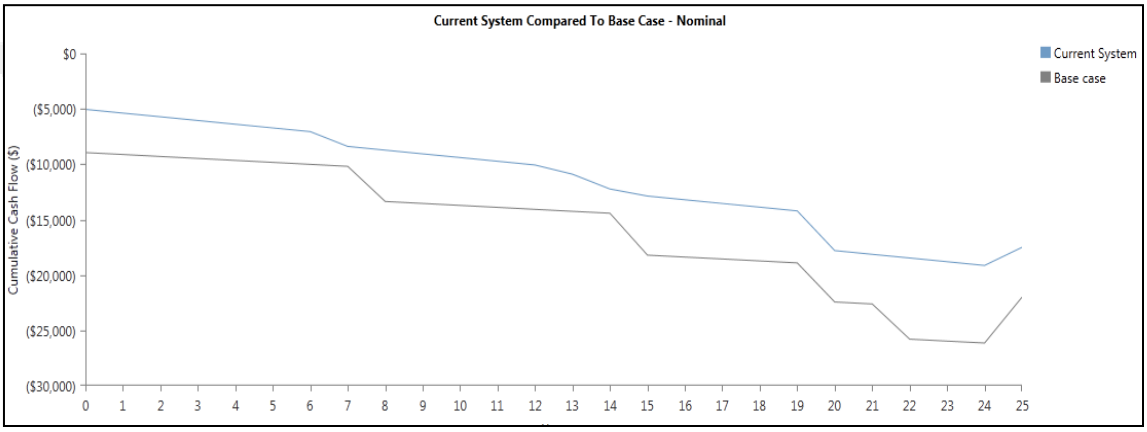
Figure 7.51: Graph of Discounted Comparison of systems



From the comparison graphs in figures 7.50 and 7.51 of the Generator-Battery and current optimal system, it is clearly visible that the 100percent hybrid system is much better than the existing system of grid connected in all the ways of costs.

The comparison of this system with the optimal system, the difference between the NPC is $4,203 and the annual worth is $394/year. The difference between the initial capitals is $3900 which is not negligible for consideration of depending 100percent renewable energies for the current load and situation.

Figure 7.52: Graph of Nominal Comparison of systems



This graph in figure 7.52 is the comparison of optimal system (current system) with 100percent renewable resources dependent hybrid system (base system). 100percent renewable resources dependent hybrid system is going to cost more at the end of the life cycle because the replacement costs of wind turbines are more and this system is using a bunch of wind turbines and it is also using more batteries which also make it costly to maintain for life cycle of the project.

7.6.3 Load Shedding Hour Hybrid Systems

7.6.3.1 Optimization Results for Load-shedding hours Hybrid System

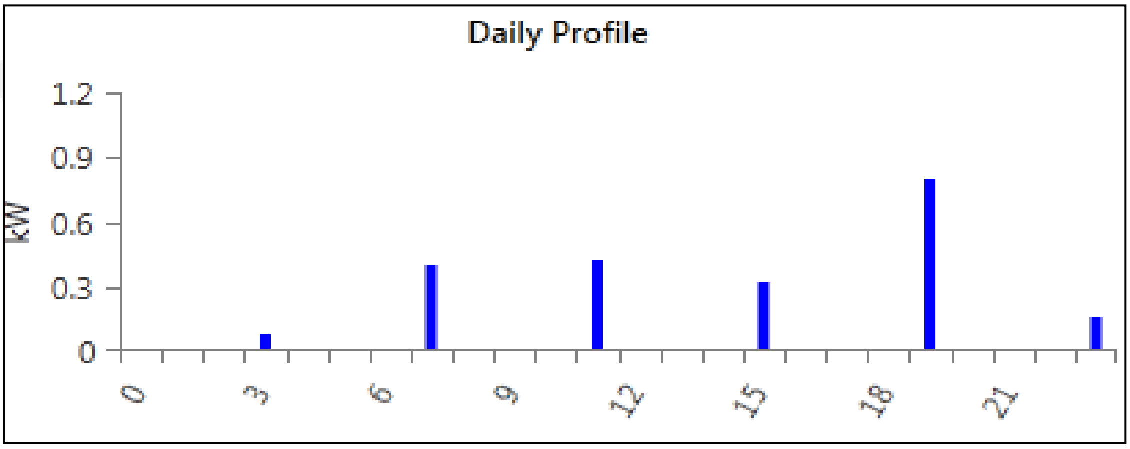
This special case is consider because in Pakistan there is the demand of electricity is more than the generation for the consumers that is why there are usually power cuts experienced everywhere in Pakistan but the time periods/schedule for load shedding is different city to city. The electric load of a house in this thesis is taken from an average house in the city of Islamabad so the load shedding hours are taken as 1 hour electric power cuts off after every 3 hours of electricity.

The electric load profile data for this case is inserted in a way that only electric load is uploaded in the HOMER software system when electric power cuts off and all other data inputs are equal to zero.

Load Profile of Load-shedding Hours

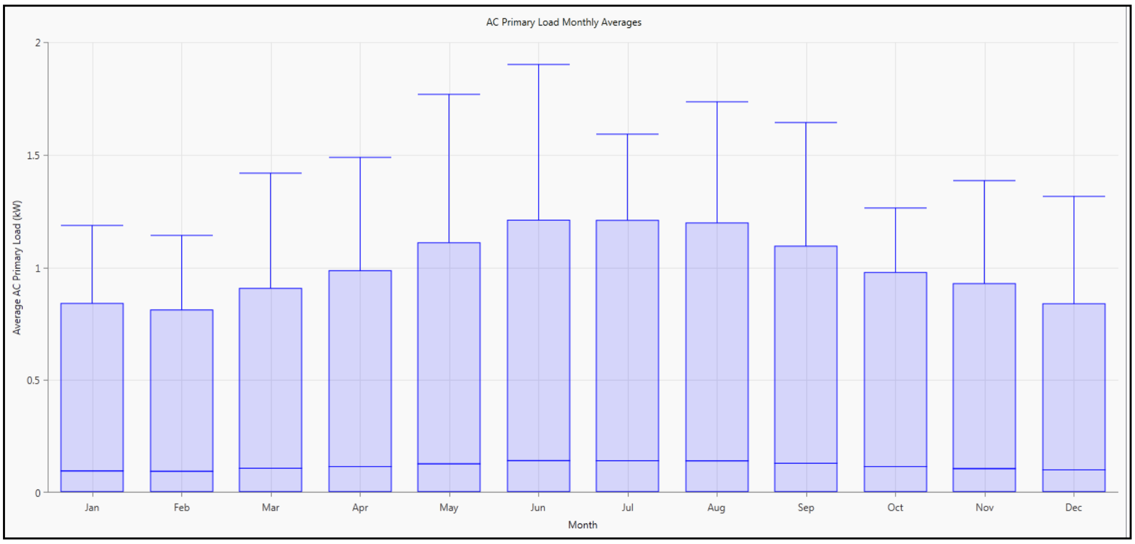
The daily load profile for load shedding hours is shown in the figure 7.53 below:

Figure 7.53: Daily load profile for load shedding hours



This figure 7.53 shows that the load is present only for 6 hours during the day (when the power cut from grid station, for 1 hour after every 3 hours). Monthly load profile is given in the figure 7.54below:

Figure 7.54: Monthly load profile for load shedding hours



The total load per day is 2.76kWh with maximum load, the peak demand around 1.9kW which is during the month of heavy electric demand of June. The mean is almost similar because the electric cut off schedule assumed same all around the year.

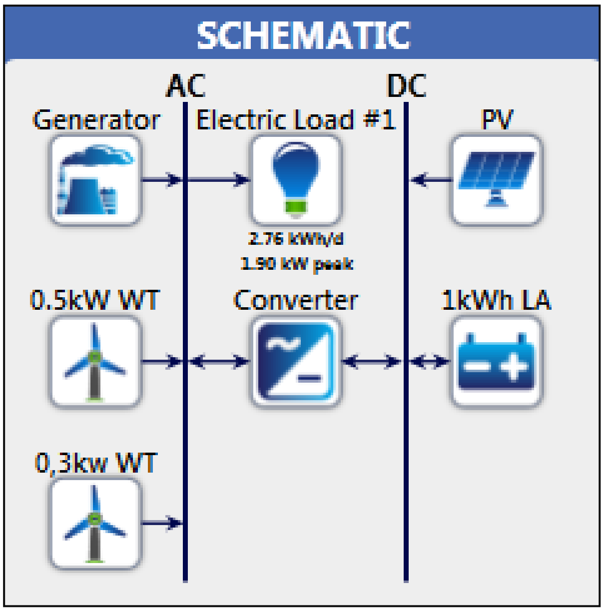
7.6.3.2 Schematic

For load shedding hours hybrid system, the components that have been used for an optimization purpose are following:

1. Photovoltaic PV
2. Generator
3. 0.3 kW Wind Turbine
4. 0.5 kW Wind Turbine
5. Converter
6. 1kWh Lead Acid Battery

The search space is already mentioned above in the table above. The schematic of load shedding hours system is shown in the figure 7.55.

Figure 7.55: Schematic of Load-shedding system



7.6.3.3 Simulation Results

From figure, the best optimal result of off-grid is displayed. In this thesis, for off-grid hybrid systems, there are 3 different kinds of sensitivity analysis has been completed with 6 categories, 2 inputs are from Electric loads, 2 inputs of wind speed and 2 inputs are from diesel fuel price are compared to get more detailed analysis which are as follows:

a. Electric Load

The real value of 2.76 kWh/day has been compared with the load until 4 kWh/day. But in this thesis we will only discuss about the basic load of 2.76 kWh/day for the purpose of simplicity.

b. Wind Speed

The annual average of the area with the speeds at the height of 10m and 50m has been evaluated to get more close to the design of best optimal solution.

c. Diesel Fuel Price

The current diesel fuel price at the rate of $0.82 is taken together with increased assumed price of $0.90 to get an idea of inflation for an optimal design. But in this thesis only hybrid systems are discussed with current price of $0.82.

The HOMER energy software simulates 8,760 hours (one year) of operation and thousands of different system configurations. The system with the overall smallest amount of net present cost, according to the given sensitivity inputs, is the one top on the list.

The first three columns of the HOMER results table shows Sensitivity inputs, in this case they are Diesel fuel price, Electrical load and Wind scaled average. The other following columns with graphic icons representing which components are present there in the optimized system. The remaining columns show the optimized capacity of each component, in this case they are, grid capacity, dispatch strategy, the total net present cost, the cost of energy (in $ per kWh), the initial capital cost and renewable energy fraction. The optimization result for off-grid hybrid system has been shown in the following figure 7.56.

Figure 7.56: Overall optimization results table for Load-shedding hours showing system configurations sorted by total Net Present Cost

Sensitivity			Architecture							Cost				System	Generator	
Diese Fuel Pri ($/L)	Electric Loac Scaled Aver (kWh/d)	Wind Scaled Aver (m/s)	PV (kW)	0.5kW W	0,3kw \	Generatc (kW)	1kWh LA	Converter (kW)	Dispat	COE ($)	NPC ($)	Operating co: ($)	Initial capital ($)	Ren Frac (%)	Fuel (L)	Hours
0.82	2.76	4.00	1.0			2	2	1	LF	$0.447	$5,829	$248	$2,620	58	158	499
0.82	2.76	6.30	0.5	1		2	2	1	LF	$0.432	$5,631	$218	$2,810	66	133	500
0.82	4.00	4.00	1.0			2	6	1	LF	$0.468	$8,830	$383	$3,880	60	204	521
0.82	4.00	6.30	0.5	2		2	4	1	LF	$0.427	$8,049	$292	$4,280	74	133	371
0.90	2.76	4.00	1.0			2	2	1	LF	$0.460	$5,992	$261	$2,620	58	158	499
0.90	2.76	6.30	0.5	1		2	2	1	LF	$0.443	$5,769	$229	$2,810	66	133	500
0.90	4.00	4.00	1.0			2	6	1	LF	$0.480	$9,056	$398	$3,910	63	188	454
0.90	4.00	6.30	0.5	2		2	4	1	LF	$0.428	$8,073	$293	$4,280	76	126	343

Categorical simulation results

7.6.3.4.1 At 4m/s with 2.76 kWh/day load at $0.82 Diesel Fuel Price:

The optimal designs of this hybrid system are shown in the figure 7.57 below. Detailed categorical results for this system have been given in Appendix C.

Figure 7.57: Overall optimization results

Architecture							Cost				System	Generator	
PV (kW)	0.5kW WT	0,3kw WT	Generator (kW)	1kWh LA	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	Fuel (L)	Hours
1.0			2	2	1	LF	$0.447	$5,829	$248	$2,620	58	158	499
1.0		1	2	2	1	LF	$0.472	$6,152	$246	$2,970	59	151	478
0.8	1		2	2	1	LF	$0.486	$6,336	$247	$3,140	61	149	500
0.7	1	1	2	2	1	LF	$0.515	$6,711	$257	$3,390	61	147	502
	1		2	2	1	LF	$0.565	$7,356	$393	$2,280	33	266	1,028
	1	1	2	2	1	LF	$0.584	$7,611	$385	$2,630	37	250	958
			2	2	1	CC	$0.615	$8,019	$502	$1,530	0	414	1,402
		1	2	2	1	CC	$0.621	$8,090	$480	$1,880	3	371	1,254

7.6.3.4.1.1 Best optimal Design

In the figure above, it is clearly seen that the best optimal solution is to have a design of renewable component of 1kW PV panel with a converter of 0.9kW attached 1 generator of 1.5kW with 2 batteries of 12V connected in 1 string with a bus of 24V which can produce 58percent of renewable fraction. From the figure, it can be seen that the best possible optimal solution at the wind speed of 4m/s with the electric load of 2.76 kWh/day at the rate of $0.82 diesel fuel price is having following results mentioned in table 7.31:

Table 7.31: System total expenses of best optimal design

Total Net Present Cost **(NPC)**	$5,829
Cost of Energy **(COE/kWh)**	$0.447
Operating Cost **(per annum)**	$248
Initial Capital	$2,620
Renewable Fraction **(percent)**	58
Generator **(kWh/year)**	425
PV Panel **(kWh/year)**	2,205
Excess Electricity (kWh/year)	1,507
Salvage NPC	$110.35

Figure 7.58: Monthly average electrical production for optimal design

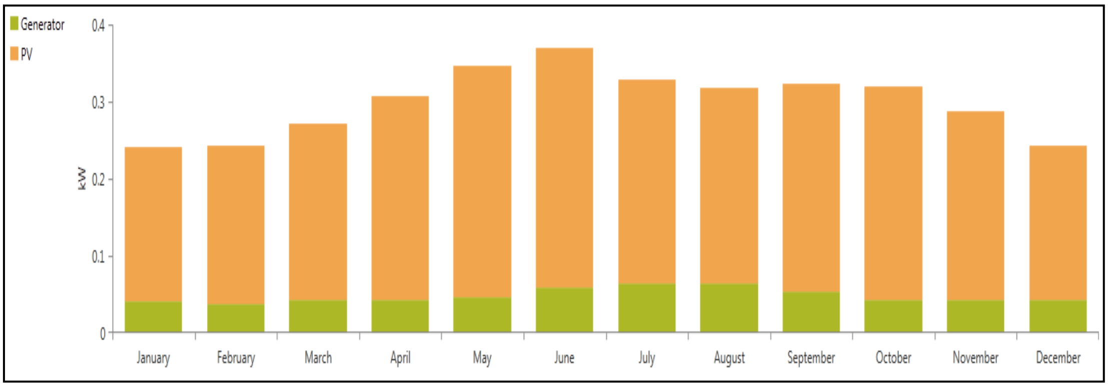


Figure 7.58 illustrate that the monthly production of renewable resource PV is the highest with the production of 83.83percent in total electricity of 2,205kWh/year and total load and generator is only providing 16.17percent with only 499 hours of operation and consumed 158 Liters of diesel per year. Total renewable fraction of this hybrid system is around 58percent together with PV and Wind turbine.

The mean values and maximum production of PV, Wind turbine and generator can be seen in the figures 7.59 and 7.60 given below:

Figure 7.59: Monthly PV production for optimal design

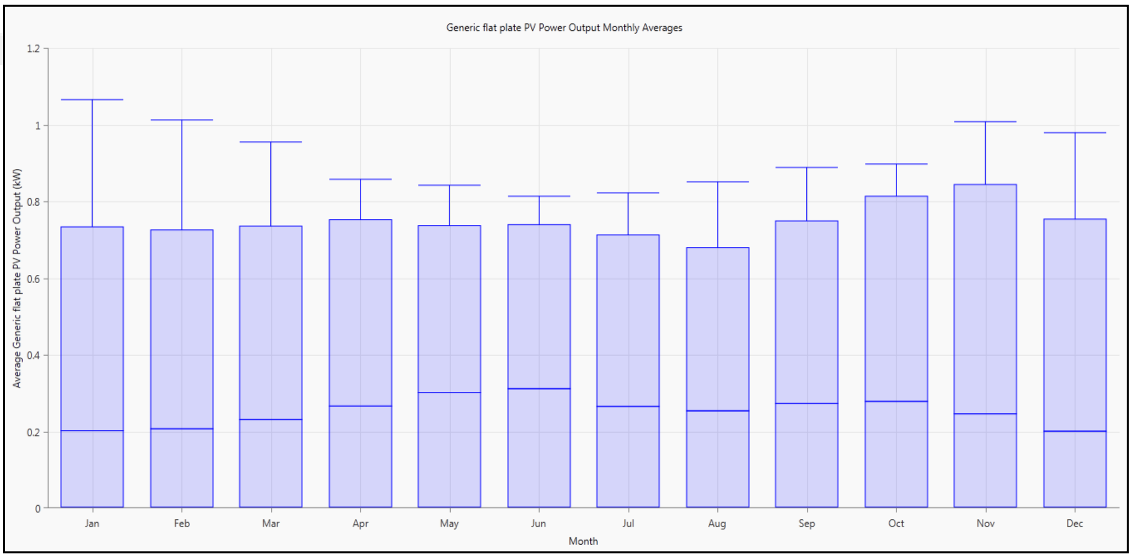
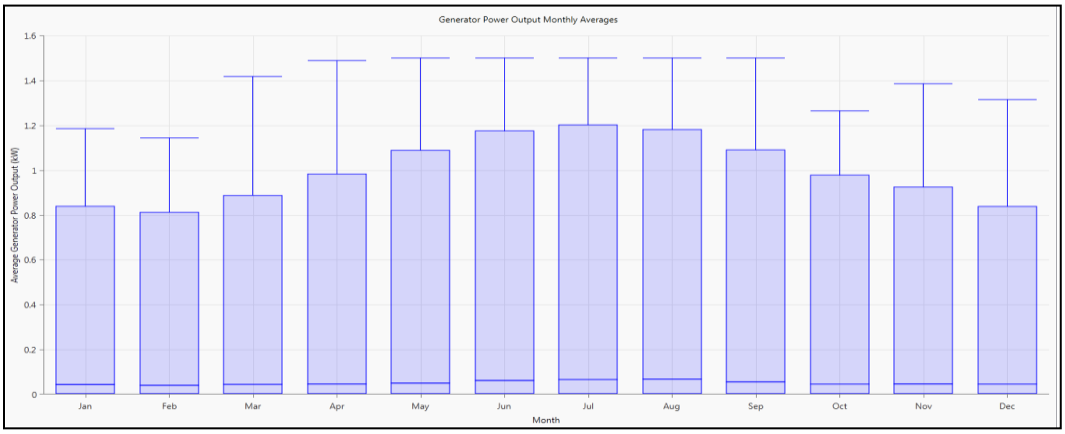


Figure 7.60: Monthly 1.5kW Generator production for optimal design



The figures 7.59 and 7.60 shown above, shows that the mean production of PV panels is greater than the generator. With the dispatch strategy of load following for generator, it is clear that the generator is not operating the load a lot until it is really important to provide electricity for the primary load. Renewable resource is more dynamic in this hybrid system, which makes it the best optimal solution.

7.6.3.4.1.2 Comparison of Optimal design with Generator-Battery system

The detailed cost of tables is shown in Appendix. The optimal design compared with the current Generator-Battery system and the cost analysis is shown below in table 7.32 and 7.33:

Table 7.32: Comparison of Generator-Battery and Current System

	PV (kW)	**Converter (kW)**	**1kWh Battery**	**Generator 1 (kW)**	**NPC ($)**	**Initial Capital ($)**
Generator-Battery System (Base System)		0.6	2	1.5	8,019	1,530
Current System	1	0.9	2	1.5	5,829	2,620

Table 7.33: Rate of Returns and Payback Periods

Metric	**Value**
Present worth	$2,187
Annual Worth ($/year)	$205
Return on investment (percent)	23.6
Internal rate of return (percent)	21.6

Simple payback (year)	4.54
Discounted payback (year)	5.43

Figure 7.61: Graph of Nominal Comparison of systems

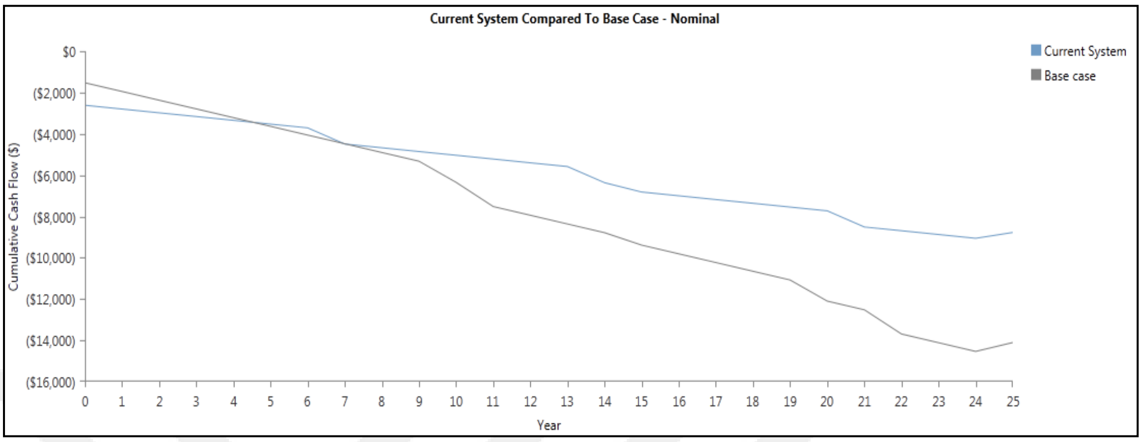
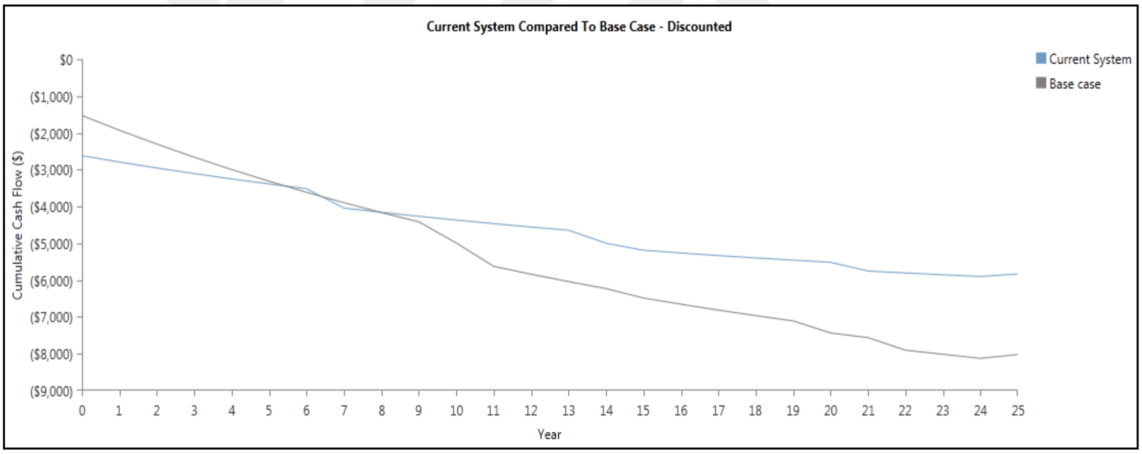


Figure 7.62: Graph of Discounted Comparison of systems



From the comparison graphs in figures 7.61 and 7.62 of the Generator-Battery and current optimal system, it is clearly visible that the optimal hybrid system is much better than the existing system of grid connected in all the ways of costs.

7.6.3.4.2 At 6.30m/s with 2.76 kWh/day load at $0.82 Diesel Fuel Price:

The optimal designs of this hybrid system are shown in the figure 7.63 below. Detailed categorical results for this system have been given in Appendix.

Figure 7.63: Overall optimization results

Architecture								Cost				System	Generator	
PV (kW)	0.5kW WT	0,3kw WT	Generator (kW)	1kWh LA	Converter (kW)	Dispatch		COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	Fuel (L)	Hours
0.5	1		2	2	1	LF		$0.432	$5,631	$218	$2,810	66	133	500
1.0			2	2	1	LF		$0.447	$5,829	$248	$2,620	58	158	499
	1		2	2	1	LF		$0.448	$5,840	$275	$2,280	54	184	721
0.8		1	2	2	1	LF		$0.455	$5,930	$247	$2,740	59	155	511
0.5	1	1	2	2	1	LF		$0.463	$6,034	$222	$3,160	68	126	482
	1	1	2	2	1	LF		$0.472	$6,153	$273	$2,630	57	174	689
		1	2	2	1	LF		$0.555	$7,233	$414	$1,880	26	297	1,159
			2	2	1	CC		$0.615	$8,019	$502	$1,530	0	414	1,402

7.6.3.4.2.1 Best optimal Design

In the figure above, it is clearly seen that the best optimal solution is to have a design of renewable component of 0.5kW PV panel with a converter of 0.7kW attached together with a wind turbines of 0.5kW and 1 generator of 1.5kW with 2 batteries of 12V connected in 1 string with a bus of 24V which can produce 66percent of renewable fraction. From the figure, it can be seen that the best possible optimal solution at the wind speed of 4m/s with the electric load of 2.76 kWh/day at the rate of $0.82 diesel fuel price is having following results mentioned in table 7.34:

Table 7.34: System total expenses of best optimal design

Total Net Present Cost **(NPC)**	$5,631
Cost of Energy **(COE/kWh)**	$0.432
Operating Cost **(per annum)**	$218
Initial Capital	$2,180
Renewable Fraction **(percent)**	66
Generator **(kWh/year)**	339

0.5 Wind Turbine **(kWh/year)**	2,220
PV Panel **(kWh/year)**	1,103
Excess Electricity (kWh/year)	2563
Salvage NPC	$254

Figure 7.64: Monthly average electrical production for optimal design

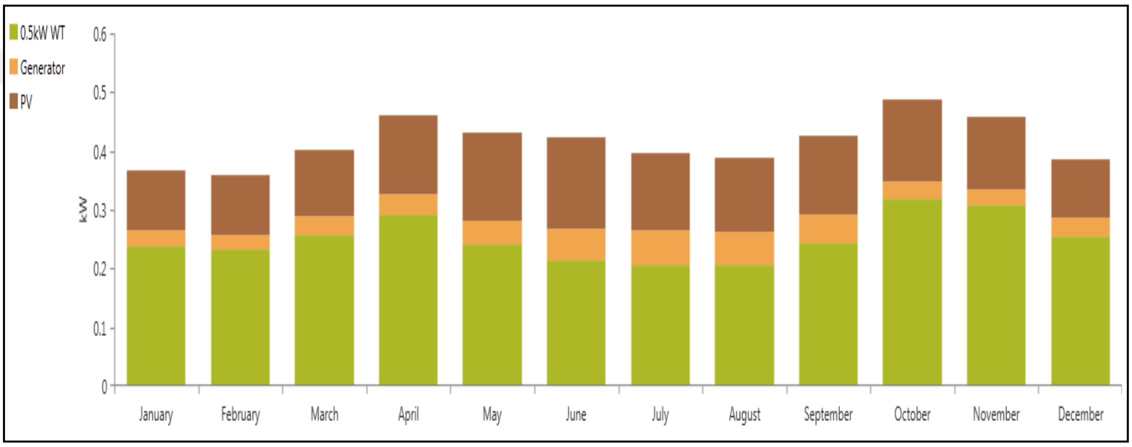


Figure 7.64 illustrate that the monthly production of renewable resource PV is producing 30.28percent in total electricity of 3,641kWh/year and after that 0.5kW wind turbine produce 60.41percent of total load and generator is only providing 9.30percent with only 500 hours of operation and consumed 133 Liters of diesel per year. Total renewable fraction of this hybrid system is around 66percent together with PV and Wind turbine.

The mean values and maximum production of PV, Wind turbine and generator can be seen in the figures 7.65, 7.66 and 7.67 given below:

Figure 7.65: Monthly PV production for optimal design

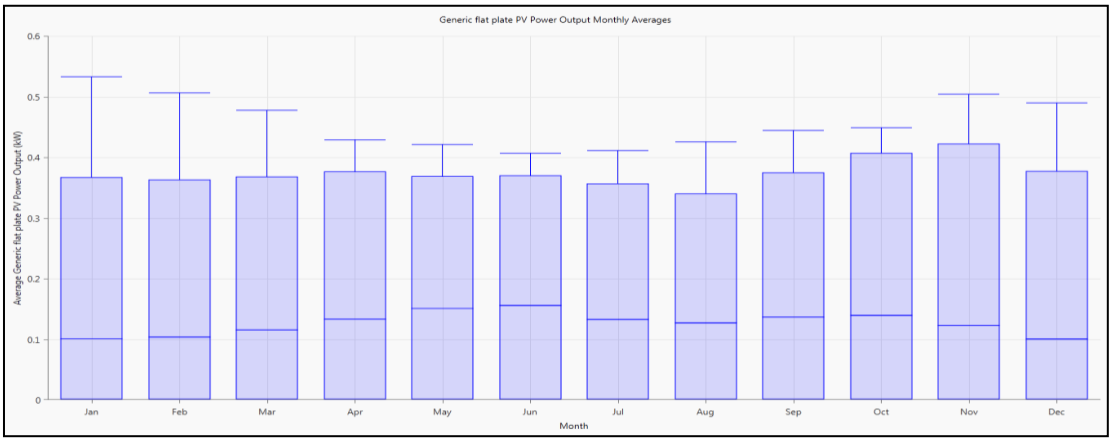


Figure 7.66: Monthly 0.5kW Wind Turbine production for optimal design

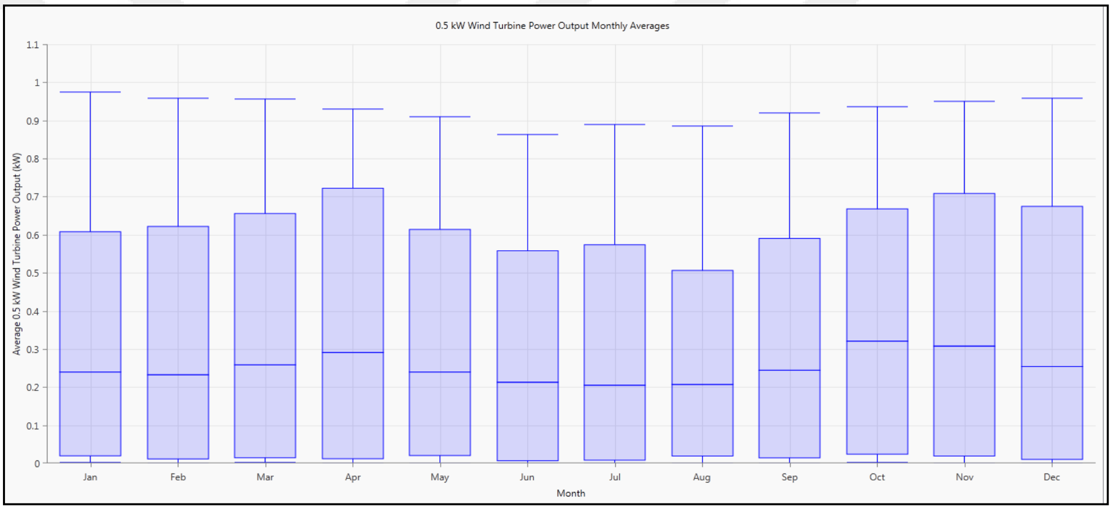
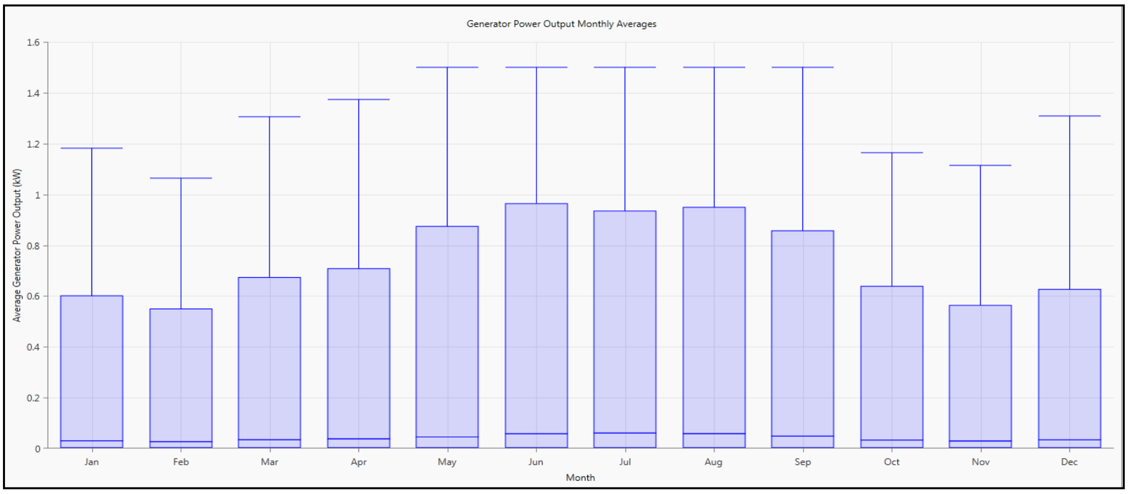


Figure 7.67: Monthly 1.5kW Generator production for optimal design



The figures 7.65, 7.66 and 7.67 shown above, shows that the mean production of 0.5kW wind turbine is greater because of the wind speed and its producing at the rate of more than 0.2kW on mean and the lowest part in this hybrid system is from generator which can save a lot of cost because its production is costly. With the dispatch strategy of load following for generator, it is clear that the generator is not operating the load a lot until it is really important to provide electricity for the primary load. Renewable resources are more active in this hybrid system, which makes it the best optimal solution.

7.6.3.4.2.2 Comparison of Optimal design with Generator-Battery system

The detailed cost of tables is shown in Appendix. The optimal design compared with the current Generator-Battery system and the cost analysis is shown in table 7.35 and 7.36 below:

Table7.35: Comparison of Generator-Battery and Current System

	PV (kW)	0.5kW Wind Turbine	Converter (kW)	Trojan Battery	Generator 1 (kW)	NPC ($)	Initial Capital ($)
Generator-Battery System (Base System)			0.6	2	1.5	8,019	1,530
Current System	0.5	1	0.7	2	1.5	5,631	2,810

Table 7.36: Rate of Returns and Payback Periods

Metric	Value
Present worth	$2,388
Annual Worth ($/year)	$224
Return on investment (percent)	22.5

Internal rate of return (percent)	20.9
Simple payback (year)	5.10
Discounted payback (year)	6.24

Figure 7.68: Graph of Nominal Comparison of systems

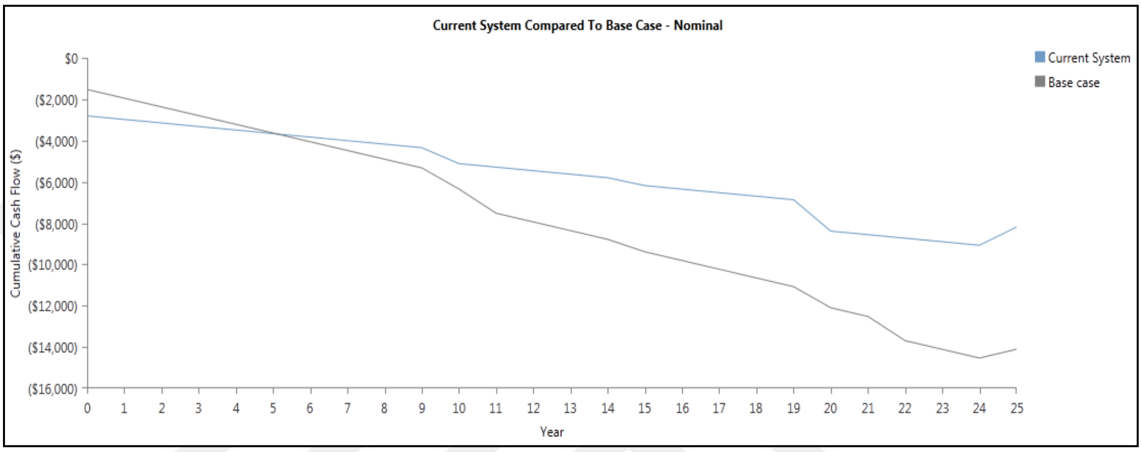
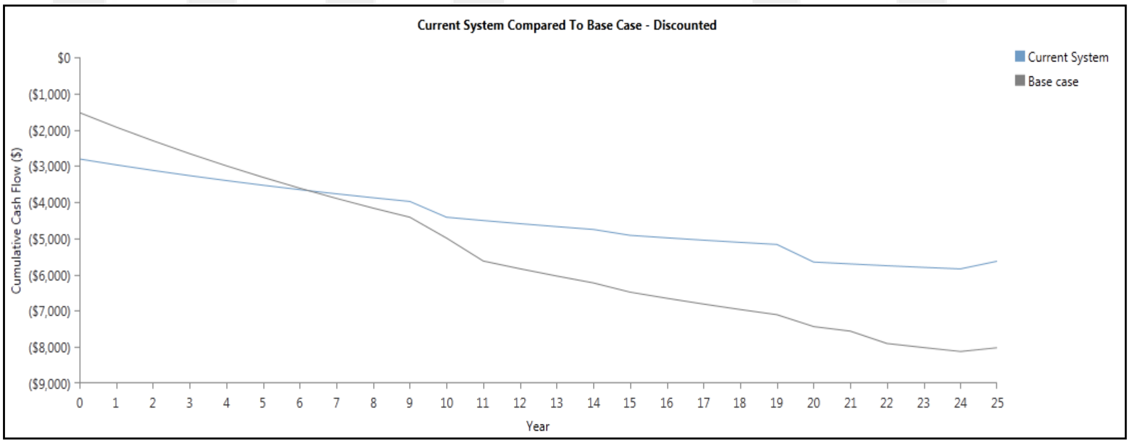


Figure 7.69: Graph of Discounted Comparison of systems



From the comparison graphs in figures 7.68 and 7.69 of the Generator-Battery and current optimal system, it is clearly visible that the optimal hybrid system is much better than the existing system of grid connected in all the ways of costs.

8. CONCLUSION AND RECOMMENDATIONS

8.1 CONCLUSION

This thesis study intended to identify alternative options and to design feasible systems to provide electricity for an average house load in city of Islamabad, Pakistan by harness power from renewable energy resources available.

In this thesis, there are three different types of scenarios are discussed for the sake of designing an optimal and best hybrid system for a house. The scenarios which are considered in this study are as follows:

8.1.1 Grid-Tied/Connected Hybrid System
8.1.2 Off Grid/Stand alone Hybrid System
8.1.3 For load-shedding/Power Cut hours Hybrid system

The HOMER simulation program developed by the NREL has been used as the design tool for both options. HOMER modeling results signify that the electric demand could be met at sizeable overall cost savings with a hybrid (wind/solar) system compared with existing grid connected system which has a total Net Present Value of $6,381.

8.1.1 Grid-Tied/Connected Hybrid System

For the grid-tied design scenario, the optimum system comprises a hybrid system of 1kW PV panel with a converter of 0.6kW attached together with grid at average wind speed of 4m/s (at 10m height) which has the Net Present Cost of $5,338 and it needs the initial capital of $1,800 and will provide 42percent of renewable power from PV panel for whole system with a cost of 0.094/kWh. However if we design this system at 6.30m/s which is available at 50m from the earth surface of the city then the optimum hybrid system can offer more better renewable fraction of 66percent with much lower Net present Cost of $4,613 with Cost of Energy 0.07/kWh and has lesser initial capital of $1,500 for the renewable energy components including 0.6kW PV panel and 1 wind turbine of 0.5kW.

8.1.1.1 Comparison of Both Optimal Hybrid Systems:

Comparison of both optimal designs at 4m/s and 6.30m/s systems is shown below table 8.2 and other return values and costs are shown in table 8.2:

Table8.1: Comparison of Both Optimal Hybrid Systems

	PV (kW)	0.5kW Wind Turbine	Converter (kW)	1kWh LA Battery	Grid (kW)	NPC ($)	Initial Capital ($)
Base System	1		0.6	0	10,000	5,338	1,180
Current System	0.6	1	0.5	0	10,000	4,613	1,500

Table 8.2: Rate of Returns and Payback Periods

Metric	Value
Present worth	$724
Annual Worth ($/year)	$66
Return on investment (percent)	25.4
Internal rate of return (percent)	27.1
Simple payback (year)	3.64
Discounted payback (year)	4.21

Figure 8.1: Graph of Nominal Comparison of systems

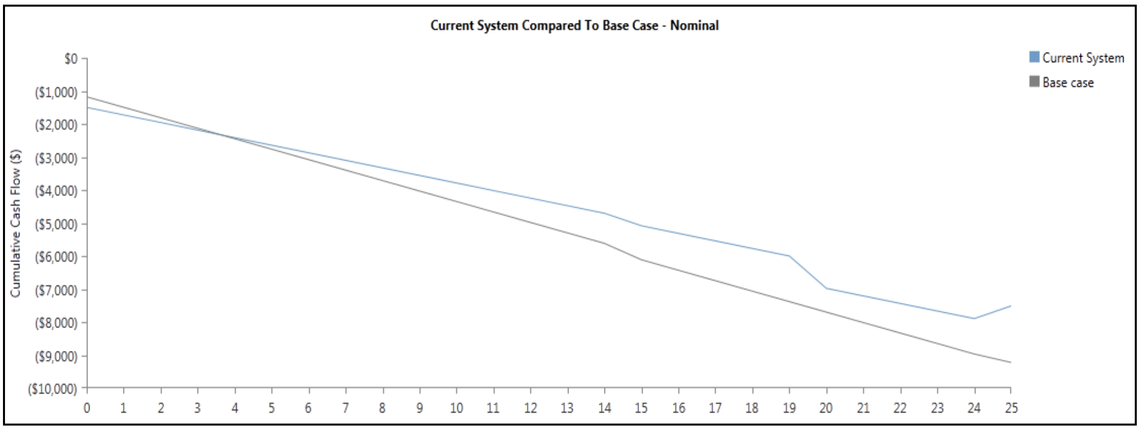
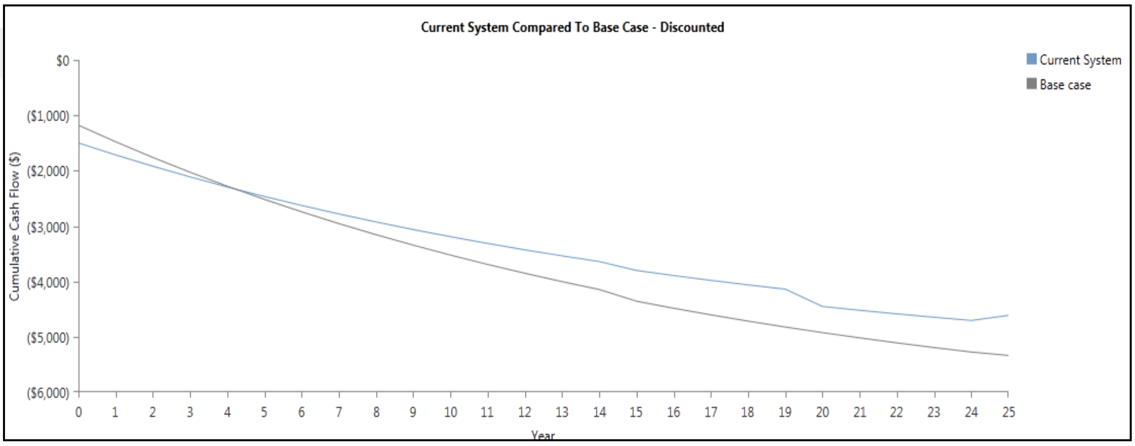


Figure 8.2: Graph of Discounted Comparison of systems



From the graphs in figures 8.1 and 8.2 of cumulative cash flows, it is clear that the hybrid system which is designed at the height of 50m with the wind speed more than 6m/s average is much better option with lower costs and better return rates of investments and shorter payback periods.

8.1.2 Off Grid/Stand alone Hybrid System

For the off-grid design scenario, the optimum system contains a hybrid system at 10m high average speed of 4m/s with the diesel price of $0.82. This optimum system has renewable component of 1.8kW PV panel with a converter of 1.5kW attached together with 2 win turbines of 0.5kW and 1 generator of 1kW with 2 batteries of 6V connected in 1 string with a bus of 12V which can produce 69percent of renewable fraction. The generator is running for 2,222 hours and will consume 474 Litres of diesel per year. The total Net Present Cost of this system is $15,772 at cost of energy $0.297/kWh with initial capital of $5250 and has Operating cost at $814/annum.

The system which could be design with the more average wind speed of 6.30m/s, then this system would comprise of renewable component of 1 kW PV panel with a converter of 1kW attached together with 3 wind turbines of 0.5kW and 1 generator of 1kW with 2 batteries of 6V connected in 1 string with a bus of 12V which can produce 83percent of renewable fraction. The Net Present Cost for this system as compared with lower wind speed is comparatively much low, which is $11,492 with $0.216/kWh cost of energy. The operating cost is almost 39percent low for this system at price of $498/annum with relatively low initial capital of $5050. The diesel generator will run 1,242 hours and will use 260 Liters of diesel per year and produce around 45percent less as compared with the other hybrid system.
On the other hand, both hybrid systems when compared with the Generator-Battery System, which has total Net Present Cost of $26,486 and lower Initial Capital of $1,950 then it is obvious that both of the optimum hybrid systems discussed above has much better possible solution with lower expenditure and better returns.

8.1.3 For load-shedding/Power Cut hours Hybrid system

For the third special scenario of load-shedding/Power Cut hours, The total load per day is 2.76kWh with the peak demand around 1.9kW. the optimum system contains a hybrid system of 1kW PV panel with a converter of 0.9kW attached 1 generator of 1.5kW with 2 batteries of 12V connected in 1 string with a bus of 24V which can produce 58percent of renewable fraction at 10m high average speed of 4m/s with the diesel price of $0.82. The Net Present Cost of $5,829 and it needs the initial capital of $2,620 and Cost of energy is $0.447/kWh and has annual $248 operating cost. The generator is providing 16.17percent of whole system with only 499 hours of operation and consumed 158 Liters of diesel per year.

At 6.30m/s with 2.76 kWh/day load at $0.82 Diesel Fuel Price, the best optimal solution is to have a design of renewable component of 0.5kW PV panel with a converter of 0.7kW attached together with a wind turbines of 0.5kW and 1 generator of 1.5kW with 2 batteries of 12V connected in 1 string with a bus of 24V which can produce 66percent of renewable fraction. The Net Present Cost of $5,631 and it needs the initial capital of $2,180 and Cost of energy is $0.432/kWh and has annual $218 operating cost. The generator is providing 9.30percent of whole system and will consume 158 Liters of diesel per year. 0.5kW wind turbine produces the most of 60.41percent of total load for this hybrid system.

In contrast, both hybrid systems when compared with the Generator-Battery System, which has total Net Present Cost of $8,019and lower Initial Capital of $1,530 then it is obvious that both of the optimum hybrid systems discussed above has much better possible solutions with lower costs and expenses with better returns on investments.

8.2 WIND SPEED CONCLUSION

Finally, it is proposed that to design best optimal hybrid system the sensitive variables are very important (Wind Speed, Fuel Prices, Electric Loads, PV Tracking i.e 2AxisTracking).

As it is observed from the study, the system with higher wind speed has lower expenses and better rate of returns. Wind speed is having a huge impact in designing a hybrid system. Comparisons of NPC of different hybrid systems regarding wind speeds are given below:

8.2.1 Comparison of NPC for Both Optimal Hybrid Systems of Grid-tied at 4m/s & 6.30m/s:

Graphs of NPC of grid-tied optimal systems at 4m/s and 6.30m/s wind speed are shown in figure 8.3 and 8.4:

Figure 8.3: Graph of NPC of grid-tied optimal systems at 4m/s wind speed

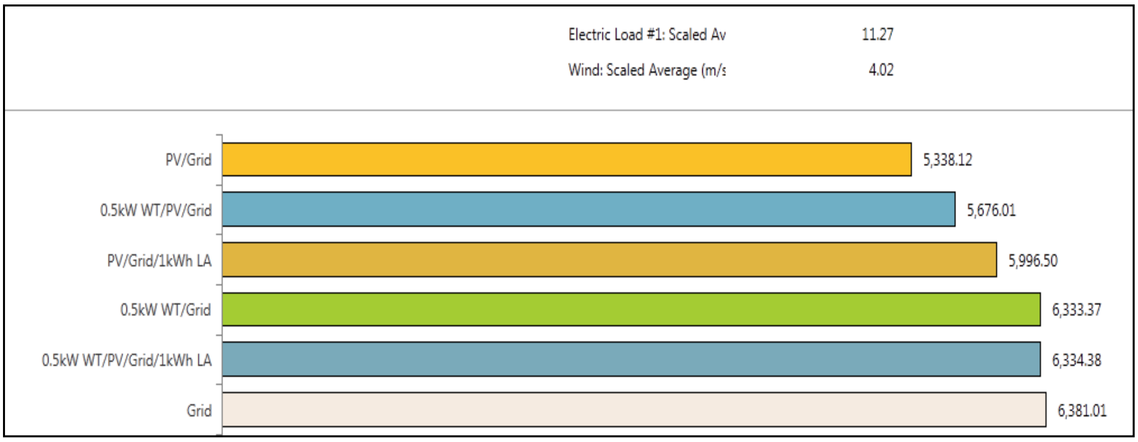
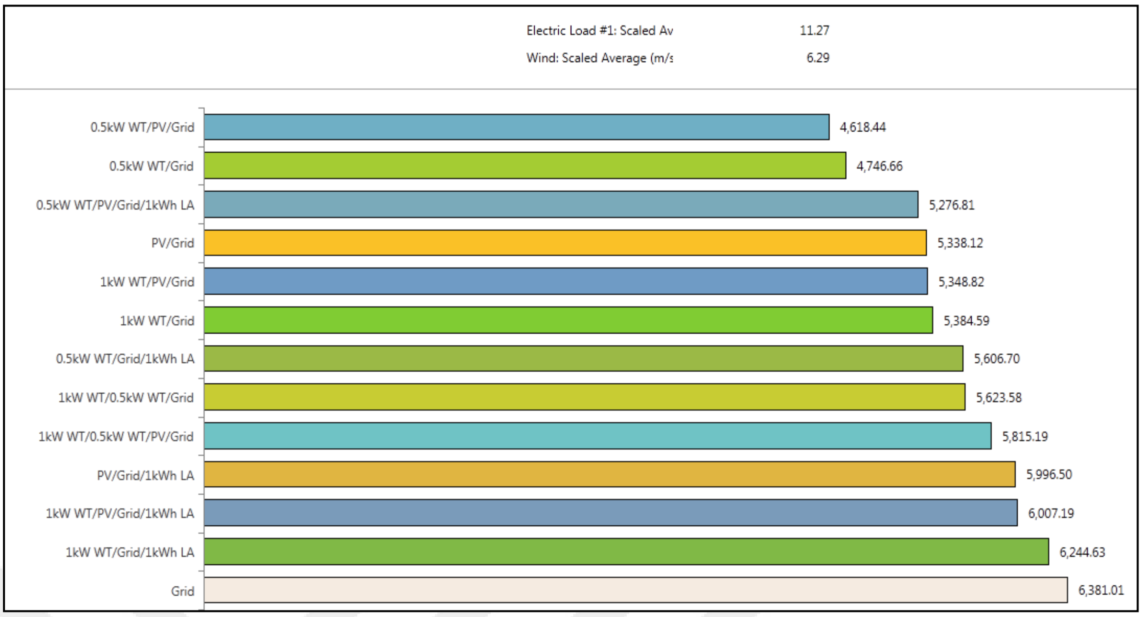


Figure 8.4: Graph of NPC of grid-tied optimal systems at 6.30m/s wind speed



From the graphs in figure 8.3 and 8.4 of NPC of different combination of renewable components, it is clear that the hybrid system which is designed at the height of 50m with the wind speed more than 6m/s average is much better option with lower costs and expenses as compared to optimal system at 4m/s wind speed.

8.2.2 Comparison of NPC for Both Optimal Hybrid Systems of Off-Grid at 4m/s & 6.30m/s:

Graphs of NPC of Off-grid optimal systems at 4m/s and 6.30m/s wind speed are shown in figure 8.5 and 8.6:

Figure 8.5: Graph of NPC of off-grid optimal systems at 4m/s wind speed

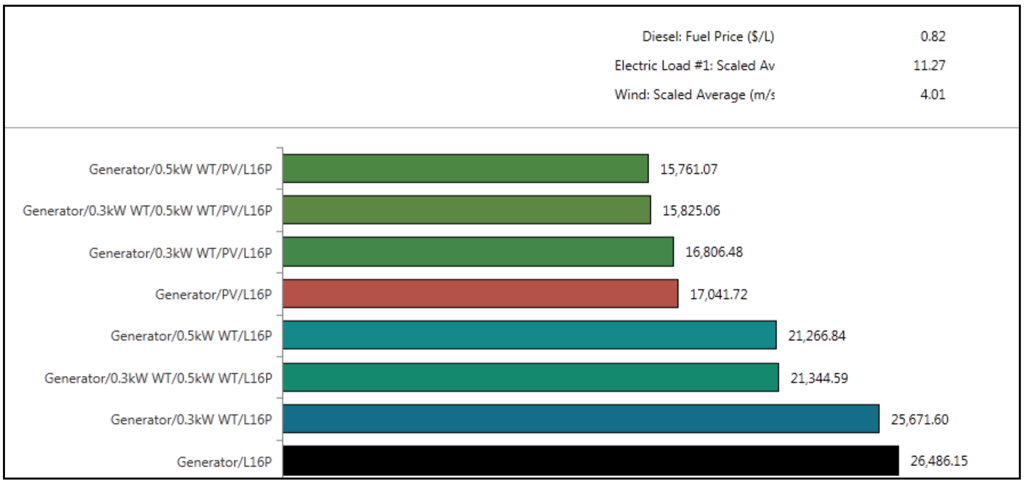
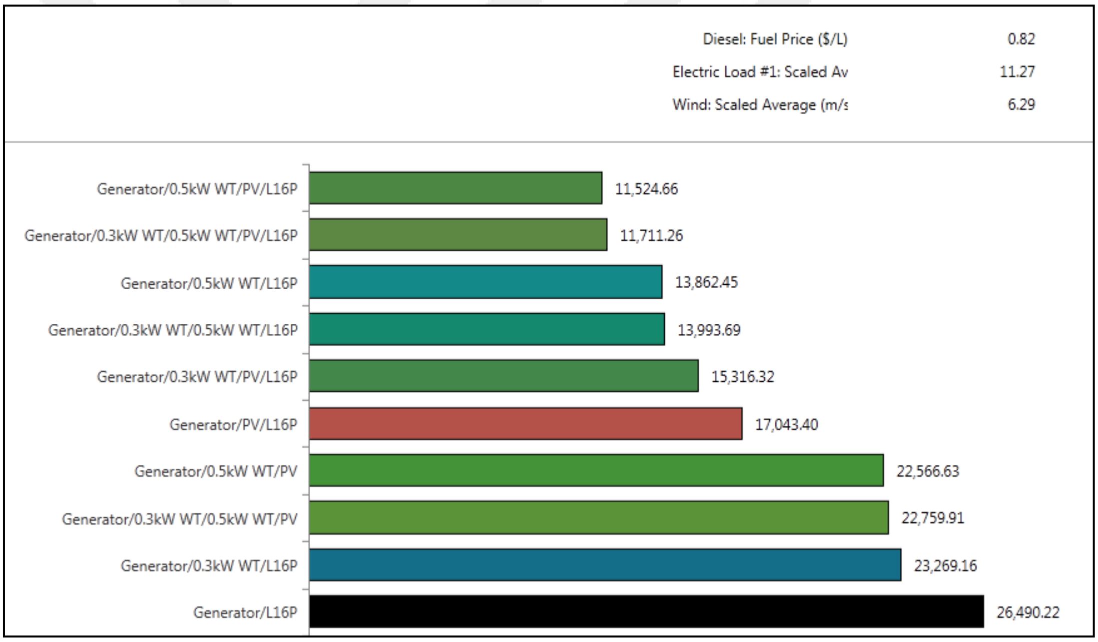


Figure 8.6: Graph of NPC of off-grid optimal systems at 6.30m/s wind speed



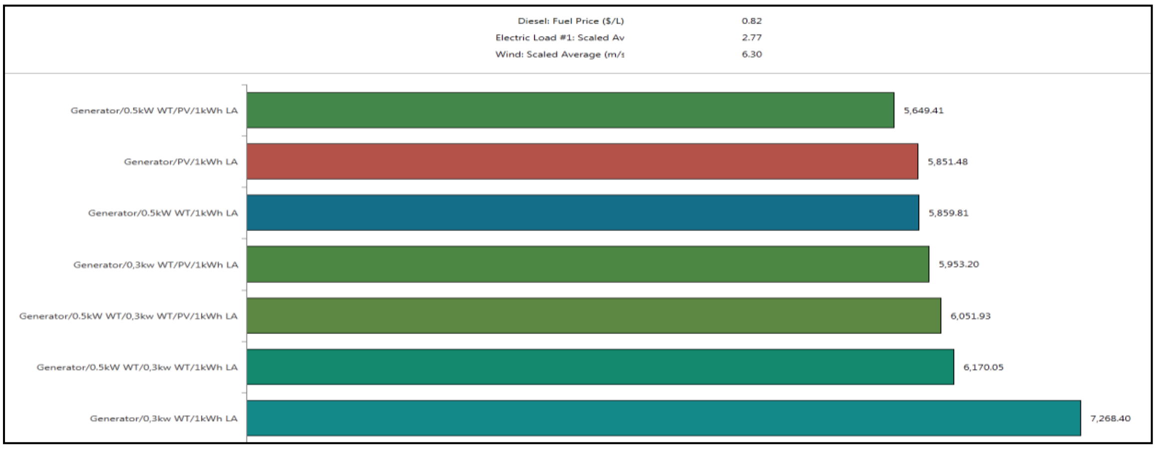
From the graphs in figure 8.5 and 8.6 of NPC of different combination of renewable components, it is clear that the hybrid system which is designed at the height of 50m with the wind speed more than 6m/s average is much better option with lower costs and expenses as compared to optimal system at 4m/s wind speed.

8.2.3 Comparison of NPC for Both Optimal Hybrid Systems of Load-shedding hour at 4m/s & 6.30m/s:

Graphs of NPC of Load-shedding hour optimal systems at 4m/s and 6.30m/s wind speed are shown in figure 8.7 and 8.8:

Figure 8.7: Graph of NPC of Load-shedding hour's optimal systems at 4m/s wind speed

Figure 8.8: Graph of NPC of Load-shedding hour's optimal systems at 6.30m/s wind speed



From the graphs in figure 8.7 and 8.8 of NPC of different combination of renewable components, it is clear that the hybrid system which is designed at the height of 50m with the wind speed more than 6m/s average is much better option with lower costs and expenses as compared to optimal system at 4m/s wind speed.

8.3 IN TERMS OF INVESTMENT IN OFF-GRID SYSTEM

It can also be seen that the off-grid system option if compared with load-shedding hours hybrid system, has good potential and it would save a lot of costs. The designed system for only load shedding hours is offering higher cost of energy per kWh. The difference between initial capital and the Total Net Present Cost is approximately around 56percent and 51percent respectively and cost of energy is also projecting the difference of only 50percent. It is better to invest in off-grid hybrid system than in hybrid system design for load shedding hour in long term.

8.4 RECOMMENDATIONS FOR ADVANCEMENTS

The study recommends getting more detailed data source of electric load for at least 3 years so that more realistic approach would be possible in designing hybrid system.

HOMER can literally provide the optimal design very close to reality but still there is a need of getting other sensitivity variable like losses in wiring of the hybrid system and other installing labour costs and other costing variables like transportation costs, shipping costs etc.

For further research work, it is recommended to study the details of losses in PV and wind turbine systems more and to get more detailed information about other real time costs as mentioned in previous paragraph.

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APPENDICES

APPENDIX A

COSTS TABLES OF GRID-TIED HYBRID SYSTEM

Table A.1: Nominal Cash flows of Optimal Hybrid System with Existing System at 4m/s

	Nominal Cash Flows					
	Current System		Base System		Difference	
Year	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
0	($1,180)	($1,180)	$0	$0	($1,180)	($1,180)
1	($317)	($1,497)	($494)	($494)	$177	($1,003)
2	($317)	($1,814)	($494)	($988)	$177	($826)
3	($317)	($2,131)	($494)	($1,482)	$177	($649)
4	($317)	($2,448)	($494)	($1,976)	$177	($472)
5	($317)	($2,765)	($494)	($2,470)	$177	($295)
6	($317)	($3,082)	($494)	($2,964)	$177	($118)
7	($317)	($3,399)	($494)	($3,458)	$177	$59
8	($317)	($3,716)	($494)	($3,952)	$177	$236
9	($317)	($4,033)	($494)	($4,446)	$177	$413
10	($317)	($4,350)	($494)	($4,940)	$177	$590
11	($317)	($4,667)	($494)	($5,434)	$177	$767
12	($317)	($4,984)	($494)	($5,928)	$177	$944
13	($317)	($5,301)	($494)	($6,422)	$177	$1,121
14	($317)	($5,618)	($494)	($6,916)	$177	$1,298
15	($497)	($6,115)	($494)	($7,410)	($3)	$1,295
16	($317)	($6,432)	($494)	($7,904)	$177	$1,472
17	($317)	($6,749)	($494)	($8,398)	$177	$1,649
18	($317)	($7,066)	($494)	($8,892)	$177	$1,826
19	($317)	($7,383)	($494)	($9,386)	$177	$2,003
20	($317)	($7,700)	($494)	($9,880)	$177	$2,180
21	($317)	($8,017)	($494)	($10,374)	$177	$2,357
22	($317)	($8,334)	($494)	($10,868)	$177	$2,534
23	($317)	($8,651)	($494)	($11,362)	$177	$2,711
24	($317)	($8,968)	($494)	($11,856)	$177	$2,888
25	($257)	($9,225)	($494)	($12,350)	$237	$3,125

Table A.2: Discounted Cash flows of Optimal Hybrid System With Existing System at 4m/s

Discounted Cash Flows					
Current System		Base System		Difference	
Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
($1,180)	($1,180)	$0	$0	($1,180)	($1,180)
($299)	($1,479)	($466)	($466)	$167	($1,013)
($283)	($1,762)	($440)	($906)	$157	($856)
($267)	($2,029)	($416)	($1,322)	$149	($707)
($252)	($2,281)	($393)	($1,715)	$141	($566)
($238)	($2,519)	($371)	($2,086)	$133	($433)
($225)	($2,744)	($350)	($2,436)	$125	($308)
($212)	($2,956)	($331)	($2,767)	$119	($189)
($201)	($3,157)	($312)	($3,079)	$111	($78)
($189)	($3,346)	($295)	($3,374)	$106	$28
($179)	($3,525)	($279)	($3,653)	$100	$128
($169)	($3,694)	($263)	($3,916)	$94	$222
($160)	($3,854)	($249)	($4,165)	$89	$311
($151)	($4,005)	($235)	($4,400)	$84	$395
($142)	($4,147)	($222)	($4,622)	$80	$475
($211)	($4,358)	($209)	($4,831)	($2)	$473
($127)	($4,485)	($198)	($5,029)	$71	$544
($120)	($4,605)	($187)	($5,216)	$67	$611
($113)	($4,718)	($176)	($5,392)	$63	$674
($107)	($4,825)	($167)	($5,559)	$60	$734
($101)	($4,926)	($157)	($5,716)	$56	$790
($95)	($5,021)	($149)	($5,865)	$54	$844
($90)	($5,111)	($140)	($6,005)	$50	$894
($85)	($5,196)	($133)	($6,138)	$48	$942
($80)	($5,276)	($125)	($6,263)	$45	$987
($62)	($5,338)	($118)	($6,381)	$56	$1,043

Table A.3: Nominal Cash flows of Optimal Hybrid System with Existing System at 6.30m/s

	Nominal Cash Flows					
	Current System		Base System		Difference	
Year	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
0	($1,500)	($1,500)	$0	$0	($1,500)	($1,500)
1	($229)	($1,729)	($494)	($494)	$265	($1,235)
2	($229)	($1,958)	($494)	($988)	$265	($970)
3	($229)	($2,187)	($494)	($1,482)	$265	($705)
4	($229)	($2,416)	($494)	($1,976)	$265	($440)
5	($229)	($2,645)	($494)	($2,470)	$265	($175)
6	($229)	($2,874)	($494)	($2,964)	$265	$90
7	($229)	($3,103)	($494)	($3,458)	$265	$355
8	($229)	($3,332)	($494)	($3,952)	$265	$620
9	($229)	($3,561)	($494)	($4,446)	$265	$885
10	($229)	($3,790)	($494)	($4,940)	$265	$1,150
11	($229)	($4,019)	($494)	($5,434)	$265	$1,415
12	($229)	($4,248)	($494)	($5,928)	$265	$1,680
13	($229)	($4,477)	($494)	($6,422)	$265	$1,945
14	($229)	($4,706)	($494)	($6,916)	$265	$2,210
15	($379)	($5,085)	($494)	($7,410)	$115	$2,325
16	($229)	($5,314)	($494)	($7,904)	$265	$2,590
17	($229)	($5,543)	($494)	($8,398)	$265	$2,855
18	($229)	($5,772)	($494)	($8,892)	$265	$3,120
19	($229)	($6,001)	($494)	($9,386)	$265	$3,385
20	($979)	($6,980)	($494)	($9,880)	($485)	$2,900
21	($229)	($7,209)	($494)	($10,374)	$265	$3,165
22	($229)	($7,438)	($494)	($10,868)	$265	$3,430
23	($229)	($7,667)	($494)	($11,362)	$265	$3,695
24	($229)	($7,896)	($494)	($11,856)	$265	$3,960
25	$384	($7,512)	($494)	($12,350)	$878	$4,838

Table A.4: Discounted Cash flows of Optimal Hybrid System With Existing System at 6.30m/s

Discounted Cash Flows					
Current System		Base System		Difference	
Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
($1,500)	($1,500)	$0	$0	($1,500)	($1,500)
($216)	($1,716)	($466)	($466)	$250	($1,250)
($204)	($1,920)	($440)	($906)	$236	($1,014)
($193)	($2,113)	($416)	($1,322)	$223	($791)
($182)	($2,295)	($393)	($1,715)	$211	($580)
($172)	($2,467)	($371)	($2,086)	$199	($381)
($162)	($2,629)	($350)	($2,436)	$188	($193)
($153)	($2,782)	($331)	($2,767)	$178	($15)
($145)	($2,927)	($312)	($3,079)	$167	$152
($137)	($3,064)	($295)	($3,374)	$158	$310
($129)	($3,193)	($279)	($3,653)	$150	$460
($122)	($3,315)	($263)	($3,916)	$141	$601
($115)	($3,430)	($249)	($4,165)	$134	$735
($109)	($3,539)	($235)	($4,400)	$126	$861
($103)	($3,642)	($222)	($4,622)	$119	$980
($161)	($3,803)	($209)	($4,831)	$48	$1,028
($92)	($3,895)	($198)	($5,029)	$106	$1,134
($87)	($3,982)	($187)	($5,216)	$100	$1,234
($82)	($4,064)	($176)	($5,392)	$94	$1,328
($77)	($4,141)	($167)	($5,559)	$90	$1,418
($312)	($4,453)	($157)	($5,716)	($155)	$1,263
($69)	($4,522)	($149)	($5,865)	$80	$1,343
($65)	($4,587)	($140)	($6,005)	$75	$1,418
($61)	($4,648)	($133)	($6,138)	$72	$1,490
($58)	($4,706)	($125)	($6,263)	$67	$1,557
$92	($4,614)	($118)	($6,381)	$210	$1,767

APPENDIX B

COSTS TABLES OF OFF-GRID HYBRID SYSTEM

Table B.1: Nominal Cash flows of Optimal Hybrid System with Existing System at 4m/s

	Nominal Cash Flows					
	Current System		Base System		Difference	
Year	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
0	($5,250)	($5,250)	($1,950)	($1,950)	($3,300)	($3,300)
1	($533)	($5,783)	($1,532)	($3,482)	$999	($2,301)
2	($533)	($6,316)	($1,532)	($5,014)	$999	($1,302)
3	($533)	($6,849)	($2,032)	($7,046)	$1,499	$197
4	($533)	($7,382)	($1,532)	($8,578)	$999	$1,196
5	($1,533)	($8,915)	($2,032)	($10,610)	$499	$1,695
6	($533)	($9,448)	($2,532)	($13,142)	$1,999	$3,694
7	($1,033)	($10,481)	($2,032)	($15,174)	$999	$4,693
8	($533)	($11,014)	($1,532)	($16,706)	$999	$5,692
9	($1,533)	($12,547)	($2,032)	($18,738)	$499	$6,191
10	($533)	($13,080)	($1,532)	($20,270)	$999	$7,190
11	($533)	($13,613)	($2,032)	($22,302)	$1,499	$8,689
12	($533)	($14,146)	($2,532)	($24,834)	$1,999	$10,688
13	($1,533)	($15,679)	($2,032)	($26,866)	$499	$11,187
14	($1,033)	($16,712)	($1,532)	($28,398)	$499	$11,686
15	($983)	($17,695)	($2,482)	($30,880)	$1,499	$13,185
16	($533)	($18,228)	($1,532)	($32,412)	$999	$14,184
17	($1,533)	($19,761)	($2,032)	($34,444)	$499	$14,683
18	($533)	($20,294)	($2,532)	($36,976)	$1,999	$16,682
19	($533)	($20,827)	($2,032)	($39,008)	$1,499	$18,181
20	($2,033)	($22,860)	($1,532)	($40,540)	($501)	$17,680
21	($2,033)	($24,893)	($2,032)	($42,572)	($1)	$17,679
22	($533)	($25,426)	($1,532)	($44,104)	$999	$18,678
23	($533)	($25,959)	($1,532)	($45,636)	$999	$19,677
24	($533)	($26,492)	($3,032)	($48,668)	$2,499	$22,176
25	$924	($25,568)	($661)	($49,329)	$1,585	$23,761

Table B.2: Discounted Cash flows of Optimal Hybrid System with Existing System at 4m/s

Discounted Cash Flows					
Current System		Base System		Difference	
Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
($5,250)	($5,250)	($1,950)	($1,950)	($3,300)	($3,300)
($504)	($5,754)	($1,447)	($3,397)	$943	($2,357)
($476)	($6,230)	($1,367)	($4,764)	$891	($1,466)
($449)	($6,679)	($1,735)	($6,499)	$1,286	($180)
($424)	($7,103)	($1,219)	($7,718)	$795	$615
($1,188)	($8,291)	($1,545)	($9,263)	$357	$972
($378)	($8,669)	($1,804)	($11,067)	$1,426	$2,398
($697)	($9,366)	($1,376)	($12,443)	$679	$3,077
($338)	($9,704)	($970)	($13,413)	$632	$3,709
($938)	($10,642)	($1,226)	($14,639)	$288	$3,997
($301)	($10,943)	($865)	($15,504)	$564	$4,561
($284)	($11,227)	($1,092)	($16,596)	$808	$5,369
($269)	($11,496)	($1,287)	($17,883)	$1,018	$6,387
($741)	($12,237)	($973)	($18,856)	$232	$6,619
($471)	($12,708)	($688)	($19,544)	$217	$6,836
($417)	($13,125)	($1,057)	($20,601)	$640	$7,476
($214)	($13,339)	($614)	($21,215)	$400	$7,876
($586)	($13,925)	($772)	($21,987)	$186	$8,062
($191)	($14,116)	($917)	($22,904)	$726	$8,788
($180)	($14,296)	($687)	($23,591)	$507	$9,295
($648)	($14,944)	($488)	($24,079)	($160)	$9,135
($620)	($15,564)	($612)	($24,691)	($8)	$9,127
($152)	($15,716)	($436)	($25,127)	$284	$9,411
($143)	($15,859)	($412)	($25,539)	$269	$9,680
($135)	($15,994)	($788)	($26,327)	$653	$10,333
$221	($15,773)	($158)	($26,485)	$379	$10,712

Table B.3: Nominal Cash flows of Optimal Hybrid System with Existing System at 6.30m/s

	Nominal Cash Flows					
	Current System		Base System		Difference	
Year	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
0	($5,050)	($5,050)	($5,050)	($5,050)	$0	$0
1	($335)	($5,385)	($335)	($5,385)	$0	$0
2	($335)	($5,720)	($335)	($5,720)	$0	$0
3	($335)	($6,055)	($335)	($6,055)	$0	$0
4	($335)	($6,390)	($335)	($6,390)	$0	$0
5	($335)	($6,725)	($335)	($6,725)	$0	$0
6	($335)	($7,060)	($335)	($7,060)	$0	$0
7	($1,335)	($8,395)	($1,335)	($8,395)	$0	$0
8	($335)	($8,730)	($335)	($8,730)	$0	$0
9	($335)	($9,065)	($335)	($9,065)	$0	$0
10	($335)	($9,400)	($335)	($9,400)	$0	$0
11	($335)	($9,735)	($335)	($9,735)	$0	$0
12	($335)	($10,070)	($335)	($10,070)	$0	$0
13	($835)	($10,905)	($835)	($10,905)	$0	$0
14	($1,335)	($12,240)	($1,335)	($12,240)	$0	$0
15	($635)	($12,875)	($635)	($12,875)	$0	$0
16	($335)	($13,210)	($335)	($13,210)	$0	$0
17	($335)	($13,545)	($335)	($13,545)	$0	$0
18	($335)	($13,880)	($335)	($13,880)	$0	$0
19	($335)	($14,215)	($335)	($14,215)	$0	$0
20	($3,585)	($17,800)	($3,585)	($17,800)	$0	$0
21	($335)	($18,135)	($335)	($18,135)	$0	$0
22	($335)	($18,470)	($335)	($18,470)	$0	$0
23	($335)	($18,805)	($335)	($18,805)	$0	$0
24	($335)	($19,140)	($335)	($19,140)	$0	$0
25	$1,636	($17,504)	$1,636	($17,504)	$0	$0

Table B.4: Discounted Cash flows of Optimal Hybrid System with Existing System at 6.30m/s

Discounted Cash Flows					
Current System		Base System		Difference	
Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
($5,050)	($5,050)	($5,050)	($5,050)	$0	$0
($317)	($5,367)	($317)	($5,367)	$0	$0
($299)	($5,666)	($299)	($5,666)	$0	$0
($283)	($5,949)	($283)	($5,949)	$0	$0
($267)	($6,216)	($267)	($6,216)	$0	$0
($252)	($6,468)	($252)	($6,468)	$0	$0
($238)	($6,706)	($238)	($6,706)	$0	$0
($910)	($7,616)	($910)	($7,616)	$0	$0
($212)	($7,828)	($212)	($7,828)	$0	$0
($201)	($8,029)	($201)	($8,029)	$0	$0
($189)	($8,218)	($189)	($8,218)	$0	$0
($179)	($8,397)	($179)	($8,397)	$0	$0
($169)	($8,566)	($169)	($8,566)	$0	$0
($411)	($8,977)	($411)	($8,977)	$0	$0
($621)	($9,598)	($621)	($9,598)	$0	$0
($270)	($9,868)	($270)	($9,868)	$0	$0
($134)	($10,002)	($134)	($10,002)	$0	$0
($127)	($10,129)	($127)	($10,129)	$0	$0
($120)	($10,249)	($120)	($10,249)	$0	$0
($113)	($10,362)	($113)	($10,362)	$0	$0
($1,146)	($11,508)	($1,146)	($11,508)	$0	$0
($101)	($11,609)	($101)	($11,609)	$0	$0
($95)	($11,704)	($95)	($11,704)	$0	$0
($90)	($11,794)	($90)	($11,794)	$0	$0
($85)	($11,879)	($85)	($11,879)	$0	$0
$386	($11,493)	$386	($11,493)	$0	$0

APPENDIX C

COSTS TABLES OF LOAD SHEDDING HOURS HYBRID SYSTEM

Table C.1: Nominal Cash flows of Optimal Hybrid System with Existing System at 4m/s

	Nominal Cash Flows					
	Current System		Base System		Difference	
Year	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
0	($2,620)	($2,620)	($1,530)	($1,530)	($1,090)	($1,090)
1	($182)	($2,802)	($422)	($1,952)	$240	($850)
2	($182)	($2,984)	($422)	($2,374)	$240	($610)
3	($182)	($3,166)	($422)	($2,796)	$240	($370)
4	($182)	($3,348)	($422)	($3,218)	$240	($130)
5	($182)	($3,530)	($422)	($3,640)	$240	$110
6	($182)	($3,712)	($422)	($4,062)	$240	$350
7	($782)	($4,494)	($422)	($4,484)	($360)	($10)
8	($182)	($4,676)	($422)	($4,906)	$240	$230
9	($182)	($4,858)	($422)	($5,328)	$240	$470
10	($182)	($5,040)	($1,022)	($6,350)	$840	$1,310
11	($182)	($5,222)	($1,172)	($7,522)	$990	$2,300
12	($182)	($5,404)	($422)	($7,944)	$240	$2,540
13	($182)	($5,586)	($422)	($8,366)	$240	$2,780
14	($782)	($6,368)	($422)	($8,788)	($360)	$2,420
15	($452)	($6,820)	($602)	($9,390)	$150	$2,570
16	($182)	($7,002)	($422)	($9,812)	$240	$2,810
17	($182)	($7,184)	($422)	($10,234)	$240	$3,050
18	($182)	($7,366)	($422)	($10,656)	$240	$3,290
19	($182)	($7,548)	($422)	($11,078)	$240	$3,530
20	($182)	($7,730)	($1,022)	($12,100)	$840	$4,370
21	($782)	($8,512)	($422)	($12,522)	($360)	$4,010
22	($182)	($8,694)	($1,172)	($13,694)	$990	$5,000
23	($182)	($8,876)	($422)	($14,116)	$240	$5,240
24	($182)	($9,058)	($422)	($14,538)	$240	$5,480
25	$279	($8,779)	$431	($14,107)	($152)	$5,328

Table C.2: Discounted Cash flows of Optimal Hybrid System with Existing System at 4m/s

Discounted Cash Flows					
Current System		Base System		Difference	
Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
($2,620)	($2,620)	($1,530)	($1,530)	($1,090)	($1,090)
($172)	($2,792)	($399)	($1,929)	$227	($863)
($162)	($2,954)	($377)	($2,306)	$215	($648)
($153)	($3,107)	($356)	($2,662)	$203	($445)
($145)	($3,252)	($336)	($2,998)	$191	($254)
($137)	($3,389)	($317)	($3,315)	$180	($74)
($129)	($3,518)	($300)	($3,615)	$171	$97
($525)	($4,043)	($283)	($3,898)	($242)	($145)
($115)	($4,158)	($267)	($4,165)	$152	$7
($109)	($4,267)	($252)	($4,417)	$143	$150
($103)	($4,370)	($577)	($4,994)	$474	$624
($97)	($4,467)	($632)	($5,626)	$535	$1,159
($92)	($4,559)	($213)	($5,839)	$121	$1,280
($86)	($4,645)	($201)	($6,040)	$115	$1,395
($353)	($4,998)	($190)	($6,230)	($163)	$1,232
($192)	($5,190)	($255)	($6,485)	$63	$1,295
($73)	($5,263)	($169)	($6,654)	$96	$1,391
($69)	($5,332)	($160)	($6,814)	$91	$1,482
($65)	($5,397)	($151)	($6,965)	$86	$1,568
($61)	($5,458)	($143)	($7,108)	$82	$1,650
($58)	($5,516)	($327)	($7,435)	$269	$1,919
($237)	($5,753)	($127)	($7,562)	($110)	$1,809
($52)	($5,805)	($341)	($7,903)	$289	$2,098
($49)	($5,854)	($113)	($8,016)	$64	$2,162
($46)	($5,900)	($107)	($8,123)	$61	$2,223
$67	($5,833)	$103	($8,020)	($36)	$2,187

Table C.3: Nominal Cash flows of Optimal Hybrid System with Existing System at 6.30m/s

	Nominal Cash Flows					
	Current System		Base System		Difference	
Year	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
0	($2,810)	($2,810)	($2,810)	($2,810)	$0	$0
1	($171)	($2,981)	($171)	($2,981)	$0	$0
2	($171)	($3,152)	($171)	($3,152)	$0	$0
3	($171)	($3,323)	($171)	($3,323)	$0	$0
4	($171)	($3,494)	($171)	($3,494)	$0	$0
5	($171)	($3,665)	($171)	($3,665)	$0	$0
6	($171)	($3,836)	($171)	($3,836)	$0	$0
7	($171)	($4,007)	($171)	($4,007)	$0	$0
8	($171)	($4,178)	($171)	($4,178)	$0	$0
9	($171)	($4,349)	($171)	($4,349)	$0	$0
10	($771)	($5,120)	($771)	($5,120)	$0	$0
11	($171)	($5,291)	($171)	($5,291)	$0	$0
12	($171)	($5,462)	($171)	($5,462)	$0	$0
13	($171)	($5,633)	($171)	($5,633)	$0	$0
14	($171)	($5,804)	($171)	($5,804)	$0	$0
15	($381)	($6,185)	($381)	($6,185)	$0	$0
16	($171)	($6,356)	($171)	($6,356)	$0	$0
17	($171)	($6,527)	($171)	($6,527)	$0	$0
18	($171)	($6,698)	($171)	($6,698)	$0	$0
19	($171)	($6,869)	($171)	($6,869)	$0	$0
20	($1,521)	($8,390)	($1,521)	($8,390)	$0	$0
21	($171)	($8,561)	($171)	($8,561)	$0	$0
22	($171)	($8,732)	($171)	($8,732)	$0	$0
23	($171)	($8,903)	($171)	($8,903)	$0	$0
24	($171)	($9,074)	($171)	($9,074)	$0	$0
25	$886	($8,188)	$886	($8,188)	$0	$0

Table C.4: Discounted Cash flows of Optimal Hybrid System with Existing System at 6.30m/s

Discounted Cash Flows					
Current System		Base System		Difference	
Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
($2,810)	($2,810)	($2,810)	($2,810)	$0	$0
($162)	($2,972)	($162)	($2,972)	$0	$0
($153)	($3,125)	($153)	($3,125)	$0	$0
($144)	($3,269)	($144)	($3,269)	$0	$0
($136)	($3,405)	($136)	($3,405)	$0	$0
($129)	($3,534)	($129)	($3,534)	$0	$0
($122)	($3,656)	($122)	($3,656)	$0	$0
($115)	($3,771)	($115)	($3,771)	$0	$0
($109)	($3,880)	($109)	($3,880)	$0	$0
($102)	($3,982)	($102)	($3,982)	$0	$0
($436)	($4,418)	($436)	($4,418)	$0	$0
($91)	($4,509)	($91)	($4,509)	$0	$0
($86)	($4,595)	($86)	($4,595)	$0	$0
($82)	($4,677)	($82)	($4,677)	$0	$0
($77)	($4,754)	($77)	($4,754)	$0	$0
($162)	($4,916)	($162)	($4,916)	$0	$0
($69)	($4,985)	($69)	($4,985)	$0	$0
($65)	($5,050)	($65)	($5,050)	$0	$0
($61)	($5,111)	($61)	($5,111)	$0	$0
($58)	($5,169)	($58)	($5,169)	$0	$0
($485)	($5,654)	($485)	($5,654)	$0	$0
($52)	($5,706)	($52)	($5,706)	$0	$0
($49)	($5,755)	($49)	($5,755)	$0	$0
($46)	($5,801)	($46)	($5,801)	$0	$0
($43)	($5,844)	($43)	($5,844)	$0	$0
$212	($5,632)	$212	($5,632)	$0	$0