# HYBRID RENEWABLE ENERGY BASED ELECTRICITY GENERATION SYSTEM

by

Mosab Adam Agbna Elnour

Final Report submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Electrical and Electronics Engineering)

MAY 2011

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

# CERTIFICATION OF APPROVAL

## HYBRID RENEWABLE ENERGY BASED ELECTRICITY GENERATION SYSTEM

by

Mosab Adam Agbna Elnour

Submitted to the

Electrical and Electronics Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
Bachelor of Engineering (Hons)
(Electrical and Electronics Engineering)

Approved by

ASSOC. PROF. DR. BALBIR SINGH
Senior Manager
Academic Central Services

(Assoc. Prof. Dr. Balbir Singh Mahinder Singh)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

December 2011

# CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MOSAB ADAM AGBNA ELNOUR

# ACKNOWLEDGEMENTS

First and foremost, I would like to thank God who through his guidance has helped me through my internship period.

Secondly, upon completing the final year project, I am indebted to all personnel in making this project a success; especially my supervisor **AP.Dr. Balbir Singh Mahinder Singh** for his advice and support throughout my project period.

I would never forget to gives grateful thanks to my family who always encouraged and stood beside me, especially to my father **Eng. Adam Agbna** who always presented better advice and guides.

Finally, am profoundly grateful to all personnel in **Universiti Teknologi PETRONAS** , who support me while working in my project. I would also like to pass a very special thanks to all the examiners for taking the time to evaluate this report.

Thank you very much, may almighty God repay you for your kindness.

# ABSTRACT

The need to explore alternative energy resources is inevitable, due to the global growing awareness on environmental pollution caused by the extensive use of conventional energy sources, coupled with the sharp increase in overall world energy demand. The focus is inclined towards the renewable energy resources as an alternative. Renewable energy is the energy that can be extracted from natural resources that can be replenish and is deemed to be longer lasting than the conventional resources. The immediate attention for utilization is in the electricity generation sector, due to the progressive increase in its consumption, as the population increases globally. There are many regions in the developing countries where access to energy is still scarce, especially in rural areas. The access to these rural locations makes it difficult to supply economical electricity, especially from the national grids. In this project, the focus is towards developing renewable energy based electricity generating system that will be able to reach the rural population in Sudan. Hybridization technique will be used to solar and wind energy technologies for electricity generation. This can result in better performance and also to ensure the sustainability of the system. Gezira state is the targeted region for implementing the proposed system as it has a relatively high solar and wind energy potential among other regions in Sudan. It is located in the center of Sudan and has the largest agriculture project in the world, known as the Gezira Scheme. In addition, the Blue Nile River passes the state which gives it an advantage of utilizing the river micro-hydro energy for electrification and irrigation. The system is applied for both residential and agriculture purposes to develop a sustainable means of energy and Agricultural products supplying, not only for the state but also for the entire country.

# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLE

# LIST OF ABBREVIATIONS

| | |
|---|---|
| FYP I | Final Year Project I |
| FYP II | Final Year Project II |
| PV | Photovoltaic |
| HAWT | Horizontal Axis Wind Turbine |
| VAWAT | Vertical Axis Wind Turbine |
| HRES | Hybrid renewable energy systems |
| Voc | Open Circuit Voltage |
| Isc | Short Circuit Current |
| Vm | Maximum Power Voltage |
| Im | Maximum Power Current |
| PMSG | Permanent Magnet Synchronous Generator |
| PWM | Pulse Width Modulation |
| MPPT | Maximum Power Point Tracker |
| ΔP | Change In Power |
| DC | Direct Current |
| AC | Alternative Current |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of Study

The growing worldwide awareness about the increase in environmental pollution due to the extensive use of conventional energy sources, and coupled with the rise in global energy demand has led to the need to explore alternative energy resources. The global focus currently is towards the renewable energy researches and development as a main alternative. Renewable energy means the energy that can be extracted from natural resources that are sustainable and would not be run out or last longer than the conventional energy resources. Renewable energy sources differ significantly from fossil fuels; oil, natural gas and coal or even the nuclear fuel that is used in nuclear reactors. Renewable energies are mainly produced from sun, wind and water, and it can be produced from the movement of waves and tides, or geothermal energy, biomass energy and other resources [2].

The project involves studies, concentrate on the potential of renewable energy that to be utilized in generating electricity. Conventionally, there are three types of utilizing renewable energy in electric power generation. The first one is the stand-alone systems where are used in locations that are difficult to be accessed by an electric grid. While the second type, is the grid-connected systems where renewable energy electric generation systems are connected to a local electricity network, which means the electricity generated by such kind of systems can either be used directly or to be sold to the electricity grid consumers when the produced electricity exceeds the demand [3].

The third and last approach being used is the hybrid-connected systems, where more than one type of electricity generators is implemented. The second generator either can be from renewable energies, like wind turbine, or conventional, such as a diesel generator or even the local grid [3].

The use of renewable energy is an effective alternative to be implemented in the electricity generation systems. The renewable energies still cost more in comparison to the conventional resources. Despite that, many researches are conducting to lower the cost or to increase the efficiency of renewable energy technologies to compete with the conventional energies in the future [4].

## 1.2 Problem Statement

An estimated 1.6 billion people in developing countries do not have totally an access to electricity [2]. Many more to meet their heating and cooking needs are still dependent on biomass and traditional cooking stoves. There is also more than 60% of the world's population, especially in Africa, who lives in small cities, often suffers from the shortage of energy sources.

The impact of fossil fuel in the industry and modern life is not only on the environment, but also in the dramatically change of the climate as well [3]. Renewable energies, especially solar and wind energies are prime choice in developing affordable and cleaner global energy resources that can be a substitute for fossil fuels around the world [1]. However, there is no simple technology of renewable energy that provides a reliable solution for securing a sustainable electricity generation. Therefore, designing a system can overcome this matter efficiently is needed.

The electrification rate in Sudan is about 45% [8], this leaves more than half of the population suffering electricity shortages and decreasing the chances of developing national projects that can drive the economical wheel of the country. An example of these projects is Gazira Scheme. Gazira Scheme is the prime agricultural project in Sudan since the country's independence. Despite that, it suffers from the traditional way of irrigation, due to the lack of technologies that consumes much energy. All these reasons raised the need to establish appropriate small units powered by the available renewable energies to produce electricity in such areas.

## 1.3 Objectives

The objectives of the project are:

- To carry out a study and indentify suitable renewable electricity generation system.
- To design the renewable electricity generation system and carry out simulation studies.
- To purpose implementation strategies for the system at a selected location in Sudan.

## 1.4 The relevancy of the project

Universities and research institutions both locally and internationally are conducting researches on renewable energy particularly for generating electricity. It is practically a relevant idea to develop a hybrid energy system that can harvest free energy from renewable sources and secure a sustainable electricity supply that is environmentally friendly and economically worthy.

In 2009, Sudan's Ministry of Science & Technology has formed the department of renewable energy mainly focusing on power generation utilization. There are several ongoing studies, data measurements and testing for some renewable systems. Recently, the government of Sudan is intending to develop a 2 GW concentrated solar power stations (CSP) in order to supply villages with electricity, access to water and for irrigation.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Current Energy Sources

Energy is considered one of the civilization key features, where, all society sectors depends on it and it is needed in many areas such as industry, transportation and even in operating personal appliances. Energy is found in several forms, such as wind energy or water flow. More likely, it can be stored in a form of fossil fuel. Fossil fuel is a term stands of oil, gas and coal; and by burning these sources a useful energy can be made by them. They are considered the main energy source and they contribute about 85% of the used energy today [1]. Because they are subjected to depletion and due to their environmental pollution, researches were initiated to provide and develop alternative energies.

### 2.1.1 Oil

Until the moment, oil is the most important source of energy. Oil has maintained its leading spot among the other sources of energy in the world during the past half century [1]. It is the key factor in the economic development of world's countries.

If the need for energy during the past half century has increased five times, the oil use globally has increased at an annual rate of 30% during the period between 1980 and 2003.

### 2.1.2 Natural Gas

Natural Gas globally takes up the second rank among energy sources currently. The natural gas reserves in Russia, Qatar and Iran have a 55% of the global reserves; about 79.57 trillion cubic meters [4].

### 2.1.3 Coal

Coal is globally still of the main sources of energy. Moreover, it can be considered as the most important source for electricity generation in the world. Current studies declared that coal is used to generate about 40% of the world's electricity today [5]. However, there are harmful environmental effects when using coal for generating electricity. That's why power industry in order to make the coal energy clean has spent billions of dollars.

### 2.1.4 Nuclear Energy

Nuclear energy results from the nuclear fission in nuclear reactors, and it is utilized in power generation and in operating ships and submarines. However, it has highlighted disadvantages which limited the usage of nuclear energy towards the fossil fuel, such as, the problem of disposal its waste, radioactive waste results, and high safety and control precautions which are needed to prevent the explosion of the reactor or the leakage of radiation, besides, one of the main reasons is the fear from changing the peaceable use of nuclear energy to a destructive one by making nuclear weapons [5].

## 2.2 The Impact of Fossil Fuel Consumption

Fossil fuels drive the economy of any nation. Oil, natural gas and coal provide electrification for homes; fuel for cars; and power all sorts of production. However, after the oil crisis in the early 1970s, the worry was on the cost of energy, and during the past two decades the risk on the environment has become clearer [1].

### 2.2.1 Economical Considerations of Fossil Fuel

Fossil fuels supply is very limited because they are non-renewable resources. In fact, no fossil fuel can be recycled. Only one-third of coal's fuel is converted to energy when coal is burned for electricity generation, the remains are waste [5]. This waste is not able to be regained. Fossil fuel consumption is 85 percent of total energy use in the world. If the world continues at current rates of consumption, oil companies must tap existing and new reserves of fossil fuels. Oil drilling and excavating and are very expensive, need long-term research and planning. The biggest disadvantage lies in the fact that fossil fuels are only stored deeply inside the earth's surface. This makes oil extraction a difficult task. Therefore, in the future , the cost of obtaining and using fossil fuels may become a problem as governments set policies for air quality controls that lead the fuel industry developer to find ways to better use fossil fuels. The cost of developing technologies to use fossil fuels more efficiently as well as reduce the impact on the environment, both require extensive research and time to develop new techniques for extraction of fossil fuels [5].

### 2.2.2 Environmental Effects of Fossil Fuel

As the energy demand increases, the production and usage of fossil fuels create grim environmental effects resulted from the emission of carbon and toxic gases. These negative effects of fossil fuel will continue until there is a successful progress towards renewable energy. The environmental effects include air pollution, climate changes and rising sea levels.

### *Air Pollution*

Fossil fuels cause in the atmosphere environmentally unsafe compounds to be formed and depleting ozone levels which can create a spike in skin cancer rates [1]. Coal burning releases sulfur oxide and emit nitrogen oxides that result on smog. Sulfur and nitrogen oxides can cause acid rain, which is dangerous for plants and human. Studies declared that populations with higher rates of asthma allocated in areas of high air pollution indexes more than in cleaner environments [5].

### *Climate changes*

Climate changes or what is generally called 'Global Warming' occur when carbon dioxide accumulates in the atmosphere. It causes the earth's surface temperature to increase significantly. This increase is adequate to change the environmental systems of the world. Implications such as floods, severe weather and temperature changes are a clear effects of climate changes.

### *Rising Sea Levels*

The climate changing results directly in rising up sea levels. This effects both human settlements and ecosystems in low-altitude areas. In fact, climate changes can speed by the impact of caused by ice melting, since ice reflects sunlight while water absorbs it [5].

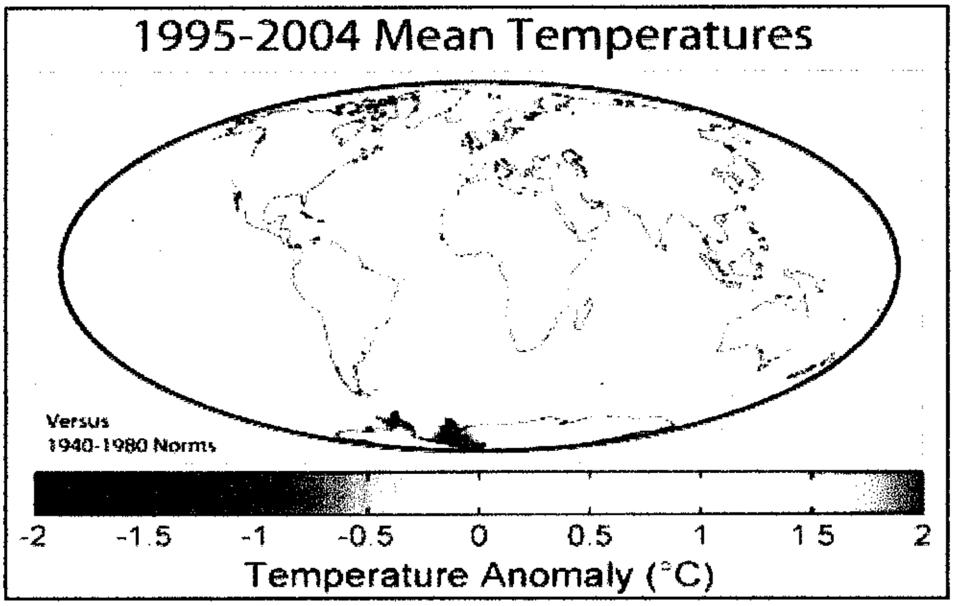


Figure 1: The effect of global warming on the earth mean temperature [1]

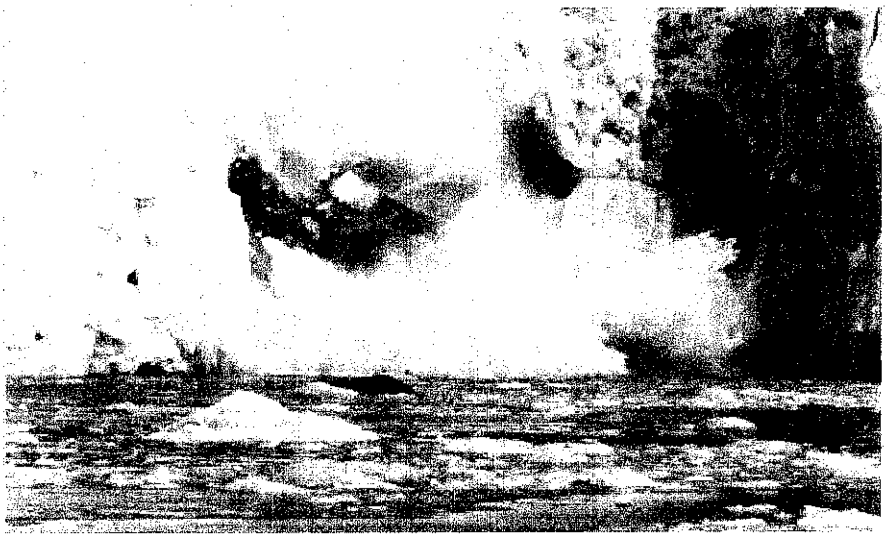


Figure 2: The effect of global warming on the poles icebergs [1]

## 2.3 Future of Renewable Energy Utilization

Now, it is normally accepted that renewable energy technologies can meet most of the growing demand at prices that are equal to or lower than the prices were provided by the local grid [3].

This promising point of view for renewable energy reflects remarkable technical gains made during the past two decades when renewable energy systems benefited from developments in material sciences, biotechnology, electronics, and in other fields [2].

The decrease in environmental pollution is the most important benefit of renewable energy systems. This is accomplished by the decrease of air emissions due to the replacement of conventional fuels that used to generate electricity [4]. Solar energy and wind power are considered as the main renewable energy sources in this project.

### 2.3.1 Solar Energy

Solar energy is produced by the Sun which can be converted to electricity using solar cells. The challenge of using solar energy lay behind the fact of the unavailability of Sun light during nigh and Sun trajectory. The earth rotates 24 hours a day, therefore, along with the earth rotation, the position of the Sun changes. As the location of the Sun changes, solar radiation intensity will be affected. Currently, solar powered electrical generation relies on photovoltaic and heat engines [3].

### 2.3.2 Photovoltaic Cells

A photovoltaic cell is a semiconductor material that converts solar radiation into direct current. A semiconductor is a material that can show properties of both conductors and insulators [6]. The semiconductor materials that PV cells are made from, when exposed to light, they produce a voltage or exhibit a change in electrical conductivity. This physical phenomenon is known as the photovoltaic effect.

The photovoltaic happens when a material absorbs the light's photos that have energy above certain levels, which leads to effect the movement of electrons within that material. Photons contain different amounts of energy depending on their frequencies; higher frequencies lead to higher energies. Photons transfer their energy to the surface's electrons of the material. The electrons that absorb sufficient energy to escape from their atoms bond are conducted as an electric current [6].

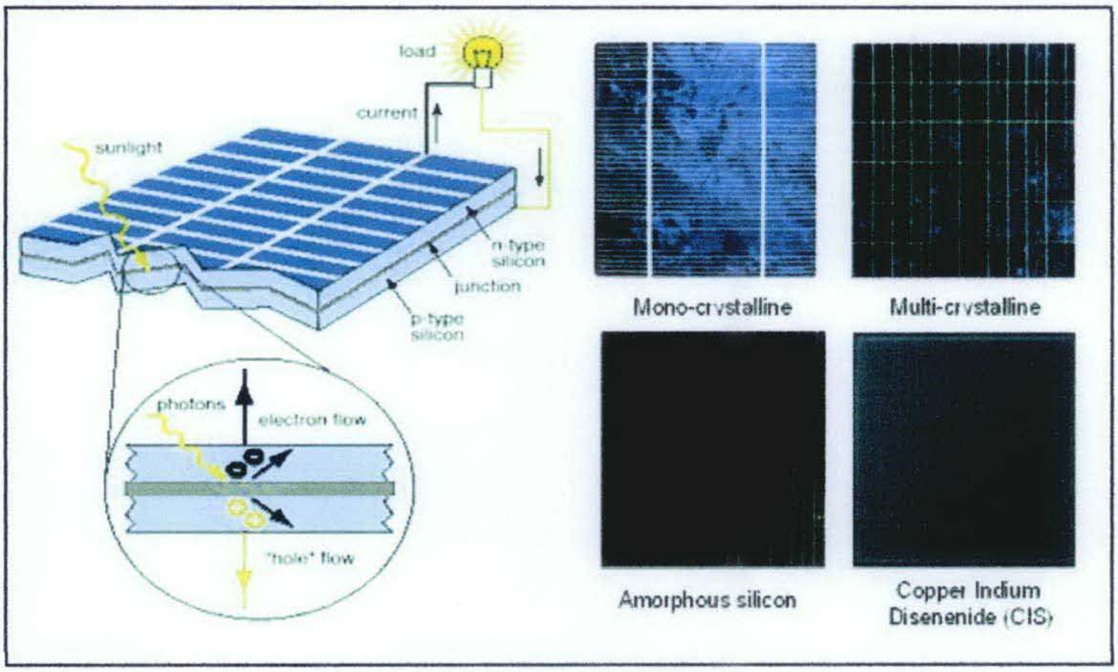


Figure 3: The photovoltaic effects (left) and solar cells type (right) [2]

There are three types of solar cells commercially are used nowadays which are: Monocrystalline, Polycrystalline and Amorphous cells or well-known as thin film solar cells. These cells are made of silicon rods through the development of single or multiple-crystallized silicon; and then pressed into flakes. After that, they are treated chemically and physically through different stages to reach the final product of solar cells [6].

The efficiency of these cells is relatively high, ranged between 9-24% in normal cases. Monocrystalline cells are considered the most expensive while Polycrystalline cells are less expensive and less efficient as well [2].

Amorphous cells consist of materials in a siliceous form and have a cracked crystal structure because of the injection of hydrogen or other elements calculatedly within its material structure to give the cell the electric characteristic and reduce the quantity of material required in cell manufacturing. Therefore, Amorphous cells are the lowest in cost as same as the efficiency where it is between 4-11%. But amorphous cells is more suitable for the automated manufacturing and thus for wide sola cell's commerce, which opens the door for a low cost solar cells industry [6].

### 2.3.3 Wind Energy

Wind energy is generated as a result of the earth, seas and oceans surfaces absorption of solar radiation with different rates. When the sun shines; this influences the atmosphere and heat up its air. This causes the density of the air to drop down which allows the air to move from the high pressure area where the solar radiation is minimum to the low pressure area where the solar radiation is maximum. Therefore, wind is produced.

Wind energy has been used for thousands of years in applications such as sailing ships, grinding grain, water pumping and irrigation, besides some other mechanical applications [5].

Wind power is the conversion of wind energy into a useful form of energy, such as using wind turbines to make electricity. Nowadays, wind powered turbines are the most popular source of generating electricity from renewable energy. Offshore wind farms are considered the latest technology of wind energy [5]. Small wind generators units are used to power houses and small villages in remote area. Wind power is non-dispatchable, which means all of the available output must be taken when it is available meaning that for economical operation [1].

### 2.3.4 Fundamentals in Evaluating Wind Resources

Evaluation of wind resources is significant for analyzing the turbine performance at a selected site. Basically, the wind resource itself is unstable resource. It varies with the season, time of day, height above the ground. The wind turbine performance increases if it is installed in windy areas, far from obstructions. In general, annual average wind speeds of 11 miles per hour (5 meter per second) are necessary for grid-connected applications. Annual average wind speeds of 7 to 9 mph (3-4 m/s) may be enough for stand-alone applications [2].

### 2.3.5 Wind Turbines Types

Basically, there are two main types of wind turbines that were developed for electricity generation. These types are: the horizontal axis wind turbine (HAWT) and the vertical axis wind turbine (VAWT). Commercially, HAWT turbines are commonly used more that the VAWT. Basically, the HAWT turbines have a rotating axis in parallel to the ground, while the VAWT turbines have a rotating axis vertical in respect to the ground. Figure (4) shows clearly the differences between HAWTs and VAWTs.

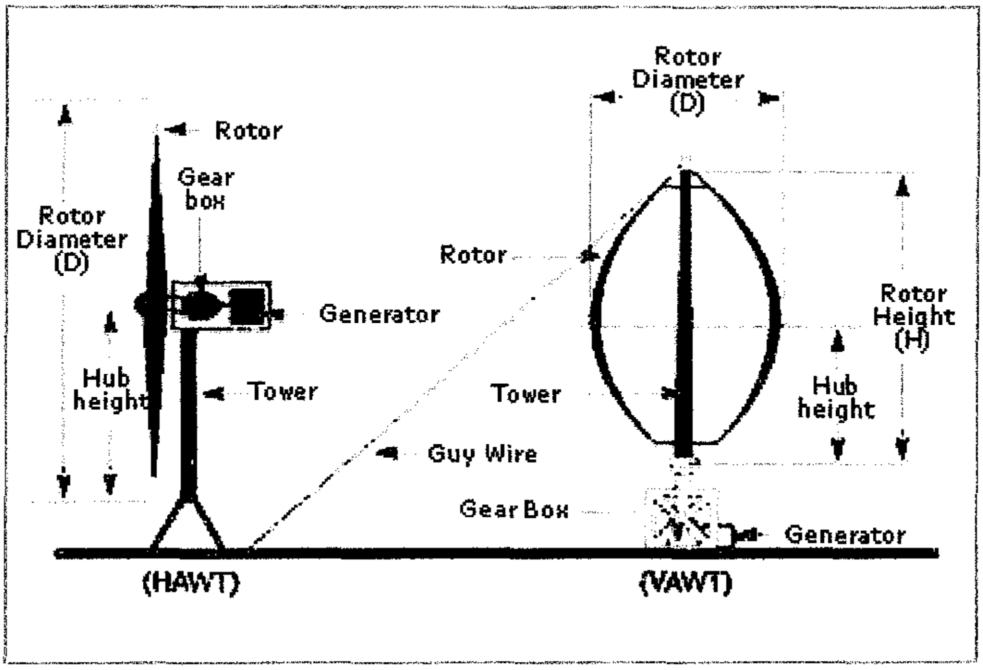


Figure 4: Wind turbines types [3]

### 2.3.6 Electricity Generation from Wind Energy

Wind turbines convert the kinetic energy of wind to electricity. Most of the commercial wind turbines are horizontal-axis machines, which have a horizontal shaft installed on it three blades, similar to figure 4. At the start up of the system, the induction generator, which is the most common used in wind generators, is supplied with electric currents drawn from the gird or external generators. This means at the beginning the wind turbine acts as motor until its blades' rotation reaches a certain speed; and that allows the main rotor to rotates as well. This main rotor consists of two parts: low speed shaft and high speed shaft. Between them there is a gearbox that converts the low speeds of the first shaft to much higher speed at the second part of the main rotor. This allows the connected induction generator with the high speed shaft to rotate at the generation speed. And to ensure the optimal operation of these turbines, a yawing system is used. Therefore, when the rotation speed of the blades goes higher than the optimum, there are brakes to stop the blades from rotating which prevent damages to the wind turbine [5].

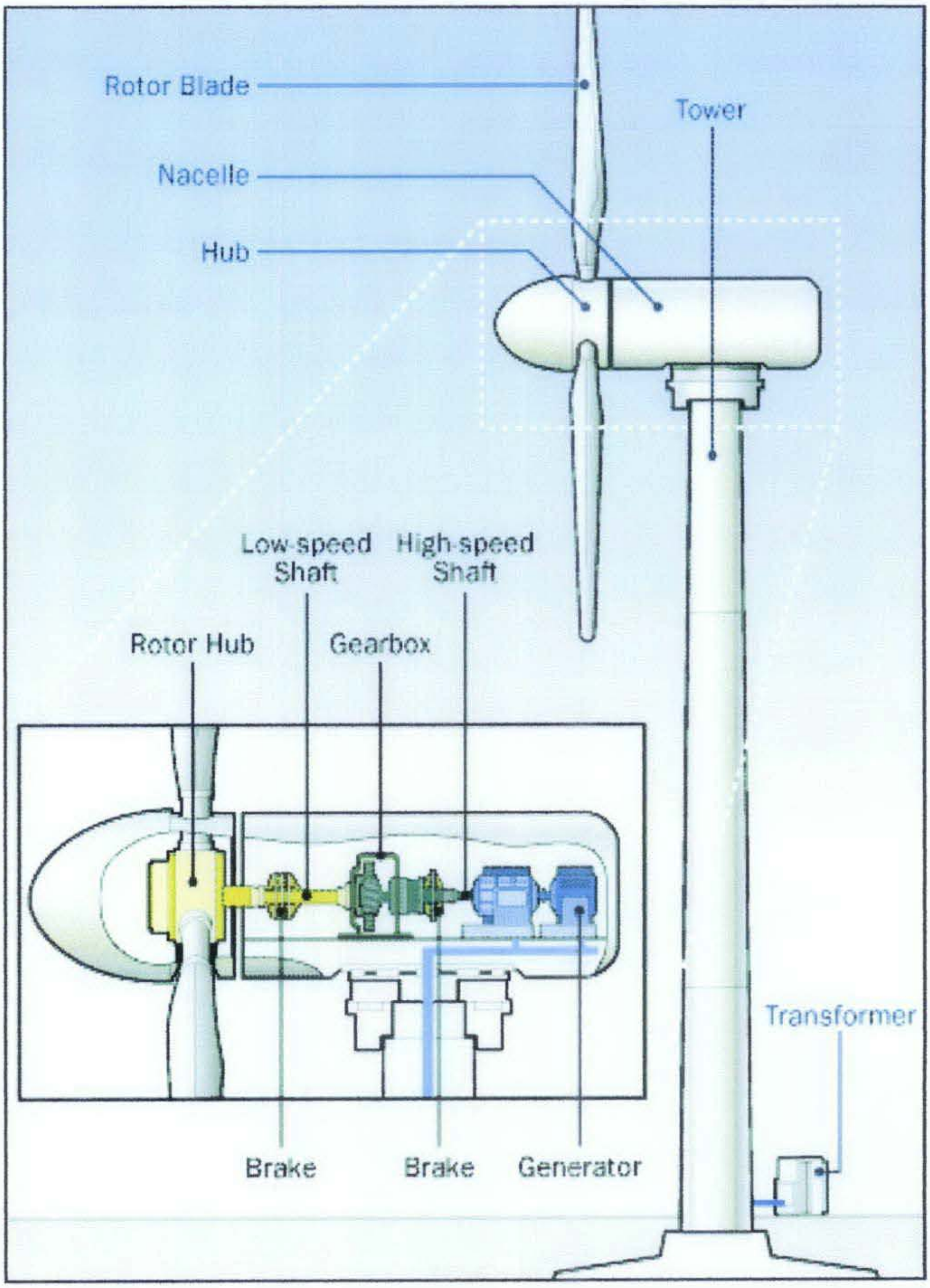


Figure 5: 1.5 MW horizontal-axis wind generator [4]

## 2.4 Sudan Energy Resources Profile

Sudan is considered one of the richest and most diverse African countries in term of energy resources. In Sudan, most of the well-known energy resources are available; starting from the fact that the world's longest rivers the River Nile is going through Sudan. And the production of oil in Sudan is considered the forth in Africa. Sudan is also located in a regional belts that considered is the world most favorable in term of solar energy and solar radiation [7].

### 2.4.1 Oil an in Sudan

Oil exploration in Sudan has taken place in two major areas; Red Sea coast and the offshore area, and the southern region since 1957. Early in 2008, twenty (20) blocks were already awarded to national and international companies and exploration activities. Significant amount of hydrocarbon reserves have been discovered in both offshore and onshore blocks. Oil production was around 500000 BOPD. It is expected to reach 600000 BOPD by 2010 [8]. The oil fields discovered so far are summarized in table (1).

Table 1: Oil fields' capacity in Sudan

| **Block** | **Oil Originally in Place (Barrel)** | **Estimated Ultimate Recovery (Barrel)** | **Remaining Ultimate Recovery (Barrel)** | **Total Production (Barrel)** |
|---|---|---|---|---|
| **Block (1,2 and 4)** | 5127.8 | 1491.0 | 729.7 | 761.3 |
| **Block (3 and 7)** | 5187.8 | 1092.5 | 1000.6 | 91.9 |
| **Block (6)** | 1290.5 | 283.91 | 252.7 | 31.2 |
| **Block (5 A)** | 1973.6 | 222.0 | 209.2 | 12.8 |
| **Total** | 13579.7 | 3089.6 | 2192.3 | 897.2 |

### 2.4.2 Hydroelectric Potential in Sudan

Sudan has considerable potential of hydroelectric power. This mainly comes from the River Nile and its tributaries in addition to a small scale (or mini hydro) potential. The available hydroelectric potential is approximately 3600 MW with a production capacity to 22600 GWh per year [8]. The main sources are Blue Nile, White Nile, Bahr El Gebel and Atbra Rivers.

Table 2: Hydroelectric capacity of Sudan Rivers

| **Site** | **Potential Capacity MWh** | **Average Annual GWh** |
|---|---|---|
| River Nile | 2775 | 12510 |
| White Nile | 35 | 150 |
| Blue Nile | 425 | 1740 |
| Atbra River | 42.5 | 140 |
| Other tributaries | 1550 | 9470 |
| **Total** | 4860 | 24132 |

### 2.4.3 Natural Gas Resources

Early exploration in the Red Sea Area started between 1959 and 1964. Six wells were drilled as exploratory wells, of which two had encouraging gas shows. Further in 1974-1976 geological and geophysical surveys were condensed gas mixture (wet gas) and another one produced dry gas. This revealed the presence of two promising structures (Suakin and Bashayer).The latest estimates of the gas reserves in the Sudan in Block (15, 6 and 8) are 418,154.2 and 8 in billion cubic feet respectively [8].

### 2.4.4 Coal and Peat Resources

Various investigators have reported indigenous sources of coal and peat to occur in great quantities. However, no feasibility studies have been conducted to identify the amount of these resources.

Most of the investigators reported that there is some of coal in the area near Dongola along the Nile. Coal beds occur in the Nubian sandstone formation. Shallow beds of varying qualities and thickness have been reported. Also, coal borehole was reported in the Gadaref region. In an arid northen area of Sudan, graphite beds are present in bands up to 4 Km wide and 100 Km long. Graphite is normally used as an industrial mineral.

A vast flooded area in southern region occupies an estimated area of 240 thousand square kilometer. This flooded area is covered by massive vegetation and is covered by the organic soil known as peat. The thickness of peat deposits exceeds 1.25 meter [8].

### 2.4.5 Solar Energy

Potential solar radiation on horizontal surface ranges from 6.9 GJ/$m^2$ in the South of Sudan to 10.1 GJ/$m^2$ in the north. It is considered relatively high potential, besides; the sky clearness index is quite high in the northern part and low in the tropical southern part [8].

### 2.4.6 Wind Energy

The Ministry of Energy and Mining represented by its National Energy Administration (NEA) analyzed available wind data for a design of a wind energy conversion system. In the north around Dongola wind density is in excess of 400 W/m2 while in Khartoum area it ranges from 285 to 380 W/$m^2$ [8].

## 2.5 Power Sector in Sudan

The electricity system in Sudan is comprised of the main National grid, a number of isolated off-grid systems and some existing private generation companies. The National Electricity Corporation (NEC) of Sudan is a governmental utility and is the sole entity in Sudan responsible of Generation, Transmission and Distribution of electricity.

### 2.5.1 Existing Power Generation Plants

In the year 2006 the total capacity available for dispatch on the National Grid was about 838 MW, of which some 59% is conventional thermal plant and the remaining 41% is hydroelectric plant [8].

### 2.5.2 Isolated Off-grid Systems

There are 15 isolated power systems supplying power for different locations. There locations are not connected to National grid. These systems comprise diesel generators and small distribution networks predominantly supplying urban consumers. In the year 2006, the total installed capacity of these systems is 154.48 MW [9].

In 2006 as only 17% of Sudan population were connected to electricity supply. The Government of Sudan is committed to Support electrification program to provide electricity up to 83% of the population by 2030 [8].

Table 3: Electrification rate and installed capacity on 2006-2009

| **Electrification rate (%)** | | **Peak Demand (MW)** | | **Installed Capacities (MW)** | |
|---|---|---|---|---|---|
| ***2006*** | ***2009*** | ***Oct-2006*** | ***May-2009*** | ***2006*** | ***2009*** |
| 17 % | 20.5 % | 800 % | 1013 % | 1500 % | 2387 % |

Table 4: Main sectors' current tariff in Sudan

| | **Domestic** | | | **Industry** | | **Agriculture** | **Unified** | **Government** | **Average Total** |
|---|---|---|---|---|---|---|---|---|---|
| | I | II | III | I | II | | | | |
| **SDG/ kWh** | 0.20 | 0.26 | 0.00 | 0.00 | 0.24 | 0.22 | 0.34 | 0.33 | 0.2395 |
| **$c/kWh** | 9.0 | 11.7 | 0.0 | 0.0 | 10.8 | 9.9 | 15.3 | 14.9 | 10.7883 |

## 2.6 Hybrid Renewable Energy System

Hybrid renewable energy systems (HRES) currently are an appropriate and common for electricity generation applications for distant area. This is because of the renewable energy technologies advancement and due to dramatic fluctuation in petroleum products' prices [4]. A typical hybrid energy system comprises of two renewable energy sources or more used together to provide better system efficiency as well as greater stability in energy supply. In this project, the system will consist of solar photovoltaic (PV) panels, wind turbines, inverters, back-up batteries and busbars. The proposed system schematic is similar to the diagram in figure 5.

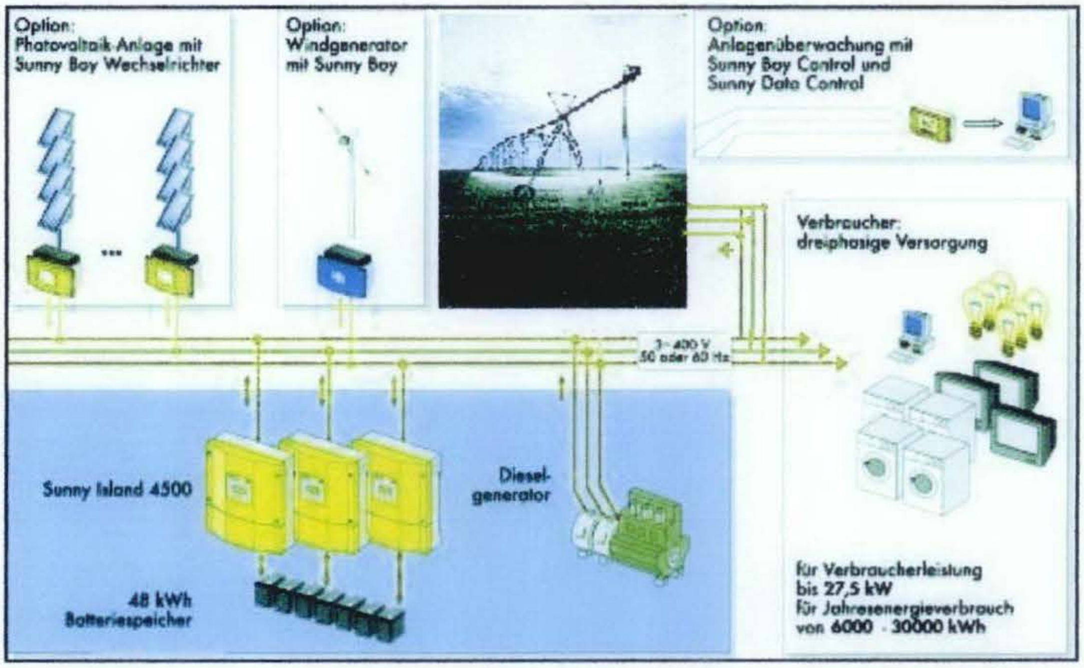


Figure 6: an example of a hybrid renewable energy system for electrification [5]

# CHAPTER 3
# METHODOLOGY

## 3.1 Procedure Identification

This project was started by intensive background studies to identify its objectives and scope clearly as mentioned in the first chapter. The background studies were analyzed very clearly in conducting the literature review. Further researches were attained to gather solar radiation and wind velocity data of the selected site. The literature review studies were focusing mainly on solar geometry and wind energy as key parameters, evaluating the types of solar and wind systems and also brief studies were conducted in irrigation and pumping methods.

The solar radiation and wind velocity data were obtained for the selected site and the load calculations were pre-estimated based on the average power demand in rural areas. The selected side was proposed to be a 240 acre land located within Gazira Scheme. Three-quarters of the land will be used for farming and the remaining area as residence. This categorizes the load into two different loads, one for agricultural purposes and the other one is domestic. All the inputs and specifications of the proposed hybrid renewable system were carefully defined. This system consists of photovoltaic panels; wind turbine, Diesel generator, battery and inverter are considered as part of back-up and storage system. The system life span is estimated to be at 25 years.

A primal design was set up and simulated using PSIM® software. This is to check how the hybrid technique is functions and to determine any difficulties might be faced. An actual model was configured and simulated using HOMER® software to optimize the system for a real application in the proposed location. At the final stage, a lab-scaled prototype was constructed to demonstrate the system how it would be in real application.

## 3.2 Project Flow Chart

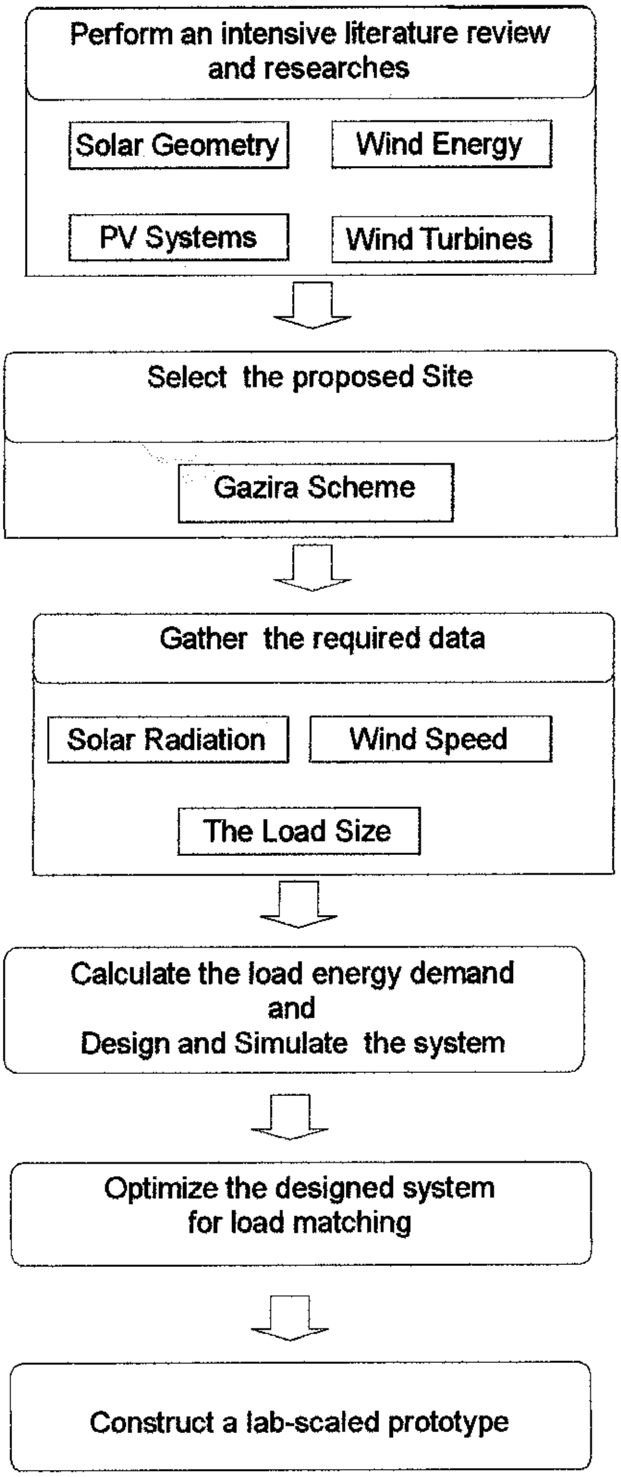


Figure 7: The Project's methodology chart

## 3.3 Tools Required

The main task of this project is to design a hybrid renewable energy system for electricity generation. The project work involves both simulation and experimental studies. Therefore, the needed tools to accomplish this work are list in the table below:

Table 5: Software and hardware used in the project

| Software | Hardware |
|---|---|
| 1. Visual Basic 6<br>2. PSIM<br>3. HOMER 2.62 | 1. Photovoltaic Panel<br>2. Wind Generator<br>3. Charge Controllers<br>4. Batteries<br>5. Power Inverter<br>6. Analog Voltage Summer |

### 3.4 PSIM® Hybrid System Simulation

In order to verify the system performance, a real application circuit was designed and simulated using PSIM®. This simulator is designed particularly for motor control and power electronics. In additional to that, it has renewable energy packet which is dedicated to solar and wind energy systems simulation.

The simulated system consists of: solar photovoltaic module, wind turbine module, permanent magnet synchronous generator, Maximum Power Point tracker (MPPT), AC to DC converter, DC center source, batteries and an electrical load.

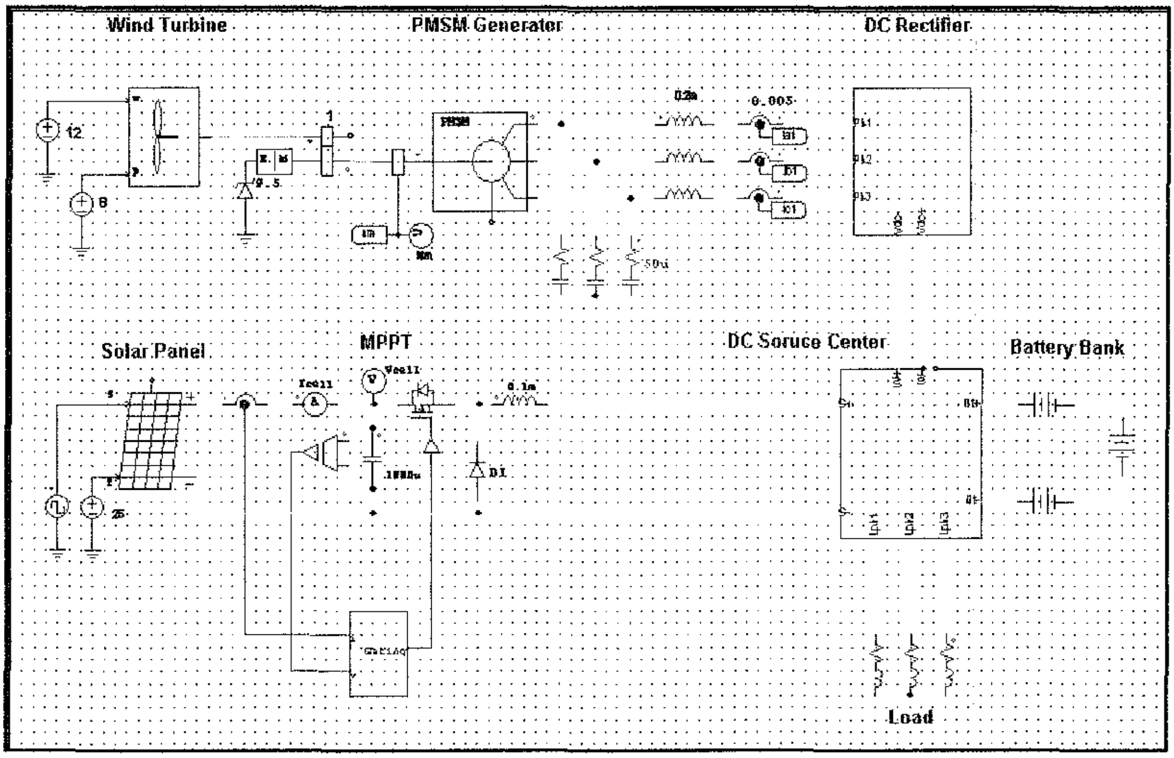
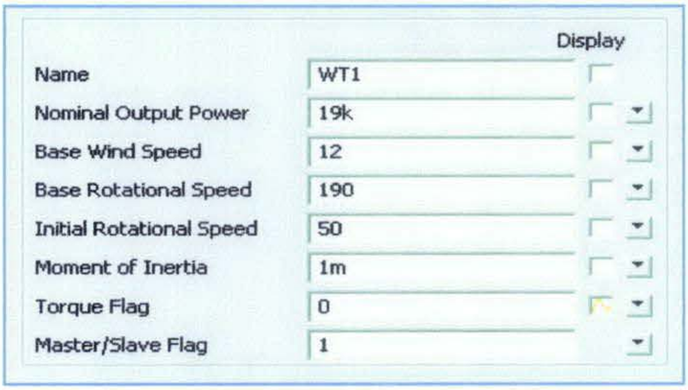


Figure 8: The simulated design using PSIM

### 3.4.1 The Wind Turbine Module

In term of designing the required wind turbine, some parameters need to be specified. The nominal output power of the turbine is the first parameter to be determined, which is the maximum power of the turbine in Watt at 0° pitch angle. The second parameter is the base wind speed that would produce the nominal output power, in m/s. While the base and initial rotational speed should be determined in rpm unit. Another parameter to be estimated is the moment of inertia of the turbine rotor.

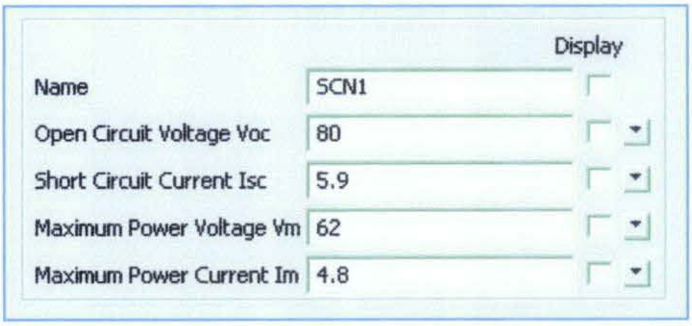


| | | Display |
|---|---|---|
| Name | WT1 | ☐ |
| Nominal Output Power | 19k | ☐ |
| Base Wind Speed | 12 | ☐ |
| Base Rotational Speed | 190 | ☐ |
| Initial Rotational Speed | 50 | ☐ |
| Moment of Inertia | 1m | ☐ |
| Torque Flag | 0 | ☐ |
| Master/Slave Flag | 1 | |

Figure 9: The wind turbine module design parameters

### 3.4.2 The Solar Panel Module

For the solar module, typical parameters were specified as well. These parameters are: the open circuit voltage (Voc), short circuit current (Isc), maximum power voltage (Vm) and maximum power current (Im).

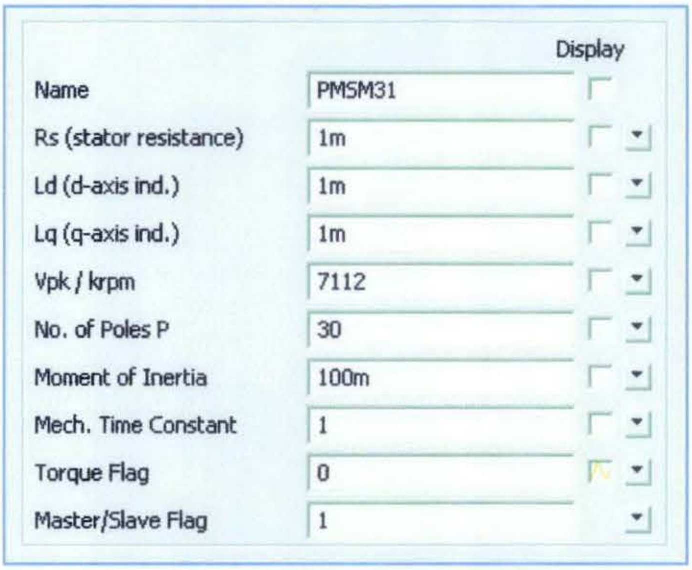


| | | Display |
|---|---|---|
| Name | SCN1 | ☐ |
| Open Circuit Voltage Voc | 80 | ☐ |
| Short Circuit Current Isc | 5.9 | ☐ |
| Maximum Power Voltage Vm | 62 | ☐ |
| Maximum Power Current Im | 4.8 | ☐ |

Figure 10: The solar panel designing parameters

### 3.4.3 Permanent Magnet Synchronous Generator

Permanent Magnet Synchronous Generator (PMSG) is a 3-phase generator with mounted permanent magnets on its rotor. This generator is connected directly with the wind turbine rotor through a gear box. These types of generators have an advantage of producing high power densities in small area which leads to a much more compact size of the wind turbine. The specified parameters are as shown in figure 11.



| | | Display |
|---|---|---|
| Name | PMSM31 | ☐ |
| Rs (stator resistance) | 1m | ☐ |
| Ld (d-axis ind.) | 1m | ☐ |
| Lq (q-axis ind.) | 1m | ☐ |
| Vpk / krpm | 7112 | ☐ |
| No. of Poles P | 30 | ☐ |
| Moment of Inertia | 100m | ☐ |
| Mech. Time Constant | 1 | ☐ |
| Torque Flag | 0 | ☑ |
| Master/Slave Flag | 1 | |

Figure 11: PMSG designing Parameters

### 3.4.4 DC Rectifier

Since the wind generator output power changes along with the wind speed variation, a proper control and regulation for the generator output is needed. A simple technique can be used, by converting the generated AC power into DC. Then, that DC power can be stored in batteries. The batteries then can supply the required AC power through Inverter. A 3-phase PWM MOSFET rectifier was applied in the simulation. Figure 12 shows the designed DC rectifier in the hybrid system.

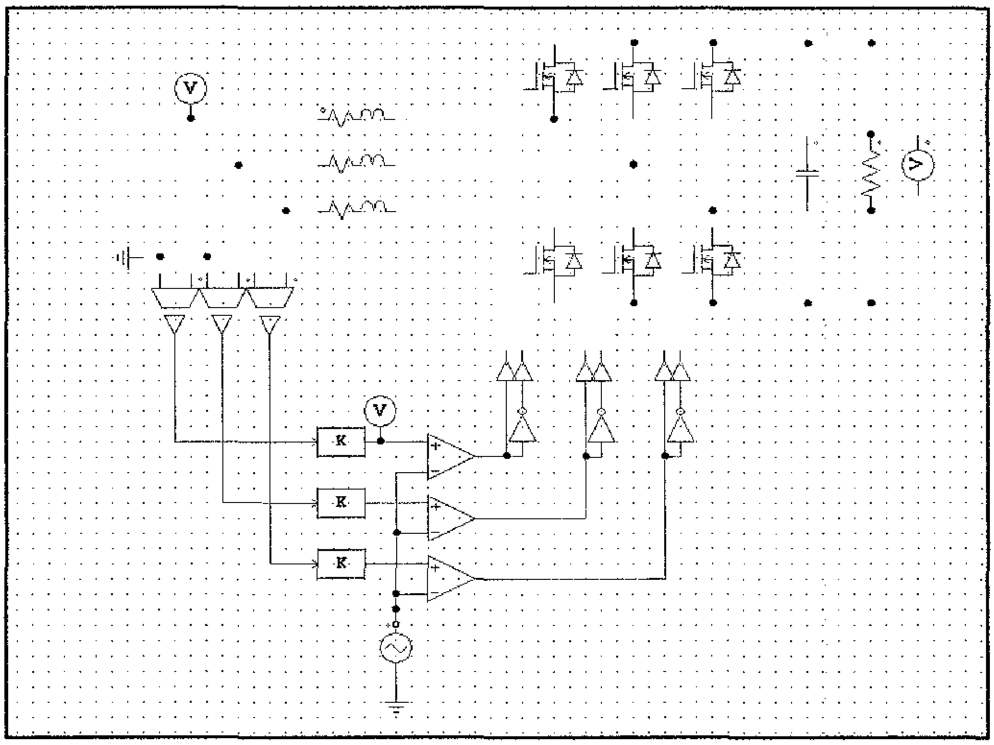


Figure 12: DC rectifier built-in circuit

### 3.4.5 Maximum Power Point Tracker:

Basically, the solar radiation varies along the day which makes the output power not steady and as a result, an oversize of the PV system is required. Therefore, the use of a maximum power point tracker (MPPT) can overcome this problem. The used algorithm in designing the MPPT is Perturb and Observe algorithm. It is a common and simple algorithm used in designing the MPPT. It observes the change in power (ΔP) if the operating voltage is perturbed by small amount, and then moves the operating point towards the maximum power point.

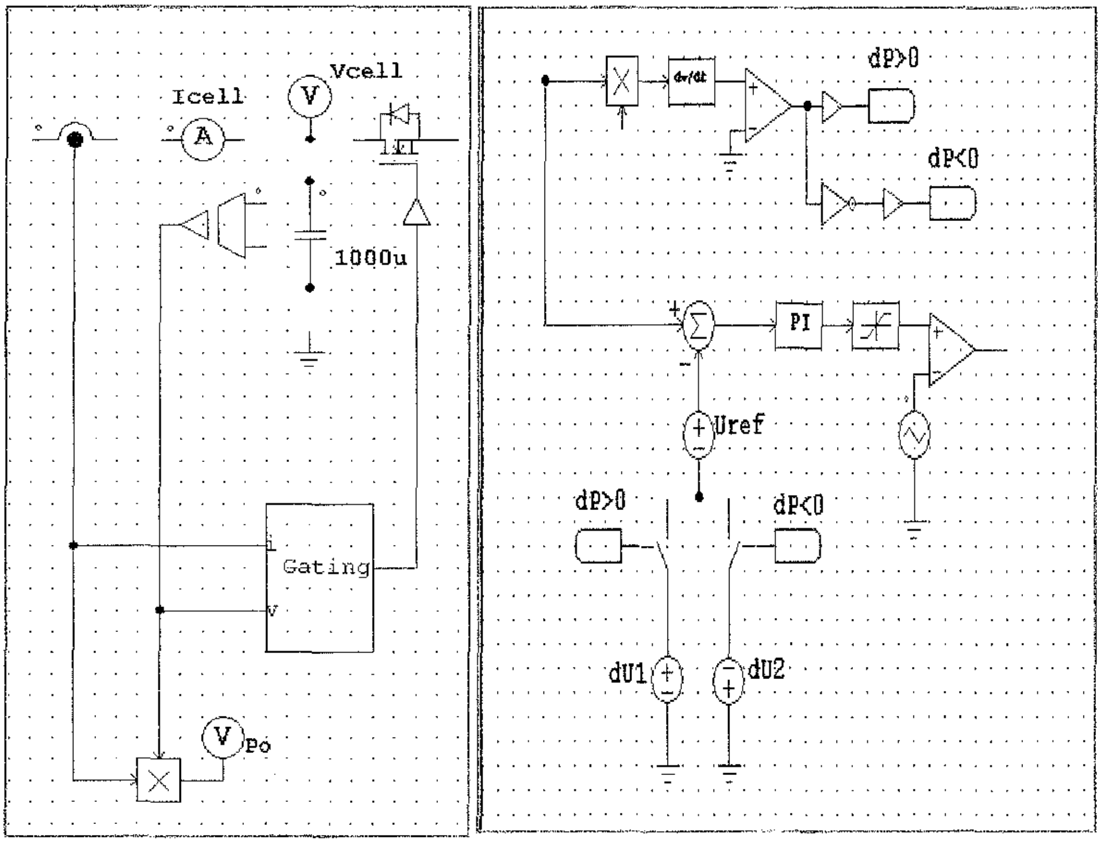


Figure 13 : MPPT tracker (left) and gating (right) Circuits

### 3.4.6 DC Source Center:

DC source is one of the main components of the system. Without this part, the hybridization technique cannot be performed. It can sum up the voltages of multiple DC sources and regulate them based on a battery charging set point and also the load nominal voltage. In addition, it can charge the battery bank simultaneously with supplying the load with AC power as it has internal inverter to convert the DC to AC. In case the sources cannot afford supplying the load, the DC source center allows the battery bank to interrupt and supply the load. The DC to AC converter uses pulse width modulation technique (PWM) signals to turn on its switches' gates.

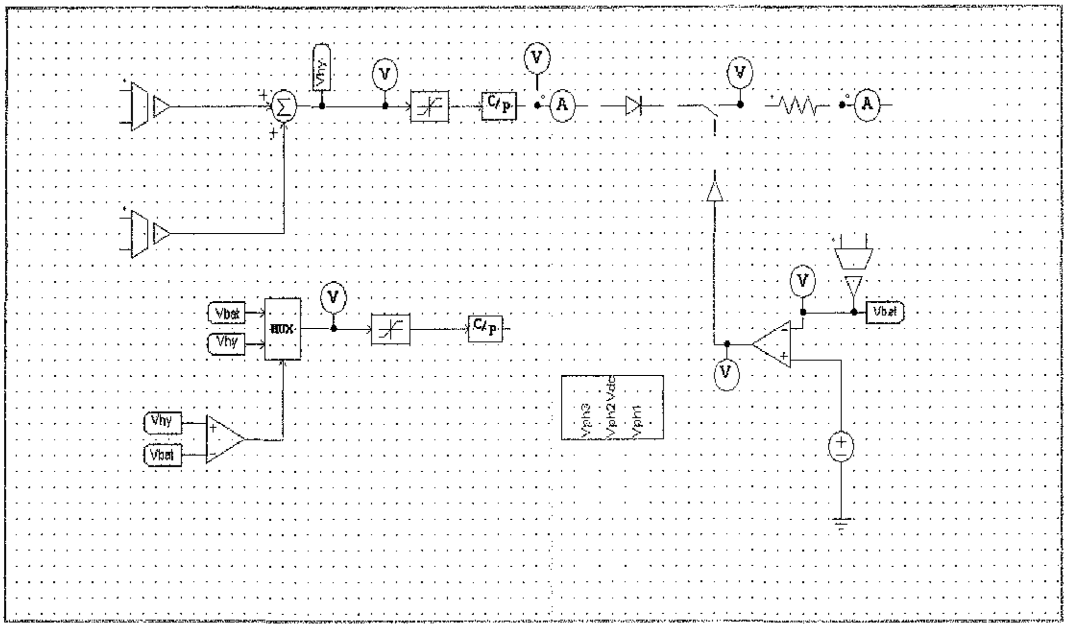


Figure 14: DC source center built-in circuit

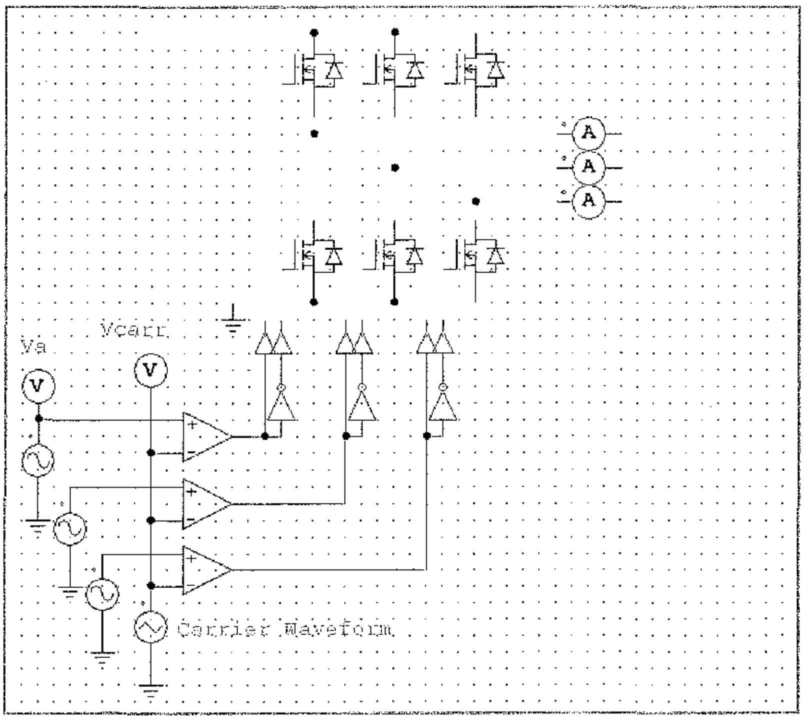


Figure 15: PWM DC to AC inverter

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 Renewable Energy Stand-alone System

In a country such as Sudan with a limited national electricity grid, an electrification rate of 42% currently, and whit a anticipated reduction in petroleum production, there is certainty of electricity shortage especially in rural area.

Using an alternative way of supplying electricity by utilizing renewable sources needs further calculations and detailed simulation for sizing the system. As many of the rural area in Sudan are isolated from the national grid, therefore, a stand-alone system is considered as a designing.

## 4.2 Electrical Energy Usage in Sudan Rural Area

In the rural area, the electricity demand comparing to urban areas is less. Thus sizing a system relying only on renewable energy is not that difficult. Mainly, a typical house in a rural area requires simple lighting system, cooling system, water pumping system, refrigerator and small entertainment appliances. The electrical appliances that are taken into account are AC load. The rate of power consumption of some devices is shown in table 6.

Table 6: Power consumption for some appliances

| **Type of Electrical Appliance** | **Rated power (Watt)** |
|---|---|
| Fluorescent Lamp | 18 |
| Television | 75 |
| Ceiling fan | 75 |
| Refrigerator | 320 (*Wh*) |

The proposed design is a stand-alone system and takes the solar energy as its main resource. Therefore, sizing the PV system is the most crucial part of the entire system as decent balancing between energy supply and load is required. Stand-alone system requires more analysis and calculations.

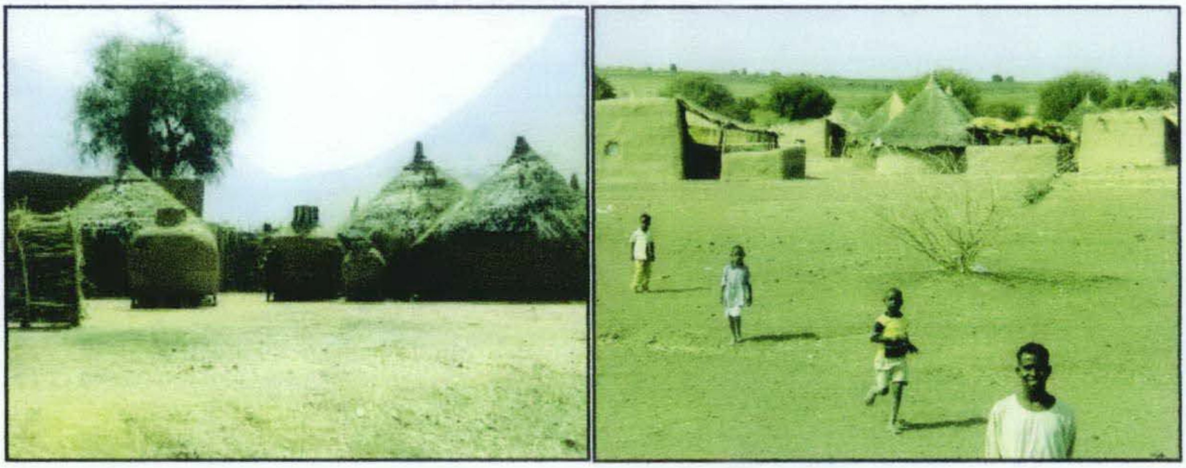


Figure 16: Typical houses in Sudan rural area (Taken for www.sudanforum.net)

## 4.3 Calculations

In the first part of this project, calculations have been performed to determine the estimated load, battery capacity and the maximum PV array size; as the most crucial part is determining the exact PV array size in a stand-alone system.

### 4.3.1 Load Calculation

By assuming each house in a rural area consists of 6 fluorescent lamps, 3ceiling fans, a television and refrigerator. And a single village has twelve houses. Therefore, the energy consumption by this village can be calculated as follows:

$$3\,Fans = 3 \times 75\,W/app. \times 12.0\,h/day = 2700\,Wh$$

$$1\,Televsion = 1\,TV \times 75\,W/\,app \times 6\,h/day = 450\,Wh$$

$$6\,flouresecent\,lamps = 6\,lamp \times 18\,W/\,lamp \times 5h/day = 540\,Wh$$

$$1\,Refrigerator = 320\,Wh$$

$$Total\,daily\,Energy\,Usage\,for\,a\,village = 4010\,Wh \times 12 = 48120\,Wh/day$$

$$Total\,daily\,Energy\,Usage = 540 + 450 + 2700 + 320 = 4010\,Wh/day$$

### 4.3.2 Battery Sizing

In order to size the system batteries, we have to bear in mind the number of days that the system can supply electricity depending only on batteries as if there is a cloudy or raining day or a system breakdown. The chosen battery for the system is described in table (7).

Table 7: Battery Specification

| | |
|---|---|
| **Type** | Vision 6FM200D |
| **Nominal Voltage** | 12 V |
| **Nominal Capacity** | 200 Ah |

Required battery capacity for the system;

$$= 48120\,Wh\,/\,12V\ = 4010\,Ah$$

Assuming that the autonomy of the battery is 4 days;

$$= 4010\,Ah\ \times 4\,days = 16040\,Ah$$

The Battery arrangement is;

$Series\ :\qquad 12\,V \div 12\,V = 1$

$Parallel:\qquad 16040\,Ah \div 200\,Ah = 81$

$Total\ :\qquad 81\,batteries$

### 4.3.3 Photovoltaic Array Sizing

The chosen PV module for the system is described in the table below:

Table 8: Solar Module Specification

| **Type** | **Si-Poly** |
|---|---|
| **Manufacturer** | Baoding Yingli |
| **Rated Voltage** | 15 V |
| **Rated Current** | 7.7 A |

Since the sunshine hours is the total number of hours required for a day's total solar irradiation to accumulate at peak sun condition [3]. 6 hours are considered as the sunshine hours for the selected area.

The amount of current required by the array to supply the system load is:

Total daily AH / number of sunshine hours

$= 16040\ Ah\ \div 6\ hours = 2674\ A$

Arrangement of the solar modules;

$Series\ :\qquad 12\ V \div 15\ V = 1$

$Parallel:\qquad 2674\ A\ \div 7.7\ Ah = 348$

$Total\ :\qquad 348\ modules$

### 4.4 PSIM® Simulation Results

At the beginning, each component of the designed system was separately tuned and simulated. The first component to be simulated is the wind turbine, with an arbitrary inductive load of L= 0.1 H and R= 1KOhm. The results were obtained for three different nominal wind speeds: 12 m/s, 4 m/s and 2 m/s and it was observed that the 3 phase output voltage and current varies by the change in wind speed, as shown in table (8) . Besides, the frequency of the outputs changes at very low wind speeds.

Table 8: The obtained output results at different wind speeds

| Wind Speed (m/s) | Maximum Output voltage (V) | Maximum Output Current (A) |
|---|---|---|
| 12 | 372.81 | 0.372 |
| 4 | 307.44 | 0.307 |
| 2 | 170.76 | 0.171 |

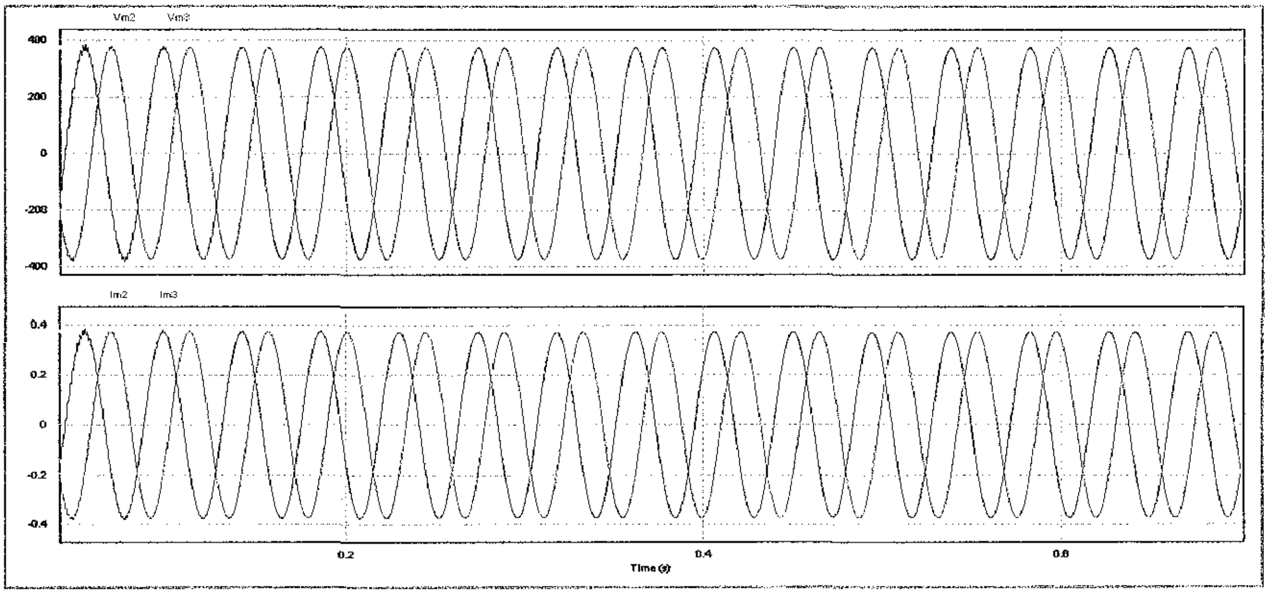


Figure 17: The wind generator output at wind speed of 12 m/s

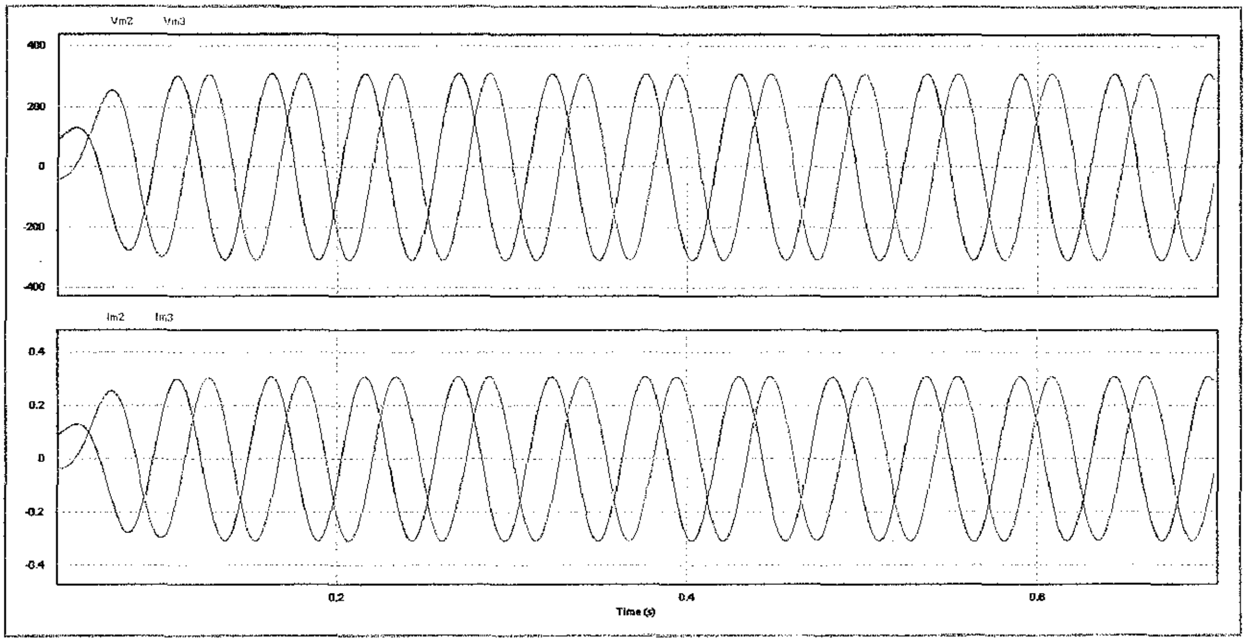


Figure 18: The wind generator output at wind speed of 4 m/s

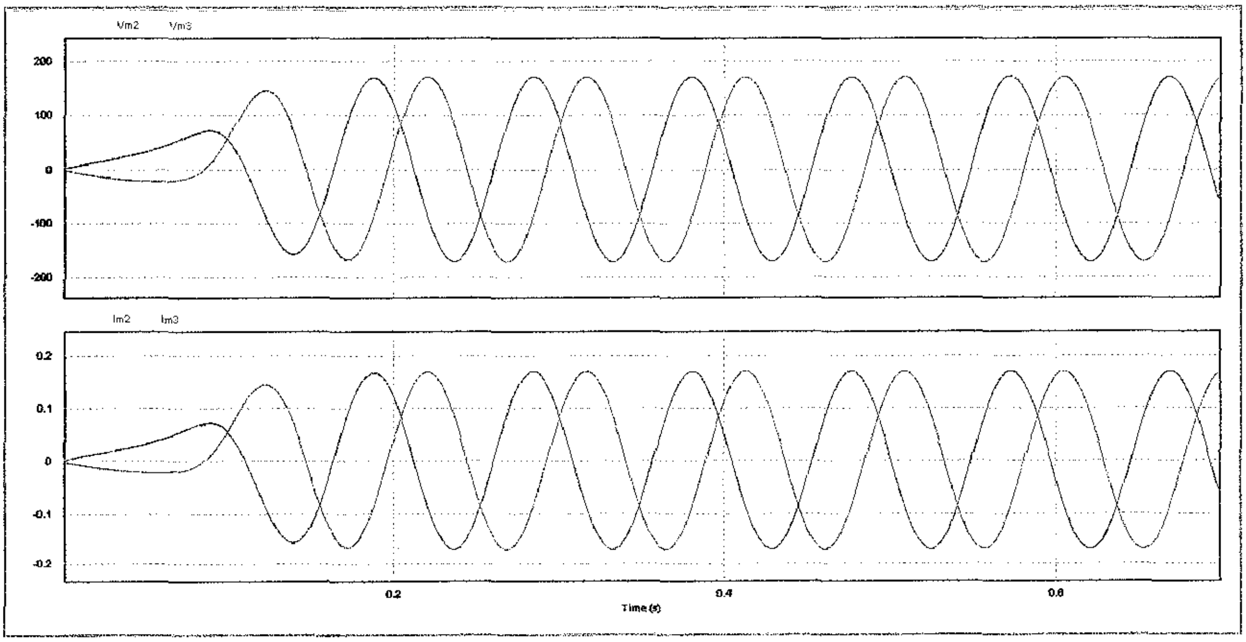


Figure 19: The wind generator output at wind speed of 2 m/s

For the solar system, which consists of 62 Watt photovoltaic panel and MPPT, the results were obtained as shown in figure (20). The solar source was simulated as square wave voltage source and its values was fluctuated between 1000 V and 800 V to observe the performance of the MPPT.

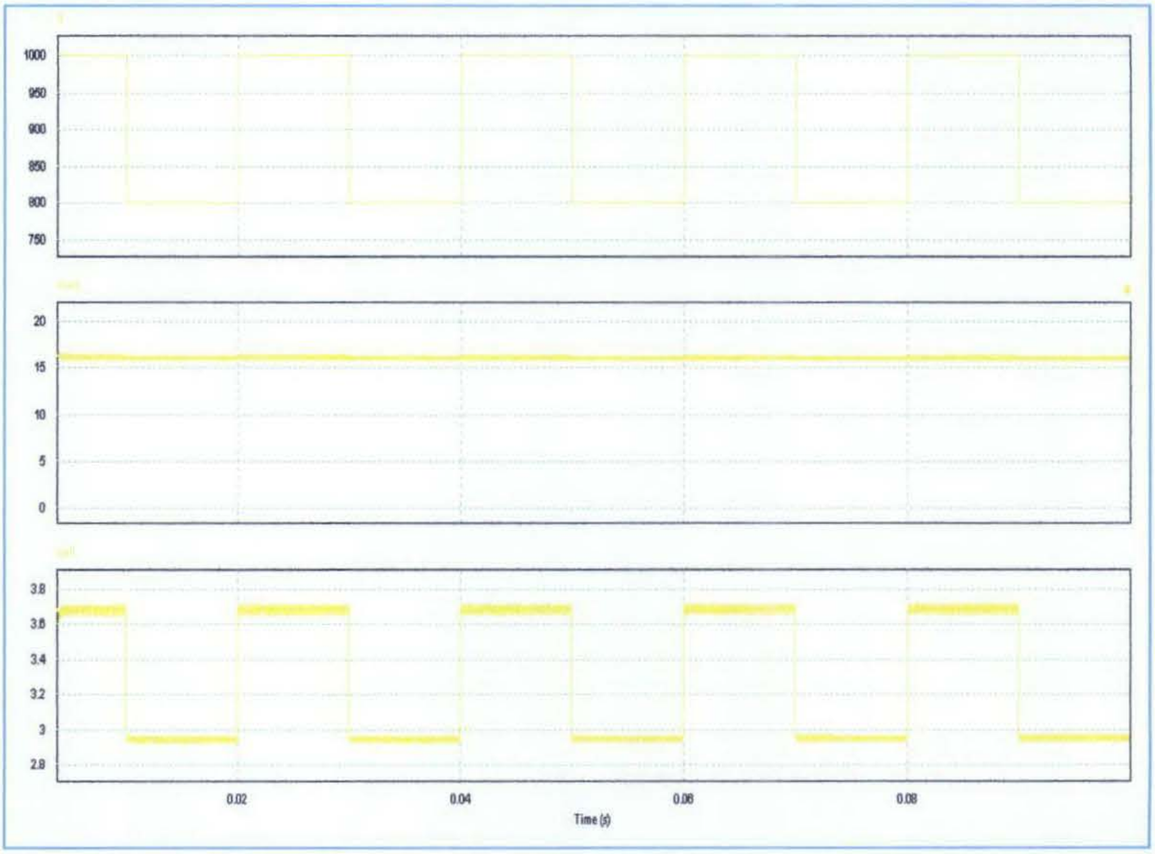


Figure 20: The fluctuated solar source vs. the PV voltage and current

Perturb and observe algorithm tracks the nominal voltage very well, although there is a change in the input value. But, this change affected the current amplitude and also the output power.

The rectifier circuit was tested based on the output voltage values of the wind turbine. And figure (21) shows the DC output voltage of the circuit.

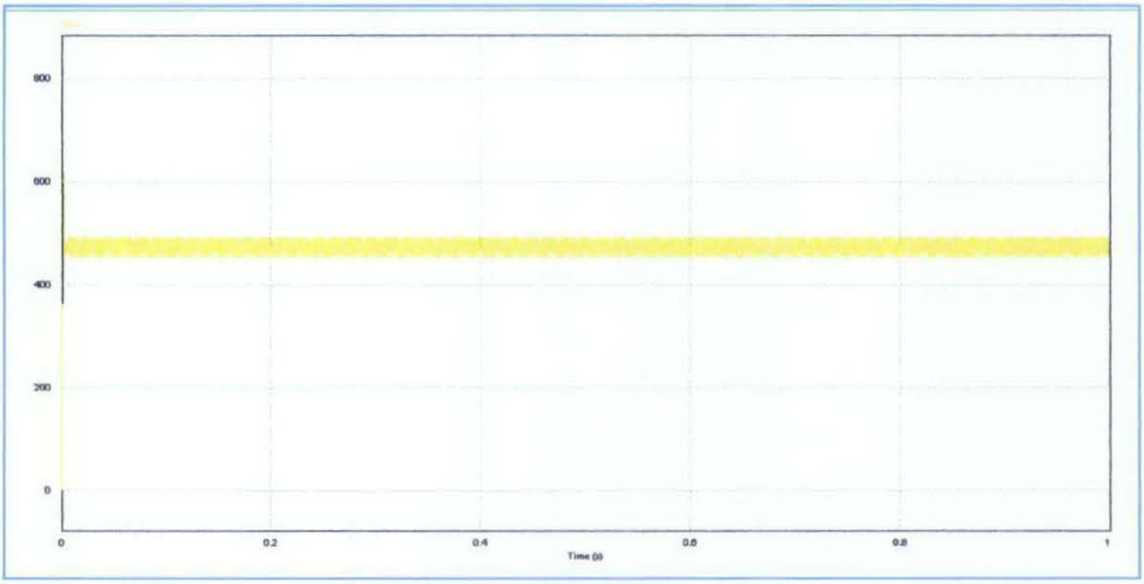


Figure 21: The DC rectifier output voltage

After that, the entire system was simulated and the results were obtained as expected. The wind a solar sources inputs were varied along the simulation period.

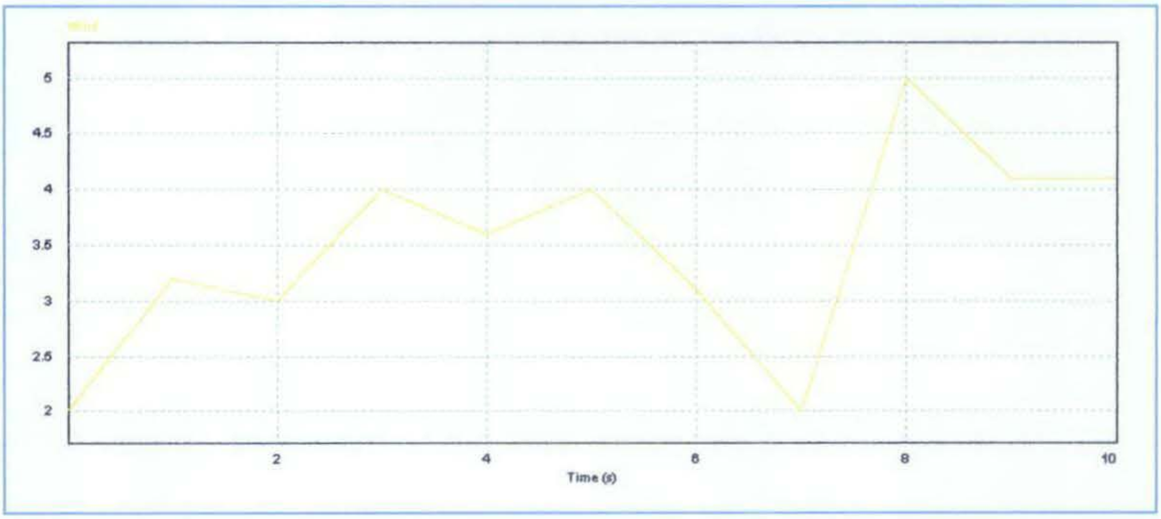


Figure 22: Wind speed source variation

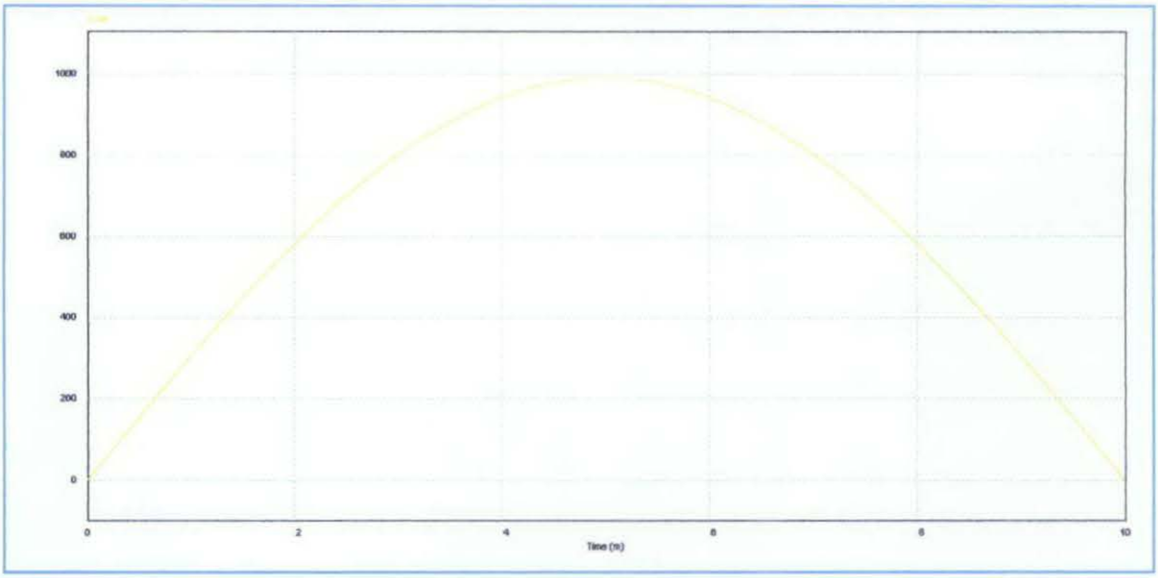


Figure 23: Solar radiation source variation

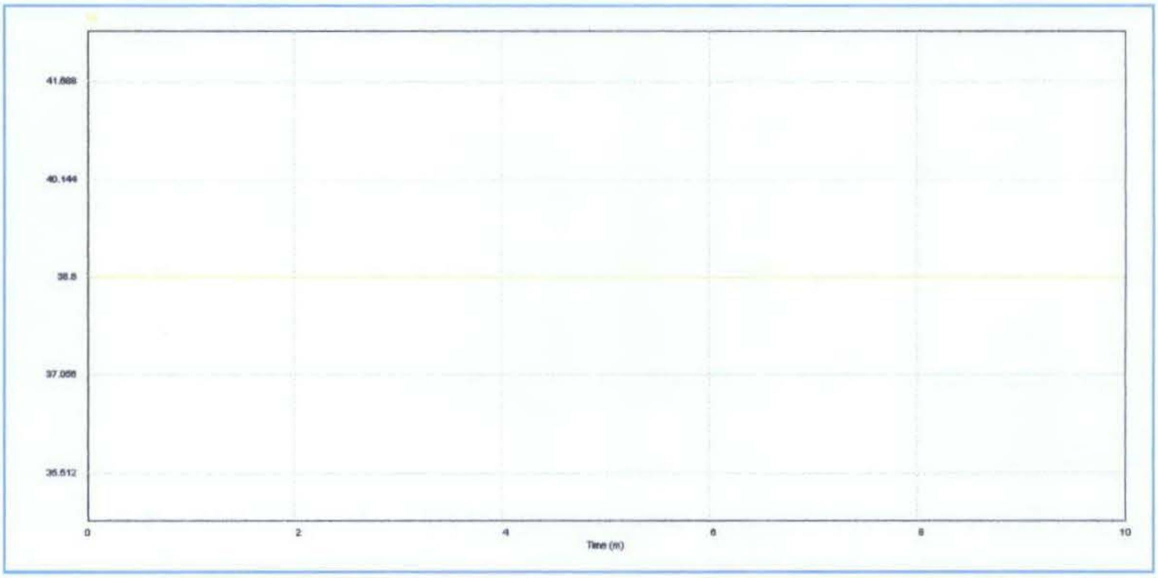


Figure 24: Battery charging output voltage

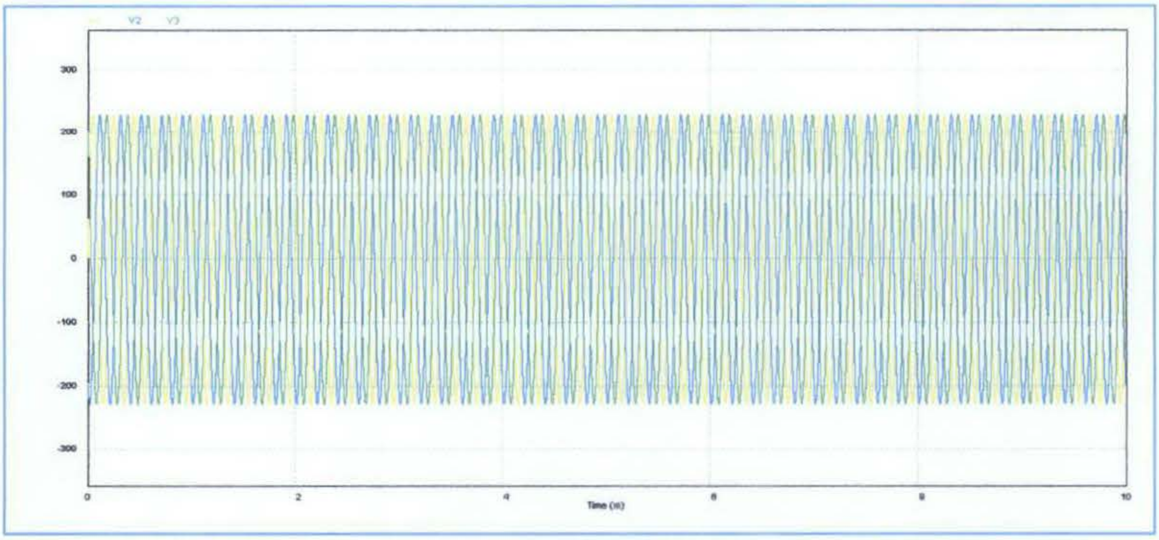


Figure 25: 3-phase AC output voltage supplying the load

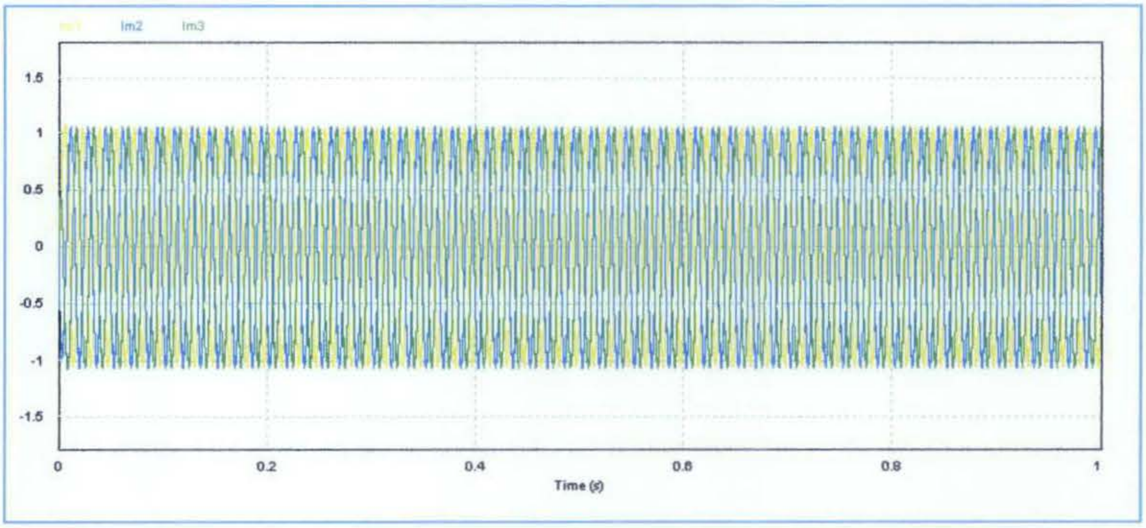


Figure 26: 3-phase AC output current supplying the load

Although there is variation in the input sources, the output voltage and current is still steady. This is due to the fact that in hybrid system each input source can compensate for each other to supply the load. In case of the system failure or there is no enough power supplied by the PVs or wind turbines, the DC center source immediately withdraws the energy from battery storages and then invert it to AC power to supply the load.

## 4.5 Hybrid Renewable Energy System Simulation: HOMER

At this stage, a system optimization was performed using HOMER software. HOMER is the micro-power optimization simulator, evaluates designs of both stand-alone and grid-connected electricity generation systems for different applications, especially for renewable energy systems.

### 4.5.1 Choosing the system components

The equipments to be used in the hybrid system are selected. The system was assumed to supply electricity to AC load, for a selected village in Sudan's Gazira scheme. And the main equipments are as listed below:

a) PV array

b) Electrical Load

c) Wind Generator

d) Battery Banks

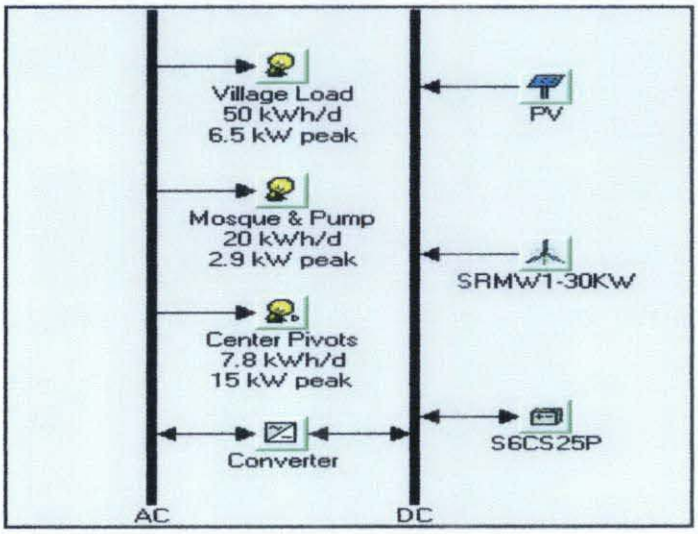
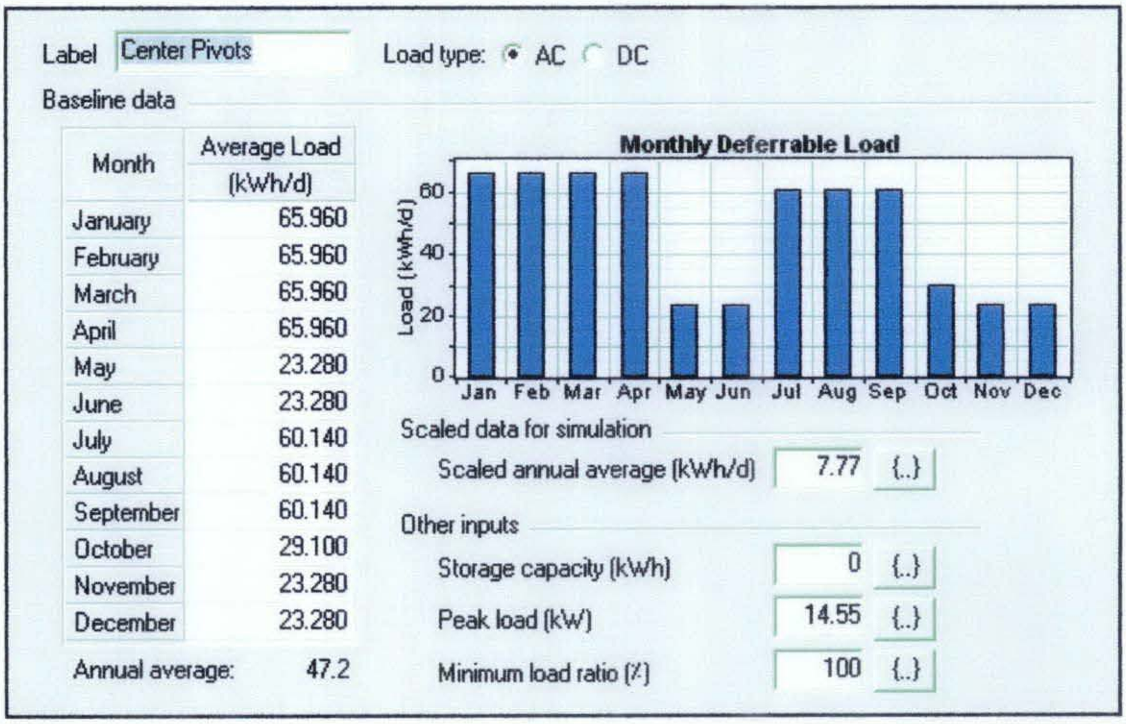


Figure 27: The hybrid system's equipments

### 4.5.2 Load Details

The load was divided into three parts: the village, the agriculture load and an auxiliary load. The village load was distributed based on the daily energy consumption of the village. The agriculture load is an irrigation system, consists of three center pivots and pumps. While, the auxiliary load is composed of a mosque and water pump for the village. The load profile of the village was entered to the simulator as shown in figure (28).



Label Center Pivots

Load type: ● AC ○ DC

Baseline data

| Month | Average Load (kWh/d) |
|---|---|
| January | 65.960 |
| February | 65.960 |
| March | 65.960 |
| April | 65.960 |
| May | 23.280 |
| June | 23.280 |
| July | 60.140 |
| August | 60.140 |
| September | 60.140 |
| October | 29.100 |
| November | 23.280 |
| December | 23.280 |
| Annual average: | 47.2 |

Scaled data for simulation

Scaled annual average (kWh/d) 7.77 {..}

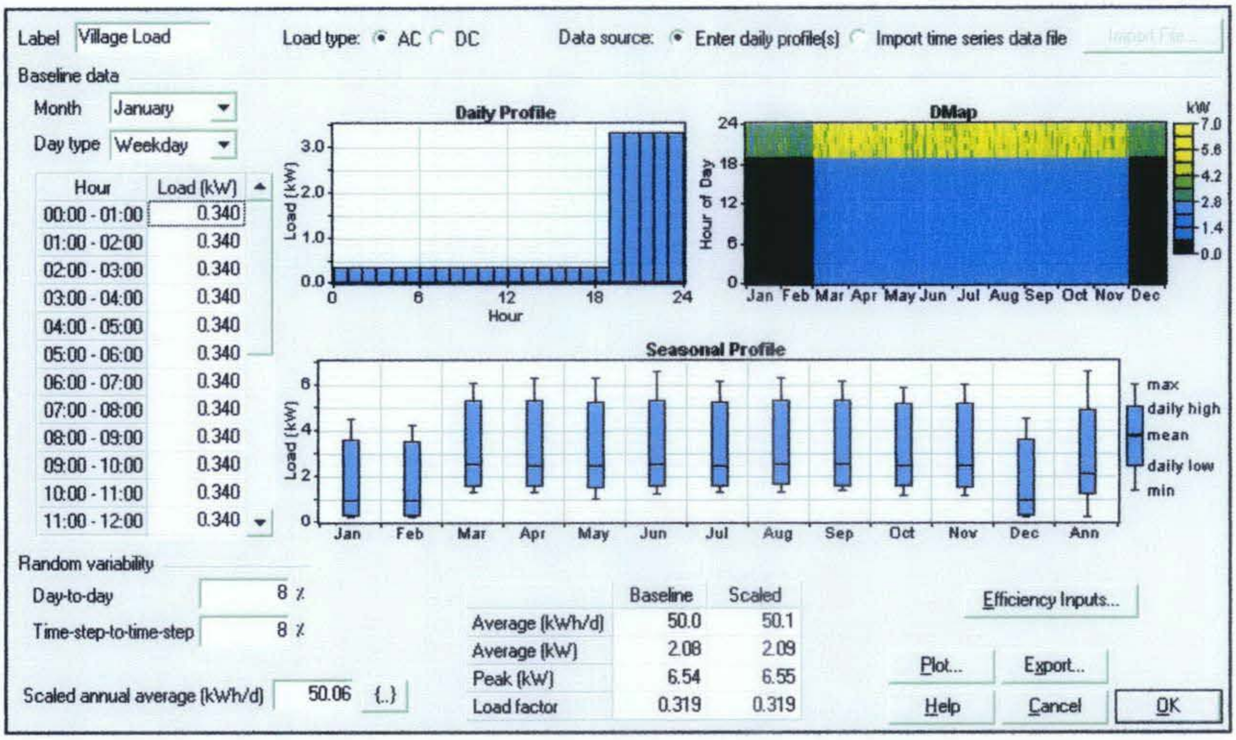
Other inputs

Storage capacity (kWh) 0 {..}

Peak load (kW) 14.55 {..}

Minimum load ratio (%) 100 {..}

Figure 28: Agricultural Energy Consumption Profile



Label: Village Load

Load type: ● AC ○ DC

Data source: ● Enter daily profile(s) ○ Import time series data file

Baseline data

Month: January

Day type: Weekday

| Hour | Load (kW) |
|---|---|
| 00:00 - 01:00 | 0.340 |
| 01:00 - 02:00 | 0.340 |
| 02:00 - 03:00 | 0.340 |
| 03:00 - 04:00 | 0.340 |
| 04:00 - 05:00 | 0.340 |
| 05:00 - 06:00 | 0.340 |
| 06:00 - 07:00 | 0.340 |
| 07:00 - 08:00 | 0.340 |
| 08:00 - 09:00 | 0.340 |
| 09:00 - 10:00 | 0.340 |
| 10:00 - 11:00 | 0.340 |
| 11:00 - 12:00 | 0.340 |

Random variability

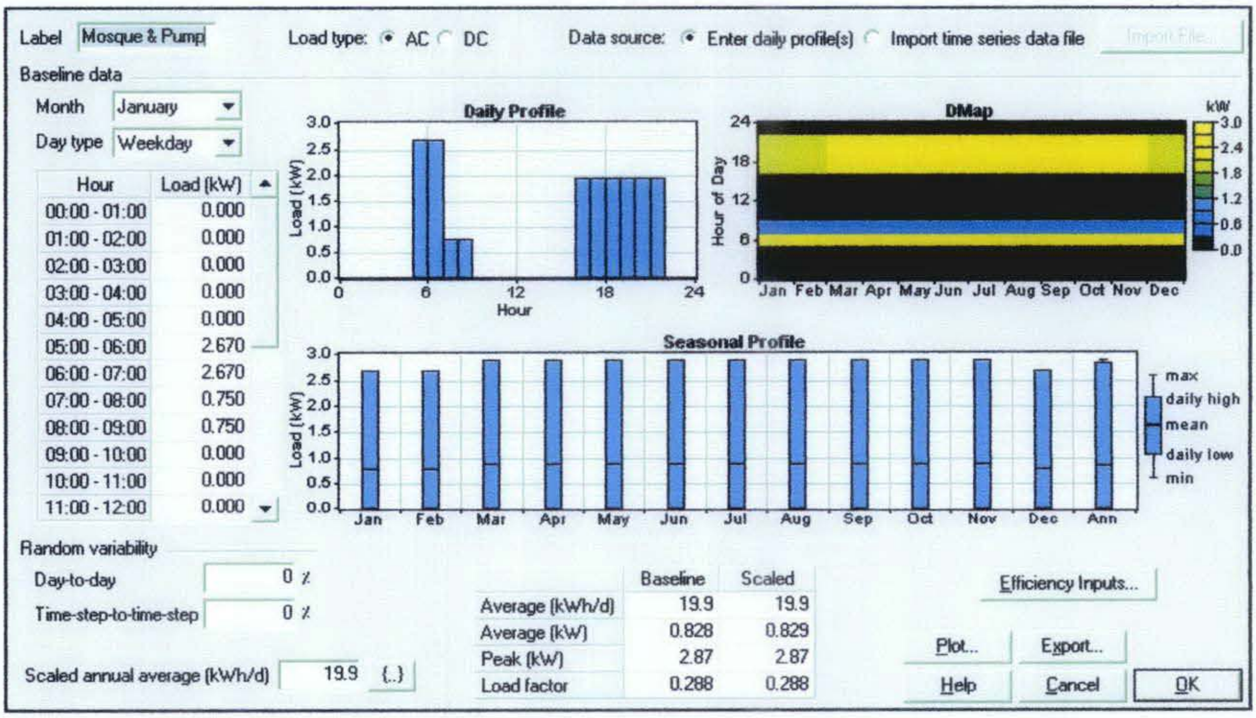
Day-to-day: 8 %

Time-step-to-time-step: 8 %

Scaled annual average (kWh/d): 50.06 {..}

| | Baseline | Scaled |
|---|---|---|
| Average (kWh/d) | 50.0 | 50.1 |
| Average (kW) | 2.08 | 2.09 |
| Peak (kW) | 6.54 | 6.55 |
| Load factor | 0.319 | 0.319 |

Figure 29: Village Energy Consumption Profile



Label: Mosque & Pump

Load type: ● AC ○ DC

Data source: ● Enter daily profile(s) ○ Import time series data file

Baseline data

Month: January

Day type: Weekday

| Hour | Load (kW) |
|---|---|
| 00:00 - 01:00 | 0.000 |
| 01:00 - 02:00 | 0.000 |
| 02:00 - 03:00 | 0.000 |
| 03:00 - 04:00 | 0.000 |
| 04:00 - 05:00 | 0.000 |
| 05:00 - 06:00 | 2.670 |
| 06:00 - 07:00 | 2.670 |
| 07:00 - 08:00 | 0.750 |
| 08:00 - 09:00 | 0.750 |
| 09:00 - 10:00 | 0.000 |
| 10:00 - 11:00 | 0.000 |
| 11:00 - 12:00 | 0.000 |

Random variability

Day-to-day: 0 %

Time-step-to-time-step: 0 %

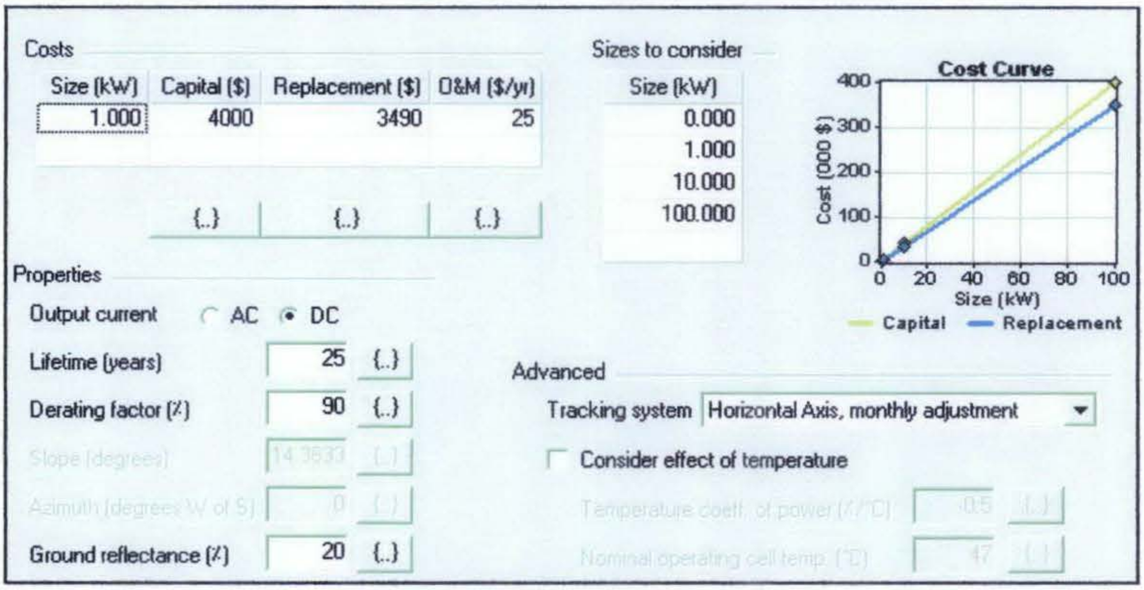
Scaled annual average (kWh/d): 19.9 {..}

| | Baseline | Scaled |
|---|---|---|
| Average (kWh/d) | 19.9 | 19.9 |
| Average (kW) | 0.828 | 0.829 |
| Peak (kW) | 2.87 | 2.87 |
| Load factor | 0.288 | 0.288 |

Figure 30: Auxiliary Load Energy Consumption Profile

### 4.5.3 System Equipment specifications

The specification of the system equipments are determined based on actual technical and economical specifications provided in the market. The specifications include: the size, cost of the installations, cost of replacement, cost of operation and maintenance. All the estimated specifications are described in the figures below.



Costs

| Size (kW) | Capital ($) | Replacement ($) | O&M ($/yr) |
|---|---|---|---|
| 1.000 | 4000 | 3490 | 25 |

Sizes to consider

| Size (kW) |
|---|
| 0.000 |
| 1.000 |
| 10.000 |
| 100.000 |

Properties

Output current ○ AC ● DC

Lifetime (years) 25

Derating factor (%) 90

Slope (degrees) 14.3633

Azimuth (degrees W of S) 0

Ground reflectance (%) 20

Advanced

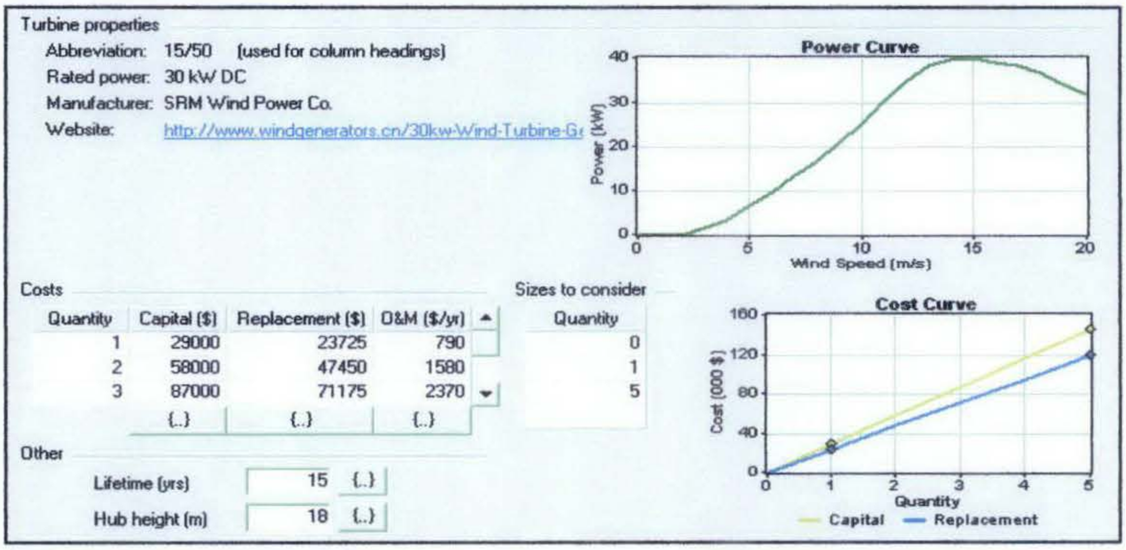
Tracking system: Horizontal Axis, monthly adjustment

☐ Consider effect of temperature

Temperature coeff. of power (%/°C) -0.5

Nominal operating cell temp. (°C) 47

Figure 31: PV array specifications



Turbine properties

Abbreviation: 15/50 (used for column headings)

Rated power: 30 kW DC

Manufacturer: SRM Wind Power Co.

Website: http://www.windgenerators.cn/30kw-Wind-Turbine-G

Costs

| Quantity | Capital ($) | Replacement ($) | O&M ($/yr) |
|---|---|---|---|
| 1 | 29000 | 23725 | 790 |
| 2 | 58000 | 47450 | 1580 |
| 3 | 87000 | 71175 | 2370 |

Sizes to consider

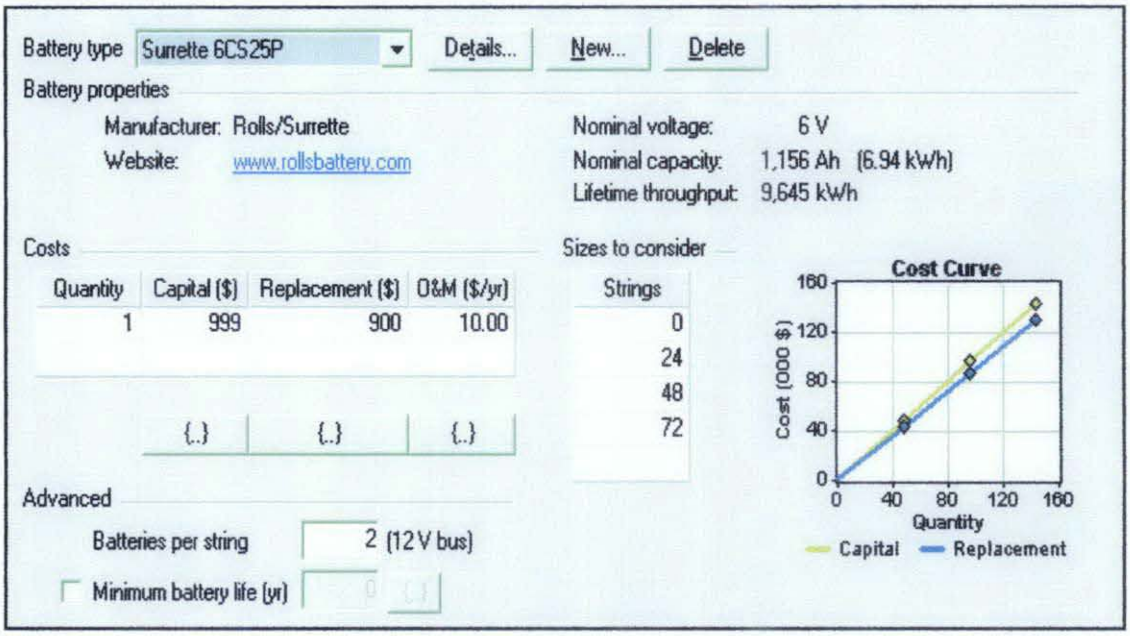
| Quantity |
|---|
| 0 |
| 1 |
| 5 |

Other

Lifetime (yrs) 15

Hub height (m) 18

Figure 32: Wind generator specifications



Battery type: Surrette 6CS25P

Battery properties

Manufacturer: Rolls/Surrette
Website: www.rollsbattery.com
Nominal voltage: 6 V
Nominal capacity: 1,156 Ah (6.94 kWh)
Lifetime throughput: 9,645 kWh

Costs

| Quantity | Capital ($) | Replacement ($) | O&M ($/yr) |
|---|---|---|---|
| 1 | 999 | 900 | 10.00 |

Sizes to consider

| Strings |
|---|
| 0 |
| 24 |
| 48 |
| 72 |

Advanced

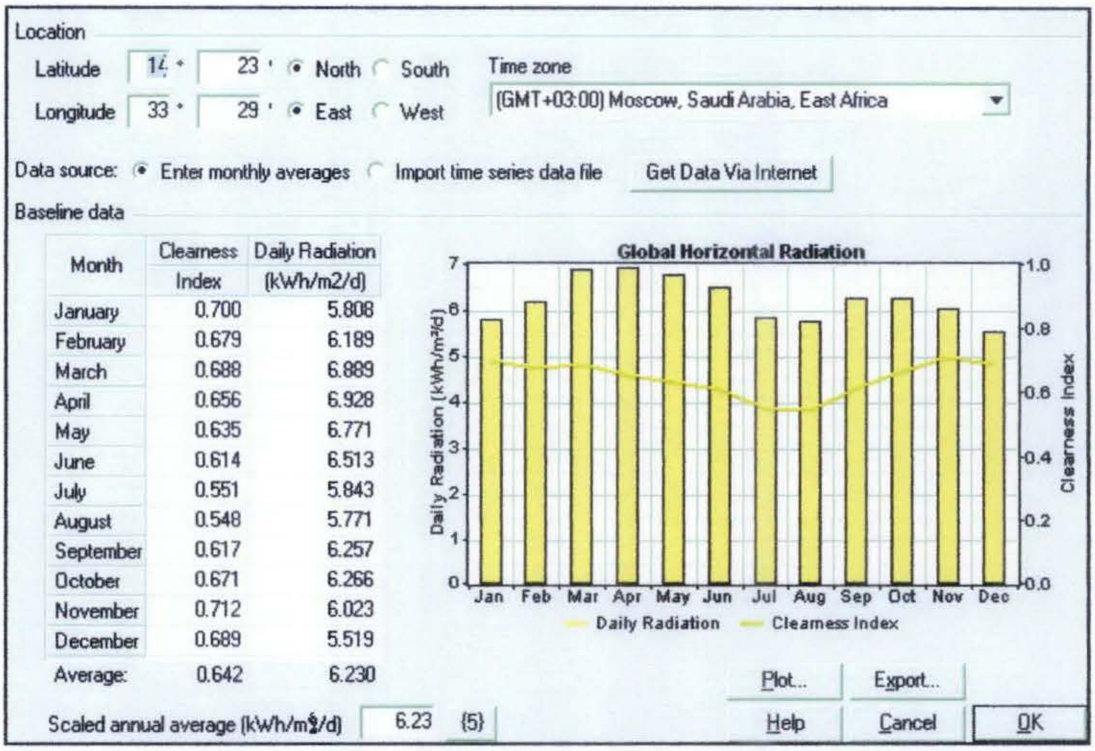
Batteries per string: 2 (12 V bus)
☐ Minimum battery life (yr): 0

Figure 33: Battery banks selection

### 4.5.4 Renewable Energy Data

There are two sources of renewable energy are utilized to be used to supply the system: solar and wind energy. The global irradiation of the site is generated from the software by entering the latitude and longitude of the selected site, besides, the time zone. The latitude of the site is 14°23’ and it has a longitude of 33°29’ [8].

For the wind energy, an annual average speed of the site is chosen based on the data provided by General Sudanese Authority for Meteorology, which are 3.87 m/s.



Latitude 14 ° 23 ' ● North ○ South

Longitude 33 ° 29 ' ● East ○ West

Time zone (GMT+03:00) Moscow, Saudi Arabia, East Africa

Data source: ● Enter monthly averages ○ Import time series data file

Baseline data

| Month | Clearness Index | Daily Radiation (kWh/m2/d) |
|---|---|---|
| January | 0.700 | 5.808 |
| February | 0.679 | 6.189 |
| March | 0.688 | 6.889 |
| April | 0.656 | 6.928 |
| May | 0.635 | 6.771 |
| June | 0.614 | 6.513 |
| July | 0.551 | 5.843 |
| August | 0.548 | 5.771 |
| September | 0.617 | 6.257 |
| October | 0.671 | 6.266 |
| November | 0.712 | 6.023 |
| December | 0.689 | 5.519 |
| Average: | 0.642 | 6.230 |

Scaled annual average (kWh/m2/d) 6.23 {5}

Figure 34: Solar irradiation data for the proposed location

### 4.5.5 Optimization Results

The software will examine all the possible configurations for the system and then optimize the best setup among them. The sensitivity analysis for the optimal system type was estimated and plotted. Variations in wind speed and solar resource determine the best system option.

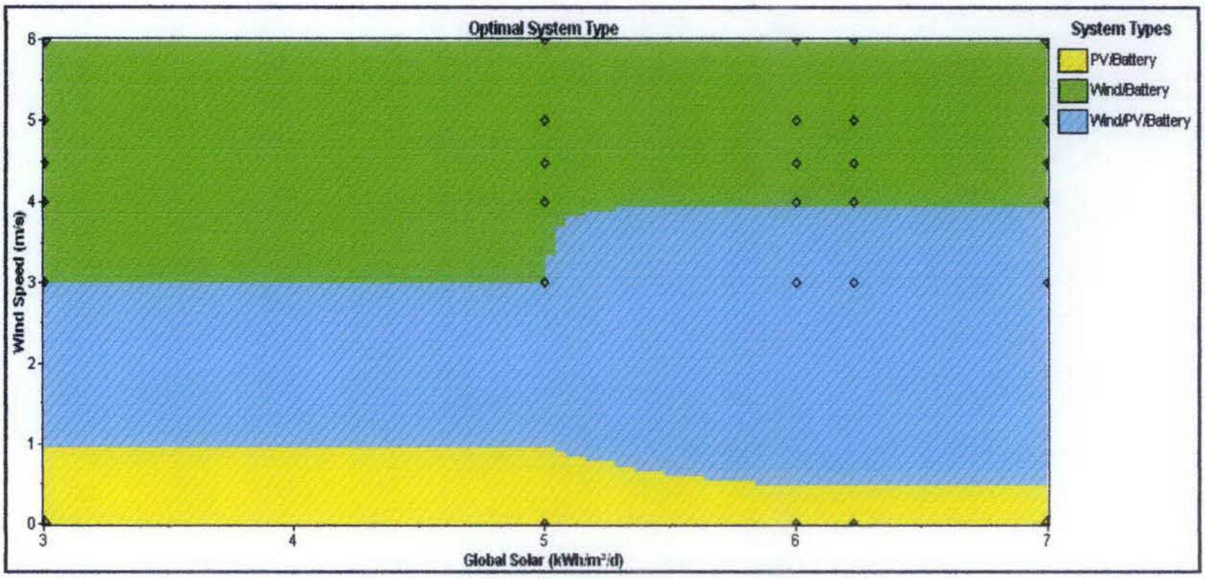
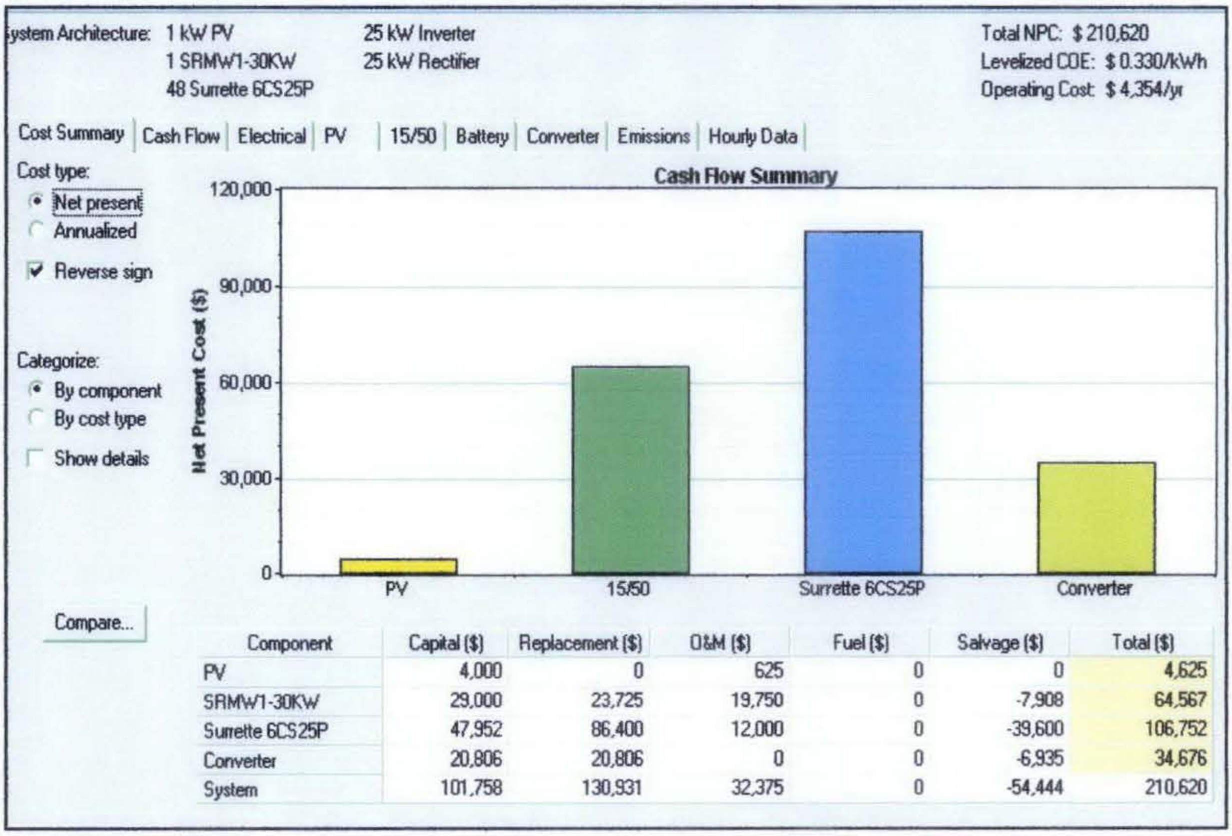


Figure 35: the sensitivity analysis graph for the optimal system options

This results obtained by performing the sensitivity analysis in HOMER. In a sensitivity analysis, a range of values for a single input variable is entered. This variable is called a sensitivity variable. The chosen sensitivity variables are: the annual average solar radiation and wind speed. Each combination of these variables' values defines a different sensitivity case. Therefore, we have thirty different sensitivity cases. The software then, performs a separate optimization process for each sensitivity case and presents the results in various graphic and tabular formats. This allows us to determine which technologies, or combinations of technologies, are optimal under various conditions.

Whereas the sensitivity analysis deals with the uncertainty in system significant variables and trades-off decisions, the optimization process decides the best possible system configuration. In HOMER simulator, the best possible, or optimal, system configuration is the one that can meet our predefined constraints at the lowest total net present cost. After the simulation was performed, the system optimal configuration was estimated as shown in figure (36). At the annual average key variables (solar radiation, wind velocity and diesel price per liter) it shows that the wind turbine only with battery storage system is the most feasibly, based on the simulation. This is because of the wind turbine selection was based on the most cost effectiveness among various similar brands. The system consists of a single SRMW-30KW wind turbine unit, 48 units of Surrette 6CS25P battery storages and inverters with a capacity of 25 KW.



ystem Architecture: 1 kW PV
1 SRMW1-30KW
48 Surrette 6CS25P
25 kW Inverter
25 kW Rectifier

Total NPC: $ 210,620
Levelized COE: $ 0.330/kWh
Operating Cost: $ 4,354/yr

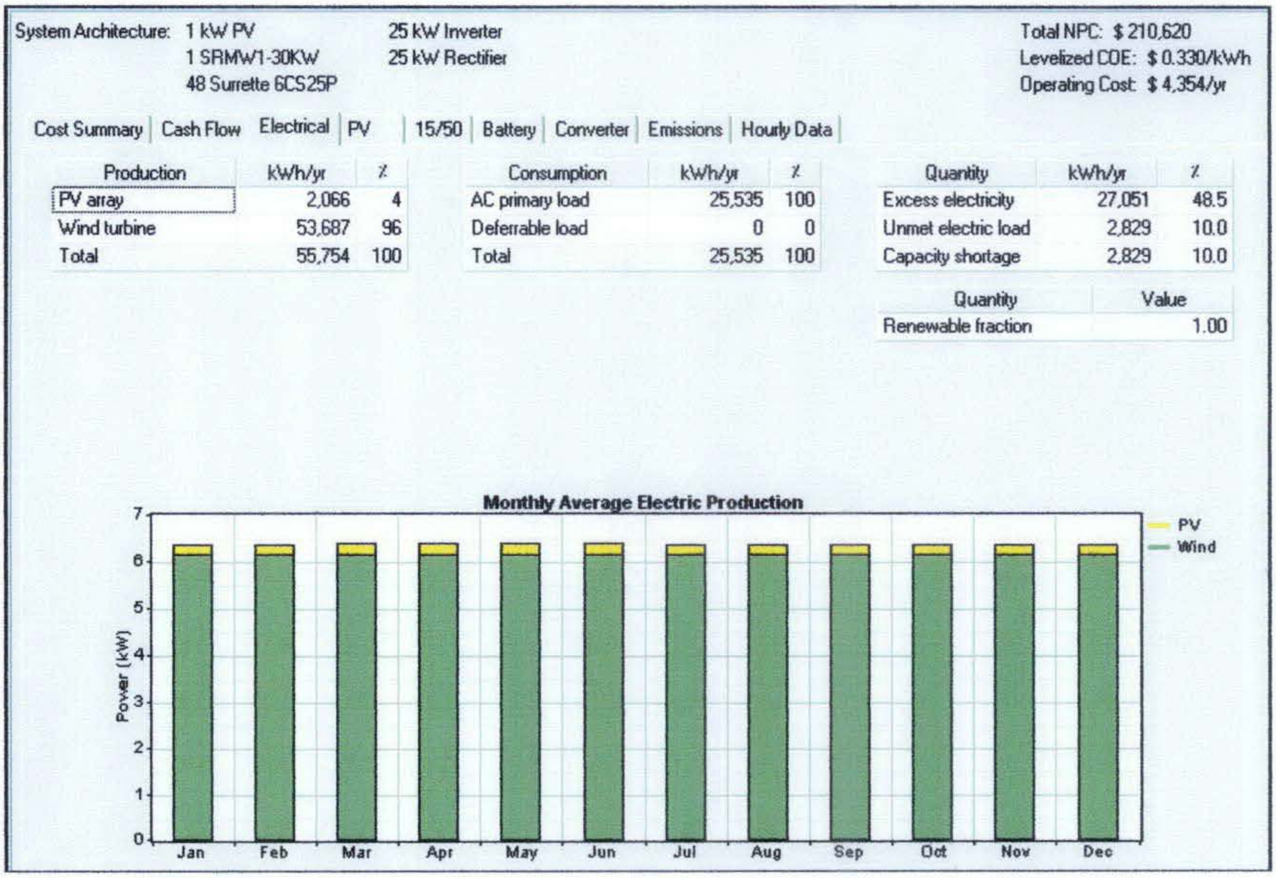
Cost type:
● Net present
○ Annualized
☑ Reverse sign

Categorize:
● By component
○ By cost type
☐ Show details

| Component | Capital ($) | Replacement ($) | O&M ($) | Fuel ($) | Salvage ($) | Total ($) |
|---|---|---|---|---|---|---|
| PV | 4,000 | 0 | 625 | 0 | 0 | 4,625 |
| SRMW1-30KW | 29,000 | 23,725 | 19,750 | 0 | -7,908 | 64,567 |
| Surrette 6CS25P | 47,952 | 86,400 | 12,000 | 0 | -39,600 | 106,752 |
| Converter | 20,806 | 20,806 | 0 | 0 | -6,935 | 34,676 |
| System | 101,758 | 130,931 | 32,375 | 0 | -54,444 | 210,620 |

Figure 36: The Optimal system architecture and costs

The produced electricity profile is shown in figure (37). As shown the load power consumption was totally met by the system but with an excess electricity of 27,051 KWh/yr. This excessive electricity can be utilized for other purposes or for load expansions.



System Architecture: 1 kW PV
1 SRMW1-30KW
48 Surrette 6CS25P
25 kW Inverter
25 kW Rectifier

Total NPC: $ 210,620
Levelized COE: $ 0.330/kWh
Operating Cost: $ 4,354/yr

| Production | kWh/yr | % |
|---|---|---|
| PV array | 2,066 | 4 |
| Wind turbine | 53,687 | 96 |
| Total | 55,754 | 100 |

| Consumption | kWh/yr | % |
|---|---|---|
| AC primary load | 25,535 | 100 |
| Deferrable load | 0 | 0 |
| Total | 25,535 | 100 |

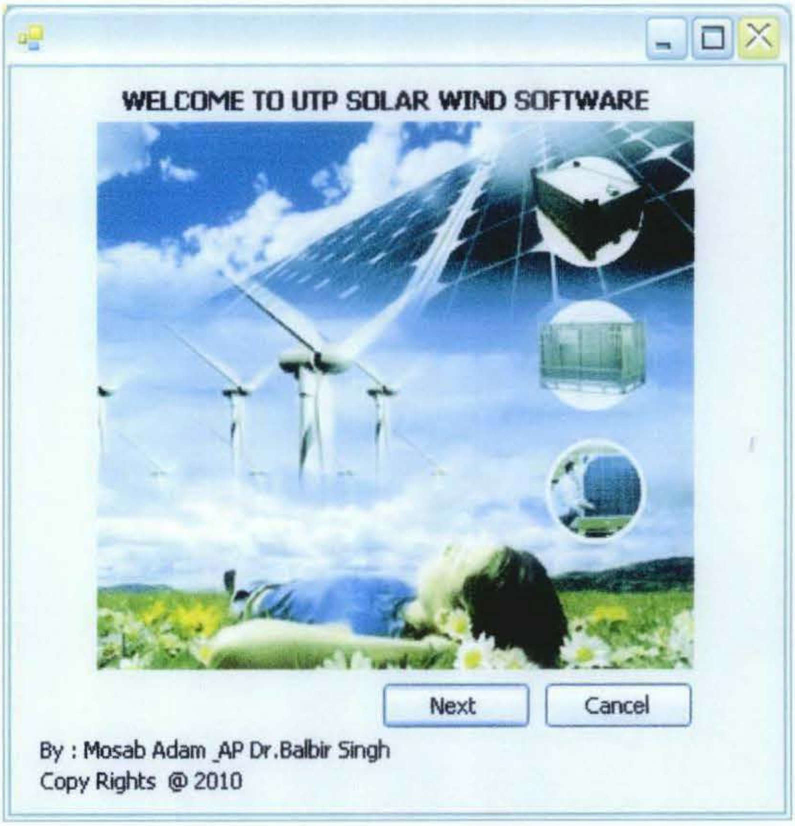
| Quantity | kWh/yr | % |
|---|---|---|
| Excess electricity | 27,051 | 48.5 |
| Unmet electric load | 2,829 | 10.0 |
| Capacity shortage | 2,829 | 10.0 |

| Quantity | Value |
|---|---|
| Renewable fraction | 1.00 |

Figure 37: The electricity generation profile of the hybrid system

## 4.5 Hybrid Renewable Energy Sizing Software: UTPSOLARWIND

This is a developed software using Visual Basic 2008 which allows the user to determine the exact size of the system equipment based on the provided options and data to be entered. At this stage, the software can calculate the most feasible arrangement of the solar modules and batteries for any stand-alone system. Besides, it can give an accurate design for a wind-powered generation system based on the technical specifications of the considered wind module.



WELCOME TO UTP SOLAR WIND SOFTWARE

By : Mosab Adam _AP Dr.Balbir Singh
Copy Rights @ 2010

Figure 38: The interface page of UTPSOLARWIND program

# CHAPTER 5

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

At the end of this project, all objectives were achieved successfully. It is found that solar-wind system is a promising and effective alternative to replace the finite sources in electricity generation in rural area in Sudan. Along the project progress, intensive literature review has been done, which allowed for better understanding of the topic. The hybrid system was designed and simulated using PSIM software. The obtained results proved that hybrid system is very effective for electricity generation. Another simulation was done using HOMER software and it showed the most optimum design to be implemented in the proposed site. Mathematical software was developed to ease the calculations of the best sizing of solar array and batteries for PV stand-alone system based on the location specifications. Also, it gives a proper design for wind-powered generation system. In conclusion, the hybrid solar-wind system can be implemented in most of Sudan regions and in the future in can be a decent choice to replace the conventional stand-alone systems in generating electricity.

## 5.2 Recommendation

In order to enhance the project in the future, several suggestion and recommendations and are noted as reference. Firstly, there is a need for designing an effective power conditioning system for hybridization of solar-wind electrical power generation. This conditioning system will be able to combine both the solar and wind generation systems together and minimize the power losses occur; besides, in the same time, it can charge up batteries. Secondly, a multi-stage batteries charging system to cater for different voltages of charging is recommended. It is because of most of the charging systems are capable to charge the batteries with only one set point and if the battery voltage is higher it will not charge it up as goes for battery with much lower charging voltages. Finally, there is a need to study and investigate the feasibility for combing more sources of renewable energies such as micro-hydro energy to the system.

# REFERENCES

[1] Howard Geller , 2003 , Fostering a Clean Energy Revolution / Co-generation and On-Site Power Production, Vol. 4, No. 5, pp. 26: 31 ,September-October 2003.

[2] Sayigh, A.A.W., 2001. Renewable energy: global progress and examples, Renewable Energy 2001, WREN, pp. 15–17.

[3] Duffie, J.A. and Beckman, W.A., 1991, Solar Engineering of Thermal Processes, 2nd Edition, John Wiley & Sons.

[4] Gary D. Burch, 2001, Hybrid Renewable Energy Systems, U.S DOE Natural Gas /Renewable Energy Workshops, August 2001.

[5] Jefferson W. Tester, Elisabeth M. Drake, Michael J. Driscoll, William A. Peters, 2005, Sustainable Energy, Choosing Among Options, The MIT Press.

[6] Larry D. Partain, Solar Cells and Their Applications. Wiley-Interscience 1995.

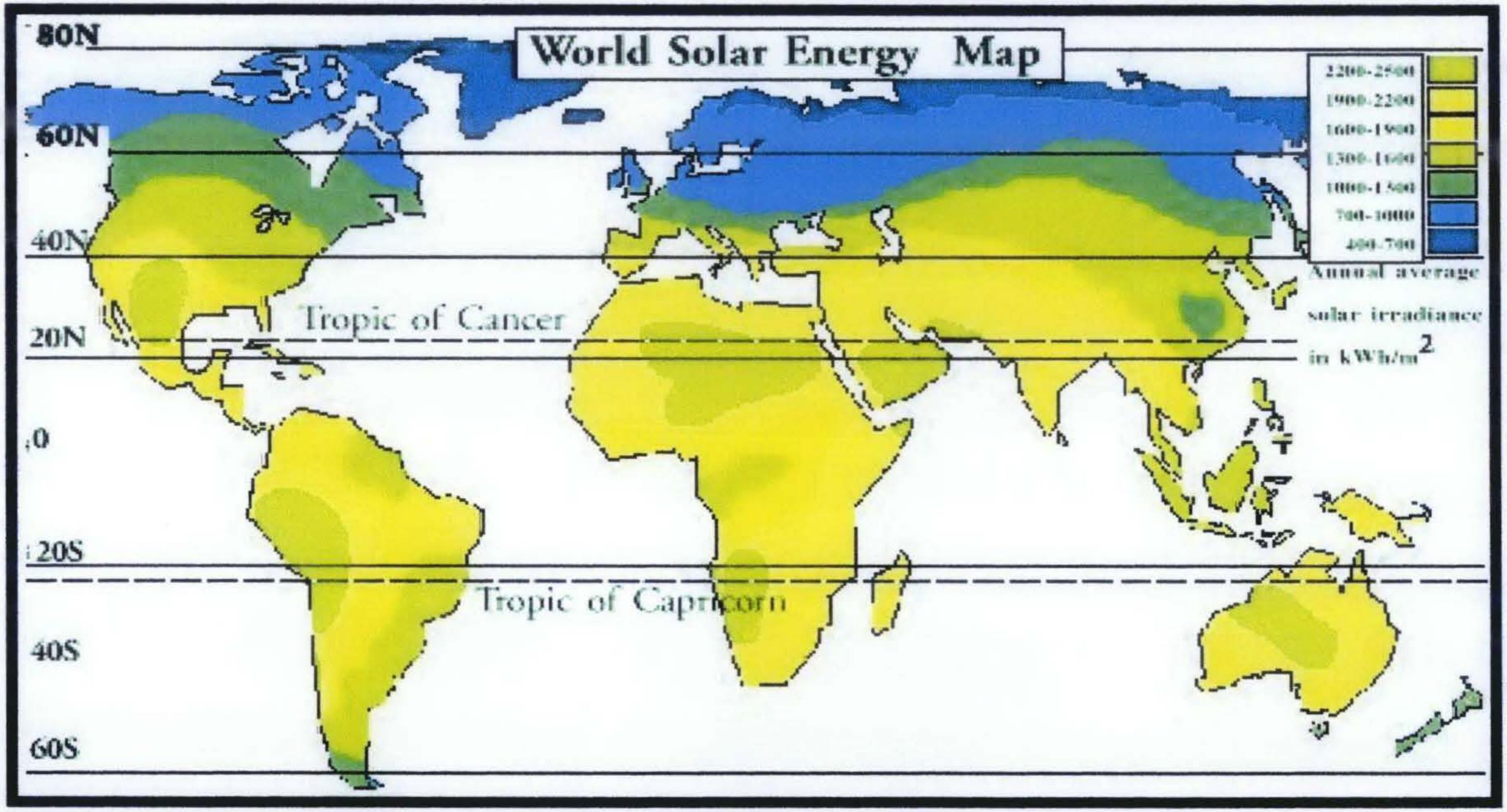
[7] A. M. Omer. "Overview of renewable energy sources in the Republic of the Sudan", Energy, 1st of November.

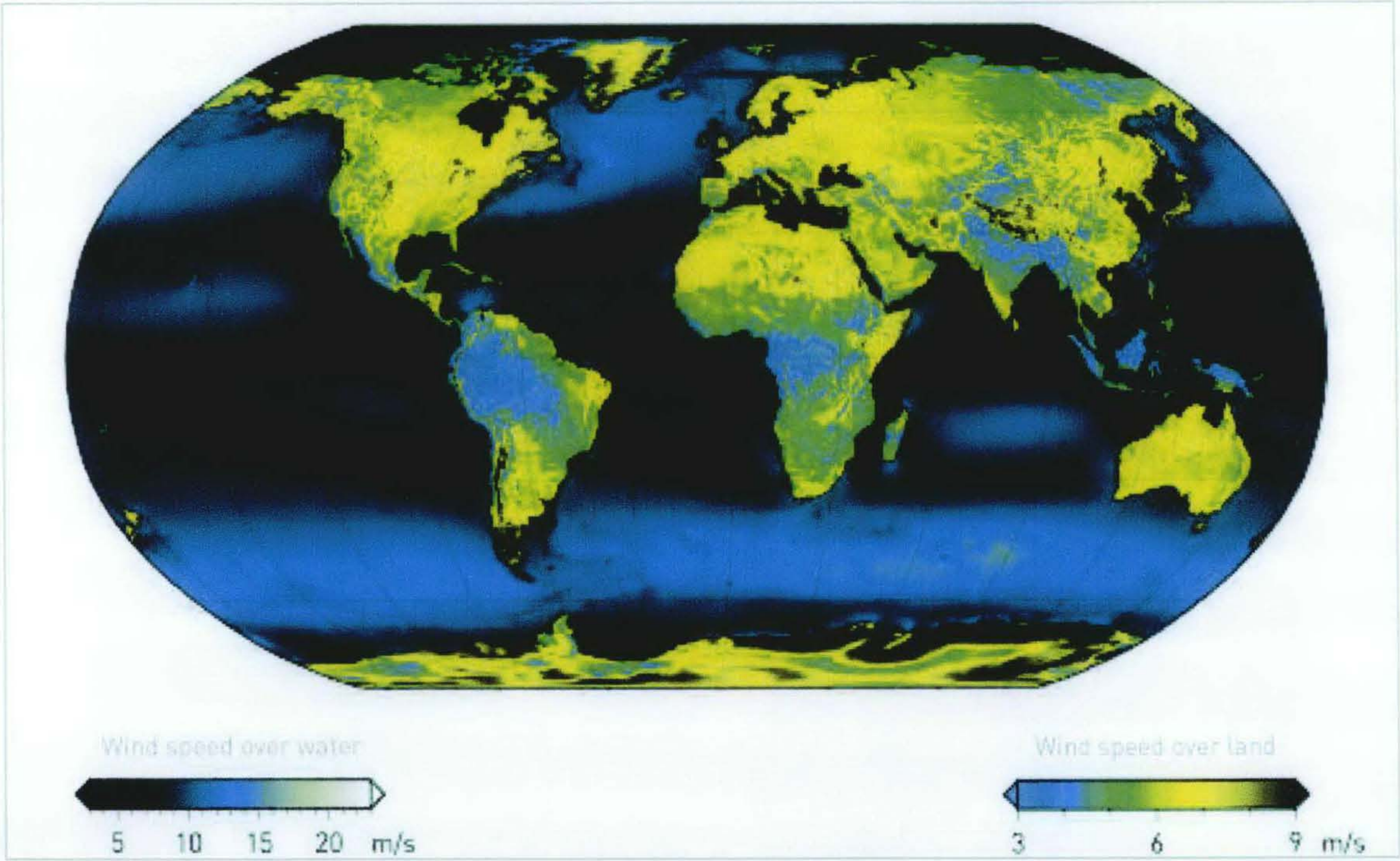
[8] Republic of the Sudan, Ministry of Energy and Mining, "Exploring the Best Options for Sustainable Energy Development", August 2009.

# APPENDICES

## APPENDIX A

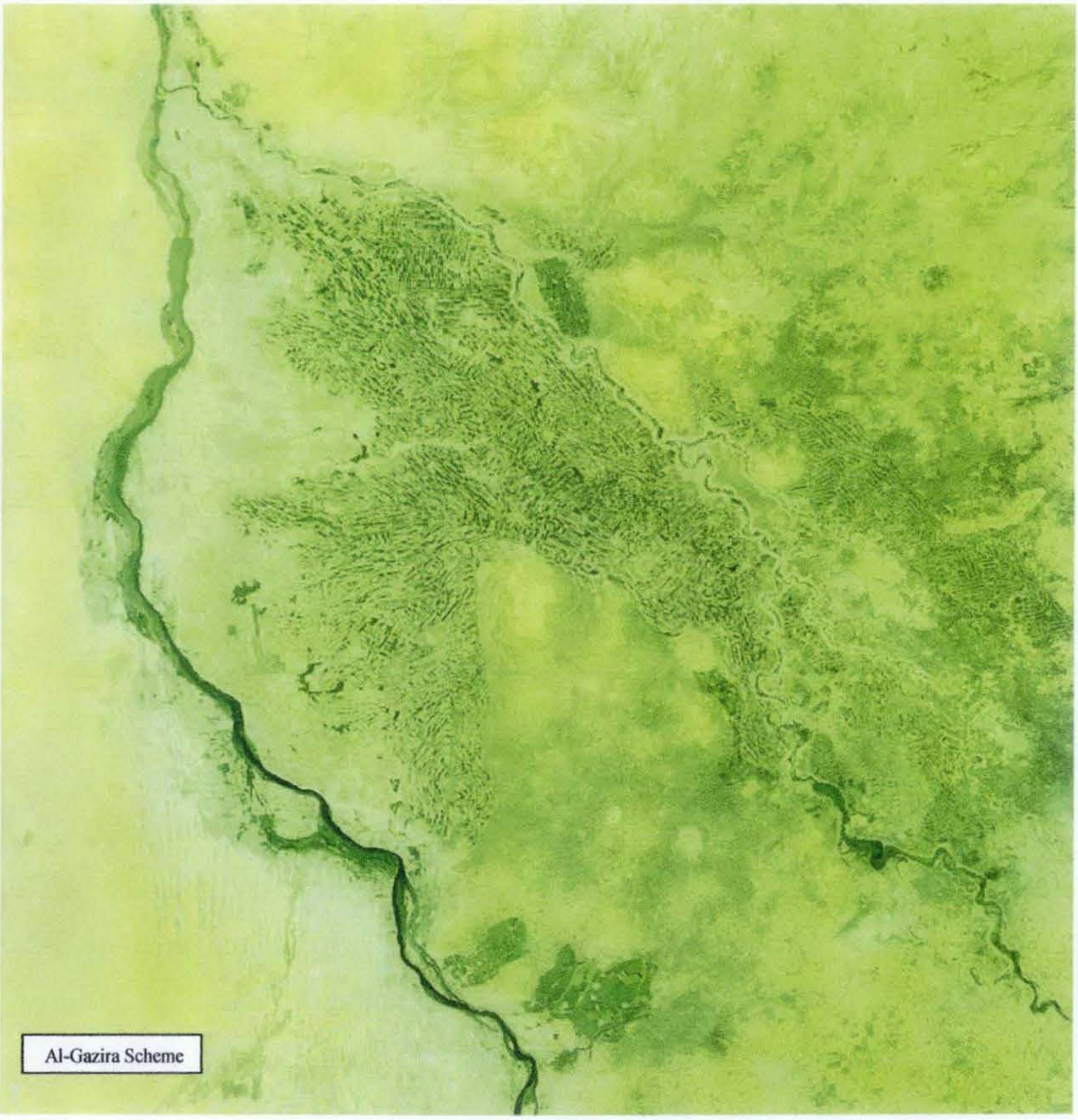
### World Solar and Wind Map




Wind speed over water
5
10
15
20
m/s
Wind speed over land
3
6
9
m/s

# APPEDIX C
# GEOGRAPHICAL MAPS

The Location of Al-Gazira state



Al-Gazira Scheme

# APPEDIX D
# HOMER INPUT DATA

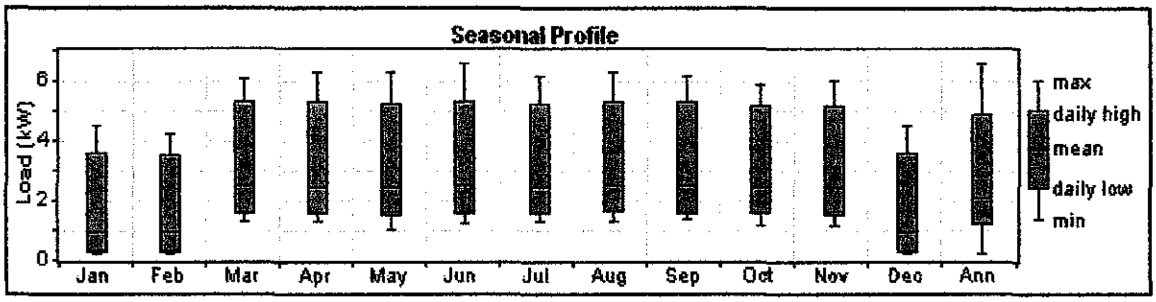
## 1) Primary Load 1 :

Type of Load: AC load (three center pivots).

| Month | Average Load (kWh/d) |
|---|---|
| January | 65.960 |
| February | 65.960 |
| March | 65.960 |
| April | 65.960 |
| May | 23.280 |
| June | 23.280 |
| July | 60.140 |
| August | 60.140 |
| September | 60.140 |
| October | 29.100 |
| November | 23.280 |
| December | 23.280 |
| Annual Average : 47.2 KWh/d | |

**2) Primary Load 2 :**

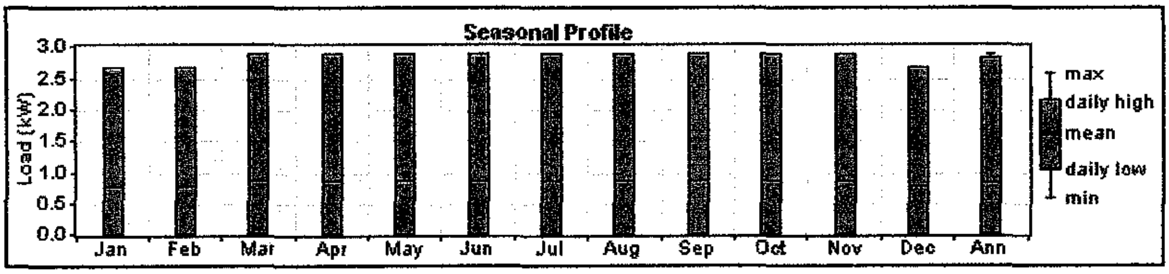
Type of Load: AC (Village load)



| Average (kWh/d) | 50.1 |
|---|---|
| Average (kW) | 2.09 |
| Peak (kW) | 6.55 |
| Load factor | 0.319 |

**3) Secondary Load:**

Type: AC (Mosque and pump load)



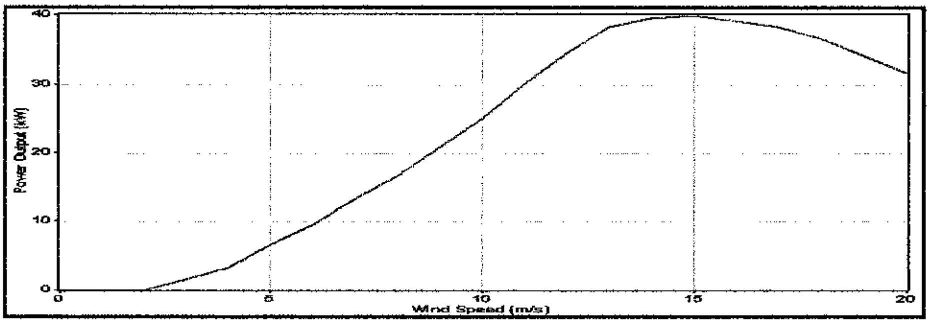
| Average (kWh/d) | 19.9 |
|---|---|
| Average (kW) | 0.828 |
| Peak (kW) | 2.87 |
| Load factor | 0.288 |

## 4) Wind Generator

### Main Parameter

| | |
|---|---|
| **Numbers of blade(P):** | 3 |
| **Materials of blade:** | FRP strengthened |
| **Diameter of wind turbines(m)** | 12.0 |
| **Startup wind speed** | 2.5 |
| **Rated wind speed(m/s)** | 11 |
| **Working wind speed (m/s):** | 3-30 |
| **Max. wind speed(m/s)** | 50 |
| **Rated speed(rotate/minute)** | 200 |
| **Start torque (n/m)** | 13 |
| **Generator rated power(W):** | 30000 |
| **Max.output power(W):** | 40000 |
| **Output voltage(V):** | 500VDC |
| **Generator:** | Permanent-magnetic ,3-phase,AC |
| **Speed regulation :** | Electromagnetic brake + Yawing |
| **Stop method:** | Electromagnetic brake + Manual |
| **Tower type:** | Free stand tower |
| **Tower height (m):** | 18 |
| **Weight exclude tower(kg):** | 1800 |
| **Annual generation Min/Max(KWh):** | 30000 / 80000 |
| **Inverter power supply:** | Pure Sine Wave(On-grid /Off-grid ) |
| **Controller Model :** | 500v200A |

The Power Curve:



| Wind Speed (m/s) | Power Output (kW) |
|---|---|
| 0.00 | 0.000 |
| 1.00 | 0.000 |
| 2.00 | 0.000 |
| 3.00 | 1.667 |
| 4.00 | 3.333 |
| 5.00 | 6.667 |
| 6.00 | 9.583 |
| 7.00 | 13.333 |
| 8.00 | 16.667 |
| 9.00 | 20.833 |
| 10.00 | 25.000 |
| 11.00 | 30.000 |
| 12.00 | 34.583 |
| 13.00 | 38.333 |
| 14.00 | 39.583 |
| 15.00 | 40.000 |
| 16.00 | 39.167 |
| 17.00 | 38.333 |
| 18.00 | 36.667 |
| 19.00 | 34.167 |
| 20.00 | 31.667 |

Cost:

| Quantity | Capital ($) | Replacement ($) | O&M ($/yr) |
|---|---|---|---|
| 1 | 29000 | 23725 | 790 |
| 2 | 58000 | 47450 | 1580 |

## 5) PV :

Cost:

| Size (kW) | Capital ($) | Replacement ($) | O&M ($/yr) |
|---|---|---|---|
| 1.000 | 4000 | 3490 | 25 |

Sizes to consider: ranges from 0-100 KW

Lifetime: 25 years

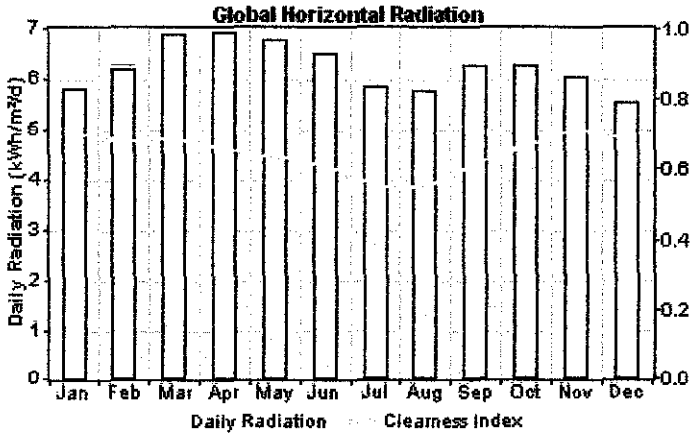
Derating factor: 90%

Tracking system: Horizontal axis, monthly adjustment

Ground reflectance: 20%

## 6) Solar Resource :

| Month | Clearness Index | Daily Radiation (kWh/m2/d) |
|---|---|---|
| January | 0.700 | 5.808 |
| February | 0.679 | 6.189 |
| March | 0.688 | 6.889 |
| April | 0.656 | 6.928 |
| May | 0.635 | 6.771 |
| June | 0.614 | 6.513 |
| July | 0.551 | 5.843 |
| August | 0.548 | 5.771 |
| September | 0.617 | 6.257 |
| October | 0.671 | 6.266 |
| November | 0.712 | 6.023 |
| December | 0.689 | 5.519 |

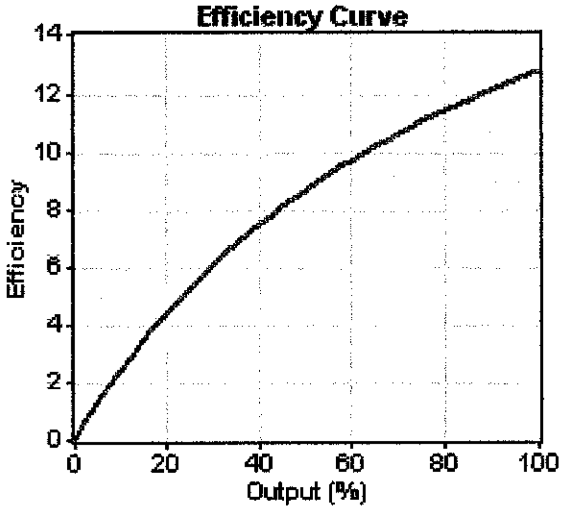


## 7) AC Generator :

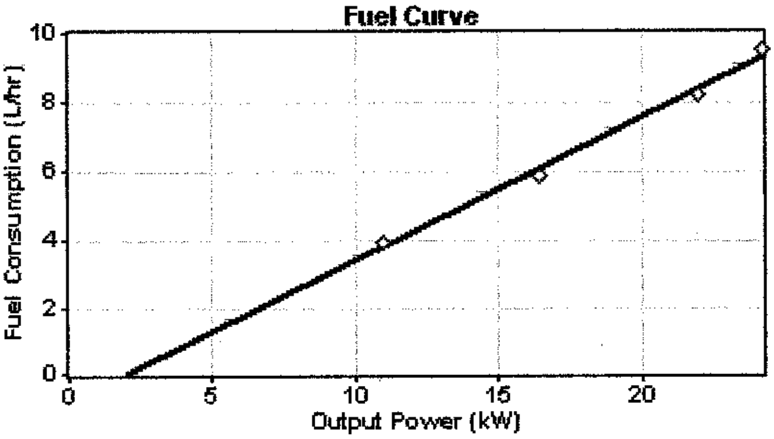
Cost:

| Size (kW) | Capital ($) | Replacement($) | O&M ($/hr) |
|---|---|---|---|
| 25.000 | 8832 | 8500 | 0.250 |

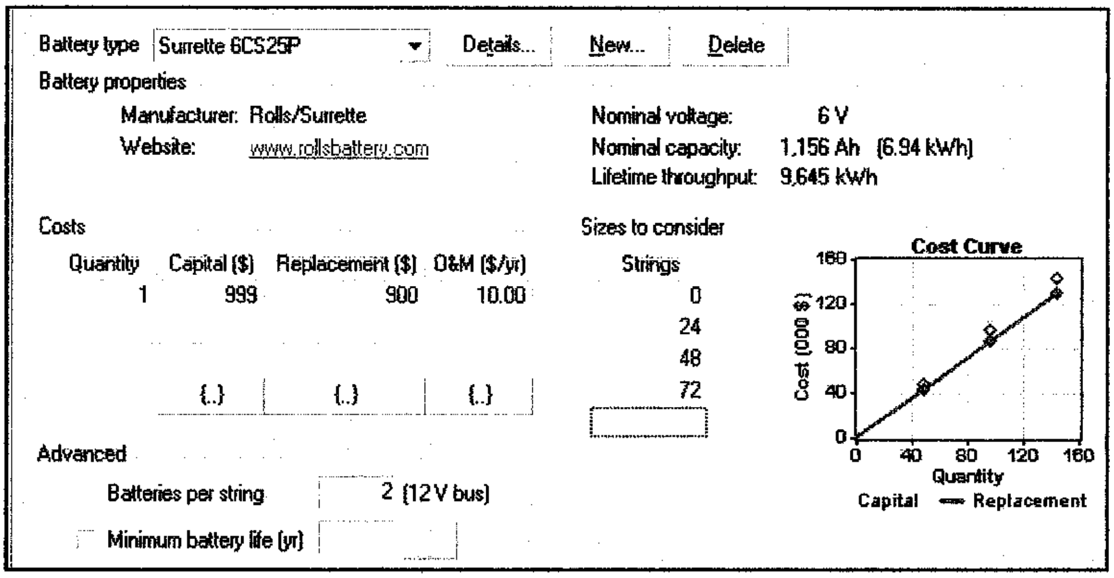
Efficiency Curve:



Fuel Curve:



## 8) Battery Inputs :



Battery type: Surrette 6CS25P

Battery properties

Manufacturer: Rolls/Surrette

Website: www.rollsbattery.com

Nominal voltage: 6 V

Nominal capacity: 1,156 Ah (6.94 kWh)

Lifetime throughput: 9,645 kWh

Costs

| Quantity | Capital ($) | Replacement ($) | O&M ($/yr) |
|---|---|---|---|
| 1 | 999 | 900 | 10.00 |

Sizes to consider

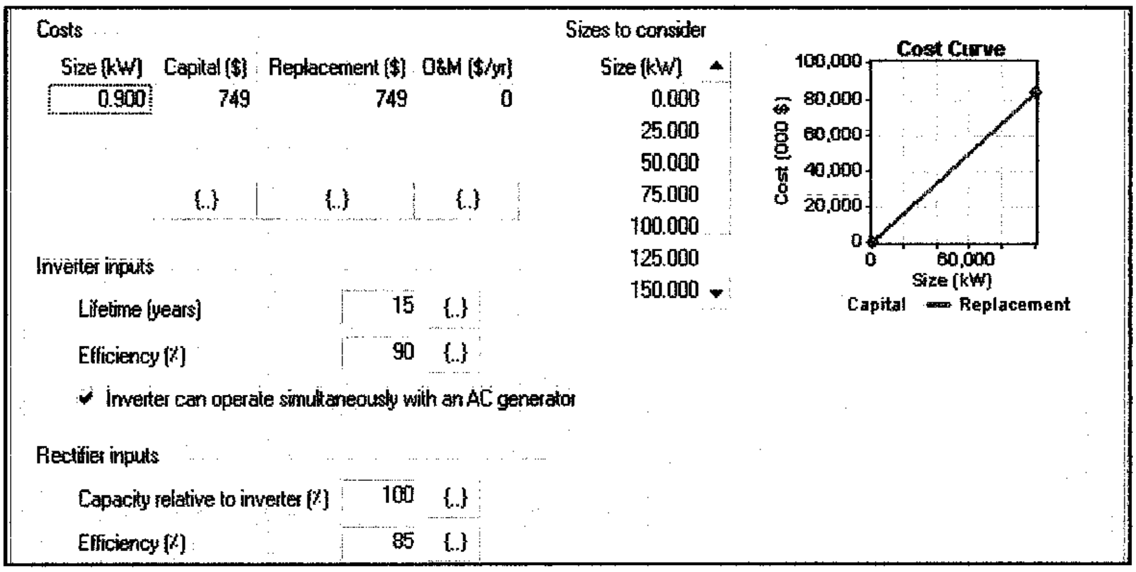
| Strings |
|---|
| 0 |
| 24 |
| 48 |
| 72 |

Advanced

Batteries per string: 2 (12 V bus)

☐ Minimum battery life (yr)

## 9) Inverter :



Costs

| Size (kW) | Capital ($) | Replacement ($) | O&M ($/yr) |
|---|---|---|---|
| 0.900 | 749 | 749 | 0 |

Sizes to consider

| Size (kW) |
|---|
| 0.000 |
| 25.000 |
| 50.000 |
| 75.000 |
| 100.000 |
| 125.000 |
| 150.000 |

Inverter inputs

Lifetime (years): 15

Efficiency (%): 90

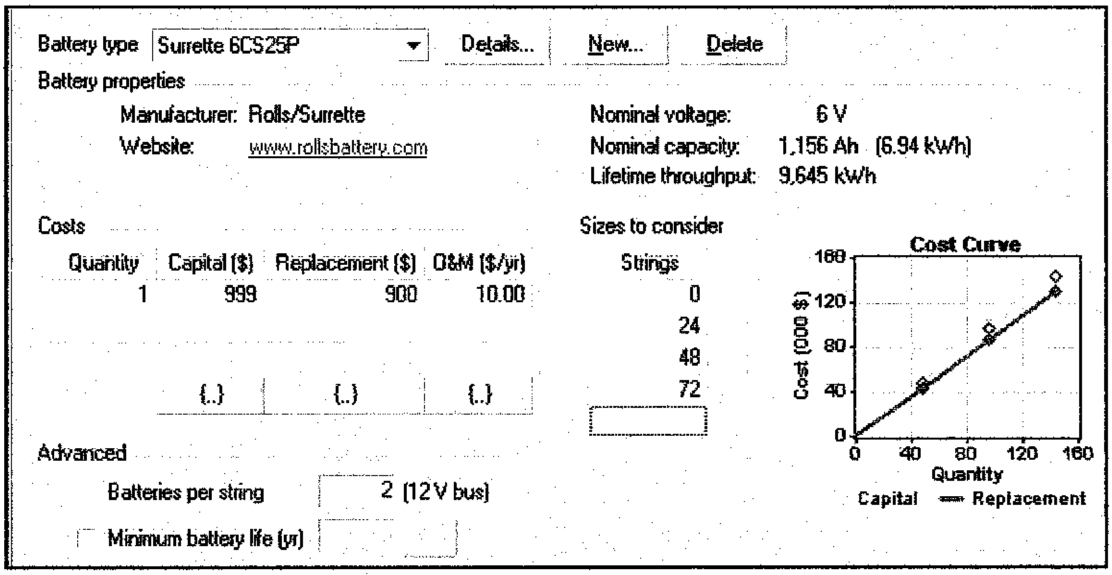
☑ Inverter can operate simultaneously with an AC generator

Rectifier inputs

Capacity relative to inverter (%): 100

Efficiency (%): 85

## 8) Battery Inputs :



Battery type: Surrette 6CS25P

Battery properties

Manufacturer: Rolls/Surrette

Website: www.rollsbattery.com

Nominal voltage: 6 V

Nominal capacity: 1,156 Ah (6.94 kWh)

Lifetime throughput: 9,645 kWh

Costs

| Quantity | Capital ($) | Replacement ($) | O&M ($/yr) |
|---|---|---|---|
| 1 | 999 | 900 | 10.00 |

Sizes to consider

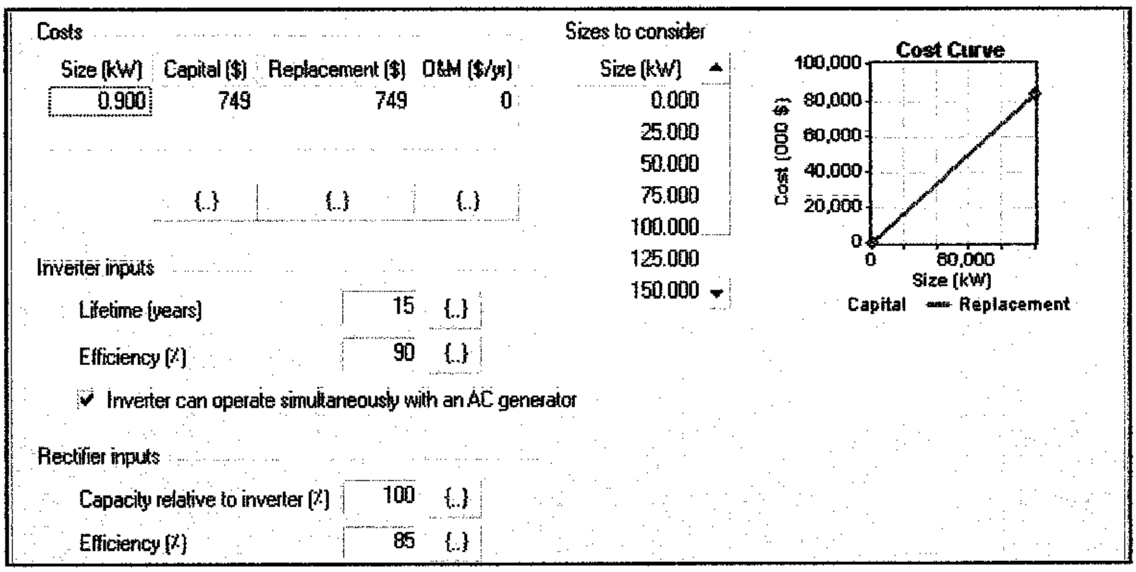
| Strings |
|---|
| 0 |
| 24 |
| 48 |
| 72 |

Advanced

Batteries per string: 2 (12 V bus)

☐ Minimum battery life (yr)

## 9) Inverter :



Costs

| Size (kW) | Capital ($) | Replacement ($) | O&M ($/yr) |
|---|---|---|---|
| 0.900 | 749 | 749 | 0 |

Sizes to consider

| Size (kW) |
|---|
| 0.000 |
| 25.000 |
| 50.000 |
| 75.000 |
| 100.000 |
| 125.000 |
| 150.000 |

Inverter inputs

Lifetime (years): 15

Efficiency (%): 90

☑ Inverter can operate simultaneously with an AC generator

Rectifier inputs

Capacity relative to inverter (%): 100

Efficiency (%): 85

# APPEDIX E

| No. | Detail/ Week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | |
| 1 | Selection of Project Topic | | | | | | | | | | | | | | |
| | -Propose Topic | | | | | | | | | | | | | | |
| | -Topic assigned to students | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| 2 | Preliminary Research Work | | | | | | | | | | | | | | |
| | -Introduction | | | | | | | | | | | | | | |
| | -Objective | | | | | | | | | | | | | | |
| | -List of references/literature | | | | | | | | | | | | | | |
| | -Project planning | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| 3 | Submission of Preliminary Report | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| 4 | Project Work | | | | ● | | | | | | | | | | |
| | -Reference/Literature | | | | | | | | | | | | | | |
| | -Simulation Work | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| 5 | Submission of Progress Report | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| 6 | Project work continue | | | | | | | | | ● | | | | | |
| | -Simulation and software development | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| 7 | Submission of Interim Report Final Draft | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |

●