People’s Democratic Republic of Algeria
Ministry of Higher Education and Scientific Research

University M’Hamed BOUGARA – Boumerdes

Institute of Electrical and Electronic Engineering
Department of Power and Control

Final Year Project Report Presented in Partial Fulfilment of
the Requirements for the Degree of

MASTER

In **Electrical and Electronic Engineering**
Option: **Power Engineering**

Title:

Design of power management algorithm for hybrid power system

Presented by:

- **KERBOUCHE Ammar**
- **CHAIB Fakhr El Islam**

Supervisor:

Pr. KHELDOUN Aissa

Registration Number:………/2019

Abstract

Solar and wind energy can be used to deliver electricity for grid utility as well as remote micro-grid. These sources are used more and more to mitigate the consequences of greenhouse gases being produced by convention power plants. However, due to their intermittence, solar as well as wind energy source alone cannot meet the requirement of micro-grids or remote loads in terms power. To this, hybrid system is preferred to ensure supplying the power demand. In general, a diesel and a battery are associated to store and supply power when there is excess and lack of power respectively. For the best operation, an energy management system must be used to connect the appropriate renewable source as the power demand varies. In this project, an energy management is proposed and simulated for a given hybrid system.

Acknowledgement

First, we would like to thank Allah, the Most Beneficent, the Most Merciful, for all that He has endowed upon us and all the opportunities that He has presented to us in life.

Throughout our thesis work, we have been extremely fortunate in having the support and the encouragement of many people. We would like to thank everyone who helped make this thesis possible. We would like to express our deepest sense of gratitude to our supervisor **Pr.KHELDOUN Aissa**, for his endless contribution and advice, it was a privilege to work under his supervision.

We would like to express our gratitude to all IGEE teachers and staff for their kindness and great help they provide to us to finish this work.

Most importantly, we are grateful to our families that supported us every time we were in need, always standing by us, guiding us into searching for answers and striving for a better tomorrow.

Last but not least, a big thank you to all of our friends with whom we shared some of the most amazing moments of our lives.

Table of Contents

Chapter 1: Renewable energy sources

Chapter 2: Photovoltaic energy conversion system

Chapter 3: Wind energy conversion system and energy storage system

Chapter 4: Power management of hybrid system

List of Tables

List of Figures

Abbreviations

PV	Photovoltaic
RES	Renewable Energy Sources
HPS	Hybrid Power System
BESS	Battery Energy Storage System
WECS	Wind Energy Conversion System
PVECS	Photovoltaic Energy Conversion System
AC	Alternative Current
DOD	Depth of Discharge
PMSG	Permanent Magentas Synchronous Generator
VSC	Voltage Source Converter
MPPT	Maximum Power Point Trucker
STC	Standard Test Condition
PWM	Pulse Width Modulation
ESR	Electrical Service Requirement
MPP	Maximum Power Point
IGBT	Insulated Gate Bipolar Transistor
DC	Direct Current
P&O	Perturb and Observe
Si	Silicon
T	Temperature
GHPs	Geothermal Heat Pumps

General Introduction

General introduction

Providing energy for a community, in a sustainable manner, nowadays has become a more and more important issue as we face global warming and climate change realities. Power generation engineers and designers have a responsibility to improve techniques of energy conversion in order to reduce emissions of CO2 and NOx, which are believed to be a source of environmental degradation. Harnessing renewable energy sources which are abundantly available in nature provides an opportunity to produce energy in an environmentally friendly way. Therefore, with an appropriate design, combining renewable energy generators can solve these problems.

A hybrid energy system usually consists of two or more energy sources combined to provide increased system efficiency as well as greater balance in the energy supply. Hybrid energy systems are best suited to reduce dependence on fossil fuel using available renewable energy sources. However, there is also disadvantage of using hybrid system such as in most cases the system is over-sized because it contains different types of power generation system and hence an individual engineering study is required for each site where there is an interest in using such a technology.

This study addresses power management of hybrid system based on wind energy conversion system (WECS), photovoltaic energy conversion system (PVECS) and a battery energy storage system (BESS). WECS and PVECS are used as primary energy sources, while BESS is used as a backup source and storage system. PVECS and WECS are controlled to track the maximum power point (MPPT). BESS is controlled in a manner to stabilize the DC bus voltage by using the appropriate charge/discharge algorithm. An appropriate power management algorithm will be selected to ensure the power balance between the generation part (PVECS and WECS) and the load side.

Chapter 1

Renewable Energy Systems

1 Introduction

Modern Electrical power systems are facing many challenges in development and expansion. These are no longer limited in technical, economic, or financial in nature but are environmental and social. Climate change and sustainable development are major challenges of the 21st century, with extraordinary implications for energy and environmental security [1]. The utilization of traditional energy sources such as natural gas, coal and oil causes the increase of electrical energy generation cost besides their pollutant effects to environment [2]. A rapid growth of the energy demand is affecting the environment and leaving a long-lasting harmful effect on the environment. Renewable energy resources like wind, solar, hydropower, biomass and geothermal energy have the potential to overcome these difficulties.

Figure 1. 1: renewable energy sources

2 Advantage of renewable energy

Renewable energies are clean sources of energy that have a much lower environmental impact than conventional energy technologies and they will not run out ever, other sources of energy are finite and will someday be depleted.

Another advantage using renewable resources is that they are distributed over a wide geographical area, ensuring that developing regions have access to electricity generation at a stable cost for the long-term future. The sun's heat also drives the winds, whose energy, is captured with wind turbines. Then, the winds and the sun's heat cause water to evaporate. When this water vapor turns into rain or snow and flows downhill into rivers or streams, its energy can be captured using hydroelectric power plants. Along with the rain and snow, sunlight causes plants to grow. The organic matter that makes up those plants is known as biomass. Biomass can be used to produce electricity. The use of biomass for any of these purposes is called bioenergy.

Not all renewable energy resources come from the sun. Geothermal energy taps the Earth's internal heat for a variety of uses, including electric power production, and the heating and cooling of buildings. And the energy of the ocean's tides come from the gravitational pull of the moon and the sun upon the Earth. In fact, ocean energy comes from a number of sources. In addition to tidal energy, there's the energy of the ocean's waves, which are driven by both the tides and the winds. The sun also warms the surface of the ocean more than the ocean depths, creating a temperature difference that can be used as an energy source. All these forms of ocean energy can be used to produce electricity [3].

3 Renewable energy in the world

Globally, the world produced approximately 5900 TWh of modern renewable energy in 2016. This represents a 5 to 6-fold increase since the 1960s. The change & mix of modern renewable consumption over the last 50 years is shown in **Fig.2** below. This is measured in terawatt-hours per year [4].

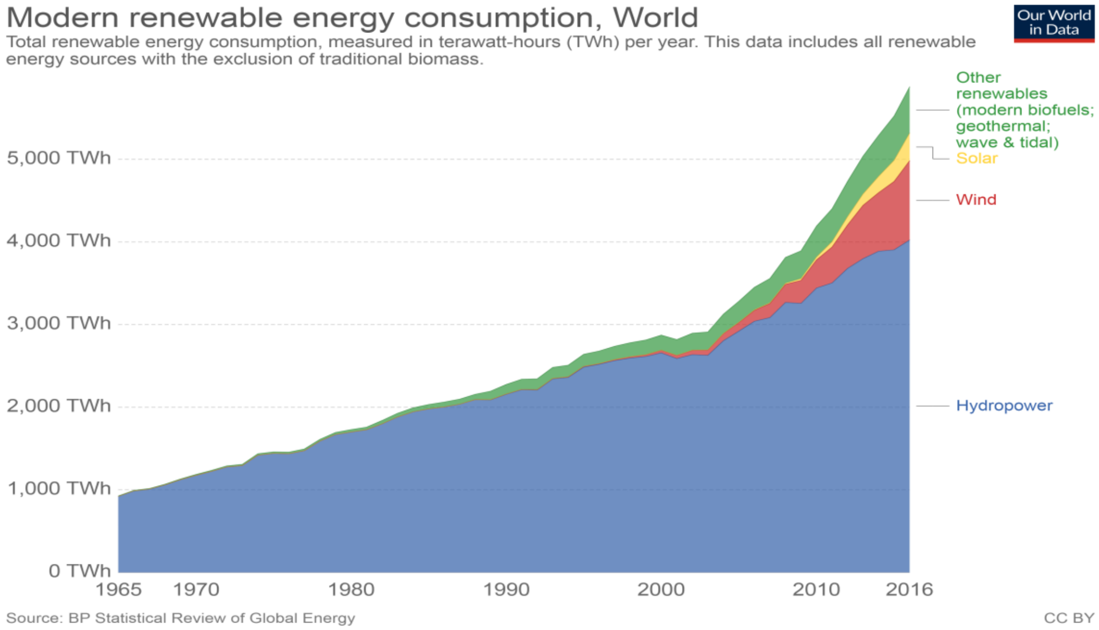


Figure 1. 2: renewable energy consumption in the word

4 Solar energy

Solar energy is radiant light and heat from the Sun that is harnessed using a range of ever-evolving technologies such as solar heating, photovoltaics, solar thermal energy, solar architecture, molten salt power plants and artificial photosynthesis. It is an important source of renewable energy and its technologies are broadly characterized as either passive solar or active solar depending on how they capture and distribute solar energy or convert it into solar power. Active solar techniques include the use of photovoltaic systems, concentrated solar power and solar water heating to harness the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light-dispersing properties, and designing spaces that naturally circulate air [5].

4.1 Photovoltaic cell

photovoltaic technology is used to describe the hardware made of semiconductor materials, which converts sunlight into electrical power. When sunlight is absorbed by these materials, the solar energy knocks electrons loose from their atoms, allowing the electrons to flow through the material to produce electricity the photovoltaic modules that perform this conversion have many benefits. They are durable, reliable, minimal maintenance requirement, completely silent and require only sunlight as fuel. However, their high dependence to weather conditions (temperature and irradiance) and relatively low conversion efficiency are their main drawbacks.

Figure 1. 3: solar photovoltaic panels

The performance of a solar cell is measured in terms of its efficiency at turning sunlight into electricity. Only sunlight of certain energies will work efficiently to create electricity, and much of it is reflected or absorbed by the material that make up the cell. Because of this, a typical commercial solar cell has an efficiency of 15%-about one-sixth of the sunlight striking the cell generates electricity. Low efficiencies mean that larger arrays are needed, and that means higher cost. Improving solar cell efficiencies while holding down the cost per cell is an important goal of the PV industry.

4.2 Photovoltaic system

A photovoltaic system is a power system designed to supply usable power by means of photovoltaic. It consists of an arrangement of several components, including solar panels to absorb and convert sunlight into electricity, a solar inverter to change the electric current from DC to AC, as well as mounting, cabling, and other electrical accessories to set up a working system. It may also use a solar tracking system to improve the system's overall performance and include an integrated battery solution[6].

Photovoltaic systems can be generally divided into two basic groups:

- pv systems not connected to the network, stand-alone systems (off-grid)
- pv systems connected to public electricity network (on-grid)

There are lots of different subtypes of photovoltaic systems according to type and method of connecting to the network, or a way of storing energy on independent system.

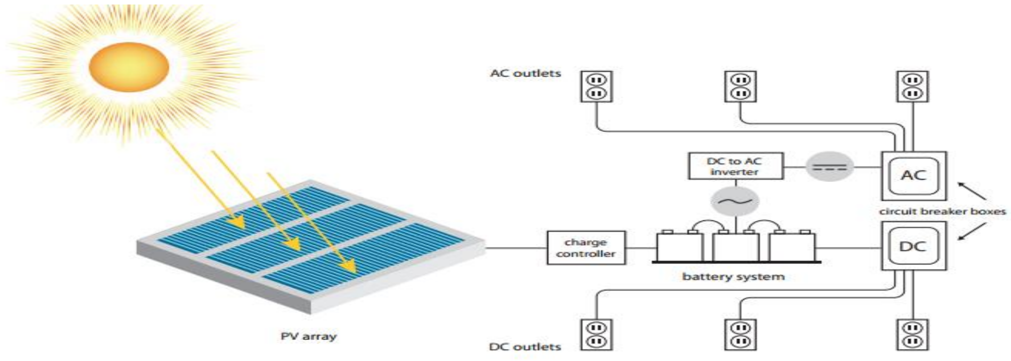


Figure 1. 4: Standalone photovoltaic system with battery

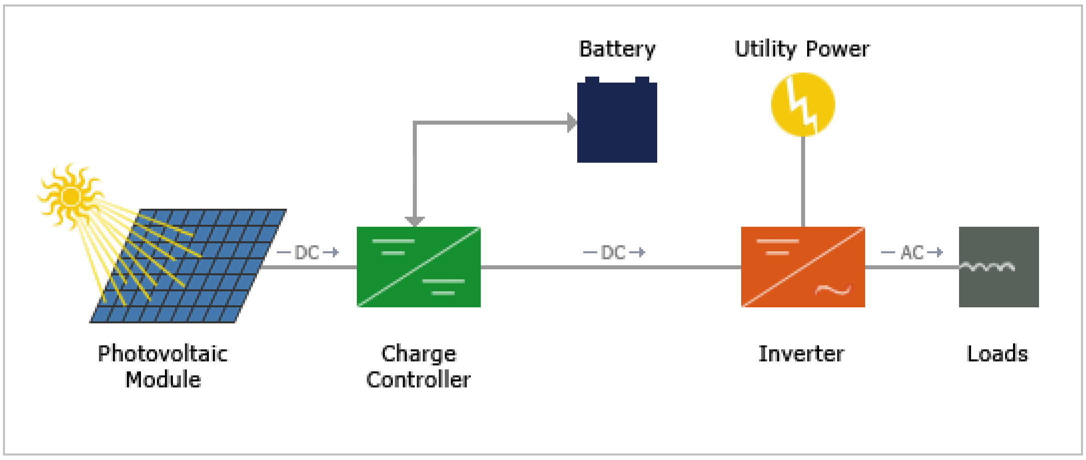
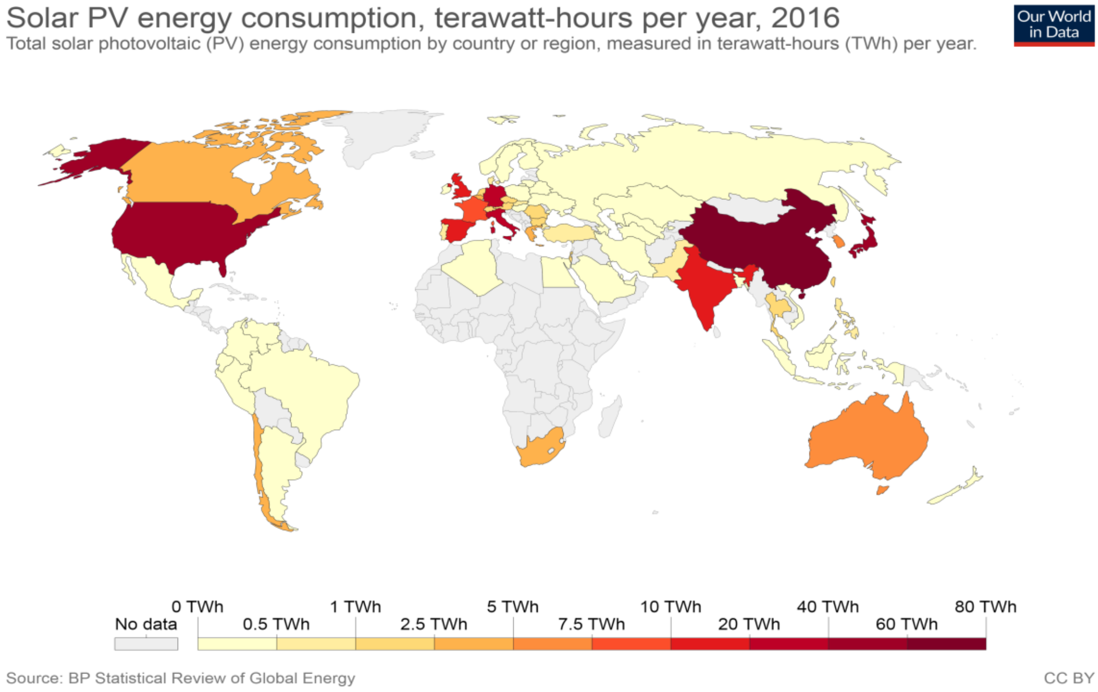


Figure 1. 5: Grid-connected photovoltaic system with battery

4.3 Solar energy in the world

Globally, the world produced approximately 333 TWh of solar pv energy in 2016 [4].



Source: BP Statistical Review of Global Energy

Figure 1. 6: solar PV energy consumption map in 2016

5 Wind energy

Wind is the result of difference in atmospheric pressure from one region to another. This difference in pressure is caused by the fact that the earth surface is not uniformly heated up by the sun, and the earth is continuously revolving around itself and the sun Wind energy is available in the form of Kinetic Energy of air [6].

Wind energy is the use of air flow through wind turbines to provide the mechanical power to turn electric generators and traditionally to do other work, like milling or pumping. Wind power, as an alternative to burning fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation, consumes no water, and uses little land. The net effects on the environment are far less problematic than those of fossil fuel sources[6].

5.1 Wind turbine

We have been harnessing the wind's energy for hundreds of years. From old Holland to farms in the United States, windmills have been used for pumping water or grinding grain. Today, the windmill's modern equivalent - a wind turbine - can use the wind's energy to generate electricity.

Wind turbines, like windmills, are mounted on a tower to capture the most energy. At 30 meters or more aboveground, they can take advantage of the faster and less turbulent wind. Turbines catch the wind's energy with their propeller-like blades. Usually, two or three blades are mounted on a shaft to form a rotor.

A blade acts much like an airplane wing. When the wind blows, a pocket of low-pressure air forms on the downwind side of the blade. The low-pressure air pocket then pulls the blade toward it, causing the rotor to turn. This is called lift. The force of the lift is actually much stronger than the wind's force against the front side of the blade, which is called drag. The combination of lift and drag causes the rotor to spin like a propeller, and the turning shaft spins a generator to make electricity.

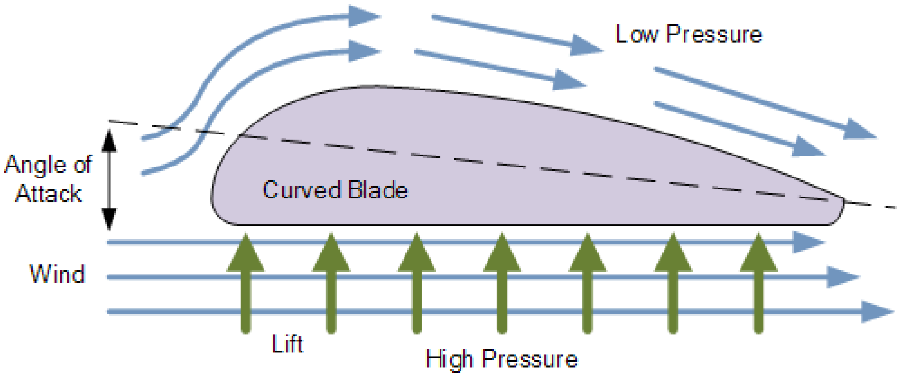


Figure 1. 7: Wind turbine blade design

5.2 Generator

Any types of three-phase generator can connect to with a wind turbine. Several different types of generators which are used in wind turbines are as follows. Asynchronous (induction) generator and synchronous generator. Squirrel cage induction generator (SCIG) and wound rotor induction generator (WRIG) are comes under asynchronous generators. Wound rotor generator (WRSG) and permanent magnet generator (PMSG) are comes under synchronous generator.

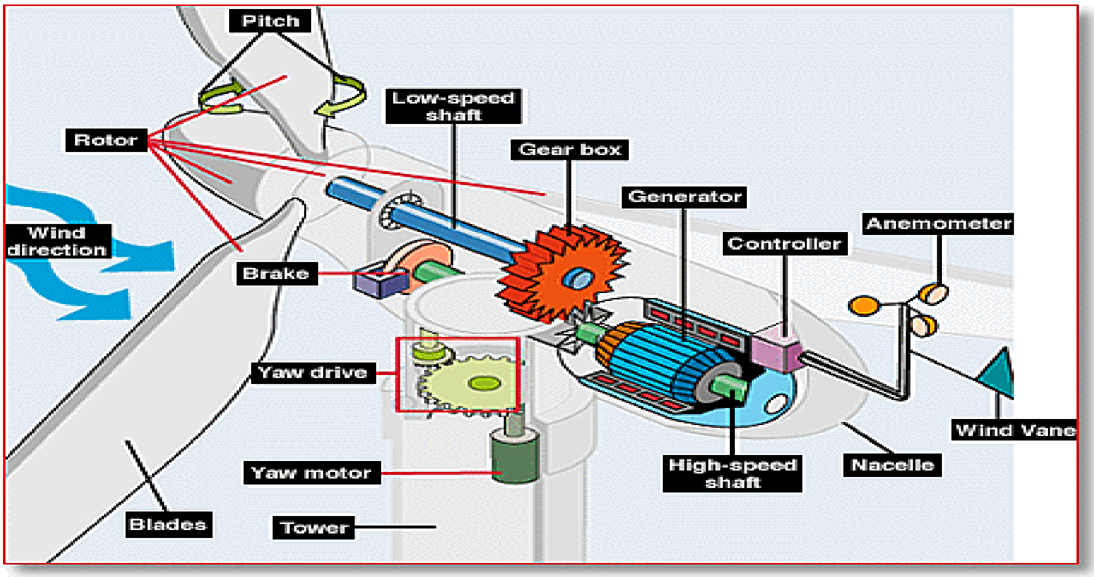


Figure 1. 8: Wind turbine diagram

Wind turbines can be used as stand-alone applications, or they can be connected to a utility power grid or even combined with a photovoltaic (solar cell) system. For utility-scale sources of wind energy, a large number of wind turbines are usually built close together to form a wind farm. Several electricity providers today use wind plants to supply power to their customers [3].

5.3 Wind energy system

Wind energy systems can be generally divided into two basic groups:

- Wind energy systems not connected to the network (off-grid), It needs a storage battery bank or a diesel generator which is involved in the system to make the energy available at low wind speeds or at days-of autonomy, sometimes called no-wind-days, when the wind speed is less than the cut-in speed or not high enough to turn the turbine blades.

- Wind energy systems connected to public electricity network (on-grid)

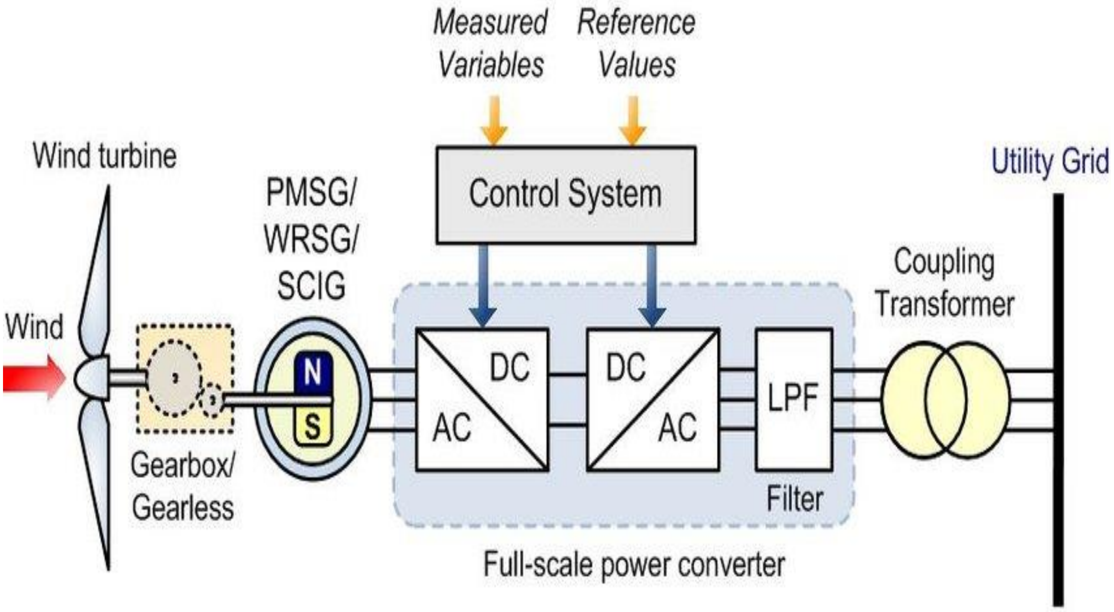


Figure 1. 9: grid connected wind energy system

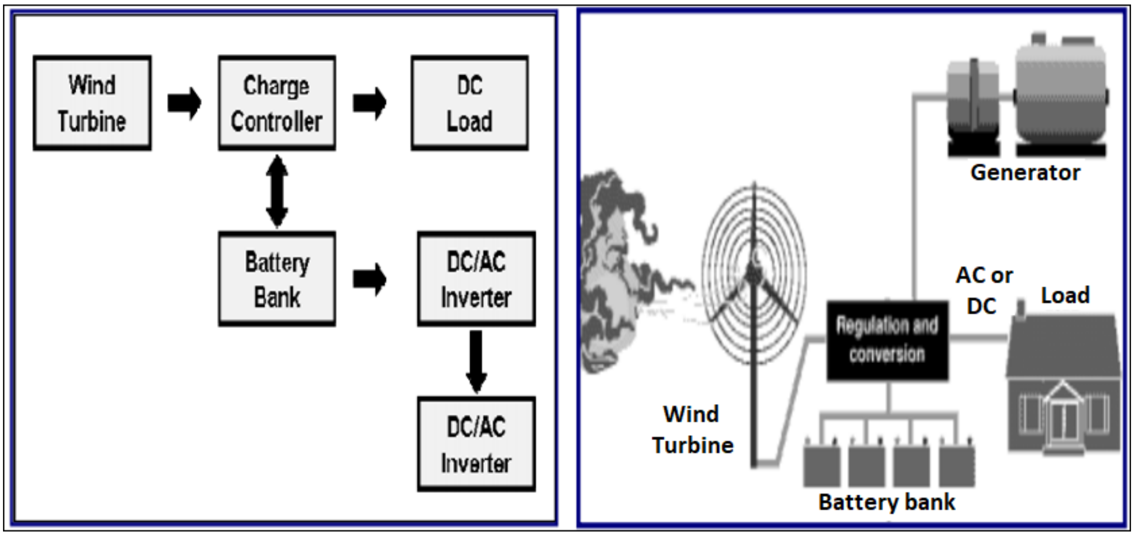
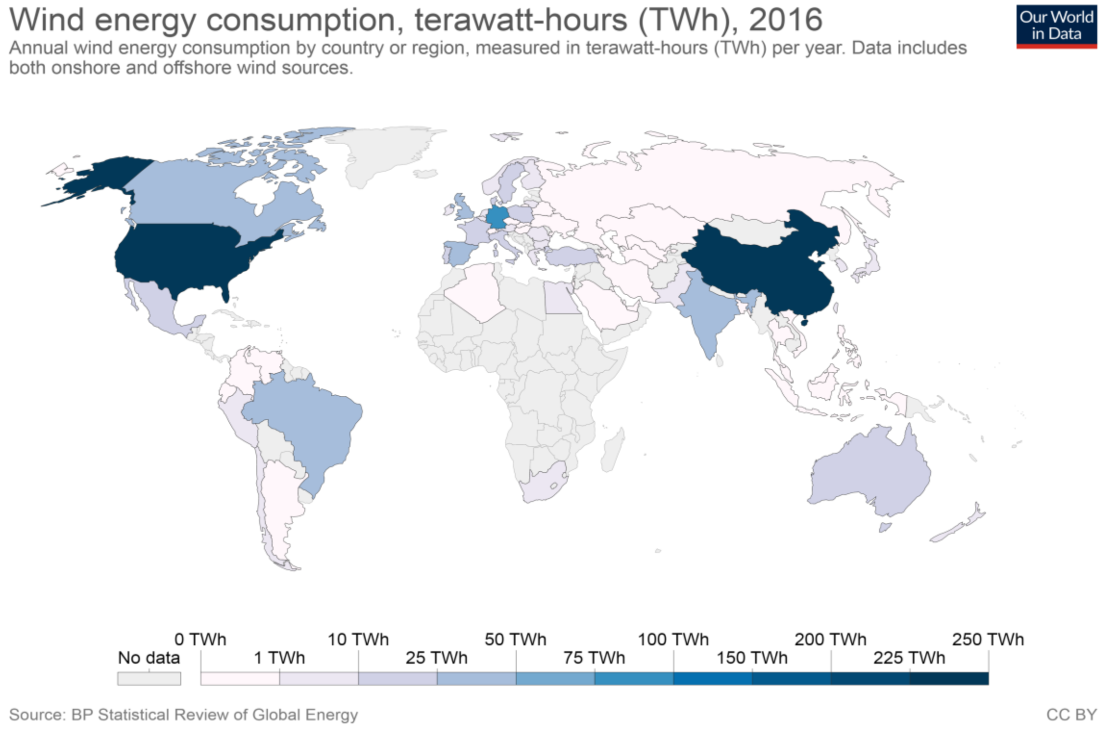


Figure 1. 10: stand-alone wind energy systems

5.4 Wind energy in the world

Globally, the world produces approximately 959.5 TWh per year of wind energy in 2016.



Wind energy consumption, terawatt-hours (TWh), 2016

Annual wind energy consumption by country or region, measured in terawatt-hours (TWh) per year. Data includes both onshore and offshore wind sources.

Source: BP Statistical Review of Global Energy

Figure 1. 11: Wind energy consumption in 2016 map

6 Hydropower energy

Hydropower or water power is power derived from the energy of falling water or fast running water, which may be harnessed for useful purposes. Since ancient times, hydropower from many kinds of watermills has been used as a renewable energy source for irrigation and the operation of various mechanical devices. In the late 19th century, hydropower became a source for generating electricity, this called hydroelectric power [7].

6.1 Hydroelectric power and electricity production

The most common type of hydroelectric power plant uses a dam on a river to store water in a reservoir. Water released from the reservoir flows through a turbine, spinning it, which in turn spins a generator to produce electricity. But hydroelectric power doesn't necessarily require a large dam. Some hydroelectric power plants just use a small canal to channel the river water through a turbine [3].

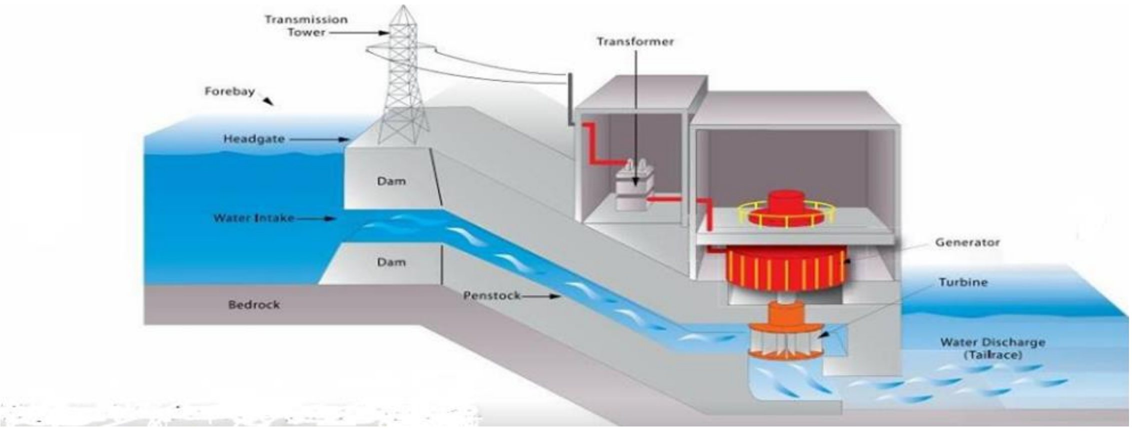
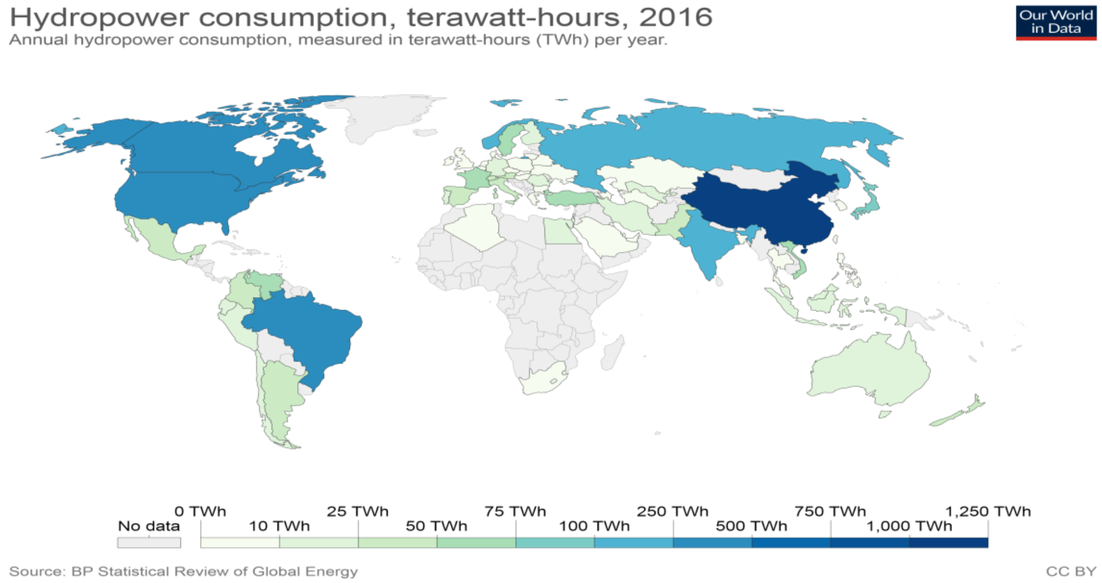


Figure 1. 12: diagram of a hydroelectric generating station

Another type of hydroelectric power plant called a pumped storage plant can even store power then, when the demand of electricity is low, a pumped storage facility stores energy by Pumping water from a lower reservoir to an upper reservoir. During periods of high electrical demand, the water is released back to the lower Reservoir to generate electricity.

6.2 Hydroelectric power in the world

Globally, the world produced approximately 4023 TWh per year of hydropower in 2016.



Source: BP Statistical Review of Global Energy

CC BY

Figure 1. 13: hydropower consumption in 2016 map

7 Geothermal energy

Geothermal energy is the heat from the Earth. It's clean and sustainable. Resources of geothermal energy range from the shallow ground to hot water and hot rock found a few miles beneath the Earth's surface, and down even deeper to the extremely high temperatures of molten rock called magma.

The Earth’s core, 4,000 miles below the surface, can reach temperatures of 9000°F.This heat -geothermal energy- flows outward from the core, heating the surrounding area, which can form underground reservoirs of hot water and steam. These reservoirs can be tapped for a variety of uses, such as to generate electricity or heat buildings. By using geothermal heat pumps (GHPs), we can even take advantage of the shallow ground’s stable temperature for heating and cooling buildings.

7.1 Geothermal power and electricity production

Most power plants need steam to generate electricity. The steam rotates a turbine that activates a generator, which produces electricity. Many power plants still use fossil fuels to boil water for steam. Geothermal power plants, however, use steam produced from reservoirs of hot water found a couple of miles or more below the Earth's surface.

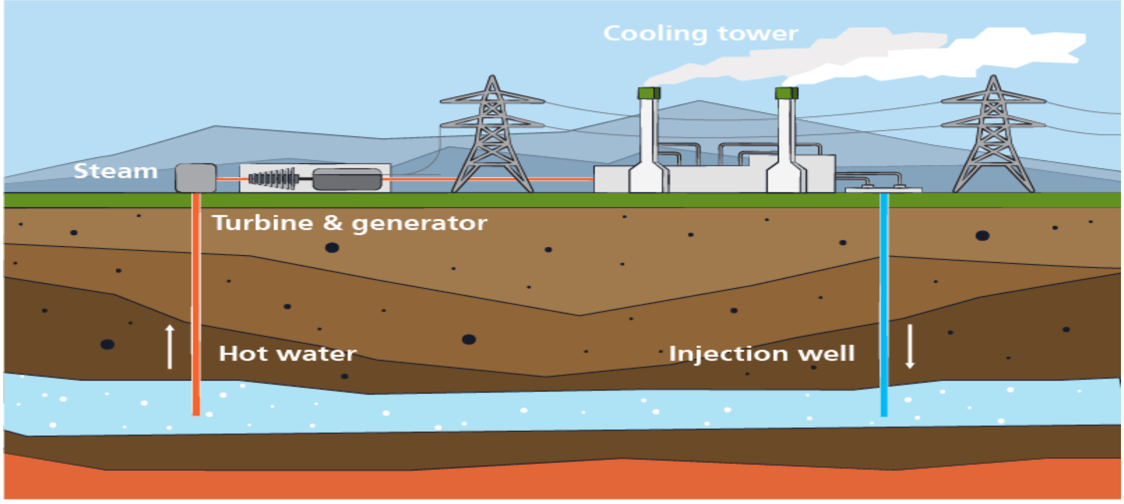


Figure 1. 14: diagram of a geothermal power plant

There are three types of geothermal power plants: dry steam, flash steam, and binary cycle.

7.3 Geothermal energy in the world

Global geothermal capacity in 2017 was 12.9 GW.

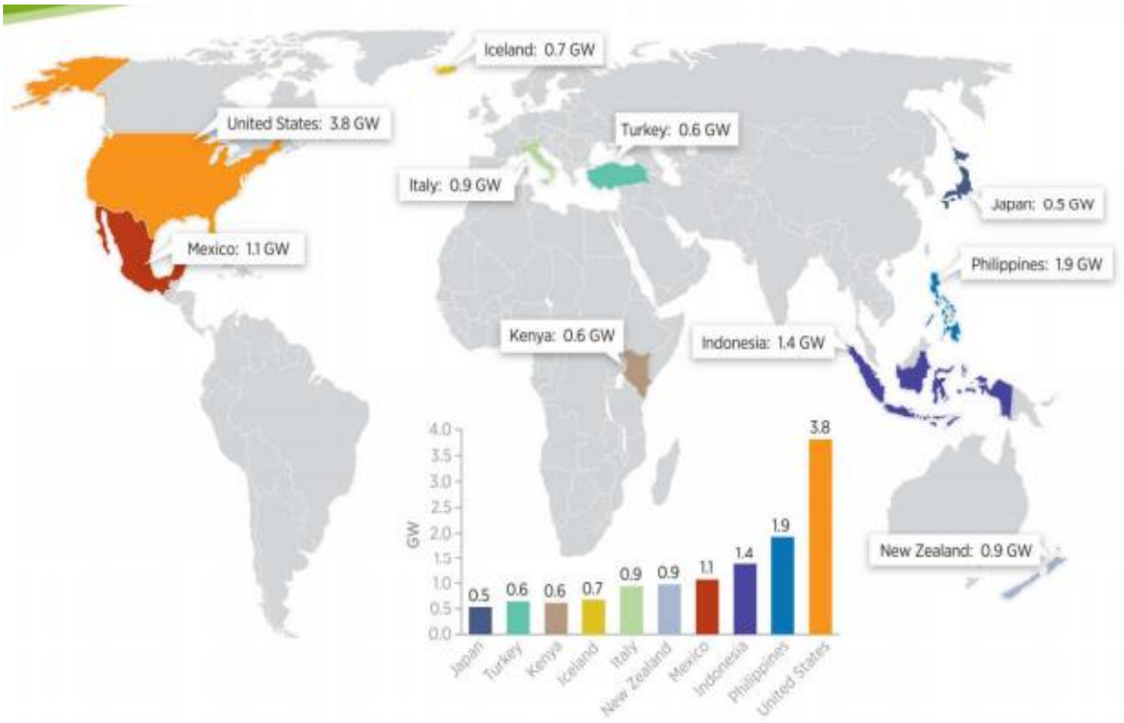


Figure 1. 15: Cumulative Geothermal Electricity Capacity

8 Biomass energy

Biomass is organic material that comes from plants and animals, and it is contains stored energy from the sun. Plants absorb the sun's energy in a process called photosynthesis. When biomass is burned, the chemical energy in biomass is released as heat. Biomass can be burned directly or converted to liquid biofuels or biogas that can be burned as fuels, for examples Wood and wood processing wastes burned to heat buildings, to produce process heat in industry and to generate electricity [8].

Unlike fossil fuels, biomass is renewable in the sense that only a short period of time is needed to replace what is used as an energy resource. Biomass also is the only renewable energy source that releases carbon dioxide in use. However, the release is compensated by the fact that the biomass grown uses the carbon dioxide from the atmosphere to store energy during photosynthesis. If the biomass resource is being used sustainably, there are no net carbon emissions over the time frame of a cycle of biomass production.

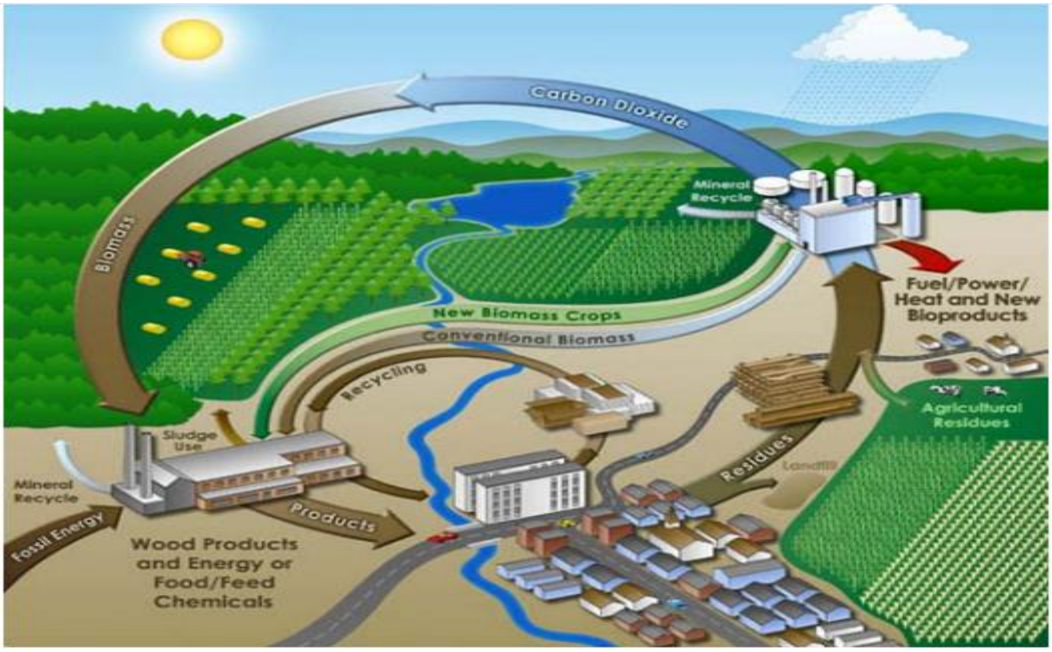


Figure 1. 16: biomass energy cycle

8.1 Biomass energy and electricity production

The energy from waste products – such as wood and agricultural waste and garbage can be used to produce electricity. Wood waste can be burned as it is or converted to a gas and burned in a boiler to produce heat for converting water to steam to run a generator. The same is true for garbage, it can be turned into refuse-derived fuel and burned in a power plant boiler. As garbage or animal waste decays in a landfill or agricultural operation, it produces methane gas. That methane gas can be used as a fuel, similar to natural gas, to produce electricity. Bioenergy global capacity in 2017 was 109 GW.

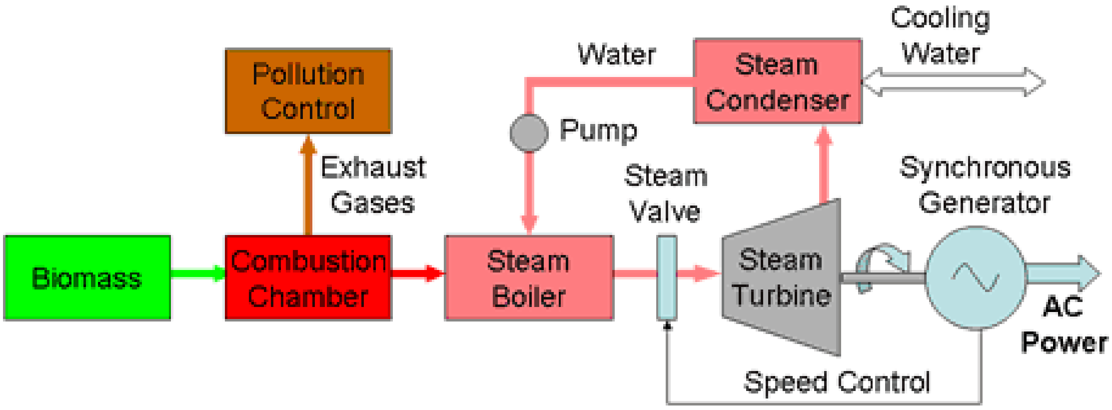


Figure 1. 17: diagram of a biomass power plant

9 Hybrid power system

hybrid power system is a combination of more than one energy source, each one generates different form of energy (DC or AC), to meet all scenarios of load demand buck up sources and storage elements are desirable. Connecting all these elements requires the use of different types of power electronic conversion drives. Different topologies of connection can be made and that what determine the category of the HPS.

9.2 Technical configuration of hybrid power system

The hybrid system can be designed following different configurations to effectively use the locally available renewable energy sources and to serve all power appliances.

9.2.1 AC/DC-coupled Hybrid Power Systems

For the hybrid power system whose demand is to be supplied from wind turbine, PV system, a diesel generator and a battery, different configurations are explained in [9], [10], [11]. In general, there are three accepted categories hybrid system technological configurations according to the voltage they are coupled with each other and the load. These are:

- AC-coupled hybrid power systems.
- DC-coupled hybrid power systems.
- Mixed-coupled hybrid power systems.

9.2.2 AC-coupled Hybrid Power Systems

With this type of configuration, the different HPSs are connected at the AC-bus with the load. The AC coupled HPSs are further divided into two sub-topologies.

- Centralized AC-coupled HPSs.
- Distributed AC-coupled HPSs.

9.2.3 DC-Coupled Hybrid Power Systems

In DC-coupled HPSs configuration, all the electrical circuits, unlike AC-coupled HPSs, are connected to a DC main bus before being connected to the load. Connection with the AC loads is done through a main inverter.

9.2.4 Mixed-coupled Hybrid Power Systems

It is also possible to combine AC-coupled and DC-coupled hybrid power systems and form mixed hybrid power system. With this type of configuration, some of the renewable energy sources (PV-array, in this case) are connected with the battery bank at the DC-bus and other RESs (wind turbine, in this case) are connected with the generator at the AC-bus.

9.2.5 Grid connected versus stand-alone HPS

HPSs can be also categorized into two other categories depending on their final stage connection. The two systems are explained in detail in [12]:

- **Stand-alone HPS**

the final stage of this system is the load and it must have some means of energy storage and buck source. The major application of the stand-alone power system is in remote area where utility lines are uneconomical to install due to terrain.

- **Grid connected HPS**

from its name we can tell that the system is connected to the utility grid, this last provides power to the site loads when needed, or absorbs the excess power from the site when available. The utility interconnection brings a new dimension in the renewable power economy by pooling the temporal excess or the shortfall in the renewable power with the connecting grid. This improves the overall economy and the load availability of the renewable plant; the two important factors of any power system.

10. Conclusion

The renewable energy sources are cost effective, user-friendly, they can easily beat the fossil fuels. By promoting renewable energy sources, we can avoid, air pollution, soil pollution and water pollution. Country’s economy will increase. Throughout the year these sources are available without affecting the Environment.

Chapter 2

Photovoltaic Energy Conversion System

1 Introduction

The concept of using renewable energy sources emerged from the need to search for alternate green sources of energy. In order to diminish the greenhouse effect and to slow the depletion of fossil fuel, the solar energy has been utilized**.**

A Photovoltaic system converts sunlight into electricity. It can be generally divided into two basic groups; stand-alone and grid connected PV systems. This chapter deals with the theoretical background of each element of a stand-alone Photovoltaic Energy Conversion system and, the basic operation of solar cells and structure will be introduced in details, along with mathematical model of it also, the effects of different parameters on the output of PV module are discussed d using the Matlab®/Simulink® [13].

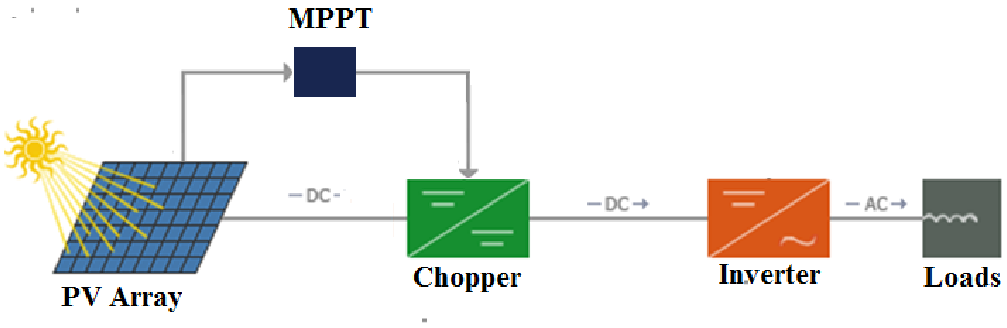


Figure 2. 1: Schematic diagram of PVECS

2 PV Cell, Module and Array

2.1 PV Cell

A solar cell is basically a p-n junction which is made from two different layers of semiconductor doped with a small quantity of impurity atoms. When the PN junction is exposed to light, photons with energy greater than the gap of energy are absorbed, causing the emergence of electron holes' pairs. These carriers are separated under the influence of electric fields within the junction, creating a current that is proportional to incidence of solar irradiation [14].

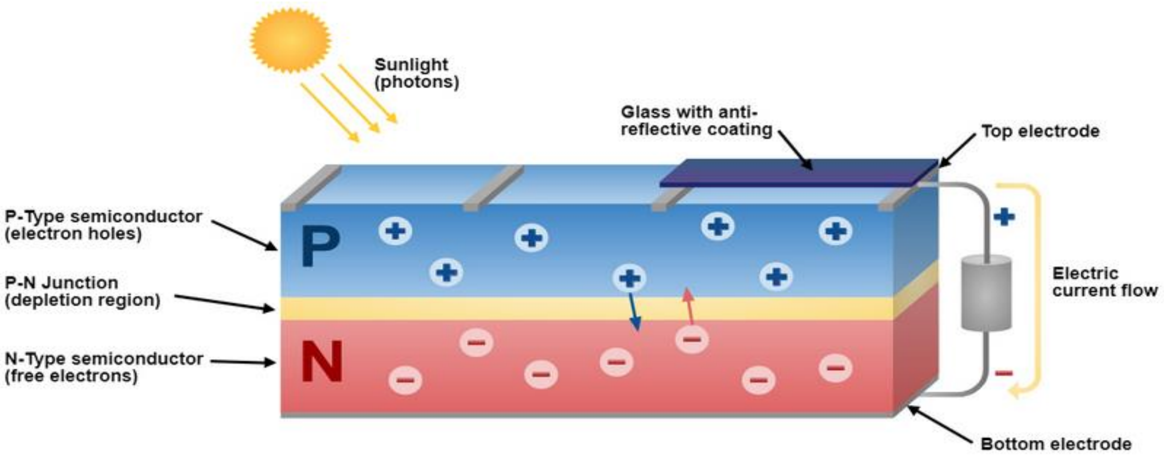


Figure 2. 2: p-n junction of PV cell

The junction of the dissimilar N (net negative charge) and P (net positive charge) layers creates a diode effect. When illuminated the layers act simultaneously as a constant current source in parallel with the diode. The equivalent circuit of a solar photovoltaic cell is given below [15].

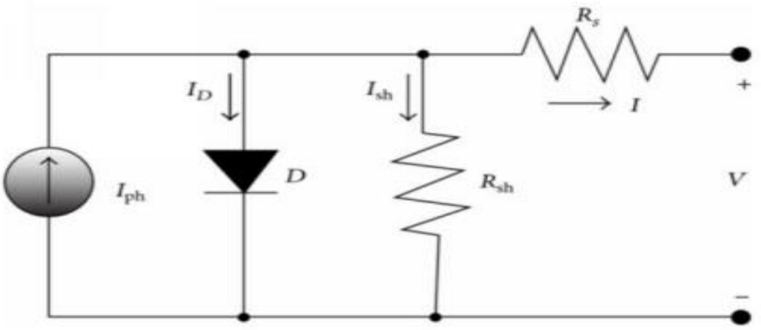


Figure 2. 3: Equivalent circuit of a solar photovoltaic cell

A general mathematical description of I-V output characteristics for a PV cell has been derived based on the circuit of **Fig 2-2**. The output current of the solar cell can be calculated by applying KCL at the node

$$I = [Iph - Io * \left(e^{(V+I*Rs)*\frac{1}{\alpha Vt}} - 1\right) - \frac{V+I*Rs}{Rsh}] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

With;

$$Iph = \frac{G}{Gn} * \left(Iphn + Ki * (T - Tn)\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.2)$$

$$Io = \frac{Iscn+Ki*(T-Tn)}{e^{\frac{Vocn+Kv*(T-Tn)}{\alpha Vt}}-1} \ldots\ldots\ldots\ldots\ldots\ldots (2.3)$$

$$Vt = \frac{K*T}{q} \ldots\ldots\ldots\ldots\ldots\ldots (2.4)$$

Where;

Iph: is a light generated photon current,

Io: cell saturation of dark current,

Vt: is thermal voltage,

Rsh: Shunt resistance in **Ω**,

Rs: Series resistance in **Ω**,

α: Ideality factor [1.6 for silicon],

Iphn: nominal photon current at STC,

T: cell temperature in Kelvin,

Tn: nominal temperature in Kelvin at STC, 25°C,

Ki: Short circuit current temperature coefficient,

G: Solar irradiation in 1 KW/m2,

Gn: Solar irradiation in KW/m2,

Iscn: is the nominal short circuit current at STC,

Vocn: is the nominal open circuit voltage at STC,

Kv: open circuit voltage temperature coefficient at Isc,

K: Boltzmann's constant 1.38×10^{-23} J/K,

q: is the charge of electron 1.6×10^{-19} C.

2.2 PV Module

Since an individual cell produces only about 0.7 V, it is a rare application for which just a single cell is of any use. Instead, the basic building block for PV applications is a module consisting of a number of pre-wired cells in series, all encased in tough, weather-resistant packages. A typical module has 36 cells in series and is often designated as a "12-V module" even though it is capable of delivering much higher voltages than that. Large 72-cell modules are now quite common, some of which have all of the cells wired in series, in which case they are referred to as 24-V modules [16]. The following equation characterized its I – V relations:

$$I = Iph - Io * \left(e^{(V+I*Rs)*\frac{1}{\alpha Vt*Ns}} - 1\right) - \frac{V+I*Rs}{Rsh} \ldots\ldots\ldots\ldots\ldots\ldots (2.5)$$

Ns: the number of cells in series.

2.3 PV Array

A PV array is set of PV module, that can be wired in series to increase voltage, and in parallel to increase current. Arrays are made up of some combination of series and parallel modules to increase power.

For modules in series, the I – V curves are simply added along the voltage axis, at any given current (which flows through each of the modules), the total voltage is just the sum of the individual module voltages.

For modules in parallel, the same voltage is across each module and the total current is the sum of the currents. That is, at any given voltage, the I – V curve of the parallel combination is just the sum of the individual module currents at that voltage [17].

$$I = Npp * Iph - Npp * Io * \left(e^{\left(\frac{V}{Ns} + \frac{I*Rs}{Npp}\right) * \frac{1}{\alpha Vt*Ns}} - 1 \right) - \frac{V*\frac{Nss}{Npp} + I*Rs}{Rsh} \text{.........................} \quad (2.6)$$

Where:

Npp: is the number of modules connected in parallel,

Nss: is the number of modules connected in series.

3 Maximum power point tracking MPPT

Maximum power point tracking (MPPT) is a technique that ensures the maximum power extraction from non-linear energy sources like solar PV systems. The algorithm allows the controller to operate PV module at optimum voltage and current so the extraction of maximum power is ensured. There are many methods for maximum power point tracking [18]. Most common methods for solar PV systems are:

- Constant voltage method
- Perturb and Observe (P&O) method and
- Incremental conductance method

Among several MPPT algorithms, Perturb and Observe (P&O) is also known as Hill Climbing (HC) method. Its working principle is making a small active voltage perturbation in a certain working voltage of photovoltaic cells and observing the change direction of output power. Disturbance observation has been widely used in photovoltaic maximum power point tracking because of its simple control structure. However, due to its fixed step, the oscillation phenomenon occurs near the maximum power point, which reduces the efficiency of power generation.

In the P&O algorithm, the operating voltage of the PV array is perturbed by a small increment, and the resulting power change (P) is measured. If P is positive, then the perturbation of the operating voltage moved the PV array's operating point closer to the MPP. The advantage of this method is its simplicity and that is easy to implement. The P&O method has a limitation to track the MPP when the sunlight decreases, therefore the power-voltage (P-V) characteristic curve flattens out. Another fundamental drawback of P&O method is that it cannot determine when it has actually reached the MPP [20].

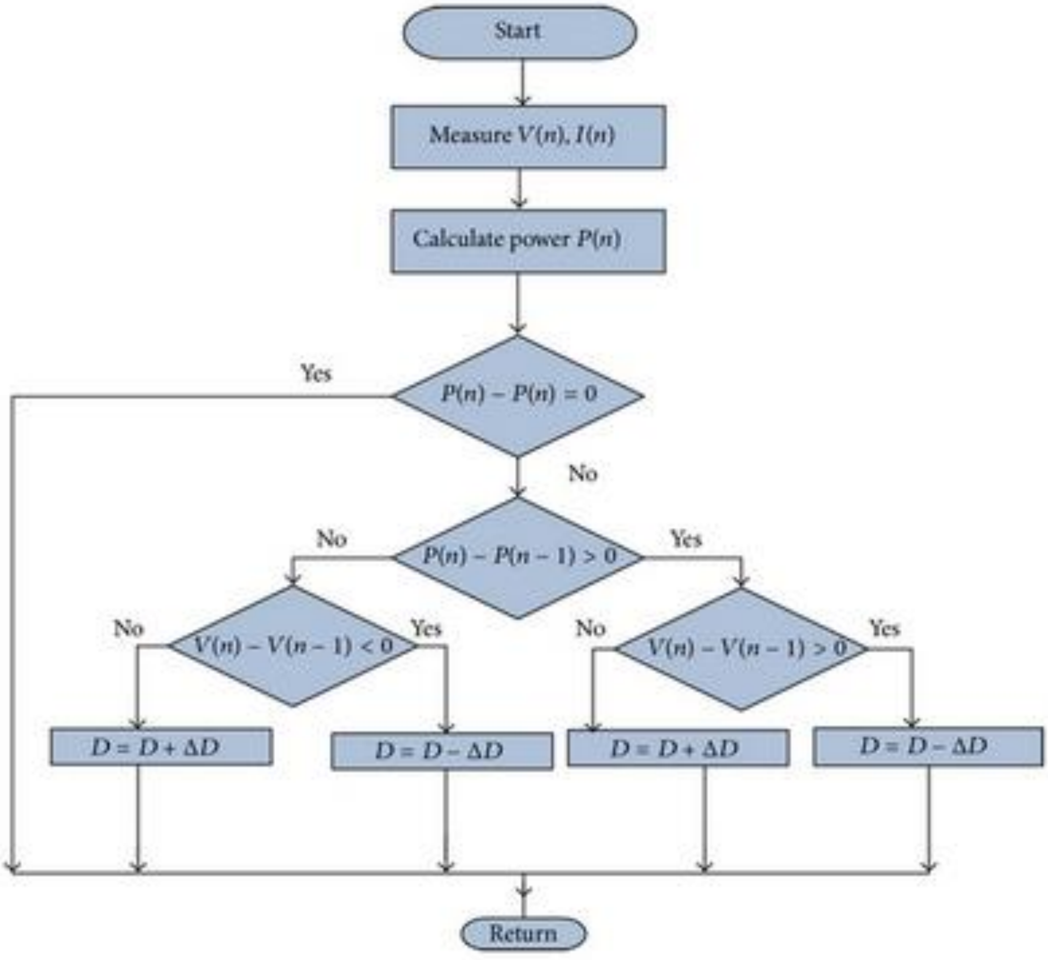


Figure 2. 4: Flow chart of P and O algorithm

4 DC-DC buck-boost converter

Since the power generated by solar PV is DC, a classic DC/DC boost converter is applied to regulate the DC link voltage. MPPT controller generates duty cycle in order to create pulse width modulation (PWM) switching signals for the converter. The switching signal allows the boost converter to operate the solar PV system at optimum voltage and current so that the maximum power extraction is possible. The voltage induced in this PV generation end is small, so a boost converter is required to synchronize with the micro-grid where the bus voltage is 600 V. A DC/AC three phase inverter is applied to connect the system with AC loads.

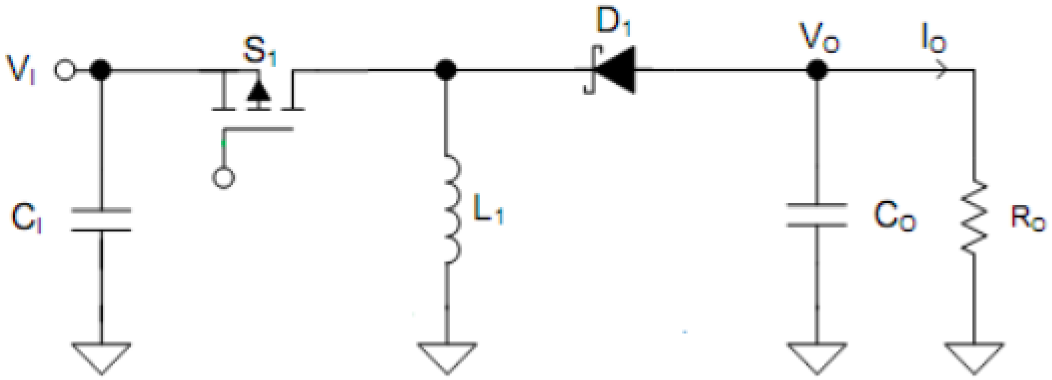


Figure 2. 5: Simplified Schematic of an Inverting Buck-Boost Stage

5 Three-phase, Two-Level Voltage Source Converter

This type of converter has been widely used in industry form different applications including solar and wind energy systems. Depending on the voltage of the device and required supply voltage the two-level voltage source converter (VSC) allows the switches to be connected in series. The converter is composed of six switches, S1 to S6, with an antiparallel free-wheeling diode for each switch as shown in **Fig 2.6**. Depending on operation type and power range these switches can be IGBT, MOSFET or IGCT devices. If the primary end of the converter takes input as DC, then the secondary end produces three-phase variable voltage with variable frequency on AC side. Whether this type of configuration is often referred as inverter and connects the system to AC loads. [20], [21].

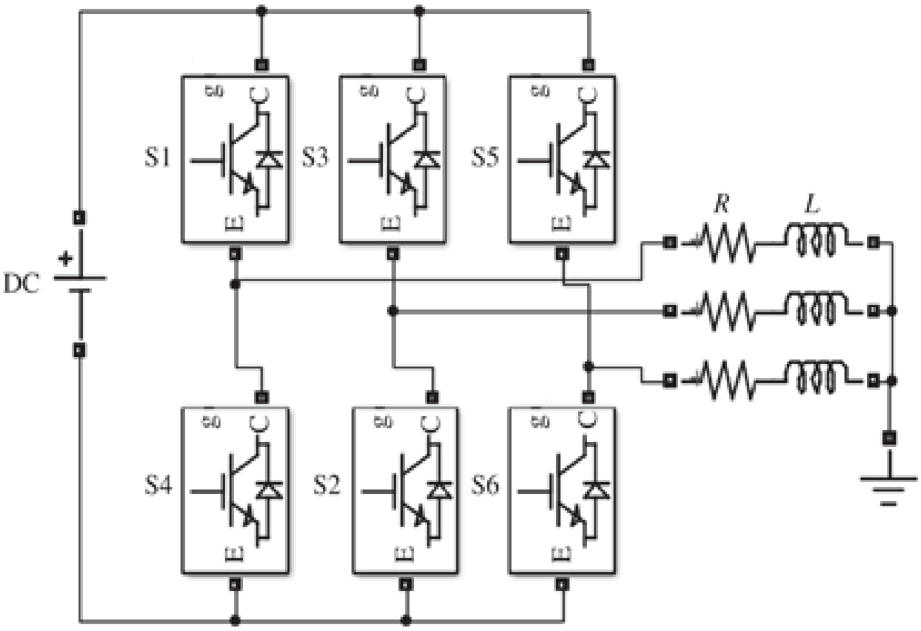


Figure 2. 6: diagram circuit of a three-phase, two-level voltage source converter

6 Simulation and results

6.1 Simulation model of CS6P-250M solar PV module

Equations; (2.2), (2.3), (2.4), (2.5), are implemented in Matlab/Simulink to design and simulate CS6P-250M solar PV module, the following table shows the key specification of the PV module under Standard Test Conditions (STC):

Table 1: Canadian Solar CS6P-250M PV module parameters

Isc	Imp	Voc	Vmp	Pmax	Ns	Ki	Kv	α	Rs	Rsh
8.74	8.22A	37.5V	30.4V	250W	60	0.005 A/^{0}C	-0.34 V/°C	0.98	0.32 Ohm	329.23 Ohm

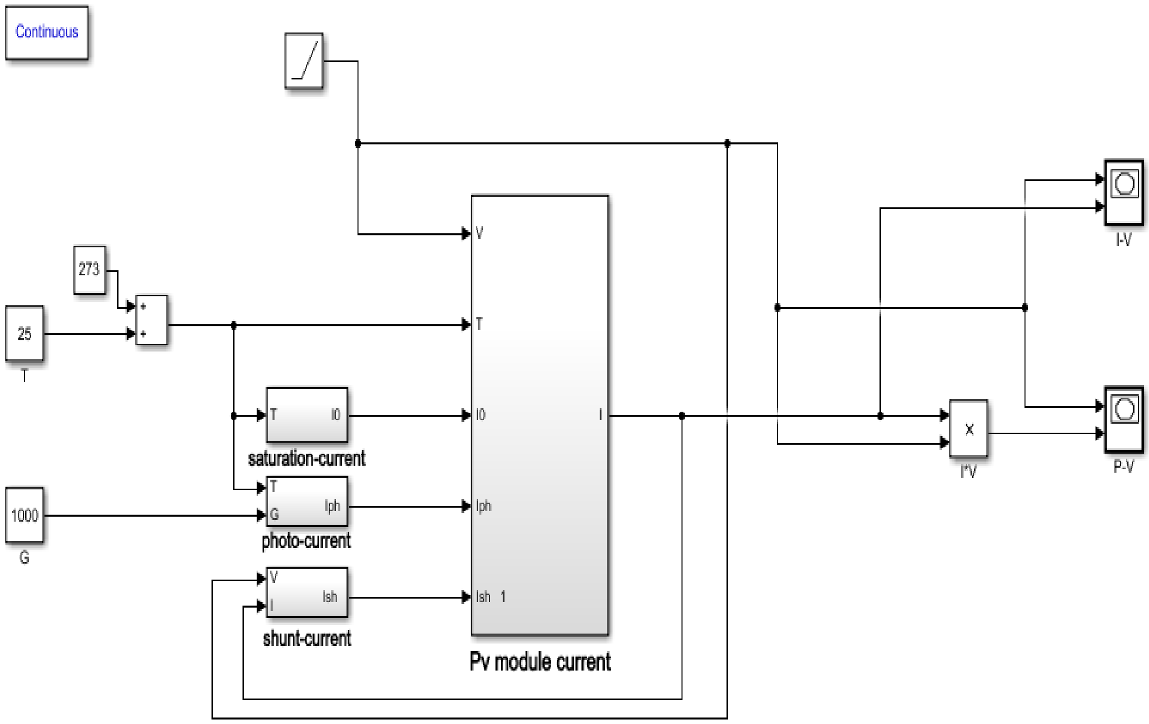


Figure 2. 7: Simulation model of CS6P-250M solar PV module

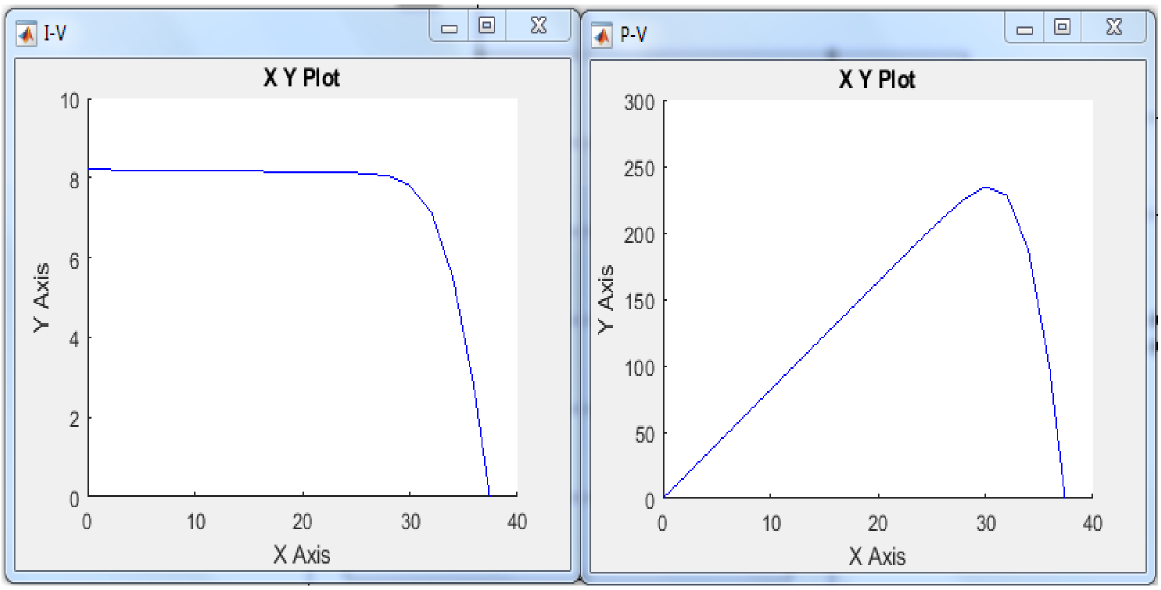


Figure 2. 8: IV and PV curves of single CS6P-250M solar PV module under STC Conditions

6.1.1 Effect of Solar Irradiance Variation

The simulation was performed for 1000, 800, 600 and 400 W/m^2 irradiation levels under the STC. Cell temperature, *T* was kept constant at 25^o C (298 K).

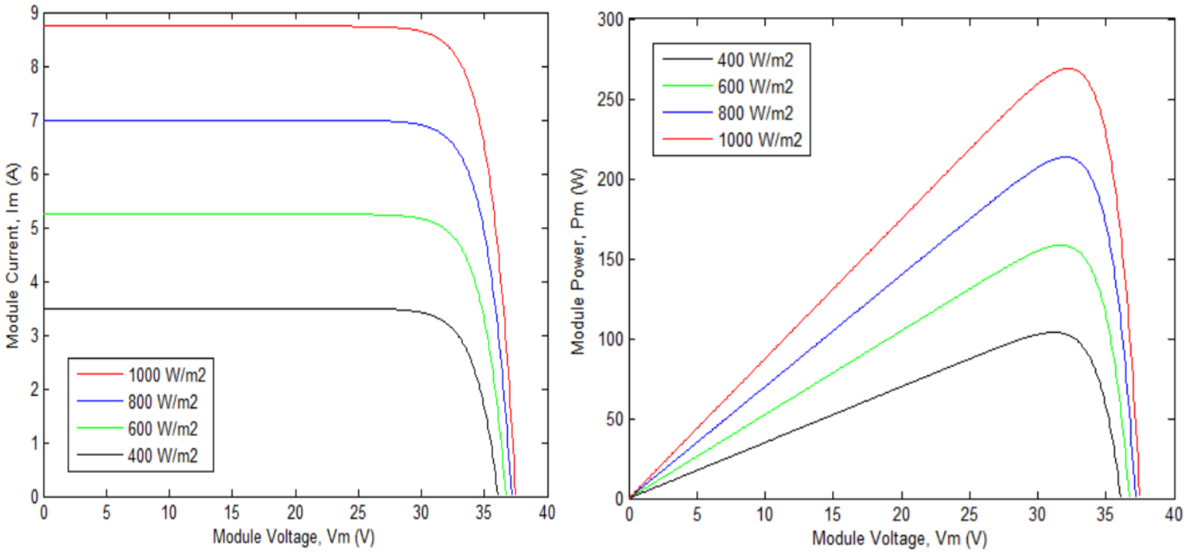


Figure 2. 9: IV and PV curves PV module for different irradiance level

As seen in **Fig 2.9**, the variation of irradiation level affects widely the current and voltage generated in PV module. According to the results; open circuit voltage, V_{OC} drops slightly and short circuit current, I_{SC} decreases widely with the decrement of solar irradiation. This behavior for different solar irradiation has been validated from the datasheet of the CS6P-250M PV module [22].

6.1.2 Effect of Temperature Variation

The simulation was performed for 5° C (278 K), 25° C (298 K), 45° C (318 K) and 65° C (338 K) under the Standard Test Conditions (STC). During this test solar irradiance, was kept constant at 1000 W/m^2.

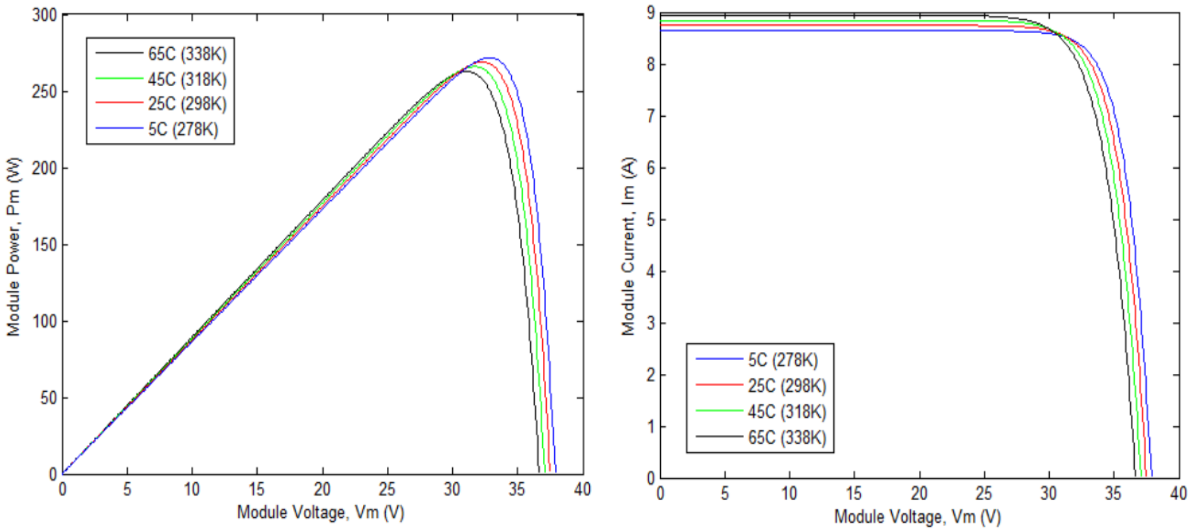


Figure 2. 10: IV and PV curves module for different temperature level

According to the I-V and P-V characteristics in **Fig 2.5**; open circuit voltage, V_{OC} drops and short circuit current, I_{SC} rises slightly when the temperature increases. This behavior for varying temperature has been validated from the datasheet of the CS6P-250M PV module [22].

6.1.3 Effect of Varying Series Resistance

Generally, the typical value of series resistance, R_S of the PV cell is very low. This model was developed to render the suitable model for any given PV cell so that it is possible to vary R_S and observe its effects on the behavior of the PV module. This simulation was performed for three different values of R_S, respectively 1 mΩ, 5 mΩ and 10 mΩ.

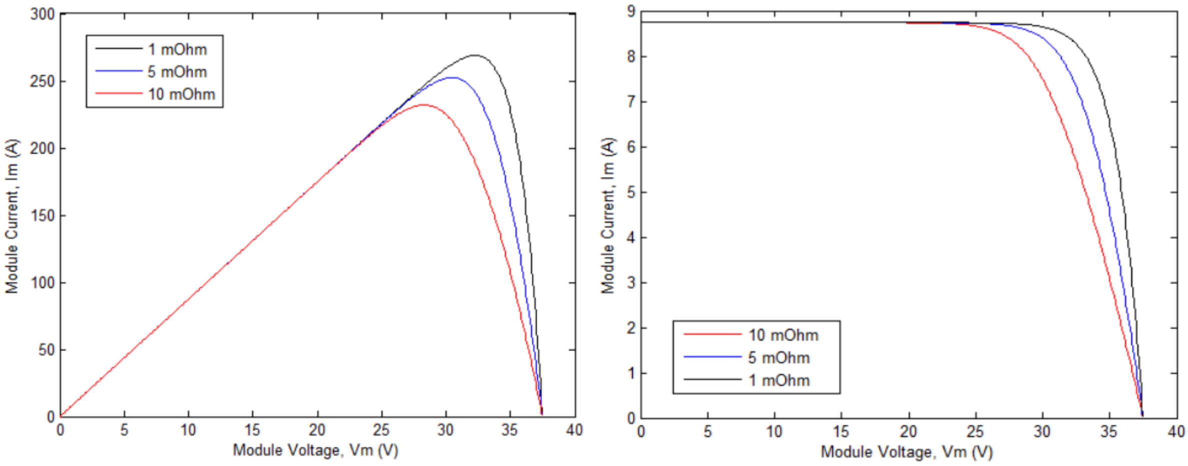


Figure 2. 11: IV and PV curves module for different values of series resistance R_S

As seen in **Fig 2.11**, the variation of R_S affects the deviation of maximum power point of the PV cell and the module as well. However, the open circuit voltage, V_{OC} and short circuit current, I_{SC} remains same.

6.1.4 Effect of Varying Shunt Resistance

In general, the value of the shunt resistance, R_{SH} of the PV cell should be large enough to achieve the maximum output from the PV module. The simulation is performed for three different values of R_{SH}, respectively 200 Ω, 500 Ω and 1000 Ω.

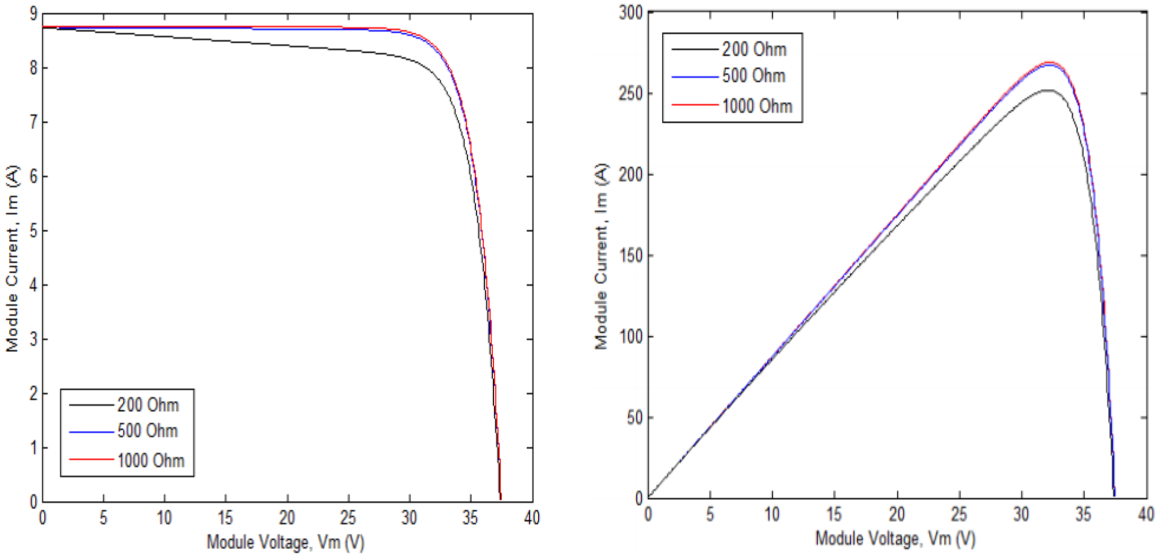


Figure 2. 12: IV and PV curves module for different values of shunt resistance RSH

As seen in **Fig 2.12**, for low value of R_{SH}, the output current of the PV cell drops so fast and it causes a high-power loss. Variation of R_{SH} also affects the deviation of maximum power point of the PV cell and module as well.

6.2 Design of the buck-boost DC-DC converter with P&O MPPT controller

The DC-DC buck-boost converter parameters are calculated using specific equations and assumptions (see appendix A), we summarized the required parameter of our system in the table 2.

Table 2: buck-boost converter parameter

f(sw)	R_{load}	L1	C_1	C_0
10 khz	100Ω	47µH	2mF	2mF

buck-boost DC-DC converter is designed using MATLAB-SIMULINK:

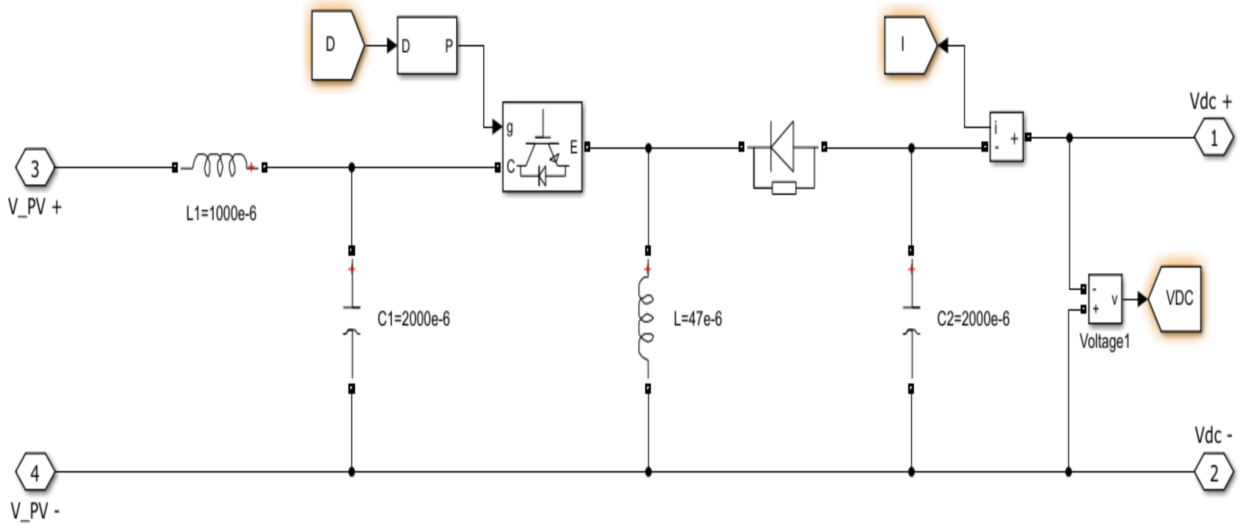


Figure 2. 13: SIMULINK model for Buck-boost DC-DC converter

The initializations used in the P&O algorithm are:

Table 3: Initial values for P&O algorithm

Incrementation (delta D)	**V_{old}**	**P_{old}**	**$D_{initial}$**
0.001	17V	120V	0.35

P&O algorithm is tested. With single Solar CS6P-250M PV module under uniform condition (G=1000 W/m² and T=25°) as shown in **Fig 2.14**.

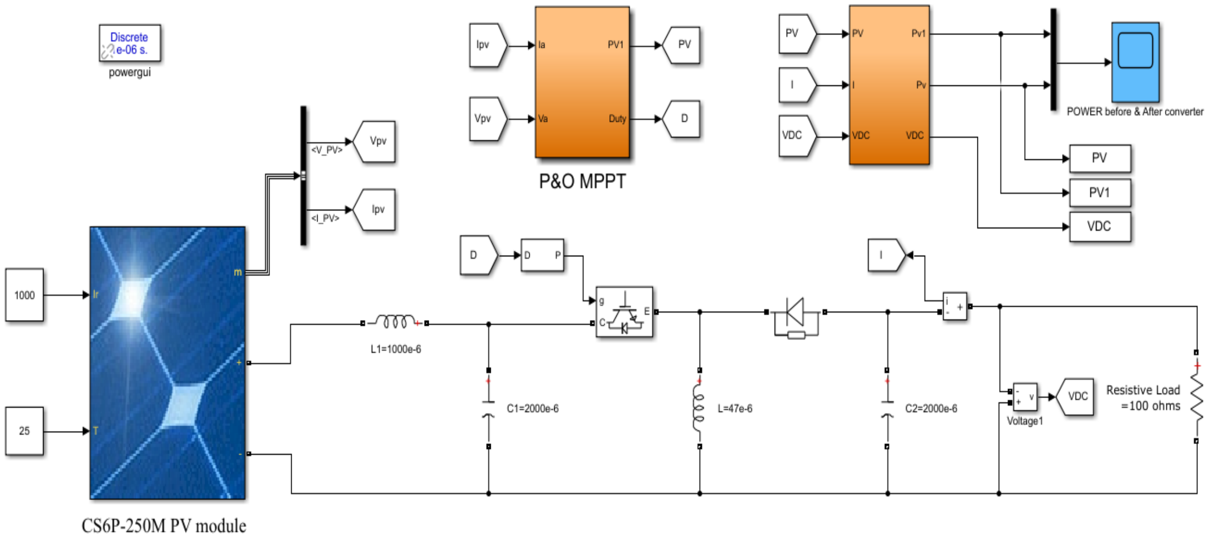


Figure 2. 14: SIMULINK model for single CS6P-250M PV module under uniform condition using P&O controller

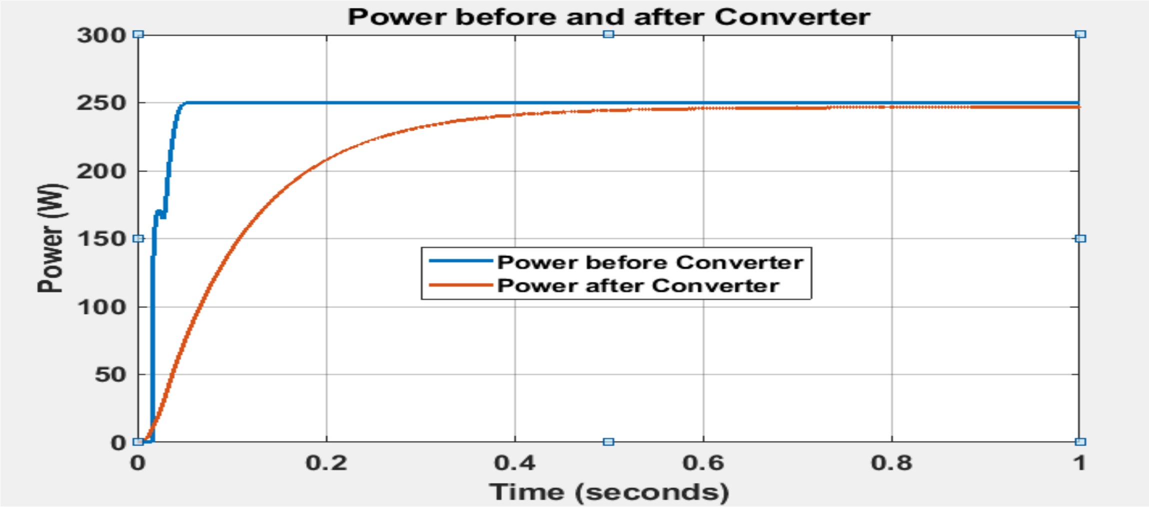


Figure 2. 15: Power before and after converter for single CS6P-250M PV module under uniform condition using P&O controller

6.3 Simulation of overall Solar Photovoltaic Energy Conversion System

As mentioned before, Matlab/Simulink is used to design and implement Solar Photovoltaic Energy Conversion System with a PV array, a MPPT controlled DC/DC boost converter, a three-phase two-level VSC controlled by load voltage regulator, and load. The schematic of the model is shown in **Fig 2.16.**

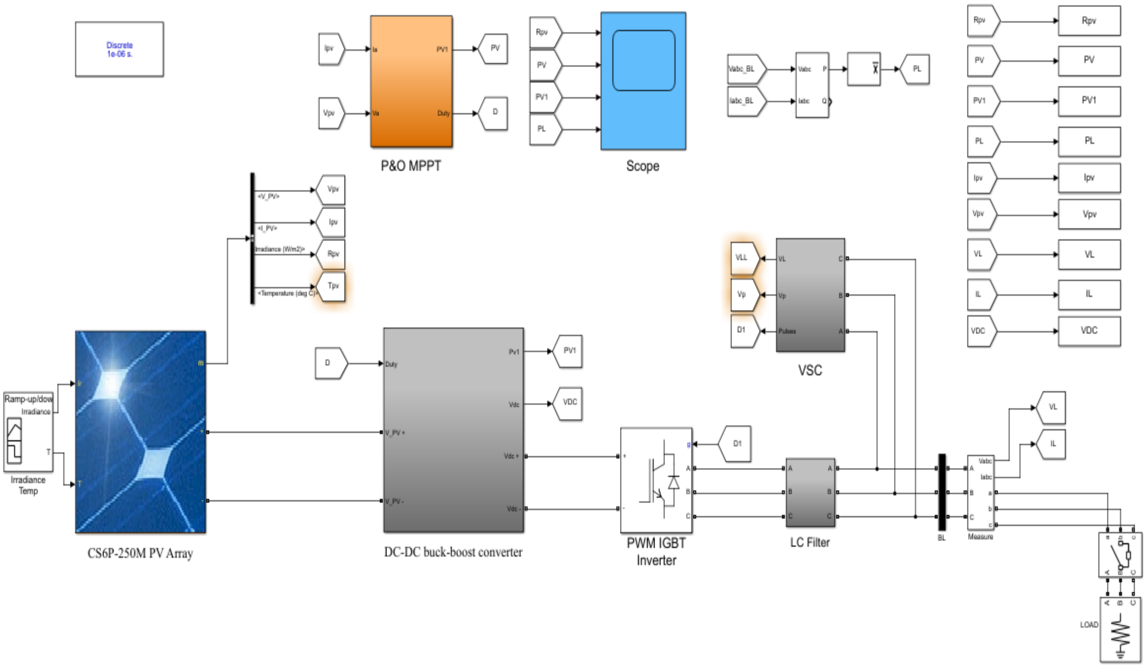


Figure 2. 16: SIMULINK model for overall Solar Photovoltaic Energy Conversion System

This simulation is executed for 3 seconds with variable solar irradiance and under STC conditions where cell temperature is 25^{o} C. Results obtained from the simulation are presented below

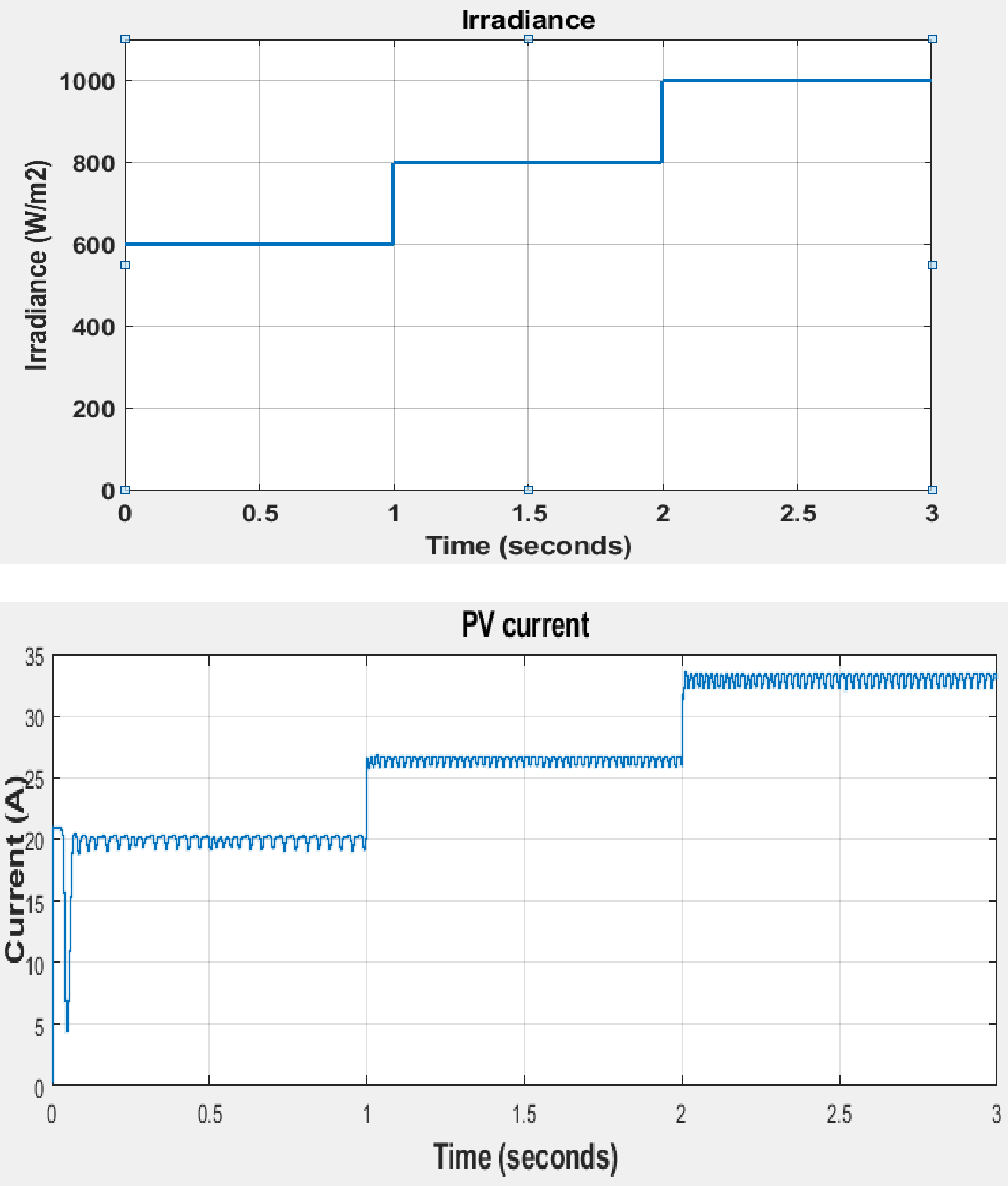


Figure 2. 17: Variable solar irradiation (W/m2) and current generated by solar PV

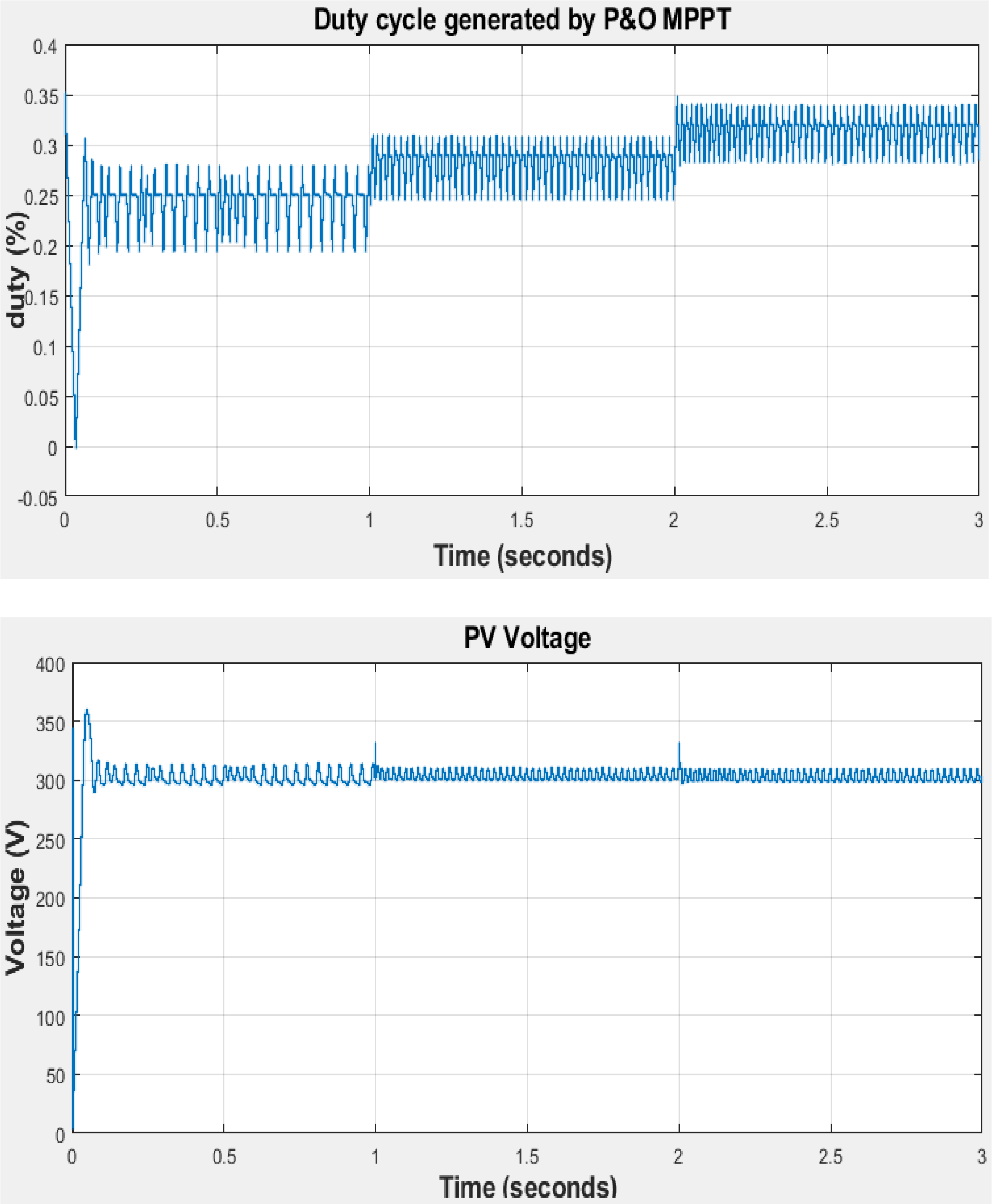


Figure 2. 18: Duty cycle generated by MPPT and voltage induced by solar PV array

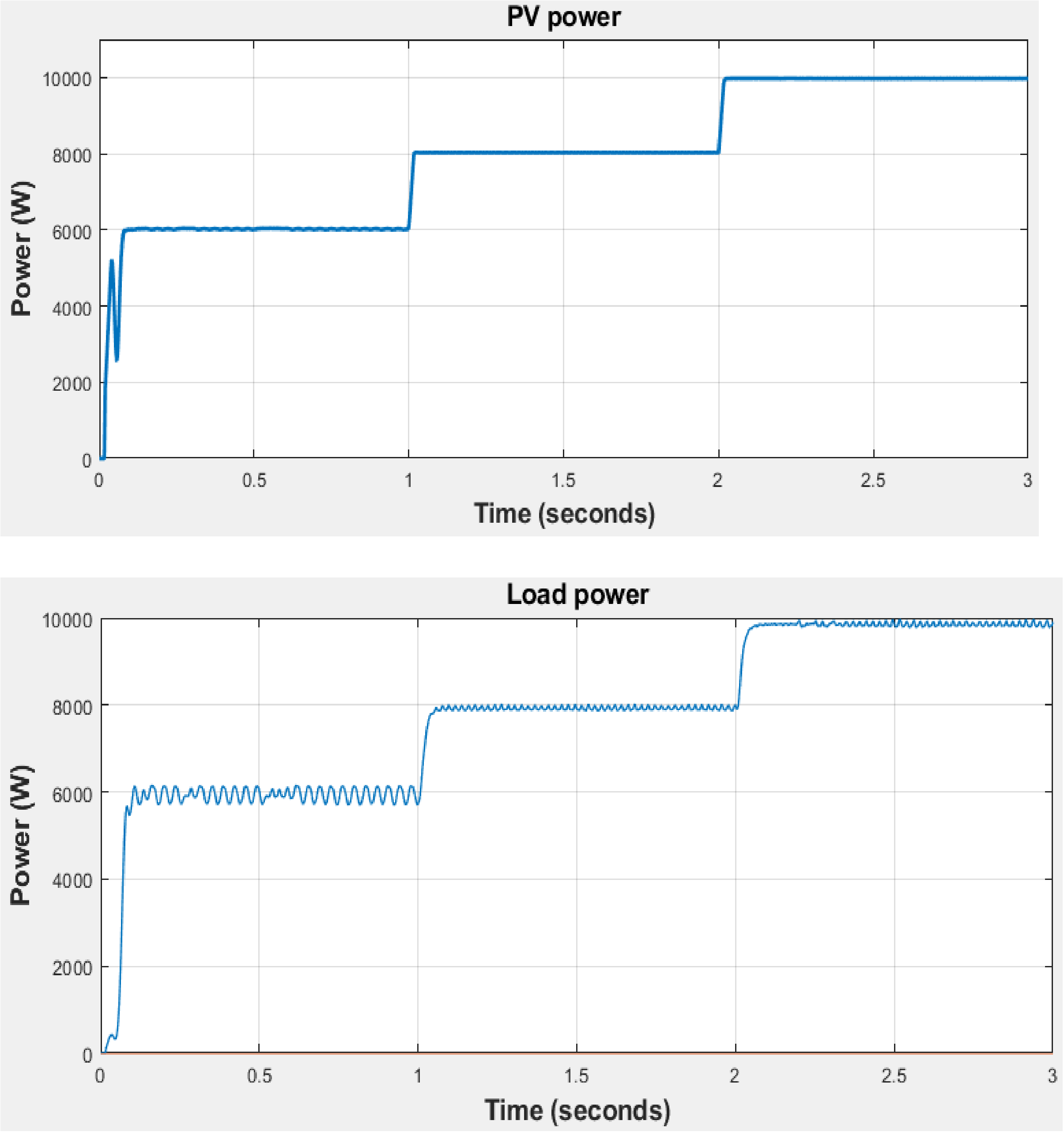


Figure 2. 19: Power Generated by solar PV (W) and load power (W)

Fig 2.17 shows the variable solar irradiance applied to the system and generated current following the variation of irradiation. In this simulation, solar irradiation varies from 600 to 1000 W/m^2 and the generated current varies in a limit from 10 A to 35 A approximately depending on the solar irradiation. A MPPT controller, based on P&O method, calculates the proper duty cycle to generate switching pulse signals for the DC/DC boost converter. **Fig 2.18**. states the duty cycle and voltage induced at solar PV array. Total power generated by solar PV and the power consumed by resistive load is presented in **Fig 2.19**.

7 Conclusion

This chapter provided an overview of solar photovoltaic energy conversion system. The fundamentals of modeling solar PV cell, module and array are described. The major components of PVECS were discussed, including maximum power point tracking algorithm, DC/DC power electronic converter, DC/AC three-phase inverter, two-level VSC control system and stand-alone operation of PVECS. Results presented in this chapter show the effect of varying solar irradiance, temperature, series and shunt resistances in I-V and P-V characteristics curve generated by the simulation models of solar PV module, Also The behavior of a stand-alone solar PVCES under variable solar irradiance, associated with MPPT controller has been simulated. Obtained result, proved the effectiveness of P&O MPPT Algorithm.

Chapter 3

Wind Energy Conversion System and Energy Storage System

1 Introduction

Renewable energy sources including wind power offer a feasible solution to distributed power generation for isolated communities where utility grids are not available. A wind energy conversion system (WECS) is converting the wind kinetic energy into electric power and injecting this electric power into the electrical load or the utility grid. In such cases, stand-alone wind energy systems (i.e., systems not connected to the utility grid) can be considered as an effective way to provide continuous power to electrical loads [23]. A WECS is composed of Wind turbine, an electric generator, a power electronic converter and a control system, as shown in **Fig. 3.1**.

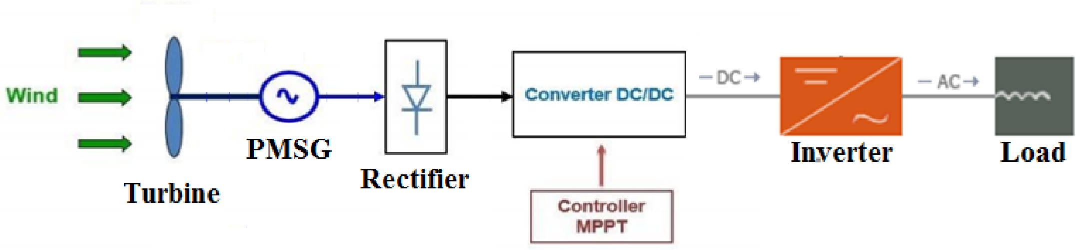


Figure 3. 1: Schematic diagram of WECS

2 Major Components of Wind Energy Conversion System

2.1 Wind turbines

Wind turbines use wind to produce electricity. Most turbines have either two or three blades. These three-bladed wind turbines are operated “up wind”, with the blades facing into wind. The wind turns the blades, which spin a shaft, being connected to a generator and makes electricity. The rotor extracts kinetic energy from the wind and converts it into mechanical torque and then a generating system will convert this torque to electricity.

Different types of wind turbines can be used for different applications (stand-alone, grid connected...) and they can be categorized into two major types: horizontal axes and vertical axes wind turbines.

2.1.1 Power extracted from wind turbine

The kinetic energy of the wind (air mass m, wind speed v) is given by the following equation:

$E_c = \frac{1}{2} m v^2$…………………………………………………………………..… (3.1)

With: $m = \rho v S \Delta t$

Where;

S: Swept area by turbine blades,

ρ: the air density. The air density varies with air pressure and temperature, and is considered $\rho = 1.08\ kg/m^3$ in this report.

The wind power, P_w has the following expression:

$P_w = \frac{d}{dt} E = \frac{1}{2} \rho S v^3$…………………………………………………...…………… (3.2)

The mechanical power that the turbine extracts from the wind, P_m, is inferior to P_w. This is due to the fact that the wind speed after the turbine isn't zero (the air needs to be carried-off after the turbine). So, the power coefficient of the turbine $C_p$can be defined by:

$C_p = \frac{P_m}{P_w}$ with $C_p < 1$

The recuperated power is given by:

$P_m = \frac{1}{2} \rho \pi R^2 v^3 C_p$……………………………………………………………….. (3.3)

Where; R: radius of the rotor.

Fig. 1.2 shows such a power tracking plot of a wind turbine under different wind speeds [24]. The algorithm that tracks the maximum power point of the wind turbine is called maximum power point tracking (MPPT). This is actually the main advantage of a variable speed wind turbine (VSWT).

C_p depends on the tip speed ratio λ of the wind turbine and β, angle of the blades.

$C_p = C_p(\lambda, \beta)$ with: $\lambda = R \frac{\omega}{v}$ ……………………………………………………… (3.4)

Where ω: is the rotation speed of the rotor.

This function has maximum and is known as the limit of Betz:

$C_{Pmax} = \frac{16}{27} = 0.593$……………………………………………………………… (3.5)

From **Eq (3.4)**, it is important to note that the value of power coefficient C_p and the torque coefficient C_t are functions of λ, and they are related by C_t = C_p /λ. From **Fig.3.6**, it is clear that there exists a point where the power coefficient is a maximum. In real cases, the wind has always a smaller maximum power coefficient than Betz factor, this is due to many aerodynamic losses that are on the rotor design and construction (number of blades, weight, stiffness, etc.). The power coefficient and the efficiency of a wind turbine system are different. The efficiency of wind turbine includes the loss in the mechanical transmission, electrical generator, electronic converter, etc. Whereas the power coefficient is the efficiency of converting the power from the wind into mechanical energy in the rotor shaft.

2.1.2 Mechanical torque from wind turbine

The wind turbine torque on the shaft can be calculated from the power:

$$T_m = \frac{P_m}{\omega} = \frac{1}{2}\rho\pi R^2 \frac{v^3}{\omega} C_p \quad \text{……………………………………………………...…… (3.6)}$$

By replacing **Eq (3.4)** in **Eq (3.5)** we get:

$$T_m = \frac{1}{2}\rho\pi R^3 v^2 \frac{C_p}{\lambda} \quad \text{……………………………………………………………...…... (3.7)}$$

Often the torque coefficient C_T is used:

$$C_T = \frac{C_p}{\lambda} \quad \text{…………………………………………………………………………..…… (3.8)}$$

This gives:

$$T_m = \frac{1}{2}\rho\pi R^3 v^2 C_T \text{……………………………………………………………...…… (3.9)}$$

2.2 Electrical Generator

A generator is an electrical machine that converts mechanical energy to electrical one. In wind turbines applications three types of generators are used [12], [25]:

- Squirrel cage induction generator.
- Wound rotor (doubly fed) induction generator.
- Permanent magnet synchronous generator (PMSG).

Each one of these generators has its own properties, PMSG are becoming increasingly popular because of their ability to reduce failures in the gearbox and lower maintenance problems.

2.2.1 Permanent magnet synchronous generators (PMSG)

From all the generators that are used in wind turbines, the PMSG's have the highest advantages because they are stable and secure during normal operation and they do not need an additional DC supply for the excitation circuit (winding). Initially used only for small and medium powers, the PMSG's are now used also for higher powers (because of their already mentioned advantages) [26].

PMSG: Another direct-drive WTGS employs a PMSG, which is dominant in small scale WTGS applications. The permanent magnet is made of rare-earth metal. With the constant flux, the excitation converter is saved and control of generator becomes much easier. With the price decrease of rare-earth metal and improvement of manufacturing technique, this configuration is expanding to small scale WTGS.

Modeling of PMSG

The voltage equations of a permanent magnet synchronous generator in the dq reference frame are given by

$$\mathrm{V_{qs}} = -R_s\, i_{qs} + \omega_m \psi_{ds} + \frac{d\psi_{qs}}{dt} \ldots\ldots\ldots\ldots\ldots\ldots \text{(3.10)}$$

$$\mathrm{V_{ds}} = -R_s\, i_{ds} - \omega_m \psi_{qs} + \frac{d\psi_{ds}}{dt} \ldots\ldots\ldots\ldots\ldots\ldots \text{(3.11)}$$

Where; V is the voltage, i the current, ψ the flux linkage, R_s the resistance, ω_m the angular velocity of turbine rotor. The subscripts ‘d’ and ‘q’ direct and quadratic components, respectively (see **Fig 3.1**), the subscript ‘s’ for stator. The quantities are given in per unit (p.u.).

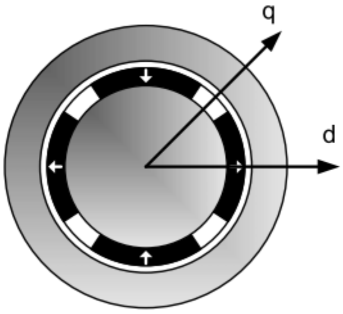


Figure 3. 2: Salient-pole permanent magnet synchronous machine in dq reference frame.

The flux linkages are given by:

$$\psi_{qs} = \left(L_{qm} + L_{\sigma s}\right) i_{qs} \ldots\ldots\ldots\ldots\ldots\ldots \text{(3.12)}$$

$$\psi_{ds} = \left(L_{dm} + L_{\sigma s}\right) i_{ds} + \psi_f \ldots\ldots\ldots\ldots\ldots\ldots \text{(3.13)}$$

Where; ψ_f is the flux produced by the permanent magnets.

In order to simplify analysis of the wind generator, the transients occurred in the stator, according to the assumptions used in PSDSs, can be neglected [27]. By substituting flux linkages **Eq (3.10), (3.11)** in system of **Eq (3.11), (3.13)** the voltage current relationship can be obtained:

$$\mathrm{V_{qs}} = -R_s\, i_{qs} + \omega_m (L_{dm} + L_{\sigma s})\, i_{ds} + \omega_m \psi_f \ldots\ldots\ldots\ldots\ldots\ldots \text{(3.12)}$$

$$\mathrm{V_{ds}} = -R_s\, i_{ds} - \omega_m(L_{dm} + L_{\sigma s})\, i_{qs} \quad \text{(3.15)}$$

The mechanical Torque equation is:

$$\mathrm{T_m} = T_{em} + J\frac{d\omega}{dt} + F\omega \quad \text{(3.16)}$$

Where;

J: Inertia moment of the turbine, axle and generator,

F: Friction coefficient,

Tem: Electromagnetic torque.

Solving for the rotor mechanical speed form **Eq (2.5)** with $\omega = \omega_r(\frac{2}{P})$. In the above equations ω_r is the rotor electrical speed where as ω is the rotor mechanical speed, and the equation of the position is given as: $\theta = \theta_r(\frac{2}{P})$.

2.3 Three-phase diode bridge rectifier

In order to supply the DC-link, the PMSG should be connected to a rectifier that converts the AC voltage into DC voltage.

For an uncontrolled three-phase bridge rectifier, six diodes are used

The uncontrolled three-phase bridge rectifier is the simplest, cheap, and rugged topology used in power electronic applications. The most disadvantage of this diode rectifier is its disability to work in bi-directional power flow.

If V_m is the peak value of the phase voltage, then the average output voltage is found from:

$$V_{d,out} = \frac{2}{2\pi/6}\int_0^{\pi/6} \sqrt{3}\; V_m \cos\omega t\; d(\omega t) \quad \text{(3.17)}$$

then the output dc voltage from bridge rectifier can be obtained from **Eq (2.12)** where the overlap due to the internal inductance of PMSG is ignored [28].

$$V_{d,out} = \frac{3\sqrt{2}\,V_{LL}}{\pi} \quad \text{(3.18)}$$

Where; $V_{d,out}$: output dc voltage of the rectifier,

V_{ll}: line to line voltage.

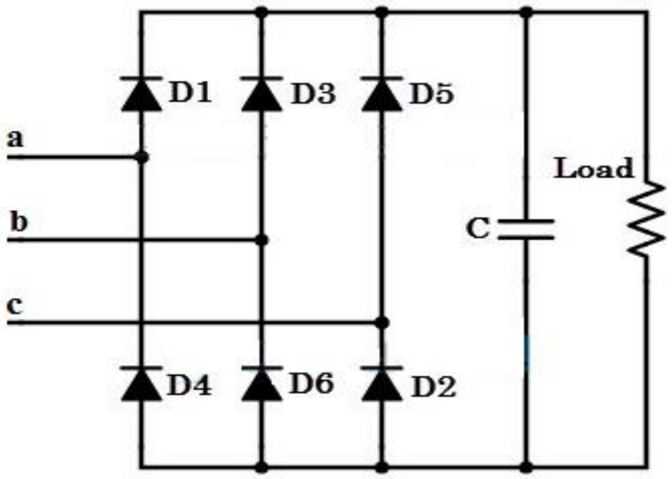


Figure 3. 3: three phase uncontrolled rectifier

2.4 DC-DC buck-boost converter

The chopper is connected at the output of the rectifier. It aims at implement the MPPT algorithm. More details about the chopper can be found in the previous chapter.

2.5 Inverter

Structure, function and control of inverter are given in the previous chapter. It is required to provide AC power to AC load or grid utility.

2.6 Maximum power point tracking MPPT

Maximum power point tracking (MPPT) is a technique that ensures the maximum power extraction from non-linear energy sources like wind energy system. In order to extract the maximum energy from the WECS, the generator rotational speed must be controlled by the MPPT algorithm; therefore, the MPPT is one of the important factor in WECS. The goal of MPPT is to maximize the wind power capture at different wind speeds by adjusting the turbine speed. Different MPPT techniques employed in VSWECS are classified as

- Tip-speed ratio (TSR) control
- Optimum relationship based (ORB) control
- Perturb and observe (P&O) control
- Hybrid control
- Intelligent control techniques like fuzzy logic control, neural network control, etc.

2.6.1 Perturb and observe control

Perturb and Observe (P&O) is the simplest MPPT algorithm that does not require any prior knowledge of the system, the turbine’s characteristic curve or any additional sensor except the measurement of the power which is subjected to maximization. The principle of P&O algorithm is perturbing the control variable in the same direction until the power is decreased. P&O observes the perturbation in power and according to that it provides the corrections in the particular parameter like duty cycle of the DC–DC converter to control the dc voltage or to regulate current in order to adjust the rotor speed and track the MPP.

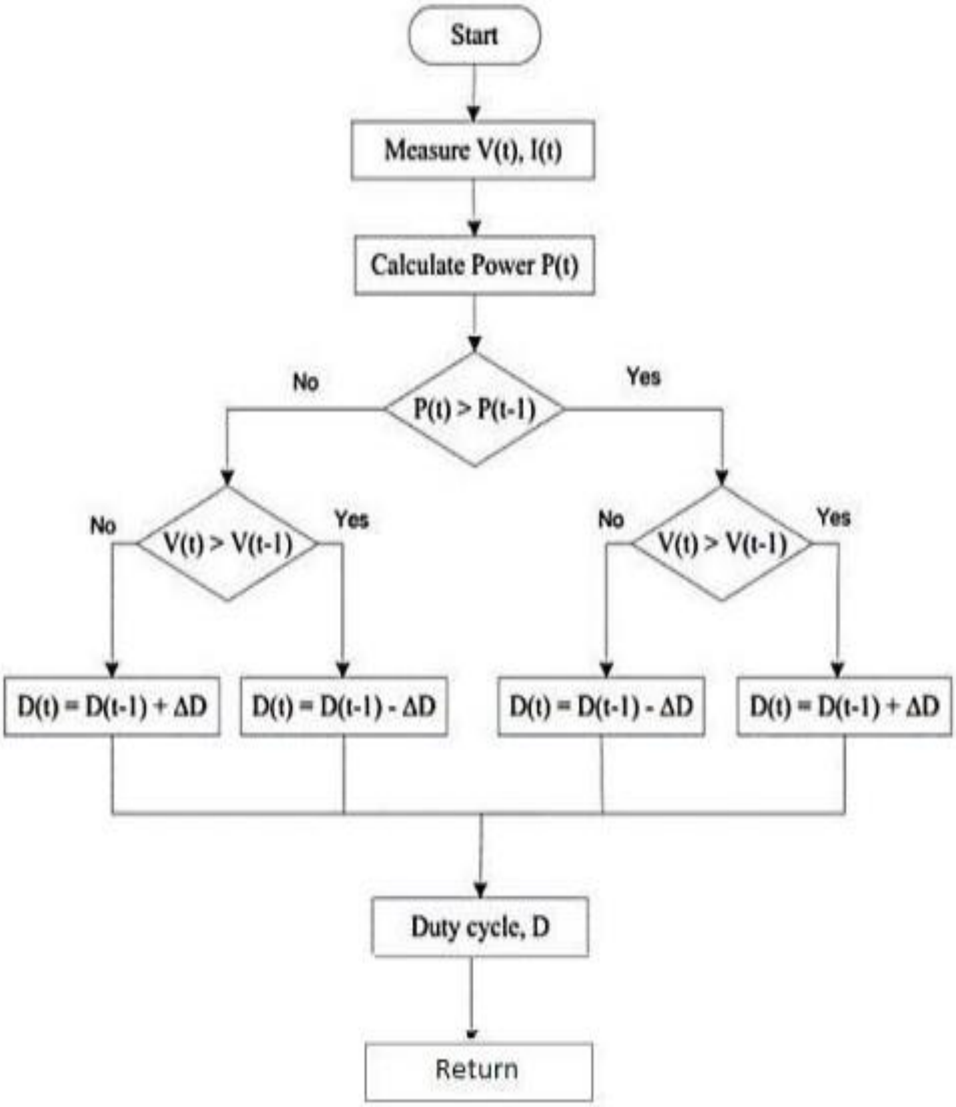


Figure 3. 4: Flow chart of P and O algorithm

In P&O method, choosing an appropriate step size is very important task. A larger step size leads to a faster response but more oscillations around the MPPT point. In reversed, a smaller step-size improves efficiency but reduces the convergence speed which can be incapable of tracking MPP under rapidly varying wind conditions.

2.7 Simulation results and discussion

The system described in **Fig 3.1** is implemented in Matlab/Simulink as shown in **Fig 3.5** and **Fig 3.6**.

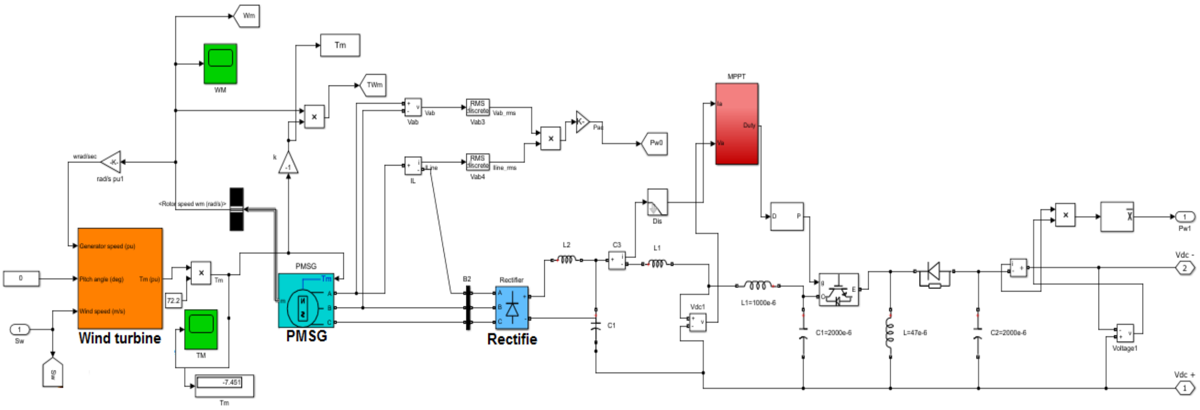


Figure 3. 5: Matlab/simulink model for WECS

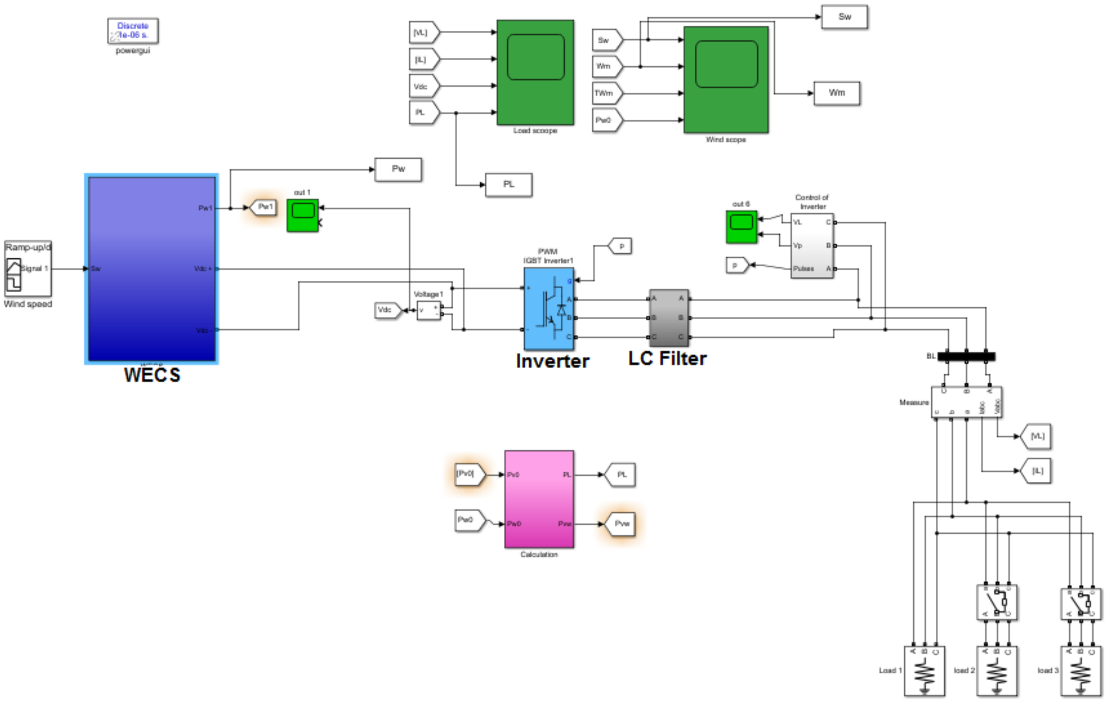


Figure 3. 6: Matlab/simulink model for WECS connected to AC load

A wind turbine with 11kW nominal output power, 12m/s base wind speed and 0.73nominal power at base wind speed. **Fig 3.7** Shows the wind turbine power characteristics.

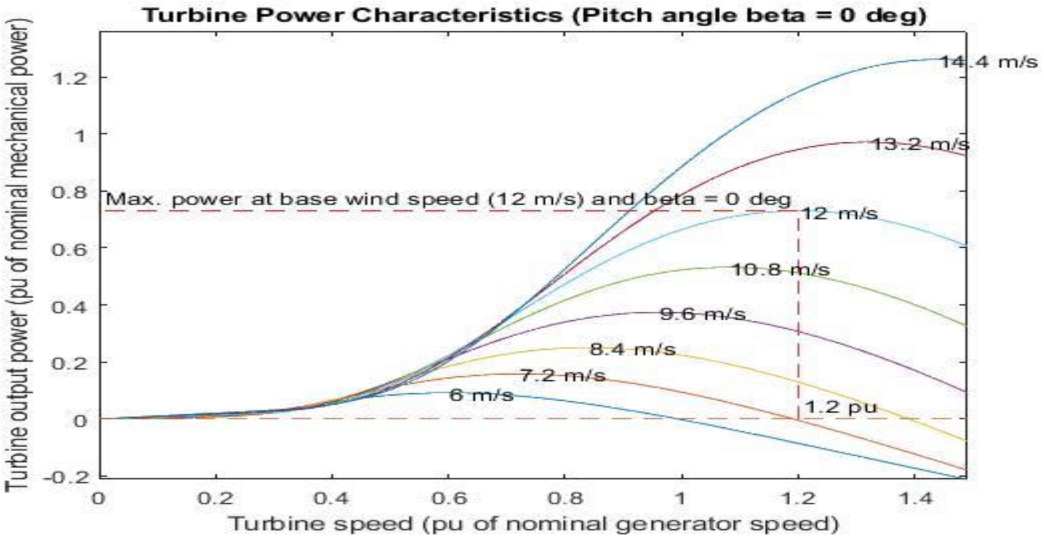


Figure 3. 7: wind turbine power characteristics

Wind speed and the load demand are varied within 6 second to see the effect of wind speed variation on the output power and to test the MPPT work in various operating conditions. Results obtained from the simulation are presented in The Following Figures.

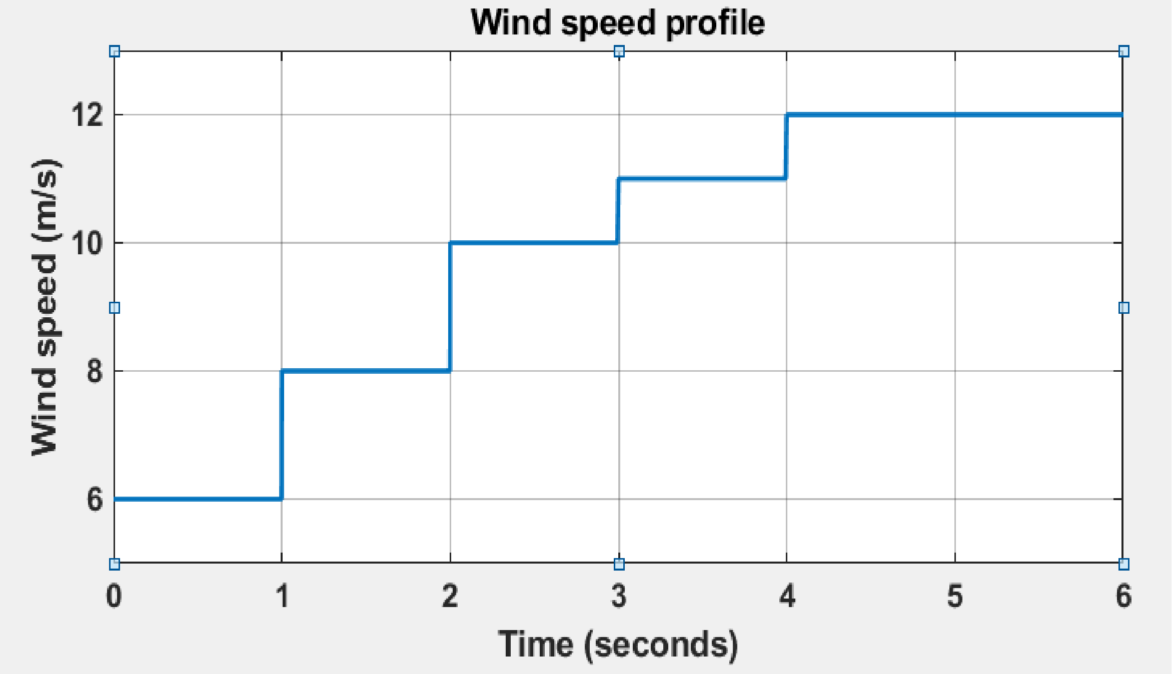


Figure 3. 8: Wind speed profile

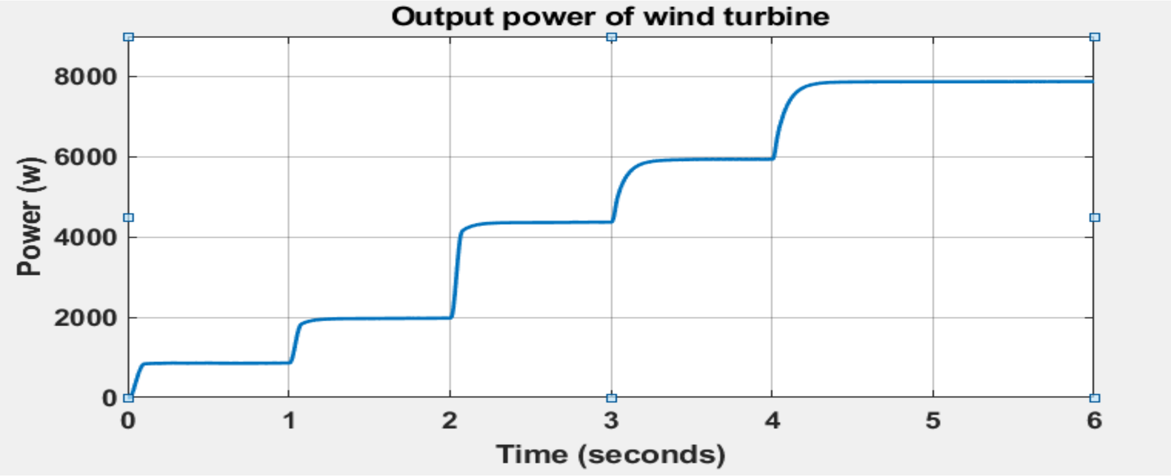


Figure 3. 9: Output power

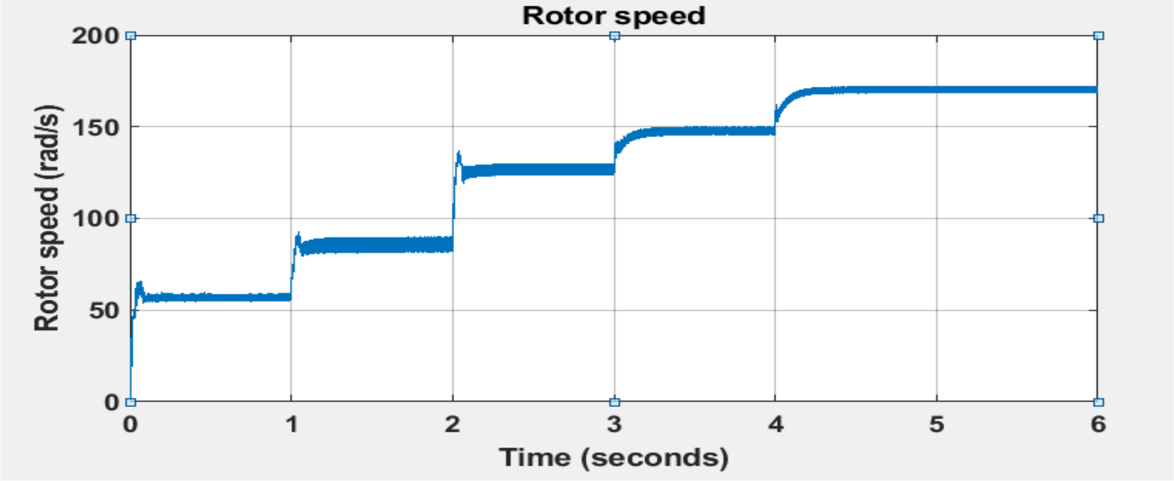


Figure 3. 10: Rotor speed

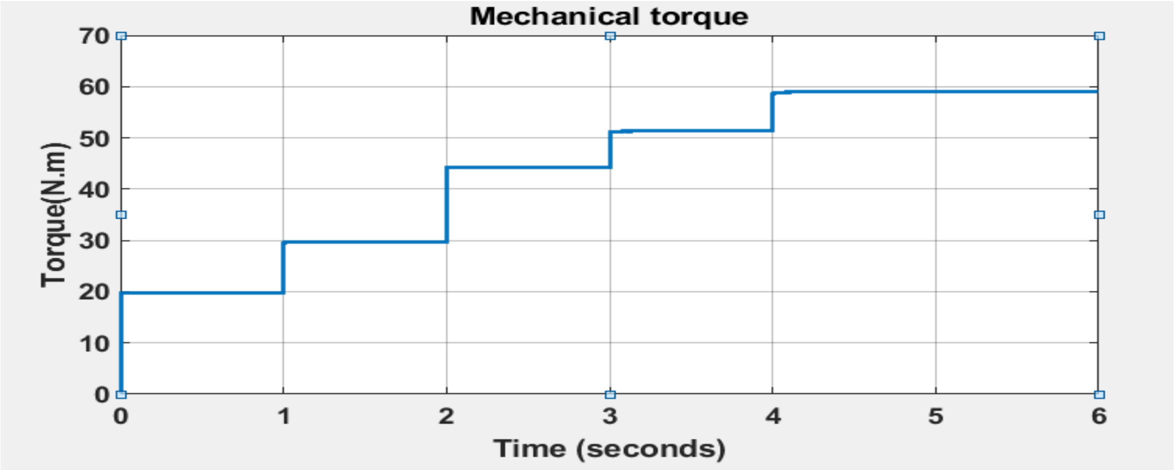


Figure 3. 11: Mechanical torque

As shown in **Fig 3.9** and **Fig 3.8** the output power increase as the wind speed increases. According to the output power in **Fig 3.9**, rotor speed in **Fig 3.10** and the wind turbine characteristics curves in **Fig 3.7** the MPTT controller has attracted the maximum power and the optimal rotor speed for each value of wind speed (according to **Fig 3.7** when wind speed is at its base 12m/s wind turbine give (0.73*Pn = 8kW). This power is attracted by the MPTT controller as shown in **Fig 3.9**. Therefore, the P&O ensures the maximum efficiency operation of the WECS based on PMSG operation.

3 Energy storage system

A disadvantage of electricity is that it cannot be easily stored on a large scale. Almost all electrical energy used today is consumed as it is generated. This poses no hardship in conventional power plants, where the fuel consumption is varied with the load requirements. The photovoltaic and wind, being intermittent sources of power, cannot meet the load demand all of the time, 24 hours a day, 365 days of the year. The energy storage, therefore, is a desired feature to incorporate with renewable power systems, particularly in stand-alone plants. It can significantly improve the load availability, a key requirement for any power system. The present and future energy storage technology that may be considered for stand-alone photovoltaic or wind power systems falls in the following broad categories:

- electrochemical battery.
- flywheel.
- compressed air.
- superconducting coil.

The different energy storage techniques have different applications in power systems. Some of them are [29]:

- Rapid reserve,
- Area control and frequency responsive reserve,
- Commodity storage
- Transmission system stability,
- Transmission voltage regulation,
- Renewable energy management.

Each technology has its own properties; we will focus our study on the battery as being the one used in our project.

3.1 The battery

The battery stores energy in the electrochemical form, and is the most widely used device for energy storage in a variety of applications. It is made of numerous electrochemical cells connected in a series-parallel combination to obtain the desired operating voltage and current.

3.2 Battery design

The battery design for given application depends on the following system requirements:

- voltage and current.
- charge and discharge rates and duration.
- operating temperature during charge and discharge.
- number of charge and discharge.
- cost, size, and weight constraints.

Once these system level design parameters are identified, the battery design proceeds in the following steps:

- select the electrochemistry suitable for the overall system requirements.
- determine the number of series cells required to meet the voltage requirement.
- determine the Ah discharge required to meet the load demand.
- for the required number of charge/discharge cycles, determine the maximum allowable depth of discharge.
- the total Ah capacity of the battery is then determined by dividing the Ah discharge required by the allowable depth of discharge calculated above.
- determine the number of battery packs required in parallel for the total Ah capacity.
- determine the temperature rise and the thermal controls required.
- provide the charge and discharge rate controls as needed.

The battery voltage is that of a fully charged battery. It depends on the number of cells and voltage per cell [12].

Where;

$$V_{bat} = N_{cells} V_{cell} \quad \ldots\ldots (3.16)$$

V bat = the battery voltage

N cells = the number of cells in series

Vcell= voltage per cell

The battery capacity is the total Ampere-hour required to support the load requirement and is given by [30], [31]:

$$BC = \frac{E_{bat}}{ŋ_{dish}(N_{cell}.V_{disch}).DOD.N_{par}}(Ah)\ldots\ldots (3.17)$$

Where;

BC = Battery capacity (Ah),

E bat = energy required from the battery per discharge,

ŋ disch =efficiency of discharge path (including inverters, wires, diodes, etc.),

Ncell = Number of series cells in one battery,

Vdisch= average cell voltage during discharge,

DOD= maximum allowed Depth of Discharge for required life cycle,

Npar = number of parallel batteries.

Batteries are generally not allowed to be discharged fully. The minimum value to which a battery can be discharged before it is recharged is called maximum depth of discharge. DOD, Deep discharge batteries can discharge up to 20- 40% of their state of charge, SOC [12].

3.3 Simulation results and discussion

A battery (6.5Ah, 220V nominal voltage) and a DC-DC converter models are implemented in matlab/simulink as shown in **Fig3.12**.

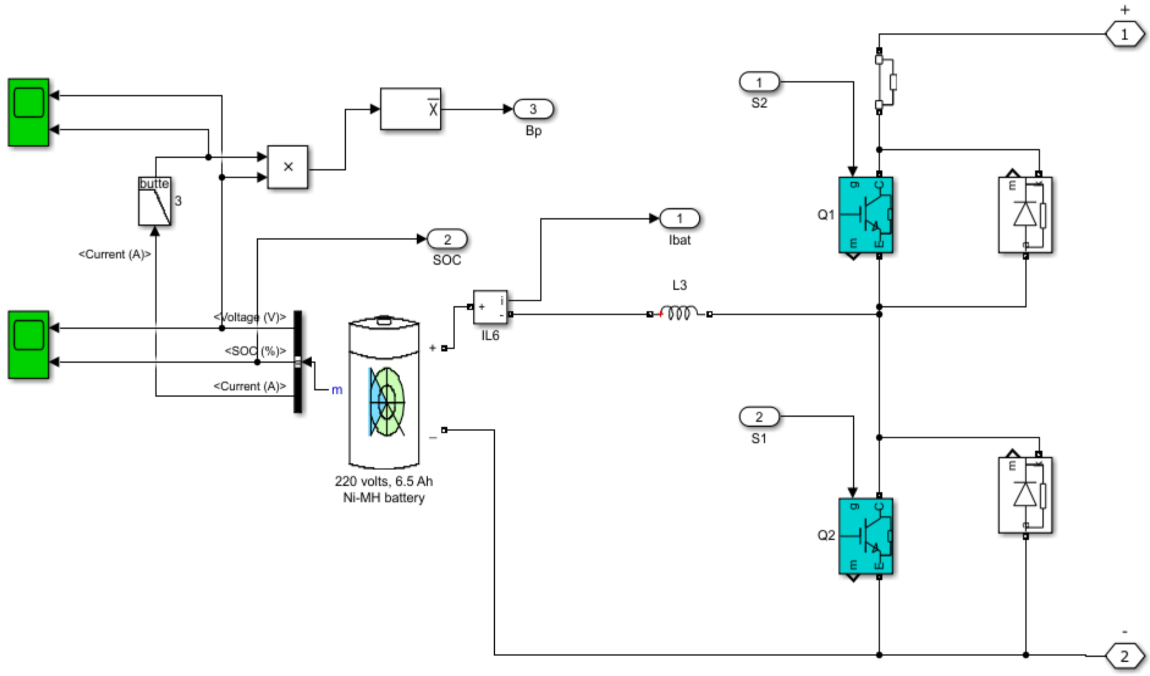


Figure 3.12: Matlab/ simulink model for battery and DC-DC converter

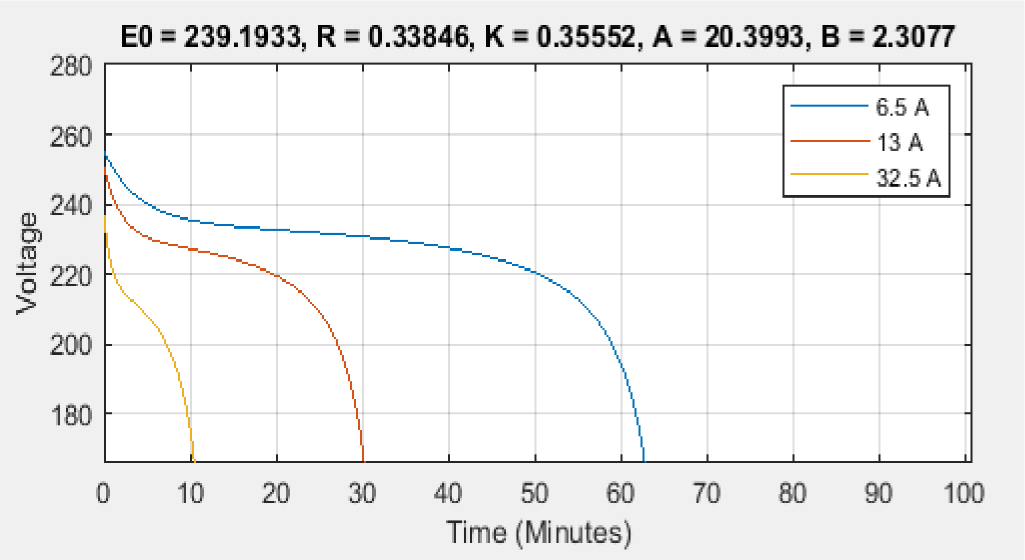


Figure 3.13: battery discharge characteristics

Fig3.13 shows the discharging curves of the selected battery with respect to time under different load consumption or current demand. As it is illustrated in the curves, the selected battery discharges within approximately 10min if it is providing 32.5A of dc current and 30min if the current is13A and about 1h if the current is 6.5A.

4 Conclusion

This chapter dealt with WECS and energy storage. The model of each component constituting the WECs. Simulation of the most used MPPT to track the maximum power, P&O technique has been simulated, obtained results have shown the effectiveness of the algorithm.

Due to the intermittence of the wind and solar energy, energy storage must be used to ensure providing power supply to load.

The next chapter, presents hybrid system that include all the components previously presented. Different scenarios will be tested in order to validate the proposed power management system.

Chapter 4

Power Management of Hybrid System

1 Introduction

As discussed, earlier hybrid power system is a combination of more than one energy source, each one generates different form of energy (DC or AC), to meet all scenarios of load demand buck up sources and storage elements are desirable. Connecting all these elements requires the use of different types of power electronic conversion systems. Different topologies of connection can be made and which determines the category of the HPS.

In this chapter, our objective is to model and simulate a hybrid power system for different scenarios based on a variable load, irradiance and wind speed along with testing the performance of the selected power management algorithm in balancing the power between the generation part (PVECS and WECS) and the load side.

2 The proposed power management system

Fig 4.1 shows a schematic diagram of a standalone hybrid power system based on photovoltaic energy conversion system (PVECS), wind energy conversion system (WECS) and a battery energy storage system (BESS). All the generation system is connected to the main 600 v DC bus, then the supply to the load is made through a dc to ac inverter with an output of 380 peak voltage and 50Hz frequency. When there is an excess in power generation from sun and wind with respect to load requirements, the system charges BESS. When there is a shortage in the supply, the energy will be drawn back from the battery. However, if these sources aren't supplying sufficient power the load will be connected directly to Grid Utility.

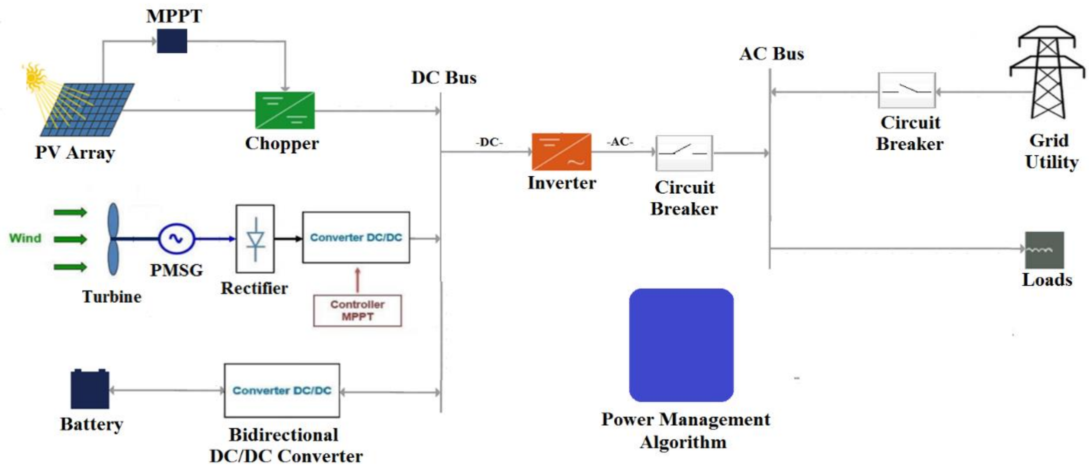


Figure 4. 1: Schematic diagram of the proposed hybrid power system

2.1 The electrical circuit model

The following circuit depicted in **Fig 4.2** shows a simple electrical circuit model for the different elements where each element is represented by a controllable current source and the powers from the sources can be used to satisfy our needs.

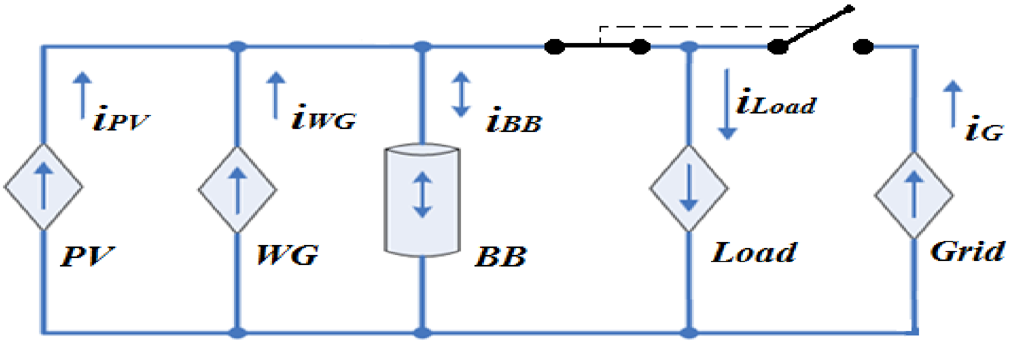


Figure 4. 2: Simplified electrical model for the proposed hybrid power system

For the above simple model, mathematical modeling is performed based on power management algorithm to check the balance of the instantaneous power or current between the supply side and the load side. The power balancing plays a big role in the control system of the hybrid power systems. Applying power balancing, we have the fundamental mathematical model expressed as:

$$P_{Load}(t) = P_{WG}(t) + P_{PV}(t) + P_{BB}(t) \quad (4.1)$$

$$P_{Load}(t) = P_G(t) \quad (4.2)$$

Where;

$P_{PV}(t)$: The injected power into the DC- bus from the PV- array,

$P_{BB}(t)$: The injected power from the battery bank into DC- bus,

$P_{Load}(t)$: The demand that needs to be satisfied,

$P_G(t)$: The injected power from the Grid.

This mathematical model is applied and must hold true. Since all Hybrid system elements are connected at the same DC-bus, the powers at the DC-bus can be divided by the voltage and the above equation can be changed into the following current equation:

$$i_{Load}(t) = i_{WG}(t) + i_{PV}(t) + i_{BB}(t) \qquad (4.3)$$

$$i_{Load}(t) = i_{G}(t) \qquad (4.4)$$

3 Power management algorithms

The Power management MATLAB/SIMULINK block consists of two main algorithms that satisfy the overall functionality of a hybrid system. These two algorithms are implemented using simple logic behavior. These algorithms are discussed below and given in a form of flowchart:

- **Battery bank charging / discharging algorithm**

The following algorithm is used mainly to protect the storage bank to ensure a maximum life cycle; it is also used to determine the times needed to use the stored energy or to store the excess power generated by the RES.

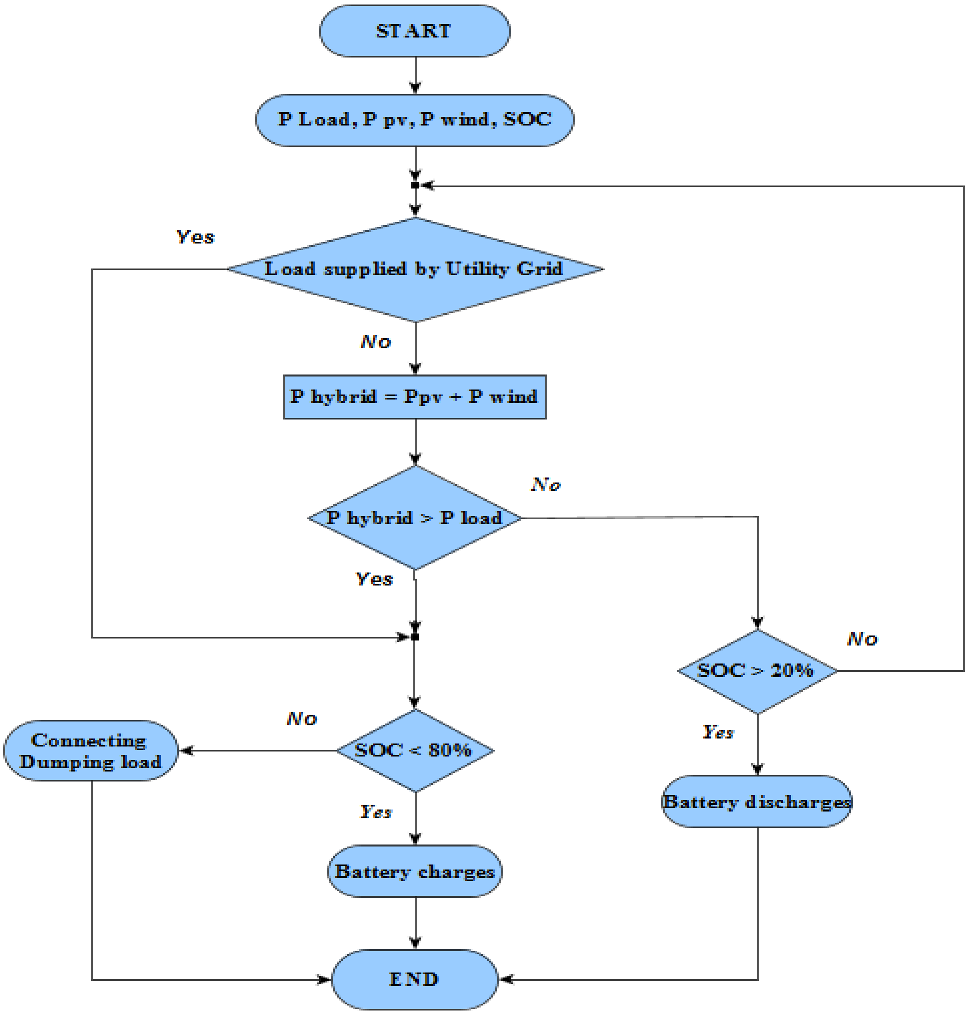


Figure 4. 3: battery bank charging /discharging algorithm

- **Power management algorithm**

The following algorithm was implemented in a MATLAB/SIMULINK software to assure serving the load with the required power.

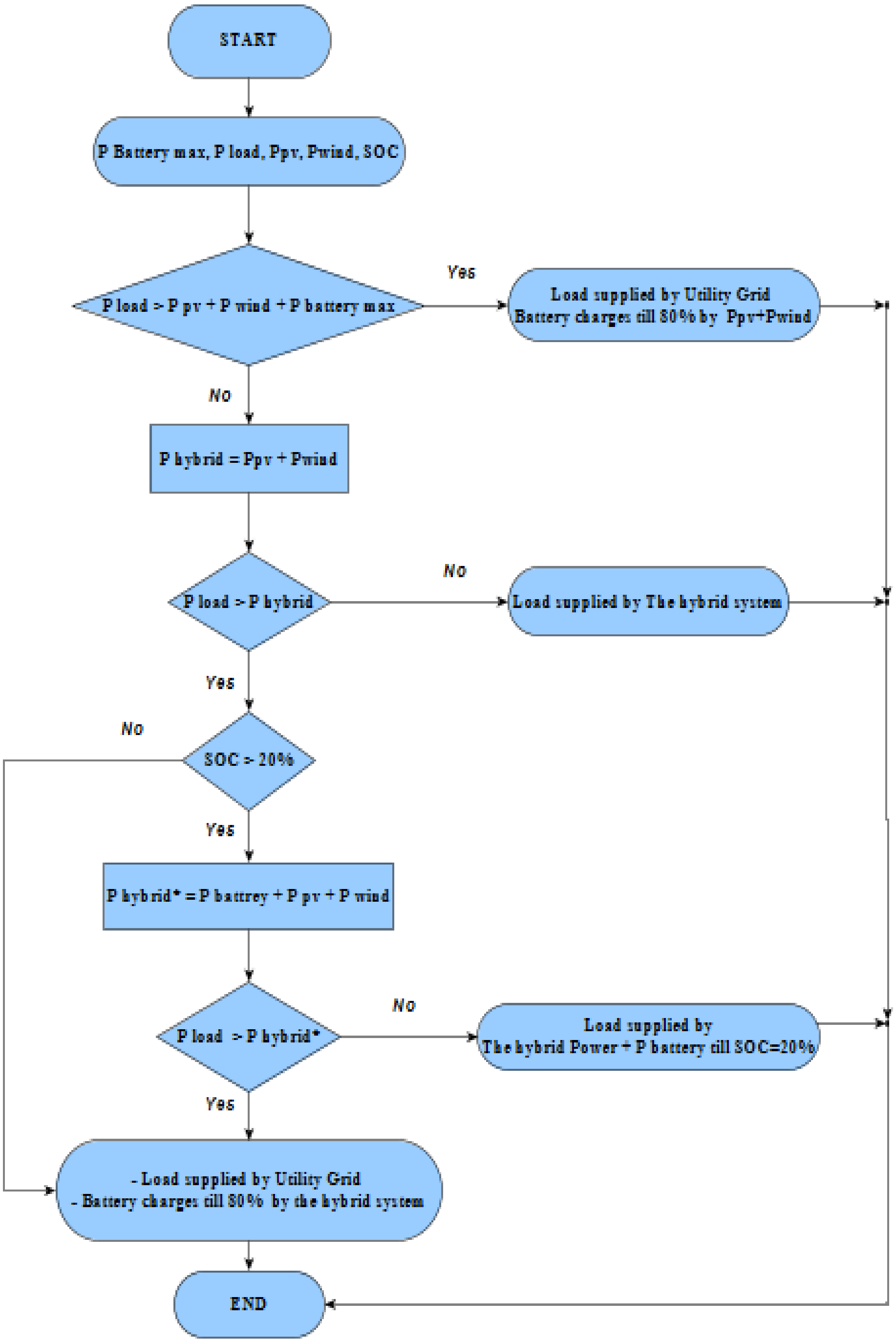


Figure 4. 4: Load power management algorithm

The Power management MATLAB/SIMULINK block consists of algorithms that satisfy the overall functionality of a hybrid system. This algorithm is implemented simple logic behavior. This algorithm is discussed below and given in a form of flowchart:

4 Simulation results and discussion

4.1 MATLAB/SIMULINK model of Utility Grid

The SIMULINK model of Utility Grid that consist of Power plant, Distribution lines, Three-phase circuit Breaker and Three-phase Transformer are provided by SIMULINK library as shown in **Fig 4.5**.

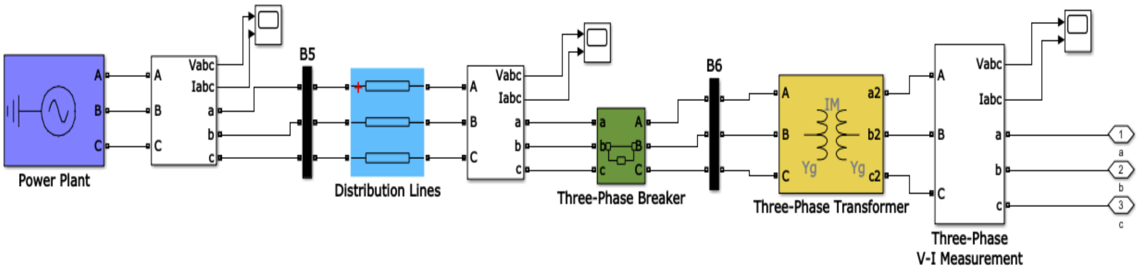


Figure 4. 5: MATLAB/SIMULINK model of Utility Grid

4.2 Simulation of the hybrid system

A simulation is performed to study the behavior of the hybrid system under the proposed power management algorithm with the same selected parameters as seen in the previous chapters. The model is constructed with Matlab®/Simulink® platform shown in **Fig 4.6.**

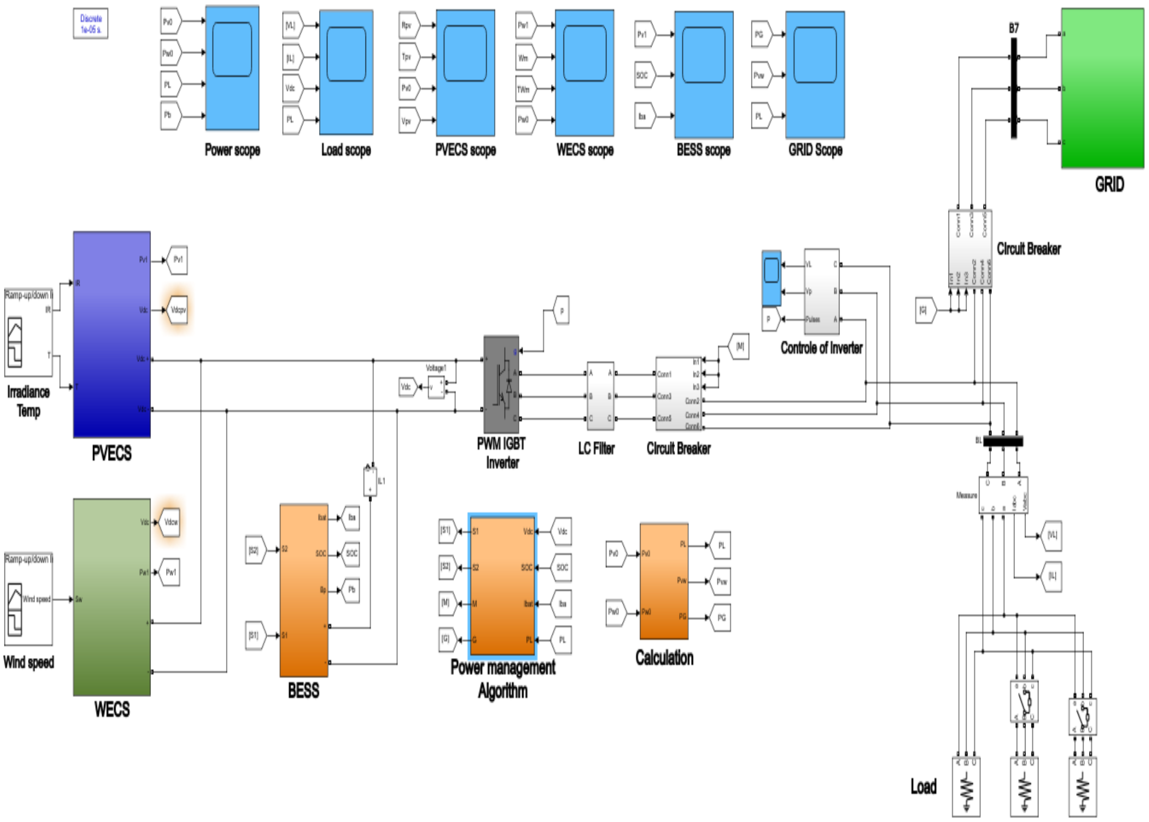


Figure 4. 6: MATLAB/SIMULINK model of the proposed hybrid power system

The simulation is executed for 20 s, the step size for discrete sampling is 1x10^{-6}, the initial SOC is considered 21%. Irradiance and wind speed are varied based on a normal day (24h) as shown in **Fig 4.7** and **Fig 4.8** bellow.

Figure 4. 7: Variable solar irradiation (W/m2)

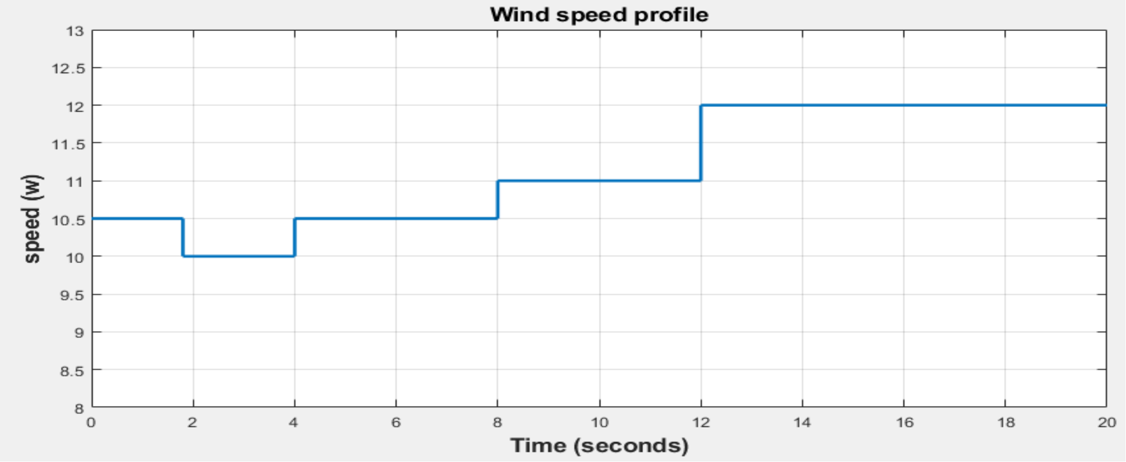


Figure 4. 8: Wind speed profile

Results obtained from the simulation are presented in The Following Figures:

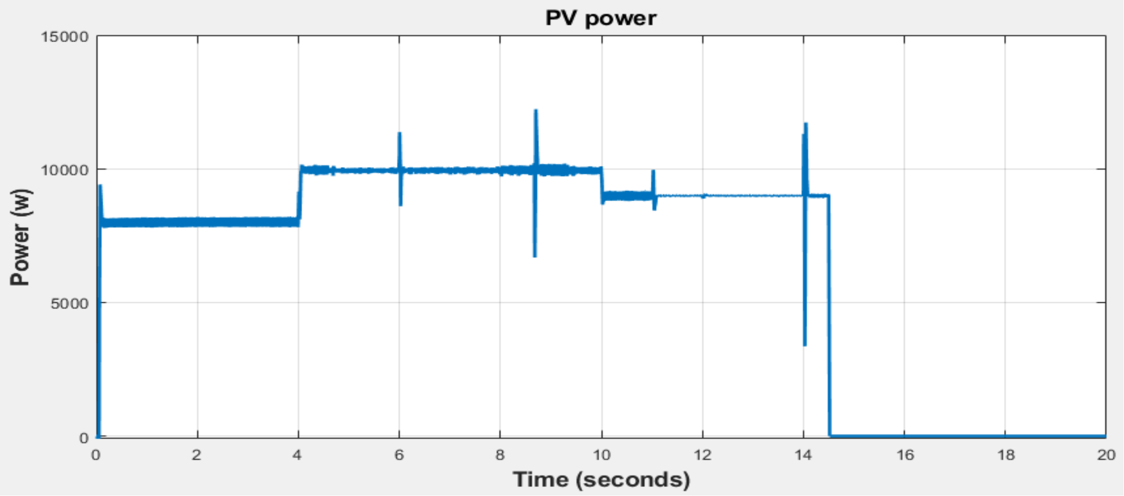


Figure 4. 9: Power generated by PVECS

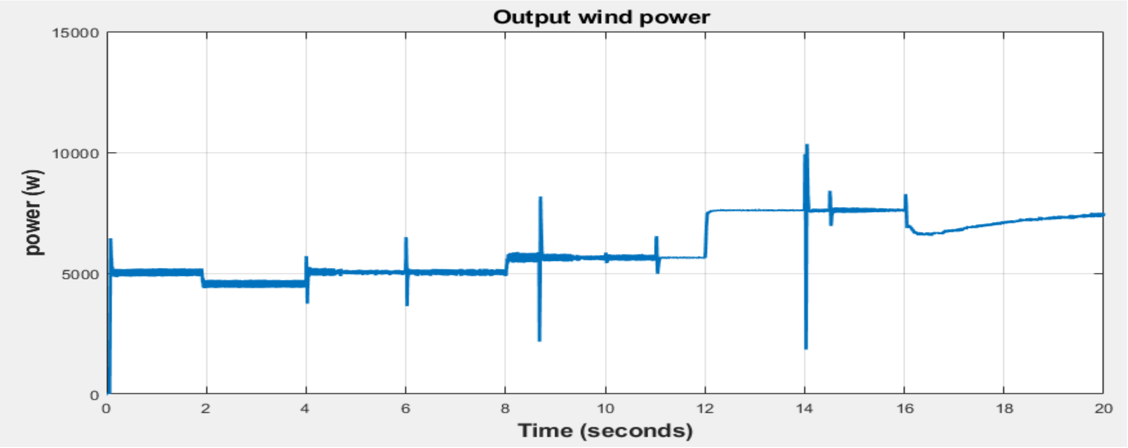


Figure 4. 10: Power generated by WECS

The effectiveness of the proposed power management algorithm clearly appears in the figures bellow.

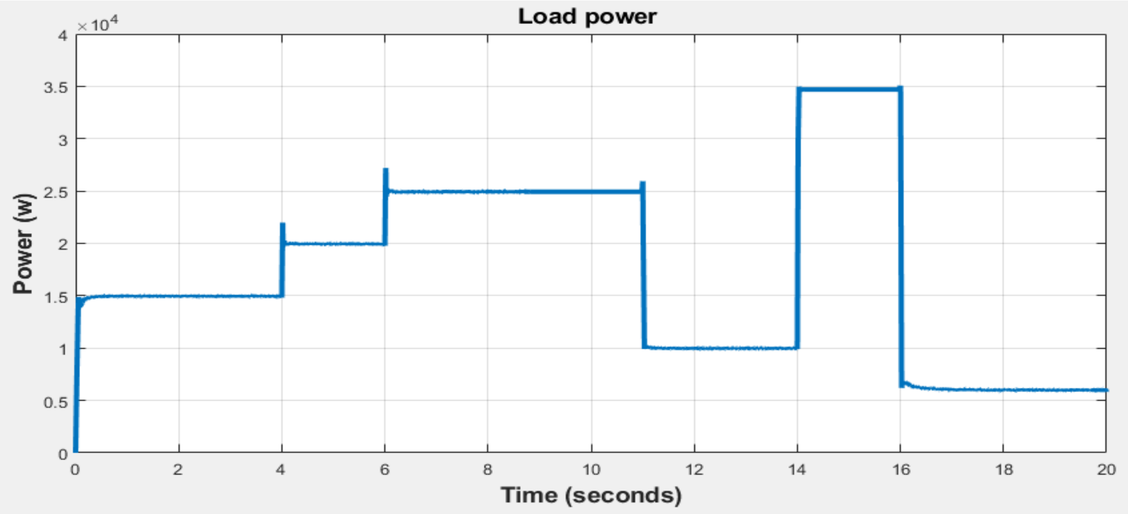


Figure 4. 11: Load power

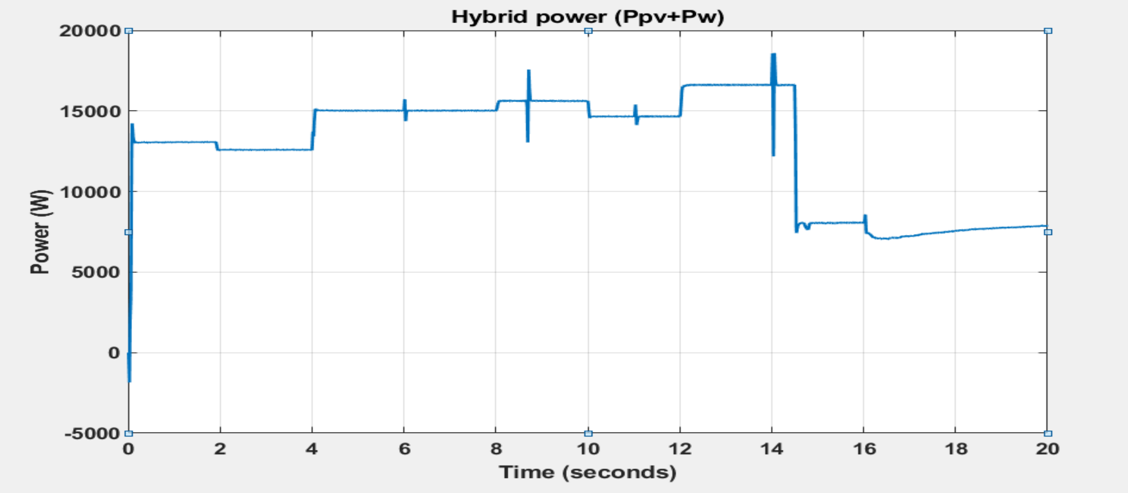


Figure 4. 12: Hybrid power generated by WECS + PVECS

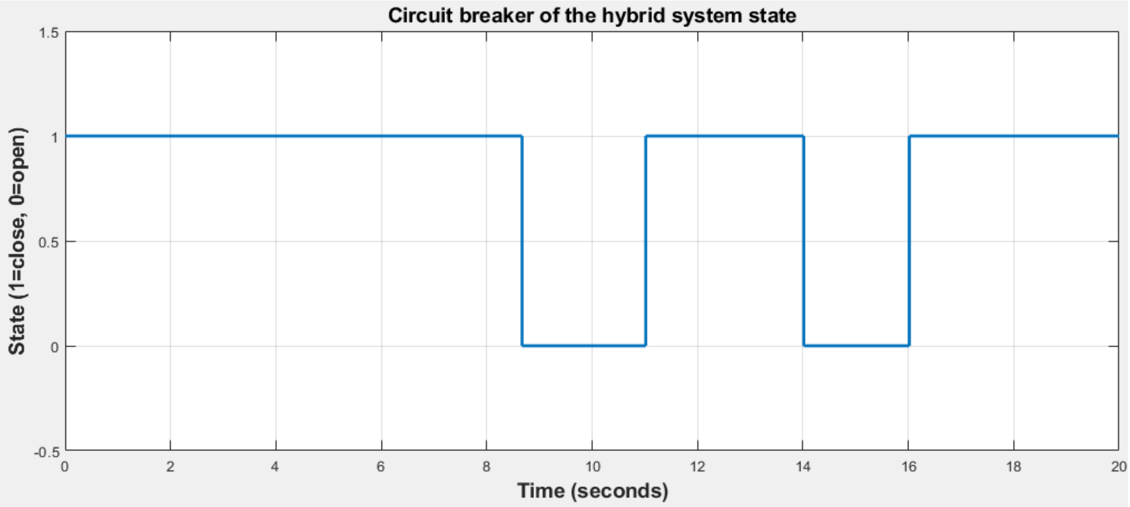


Figure 4. 13: Circuit breaker state of the hybrid system

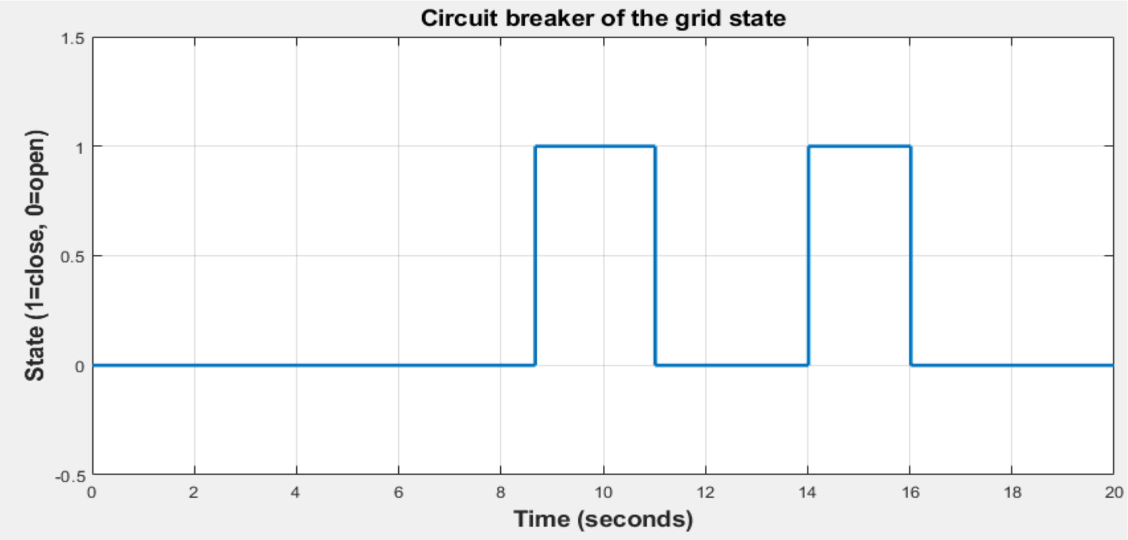


Figure 4. 14: Circuit breaker state of the grid

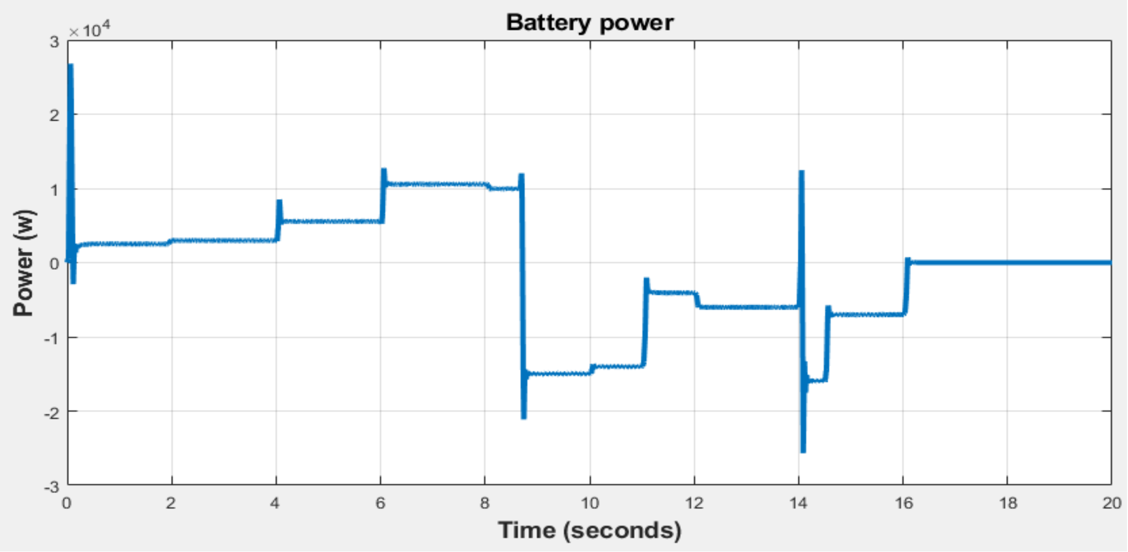


Figure 4. 15: Battery Power

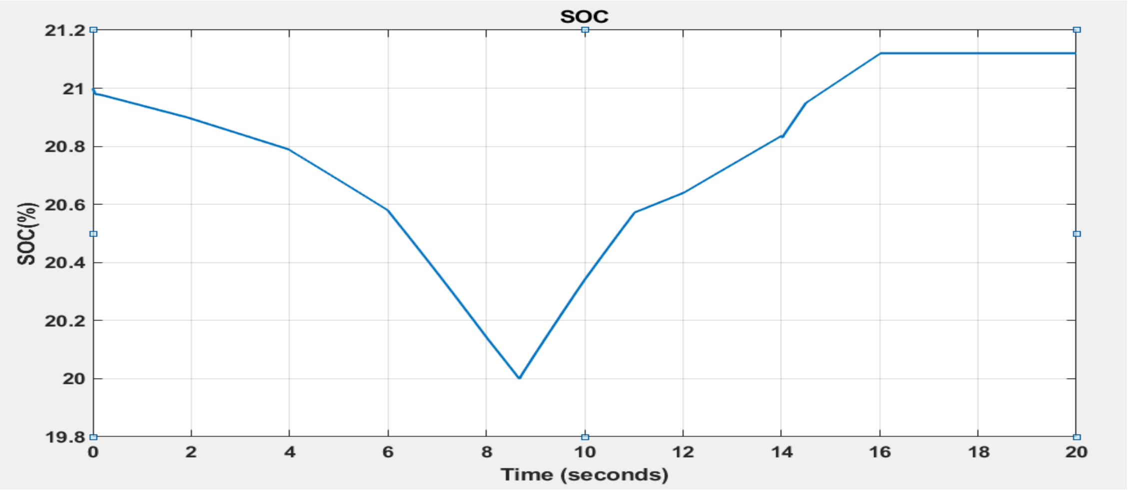


Figure 4. 16: Battery state of charge

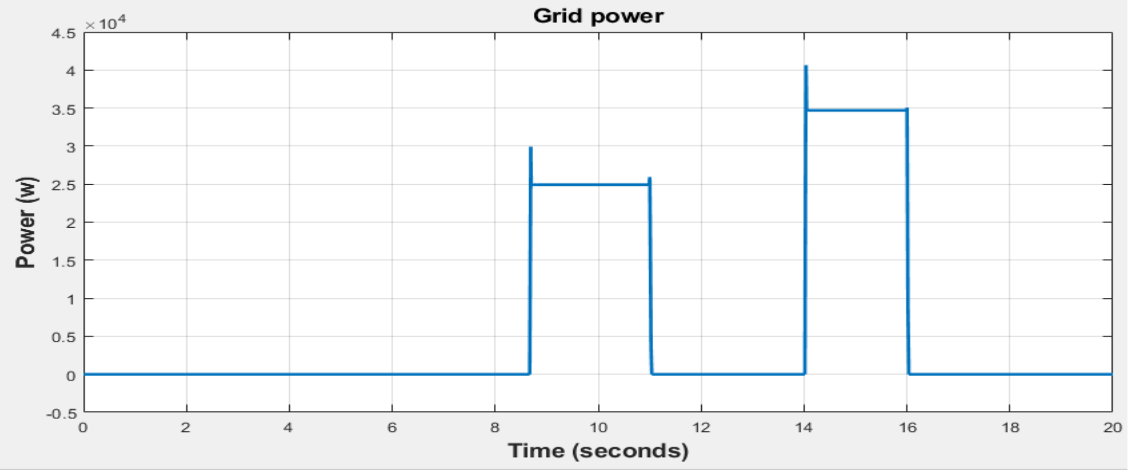


Figure 4. 17: Grid power

The above figures introduce the final simulation result of the complete system model, as shown there are multiple simulation scenarios that cover most of the possible situations that the system may face in one day of utilization, below is the description of these scenarios.

- **Scenario: [0s – 11s]**

The load demand is varied from 15kw to 25kw and the hybrid power is approximately between 13kw and 16kw, the power management algorithm connects the load to the hybrid system and the battery discharges to cover the lack of power demand till SOC=20% Where the load will be connected to the grid and the battery charges by the hybrid system.

- **Scenario: [11s – 14s]**

The load demand is 10kw and the hybrid power is approximately between 14kw and 17kw, the power management algorithm connects the load to the hybrid system and since the SOC < 80% battery charges.

- **Scenario: [14s – 16s]**

Load demand is 35kw which is greater than the power generating by the hybrid system plus the maximum power of battery hence the load will be connected to the Grid at the same time since the SOC < 80% battery charges by the hybrid system power.

Scenario: [16s – 20s]

The hybrid system is generating power approximately equal to the load demand one hence the load is disconnected from the grid and will be fully supplied by the hybrid system.

5 Conclusion

This chapter dealt with the design and the simulation of solar-wind-battery hybrid energy system with Grid Utility as backup source. An appropriate power management algorithm is selected to ensure providing power supply to load. Different scenarios are tested and validate the effectiveness of the proposed power management algorithm.

General Conclusion

General Conclusion

In this project, modelling of hybrid system components has been presented such as PVCS, WECS, battery storage system. The control allowing to obtain maximum power from solar and wind energy conversion system has been detailed.

A new power management has been proposed in this project in order to manage the power generated by the hybrid system and the connection of load to the grid utility which is used as a backup source.

Simulation results for a whole day considering the intermittence of solar and wind energy sources has been done. These results have shown the effectiveness of the proposed algorithm.

Different topologies of hybrid power system exist. So, it is proposed for further work to develop the other topologies with the integration of other energy sources (like hydraulic energy), using diesel generator as a backup source instead of the grid utility in order to create a standalone system and integrating the cost and reliability in the power management algorithm as factors of operation.

References

References

[1] H. Rudnick and A. Rudnick, "Expansion of power; facing environmental and social challenges," IEEE Power & Energy Magazine, pp. 14-29, 109 may.2019

[2] E. Kabalci, "Design and analysis of a hybrid renewable energy plant with solar," Energy Conversion and Management, vol. 72, pp. 51-59

[3] https://www.renewableenergyworld.com/index/tech.html.May 2019.

[4] https://ourworldindata.org/renewable-energy#empirical-view.May 2019.

[5] https://en.wikipedia.org/wiki/Solar_energy#cite_note-ie11-1.May 2019.

[6] https://en.wikipedia.org/wiki/Wind_power.May 2019.

[7] https://en.wikipedia.org/wiki/Hydropower.May 2019.

[8] https://www.eia.gov/energyexplained/page=biomass_home.May 2019.

[9] Osama Omari, Egon Ortjohann, Alaa Mohd, and Danny Morton, "An Online Control Strategy for DC Coupled Hybrid Power Systems," in 2007 IEEE Power Engineering Society General Meeting, Tampa, FL, 23 July-2007, pp. 1- 8, ISSN:1932-5517, ISBN:1-4244-1298-6.

[10] Ahmed Agus Setiawan, Yu Zhao, Rob Susanto-Lee, and Chem. V. Nayar, "Design, economic analysis and environmental considerations of mini-grid hybrid power system with reverse Osmosis desalination plant for remote areas, » Renewable Energy-Elsevier, vol. 34, Iss.2, pp. 374-383, February 2009.

[11] Prof. Dr.-Ing. E. Ortjohann, M.Sc. Engineer O. Omari, Engineer R. Saiju, Dip. -Ing. N. Hamsic, and Dr. D. Morton, "A simulation Model for Expandable Hybrid Power systems," in 2nd European PV-Hybrid and Mini-Grid Conference: University of Applied Sciences Südwestfalen, Division Soest, Germany, September 2003.

[12] Wind and Solar power systems, Mukund R.Patel, 1999 by CRC press LLC.

[13] J. Surya Kumari and Ch. Sai Babu, “Mathematical Modeling and Simulation of Photovoltaic Cell using Matlab-Simulink Environment, (Vol.2, No.1, February 2012, pp. 26~34).

[14] Prof. Dr. Volker Wittwer “Solar energy” Fraunhofer Institute for Solar Energy Systems ISE, Freiburg.

[15] Markvart T.: “Solar Electricity”, John Wiley & Sons, 1994.

[16] Syahrul Ashikin Azmi PPKSE, “Photovoltaic Material and Electrical Characteristic”.

[17] M.G.Villalva, J.R.Gazoli and E. Ruppert F. “Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays”. IEEE Transactions on power electronics. (Vol.24, No. 5, 2009. pp 1198 – 1208).

[18] S. Kebaili and A. Betka, "Design and Simulation of Stand-Alone Photovoltaic Systems," WSEAS Transactions on Power Systems, vol. 6, no. 4, pp. 89-99, 2011.

[19] Mamarelis, E.; Petrone, G.; Spagnuolo, G. “A two-steps algorithm improving the P & O steady state MPPT efficiency”. (Appl. Energy **2014**, 113, 414–421.)

[20] B. Wu, Y. Lang, N. Zargari and S. Kouro, Power conversion and control of wind energy systems, John Wiley & Sons, 2011.

[21] O. Anaya-Lara, N. Jenkins, J. Ekanayake, P. Cartwright and M. Hughes, Wind energy generation: modeling and control, John Wiley & Sons, 2011.

[22] Canadian Solar, "Canadian Solar CS6P 240/245/250/255/260M Datasheet," 2013. [Online]. Available: http://www.canadiansolar.com/.

[23] Prof Chem Nayar “Workshop wind energy, technology”, International Conference Renewable Energy Generation and Applications, ICREGA, UAE, March 2010.

[24] “Sim Power Systems: for use with Simulink," http: //www.mathworks.com/ access/ helpdesk/help/pdfdoc/physmod/powersys/powersysref.pdf.

[25] Control of Power Inverters in Renewable Energy and Smart Grid Integration, Qing-Chang Zhong and Tomas Hornik, John Wiley & Sons, 2013.

[26] C. Ghiţă, A.– I. Chirilă, I. – D. Deaconu, and D. I. Ilina, “Wind turbine permanent magnet synchronous generator magnetic field study”.

[27] T. Ackermann, “Wind Power in Power Systems”, ISBN 0-47085508-8, John Wiley & Sons, Chichester, England, 2005.

[28] Mohan, N.; Undeland, T. and Robbins, “W. Power Electronics Converters, Application and Design”. New York: John Wiley & Sons, 2003.

[29] Hussein Ibrahimab, Adrian Ilincaa, and Jean Perronb, "Comparison and Analysis of Different Energy Storage Techniques Based on their Performance Index," in IEEE Electrical Power Conference Ca.

[30] Modeling and Comparison of Dynamics of an AC and a DC Coupled Remote Hybrid Power Systems, Tanjila Haque, M.Tariq Iqbal. Faculty of Engineering and Applied Science, Memorial University of Newfoundland St. John’s, NL A1B3X5 Canada.

[31] Renewable Energy Development Center.

APPENDICES

Appendix A: Buck-Boost converter parameters calculation

The necessary data needed to estimate the buck-boost converter parameter are shown in the table A.1.

Table A.1: Needed data in computation of buck-boost converter

Descriptions	Parameter	Unit
Input voltage range	$V_{1(min)}$ to V_{1M}	V
Output voltage	V_0	V
Maximum average output current	I_{OM}	A
Allowed inductor current ripple	$I_{(LI)(PP)}$	mA
Switching frequency of the internal switch	$f_{(SW)}$	kHz

The DC conversion ratio V_O / V_I:

$$\frac{Vo}{Vi} = \frac{-D}{1-D} \quad \text{(A.1)}$$

A.1 Selection of inductor

The required inductance:

$$L1 = \frac{V_i D}{I_{(LI)(PP)} f_{(SW)}} \quad \text{(A.2)}$$

A.2 Select the rectifier diode

Generally, it is recommended to use Schottky diodes for inductive low- to middle-power DC/DC converters. This is due to the low forward voltage drop which leads to higher efficiency.

A.3 Selection of the capacitors

The minimum effective value for this capacitor $C_{1(\min)}$can be estimated with:

$$\mathrm{C1(min)} = \frac{I_{(L1)(AVG)} \times D}{f_{SW} \times [V_{i(PP)} - (I_{(L1)(PP)} \times ESR_{CI})]} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(A.3)}$$

The minimum required capacitance $C_{O(\min)}$ at an output voltage ripple requirement of $V_{O(PP)}$, given by:

$$\mathrm{C0(min)} = \frac{I_0 \times D}{f_{SW} \times [V_{i(PP)} - (\frac{I_0}{1-D} + \frac{I_{(L1)(pp)}}{2}) \times ESR_{C0})]} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(A.4)}$$