Sudan University of Sciences andTechnology

College of Engineering

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Hybrid Renewable (Solar/Wind) System

نظام الطاقة المتجددة(الشمسية/ الرياح) الهجيني

A project Submitted In Partial Fulfillment for the Requirements of the Degree ofB.Sc. (Honor) in Electrical Engineering

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الآيـة

قال تعالى:

{وَسَخَّرَ لَكُمُ الشَّمْسَ وَالْقَمَرَ دَائِبَيْنِ وَسَخَّرَ لَكُمُ اللَّيْلَ وَالنَّـهَارَ }

سورةابراهيم 33

{إِن يَشَأْ يُسْكِنِ الرِّيحَ فَيَظْلَلْنَ رَوَاكِدَ عَلَىٰ ظَهْرِهِ إِنَّ فِي ذَٰلِكَ لَآيَاتٍ

لِّكُلِّ صَبَّارٍ شَكُورٍ }

الشوري 33

DEDICATION

To Those Who Gave Us Their Time, Love and Care
Our Parents, Our teachers and every one inside Sudan University

To Our New Family
29 Batch

ACKNOWLEDGEMENT

Unlimited praise for Allah as the number of his creatures, the might of himself, the weight of his throne, and the extension of his words. The work on this project has been an inspiring, over exciting, sometimes challenging, but always interesting experience. It has been made possible by many other people, who have supported us.

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ABSTRACT

Renewable energy is that clean, unpolluted, environmental friendly type of energy which is obtained from natural resources that exist every day and always well as earth exists, such as sun light, wind, hydro, tides and geothermal energy.

The term electrification refers to the operation of supplying electricity by one of electricity generation means. Generally this project aims to electrify rural area that is far from the nearest point of the national electricity grid. Many rural areas are electrified using diesel generators, these generators emit CO2 which is considered as a major damage to the environment. Also these generators have a high operating cost due to the cost of fuel.

The project focuses on electrification using the hybrid photovoltaic/wind technology.

Photovoltaic system is a system that converts direct sunlight into electricity using plates manufactured from silicon, metal and glass called photovoltaic modules. There is a battery bank for storing energy to use it at night or when the sun light is not available or wind energy is not sufficient.

Wind energy work together with a photovoltaic system to match the load demand; Wind turbine is a rotating machine that converts the kinetic energy into mechanical energy. It is called a wind turbine generator when connected to a generator, which can be operating either at fixed or variable speeds, these generators convert the mechanical power into an electric power, and when located as a group in same place they called wind farm. The diesel generators introduced in this system are considered to be standby units, they only work when the hybrid system fails to supply electricity to the load. They are connected with an Automatic Transfer Switch (ATS). Using this technique will reduce the emission of CO2.

المستخلص

الطاقة المتجددة هي ذلك النوع من الطاقة النظيفة، الغير ملوثة للبيئة الذي يتم الحصول عليها من المصادر الطبيعية التي تتواجد بشكل يومي وستظل متواجدة مادامت الارض متواجدة ومن أمثلتها ضوء الشمس، الرياح، الأنهار، المد والجزر والحرارة في باطن الأرض.

مصطلح كهربة يعني عملية الامداد بالكهرباء بأحد طرق توليد الكهرباء. عموما يهدف هذا المشروع الي امداد المناطق الريفية التي تفصلها مسافات بعيدة عن أقرب جزء من الشبكة القومية للكهرباء. العديد من المناطق الريفية يتم كهربتها باستخدام مولدات الديزل، هذه المولدات تبعث غاز ثاني اكسيد الكربون الذي يعتبر ضرر كبير علي البيئة. أيضا هذه المولدات لديها تكلفة تشغيلية عالية نسبة لتكلفة الوقود.

ينصب التركيز الأساسي في هذا المشروع علي توليد الكهرباء باستخدام نظام هجين من الطاقة الشمسية – بمايعرف بالخلايا الفلطائية أو الكهروضوئية – وتوربينات الرياح. نظام الخلايا الكهروضوئية هو عبارة عن نظام يحول ضوء الشمس المباشر الي تيار كهربائي مستمر باستخدام الواح يتم تصنيعها من مادة السيلكون، المعدن بالاضافة الي الزجاج تسمي بالالواح الشمسية. هناك بنك بطارية لتخزين الطاقة لاستخدامها في الليل او عندما يكون ضوء الشمس غير متوفر او طاقة الرياح غير كافية.

توربينات الرياح عبارة عن ماكينات دوارة تعمل علي تحويل الطاقة الحركية الي طاقة ميكانيكية، وتسمي بتوربينات مولدة للطاقة عندما يتم ربطها بمولدات تعمل بسرعات ثابتة أومتغيرة، هذه المولدات تعمل علي تحويل الطاقة الميكانيكية الي طاقة كهربائية، كما تسمي بحقل رياح عندما توضع في شكل مجموعة من التوربينات في مكان واحد.

مولدات الديزل التي ادخلت في هذا النظام تعتبر وحدات احتياطية، فانها تعمل فقط عند فشل النظام الهجيني في توفير الكهرباء للتحميل. وترتبط مع ناقل التبديل التلقائي. استخدام هذه التقنية يقلل من انبعاث غاز ثاني أكسيد الكربون.

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LIST OF ABBREVIATIONS

AC	Alternative Current
Ah	Ampere Hour
ATS	Automatic Transfer Switch
DC	Direct Current
DG	Diesel Generator
GHI	Global Horizontal Irradiation
GW	Gega Watt
Isc	Short Circuit Current
KW	Kilo Watt
LDV	Low Voltage Disconnect
NASA	National Aeronautics and Space Administration
MW	Mega Watt
P	Power
PCU	Power Conditioning Unit
PV	Photovoltaic
PW	Peta Watt
TWh	Tera Watt hour
UN	United Nations
V	Volt
W	Watt
WP	Watt Peak
WECS	Wind Energy Conversion System
ETAP	Electrical Transient and Analysis Program
PW	Peta Watt
CIS	Copper Indium Dieseline
CdTe	Cadmium Telluride
HAWT	Horizontal-Axis Wind Turbines

VAWT	Vertical-Axis Wind Turbines
DFIG	Doubly Fed Induction Generator
SCIG	Squirrel Cage Induction Generator
SG	Synchronous Generators
WRSG	Wound Rotor Synchronous Generators
PMSG	Permanent Magnet Synchronous Generators
THM	Tap Head Mass
HP	Horse Power
WH	Watt Hour

List of Symbols

P	Turbine power coefficient
P	Air density, kg/m3
A	Rotor swept area, m2
D	Rotor blade diameter, m
V	Mean wind speed, m/s

CHAPTER ONE

INTRODUCTION

1.1 Overview

As the world’s demand for electricity grows, rural areas in developing nations once without energy will soon have accesses to options that were inaccessible before. More importantly, where nations with established grids cling to old technology for power generation, the developing nations can assess a multitude of choices for their energy needs. Renewable energy is one area that continues to evolve and solidify its places as a viable option for power generation. While supranational organizations such as the U.N. enact policies to limit carbon emissions and curb global warming, these developing nations and the populations within can now make the decision to aid in this progression.

Electricity generation from solar photovoltaic technology globally has increased tremendously over the past 20 years. From an average annual demand of only 21MW in 1985, it grew to 1460MW in 2005 and 1744MW in 2006 [1], with cumulative global deployment estimated at 7.204GW in the same year. Solar energy utilization in power supply is expected to reach 119TWh in 2030 and over 80% of this is projected to come from photovoltaic's, with the rest coming from solar thermal power plants [2]. These are however expected to be grid-connected applications.

Solar systems merits are indicated in the low operational costs; obviously no need for continuous maintenance because there are no moving parts in the system and no fuel is being consumed.

Solar systems demerits are indicated in the high capital costs, but now researches are being developed to reduce these costs, obviously solar systems produce an excellent choice for remote area power demand which is off-grid, because the costs to join these areas to the grid will cost more times higher than the capital cost of such solar systems.

Wind energy has been used for hundreds of years for milling grains, pumping water, and sailing the seas. The use of windmills to generate electricity can be traced back to the late nineteenth century with the development of a 12 kW DC windmill generator [3]. It is, however, only since the 1980s that the technology has become sufficiently mature to produce electricity efficiently and reliably. Over the past two decades, a variety of wind power technologies have been developed, which have improved the conversion efficiency of and reduced the costs for wind energy production. The size of wind turbines has increased from a few kilowatts to several megawatts each. In addition to on-land installations, larger wind turbines have been pushed to offshore locations to harvest more energy and reduce their impact on land use and landscape. This chapter provides an overview of solar energy system and wind energy conversion systems (WECS) with their related technologies.

1.2 Problem Statement

Sudan is a country located in northeastern of Africa, on the real side: the country faces a serious problem of instability of electricity supply especially in the capital and the main big cities. The hydro-power generators could not feed their rated electricity supply mainly in the rainy season – June to October - because of the accumulation of the mud in the dams. There are some other factors that make the problems of electricity supply and demand in urban areas bigger than similar problems in rural areas, such as the increase of population and building density.

Some of the most important considerations in electrifying areas far away from the national grid are the capital and operational costs of powering them with electricity. Obviously connecting these areas with the national grid costs more than using alternative resources such as photovoltaic and wind systems due to that photovoltaic and wind systems require no operational cost. The purpose of this project is to design a hybrid photovoltaic/wind system to supply a small rural area far from the grid with electrical power.

1.3 Objectives

The main objectives of this project are:

1. Design an appropriate hybrid solar/wind system for the electrification of Wad Shukab village.

2. Increase the standard of living of the villagers economically, socially and culturally.

3. Raise the academic level of the village students by supplying light and protection from gases caused by the conventional lighting methods.

4. Future recommendation for improvement.

1.4 Methodology

- Theoretical analysis of hybrid system.
- Collecting data for proposed locations.
- Analysis of the wind/solar data of the location.
- Design and modeling of hybrid system.
- Simulation and testing the devised system through ETAP program.

1.5 Project Layout

This project is organized into five chapters and several appendices as following:

Chapter 1 (Introduction): This chapter explains the overview of Renewable energy generally. Also, explain the objective of this project.

Chapter 2 (Literature Review): This chapter provides description and explanation of solar and wind systems and their components.

Chapter 3 (Methodology): This chapter provides full description of the method used to design the system.

Chapter 4 (Standalone hybrid system design with simulation result): This chapter contains the design steps for the hybrid solar/wind power plant and contains the simulation using ETAP program, list of results that have been obtained in this chapter and comments on them..

Chapter 5 (Conclusion and future recommendations): This chapter summarizes the work that has been done in this project also it contains future recommendations to be done In order to improve the system performance in future.

Appendix A: Shows the Sudan irradiation maps.

Appendix B: Shows the specifications of the selected equipments.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The sun is probably the most important source of renewable energy available today. Traditionally, the sun has provided energy for practically all living creatures on earth, through the process of photosynthesis. The solar energy is a highly familiar alternative clean energy type. The intensity of the sun’s irradiation that reaches the globe yearly is equivalent to 92 billion tons of petroleum. The Earth receives 174 petawatts (PW) of incoming solar radiation (insolation) at the upper atmosphere. Approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses. The spectrum of solar light at the Earth's surface is mostly spread across the visible and near-infrared ranges with a small part in the near-ultraviolet [4].

The spectrum of the Sun's solar radiation is close to that of a black body with a temperature of about 5,800 K. The Sun emits Electromagnetic radiation across most of the electromagnetic spectrum. Although the Sun produces Gamma rays as a result of the nuclear fusion process, these super-high-energy photons are converted by internal absorption and thermalization to lower-energy photons before they reach the Sun's surface and are emitted out into space. As a result, the Sun does not emit gamma rays, from this process, although it does produce gamma rays from solar flares. The Sun does also emit X-rays, ultraviolet, visible light, infrared, and even radio waves. The only direct signature of the nuclear process is the emission of neutrinos. Solar energy has two main types of systems that are used globally nowadays: the Solar Photovoltaic (PV) systems and the Solar Thermal systems. Figure 2.1 shows the sun light spectrum [4].

A wind energy conversion system (WECS) transforms wind kinetic energy to mechanical energy by using rotor blades. This energy is then transformed into electric energy by a generator. The system is made up of several components, participating directly in the energy conversion process. There are also other components that assist the system to achieve this task in a controlled, reliable, and efficient way. In order to beer understand the process of wind energy conversion, descriptions of the major parts of a wind turbine are given in this chapter. Since the energy source for a WECS is wind kinetic energy, wind speed plays a key role in several aspects of the conversion process, especially in relation to the maximum power output. Therefore, part of this chapter introduces basic concepts of and relations between wind speed and power captured by the blades. This provides the necessary insight to explain how the power output of a wind turbine can be regulated by adjusting the blade pitch angle or by controlling the generator's torque or speed. These power control methods are essential to ensure a maximum power output over a wide range of wind speeds. They also enable reliable and safe operation, protecting the mechanical and structural parts of the wind turbine from damage during strong wind gusts.

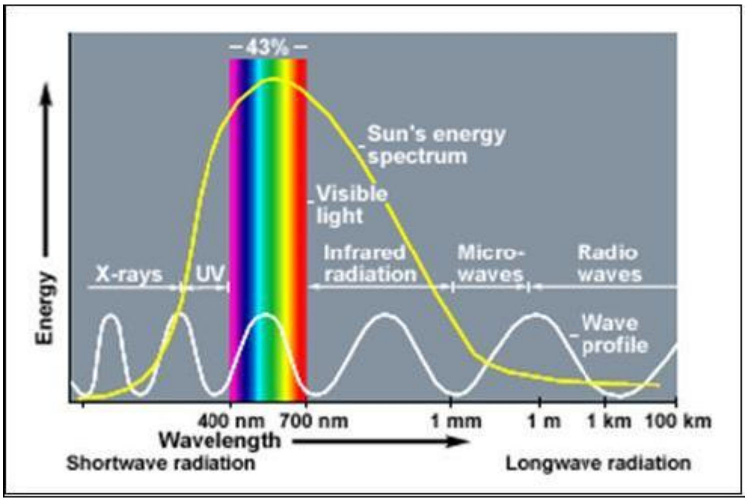


Figure 2.1: Sunlight Spectrum

2.2 Solar Energy

2.2.1 Advantages of Solar Energy

1. Solar energy is the world’s major renewable energy source and is available everywhere in different countries.
2. Photovoltaic panels do not have any moving parts, operate silently and generate no emissions.
3. The solar technology is highly modular and can be easily scaled to provide the required power for different loads.
4. Solar electric generation is economically competitive where grid connection or fuel transport is difficult, costly or impossible, such as satellites and island communities.
5. Once the initial capital cost of building a solar power plant has been met, operating costs are low when compared to conventional power technologies.
6. They are applicable for low-power uses such as solar powered garden lights and battery chargers [5].

2.2.2 Photovoltaic

Photovoltaic (PV) is the method of generating electrical power by converting solar radiation into direct current electricity using semiconductors and an effect called the photovoltaic effect. To generate electricity and make use of it using the Photovoltaic effect, an electrical device is needed to do the conversion process of light into electricity called the Photovoltaic Cell (also called the Solar Cell).

2.2.2.1 Photovoltaic Effect

The photoelectric effect was first noted by a French physicist, Edmund Becquerel, in 1839, who found that certain materials would produce small amounts of electric current when exposed to light. Albert Einstein won a Nobel Prize in 1921 due to his description of the nature of light and the photoelectric effect on which photovoltaic technology is based. In simple terms, the photovoltaic effect describes the conversion of light into an electric current. To describe this mechanism more formally, it is best to think of light in terms of a stream of photons where each photon carries one quantum of energy [6].

2.2.2.2 Photovoltaic Cell

Photovoltaic cell or solar cell is a device which converts the light energy into electrical energy. When light is allowed to fall on this cell, the cell generates a voltage across its terminals. This voltage increases with the increase in light intensity. The cell is so designed that a large area is exposed to light which enhances the voltage generation across the two terminals of the cell.

The solar cell essentially consists of a silicon PN junction diode with a glass window on top surface layer of P material is made extremely thin so, that incident light photons may easily reach the PN junction. When these photons collide with valence electrons, they comport them sufficient energy as to leave their parent atoms. In this way free electrons and holes are generated on both sides of the junction. Due to these holes and electrons current is produced. This current is directly proportional to the illumination, and also depends on the size of the surface area being illuminated [7]. Figure 2.2 shows the solar cell.

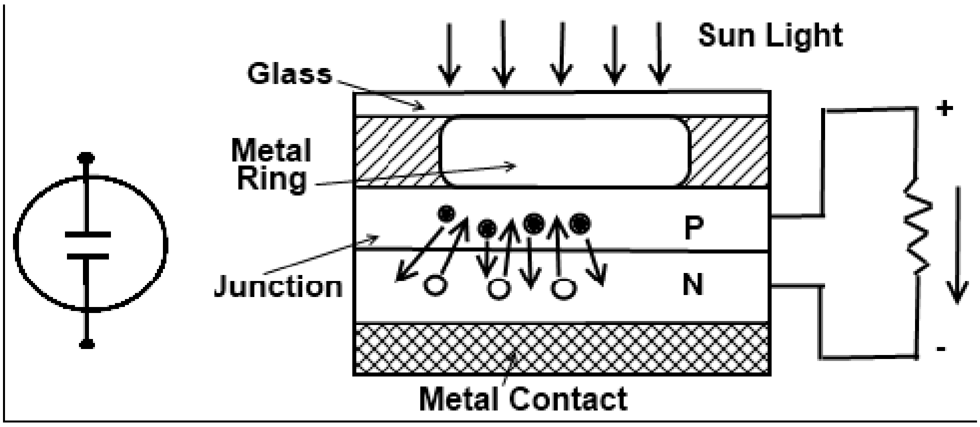


Figure 2.2: Solar Cell

The P-Type material is made very thin and wide so that the incident light photon may easily reach to PN junction. The P nickel plated ring around the P layer acts as the positive output terminals (anode), and the metal contact at the bottom acts as a Cathode. Silicon and germanium are the most widely used semiconductors materials for solar cells, although gallium arsenide, Indium arsenide and Cadmium arsenide are also being used nowadays.

In a crystal of pure silicon, the atoms form a lattice. These atoms, like any others, have nucleus which includes positive charged protons, while around the nucleus are negatively charged electrons in layers or shells. The outer shell of electrons is not full, so neighboring atoms share electrons and hold each other together in the crystal. These electrons are held quite firmly in place and do not readily move around.

However, the pure silicon crystal can be "doped" with a different element (i.e. small amounts of an "impurity" are added). If the doping is done with an element that has more electrons in its outer shell than silicon, there will be negatively charged electrons that are free to move around, and this is called "n-type" silicon. This material will conduct electricity much better than pure silicon as these spare electrons are free to move, then semiconductor is created. The crystal does not have an overall negative charge, however as the negative electrons are still balanced by positive protons in the nucleus. If instead, the silicon is doped with an element having fewer electrons in its outer shell, there will be an overall shortage of electrons, and the material will be p-type silicon. The minute areas where electrons are effectively missing are called holes, and these holes can also freely move around.

In a solar cell, there will be both n-type and p-type silicon in contact with each other. Electrons will move across from the n-type to the p-type at their junction as they will be attracted to the nearby holes. Once this has happened at the junction, this area acts a barrier, stopping further electrons moving across and an electric field exists across the junction. Figure 2.3 shows the silicon P-N junction.

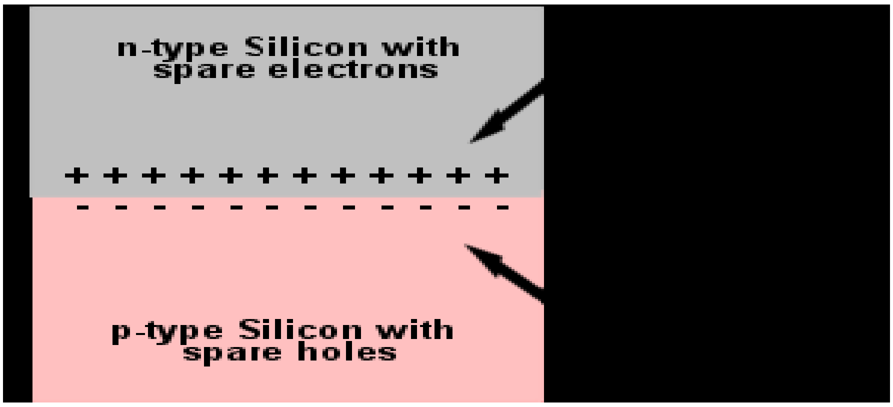


Figure 2.3: Silicon P-N Junction

If light energy is absorbed by the cell, the energy will push electrons across the junction and, if an electrical circuit is made between the two silicon types, the electrons will flow through it, back to where they came from, and continue to do so.

The flow of electrons (in other words, the electric current) can be made to work on the way round (i.e. charging batteries). This type of cell may be 15-20% efficient, partly due to the silicon wafers not absorbing all the light energy. A more sophisticated type of cell, known as a Multi-Junction Cell, may have further wafer pairs above or below, using different doping chemicals, each able to absorb different wavelengths of light [7].

2.2.3 Photovoltaic System

A PV system is the system that uses the photovoltaic effect to convert the solar radiation into electricity depending on the PV effect. PV system in its simplest form may contain an array of PV modules, one or more DC to AC power converter (inverter), electrical wiring, and either batteries with a charge controller or no batteries to store energy.

Solar systems can be small PV system which is capable of providing enough AC electricity to power a single home, or even an isolated device in the form of AC or DC electric (rooftop systems), or it can be large grid-connected PV power system capable of providing an energy supply for multiple consumers, or even off-grid plants to supply villages or small towns .

2.2.4 Photovoltaic System Components

PV systems -with their different sizes, applications and usages- usually consist of the following components:

2.2.4.1 Photovoltaic Modules

A PV module is a group of solar PV cells connected in series or parallel in one oriented plane to construct one panel. Each module is rated by its DC output. The PV module is considered as the main component of the PV system, as it's converts the sun light into DC current. A typical PV module is shown in Figure 2.4.

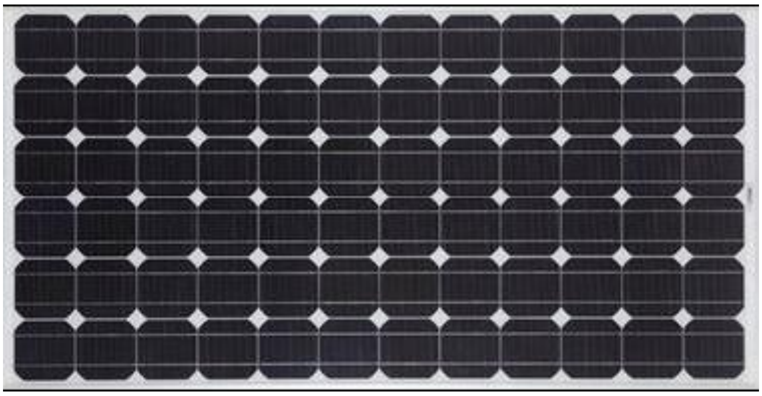


Figure 2.4: PV module

PV modules often have a sheet of glass on the front (sun up) side, allowing light to pass while protecting the semiconductor wafers from abrasion and impact due to wind-driven debris, rain and hail.

Solar cells are also usually connected in series in modules, creating an additive voltage while connecting cells in parallel will yield a higher current. However, very significant problems exist with parallel connections. For example, shadow effects can shut down the weaker (less illuminated) parallel string (a number of series connected cells) causing substantial power loss. Although modules can be interconnected to create an array with the desired peak DC voltage and loading current capacity.

By far, the most prevalent bulk material for solar cells is crystalline silicon (c-Si), also known as "solar grade silicon". Bulk silicon is separated into multiple categories according to crystallinity and crystal size in the resulting ingot, ribbon, or wafer. Figure 2.5 shows the PV (cell-module-array).

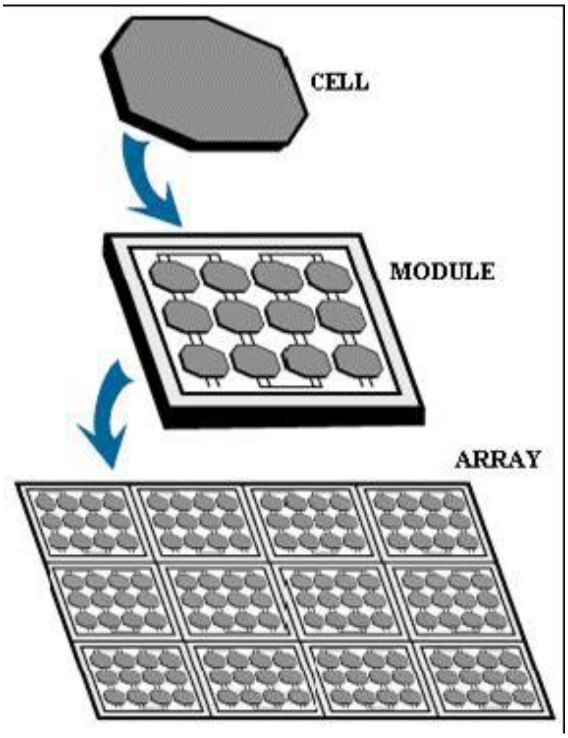


Figure 2.5: PV (Cell – Module – Array)

There are four main types of photovoltaic solar panels for both commercial and residential use. They are:

i. Monocrystalline.
ii. Polycrystalline.
iii. Amorphous Silicon.
iv. Mono-like Multicrystalline.

All four types of solar panels have both advantages and disadvantages depending on the user's budget, the size and type of environment where they are used and the expected output of the system.

a) MonocrystallineCells:

Made of large silicon crystal, single-crystal wafer cells tend to be expensive, and because they are cut from cylindrical ingots, do not completely cover a square solar cell module without a substantial waste of refined silicon. Hence most c-Si panels have uncovered gaps at the four corners of the cells [8]. Figure 2.6 shows the Mono-crystalline PV cell.

Figure 2.6: Mono-crystalline PV Cell

b) Polycrystalline Cells:

Also called multi-crystalline silicon (poly-Si or mc-Si). Characterized by its shattered glass look because of the manufacturing process of using multiple silicon crystals. They are made from cast square ingots, large blocks of molten silicon carefully cooled and solidified. Poly-Si cells are less expensive to produce than single crystal silicon cells, but are less efficient [8]. Figure 2.7 shows Polycrystalline PV Cell.

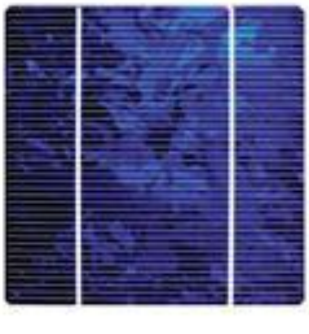


Figure 2.7: Polycrystalline PV Cell

c) Amorphous Silicon Cells:

These panels can be thin and flexible which is why they are commonly referred to as "Thin Film" solar panels. Amorphous silicon solar panels are common for building integrated photovoltaic applications because of their many application options and aesthetics. They are cheaper and are not affected by shading. Drawbacks are low efficiency; loss of wattage per sq. ft. installed and heat retention. They can be manufactured using silicon, copper indium dieseline (CIS) or cadmium telluride (CdTe) [8].

Figure 2.8: Amorphous Silicon (Thin Film) PV Cell

d) Mono-like Multi-crystalline Cells:

Developed in the 2000s and introduced commercially around 2009, mono-like-multi, or cast-mono, uses existing polycrystalline casting chambers with small "seeds" of mono material. The result is a bulk mono-like material with poly around the outsides. When sawn apart for processing, the inner sections are high-efficiency mono-like cells (but square instead of "clipped"), while the outer edges are sold off as conventional poly. The result is line that produces mono-like cells at poly-like prices [8].

Figure 2.9: Mono-like Multi-crystalline PV Cell

2.2.4.2 Batteries

In photovoltaic power systems, the electrical energy produced by the PV panels cannot always be used directly. As the demand from the load does not always equal the solar panel capacity. Battery banks are generally used to store electrical energy when it’s not being used.

PV systems increasingly use rechargeable batteries to store a surplus to be later used at night. Batteries used for grid-storage also stabilize the electrical grid by leveling out peak loads, and play an important role in a smart grid, as they can charge during periods of low demand and feed their stored energy into the grid when demand is high.

Common battery technologies used in today's PV systems include, the valve regulated lead-acid battery a modified version of the conventional lead–acid battery, nickel– cadmium and lithium-ion batteries. Compared to the other types, lead-acid batteries have a shorter lifetime and lower energy density. However, due to their high reliability, low self-discharge as well as low investment and maintenance costs, they are currently the predominant technology used in small-scale, residential PV systems, as lithium-ion batteries are still being developed and about 3.5 times as expensive as lead-acid batteries. Furthermore, as storage devices for PV systems are used stationary, the lower energy and power density and therefore higher weight of lead-acid batteries are not as critical as, for example, in electric transportation [9].

Other rechargeable batteries that 2are considered for distributed PV systems include, sodium–sulfur and vanadium redox batteries, two prominent types of a molten salt and a flow battery, respectively. Batteries that are able to handle the constant charging and discharging are known as deep-cycle batteries. Batteries need to have a good charging efficiency, low charging currents and low self-discharge. Under ideal conditions a new deep-cycle battery would be 90% efficient [9].

The important characteristics to look for are:

i) Capacity
ii) Cycle life / price / performance
iii) Size and space requirements
iv) Efficiency
v) Self-discharge rate
vi) Installation - vertical or horizontal
vii) Environmental - will batteries be placed in high temperatures, near water supplies or in wildlife parks … etc.

2.2.4.3 Inverter

A power inverter, or inverter, is an electronic device or circuitry that changes direct current (DC) to alternating current (AC).

The input voltage, output voltage, frequency, and overall power handling depend on the design of the specific device or circuitry. The inverter does not produce any power; the power is provided by the DC source .The DC input to the inverter can be from any of the following sources:

- Rectified DC output of the variable speed wind power system or generators.
- DC output of the photovoltaic power modules.
- DC output of the battery used in photovoltaic power system.

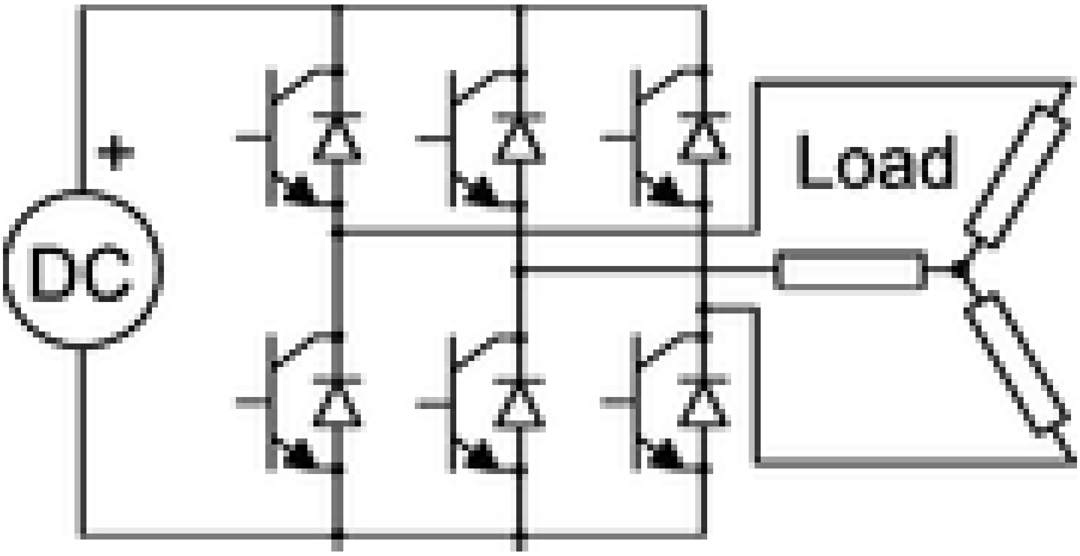


Figure 2.10: Three Phase Inverter Circuit

Mainly Solar inverters may be classified into three broad types:

- Stand-alone inverters: used in isolated systems where the inverter draws its DC energy from batteries charged by PV arrays. Many stand-alone inverters also incorporate integral battery chargers to recharge the battery from an AC source, when available. Normally these do not interface in any way with the utility grid.

- Grid-tie inverters: which match phase with a utility supplied sine wave. Grid-tie inverters are designed to shut down automatically upon loss of utility supply, for safety reasons. They do not provide backup power during utility outages.

- Battery backup inverters: are special inverters which are designed to draw energy from a battery, manage the battery charge via an onboard charger, and export excess energy to the utility grid. These inverters are capable of supplying AC energy to selected loads during a utility outage [10].

2.2.4.4 Charge Controller

The charge controller is a necessary part of any power system that charges batteries, whether the power source is PV, wind, hydro, fuel, or utility grid. Its purpose is to keep the batteries properly fed and safe for the long term.

A charge controller is an electronic voltage regulator, used in off-grid systems and grid-tie systems with battery backup that controls the flow of power from the charging source to the battery. The charge controller automatically tapers, stops, or diverts the charge when batteries become fully charged.

The most important feature of charge controller is to measure the battery voltage and protects the battery against the overcharging. This can be achieved by the following ways: Switching off the source when the charge cut-out voltage is exceeded.

Short-circuiting the PV array with a shunt controller and adjusting the voltage.

The reserve diode which prevents the battery to be discharged via the array during low irradiation level is integrated to the charge controller. Operation of batteries over long time of operation requires a charge controller to be flexible. The charge cut-off and discharge cut-off voltages are dependent on the state of charge of the battery.

The main jobs of the charge controller are:

1- Allow the optimum charge for the battery.
2- Protect the battery from the overcharge.
3- Prevent the battery from unwanted discharge and from deep discharge.
4- Get information of state of charge of batteries.

In case of hybrid system with common DC bus to provide batteries in order to insure sustainability the charge controller work will be :

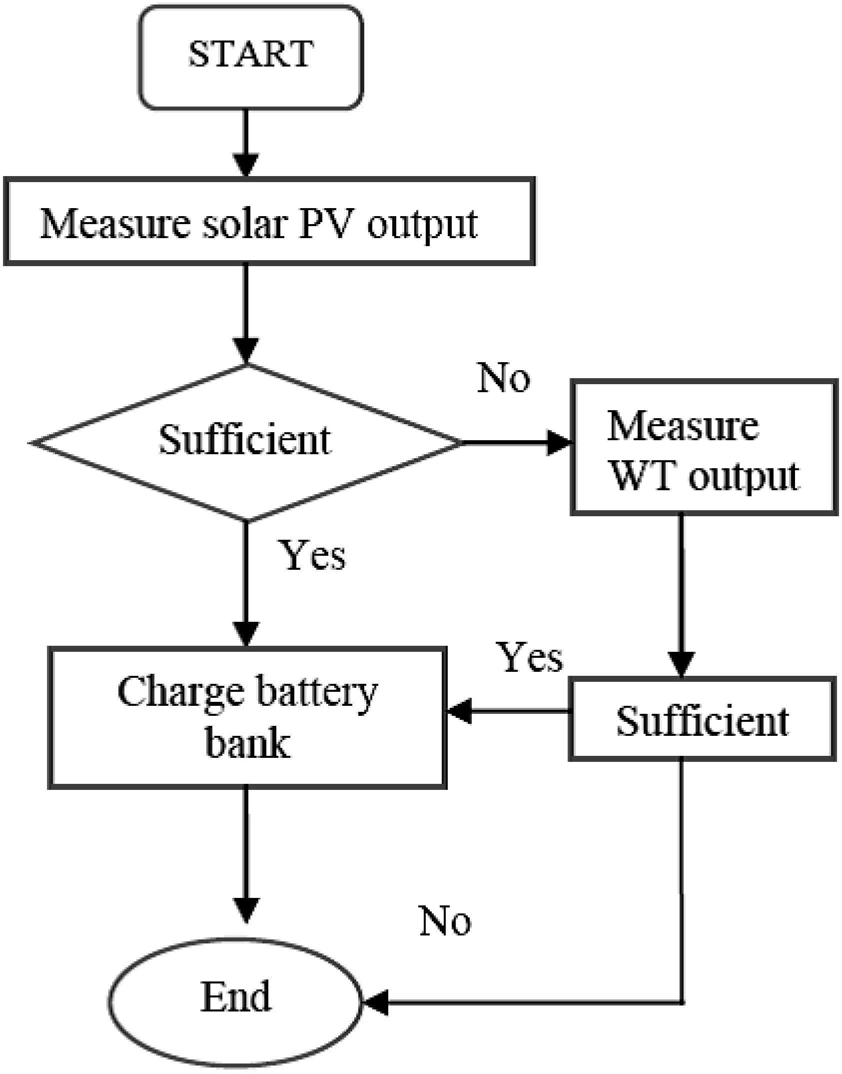


Figure 2.11: Flow diagram of the controller algorithm

Some charge controllers have additional features, such as a low voltage disconnect (LDV), which preventing completely draining "deep discharging" a battery that may entirely ruin some batteries. Also they perform controlled discharges, depending on the battery technology, to protect battery life. The terms "charge controller" or "charge regulator" may refer to either a stand-alone device, or to control circuitry integrated within a battery pack, battery-powered device, or battery recharger.

Charge controllers may also monitor battery temperature to prevent overheating. Some charge controller systems also display data, transmit data to remote displays and data logging to track electric flow over time.

2.3 Wind Energy

2.3.1 Horizontal and Vertical Axis Wind Turbines

Wind turbines can be categorized based on the orientation of their spin axis into horizontal-axis wind turbines HAWT and vertical-axis wind turbines VAWT [11], as shown in Figure (2.12). In horizontal-axis wind turbines, the orientation of the spin axis is parallel to the ground as shown in Figure (2.12). The tower elevates the nacelle to provide sufficient space for the rotor blade rotation and to reach beer wind conditions. The nacelle supports the rotor hub that holds the rotor blades and also houses the gearbox, generator, and, in some designs, power converters. The industry standard HAWT uses a three blade rotor positioned in front of the nacelle, which is known as upwind configuration. However, downwind configurations with the blades at the back can also be found.

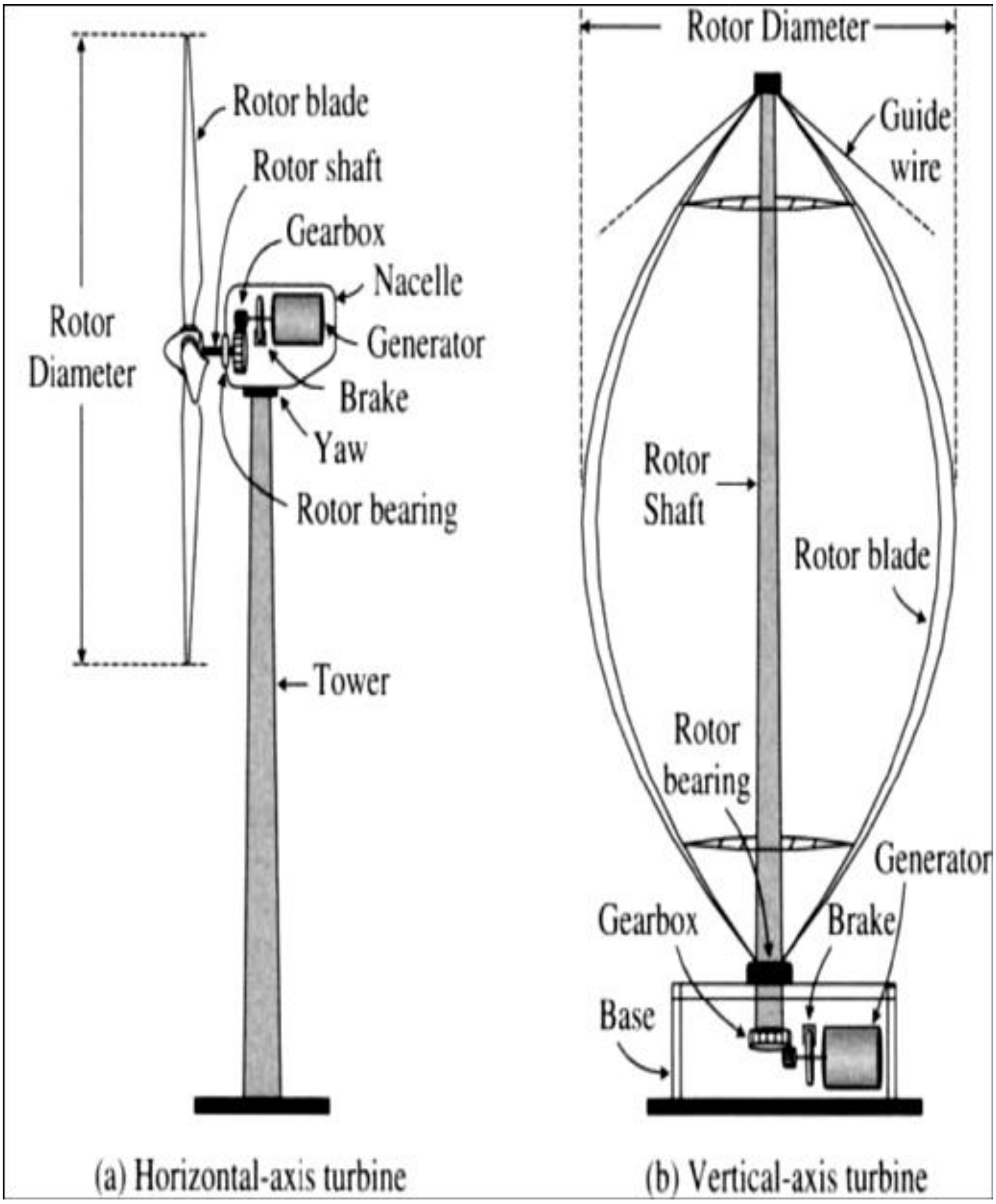


Figure 2.12: Horizontal and vertical axis wind turbines.

In practical applications, turbines with one, two, or more than three blades can also be seen in wind farms. In vertical-axis wind turbines, the orientation of the spin axis is perpendicular to the ground. The turbine rotor uses curved vertically mounted airfoils. The generator and gearbox are normally placed in the base of the turbine on the ground, as shown in Figure (2.13) . The rotor blades of the VAWT have a variety of designs with different shapes and number of blades. The design given in the figure is one of the popular designs. The VAWT normally needs guide wires to keep the rotor shaft in a fixed position and minimize possible mechanical vibrations.

A comparison between the horizontal and vertical-axis turbine technologies is summarized in Table (2.1). The HAWT features higher wind energy conversion efficiency due to the blade design and access to stronger wind, but it needs a stronger tower to support the heavy weight of the nacelle and its installation cost is higher. On the contrary, the VAWT has the advantage of lower installation costs and easier maintenance due to the ground-level gearbox and generator installation, but its wind energy conversion efficiency is lower due to the weaker wind on the lower portion of the blades and limited aerodynamic performance of the blades. In addition, the rotor shaft is long, making it prone to mechanical vibrations. It is these disadvantages that hinder the practical application of vertical-axis turbines for large-scale wind energy conversion. Horizontal-axis turbines dominate today's wind market, especially in large commercial wind farms.

Table (2.1): Comparison between horizontal – and vertical – axis wind turbine.

Turbine type	Advantage	Disadvantages
HAWT	Higher wind energy conversion efficiency	Higher installation cost, stronger tower to
	Access to stronger wind due to high tower.	Longer cable from the top tower to ground.
	Power regulation by stall and pitch angle control at high wind speeds.	Orientation required (yaw control).

VAWT	Lower installation cost and easier maintenance due to the ground-level gearbox and generator	Lower wind energy conversion efficiency.
	Operation independent of wind direction.	Higher torque fluctuations and prone to mechanical vibrations.
	Suitable for rooftops (stronger wind without need of tower)	Limited options for power regulation at high wind speed

2.3.2 Wind Turbine Components

A wind turbine is composed of several parts to achieve kinetic-to electric energy conversion. The side view of a typical wind turbine is shown in Figure (2.13). There are several variants to this layout of components, particularly for direct-drive (gearless) wind turbines. Nonetheless, the figure serves as a general reference to locate and describe the different parts in modern wind turbines. The wind kinetic energy is converted to mechanical energy by the blades mounted on the rotor hub. The rotor hub is installed on the main shaft, also known as the low speed shaft. The mechanical energy is transmitted through the drive train (shafts, bearings, and gearbox) to the generator, which converts mechanical energy into electric energy. This conversion is usually assisted by a power converter system which delivers the power from the generator to the grid. Most of the wind turbine components are enclosed in a nacelle on top of the tower. There are other parts that are not directly involved in the power conversion but are important to ensure the proper, efficient, and reliable operation of the system. Examples include the pitch system, yaw system, mechanical brake, wind speed and direction sensors, power distribution cables, heat dissipation/exchange system, lightning protection system, and structural components such as the tower, foundation, and nacelle enclosure. Large wind turbines are also equipped with an uninterruptable power supply or backup energy system that ensures uninterrupted operation of essential parts such as the control system, pitch drive, and brakes. In direct-drive (gearless) turbines, the absence of the gearbox and high-speed shaft leads to a more compact drive train and, hence, a shorter nacelle. However, the wider diameter of low-speed generators requires a taller nacelle structure. This phenomenon is more evident in wound rotor synchronous generators than permanent-magnet synchronous generators.

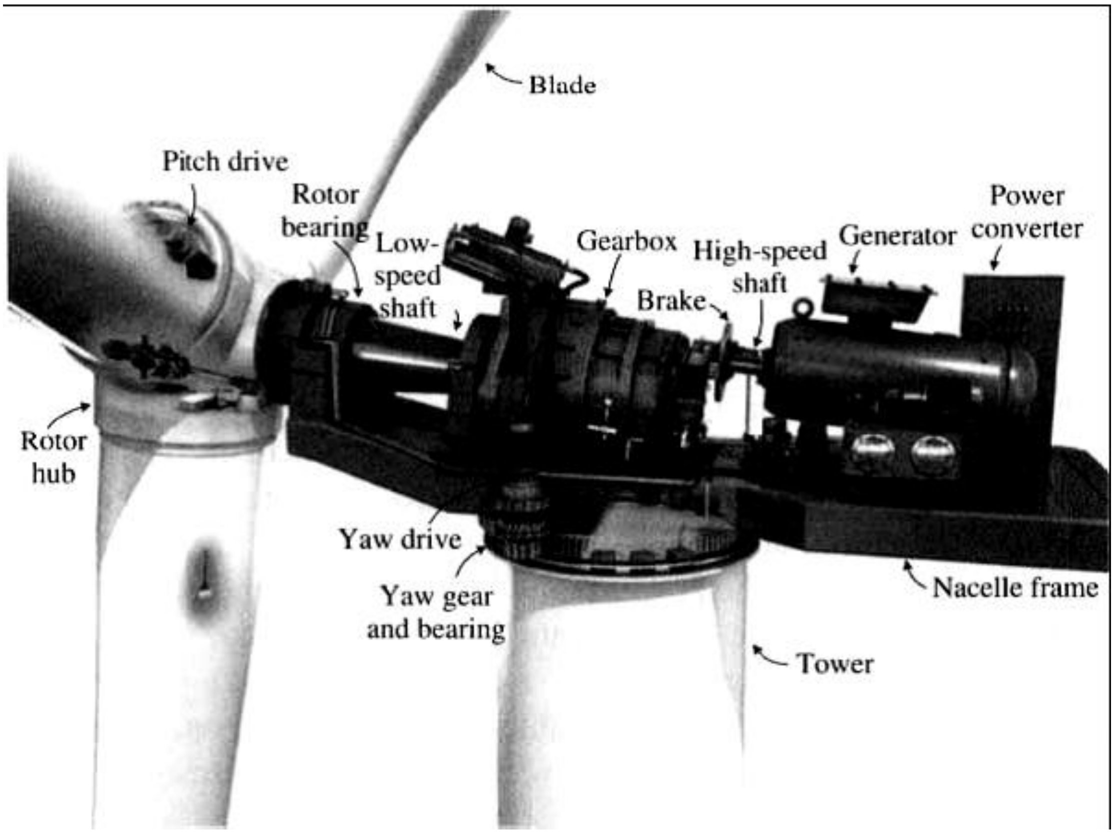


Figure 2.13: Main components of a wind turbine.

2.3.2.1 Turbine Blade

The blade is the most distinctive and visible component of a wind turbine. It is also responsible for carrying out one of the most essential tasks of the energy conversion process: transforming the wind kinetic energy into rotational mechanical energy. Blades have greatly evolved in aerodynamic design and materials from the early windmill blades made of wood and cloth. Modern blades are commonly made of aluminum, fiberglass, or carbon-fiber composites that provide the necessary strength-to-weight ratio, fatigue life, and stiffness while minimizing the weight [12]. Although single- and two-bladed wind turbines have found practical applications, the three-blade rotor is considered the industry standard for large wind turbines.

Turbines with fewer blades operate at higher rotational speeds. This is an advantage from the drive train point of view since they require a gearbox with a lower gear ratio, which translates into lower cost. In addition, fewer blades imply lower costs. However, acoustic noise increases proportionally to the blade p speed. Therefore, acoustic noise is considerably higher for single- and two-bladed turbines, which is considered an important problem, particularly in populated areas. Singe-blade turbines have an asymmetrical mechanical load distribution. The turbine rotors are aerodynamically unbalanced, which can cause mechanical vibrations. Moreover, higher rotational speed imposes more mechanical stress on the blade, turbine structure, and other components, such as bearings and gearbox, leading to more design challenges and lower life span. Rotors with more than three blades are not common since they are more expensive (more blades). Operating at lower rotational speeds requires a higher 25 gear ratio. The lagging wind turbulence of one blade can affect the other blades since they are closer to each other. Hence, the three-blade rotor presents the best trade-off between mechanical stress, acoustic noise, cost, and rotational speed for large wind turbines.

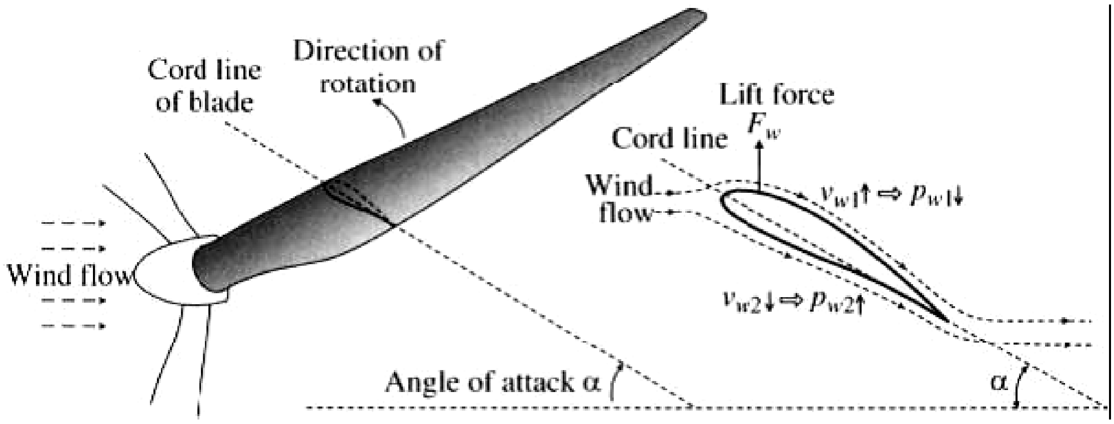


Figure 2.14: Wind turbine blade aerodynamics and angle of attack.

2.3.2.2 Pitch Mechanism

The pitch mechanism in large wind turbines enables the rotation of the blades on their longitudinal axis. It can change the angle of attack of the blades with respect to the wind, by which the aerodynamic characteristics of the blade can be adjusted. This provides a degree of control over the captured power to improve conversion efficiency or to protect the turbine. When the wind speed is at or below its rated value, the angle of attack of the blades is kept at an optimal value, at which the turbine can capture the maximum power available from the wind. When the wind speed exceeds the rated value, the pitch mechanism is activated to regulate and limit the output power, thus keeping the power output within the designed capability. For this purpose, a pitch range of around 20 to 25 degrees is usually sufficient. When the wind speed increases further 26 and reaches the limit of the turbine, the blades are completely pitched out of the wind (fully pitched or feathering), and no power will be captured by the blades. The wind turbine is then shut down and protected. The pitch mechanism can be either hydraulic or electric. Electric pitch actuators are more common nowadays since they are simpler and require less maintenance. Traditionally, all blades on the rotor hub are pitched simultaneously by one pitch mechanism. Modern wind turbines are often designed to pitch each blade individually, allowing an independent control of the blades and offering more flexibility. The pitch system is usually placed in the rotor hub together with a backup energy storage system for safety purposes (an accumulator for the hydraulic type or a battery for the electric type). An electric pitch mechanism is shown in Figure (2.14), where the three motor drives and pitch gears can be seen inside the rotor hub.

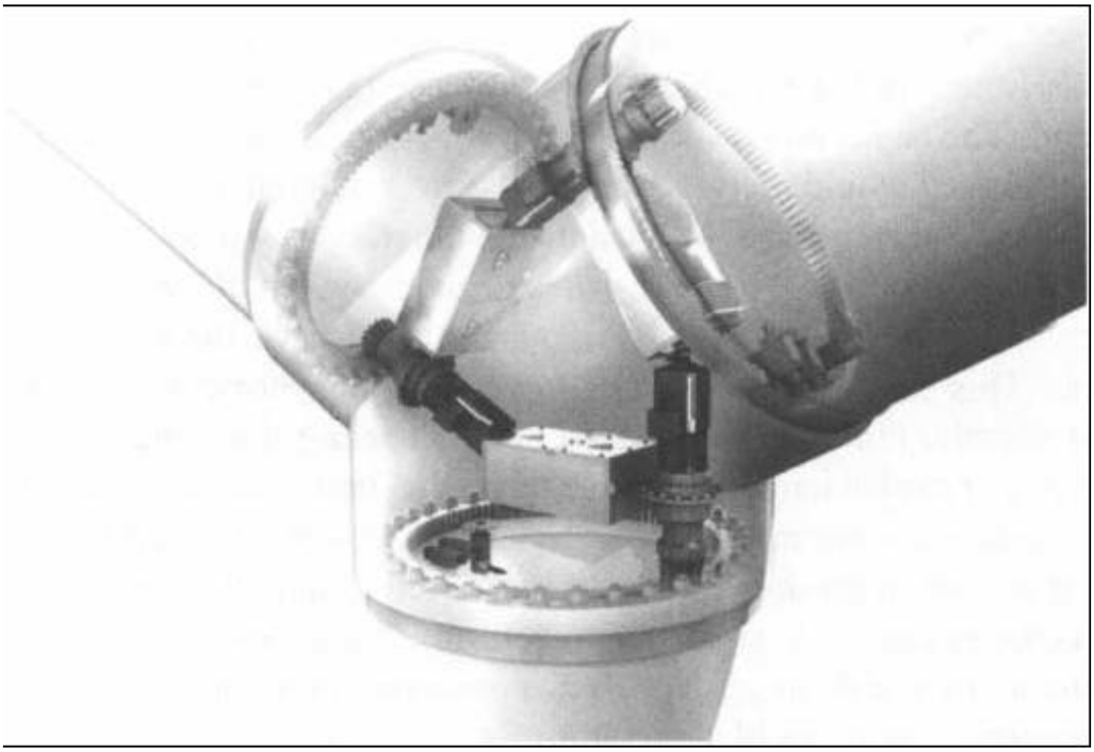


Figure 2.15: Blade pitch system with three pitch drives and gears.

2.3.2.3 Gearbox

The rotor of a large three-blade wind turbine usually operates in a speed range from 6-20 rpm. This is much slower than a standard 4- or 6-pole wind generator with a rated speed of 1500 or 1000 rpm for a 50 Hz stator frequency and 1800 or 1200 rpm for a 60 Hz stator frequency. Therefore, a gearbox is necessary to adapt the low speed of the turbine rotor to the high speed of the generator. The gearbox conversion ratio (also known as the gear ratio), is designed to match the high-speed generator with the low-speed turbine blades. For a given rated speed of the generator and turbine.

the generator and turbine rated speeds in rpm, is the rated slip, is the rated stator frequency in Hz, and the number of pole pairs of the generator. The rated slip is usually less than 1% for large induction generators, and zero for synchronous generators. Considering the rated slip of 1% for an induction generator, the gear ratio as a function of the rated turbine speed is given in Figure (2.16) for different pole numbers and rated stator frequencies. The wind turbine gearboxes normally have multiple stages to achieve the high conversion ratio needed to couple the turbine rotor and generator .

The gearbox usually generates a high level of audible noise. The noise mainly arises from the meshing of individual teeth. The efficiency of the gearbox normally varies between 95% and 98%. The gearbox is a major contributor to the cost of the wind turbine in terms of initial investment and maintenance. Random changes in wind speed and strong wind gusts result in sudden load variations on the gearbox. These sudden changes produce wear and tear on the gearbox, reducing its life span. As a result, the gearbox needs regular maintenance. The elimination of the gearbox contributes to reliability improvements and cost reduction. In order to eliminate the gearbox, a generator with the same rated rotational speed of the turbine is required.

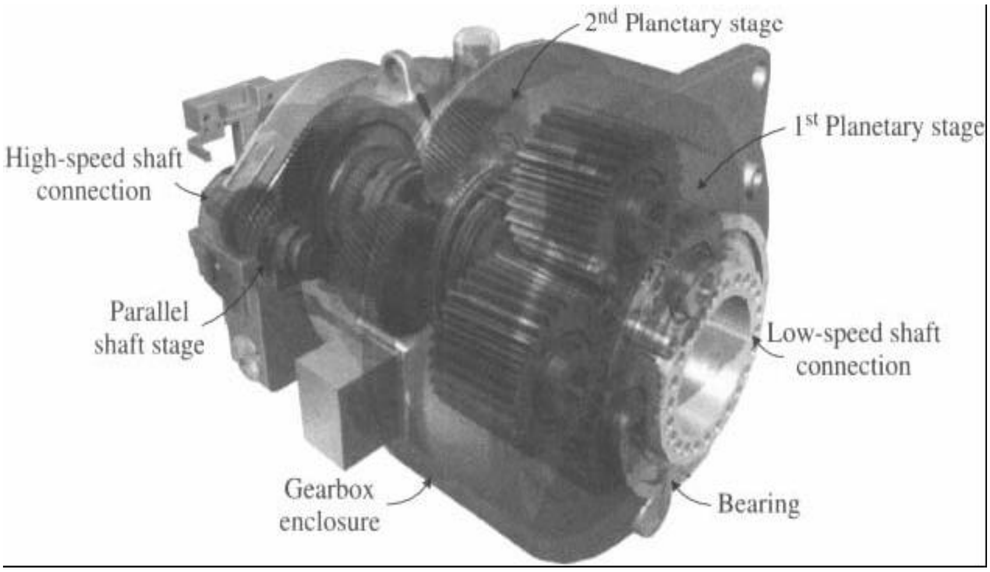


Figure 2.16:Gearbox of a large wind turbine.

This can be achieved by a low-speed generator. Gearless configurations have been adopted by several manufacturers due to the reduced cost, maintenance, audible noise, and power losses. Single-stage gearboxes have also been used in practical wind turbines. This is achieved by using a special medium-speed generator that has a proper number of poles and operates at certain stator frequencies. Compared with the multistage gearbox, the single-stage gearbox is more reliable and costs less.

2.3.2.4 Rotor Mechanical Brake

A mechanical brake is normally placed on the high-speed shaft between the gearbox and the generator, as shown in Figure (2.17), but there are some turbines in which the brake is mounted on the low-speed shaft between the turbine and gearbox. The main advantage of placing the brake on the high-speed shaft is that it handles much lower braking torque. The brake is normally used to aid the aerodynamic power control (stall or pitch) to stop the turbine during high speed winds or to lock the turbine into a parking mode during maintenance. Hydraulic and electromechanical disc brakes are often used [13].

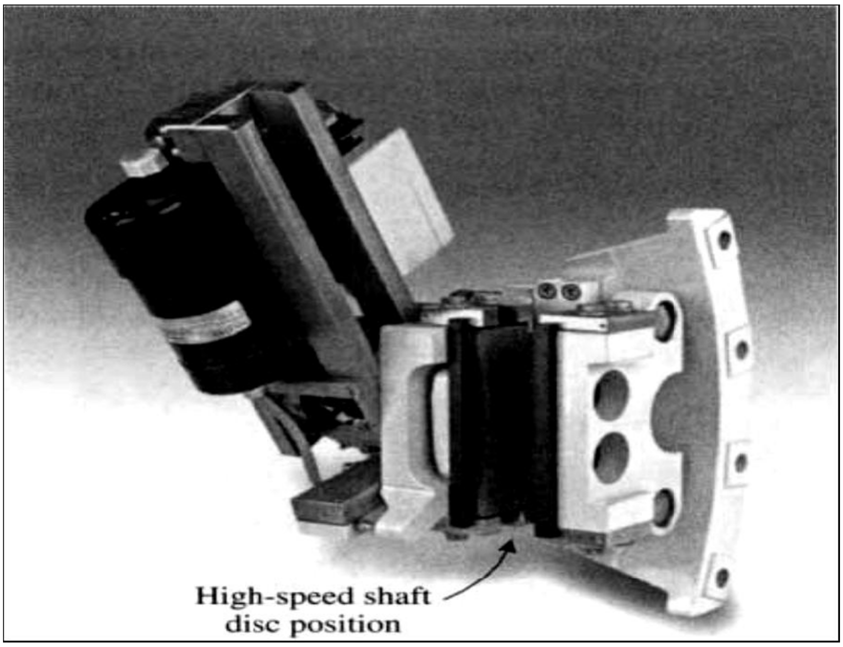


Figure 2.17: Electromechanical disc brake for high-speed shaft.

Figure (2.17) illustrates an electromechanical disc brake used on a high-speed shaft. To minimize the wear and tear on the brake and reduce the stress on drive train during the braking process, most large wind turbines use the aerodynamic power control to reduce the turbine speed to a certain level or zero, and then the mechanical brake to stop or lock the wind turbine.

2.3.2.5 Generator

The conversion of rotational mechanical energy to electric energy is performed by the generator. Different generator types have been used in wind energy systems over the years. These include the squirrel cage induction generator (SCIG), doubly fed induction generator (DFIG), and synchronous generator (SG) (wound rotor and permanent magnet) with power ranges from a few kilowatts to several megawatts [14].

The SCIG is simple and rugged in construction. It is relatively inexpensive and requires minimum maintenance. Traditional direct grid-connected wind energy systems are still available in today's market. All these turbines use SCIGs and operate at a fixed speed. Two-speed SCIGs are also commercially available, in which a tapped stator winding can be adapted to change the pole pairs to allow two-speed operation. An example of a 2 MW two-speed SCIG with 6/4 poles rated at 1000/1500 rpm. The SCIGs are also employed in variable-speed wind energy systems. The largest SCIG wind energy systems are around 3.5 MW in offshore wind farms.

The DFIG is the current workhorse of the wind energy industry. The stator of the generator is connected to the grid directly, while the rotor is interfaced with the grid through a power converter system with reduced power capacity. The DFIG typically operates about 30% above and below synchronous speed, sufficient for most wind speed conditions. It also enables generator-side active power control and grid-side reactive power control. The reduced-capacity converter is less expensive and requires less space, which makes the DFIG WECS popular in today's market.

The synchronous generator is very well suited for direct-drive wind turbines. Wound rotor synchronous generators (WRSGs) and permanent magnet synchronous generators (PMSGs) are used in wind energy systems with a maximum power rang up to 7.5 MW. Permanent magnet generators have higher efficiency and power density as compared to wound rotor generators. Recent trends indicate a move toward direct drive turbines with PMSG. Although most SG-based turbines are direct driven, some manufacturers have developed SG turbines with gearbox drive trains, and d for 4-pole and 120-pole PMSGs, respectively. A multi pole WRSG for a direct-drive WECS.

2.3.2.6 Tower and Foundation

The main function of the tower is to support the nacelle and the turbine rotor, and provide the rotor with the necessary elevation to reach beer wind conditions. Most towers for wind turbines are made of steel. Concrete towers or towers with a concrete base and steel upper sections are sometimes used as well. The height of the tower increases with the turbine power rang and rotor diameter. In addition, the tower must be at least 25 to 30 m high to avoid turbulence caused by trees and buildings. Small wind turbines have towers as high as a few blade rotor diameters. However, the towers of medium and large turbines are approximately equal to the turbine rotor diameter.

The highest tower to date is a 160 m steel lace tower for a 2.5 MW wind turbine. The tower also houses the power cables connecting the generator or power converters to the transformer located at the base of the tower. In some cases, the transformer is also included in the nacelle and the cables connect the transformer to the wind farm substation. In large multi megawatts turbines, the power converters may be located at the base of tower to reduce the weight and size of the nacelle. The stairs to the nacelle for maintenance are often attached along the inner wall of the tower in large wind turbines.

Special attention should be given to the structural dynamics in order to avoid vibration caused by the mechanical resonance modes of the wind turbine. The top head mass (THM) of the nacelle and the turbine rotor has a significant bearing on the dynamics of the tower and foundation. In practice, low THM is generally a measure of design for reduction of manufacturing and installation costs.

The wind turbine foundation is also a major component in a wind energy system. The types of foundations commonly used for on-land wind turbines include slab, multi pile, and mono pile types. Foundations for offshore wind turbines are particularly challenging since they are located at variable water depths and in different soil types. They have to withstand harsh conditions as well. This explains the wide variety of foundations developed over the years for offshore turbines, some more proven than others [13]. The gravity foundation and mono pile foundation are more common in shallow waters. The tripod, triple, and jacket foundations can reach greater depths, and are usually located farther away from the coastline. New technologies such as the floating (anchored) foundation are currently under development for more challenging water depths.

CHAPTER THREE

MOTHODOLOGY

3.1 Introduction

Photovoltaic power systems are generally classified according to their functional and operational requirements, their component configurations, and how the equipment is connected to other power sources and electrical loads. The two principal classifications are grid-connected or utility-interactive systems and stand-alone systems. Photovoltaic systems can be designed to provide DC and/or AC power service, can operate interconnected with or independent of the utility grid, and can be connected with other energy sources and energy storage systems. In this Hybrid System we will use it with wind energy system which is one of renewable energy source and can be utilized to generate electrical power and to drive water pump or other machineries. The output power of a wind turbine is determined by the aerodynamic force created by the interaction between the rotor blades and the wind practical horizontal axis wind turbine designs use airfoils to convert the kinetic energy inthe wind into useful electrical energy.

3.2 Wind/ Solar PV Systems

Wind /PV systems are designed to operate in parallel to supply the load. The primary component in PV systems is the inverter, or power conditioning unit (PCU). The PCU converts the DC power produced by the PV array into AC power consistent with the voltage and power quality requirements of the utility grid, and automatically stops supplying power to the grid when the utility grid is not energized. A bi-directional interface is made between the PV system AC output circuits and the electric utility network, typically at an on-site distribution panel or service entrance. This allows the AC power produced by the PV system to either supply on-site electrical loads or to back-feed the grid when the PV system output is greater than the on-site load demand. At night and during other periods when the electrical loads are greater than the PV system output, the balance of power required by the loads is received from the wind or back up generator This safety feature is required in all grid-connected PV systems, and ensures that the PV system will not continue to operate and feed back into the System when the system is down for service or repair [15].

3.3 System Sizing

System sizing is the process used for determining the minimum panel for wind generator rated power, solar cells and battery size needed to deliver the required electrical energy to the load.

As mentioned in the previous chapters, solar PV power is a concept of generating electricity from the sun light and converting it to the AC energy that we use in our daily lives. PV modules are installed on fixed metallic support structures arranged in long rows, adequately spaced themselves, facing south (in the Northern Hemisphere) with an appropriate tilt, or deployed on tracking devices to follow the sun. In this chapter an explanation of the methodology to design a hybrid PV/wind system, in order to apply it in a case study for a rural area in Sudan. This will be clear in the upcoming chapters.

In a brief description of the design, PV modules are electrically connected together in series or parallel configurations and then connected by charge controllers, which is connected to a battery bank. Then, connection goes though inverters in order to provide AC load with power. This power must be sufficient to cover the power consumption of the load.

But, the case of that the sun light may not be available sometimes must be taken into account. The unavailability of this source is caused due to several reasons, such as cloudy days, at night, or any other causes represented in failure of the PV modules to generate power. In such cases, if the batteries are unavailable to meet the demand of the load consumption and wind generator doesn't match the load demand, a standby generator should be used to supply electricity to the load. So the connection should go through an automatic transfer switch (ATS) in order to swap between the sources (PV/wind system and standby generator). Figure 3.1 below illustrates the schematic diagram of the hybrid PV/wind system.

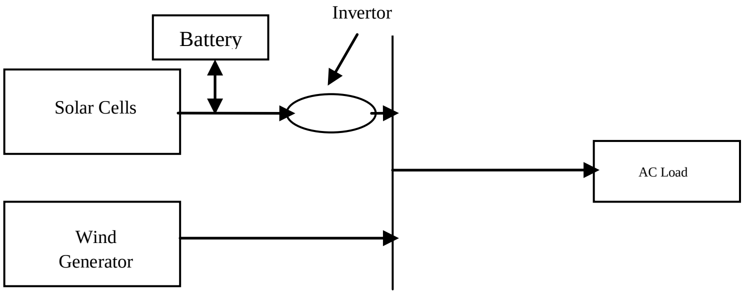


Figure 3.1: Hybrid Wind and Solar Power System

3.3.1 Load Estimation

The first step in designing a solar PV system is to find out the total energy consumption of all loads that needs to be supplied by the solar PV system. So we need to calculate the total power consumption demand (in Watt.hour per day) for each appliance used. This can be done by using table 3.1 to know the hourly consumption of each appliance used, in order to find out their daily consumption (in watt-h/day) according to the duration of using each one of them daily. The electrical loads in the house are small appliances such as TV, radio, lighting and refrigerator, as noted in table 3.1.

Table 3.1:The electrical loads in the house

Appliance	**Wattage / W**	**No. of hours for 1 KW consumption**
Light Bulb	10	100
Tube Light	40	18.11
Ceiling Fan	60	16.40
Fridge (165 liter)	85	5.40
Ironer	750	1.25
Submersible pump (1 hp)	746	1.25
TV 24"	70	14.28
Receiver	25	40
Mobile Charger	5	200

3.3.2 PV Array Sizing

After finding out the total (watt.h/day), calculations must be done to find the total energy required from the PV modules. This is done by multiplying the total appliances Watt.hours per day times 1.3 (the energy lost in the system) which increases the size of the PV array by 30%. This losing in the energy is caused by several reasons, such as temperature degradation, wiring and connection losses, in addition to other losses in batteries, inverters and controllers. Total losses around 30%, so the panel will produce enough Wh/day for the load plus more energy to cover the losses. Hence it will have to produce about 130% of the energy required by the load [16].

The primary load distribution is essential for the designing process because the variation of the load through the day and night will affect the number of PV panels, and hence the capacity of storage battery and inverter.

Also, one of the important factors in the PV power is the peak power. Peak power or Nominal power is determined by measuring the electrical current and voltage in a circuit, while varying the resistance under precisely defined conditions. 25 °C, light intensity is 1000 W/m2, the highest power thus measured is the 'nominal' power of the module in watts as shown in figure 3.2. Wp is the most common unit encountered [16].

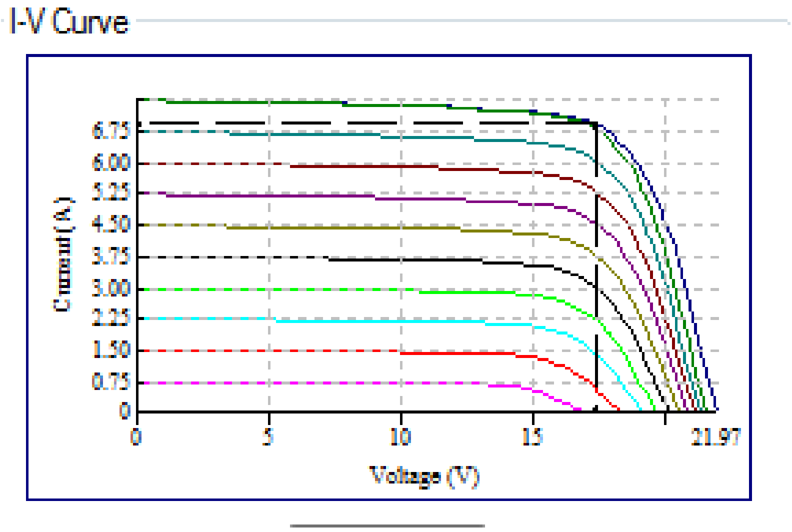


Figure 3.2: Peak Power in the I-V Curve.

Different size of PV modules will produce different amount of power. The peak watt (Wp) produced depends on size of the PV module and climate of site location. To find out the total energy required from the PV modules, multiply the daily consumption by 1.3. Then to find out the total peak power must be produced by the PV modules, divide the total energy required from the PV modules by the solar insolation of the location of the PV system.

The worst case is used which is during the lowest solar month. Finally, to find out the total number of the PV modules must be used to produce such power, divide the total peak power required by the peak power of a single module [11].

$$\text{Number of Module} = \frac{(total\ \ watt\ .hour\ /day\ )\times 1.3}{solar\ \ insolation\ \ \times Module\ \ peak\ \ power} \quad (3.1)$$

3.3.3 Inverter Sizing

An inverter is used in the system where AC power output is needed. A DC to AC inverter as it's clear from its name converts the DC output from the solar a modules into an AC that can be fed into a commercial electrical grid or used by a local, off-grid electrical network. An example of solar inverter is shown in figure 3.3.

For stand-alone systems, the inverter must be large enough to handle the total amount of Watts you will be using at one time. The inverter size should be 25-30% bigger than total Watts of appliances. In case of appliance type is motor or compressor then inverter size should be minimum 3 times the capacity of those appliances and must be added to the inverter capacity to handle surge current during starting. The input rating of the inverter should never be lower than the total watt of appliances. The inverter must have the same nominal voltage as the battery [16].

Hence,

$$\text{Inverter Sizing} = \text{total watt of the appliances} \times 1.3 \qquad (3.2)$$

Figure 3.3: PV System Inverters

3.3.4 Charge Controller Sizing

The solar charge controller is typically rated against Amperage and Voltage capacities. Selecting the solar charge controller to match the voltage of PV array and batteries and then identifying which type of solar charge controller is right for the application. Solar charge controller must have enough capacity to handle the current from PV array.

For the series charge controller type, the sizing of controller depends on the total PV input current which is delivered to the controller and also depends on PV panel configuration (series or parallel configuration).

According to standard practice, the sizing of solar charge controller is to take the short circuit current (Isc) of the PV array, and multiply it by 1.1, which is considered as safety factor [16].

Charge Controller Sizing = Total S/C current of the PV array × 1.1(3.3)

3.3.5 Battery Sizing

Batteries store DC electrical energy in chemical form for later use. In PV system, the energy is used at night and during periods of cloudy weather so there is another source in this system.

A battery is charging when energy is being put in and discharging when energy is being taken out. A cycle is considered one charge-discharge sequence, which often occurs over a period of one day in residential PV systems [16].

The performance parameters for storage battery type selection are described below:

-Ampere-hour capacity

The number of amp-hours a battery can deliver is simply the number of amps of current it can discharge, multiplied by the number of hours it can deliver that current. System designers use amp-hour specifications to determine how long the system will operate without any significant amount of sunlight to recharge the batteries. This measure of "days of autonomy" is an important part of design procedures.

Theoretically, a 200 amp-hour battery should be able to deliver either 200 amps for one hour, 50 amps for 4 hours, 4 amps for 50 hours, or one amp for 200 hours [16].

- Charge and discharge rates

If the battery is charged or discharged at a different rate than specified, the available amp-hour capacity will increase or decrease. Generally, if the battery is discharged at a slower rate, its capacity will probably be slightly higher. More rapid rates will generally reduce the available capacity. The rate of charge or discharge is defined as the total capacity divided by some number. For example, a discharge rate of C/20 means the battery is being discharged at a current equal to 1/20th of its total capacity. In the case of a 400 amp-hour battery, this would mean a discharge rate of 20 A [16].

Temperature

Batteries are rated for performance at 80oF. Lower temperatures reduce amp-hour capacity significantly. Higher temperatures result in a slightly higher capacity, but this will increase water loss and decrease the number of cycles in the battery life.

Depth of discharge

This describes how much of the total amp hour capacity of the battery is used during a charge-recharge cycle.

In contrast, most "deep cycle" batteries designed for photovoltaic applications are designed to discharge up to 80% of their capacity without damage. Even deep cycle batteries are affected by the depth of discharge. The deeper the discharge, the smaller the number of charging cycles the battery will last [16].

The battery type recommended for using in solar PV system is deep cycle battery. The battery should be large enough to store sufficient energy to operate the appliances at night and cloudy days.

To find out the size of battery, calculations must be as follows:

(1) Calculating total Watt-hours per day used by appliances.

(2) Dividing the total Watt-hours per day used by the battery loss.

(3) Dividing the answer obtained in item (2) by the depth of discharge.

(4) Dividing the answer obtained in item (3) by the DC bus voltage.

(5) Multiplying the answer obtained in item (4) with days of autonomy (the number of days that the system needed to operate when there is no power produced by PV panels) to get the required Ampere-hour capacity of deep-cycle battery.

$$(\text{Ampere. hour})\text{capacity} = \frac{(total\ \ watt\ .hour\ /day\ )\times dayof\ \ autonomy}{Battery\ \ loss\ \times Depth\ of\ \ discharge\ \times DC\ bus\ voltage} \quad (3.4)$$

3.3.6 Power generated in Wind System

The amount of power transferred by a wind turbine isdirectly proportional to the area swept out by rotors, to thedensity of air and the cube of the wind speed.

The power P is given by:

$P=0.5\times \boldsymbol{A}\times \rho\times C_p\times V^3$ (3.5)

Where

P=Turbine power coefficient

ρ =Air density (kg/m3)

A=Rotor swept area (m2)

v=Mean wind speed (m/s)

3.3.7 Generator Sizing

The standby diesel generator rating should be 20% greater than the total load. The generator should not work with its rated power for a long time because this could reduce the lifetime of the generator. Hence,

Generator Sizing = total watt of the appliances × 1.3(3.6)

3.3.8 ATS Sizing

ATS rating should be 10% greater than current supplied by each of the two sources. To find out the current supplied by each alternative, equation 3.6 should be used.

$P = 3VI\cos\emptyset \rightarrow I = \frac{P}{3\,V\,\cos\,\emptyset}$(3.7)

Hence,

$$\text{ATS Rating} = I \times 1.3 \tag{3.8}$$

CHAPTER FOUR

HYBRID SYSTEM DESIGN CASE STUDY: WAD SHUKAB

4.1 Case Study

Wad Shukab village is one of the villages which are not connected to the national grid of electricity in Sudan. This village is about 8 km far away from the grid. The purpose of this project is to design a hybrid photovoltaic/wind system to provide this village with electrical power. Sudan is a country located in northeastern of Africa, on the real side: the country faces a serious problem of instability of electricity supply. The problem is that the village is far away from the grid, so connection with the national grid will be expensive economically in comparison to a the PV/wind system. However, a description of the nature and location of this village will be introduced in this chapter.

4.1.1 Location

Wad Shukab village is located in South-West Sudan in West-Kurdufan state about 8 kilometers to the south-west of El-Nuhud city. Figures 4.1 and 4.2 show West-Kurdufan and Wad-Shukab locations respectively. A view of wad shukab village is shown in Figure 4.3.

Figure 4.1: West-Kurdufan State (Sudan)

Figure 4.2: Wad Shukab Location

Coordinates: Longitude 28° 22' 9" E, Latitude 12° 39' 33" N (28.369443, 12.659302).

Figure 4.3: A view of Wad Shukab village

4.1.2 Social Study

Wad Shukab village has about 28 houses. They are almost same in size. It has a population of about 182 people. Villagers live in separated houses. They are simple in their living. Their houses are made of hay and wood. Each house contains 2 rooms, a kitchen, a bathroom and a small yard.

Mosque:

There is only one mosque in this village, made of brick.

Water System

There is only one source of water in this village, which is a well founded in 1812 by Shukab himself. Unfortunately there is no pump to get there daily need of water from it. So they use this well manually. Depth of this well is about 50 meters.

To get water out of this well, a submersible pump is used. This pump will be used to provide 6000 liters of water (tank capacity) daily.

Also there is a clinic under construction. This clinic is supposed to be a small one, which contains some of the first aid therapies beside some of the important medications. It contains two rooms (patient's room for waiting besides saving the medications in it and a doctor's room for diagnosis).

The struggles of the villagers lie in the following aspects:

Healthcare Struggle:

The unsuitable environment is a crucial factor that causes the deterioration of the healthcare in the village; the absence of cooling units and refrigeration affects both patients and pharmaceuticals.

Educational Struggle:

Students’ educational procurement is continuously decreasing because studying hours are limited by daylight; which affects their quest and desire of education, while they are busy in work in agriculture and grazing. In addition to that they are going to get there education in the nearest town (El-Nuhud) which is about 8 kilometers away.

Water struggle: One well without an electric pump requires too much effort to satisfy the need of water.

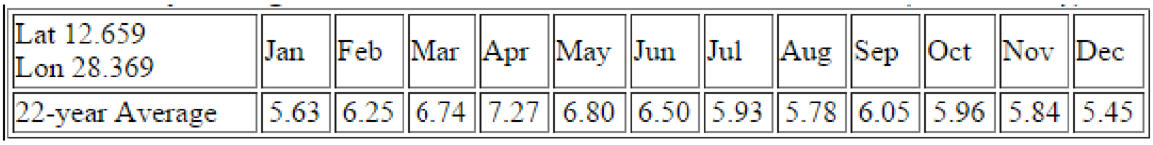
Social Struggle:

Villagers feel isolated from the outer world due to the lack of news sources and updates which makes them blinded and unaware of the world’s advancement and development.

4.2 Site Radiation Intensity

Since the solar plant was suggested to be at a location of 28° 22' 9" E Longitude and 12° 39' 33" N Latitude. The annual average of the daily solar radiation on a horizontal surface for this area is 6.183 KWh/m2/d [17].

Table 4.1: Monthly Solar Energy on Horizontal Surface for Wad-Shukab village



Lat 12.659 Lon 28.369	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
22-year Average	5.63	6.25	6.74	7.27	6.80	6.50	5.93	5.78	6.05	5.96	5.84	5.45

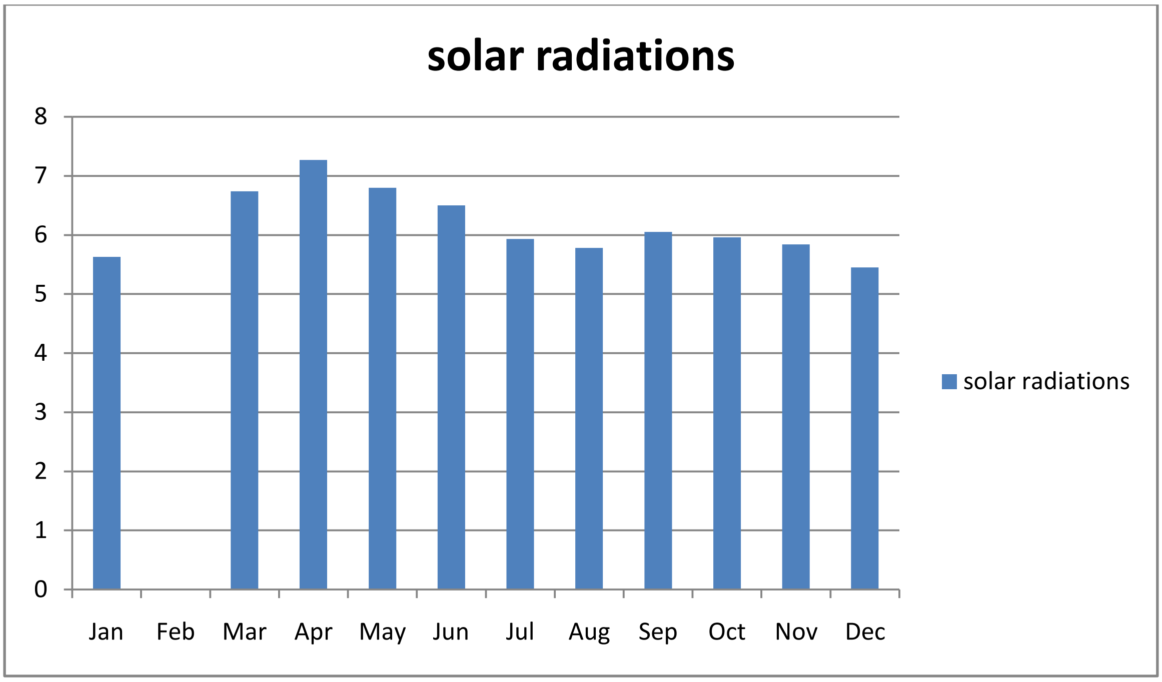
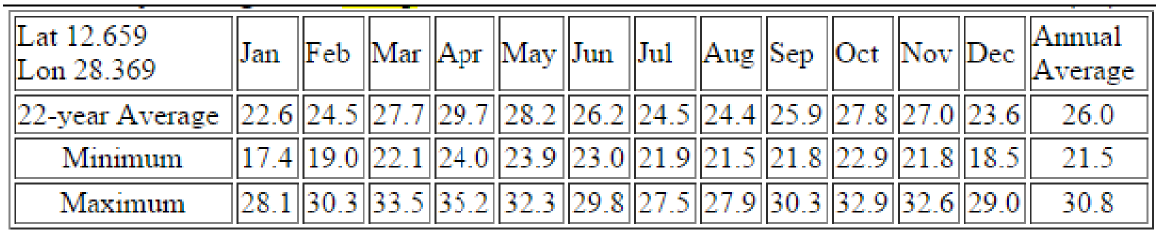


Figure 4.4: Monthly average solar radiation in Wad Shukab

The average sunlight hours West-Kurdufan - range between 11.2 hours per day in May and 10.4 hours per day in January, this gives a yearly average of sunlight around 3800 hours/year [12].

Table 4.2: Monthly Ambient Temperature for Wad-Shukab



Lat 12.659 Lon 28.369	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	22.6	24.5	27.7	29.7	28.2	26.2	24.5	24.4	25.9	27.8	27.0	23.6	26.0
Minimum	17.4	19.0	22.1	24.0	23.9	23.0	21.9	21.5	21.8	22.9	21.8	18.5	21.5
Maximum	28.1	30.3	33.5	35.2	32.3	29.8	27.5	27.9	30.3	32.9	32.6	29.0	30.8

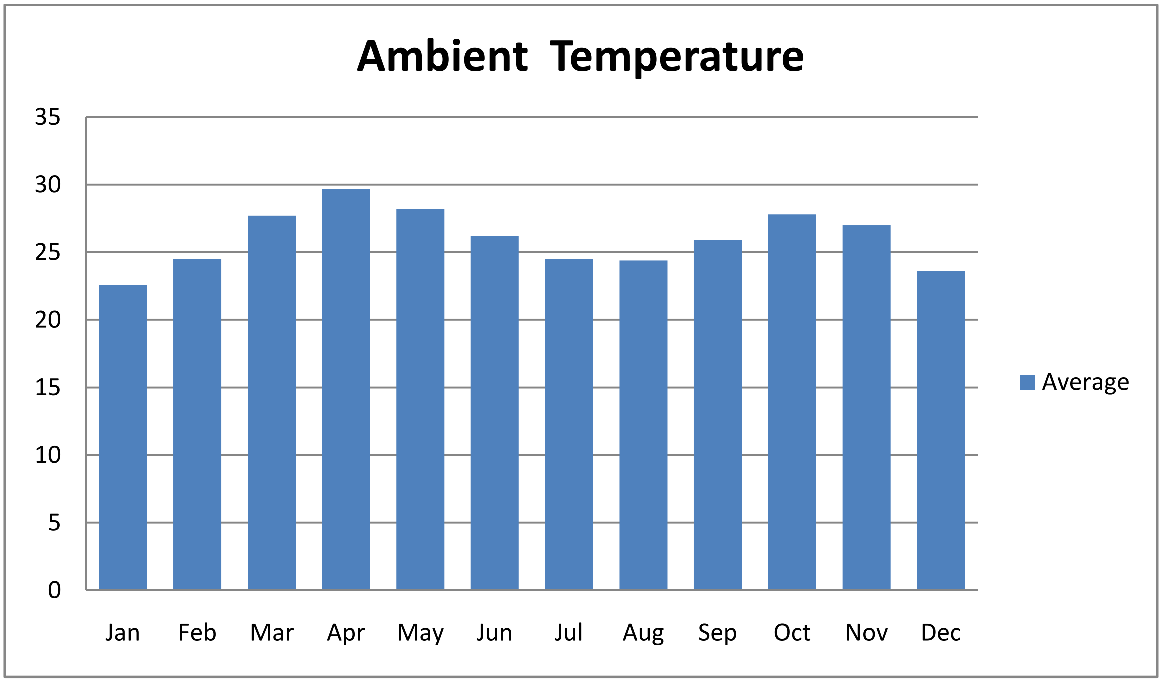


Figure 4.5: Monthly Ambient Temperature for Wad-Shukab

4.3 Standalone Hybrid System Design

A full design of hybrid PV/wind system is introduced below.

4.3.1 Load Calculations

According to the description of Wad-Shukab village made above the load is classified into: houses, clinic, mosque and water pump system . To find the total energy needed to operate the appliances per day, calculations as follow:

Houses

Table 4.3: Load calculations for houses

Variable	appliances	No. of running hours/day	Total watt.hour/day
Rooms	(2) tube light	5	400
	(2) ceiling fans	9	1080
Kitchen	(1)tubelight	5	200
	(1) fridge	12	2220
Yard	(1)tubelight	5	200
Bathroom	(1)lightbulb	5	50
Others	Ironer	1	750
	Mobile charger	5	25
	TV and receiver	8	760
Sum			5685

For 28 typical houses, **total** houses daily consumption = 5685 * 28 = 159180 W.h/d

Mosque

A single mosque requires:

4 tube lights working for 3 hours =480 watt.hour/day

3 ceiling fans working for 3 hours =540 watt.hour/day

Total consumption of the mosque = 1020 watt.hour/day

Clinic:

In the clinic there are two rooms, so it requires 2 tube light, 2 fans, a refrigerator and 2 tube lights working for 8 hours =640 watt.hour/day, 2 ceiling fans working for 8 hours =960 watt.hour/day.

1 refrigerator working for 12 hours =2220 watt.hour/day.

Total consumption of the clinic = 3820 watt.hour/day .

Water Submersible Pump:

A 1 hp submersible pump is used to supply 6000 liters of water (capacity of the tank). This pump is operating 3 hours per day filling the tank twice a day.

So the consumption of the pump per day equals = 746 * 3 = 2238 watt.hours/day

Hence, the total load consumption of power per day equals = 166258 watt.hour/day

4.3.2 PV Array Sizing

The panel generation factor is replaced by the worst case isolation of the location of Wad Shukab which is 5.45 kWh/m2/day, as shown in table 4.1.

The peak power of the modules used in this design is 120 Wp according to the specifications of the module (specifications are attached in APPENDIX B1).

The number of required PV modules is calculated using equation (3.1).

Number of PV modules $= \frac{166258 \times 1.3}{5.45 \times 120} \cong 330$ module

336 PV modules is recommended in order to make this system perform better and to improve the battery life.

4.3.3 Installation of the PV System

If the output voltage and current from a single module is smaller than desired, the modules can be connected into arrays. The connection method depends on which variable that needs to be increased. For a higher output voltage the modules must be connected in series, while connecting them in parallel in turn gives higher currents. It is important to know the rating of each module when creating an array.

To make recommended panels arrangement, the following steps must be done.

a. Panels Arrangement

According to the calculations done in above, the total number of solar PV modules = 336 module. To make recommended panels arrangement for this system, configuration will be as follow.

- 336 modules are divided into 2 groups, each group containing 168 modules.
- In each group, 168 modules are further divided into 12 strings.
- Each string contains 14 modules.

So the PV modules connecting technique is that in each string, the panels are connected in series to increase the voltage. And in each group, the strings are connected in parallel to increase the current.

b. Electrical Calculations

Calculations of the output parameters (current, voltage and power) are as follow:

i) Calculations according to the configuration.

- Output voltage of each string = 17.41 V
- Output current of each string = 6.91.A
- Output voltage of each group = 17.41*14 =243.74 V
- Output current of each group = 6.91 * 12 = 82.8 A

ii) DC output power calculations

- Output power of each string = 243.74 * 6.9 = 1.681 KW
- Output power of each group= 1.681 * 12 = 20.172 KW
- Output power of 2 groups = 20.172 * 2 = 40.344 KW

c. PV Modules Architecture

Connection configuration of the PV modules is done as follow.

i) String interconnection

14 PV modules are connected in series to form a string. Figure 4.6 illustrates string connection.

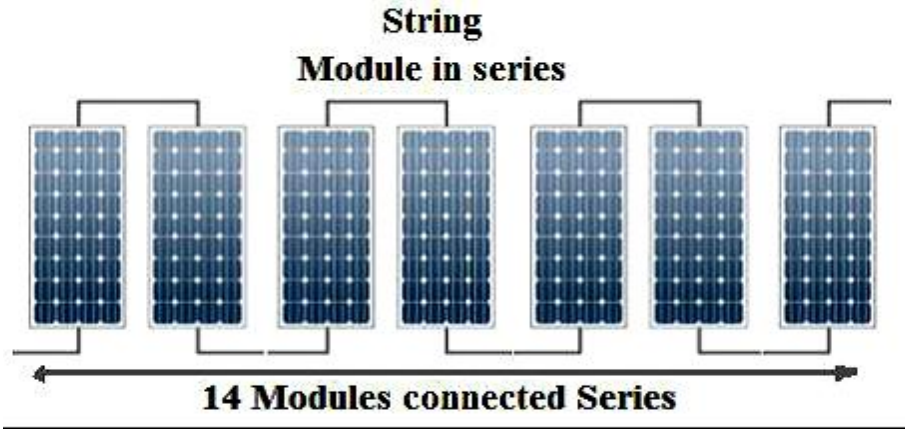


Figure 4.6: String Connection

ii) Group interconnection

12 strings are connected in parallel to form a group as shown in figure 4.7.

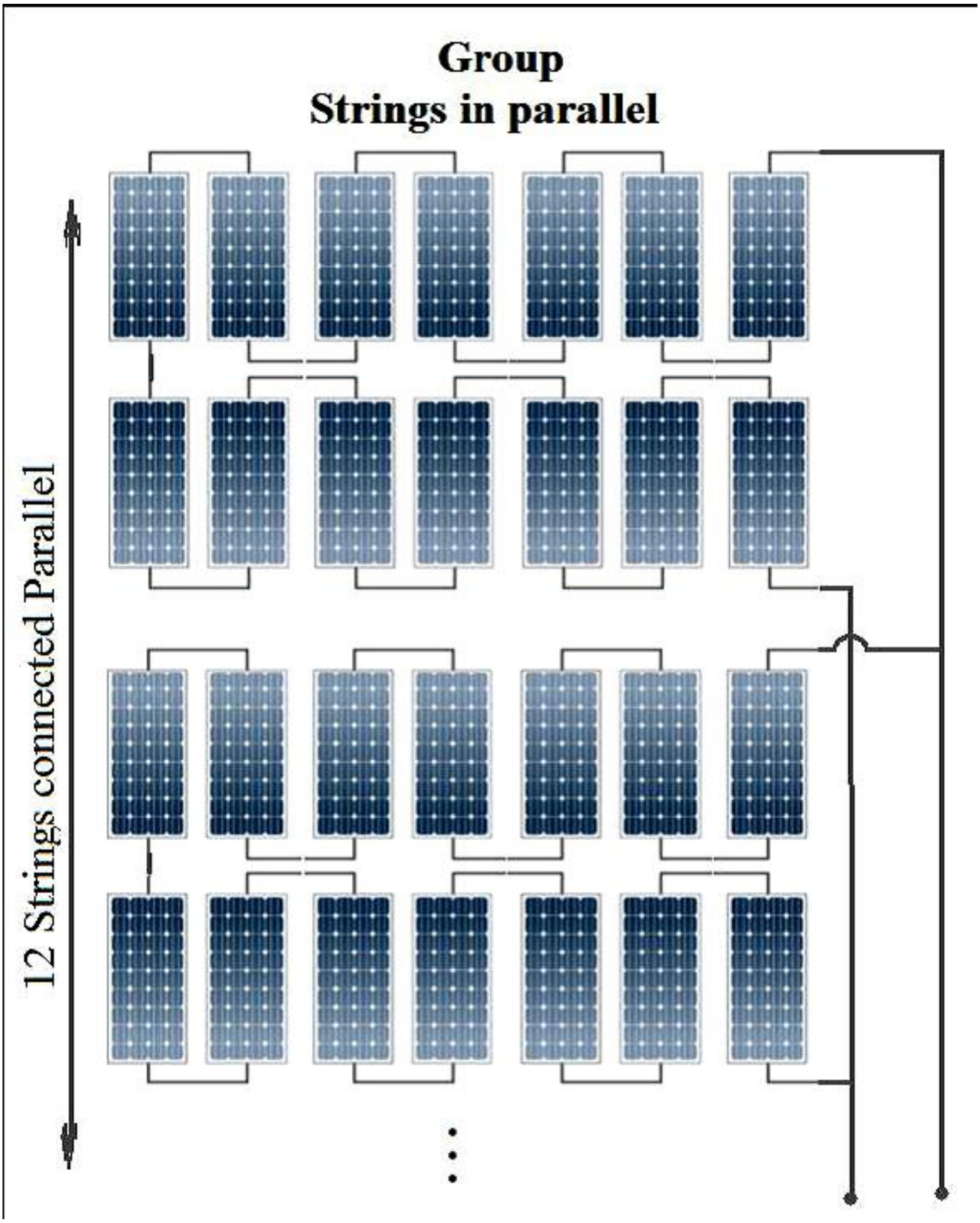


Figure 4.7: Group Connection

iii) Overall connection

2 groups will form the overall PV panels' arrangement in this system. Each group is considered as a separate PV system, which has its own connections separated from the other. The overall connection is shown in figure 4.8.

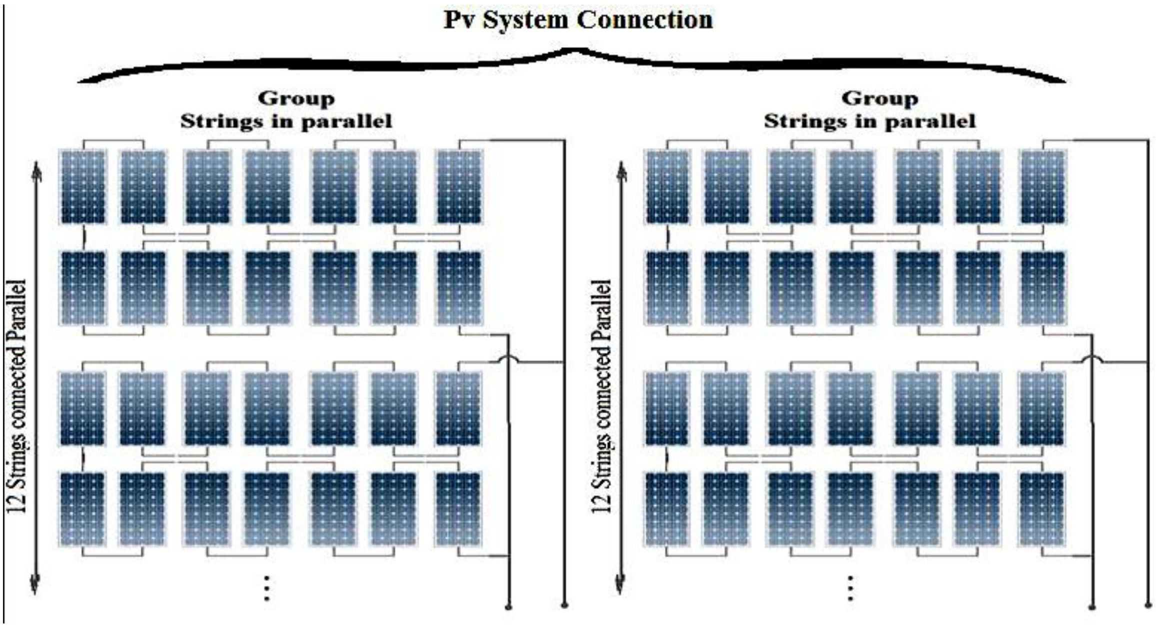


Figure 4. 8: System Connection

4.3.4 Inverter Sizing

According to equation 3.2, inverter sizing of each group calculated as follow.

The total watt of the appliances is calculated as follows:

i) 112 tube lights = 112*40 = 4720 watt
ii) 61 ceiling fans = 61*60 = 3660 watt.
iii) 28 light bulbs = 28*10 = 280 watt.
iv) 28 TV and receiver = 28*95 = 2660 watt.
v) 29 Fridge with a compressor = 3*29*185 = 16095 watt.
vi) 1 hp motors = 3*746 = 2238 watt.

Total watt = 29653 watt.

Since the inverter sizing must be 30% greater than the total watts, so:

Inverter sizing = 29653×1.3=38.550 Kw

So each group should have a 19.275 KW =20 kw inverter size.

A 20KW, 3-phase inverter is recommended to be used for each group. Specifications are attached in APPENDIX B4.

4.3.5 Charge Controller Sizing

According to equation 3.3 in the previous chapter, the sizing of the charge controller for each group of this system was calculated as follow:

Charge control capacity = $(12\times7.3)\times1.1=96.36\cong 100$A

A 240V, 100A Charge controller from Sunway power company model (SSCP -240V - 100A – TA) is recommended to be used to supply power from PV array to the batteries. For more details about the specifications see APPENDIX B3.

4.3.6 Battery Sizing

According to equation 3.4 in Chapter 3, battery sizing of this system was calculated as follow:

Since each group is separated from the other similarly, so the total energy consumption is divided by 2. Yields

each group requires $=\frac{166258}{2}= 83129 \text{ watt.hour/day}$

(Ampere.hour) capacity$=\frac{83129\times1}{0.85\times0.6\times240}=679.158$

12V, 207 Ah Trojan Battery is recommended to be used. Specifications and datasheet of this battery type are attached in APPENDIX B2.

Connections must be as follow:

20 batteries are connected in series to produce 240 VDC forming a string.

4 strings of batteries are connected in parallel producing 828 Ah of the group.

Figure 4.9 illustrates the battery connection for each group.

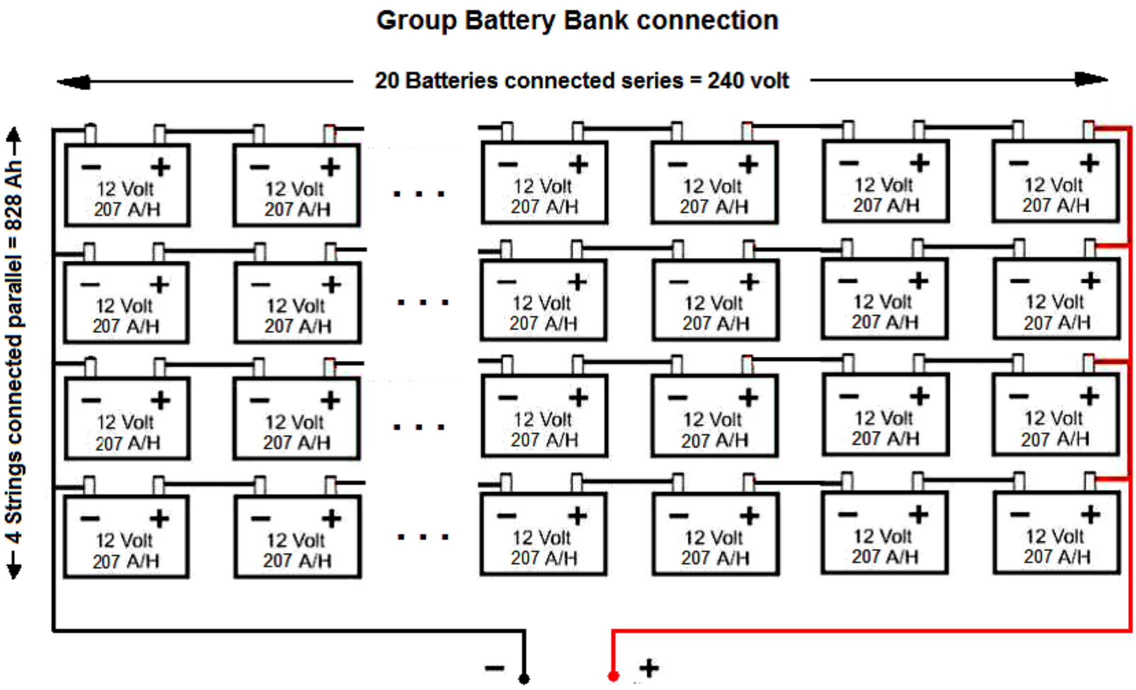


Figure 4.9: Battery Bank Connection

4.3.7Wind calculation:

At this moment in time, the world is going the way of green energy (renewable energies) in its energy consumption. Wind energy or wind power describe the process by which wind is used to generate mechanical or electric power. Use of wind energy for electricity generation purposes is becoming an increasingly attractive energy source partly due to the increase in energy demand worldwide and environmental concerns. Burning of fossil fuels emit gases such as carbon dioxide into the atmosphere that lead to global warming. Wind energy does not rely on fossil fuels for energy generation. A typical wind energy conversion system consists of three major devices making up a wind turbine that convert wind energy to electric energy. The first device is the rotor which consists of two or three fibre glass blades joined to a hub that contains hydraulic motors that change each blade according to prevailing wind conditions so that the turbine can operate efficiently at varying wind speeds. The nacelle is a large housing behind the rotor that houses the drive shaft, gearbox, transformer and generator. Nacelle is usually mounted over a yaw gear which turns it and the rotor so that the wind is normal to the rotor plane all the time for maximum tapping of energy from the wind. The tower supports the rotor and the nacelle.

The kinetic energy in the wind is converted into mechanical energy by the turbine by way of shaft and gearbox arrangement because of the different operating speed ranges of the wind turbine rotor and generator. The generator converts this mechanical energy into electrical energy. The mechanical power obtained can be used to perform important tasks such as grinding of grain or pumping of water. The electricity generated can be used in human daily activities. It can be used to power homes, schools, hospital, industries, businesses etc. The major wind energy system components that lend themselves to modeling can be grouped as follows:

(i) the wind model,

(ii) the turbine model,

(iii) the shaft and gearbox model,

(iv) the generator model and

(v) the control

The nameplate of Wind Turbine used is shown in Fig.4.10 and as inserted in ETAP in Figure4.19

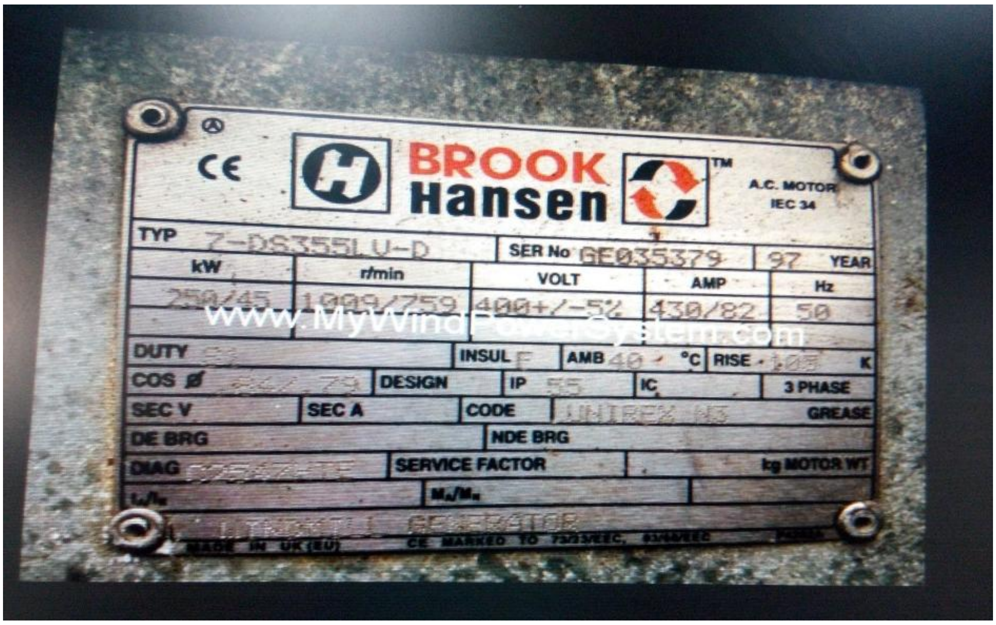


Figure 4.10 Nameplate of Wind Turbine

4.3.8 Generator Sizing :

LV Generator Sets are mainly used:

- To Supply Safety Equipment
- To Replace The Main Source
- To Supply Temporary Installations

A DG set rated selected upon the Continuous Capacity Calculations criteria.

Table 4.4:Total load

Equipment Description	KVA
Residential Load	19.9
Motor 1,2	2*1.4
Motor3	3*13.4

Continuous Capacity Calculations:-

The minimum size of the DG set, from capacity calculations point of view.

According to equation 3.5, generator sizing was calculated as follow:

Gen Set Size =Total load X Contingency(10%)+ Future load (20 %)

=19.9+(2*1.4)+(3*13.4)=62.9KVA

62.9*1.3=81.77KVA

Upon the standard the next size of DG is 100KVA

A 3-phase, 50Hz, 85KW,100 KVA Diesel Generator by Perkins Company is recommended to be used in this system. Specifications are attached in APPENDIX B5.

4.3.9 ATS Sizing

According to equation 3.6, current produced by generator equals:

Generator current $=\frac{85\ kw}{3\times 240\times 0.85} \cong 140$ Amp

Current produced by inverters equals:

Inverter Current$=\frac{2\times 20 kw}{3\times 240\times 0.85} \cong 66\ Amp$

Since the two currents are not equal, so the greater current is substituted in equation 3.7 in order to find the ATS rating. Hence,

ATS Rating = 140×1.3=14420Amp

4.4 Simulation of Hybrid System

The following steps were done in ETAP program order to run the simulation program for the design results:

1. Open ETAP window and new project
2. From project choose IEC standard, the frequency is 50HZ and the unit is Metric
3. Insert the components of network and their parameters as shown in Figure 4.11
4. From the Toolbar choose Switching Sequence Management to make function scenario
5. In Switching Sequence Management click on Edit Switching Sequence to make the main sequence scenario, and repeat to make the backup sequence scenario as shown in Figure4.12
6. Run Switching Sequence as illustrated in Fig. 4.13 for both cases
7. From report manager display the results to each scenario
8. The results is shown below in Figure 4.14 &4.15.

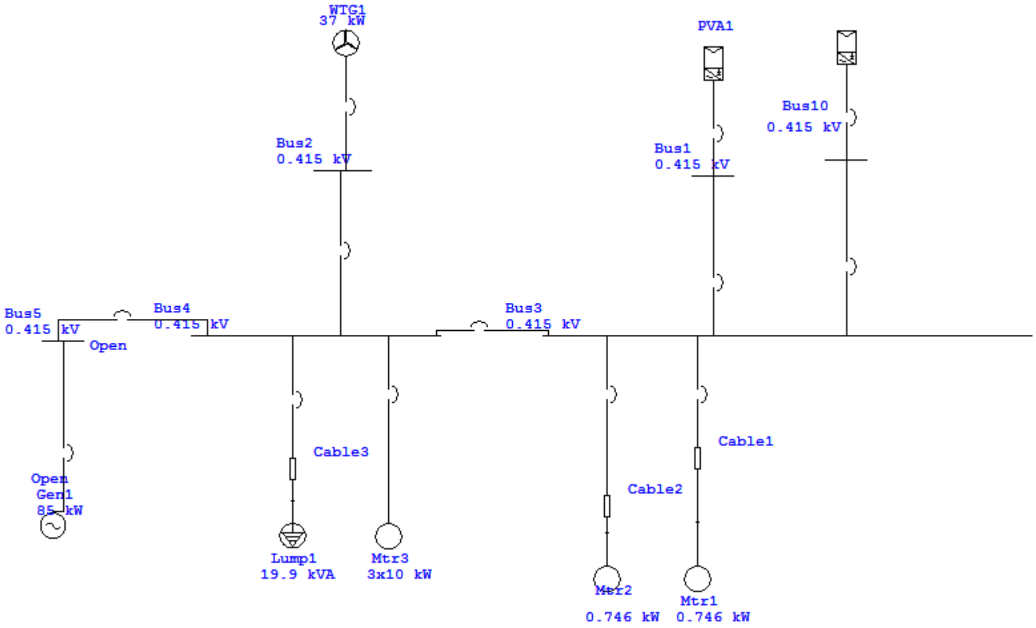
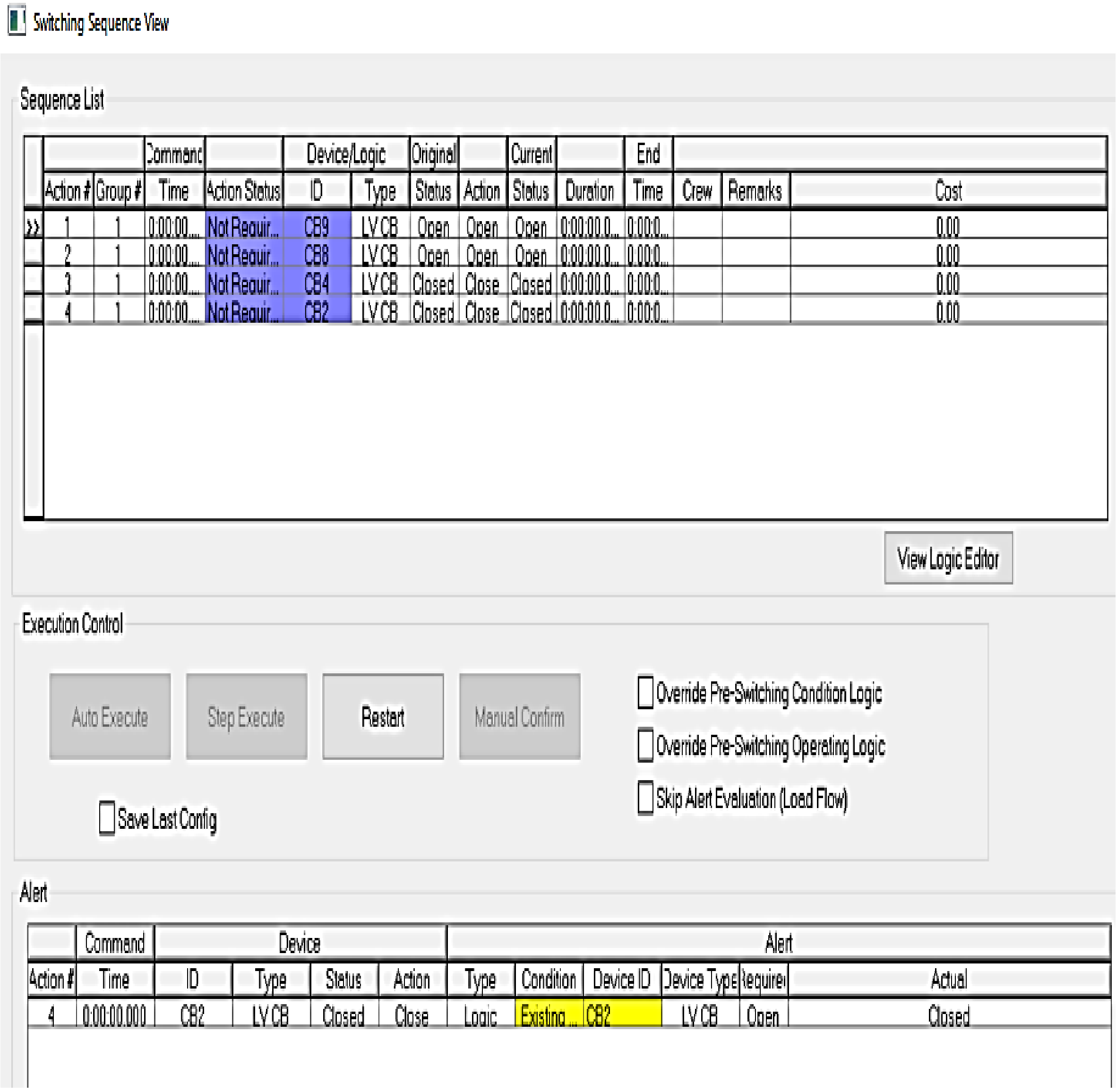


Figure 4.11 illustrate the single line diagram



			Command		Device/Logic		Original		Current		End			
	Action #	Group #	Time	Action Status	ID	Type	Status	Action	Status	Duration	Time	Crew	Remarks	Cost
>>	1	1	0:00:00...	Not Requir...	CB9	LV CB	Open	Open	Open	0:00:00.0...	0:00:0...			0.00
	2	1	0:00:00...	Not Requir...	CB8	LV CB	Open	Open	Open	0:00:00.0...	0:00:0...			0.00
	3	1	0:00:00...	Not Requir...	CB4	LV CB	Closed	Close	Closed	0:00:00.0...	0:00:0...			0.00
	4	1	0:00:00...	Not Requir...	CB2	LV CB	Closed	Close	Closed	0:00:00.0...	0:00:0...			0.00

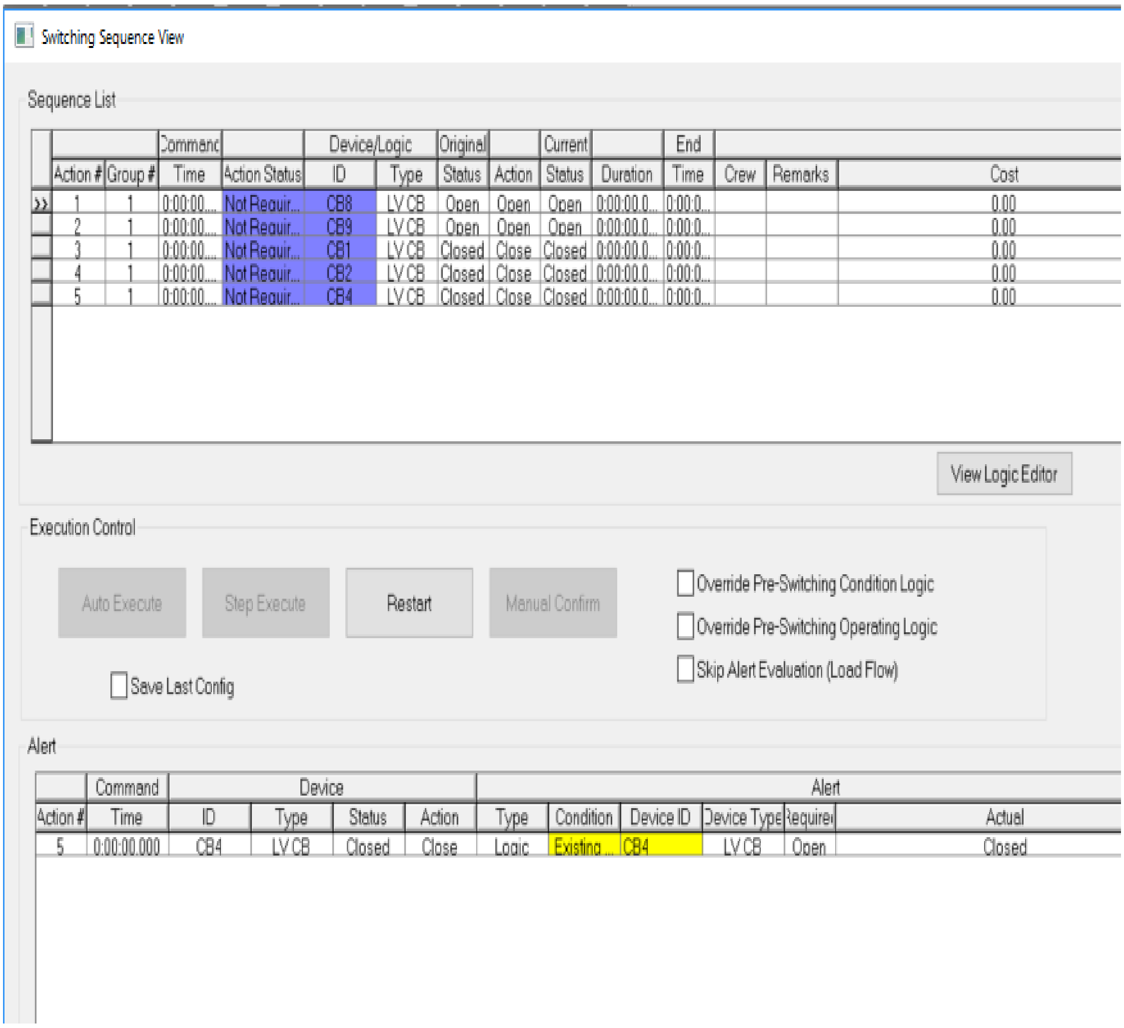
☐ Override Pre-Switching Condition Logic

☐ Override Pre-Switching Operating Logic

☐ Skip Alert Evaluation (Load Flow)

☐ Save Last Config

	Command	Device				Alert					
Action #	Time	ID	Type	Status	Action	Type	Condition	Device ID	Device Type	Require	Actual
4	0:00:00.000	CB2	LV CB	Closed	Close	Logic	Existing ...	CB2	LV CB	Open	Closed



Sequence List

			Commanc		Device/Logic		Original		Current		End			
	Action #	Group #	Time	Action Status	ID	Type	Status	Action	Status	Duration	Time	Crew	Remarks	Cost
››	1	1	0:00:00....	Not Requir...	CB8	LV CB	Open	Open	Open	0:00:00.0...	0:00:0...			0.00
	2	1	0:00:00....	Not Requir...	CB9	LV CB	Open	Open	Open	0:00:00.0...	0:00:0...			0.00
	3	1	0:00:00....	Not Requir...	CB1	LV CB	Closed	Close	Closed	0:00:00.0...	0:00:0...			0.00
	4	1	0:00:00....	Not Requir...	CB2	LV CB	Closed	Close	Closed	0:00:00.0...	0:00:0...			0.00
	5	1	0:00:00....	Not Requir...	CB4	LV CB	Closed	Close	Closed	0:00:00.0...	0:00:0...			0.00

☐ Override Pre-Switching Condition Logic

☐ Override Pre-Switching Operating Logic

☐ Skip Alert Evaluation (Load Flow)

☐ Save Last Config

Alert

	Command	Device				Alert					
Action #	Time	ID	Type	Status	Action	Type	Condition	Device ID	Device Type	Require	Actual
5	0:00:00.000	CB4	LV CB	Closed	Close	Logic	Existing ...	CB4	LV CB	Open	Closed

Figure 4.12 illustrate the switching sequencing management scenario in both Main and Backup Cases

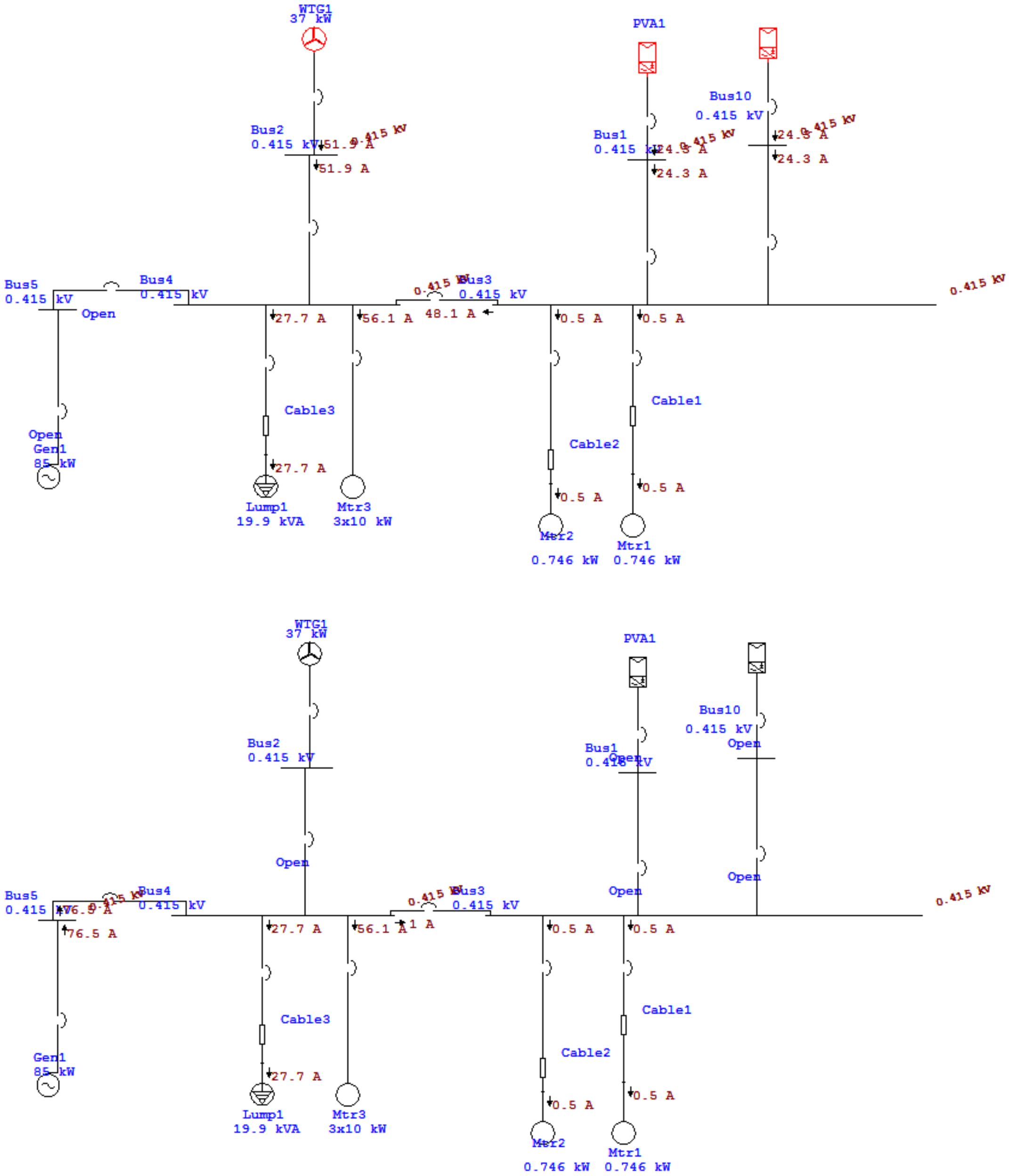
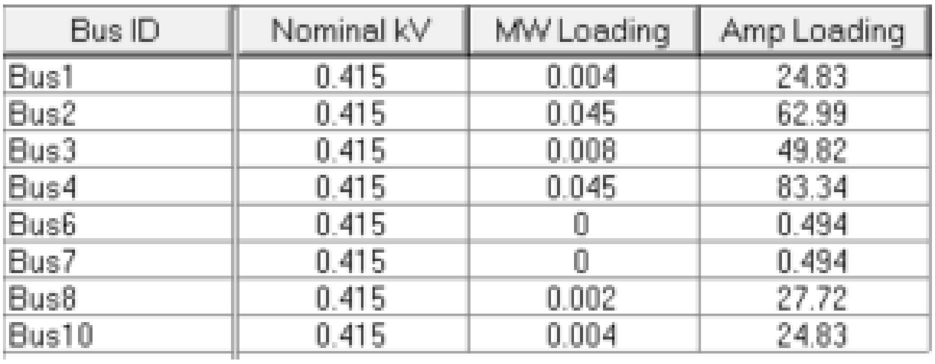
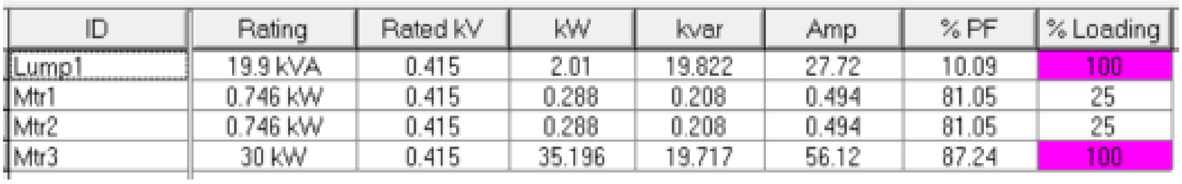


Figure 4.13 illustrate the Results for Main and Backup Cases

Main Source Case Result:



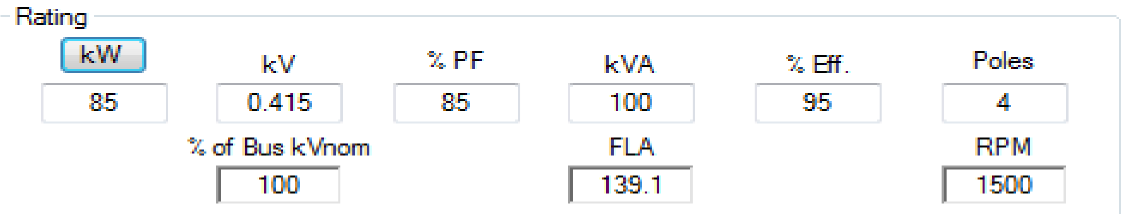
Bus ID	Nominal kV	MW Loading	Amp Loading
Bus1	0.415	0.004	24.83
Bus2	0.415	0.045	62.99
Bus3	0.415	0.008	49.82
Bus4	0.415	0.045	83.34
Bus6	0.415	0	0.494
Bus7	0.415	0	0.494
Bus8	0.415	0.002	27.72
Bus10	0.415	0.004	24.83



ID	Rating	Rated kV	kW	kvar	Amp	% PF	% Loading
Lump1	19.9 kVA	0.415	2.01	19.822	27.72	10.09	100
Mtr1	0.746 kW	0.415	0.288	0.208	0.494	81.05	25
Mtr2	0.746 kW	0.415	0.288	0.208	0.494	81.05	25
Mtr3	30 kW	0.415	35.196	19.717	56.12	87.24	100

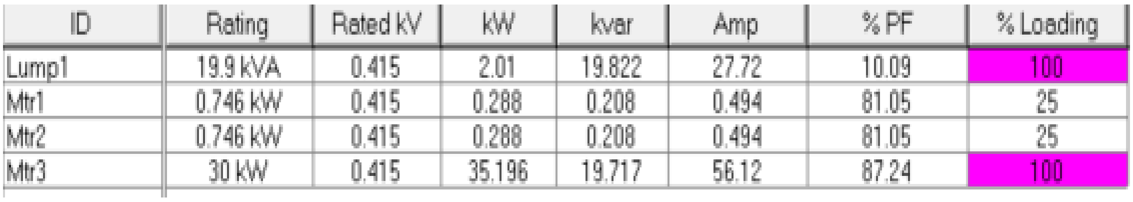
Figure 4.14 The Main Case Result

Backup Case Result:

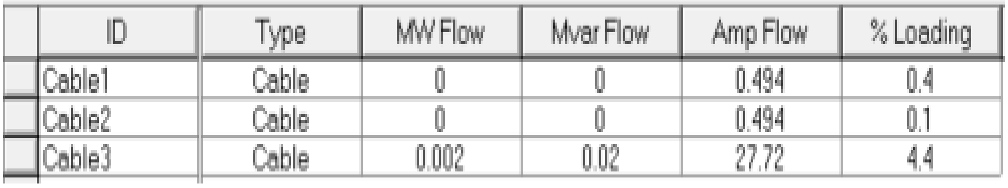


Rating

kW	kV	% PF	kVA	% Eff.	Poles
85	0.415	85	100	95	4
	% of Bus kVnom		FLA		RPM
	100		139.1		1500



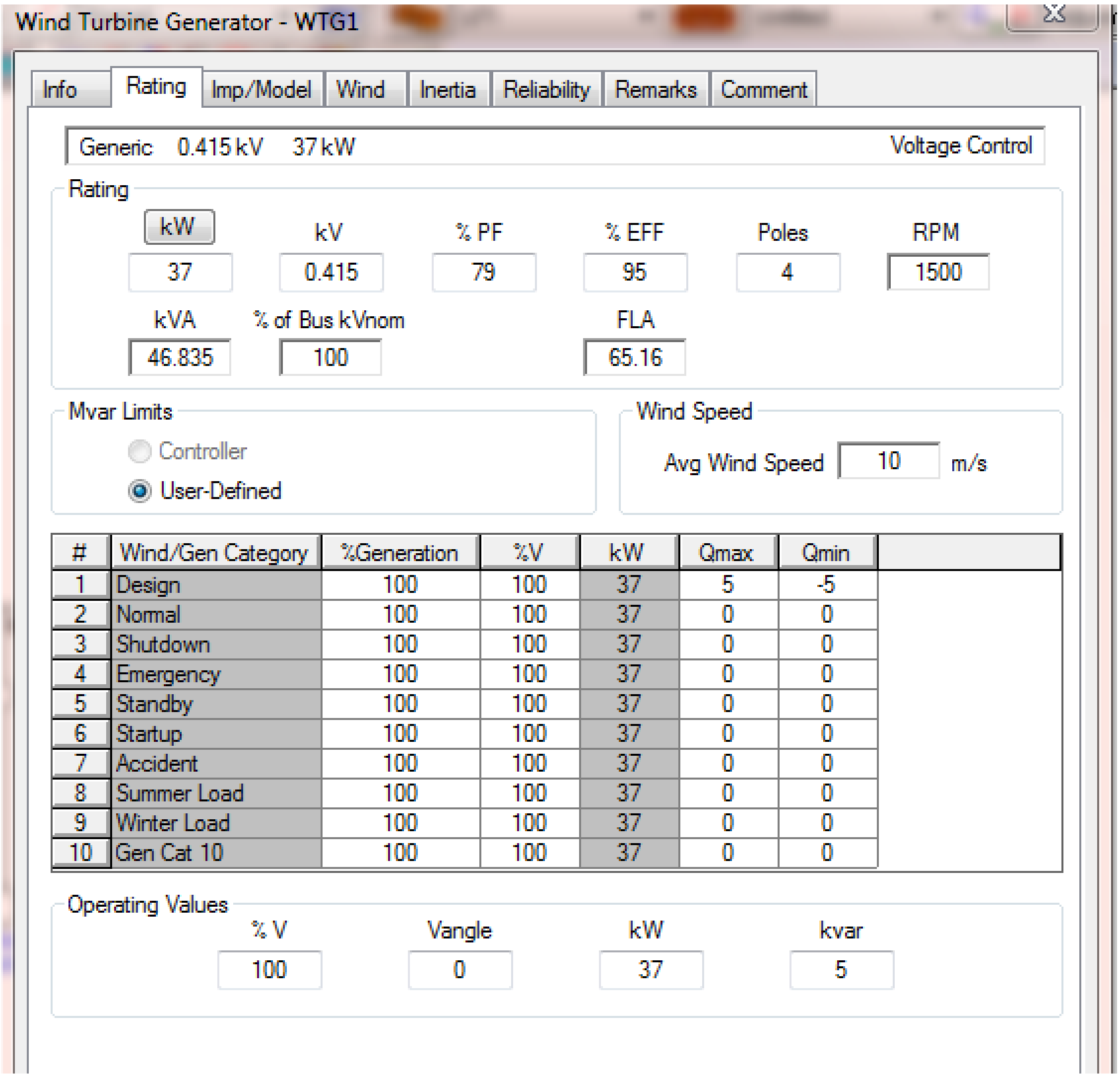
ID	Rating	Rated kV	kW	kvar	Amp	% PF	% Loading
Lump1	19.9 kVA	0.415	2.01	19.822	27.72	10.09	100
Mtr1	0.746 kW	0.415	0.288	0.208	0.494	81.05	25
Mtr2	0.746 kW	0.415	0.288	0.208	0.494	81.05	25
Mtr3	30 kW	0.415	35.196	19.717	56.12	87.24	100



ID	Type	MW Flow	Mvar Flow	Amp Flow	% Loading
Cable1	Cable	0	0	0.494	0.4
Cable2	Cable	0	0	0.494	0.1
Cable3	Cable	0.002	0.02	27.72	4.4

Fig.4.15 The Backup Case Result

The nameplate of Wind Turbine used is shown in Figure 4.11 and as inserted in ETAP in Figure 4.16



Generic 0.415 kV 37 kW Voltage Control

Rating

kW	kV	% PF	% EFF	Poles	RPM
37	0.415	79	95	4	1500

kVA	% of Bus kVnom	FLA
46.835	100	65.16

Mvar Limits

○ Controller

● User-Defined

Wind Speed

Avg Wind Speed 10 m/s

#	Wind/Gen Category	%Generation	%V	kW	Qmax	Qmin
1	Design	100	100	37	5	-5
2	Normal	100	100	37	0	0
3	Shutdown	100	100	37	0	0
4	Emergency	100	100	37	0	0
5	Standby	100	100	37	0	0
6	Startup	100	100	37	0	0
7	Accident	100	100	37	0	0
8	Summer Load	100	100	37	0	0
9	Winter Load	100	100	37	0	0
10	Gen Cat 10	100	100	37	0	0

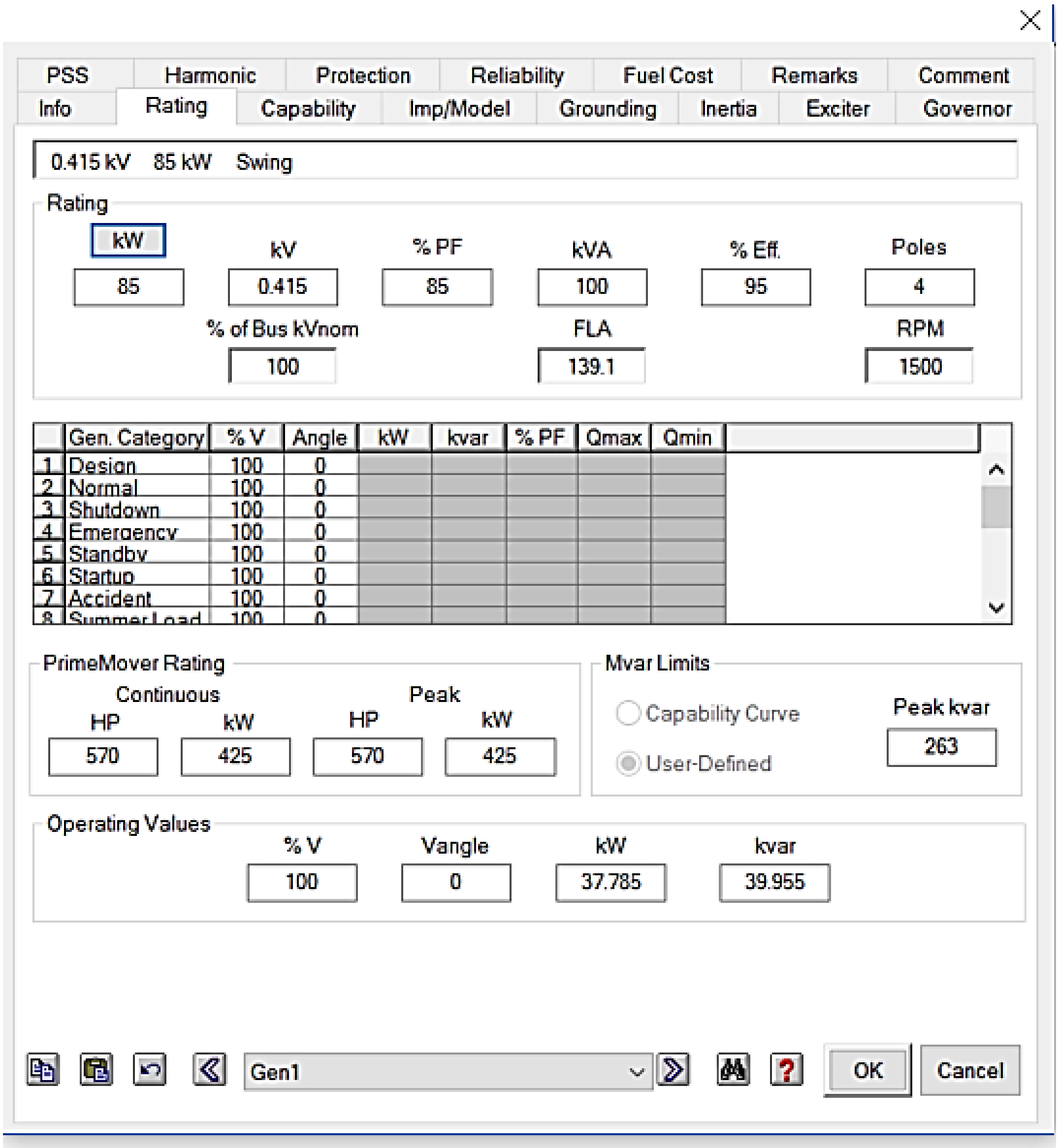
Operating Values

% V	Vangle	kW	kvar
100	0	37	5

Figure 4.16 Wind Turbine Nameplate as inserted in ETAP

Back up Diesel Generator:

The data is inserted in ETAP as shown in Figure 4.25 below:



0.415 kV 85 kW Swing

Rating

kW	kV	% PF	kVA	% Eff.	Poles
85	0.415	85	100	95	4
	% of Bus kVnom		FLA		RPM
	100		139.1		1500

	Gen. Category	% V	Angle	kW	kvar	% PF	Qmax	Qmin
1	Design	100	0					
2	Normal	100	0					
3	Shutdown	100	0					
4	Emergency	100	0					
5	Standby	100	0					
6	Startup	100	0					
7	Accident	100	0					
8	Summer Load	100	0					

PrimeMover Rating

Continuous		Peak	
HP	kW	HP	kW
570	425	570	425

Mvar Limits

○ Capability Curve

● User-Defined

Peak kvar: 263

Operating Values

% V	Vangle	kW	kvar
100	0	37.785	39.955

Figure 4.17 illustrate the data of generator

4.5 Results

In this section of the project the results obtain in the previous chapters were collected andlisted in tables.

4.5.1 Number of Solar Modules Used

Table 4.5: Number of PV modules

Calculated number of PV modules	330 module
Recommended number of PV modules	336 module
Number of PV modules per group	168 module

4.5.2 Recommended PV Panels' Arrangement

Two groups form the system, each group has PV panels' arrangement.

Table 4.6: Group panels arrangement

Unit	Content	Connection
String	14 modules	Series
Group	12 strings	Parallel

4.5.3 Electrical Calculations According to the Configurations

Table 4.7: Output current and voltage

String	Output voltage	245 V
Output current	6.9 A	
Group	Output voltage	245 V
Output current	82.8 A	

4.6 Results Discussion

4.6.1 Solar PV Power Plant Design

According to the design calculations The needed number of solar PV modules is 330module , but as shown in results the number approximated to higher number of panelswhich is 336 module , this approximation has been done due to three reasons :

i. This number of modules is incapable of supplying 240 volt dc output to the system.
ii. Solar panel output and the rest of the power plant components are not ideal, so lossescan be decreased to the minimum value by adding an additional number of solarpanels to meet the losses in the output.
iii. To make this system perform better and to improve the battery life.
    a. The above modification yields the desired power output, if the above three reasons havebeen ignored the output will exhibit undesired losses.

4.6.2 Power Plant Output

- As mentioned previously the voltage output is maximized by connecting PV panels insidethe string in series “the voltage output of the string became the summation of the PV panels voltage output”
- Notice that the string current output remains the same as the panel current output.
- The current output is maximized by connecting strings inside the group in parallel “thecurrent output of the group became the summation of the strings current output”.
- Notice that the group voltage output remains the same as the string voltage output.

- DC power output exceeded the calculated output due to the approximation of the solarpanels number.
- Usually solar PV systems have a very low efficiency when it designed to stand alonebecause power is generated only during day time nearly 10.5 hours per day which yieldssupplying of energy per day up to 45 %, when batteries introduced to the solar systemthis percentage will step up to a higher value.
- When the solar system operate together with another power plant for example in ourcase a wind generator the continuity of supply stepped up to the maximum values andhybrid PV/wind system became the best choice; because this system make the perfectmix between renewable resources because both have a positiveeffect that solve each other limitations.

CHAPTER FIVE

CONCLUSION AND FUTURE RECOMMENDATIONS

5.1 Conclusion

The main objective of the project was to improve the life of humans of rural area byproviding one of the most important living requirements in the last two centuries which iselectricity by designing a suitable, affordable and simple electrification system.

In this project a comprehensive and simple procedure for designing a hybrid PV/wind systems for rural residential applications is provided. The design was based on commercially available equipments. The consumption of typical load was estimated and the number of PV modules required to cover the load was calculated. Also there is a battery bank to supply the load at night and cloudy days. In addition to the capacity of the inverter, charge controller and the wind generator rated was selected carefully to match the load demand, then generator was also taken into account.

The major components are PV arrays and wind turbines. The major advantage of these components is that when used together, the reliability of the system isenhanced. Additionally, the size of storage systems can be reduced as there is less relianceon one method of power production. Often, when there is no sun, there is plenty of windand vice versa. The number of components is directly dependent on the load pattern. In this study, the batteries are employed as the energy storage system. Optimal combinationof components is achieved by particle swarm optimization. The optimization problem issubject to economical and technical constraints. Best configuration with consideredreliability constraint is achieved and the system is simulated.

In the future work of this study, uncertainty factors such as generator failures and renewablepower availability will also be taken into account in calculating system reliability indexes.

The study shows that, the PV solar energy can be used separately or together with thewind generator as a replacement energy resource, to solve the power supply problems, and also to reduce the need of carbon-based energy. Due to the low operating sustainability of supply in the hybrid system, the diesel generator used as back up.

It is more environmentally sound because the system emits no CO2 during the electricityproduction, while the Diesel generator system emit considerable amounts of the greenhouse gas.

As design was successfully obtained and satisfactory results gained, Wad-Shukab villagecan be electrified and it is hoped that this design helps making their lives better as aimed for.

5.2 Recommendations

The national electricity grid covers only 40% of the country so alternative resources such as renewable energy should be considered. It is suggested that future plans may help the country to fight poverty and lack of awareness by:

i. Further studies to increase the efficiency and reliability of these standalone systems in addition to cost decrement.
ii. Develop the mentality of the usage of renewable energy technologies.
iii. Increase the capacity of the PV generation and increase the capacity of wind turbines in national grid.

iv. Apply this project in as many cities and villages as possible in Sudan to increase the degree of fuel independence.

v. Used the power electronics techniques to control the speed of the wind shaft to get wide range for different applications.

REFERENCES

[1] Solarbuzz LLC. (2007). 2006 WORLD PV INDUSTRY REPORT HIGHLIGHTS: " http://www.solarbuzz.com/ " accessed Oct 2007.

[2] IEA. (2004). World Energy Outlook. http://maecourses.ucsd.edu/MAE119/WI_2015/PDFPublishedDocuments/InternationalEnergyOutlook-2004.pdf.

[3] Bertin, J. J. And Smith M. L., “Aerodynamics for Engineers”, 5th edition Prentice, Hall, Inc., Upper Saddle River, New Jersey, 2008

[4] Iqbal,M., "An Introduction to Solar Radiation", Toronto New York : Academic Press, (1983).

[5] Mukund R. Patel, Ph.D., P.E.U.S. Merchant Marine Academy Kings Point, New York, "Wind and Solar Power Systems", Boca Raton London New York Washington, D.C..

[6] cleantechnica. [online]."http://cleantechnica.com/2011/09/30/solar-basics-how-do-solarpanel-work/ ".

[7] solar-facts. [online]."http://www.solar-facts.com/panels/how-panel-work.php ".

[8] energyinformative. [online] "http://energyinformative.org/best-solar-panel-monocrystallinepolycrystaline-thin-film/ ".

[9] JoernHoppmann, Jonas Volland, Tobias S. Schmidt, Volker H. Hoffmann. "The Economic Viability of Battery Storage for Residential Solar Photovoltaic Systems - A Review and a Simulation Model".(July 2014).

[10] Wikipedia. [online]. "http://en.wikipedia.org/wiki/Power_inverter”.

[11] E. Hau, “Wind Turbines Fundamentals”, Technologies, Applicaon, Economics, 2 ndedion, Springer press, 2005.

[12] I.Boldea, “The Electric Generators Handbook: Variable Speed Generators”, CRC Press. 64

[13] P. Krause, O. Wasynczuk, and S. Sudhoff, “Analysis of Electric Machinery and Drive Systems”, 2 ndEdion, Wiley-IEEE Press, 2002.

[14] B. Wu, “High-Power Converters and AC Drives”, Wiley-IEEE Press, 2006.

[15] University of Central Florida. The Florida Solar Energy. [online]. "http://www.fsec.ucf.edu/en/consumer/solarelectricity/basics/types_of_pv.htm".

[16] Elena Papadopoulou. "Energy Management in Buildings Using Photovoltaics", 2012.

[17] Nasa Surface Meteorology and Solar. [online]. https://eosweb.larc.nasa.gov/cgibin/sse/grid.cgi?&num=209103&lat=12.659&submit=Submit&hgt=100&veg=17&sitelev=-999&email=skip@larc.nasa.gov&p=grid_id&step=2&lon=28.369

APPENDIX A

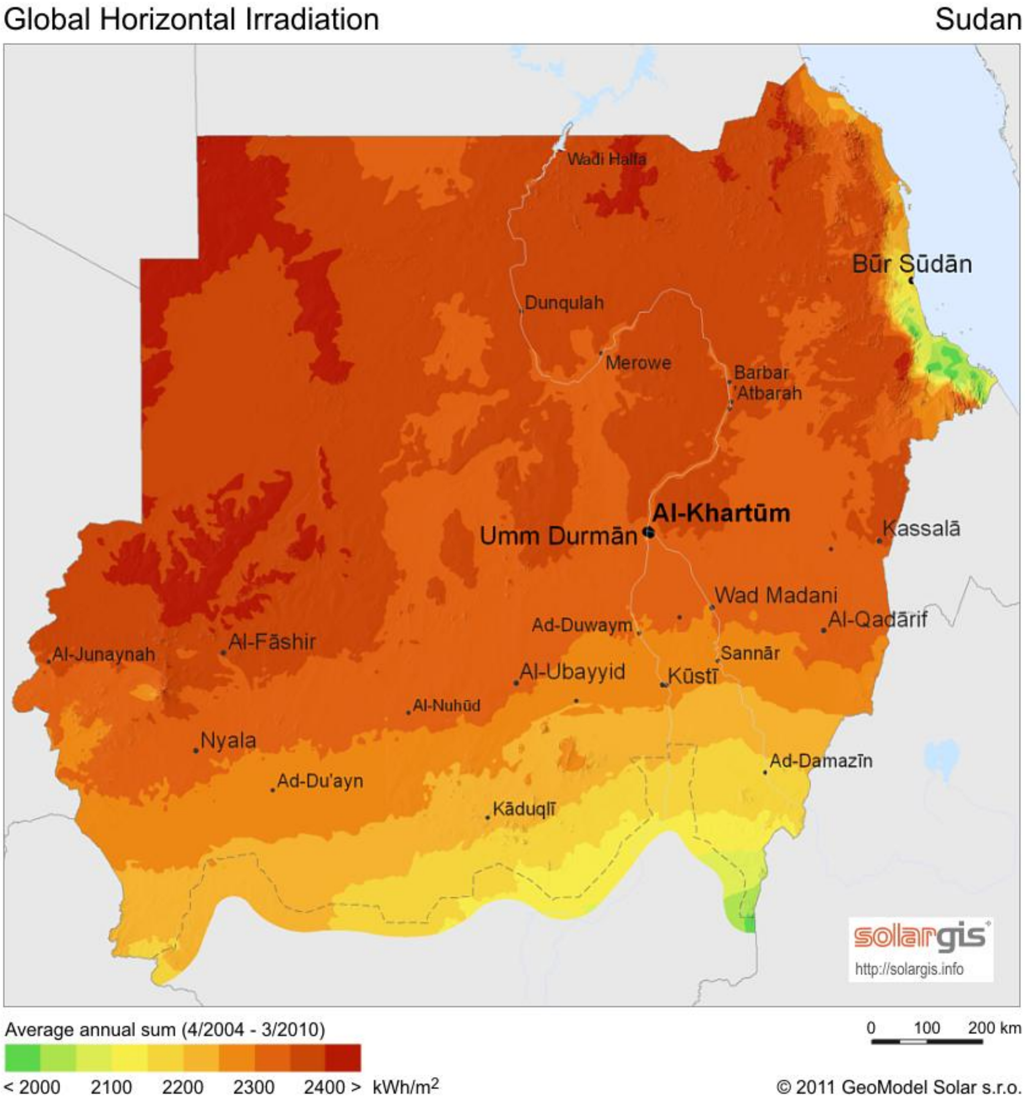


Figure A.1 SUDAN Horizontal Irradiation Map

APPENDIX B

B.1 PV Module Specifications

The PV module selected in this project is a poly-crystalline PV module type GH Solar

GH120p-18 by Zhejiang Ganghang Solar Technology Co., Ltd.. It has specifications listed intable B.1.

Figure B.1: Zhejiang Ganghang Solar TechnologyPV Module

Table B.1: PV Module Specifications

Model	GH-0401A4
Pmax	120W
power tolerance:	±3%
Vmp	17.41V
Imp	6.91A
Voc	21.60V
Isc	8.02A
Cell Type	156*156 polycrystalline solar cell
Size	1486*676*30mm
Net weight	12kg
STC	1000W/m2,AM 1.5,25Oc
Warranty	3 year warranty for products,10 years for 90% power ,25 years for 80% power
Accessory	3.2mm thick tempered glass,aluminium frame
Others	There are drainage holes on the Border components, eliminating the framework of deformation caused by rain or snow accumulated in the framework

B.2 Battery Specifications

The battery type selected in this project is TROJAN J185H-AC. The battery

specifications are as follow:

Figure B.2: TROJAN Battery

❖**Specifications**

- MODEL: J185H-AC
- VOLTAGE: 12
- BATTERY: Flooded/wet lead-acid battery
- DEPTH OF DISCHARGE: 0.6
- MATERIAL: Polypropylene

Table B. 2: Battery Specifications

Type	Capacity (Ah)	Energy (KWh)	Length (mm)	Width (mm)	Height (mm)	Weight (Kg)
J185H-AC	207	2.99	380	176	374	56

B.3 Charge Controller

A 240V, 1440A Charge controller from Sunway Power company model (SSCP -240V -100A – TA) is used. Specifications listed in table B.3

Figure B.3: SUN WAY Charge Controller

Table B.3: Charge Controller Specifications

Model	SSCP -240V - 100A – TA
Rated PV power watts	24KW
Rated charging current	100A
VOC of PV arrays Max.	≤ 420V
Rated battery bank voltage	240V
Over-charge voltage of batteries	300V
Over-charge recovery voltage	270V
Battery float charging voltage	280V
Time delay to cut-off charge	default are 5 minutes
Time delay to charge recovery	default are 10 minutes
Self-consumption (day)	≤ 50mA (backlight off)
Self-consumption (night)	≤ 20mA (backlight off)
Ambient temperature	-25°C ~ +50°C
Humidity	85%. NC(25°C±5°C)
Protection class	IP20
Net weight	8.0 KG

B.4 Inverter

20KW, 3-phase inverter by FoshanOuyad Electronic Co., Ltd. is used . Specifications listed in table B.4.

Figure B.4: FoshanOuyad Electronic inverter

Table B.4: Inverter Specifications

Model	3P2073	
Working Way	Continuous Working	
AC Connected Way	Three-phases Four-wire Power Cable	
Rated Output Power	20KW	
Output Overload Capacity	120% <1min	
input parameter	Maximum input current	114.3A
DC voltage range	210VDC~280VDC	
maximum DC power	24.4KW	
Output Parameter	rated output voltage	400V
rated frequency of power grid	50HZ ±1%	
Voltage range of the transition changes	Within10% resistance load 0%~100%	
degree of distortion of output voltage	<3% linear load	
power factor	Rated power ≥0.99	
protection against out-put over voltage	447V	
protection against out-put under voltage	352V	
maximum transfer efficiency	>90%	

B.5 Generator

Silent 3-phase, 50Hz, 85KW, 100KVA Diesel Generator powered by Perkins, TOPOWER GENERATORS CO., LTD.

Figure B.5: Perkins Generator

•Basic Specification

Table B.5 shows the full specifications of the generator used.

Table B.5: Generator Specifications

Control panel	DES6020/DES7320
Generator Rate	1500rpm
Generator Rated Current	63-68108-118125-137 amps
Engine and Alternator	Original, brand new
Cooling Type	water cooling
Frequency	50Hz
Fuel	Diesel
Maximum Power	85kw
Output Type	AC Three Phase