UNIVERSITY OF GAZİANTEP

GRADUATE SCHOOL OF

NATURAL & APPLIED SCIENCES

SIMULATION OF GRID CONNECTED OF HYBRID RENEWABLE POWER SYSTEM

M.Sc. THESIS

IN

ELECTRICAL AND ELECTRONICS ENGINEERING

BY

RONAK AHMAD SAEED

JUNE 2016

Simulation of Grid Connected of Hybrid Renewable Power System

M.Sc. Thesis

in

Electrical and Electronics Engineering

University of Gaziantep

Supervisor

Prof. Dr. Ergun ERÇELEBİ

By

Ronak Ahmad SAEED

June 2016

REPUBLIC OF TURKEY
UNIVERSITY OF GAZİANTEP
GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES
ELECTRICAL AND ELECTRONIC ENGINEERING DEPARTMENT

Name of the thesis: Simulation of Grid Connected of Hybrid Renewable Power System

Name of the student: Ronak Ahmad SAEED

Exam date: June 30, 2016

Approval of the Graduate School of Natural and Applied Sciences.

Prof. Dr. Metin BEDİR
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

Prof. Dr. Ergun ERÇELEBİ
Head of Department

This is to certify that we have read this thesis and that in our consensus / majority opinion, it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

Prof. Dr. Ergun ERÇELEBİ
Supervisor

Examining Committee Members:	Signature
Prof. Dr. Ergun ERÇELEBİ	....
Assist. Prof. Dr. Furkan DİNÇER	....
Assist. Prof.Dr. Ahmet Mete VURAL	....

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Ronak Ahmad SAEED

ABSTRACT

SIMULATION OF GRID CONNECTED OF HYBRID RENEWABLE POWER SYSTEM

SAEED, Ronak Ahmad
M.Sc. in Electrical and Electronic Engineering
Supervisor: Prof. Dr. Ergun ERÇELEBİ
June 2016, (72)Pages
In this thesis, modeling of grid connected hybrid power system consisting of different power sources as photovoltaic (PV), wind turbine based permanent magnet synchronous generator (PMSG), diesel generator and battery has been studied. Photovoltaic and wind turbine which are the renewable energy sources are composed of main components of hybrid power system. In this study, we have analyzed the architecture of power system sources to achieve a good performance of the individual sub models for the hybrid system. And we have chosen the source that can supply the load demand in order to minimize the kWh cost and maximum availability while preserving the reliability of the system. The control strategy has been adopted to the model considered in the study for operating the system (PV/wind/diesel/battery/grid) in the most efficient way. Simulation studies of hybrid power system for different power sources have been done.

Keywords: Grid connected hybrid power system, photovoltaic, wind turbine, diesel generator, battery.

ÖZET

ŞEBEKEYE BAĞLI HİBRİT YENİLENEBİLİR ENERJİ SİSTEMİNİN BENZETİMİ

SAEED, Ronak Ahmad
Yüksek Lisans Tezi, Elektrik ve Elektronik Mühendisliği Bölümü
Tez Yöneticisi: Prof. Dr. Ergun ERÇELEBİ
Haziran 2016, (72)Sayfa

Tezde, fotovoltaik, sabit mıknatıslı senkron jeneratör temelli rüzgar türbini, dizel jeneratör ve batarya gibi farklı enerji kaynaklarından oluşan şebeke bağlantılı melez güç sisteminin modellenmesi çalışılmıştır. Fotovoltaik ve rüzgar türbini yenilenebilir enerji kaynakları melez güç sisteminin ana bileşenleri oluşturmaktadır. Çalışmada, melez sistem için bağımsız alt modellerin iyi performansını elde edebilmek için güç sistem kaynaklarının mimarisini analiz ettik. Ve sistem güvenilirliğini koruyarak kWh maliyeti en aza indirmek ve kullanabilirliği maksimum edebilmek için yük talebini sağlayan güç kaynağını seçtik. Melez güç sistemini en etkili şekilde çalıştırmak için kontrol stratejisi bu çalışmada ele alınan modele adapte edildi. Farklı güç kaynakları için melez güç sisteminin benzetim çalışmaları yapıldı.

Anahtar Kelimeler: Şebeke bağlantılı hibrit güç sistemi, fotovoltaik, rüzgar türbini, dizel jeneratör, batarya

Dedicated to

All of my family

ACKNOWLEDGEMENTS

In the name of Allah, the Most Gracious, the most Merciful. First of all I would like to thank to Allah for all His guidance and giving while I was preparing, doing and finishing this master thesis.

I would like to express my gratefulness to my supervisor Prof. Dr. Ergun ERÇELEBİ for his guidance, patience, kindness, and encouragement throughout this research.

I would like to express my thanks to the staff members of the Department of Electrical and Electronics Engineering at the University of Gaziantep and my thanks to all other friends for their helping me in preparing this research.

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

Page

LIST OF SYMBOLS /ABBREVIATIONS

HPSS	Hybrid Power systems sources
PV	Photovoltaic
PMSG	Permanent magnet synchronies generator
I	PV output current
IL	Solar generated current
I_D	Diode current
I_S	Diode saturation current
RS	Series resistance
RSh	Shunt resistance
Is	Reveres saturation current of diode
q	Electron charge
K	Boltzmann's constant
T	Cell junction point temperature
N	Diode ideality factor
Pmax	Maximum Power
Vmax	Maximum Voltage
Imax	Maximum current
Voc	Open-circuit voltage
Isc	Short-circuit current
MPPT	Maximum power point tracking
K.E	Kinetic energy
m	Air mass
v	Velocity
A	Swept area
T	Time duration
m/T	Mass flow rate
ρ	Air density
P_T	Turbine power
λ	Tip speed ratio

β	Pitch angle
SOC	State of Charge
HRES	Hybrid renewable energy system
RESS	Renewable energy system sources
BC	Battery Capacity
NICad	Nickel cadmium battery
NIMH	Nickel metal-hydride battery
IGBT	Insulated-gate bipolar transistor
MOSFET	Metal-oxide-semiconductor field-effect transistor
MVA	Mega volt amper
PWM	Pulse width modulation

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Due to the critical condition of industrial fuels and raising the price of petroleum product's and the increase in population the demand for electric power is growing and hybrid power system sources (HPSS) has been getting more importance. The development of hybrid Power systems sources is continuously getting better which is becoming popular in power systems for providing the electricity and difficult to reach zones in remote areas. A hybrid power system contains more than one renewable energy system which are applied to each other to supply power system efficiency as well as greater balance in energy supply [1].

Hybrid power system is the combination of two or more energy sources. The fundamental point of preference hybrid energy system is the improvement of unwavering quality, decreasing the overall cost and enhancing reliability of renewable power generation to feed its load, which becomes more economical to run at the case feebleness of one system can be consummated by the power of the other one [2].

Hybrid power system can be categorized into two types, stand-alone and with grid connected to the system. A standalone power system is defined as an off-grid system, which works without a grid support. For stand-alone applications hybrid power generation system become very attractive to supply continuous power for providing electricity in remote areas, stand-alone systems need to have generation and storage capacity large enough to handle the load. Otherwise on grid system which works with a grid support and insufficient power can be acquired from the grid therefore the size of storage device can be relatively smaller[3].

The Renewable energy sources have become a popular alternative electrical energy source the photovoltaic and wind power generation have been increased significantly and are the world's fastest growing energy resources with no emission of pollutants rather than the other types of sources [4].

Hybrid power system from renewable energy technologies consists of Photovoltaic (PV) system with the wind turbine based permanent magnet synchronous generator (PMSG), conventional backup energy source (Diesel engine generator), battery power system, grid connection and Power electronic devices (inverter, rectifier).

The Photovoltaic (PV) system mainly entails generating power from solar radiation, which is generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect [5]. Wind is a great source of renewable energy, wind turbines is primarily used for the generation of electricity from the kinetic power of wind. It is converted the kinetic energy of air moving into mechanical energy and the generator converted the mechanical energy into electrical energy which is connected to the turbine directly or indirectly [6].

The diesel generator sets entail a diesel engine that is combined with an electrical generator through a rotating part for the purpose of producing electrical energy, when a general power grid is not available the set of diesel generator are applied as an emergency or auxiliary power supply [7].

Battery is a storage device which is stored the excess power generated and it uses to supply the load when power is required. When there is a surplus of energy and is greater than demand then the battery is charged. When there is a deficit in power the supply is less than demand then the battery starts discharging supplying the deficit of power to the load[4].

Hybrid system often needs a power converter to interchange energy between AC and DC devices that allow convenient the final load requirement. A converter is powered electronic devices that change electric power from DC to AC in a process called inversion, and or from AC to DC in a process called rectification. The rectifier is the transformation of our power (AC) from a wind turbine to power (DC). Inverters usually have the opposite purpose of a rectifier, which entails converting DC power to AC power[8].

In this thesis, the model of hybrid power system sources is studied and simulated in software Simulink. The proposed hybrid power generation system is connected to the grid to produce electricity and supply the load with considering and studying three cases of loads. The system consists of the photovoltaic (PV) with the wind turbine based permanent magnet synchronous generator (PMSG) and the battery (Nickel-Metal-Hydride) type is connected to the DC bus then the inverter is converted DC to AC to supply the loads. Moreover the system contains the diesel generator and grid to meet the load demand in the case of the power sources of (solar and wind) are not sufficient for the load demand. A control strategy for the hybrid power system sources is used to operate the system in the most efficient way and more utilization of the renewable energy sources to satisfy the load requirements in order to reduce the kWh cost while preserving the reliability and maximum availability of the system.

1.2 Specific Objectives

The major objective of this work is to study a model of hybrid power system sources and modeling in Simulink to generate the electricity to supply the load. A control strategy for energy management in hybrid power systems is utilized to select the power source, to increase the system reliability and to minimize the kWh cost of the system in order to satisfy the load requirements.

1.3 Overview of the Chapters

As a brief of this thesis's content, it consists of five chapters and description of each chapter is as follows:

Chapter 1: This chapter provides a general introduction of the hybrid power system, Specific objective and organization of the thesis.

Chapter 2: This chapter mentions the literature related to the work and the place of this work in the literature.

Chapter 3: This chapter provides the backgrounds on the each component of the hybrid power system in details with their performance characteristics that are used for composing renewable hybrid power system.

Chapter 4: This chapter presents the modelling, simulation of the proposed hybrid power system in Software simulink with the presenting the results and discussion.

Chapter 5: The last chapter draws conceptual conclusions about the success and limitations of the results of this thesis and recommendations with suggests for further work. Also presents all the sources of information that were used for creating this study. These sources are: scientific literature, books, and internet sources.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter entails a critical review of the sources of the hybrid power system. This process of review comprises of meteorological generation, optimization, modeling, as well as system control for both energy flow and management. By the end of this process of review, there is a formulation of research questions, and the establishment of the main purpose of this thesis. In order to understand the working of the PV/Wind/Battery/Diesel/ Grid hybrid power system diverse topologies, which can be used for hybrid system, as well as about the merits and demerits of hybrid system. Literature review regarding hybrid energy system is widely extensive. Nonetheless, the literature review is done in brief form to enhance work conducted in this study. This is mainly because the study entails the operation of hybrid energy system that consists of solar, wind, battery, grid, and diesel energy systems. There are different efforts of research by applying the renewable energy options that have been conducted to enhance the access of renewable energy resource potentials, as well as hybrid systems. There are different authors that have already conducted research on hybrid systems at different time frames, sites, and different countries. The main objective of this chapter is to describe the background of resources of energy throughout the world, as well as the development of the current power grid system. Also, more studies through this chapter will cover the definition of hybrid power system. Moreover, the studies will also emphasize on several basic ideas emerging from researchers who have great interest in this technology. The relevant research reports in the literature with regards to the field of hybrid wind, PV, diesel generator battery on grid, and their conclusions are briefly cited below:

2.2 Related Work

Borowy, B. S., & Salameh, Z. M. (1996) demonstrated a methodology for computation of the optimum size of a battery bank and a PV array in a hybrid wind/PV system for a given load and desired reliability of the hybrid system. It is based on the use of long term data for ordinance and wind speed together for the location under consideration. The project was calculated an optimum number of batteries and PV modules based on the minimum cost of the system. The average power outputs were calculated from both the wind turbine and PV module [9].

M.ASHARI and C. V. NAYAR (1999) designed the modeling of hybrid power systems including the optimization of the dispatch strategy. Developed a computer program for a typical dispatch strategy to determinate the optimum values of using the diesel generator to minimise the overall hybrid power system costs . An optimum condition, which was the optimum fuel consumption cost and the battery cost applied by the hybrid system [10].

H.X. Yang, L. Lu, J. Burnett (2003) described a simulation model for analyzing the probability of power supply failure in hybrid photovoltaic–wind power generation systems incorporating a storage battery bank, and also analyzed the reliability of the systems. provided a good utilization factor for renewable energy applications. Simulation models for hybrid photovoltaic–wind systems with a storage battery are set up for the loss of power supply probability(LPSP) calculation. The optimized combinations of photovoltaic modules, wind turbine and battery bank are obtained for different desired LPSPs [11].

Jeon, J., Kim, et al (2007**)** show cases a prototype system design and principle of a hybrid system, which is wind/PV/battery hybrid system. The authors describe both the design and principle of this system in grid interface operation, and thus, its tests results from numerous modes of operations, which entailed normal operation, dispatch of power, and power averaging, were conducted. There is a regulation of wind and solar systems to ensure maximum energy from both wind and solar irradiance are utilized for efficient operation. Also, battery storage system was used system to smoothen the output as it prevents fluctuation of the entire hybrid system. The control of energy in the whole system, as well as the flow of energy between the grid and system are mainly based on power electronic interface [12].

Karasavvas, K. C. (2008**)** utilized thee MATLAB Simulink model of hybrid power system that relies on wind and diesel power generation, as well as a grid that is connected to the PV inverter. The authors demonstrated a modular simulation system that was enhanced through the use of the MATLAB programming environment. This is highly essential as it contain useful tools for both analysis and design of such systems. In this regard, a designer can use this tool to develop control strategies that can be used to balance the power flows of the system under diverse generator or load conditions. It is the study of dynamic behavior of such system that is of paramount importance in determining the higher limits of penetrations of wind turbines, as well as PV generators. This is important in the selection of both control and protection equipment such that the achieved performance of the system is acceptable. Also, studies entailing simulation that have utilized the proposed control approach vividly show that the application of these policies tend to result in reduction in load flow requirements, particularly for the traditional power generation units, as well as to improve the quality of power and help in stabilizing the interconnected systems [13].

M.K. Deshmukha, S.S. Deshmukh (2008) described methodologies to model HRES components, HRES designs and their evaluation. The trends in HRES design showed that the hybrid PV/wind energy systems are becoming gaining popular. The issues related to penetration of these energy systems in the present distribution network are highlighted. HRES provided prospects of incorporating in power generation capacity to improve power quality, due to the dispersed generation [14].

Saheb-Koussa, D., Haddadi, M., & Belhamel, M. (2009) developed optimal design of a hybrid system using a mathematical modeling and reported the outputs of the technical–economic optimization research of wind /photovoltaic/diesel hybrid with battery storage. The economic analysis investigated in the calculation of kWh cost of energy for different types of resources and optimized cost of hybrid energy system [15].

Nagaraj, R. (2012) shows cases a review of a renewable-energy based desalination system that relies on both PV and wind turbines used for generation of power. The author further introduces the hybrid power system that consists of PV and Wind turbine with storage batteries available. The hybrid system show cased by the author was further subjected for optimization analysis in order to find out the configuration that would offer the least cost energy using minimum capital investment, and equally, the net value. Based on the study, it is widely evident that the combination of the PV modules, wind turbines, storage battery, and power converter as the most viable in supplying power at relatively low cost in accordance with energy with least minimum capital investment and without posing harm to the environmental systems. According to the author, the typical values illustrated are essential for scaling up to a larger system since solar PV and storage battery are entirely modular in their nature [16].

Saib, S. et al (2013) used the MATLAB model to simulate grid-connected hybrid systems. Such systems typically comprise of PV array and wind turbine, as well as a storage battery. The objective of modeling hybrid systems mainly involves the extraction of power produced by solar or wind systems, and equally, the power flow into the electricity network. For effective storage of power, the Nickel-Cadmium battery are used, with their connection to the system mainly achieved through a DC bus. The parameter the power grid are thus tuned through designing an inverters, and through designing a filter for grid interface. In this regard, an MPPT algorithm that formed using the inductive incremental method has been used to seek the point whereby it is possible to achieve the maximum power from the PV Array [17].

Kazem, H. A., & Khatib, T. (2013) installed hybrid power system by using a process for determining optimal sizes of the PV array, wind turbine, diesel generator, and storage battery. Designed the system that can feed a load demand at minimum cost and maximum availability. The mathematical models are employed for the system components like meteorological variables such as solar energy, temperature, and wind speed . Investigated Optimization of a combined PV/wind/diesel generator and battery system utilizing a method based on iterative simulation [18].

Venkobarao, V., et al (2013) proposed the development of a rather unified control law that can be utilized in the simulation of supervisory control of the hybrid power system. The numerous zones of power generation that are discussed demonstrate the several entry and exit conditions of every operational zone, and thus, it is possible to switch between the various units of power generation to meet the demand. In the event of insufficient generation, there is typically no option rather than having a load shedding, which is highly essential state of the emerging markets [19].

Nair, N. R., et al (2014) presented the operation and control of a system that is powered by both wind and PV sources. In the hybrid system presented by the authors, there is a utility grid connection that is provided to replenish the levels of energy in events of power shortage mainly from the renewable sources of energy. The hybrid power system is basically a combination of two sources, which is facilitated using a common DC bus. These two sources utilize a multiple input converter in the main bus to enhance connected. In this case, a PMSG (Permanent Magnet Synchronous Generator is utilized for driving the wind turbine. More importantly, considerations of variations in both solar irradiance and wind power are observed. It is the MI Cuk Converter that is used to track the maximum point in each of the sources. Also, there are major discussions regarding the input current control method on the MPPT of the wind turbine, as well as the incremental conductance method in the case of Solar PV. In this regard, simulation is executed using the MATLAB/Simulink platform based on 30kW wind/solar hybrid power system, as well as the performance of the system analyzed using available sources. It is essential to acknowledge that the control of the grid that is connected to the inverter maintains AC voltage as load, which is also constant together with the frequency of the system [20].

Pachori, A. et al (2014) utilized the MATLAB/Simulink model to design a hybrid system, which entailed PV array system, Wind turbine, and diesel generator systems for power generation. The system relied on blocks like PV model, wind model, diesel generator, a system to convert energy, storage battery, and load, which were implemented and the results of the simulation presented [21].

Athulya, J. V., et al (2014) used the MATLAB/Simulink model to simulate a PV/Wind hybrid electric power system while utilizing the isolated operation mode. In this regard, the primary sources are wind and solar energy while the battery is used to back up the energy supply. Using the MATLAB model, a computer simulation is presented where it is viewed to apply a rather realistic model of the system's circuit. In the simulation, there are waveforms shown to present voltage and power emerging from the energy sources used, which are generated using PV array and wind energy system. Also, the output waveforms emerging from the inverter and the low pass filters are viewed and are useful in obtaining the required load voltage, as well as power waveforms[22].

Chowdhury, M. S. F. (2014) proposed development of simulating a hybrid system that the wind model and the Photovoltaic mode are combined. The objective was also to reinforcement a hybrid model for greener energy. The overall hybrid system has been tested wind speed for the wind model and with a varying irradiation level in the PV module to define the function inside a hybrid system. This simulation results presented that hybrid system has greater reliability for electric power generation. Both of the system have worked with each other for fulfilling the load demand and supplying the power to the grid [23].

Alalwan, S. H, & Kimball, J. W. (2015) studied and analyzed typical meteorological data through using the forever power method to optimize the size of hybrid micro sources for an island micro grid (MG) with minimum operational cost and to allow the designer to select the size of the best fits of the targeted availability, environmental benefit, cost and reliability. Economic analysis has been done to select the most feasible combination between the PV panels and wind generators [24].

Gan, Leong Kit, et al (2015 provided incredible insights and considerations that are essential while sizing the storage amplitude of the hybrid PV/wind/Diesel systems, for daily running, as well as long term operation. The authors described a methodology that can be used as focuses on the tops and troughs of wind profile for wind energy and solar irradiance when harvesting solar energy [25].

Etamaly, A. M. et al (2015) proposed and designed a general program for sizing and optimization of stand-alone hybrid PV/wind/diesel/battery energy systems to feed loads in remote areas. Data for five locations in Saudi Arabia and ten types of wind turbine generator have been used as a case study. To determine the best size of the hybrid system components a techno-economic strategy based on the iterative optimization technique has been developed. This strategy has been described by the reliability model which is represented by the concept of LOLP, and the economic model in a form of LEC to select the optimal size of the system components. By applying the NPSP, the best site out of the available sites and the best WT for this site have been deterred determined. The hybrid ACDC coupling system has been used to increase the efficiency and reliability. Dummy load has been suggested in this paper to store the system surplus power in the full-powered case of batteries [26].

Prema, V., Datta, S., & Rao, U. (2015) was developed an algorithm for economic dispatch of an off-grid micro grid, including of a PV-array and wind turbine integrated with a battery and variable speed diesel generator backup and simulated. The sharing of the load amongst the different sources has been simulated for the given system and the results were analyzed [27].

Charfi, S., et al (2016) proposed a global model to analyze the performance of three different power generating configurations including diesel generator only, PV/battery storage bank and hybrid PV/DE/battery bank. The overall model is established on the basis of sub-models for different modules used in these systems. The performance of these power generating systems are investigated, then the operating cost is compared for three different countries: Tunisia, Jordan and KSA [28].

Khare, V., Nema, S, & Baredar, P. (2016) the objective of the proposed was to present overall review of different parts of hybrid renewable energy system (HRES) like wind turbine and solar system. Discussed pre- feasibility analysis, optimum sizing, modeling, control types and reliability issue. Presented the application of evolutionary technique and game theory in hybrid renewable energy [29].

CHAPTER 3

BACKGROUND OF THE HYBRID POWER SYSTEM

3.1 Introduction

This study focuses on the background of renewable energy (wind- solarPV), battery, diesel generator, utility grid and power electronic device (rectifier and inverter).

3.2.1 Photovoltaic Power Generation

Photovoltaic (PV) power system is a method that is used in the generation of electrical power through the conversion of solar radiation into direct current electricity, which is mainly achieved using semi-conductors that subsequently exhibit the photovoltaic effect. The PV power generation utilizes solar panels that consist of a number of cells with a semiconductor material. The generation of power is available when the light is shining on the solar cells [8].

3.2.2 The Solar Cell

The solar cell, similar to the crystalline silicon-based solar cell that is shown in Figure 3.1 [32] . It is the solid state semiconductor p-n junction device that allows the conversion of sunlight into DC (direct-current) electricity, a process that is based on the principle of photo-voltaic effect.

In a PV cell there are two doped semiconductor layers, P-type (hole) and N-type layer (electron) which is separated to each other by a junction. A spontaneous, electric field is developed at the boundary which defines the direction of the current flow across the junction. In order to get electricity from a PV, the sunlight should penetrate a glass cover and antireflection coating [30].

The power that is produced from solar by a PV solar cell is direct current, which is the same as power from a battery. The majority of PV cells typically produce a “no load” open circuit voltage of between 0.5 volts and 0.6 volts in the absence of external circuit connection. Therefore, the output voltage is mainly dependent on the load current (I) and the demands of the photovoltaic cell [31].

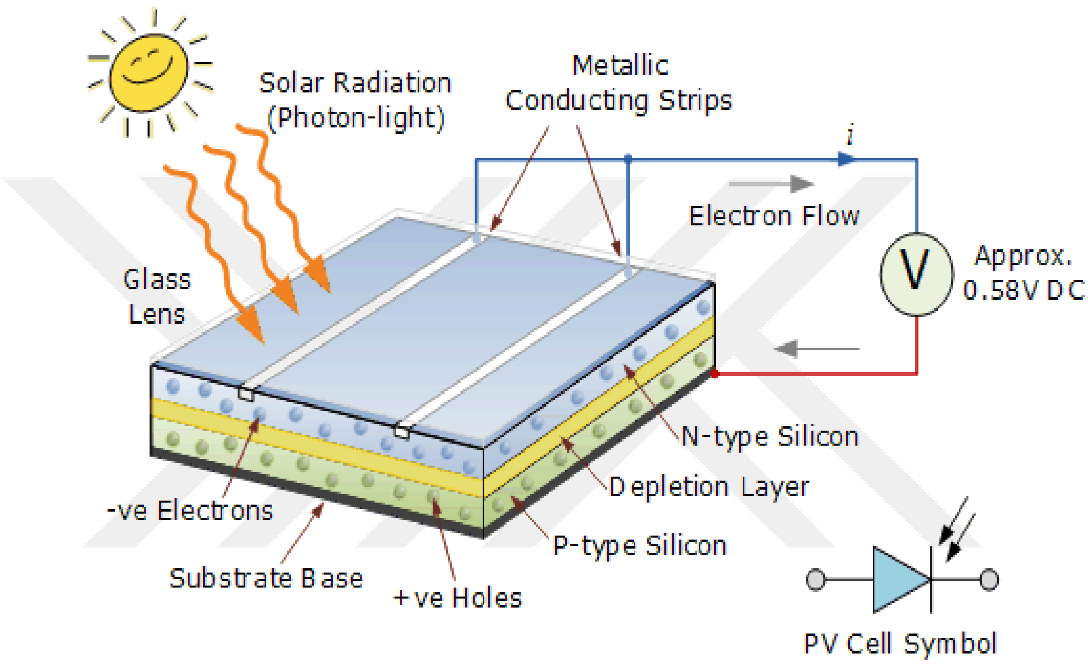

Figure 3.1 Diagram of Solar cell

3.2.3 PV MODULE

A PV module is formed when several PV cells are connected in serial or parallel (both serial and parallel). The PV module is commonly formed when a single cell generates very low voltage. For generation of higher voltage series connection of PV cells is done, while when there is demand for high current, connection of PV cells is done in parallel. It is essential to note that there are either 36 or 76 cells in general PV modules. In this context, there are using a PV module that has 54 cells [32].Photovoltaic Solar panel Construction is shown in Figure 3.2 from [33].

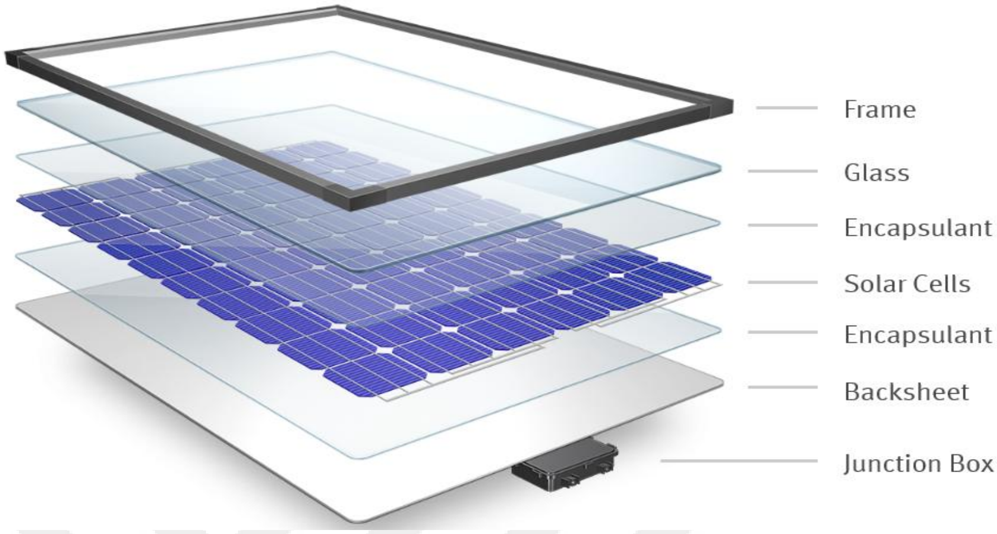

Figure 3.2 Photovoltaic Solar panel Construction

3.2.4 A Photovoltaic Solar Array

Photovoltaic cells and panels are used in the conversion of solar energy into DC (direct current) electricity. In a single photovoltaic array, the connection of the solar panels is usually similar to that of PV cells in a single panel. The panels in a photovoltaic array can have their electrical connected in series, parallel, or in the mixture of the two, but on a general perspective, series connection is most preferred as it gives an increased output voltage. For instance, when two solar panels are wired together using series connection, it doubles the output voltage, although current does not change. Therefore, a solar array or panel can be regarded as a group of several modules that are electrically connected in series-parallel combination, which then leads to the generation of the required current and voltage, and thus, the power as shown in Figure 3.3 is taken from [32].

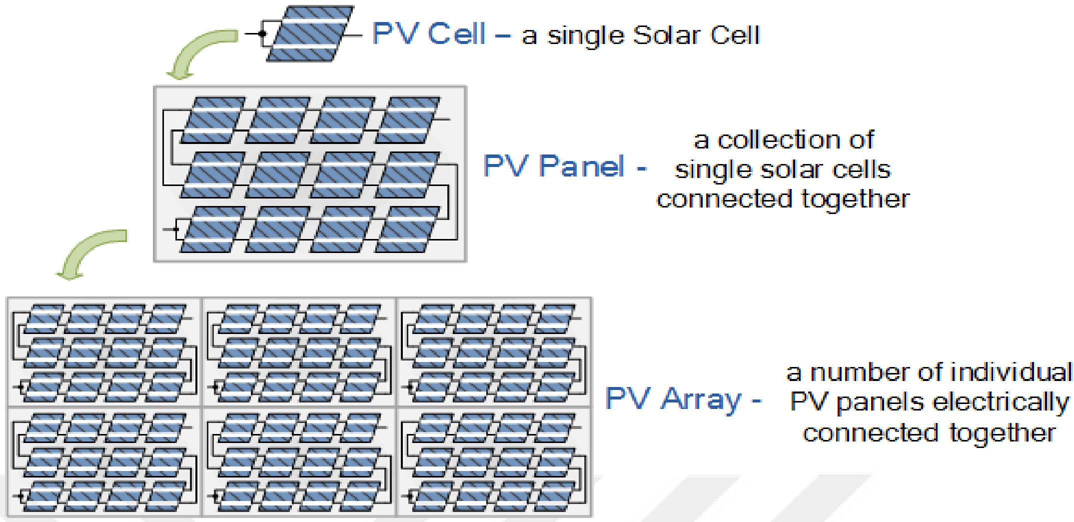

Figure 3.3 PV cell, module and array

3.2.5 Summary of Advantages and Drawbacks of the PV-Array Energy

Advantages

a. Environmentally friendly and pollution free (emission free)
b. Fuels and water are not used
c. Requires minimum maintenance and low running cost
d. It is durable, as most have a lifetime of up to 30 years
e. It is a custom-made (Modular) energy, and thus can be designed for a wide range of applications ranging from a simple watch, to a multi-megawatt power plant
f. No restriction on harvesting as far as there is light

Drawbacks

a. High initial cost
b. PV can't operate without light
c. PV generates DC current: energy storage, like batteries, and inverters are needed
d. Large area needed for large scale applications
e. PV cannot always generate stable output with ever-changing weather condition [34].

3.2.6 Modeling Of PV Cell

The Photovoltaic energy system is a process of generating electrical power by converting the power from sunlight into D.C electricity using semiconductors that show the photovoltaic effect. Main part of the PV array is a photovoltaic cell, which is just a simple p n junction device. The typical model of solar cell is represented by an equivalent circuit shown in Figure 3.4. Equivalent circuit has a current source (photocurrent), a diode parallel to it, a resistor in series describing an internal resistance to the flow of current and a shunt resistance which expresses a leakage current. The current supplied to the load can be given by the equation (3.1)

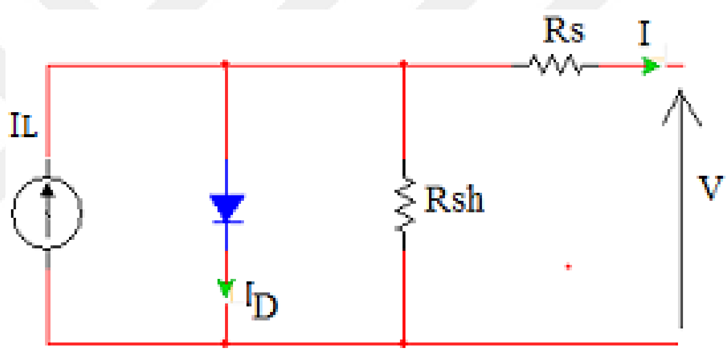

Figure 3.4 Equivalent circuit of Solar cell

$$I = IL - Is\left[\exp\frac{q(v+IRs)}{NKT} - 1\right] - \frac{(v+IRs)}{Rsh} \tag{3.1}$$

where:

I: PV output current [A]

IL: solar generated current [A]

I_D: Diode current [A]

I_S : diode saturation current[A]

Rs: series resistance

Rsh : shunt resistance

Is: Reveres saturation current of diode [A]

q: Electron charge [C]

K: Boltzmann's constant [J/k]

T: Cell junction point temperature [k]

N: the diode ideality factor

PV module's (I-V and P-V) characteristics are shown in Figures 3.5 respectively.

(a) (b)

Figure 3.5 PV and IV characteristics

The maximum power is given as,

$$P_{max} = V_{max} I_{max} \tag{3.2}$$

The parameters which are used to relate the electrical performance are the open-circuit voltage of the cell Voc and short-circuit current of the cell Isc [35].

3.2.7 Solar PV Installation Methods

Solar energy exploitation depends on the tracking system that mounts the PV panel. The tracking system is basically applied to direct the panel to the direction of the sunlight which enhances the radiation that strikes the surface of the PV module. Most PV arrays are typically mounted with no tracking systems. There is the possibility to track the radiation of the sun for the power output maximization. Below are the techniques to be considered during the design of the PV system.

No tracking: Photovoltaic Panels are mounted on a fixed slope and azimuth moreover, it is the simplest and cheapest method. Preferable to orient the panel to the equator (south in the northern hemisphere) usually the angle of tilt is equal to the latitude of the specific site under study. A small increase and decrease from the latitude will be better in the winter and summer sun tracking respectively [36].

Solar Tracker (Solar Tracking)

A solar tracker can be defined as the device used to adjust or move the position angle of solar PV panel towards the direction of the sun. It is essential to note that he position of the sun varies with the season, as well as time of day as the it moves across the sky. The solar tracking will lead to increased effectiveness of the solar panels as compared to fixed solar array or panel.

Power = (W)
Irradiance = (W/m^2)
Insulation = $W/m^2/day$

There are various factors that must be considered in the process of determining how trackers are used. These factors include: the type of solar technology in use, intensity of irradiation from the solar, and installation and maintenance costs among others.

3.2.8 Maximum Power Point Tracking

Maximum power point tracking (MPPT) system can be defined as the electronic control system, which can compel the maximum power from the PV system. The process does not rely on only one mechanical component, enabling the movement of the PV modules during which they shift their position to ensure their direction is towards the sun. on the contrary, the MPPT control system comprises of an electronic system that is designed to enhance maximum delivery of power through variation of the modules' points of operation electrically [35].

The Maximum Power Point Tracking Algorithm

The MPPT algorithm is a sophisticated technique aimed at maximum extraction of power from the non-linear resources of energy, such as solar PV, tidal energies, and wind energy systems. For instance, when considering a solar PV system, the MPPT algorithm enables the controller earnest both maximum voltage and current from the PV module. Some of the commonly used MPPT algorithms can be listed as follows:

a) Follow the optimum voltage and current from a photovoltaic module. Most Widely used MPPT algorithms are:

b) Constant voltage method

c) Perturb & Observe (P&O) method

d) Incremental conductance method [37].

3.3 Wind Turbine

Wind can be defined as the movement of air masses. It is essential to acknowledge that wind has kinetic energy. The conversion of wind's kinetic energy to mechanical energy is usually enabled using wind turbines, which have several rotor blades. From the mechanical energy in the wind turbines, the conversion then proceeds to electrical energy, which is achieved using a generator [38].

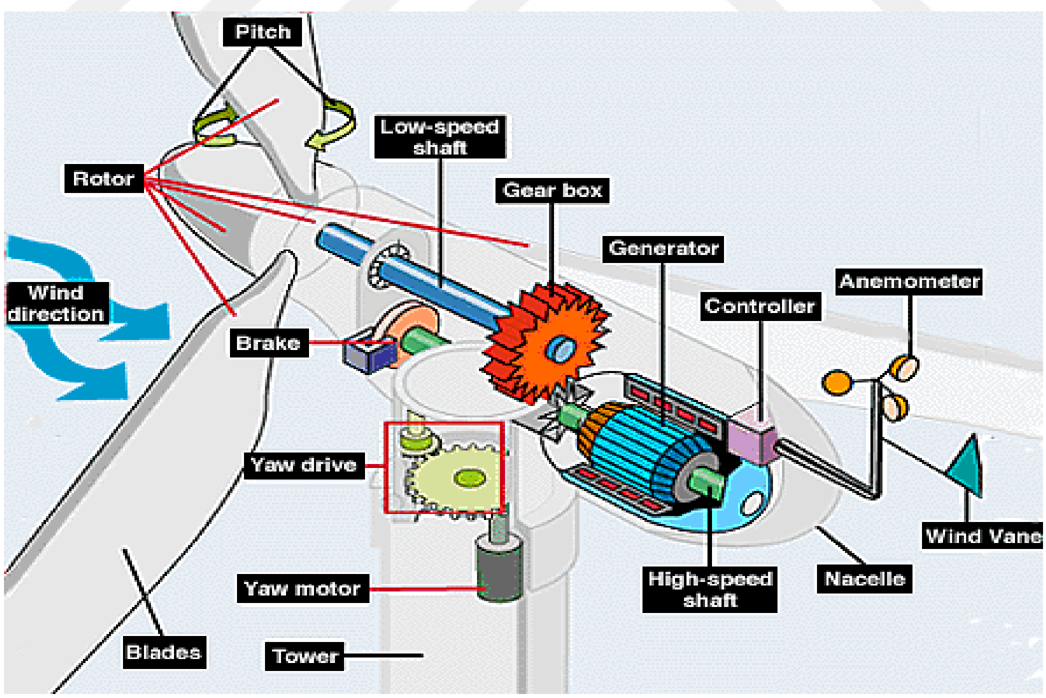

Figure 3.6 Wind turbine components

The production of electricity using wind turbines is achieved when the wind power or energy is conveyed to drive or rotate an electrical generator. As the wind pass over the rotator blades of a wind turbine, it exerts a turning force, which then causes the turbine to rotate. Technically, rotating blades are connected to a shaft inside the nacelle that is further connected to a gearbox. It is the gearbox that increases the speed of rotation, such that they are appropriate for the generation of energy. The generator utilizes magnetic fields for enhancing the conversion of rotational energy, subsequently yielding electrical energy. The output of the generator is power, which is then channeled to a power electronic converter or transformer, which is then responsible for them conversion of electricity.

Wind energy or wind power is a term that technically describes the process of using wind to generate electricity or mechanical power. On a general perspective, wind turbines usually comprise of a set of rotor blades that are fixed to a rotating hub, and gearbox generator that is located inside the nacelle. The basic components of a wind turbine system are shown in Figure 3.6 [37].

3.3.1 Advantages and Disadvantages of Electricity generated from Wind

Wind energy is **a** free, renewable resource, so no matter how much is used today, and thus, it has the greatest potential as the energy source of the future. This means that is supplied cannot be changed, either currently or in future. Also, wind energy is categorized as one of the cleanest sources of energy, non-polluting, and that can be effectively used for generation of electricity. It is different from the conventional power plants, as it does not emit greenhouse gases or air pollutants.

In the investment of wind energy, the technology, unfortunately, the initials is relatively high as compared to the conventional generators fuelled using fossil products. In a roughly estimates, the machinery of wind power is about 80 percent of the initial investment cost, while the rest balance is incurred in site preparation and installation. In the event of comparing wind generating systems with systems that rely on fossil fuels using a "life-cycle" cost basis, the cost of wind energy would be highly competitive as the other generating technologies having limitations on fuel cost, as well as expenses on operations.

The advantages of using wind turbines to generate power can be listed as follows:

- Environmentally friendly
- Produce no pollution
- No traditional fuel required
- Requires relatively little maintenance
- Long life time (up to 30 years).

The disadvantages can be briefly presented as follows:

a. Interfere with radio/TV signals in the event they are inappropriately located
b. Power generation is only limited to, wind speed, which may not be available at times
c. High initial cost [34].

3.3.2 Types of Wind Turbines

The wind turbines commonly used for power generation usually rotate in horizontal axis or in the vertical axis. The most common and older wind turbines rotate in horizontal axis. The wind turbines entail rotating blades, which can be either transparent or opaque, with some types being Bladeless.

a) Horizontal axis wind turbines

Figure 3.7 Horizontal Axis Wind Turbine

The horizontal axis wind turbines are shown in Figure 3.7 from [39] usually have a rotation axis that is horizontal to the ground , and thus, parallel the wind direction. In this type of wind turbine, the components comprise of a gearbox, rotor shaft, as well as a brake, which are typically assembled before being lifted into their rightful position. At the top of the tower, these turbines have the rotor shaft and electrical generator. The wind turbine must be placed in such a way that they point into the wind. In small wind turbines, a simple wind vane is used to point into the wind. However, in large wind turbines, a wind sensor that is coupled with a servo motor is used to point to the direction of wind. Technically, the majority of wind turbines has a gearbox that is placed to change the slow rotation of the blades into quick and speed rotation suitable for driving the electrical generator. Due to the turbulence produced behind the tower, these turbines are mainly positioned in the upwind direction of the supporting tower. More importantly, the blades of the turbine are usually made of stiff material such that they cannot be pushed into the tower when high winds occur. Also, the turbine blades are usually at considerable distance from the tower, while at other times, they are tilted forward into the wind. However, the horizontal axis wind turbines are associated with a few disadvantages, such as having a complex design, relatively high cost of investment, and finally, it needs a specific orientation of the blades of the wind.

b) Vertical-axis wind turbines

Figure 3.8 Vertical-Axis Wind Turbine

Vertical-axis turbines are shown in Figure 3.8 [40] are usually designed in such a way that the main rotor shaft is vertical to the ground. The main advantage of the vertical axis design is that the effectiveness of the turbine does not rely on it being pointed into the wind, hence, suitable in sites where the direction of wind varies more often. Also, it is advantageous as the turbine can be integrated into a building since it less steerable. Furthermore, both the generator and gearbox are commonly placed near the ground, as the design uses a direct drive eight from the rotors to the gearbox located on the ground, and thus, it improves its accessibility for easy maintenance. However, the main disadvantages of this turbine entail the following. First, it typically provides low rotational speeds with the consequential higher torque, which reflects to higher cost of the drive train. Secondly, it yields inherently a low power coefficient. Thirdly, it makes 360 degree rotation of the within the wind flow in every cycle, and thus, there is a high dynamic loading on the rotor blade[41].

3.3.3 Modeling of Wind Turbine

A wind turbine converts the kinetic energy in the wind into mechanical energy using the rotor blades. Then through using a generator the mechanical energy is converted to electrical energy. The amount of energy which the wind transfers to the rotor depends on the density of the air, the rotor swept area, and the wind speed. The rotor blades of the wind turbine capture only part of the available wind power, and the actual power extracted by a wind turbine is given by [38].

$$K.E = \frac{1}{2}mv^2 \qquad (3.3)$$

Where,

m = air mass (The power is energy per unit time, the power represented by a mass of air moving with a velocity of *v* through an area *A* for a duration of time *T* is given by

$$\text{Pwind} = \frac{1}{2} \times \frac{\text{mass}}{\text{Time}} \times \mathrm{v}^2 \times \frac{1}{2} \times \frac{\mathrm{m}}{\mathrm{T}} \times \mathrm{v}^2 \qquad (3.4)$$

Since the mass flow rate (*m/T*) through area *A* is the product of air density ρ , air speed *v*
and cross-sectional area *A*, then equation (3.4) can be written as

$Pwind = \frac{1}{2} \times \rho A v^3$ (3.5)

Where,

$Pwind$ = power in the wind (W)

ρ = air density (kg/m3) (at 15^0 C and 1 at m, ρ = 1.225 kg/m3)

A = cross-sectional area through which the wind passes (m2)

$P_T = Cp \times Pwind = \frac{1}{2} \times \rho A v^3 \times Cp(\lambda, \beta)$ (3.6)

P_T = Turbine power (W)

CP = Coefficient of performance or power coefficient known as the Betz Limit is the turbine rotor power coefficient, which is a function of the tip speed ratio (λ) and pitch angle (β

Equation (3.6) indicates that there are three options for increasing the power captured by a wind turbine. These are:

1- wind speed v

2- power coefficient CP

3-Swept area A=π/2, where L is the blade length

3.3.4 Wind Turbine Power Characteristics

The most important technical information on wind turbines is power curve. The characteristics of the power of wind turbines are mainly described using the power curve, whereby the power curve provides the relation between the mechanical power of the turbine and the wind speed. Therefore, the power curve is basically the certificate of performance of the wind turbine that is usually guaranteed by the manufacturer. The certificate of performance is typically presented in Figure 3.9 three speeds, which are:

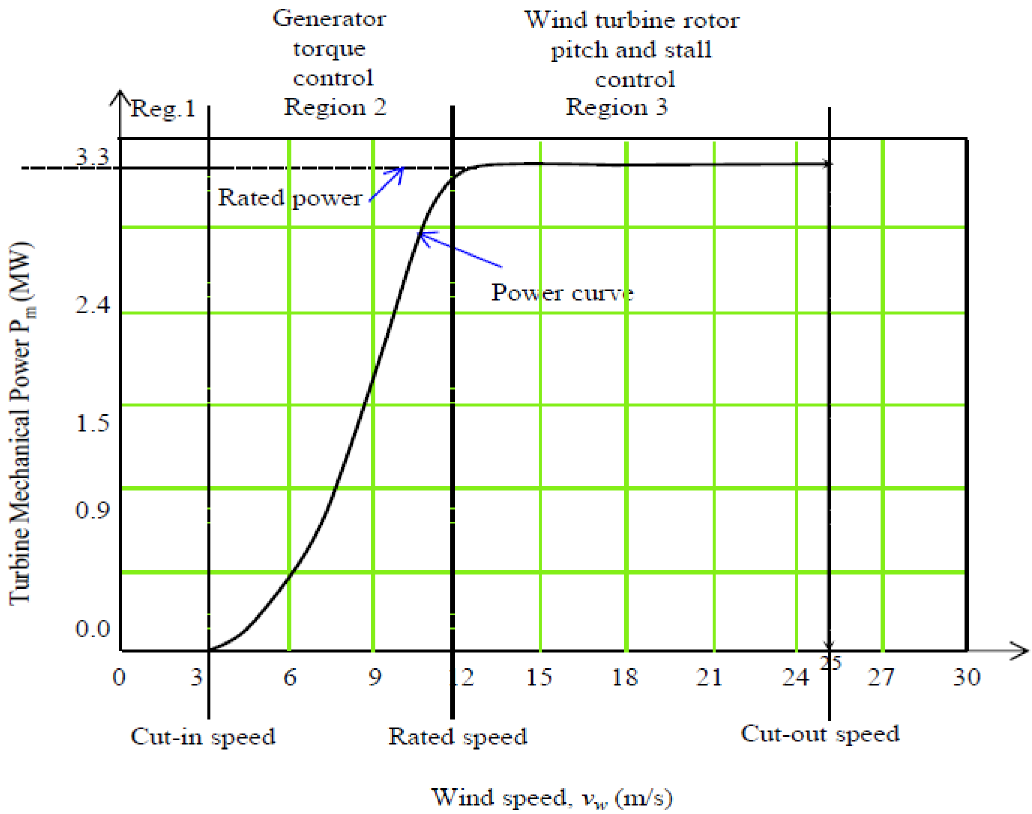

Figure 3.9 Power curve in different operating region for wind turbine

a) The cut-in speed

b) The rated wind speed

c) The cut out wind speed

The **cut-in wind speed** entails the speed that the wind turbine begins to operate and delivers power. Essentially, any speed below, then cut-in wind speed is an indication that the turbine yield adequate power to allow for compensation of power losses in the drive train of the turbine. As a result, the turbine is should be shut down. On the other hand, **rated wind speed** entails the optimum speed of the wind turbine to produce rated power. Finally, **the cut-out speed** refers to the highest speed of wind through which the wind turbine operates before being shut down. In such scenarios, shutting down of the turbine is meant to prevent any mechanical damage when speed of wind goes past the cut-out speed [38].

3.3.5 Permanent Magnet Synchronous Generator

The permanent magnet synchronous machine (PMSG) is useful in the conversion of wind energy or power to electrical energy or power. 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. PMSG provide higher efficiency in lower speed applications.

PMSGs have become popular for wind turbine applications because of their advantages as they have advantages like their self-excitation properties, their small size, losses are typically low, as well as they have efficiency and relatively high power factor. Also, PMSGs provide high power per volume through their mechanism to exploit rotor saliency. The different research that suggests the PMSG application in wind turbines. Essentially, the PMSGs do not rely on magnetizing current since their rotor flux is usually offered through the permanent magnet, as well as stator current, and thus they need torque to produce power wind energy system is shown in Figure 3.10 [42].

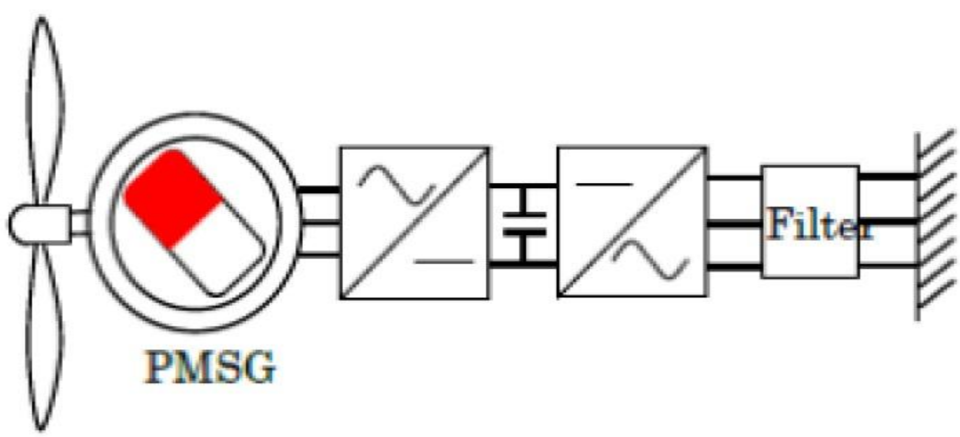

Figure 3.10 Block diagram of wind energy system

3.3.6 Advantages of a PMSG Based Wind Turbine

Due to lower losses and cost of maintenance, PMSG have a higher efficiency in lower speed applications.

a) Higher efficiency, lower losses

b) Reliability is relatively high

c) Simple structures, hence there is no need for no slip rings.

d) Do not require reactive power, such as induction generator

e) Do not require excitation control

f) Loss of excitation is not possible

g) Most suited for direct drive gearless operation [38].

3.4 Battery

The battery can be described as a device that is commonly used in most electrical systems for purposes of storing energy. It can be termed as electrochemical device, as it allows energy changes from electrical to chemical and vice versa. Therefore, energy is either stored or consumed from the battery. The used on battery is based on the concept of the electrical energy supply system that is oriented towards a decentralized system. It is essential to note that decentralized system is made possible using HPSS. In this regard, the HPSS comprise of diverse sources of energy sources, as well as the supply energy [43].

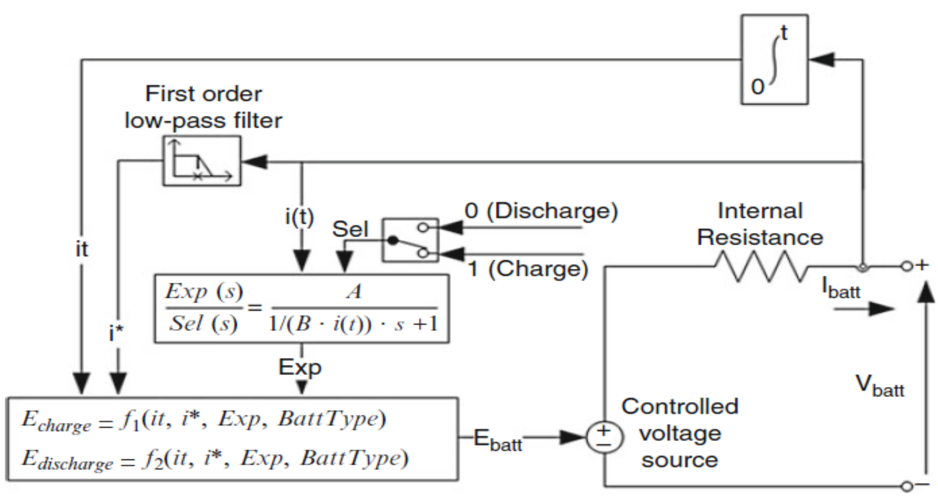

Figure 3.11 Equivalent circuit of the batteryy

Figure 3.11 shows Equivalent circuit of battery is taken from [44]. As mentioned earlier, the battery is primarily used as a storage device, in which excess power that is generated is stored and thus, used to supply the load when power is needed. When the PV and wind energy systems are integrated into the battery usually connected to the DC bus. Any form of power transfer either from the generator to the battery or from the generator to the load, or even from the battery to the load, the entire process takes place through a constant voltage DC bus. Essentially, associating the power flow with the battery bank is not uni-directional, and thus, there is a need for a bidirectional converter for purposes of charging or discharging the battery when there is excess or power deficit

In the event of a surplus of energy, which means a greater supply than demand, therefore, charging of the battery is necessary. Hence, the system allows the operation of the converter in forward direction. In scenarios of deficit in power, which occur when the supply is less than demand, therefore, the battery subsequently begins to discharge by supplying the deficit of power to the load. The process needs the operation of the converter to be in the reverse direction. Finally, the process of either charging or discharging the battery is facilitated by a bidirectional converter [35].

3.4.1 State of Charge (SOC)

The state of charge, usually abbreviated as SOC, is defined as the amount of energy or the percentage of energy that is stored in a battery that is fully charged. The process of discharging a battery leads to decrease in the state of charge. On the other hand, charging leads to increase in the state of charge [44].

When determining the SOC for an energy storage device, the following constraint must be satisfied.

$SOC_{min} \leq SOC \leq SOC_{max}$

Where SOC_{min} and SOC_{max} are the minimum and maximum state of charge respectively [3].

State Of Charge (SOC): the available capacity remaining in a battery, expressed as a percentage of the rated capacity (0% = empty; 100% = full) [34].

3.4.2 Types of batteries

Batteries are classified into two types, which include the following:

a) Primary batteries, are also called disposable batteries. They are designed to be only used once and then to be discarded.

b) Secondary batteries, and are also referred to as rechargeable batteries. They are rechargeable and can be used multiple times.

The majority of batteries commonly used today is based on a hybrid power system and are rechargeable [44].

3.4.3 Battery Modeling

Batteries play an important part in hybrid renewable energy system HRES, and typically form a large share in the initial cost. They are commonly utilized as backup option and are also used for storing power in the event of excess power production. The power supply from the battery is usually required during the peak hours where demand of power is greater than that being production. Batteries are also used as story buffer, in several models of HRES, in which electricity is primarily supplied using the battery. Moreover, because of seasonal variations, batteries may commonly experience a low state of charge for any period. It is such inconsistency in either charging or discharging that decrease in the lifetime of a battery. When the battery life is diminished, there are significant impact characterized in HRES life cycle cost [45].

3.4.4 Rechargeable battery

Battery bank is an electrochemical device which uses electrochemical reactions to store electricity in the form of potential chemical energy. The energy storing batteries used with HPSS is rechargeable in a sense that they can charge when there is enough supply from the RESS and discharge when there is larger load demand than there is supply. The charging time for the battery bank is

$$\text{tcharg} = \frac{\text{BC}}{\text{Irated .source}} (\text{hr}) \quad (3.7)$$

Where,

t_{charge} = charging time of the battery (hr)

BC = Battery Capacity(Ah)

I = Rated source current (A)

There are different types of batteries, but the most commonly used rechargeable batteries are:

a) Lead acid battery
b) Nickel cadmium battery – NiCad
c) Lithium-polymer battery
d) Nickel metal-hydride battery - NiMH
e) Zinc-air battery
f) Lithium-ion battery [34].

A Nickel Metal - Hydride battery (NiMH) is a type of rechargeable battery has the following advantages:

1- High energy density
2- Long cycle life
3- Charge or discharge efficiency is high
4- The highest environmental impact [46].

3.5 Diesel Generator set

The diesel generator is among the key elements in HPSS. Diesel generator provides power supply to the load when there is low supply as compared to the load demand and often applied when a general power grid is not available, as an auxiliary power supply. Diesel generators entail a diesel engine that is connected to an alternator or electrical generator using a rotating part to allow the generation of electricity. It is the diesel engine that converts the chemical energy of the fuel into mechanical energy emerging for the mechanical power rotations of the shaft of the engine, which is directly connected to the alternator [34]. Therefore, the engine provides power to the electric generator and equally control the shaft's speed using a governor. The shaft speed, as well as the fuel intake act as inputs, and thus provides the required mechanical torque.

The fuel energy is converted into mechanical energy by using the internal combustion engine. After that, the process leads to electric energy achievable through electric machine that works at generator [47].

3.5.1 Advantages and Disadvantages of the Diesel Generator

The diesel generator is used to generate electric energy

- In areas that have are not connected to the power grid.
- For emergency supplies.
- In the event the grid does not supply the desired power demand.
- For temporary purposes.

The Diesel Generator -set has the following drawbacks.

- It is heavy and difficult to operate.
- Noisy.
- Low efficiency [34].

a) Synchronous Machine

The synchronous generator comprises of two crucial elements which include; field and armature. The location of the field is on the rotor while that of the armature is at the stator. Also, winding field is responsible for carrying the DC electricity so as to produce the desired magnetic field from the rotor shaft. It is the magnetic field that shuts or cuts the stator conductors, as well as the three voltages during its rotations.

b) The excitation system

The excitation system of the diesel generator comprises of exciter and voltage regulator. To facilitate a supply that is adjustable DC power to the main generator field winding, there should be an excitation system. The exciter could be a DC generator on the small set sizes. Therefore, it becomes possible for regulation of terminal voltage in the event of operating in generator mode. Therefore, excitation system that is used in this work entails a DC exciter, with the assumption that his system does not experience saturation [37].

c) Diesel Engine

In the diesel generator set, the diesel engine acts as the main source of impulsion. The speed control of the engine is not automated and thus, there is a need to furnish the governor. The objective here is to ensure that the diesel engine has a specified speed to enhance a stable operation. Also, diesel engine provides the power to electricity generation, and further, controls the shaft's speed using a governor. Tentatively, speed of shaft and the intake of fuel act as inputs, while the supplied mechanical torque is the output.

3.5.2 Modeling of diesel generator set

Modeling of diesel generator set from the initial or first step in micro-grid modeling. The objective of this part introduces diesel generator set, and equally provide a description of the modeling in each and every component used. The set consists of a diesel combustion engine driving that is synchronized with an electrical generator, and thus it is used general power grid is unavailable [7].

3.5.3 Governor Control System

It is the device in diesel generators to regulate the speed of a diesel engine by controlling the flow of diesel into the cylinders with the help of injectors. For any change occurring in the demand, the governor is responsible to operate the engine at a constant speed. The governor control system provides access to regulate the speed of the engine and in turn the power produced by controlling the diesel flow to the engine. The operating speed of a diesel generator is related to the frequency of the voltage generated as given in the below expression:

$$\text{Generator frequncy} = \frac{\text{speed of engine (inRPM)} * \text{Number of magnetic poles}}{120} \tag{3.8}$$

The governor can be controlled using either speed or the frequency machine that works as a generator [37].

3.6 Converters

The power conditioning units are electronic devices and grouped into DC/AC, AC/DC. The DC/AC converter uses to switch the DC voltage or current produced by the hybrid system to the AC type voltage output. This type of power converter is called power inverter. The AC/DC power converter functions as an inverse of the inverter and it is called a rectifier. It converts the AC input voltage to rectified direct current, output voltage [5]. The converter is typically used in the conversion of DC to AC this process of conversion is referred to as inversion. Also, the conversion from AC to DC is termed as rectification. The size of converter as it is decision variable, entails the capacity of the inverter capacity, which means the maximum AC power amount that is produced in device in the process of inverting the DC power. The capacity of rectifier entails the maximum DC power amount produced in the device when rectifying AC power [8].

3.6.1 Inverters and rectifiers

The purpose of the rectifier is to facilitate the conversion of AC to DC. It is commonly called guided and unguided. The unguided rectifier comprises of diodes while the guided consists of thyristors or transistors. Since the diodes are controllable using the control signal as they lack gates, the rectified voltage is primarily based on voltage that is supplied to the circuit. Therefore, they are termed as unguided. For the inverters, they serve the opposite purpose of rectifiers, which entails conversion of DC to AC. Since inverters have made sine or square waves from the DC diodes cannot be used. Thus, Thyristors or transistors are required to be used. The common components utilized in inverters include the IGBT (Insulated-gate bipolar transistor), as well as the MOSFET (metal-oxide-semiconductor field-effect transistor). As suggested by the names, they comprise of transistors that have gates used in controlling the switch [48].

3.6.2 Three phase diode rectifier

The rectifier is used to convert power from AC power to DC power, the AC-DC rectifier is connected directly to three-phase generator. For full rectification for three phases a total of six diodes are needed, two for each phase as shown in Figure 3.12 [1]. Three-phase diode rectifiers are usually applied for high-power applications. It is very effective and popular wherever both DC-voltage and current requirements are high [49].

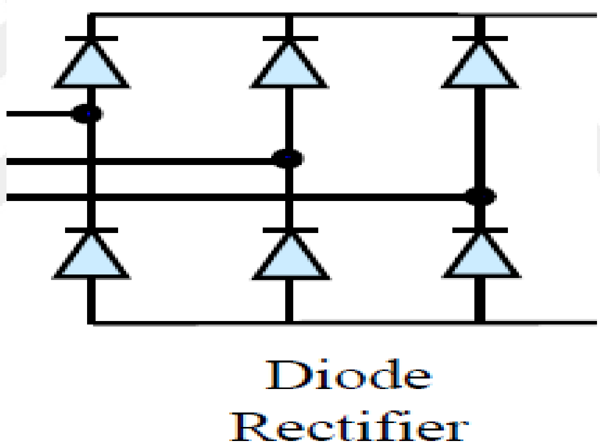

Figure 3.12 Three phase diode rectifier

3.6.3 Inverter (IGBT Controlled by PWM)

Inverters usually have the opposite purpose of a rectifier, which entails converting DC to AC. Since the inverter is meant to make a sine or s square wave from DC, and thus it cannot consist only of diodes, but rather transistor or Thyristors have to be used. The typical components that are used in inverters are the IGBT

(Insulated-gate bipolar transistor) and also the MOSFET (metal-oxide semiconductor field-effect transistor). As suggested by their names, inverter consists of a combination with gates that control switch.

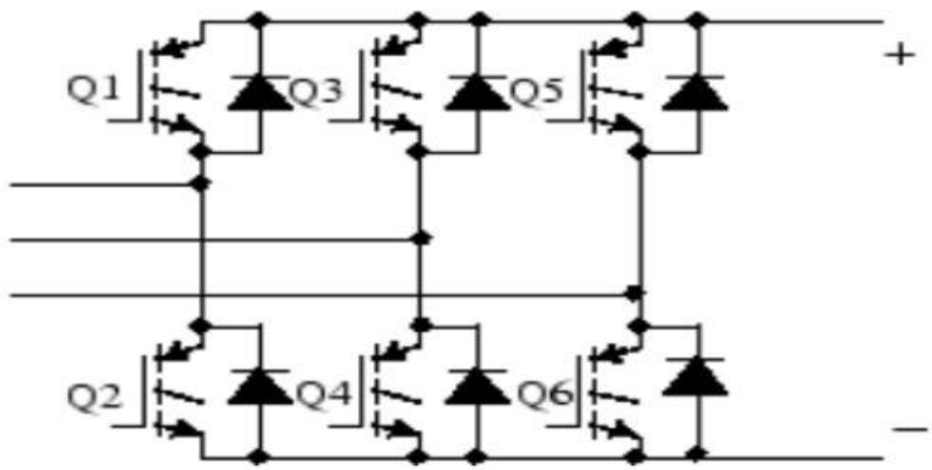

Figure 3.13 Three phase bridge inverter using IGBT

The Figure above shows a three phase bridge inverter using IGBTs. In the gates enable ignition and drainage of transistors that allows the output frequency and amplitude, which is a wide interval depending on their application. As compared to the MOSFET, inverter that uses IGBT produces a rather smoother output signal as it has the capability of switching faster, and thus, its dominating component within a low voltage [48].

3.7 Electrical Grid

Electrical grid can be described as an interconnected network that is used to deliver electricity from suppliers to consumers. Electrical grid comprises of generating stations that are used to produce electrical power, transmission lines with high voltage that carry power over long distance to demand centers, as well as distribution lines used in connecting individual customers. The location of power station greatly varies as they may be located at a dam site, near a fuel source, or utilize renewable sources of energy, and they are commonly located in areas which are not densely populated. Also, they are typically large such that they take advantage of scale of economies. It is essential to note that the electric power generated is usually stepped up to a relatively high voltage, which is then connected to the network of electric power transmission. It is the bulk power transmission network that is used for moving electric power over long distances. The power grid is shown in Figure 3.14 [51] thus an electrical system that provided the electrical connection between producers and the consumers [50].

Figure 3.14 Power Grids

3.7.1 Modeling Electric Grid

Modeling the grid is necessary for analyzing its interaction with other components. The main infrastructure in this case is the grid, which is used to deliver electricity. Thus, reduction of burden can be done by integrating renewable energy, storage, and sophisticated technologies of both communicating and monitoring. Hence, the modeling of the grid is essential as it offers insight regarding the electricity amount that is required in a given supply and demand [52].

Electric Generation Costs

The cost of generating electricity includes the capital cost, the financing charges, and the production or operating costs (including fuel and maintenance of the technology) at the point of connection to an electrical load or the electricity grid. When determining what new plant to build, a utility company will compare all these costs across the slate of available generating units. Once the capital and finance costs are paid, usually after 20 to 30 years, the cost of operation is just the fuel and maintenance costs. As a result, the generating costs for a plant paying sizable capital costs are much different from those for a plant where those costs have been totally paid.

Costs Analysis in hybrid power system

When hybrid power systems are installing to areas, the cost of the system importantly matters to the customers, The system cost accounts for capital, replacement, operational& maintenance and fuel. The lifetime cost of a power system includes

- Capital costs of the system .
- Operation& Maintenance (O&M) costs of the system through its life.
- Fuel cost of the system through its lifetime
- Replacement costs of the system through its lifetime[34].

The capital cost of components: It is the total installed cost deployed to purchase and install the component at the commencement of the project.

O&M cost: It is the cost accounted for maintenance and operation of the system.

Replacement cost: This is the cost required to replace wear out components at the end of its life cycle.

Fuel cost: : It is the cost for fuel of the system during operation.

The basic factor in the strategy industrial project is the cost, divided by two types; capital cost and running(operating)cost, capital cost include design, construction and implementation of the project but the operating cost is the cost after finishing the project. The operating and capital cost are different from country to another country. Cost increases with increase in load for all the systems and this may be due to use of higher sizes of system configurations for higher loads.

Table3.1 shows assuming summary of each variety of the cost system expressed in U.S. dollars, the cost of each system, sizing of the equipments that are used of Photovoltaic(100Kw), wind turbine(10Kw) and diesel generator(100Kw), as well as the value of Capital cost, Replacement Cost, Operation and maintenance cost and Fuel cost of the system. Cost Type ($) and Cost breakdown of Components are shwon in Figures 3.15 - 3.16 [5].

Table 3.1 Summary of various costs related to the wind- PV- diesel hybrid power system.

Hybrid system sources	Capital Cost ($)	Replacement Cost ($)	O&M Cost($)	Fuel Cost ($)	Total Cost($)
PV	278400	0	32630	0	311030
Wind Turbine	540000	97682	125859	0	763541
Diesel	45000	16470	7070	575107	643647

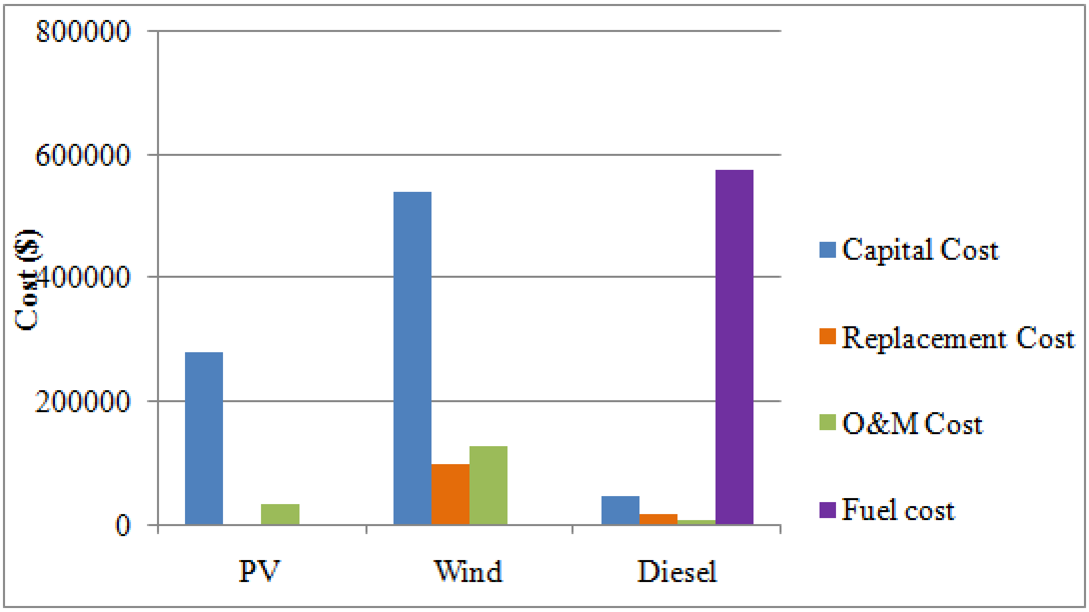

Figure 3.15 Cost Type ($) by Components

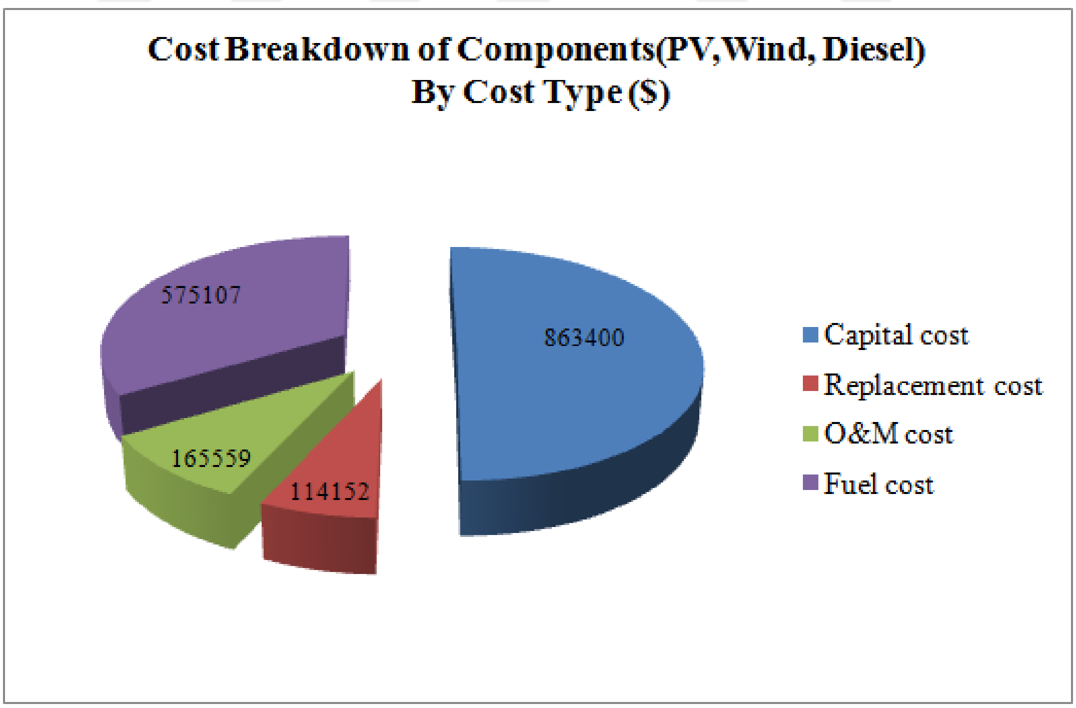

Figure 3.16 Cost breakdown of Components(PV, Wind, diesel) by Cost Type($)

CHAPTER4

HYBRID POWER SYSTEM MODELING SIMULATION AND RESULTS

4.1 Introduction

System modeling and simulation are fundamental part to optimize control and enhance system operations in power applications and system design. in this chapter simulation model is described in a hybrid power system comprises of photovoltaic(PV) panels, wind turbine biased permanent magnet synchronous generator(PMSG), diesel generator, grid, inverter, rectifier and control strategy . The control strategy is used to ensure the continuous power supply for the load demand and a case study is presented . Moreover the simulation results of the proposed hybrid system are presented and discussed by considering a case study of the operation.

4.2 Modeling photovoltaic (PV) Module

The PV module consists of 40 parallel strings and each of them consists of 10 series connected module of the 1Soltech 1STH-215-P solar panel provided by 1Soltech and in each module there are 60 cells. The solar photovoltaic array is being operated at a constant irradiance of 1000 W/m2 and solar photovoltaic panels are tested at 25^0c as shown in Figure 4.1.

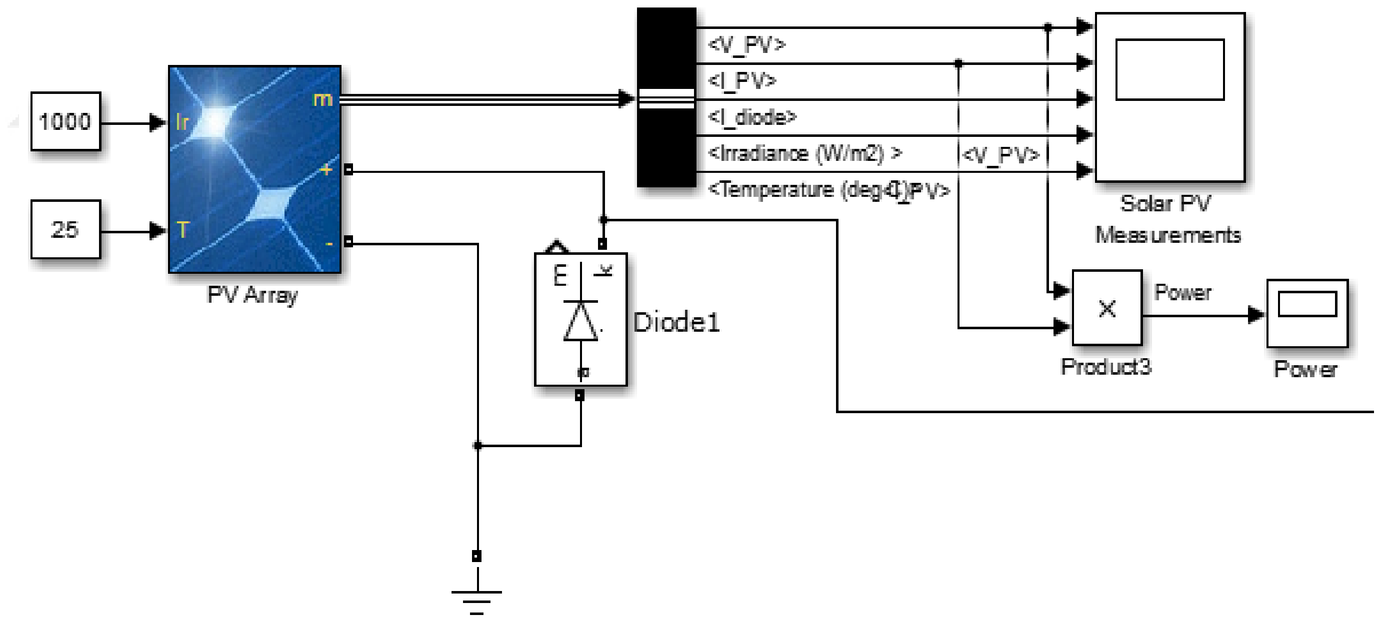

Figure 4.1 Solar PV model in Simulink

The model is developed based on the value of used parameters in the PV modeling are presented in Table 4.1 and Table 4.2. Figure 4.2 shows subsystem of the PV model from [53].

Table 4.1 Specification of 1Soltech 1STH-215-P

Electrical Characteristics	**1Soltech 1STH-215-P**
Maximum Power (w)	213.15
Cells per module (Ncell)	60
Open Circuit Voltage, VOC (V)	36.3
Voltage at maximum power point Vmp (V)	29
Current at maximum power point Imp (A)	7.35
Short Circuit Current, ISC (A)	7.84
Series cells number (NS)	10
Parallel cells number (NP)	40
Temperature coefficient of Voc (%/deg.C)	-0.36099
Temperature coefficient of Isc (%/deg.C)	0.102

Table 4.2 Parameters of PV model

Parameters	**Values**
Light-generated current IL (A)	7.8649
Diode saturation current Is (A	2.9259e-10
Diode ideality factor	0.98117
Shunt resistance Rsh (ohms)	313.3991
Series resistance Rs (ohms)	0.39383

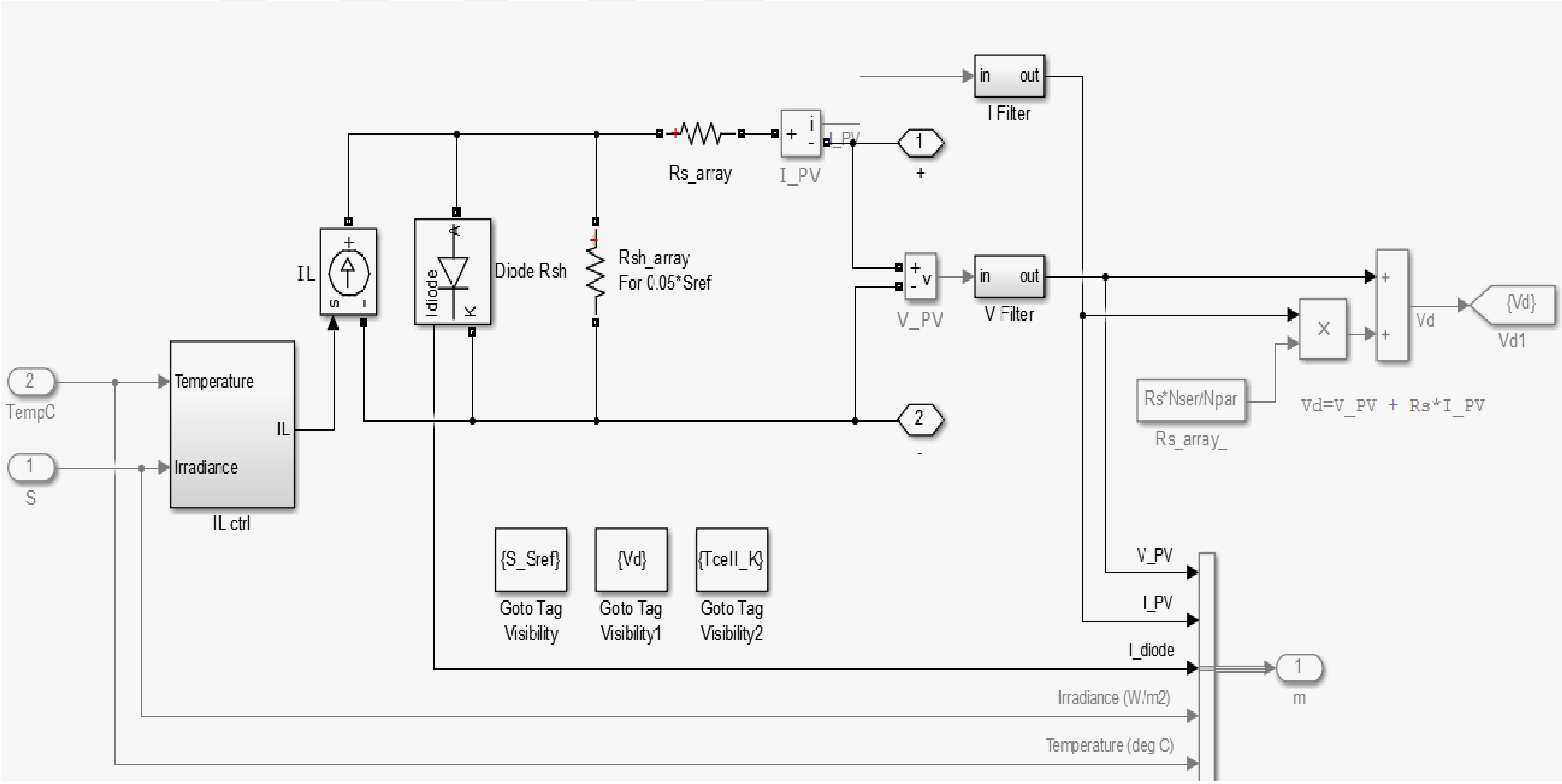

Figure 4.2 Subsystem implementation of the PV model

The solar photovoltaic array is simulated at different temperatures to show the effect of temperature variation on the P-V and I-V characteristics as plotted in the Figure 4.3 from the result of variation of temperature it can be seen in Figure (a) I-V characteristics, as increase the temperature voltage decreases but current remains about unchanged also in Figure (b) shows effect of temperature variation on the P-V characteristics, power generated decreases as temperature increases , because on increment of temperature voltage decreases.

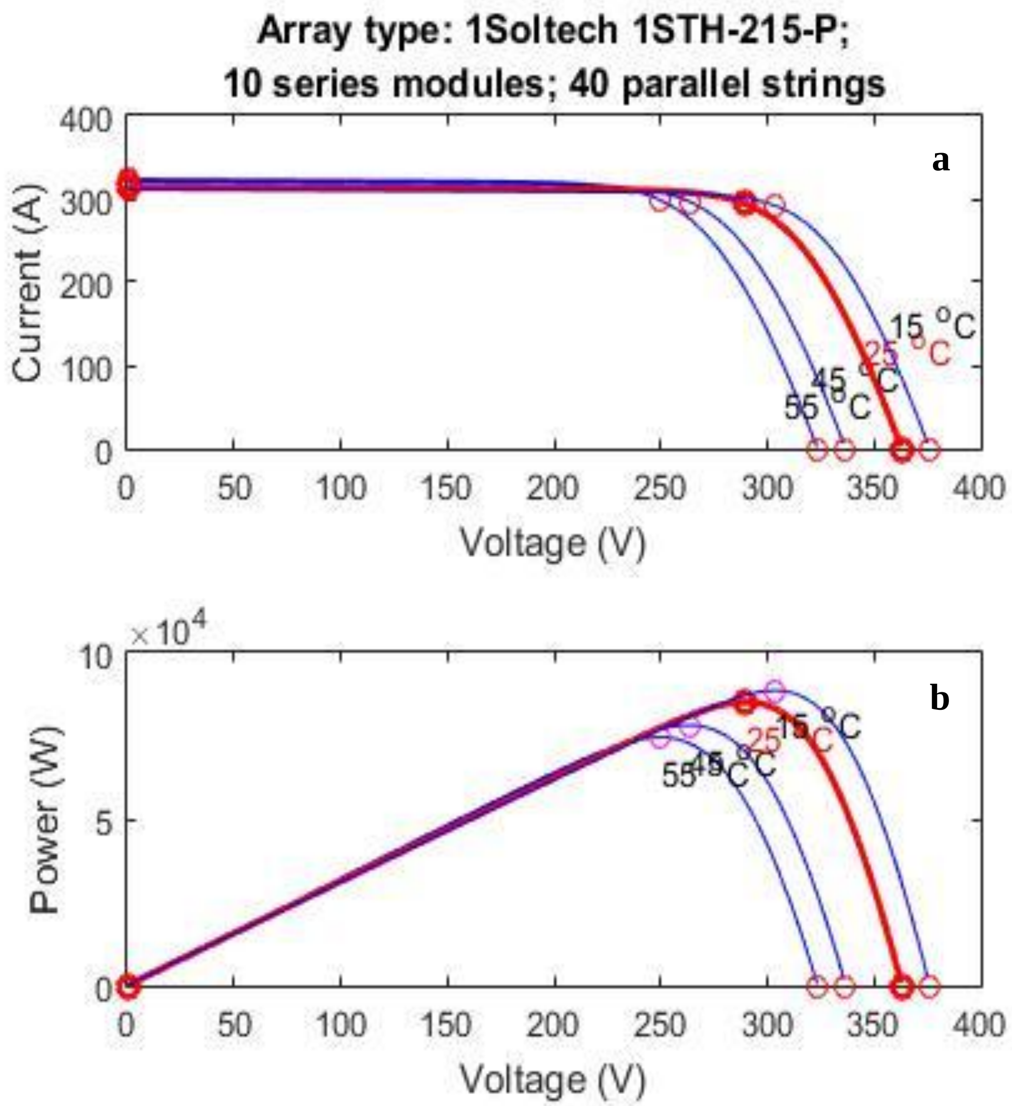

Figure 4.3 Solar PV module characteristics at various temperatures

Figure 4.4 depicts the maximum power operating point at different irradiance values. I-V and P-V characteristics are affected by variation of irradiation are presented respectively. Variation in Solar irradiation impacts, especially on current as shows in (a), as increase solar irradiation current increases, but effects on voltage is very low. Also on P-V characteristics is shown in (b), as solar irradiation increases, power generated increases, increment in power is fundamentally due to increases in current.

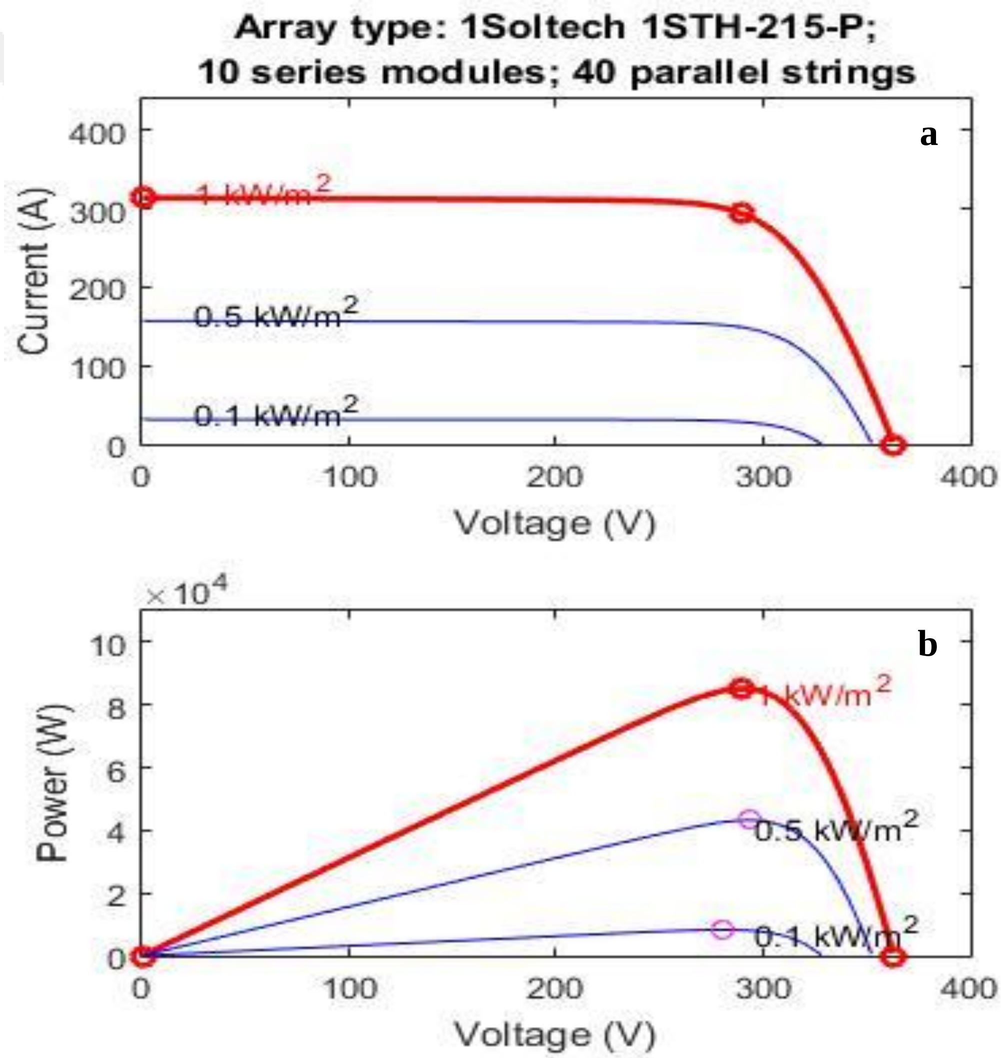

Figure 4.4 Maximum power produced by solar PV array

4.3 Modeling of Wind Turbine

The model of wind system is based on the steady-state power characteristics of the wind turbine is shown in Figure 4.5 is taken from [53]. The hardness of the drive train is infinite ,the friction factor and the inertia of the turbine must be jointed with those of the generator coupled to the turbine.

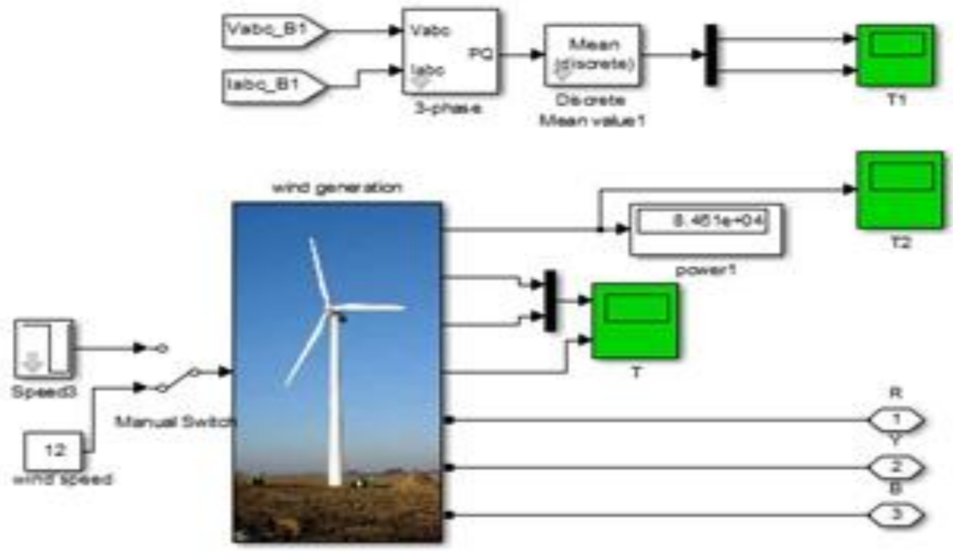

Figure 4.5 Wind power generation model in Simulink

Table 4.3 Parameters of wind turbine

Parameters	**Values**
Nominal mechanical output power (w)	8.5e3
Base power of the electrical generator (VA)	8.5e3/0.9
Base wind speed (m/s)	12
Maximum power at base wind speed (pu of nominal mechanical power)	0.8
Base rotational speed (p.u. Of base generator speed)	1
Pitch angle beta to display wind-turbine power characteristics (beta >=0) (deg)	0

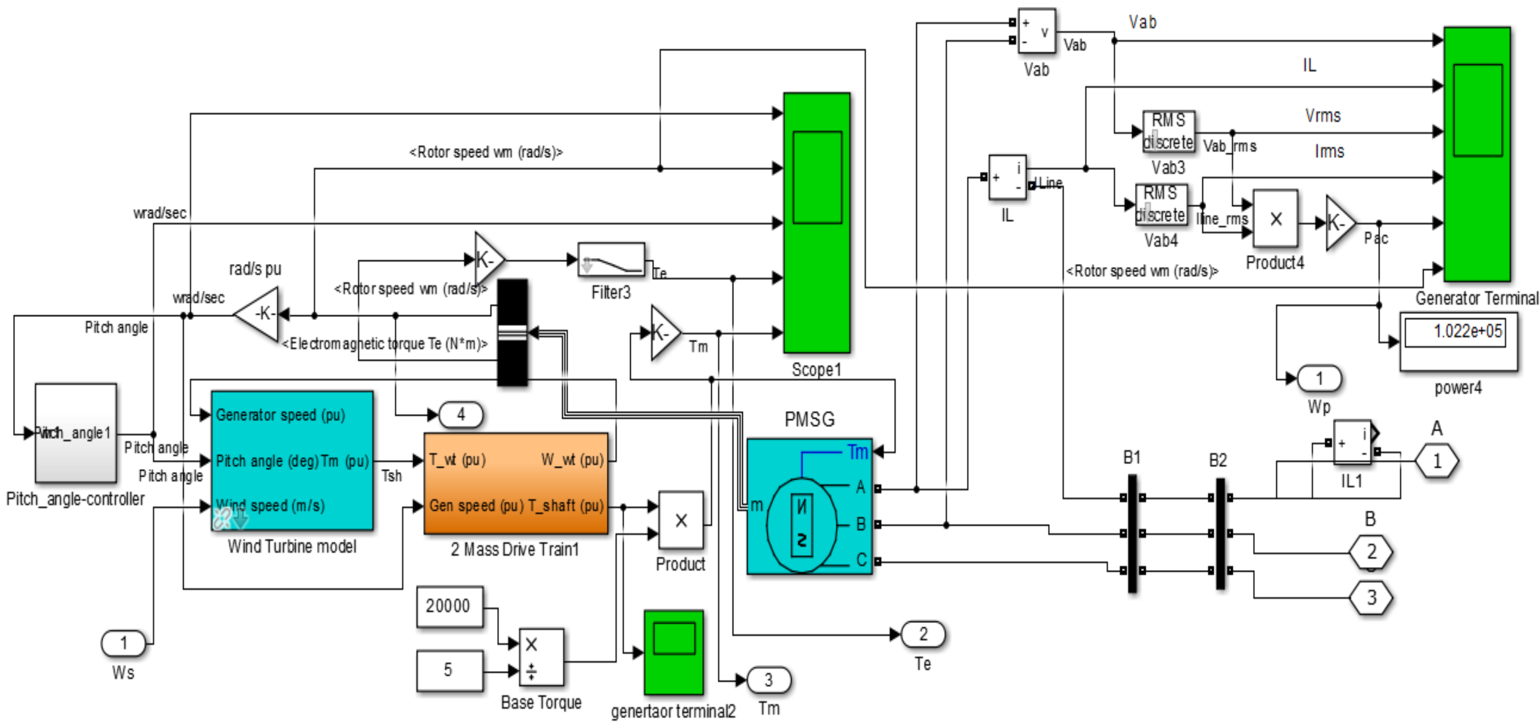

Figure 4.6 Wind Turbine and PMSG Connection model in Simulink

The Wind turbine and PMSG models in the Figure 4.6 are from math works, 2-mass model based wind turbine is used in this system for providing mechanical torque/input to Permanent Magnet Synchronous Generator. 3-phase power generated from this system, changing wind velocity is also presented in this model [54].

Figure 4.7 presents wind power characteristics model at different wind speed is taken from [53]. It can be observed that the output power of the turbine is increased with increasing the speed of the wind. Maximum power could be extracted when the wind turbine speed can keep track of the wind speed changes, when speed of wind is 12m/s, maximum power is obtained the turbine speed is at 1 per unit.

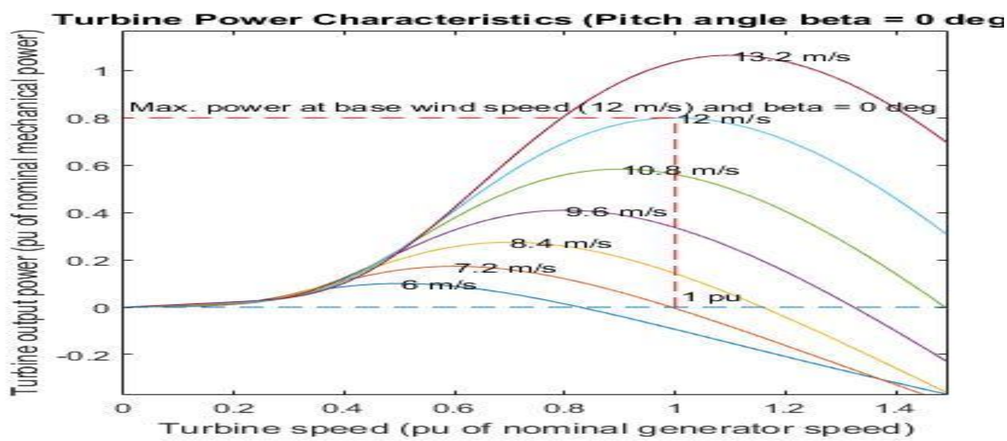

Figure 4.7 Wind power Characteristics model in Simulink

Table 4.4 parameters of permanent magnet synchronous generators

Parameters	**Values**
Stator phase resistance Rs (ohm)	0.425
Armature inductance (H)	0.000395
Specif	Flux linkage established by magnets(v.s)
Flux linkage	0.433
Inertia, viscous damping, pole pairs, static friction [J(kg.m^2) F(N.m.s) p() Tf(N.m)	[0.01197 0.001189 5]
Initial conditions [wm(rad/s) the tam(deg) ia,ib(A)]	[0,0, 0,0]

4.4 Modeling of Battery

Nickel-Metal-Hydride battery is being used to store the power generated by renewable sources as solar PV and wind generator [55]. Battery system Model in Simulink is shown in Figure 4.8 and Figure 4.9 subsystem is taken from [53]. The stored power into battery further being used to meet the load demands use of ultra-capacitor can improve the overall system efficiency and reliability. The DC power is converted into AC power through an inverter before reaching the load.

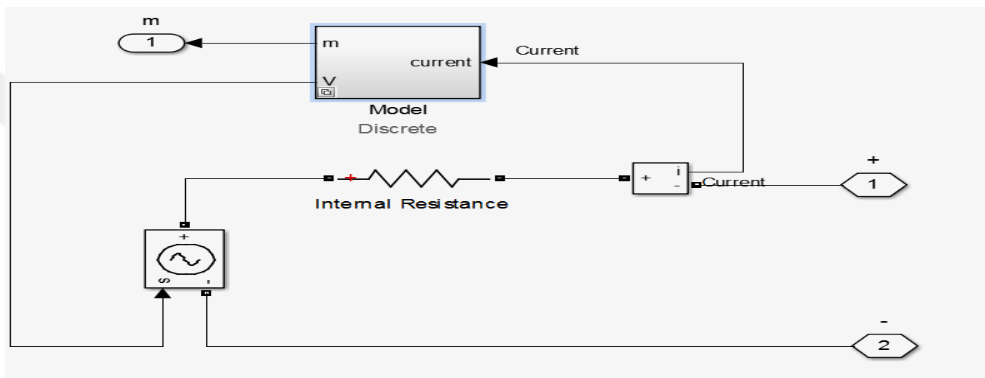

Figure 4.8 Battery system Model in Simulink

Table 4.5 parameter's Battery model

Type of battery	**Nickel-Metal-Hydride**
Nominal Voltage (V)	250
Rated Capacity (Ah)	6.5
Initial State-Of-Charge (%	10
Maximum Capacity (Ah)	7
Fully Charged Voltage (V)	294.4915
Nominal Discharge Current (A)	1.3
Internal Resistance (Ohms)	0.38462
Capacity (Ah) @ Nominal Voltage	6.25
Exponential zone [Voltage (V), Capacity (Ah)]	[271. 186 1.3]

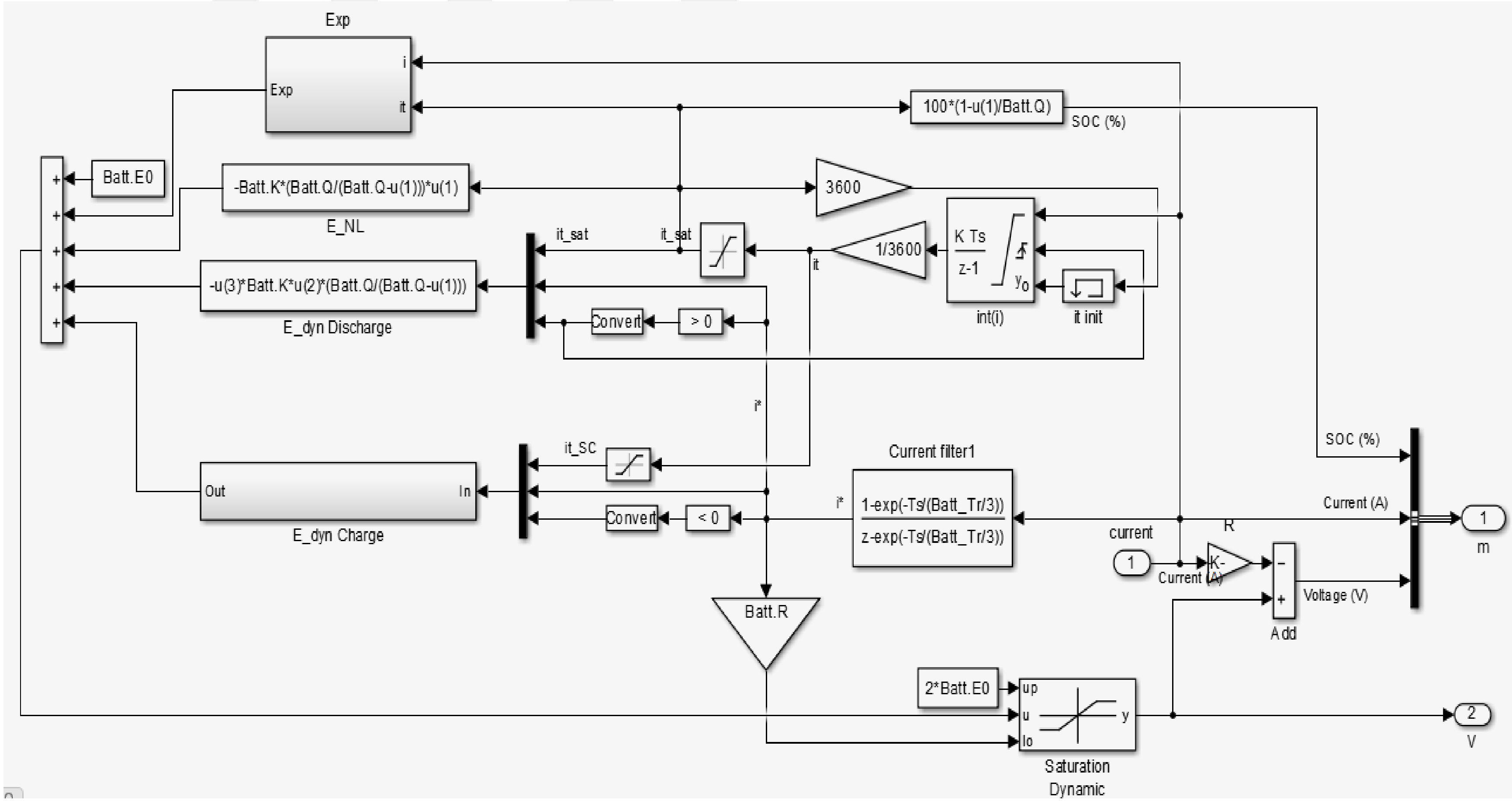

Figure 4.9 Subsystem of the Nickel-Metal-Hydride battery model

The battery characteristics are shown in the Figures 4.10 - 4.11 below from [53].

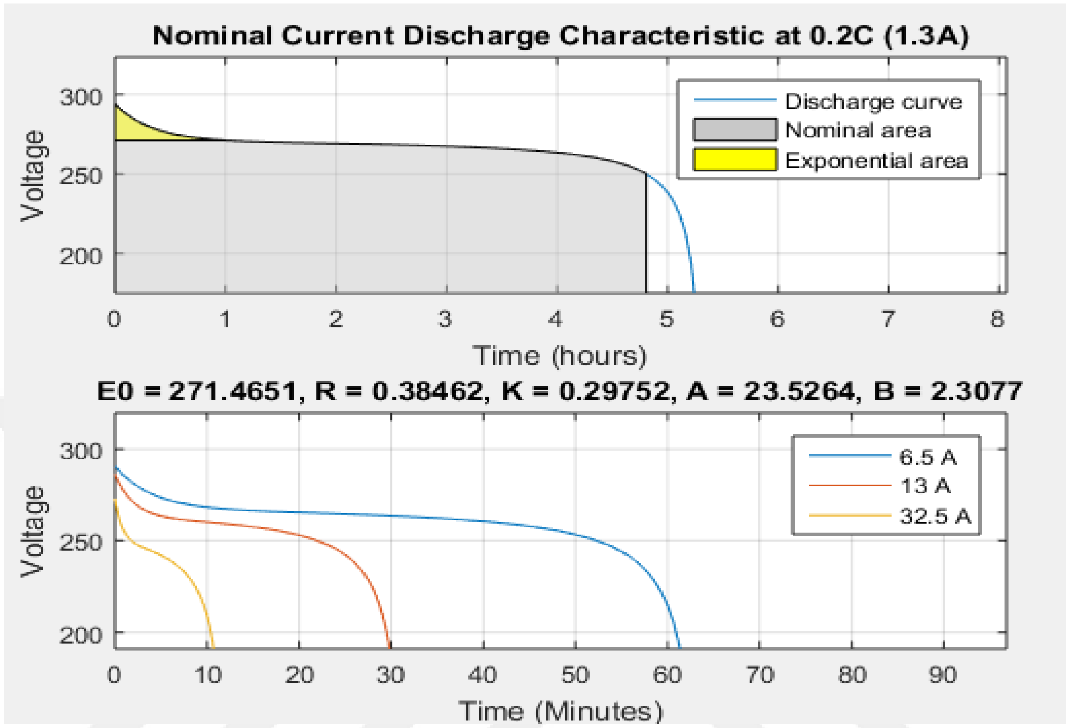

Figure 4.10 Battery discharge characteristics plotted against time

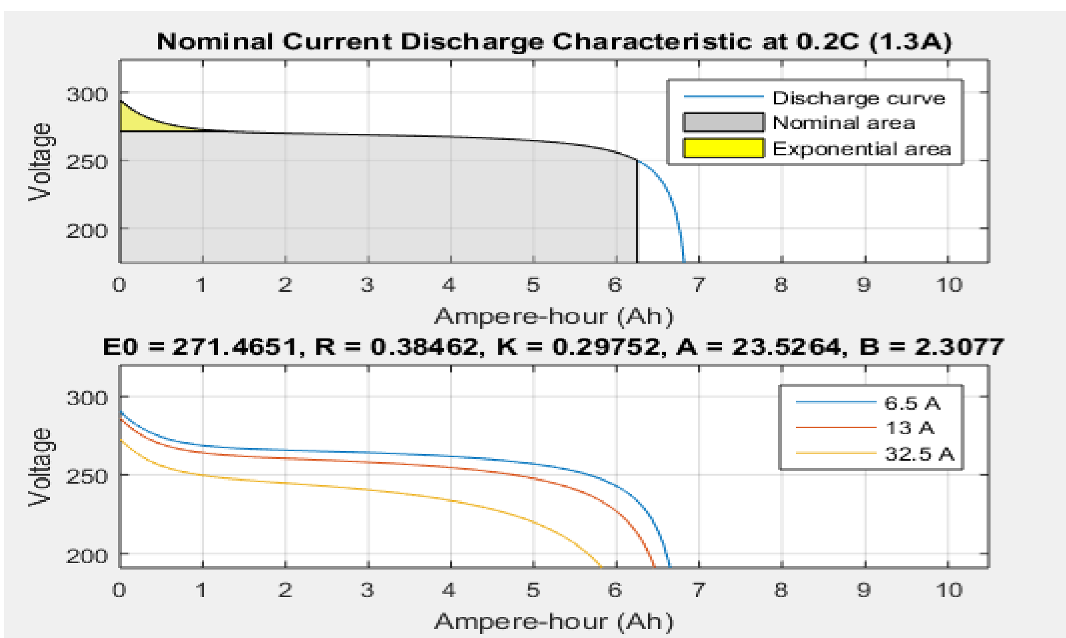

Figure 4.11 Battery discharge characteristics plotted against Amp-hour

4.5 Modeling of Diesel Generator

A diesel power system is considered for emergency situations. A synchronous machine of 3.125 MVA connected with the diesel engine governor is generating 3 phase AC power. An excitation system is providing the DC voltage to the field winding of synchronous machine [56]. Figure 4.12 and Figure 4.13 show diesel generation simulink model diesel engine with the governor control Simulink model is taken from [53].

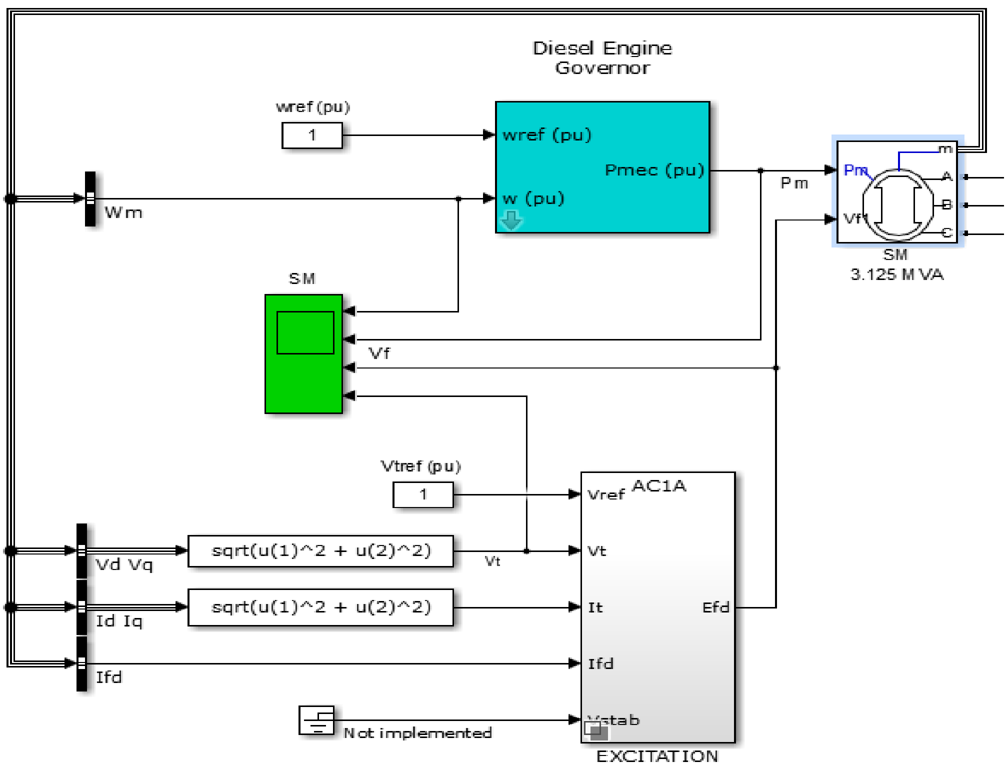

Figure 4.12 Diesel generation Simulink model

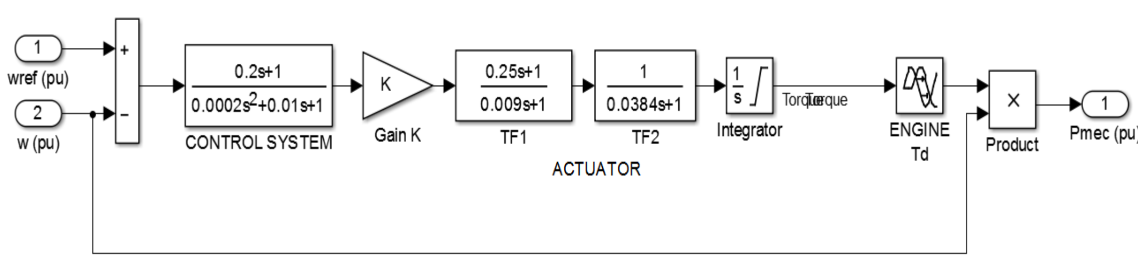

Figure 4.13 Diesel engine with governor control system model

4.6 Modeling of Grid

The utility grid is usually modeled as a three phase voltage source connected to the system through a transformer. This simplified model is only used for the proposed systems.

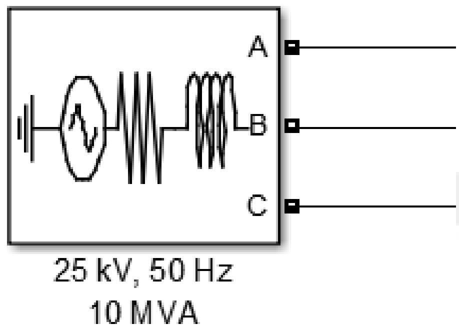

Figure 4.14 25kV Grid model in Simulink

Table 4.6 Block parameters: 25KV, 50Hz 10MVA

Three-phase source (mask)(link) **Three-phase voltage source in series with RL branch**	
Phase-to-phase rms voltage (V):	25e3
Phase angle of phase A (degrees):	0
Frequency (Hz):	50
Internal connection:	Yg
Specify impedance using short circuit level	
3-phase short-circuit level at base voltage(VA):	10e6
Base voltage (Vrms ph-ph):	25e3
X/R ratio	7

4.7 Modeling of Inverter

The model of an IGBT inverter is controlled by pulse width modulation (PWM) is shown in Figure 4.15, which is used to change the DC power into AC power. A voltage regulator along with a LC Filter is being used as the input to PWM generator. DC/AC inverter acts as an interface between the power sources and the loads to provide the required power to the load by regulating the AC output voltage .

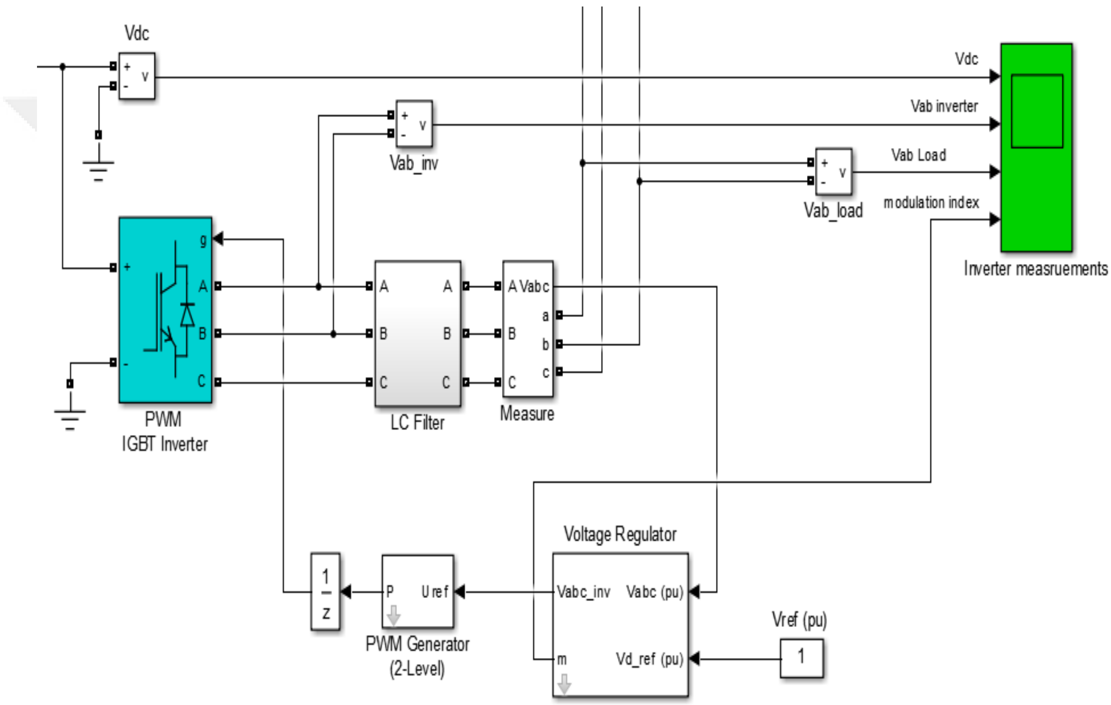

Figure 4.15 Inverter model

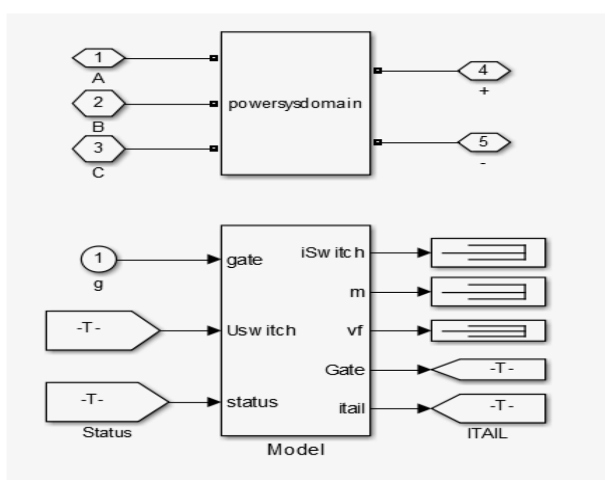

Figure 4.16 PWM IGBT inverter subsystem model

4.8 Modeling of Rectifier

Rectifier converts AC power to DC power, the rectifier is directly connected to the three-phase generator of wind turbines. A 3-phase diode bridge circuit is the simplest type of rectifier utilizes to convert AC power to DC power. The parameters are used in this model is in Table 4.7.

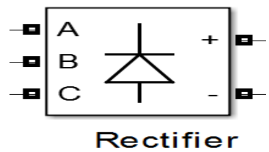

Figure 4.17 Rectifier model

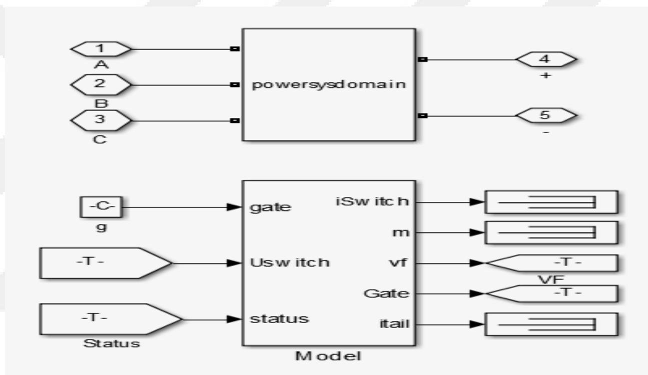

Figure 4.18 Subsystem model of rectifier

Table 4.7 parameters of rectifier model

Parameters	Values
Number of bridge arms	3
Snubber resistance Rs (Ohms)	10e3
Snubber capacitance Cs (F)	20e-9
Power Electronic device	Diodes
Ron (Ohms)	1e-3
Lon (H)	0
Forward voltage Vf (V)	1.3
Measurements	All voltages and currents

4.9 Loads

The system includes three loads modelled are shown in Figure 4.19, load1(50Kw) is always connected to the system, load2 (100Kw) and load3 (3.125Mw) availability is to be controlled manually.

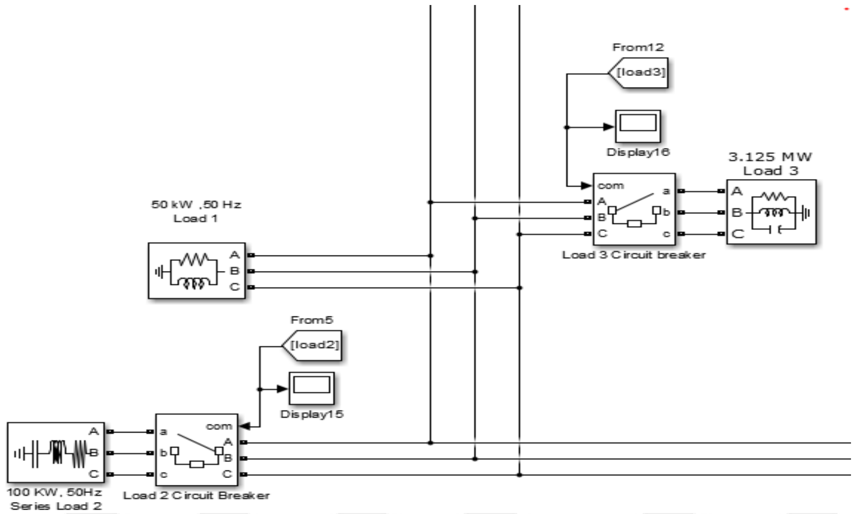

Figure 4.19 Three phase load modeled

4.10 Control Strategy

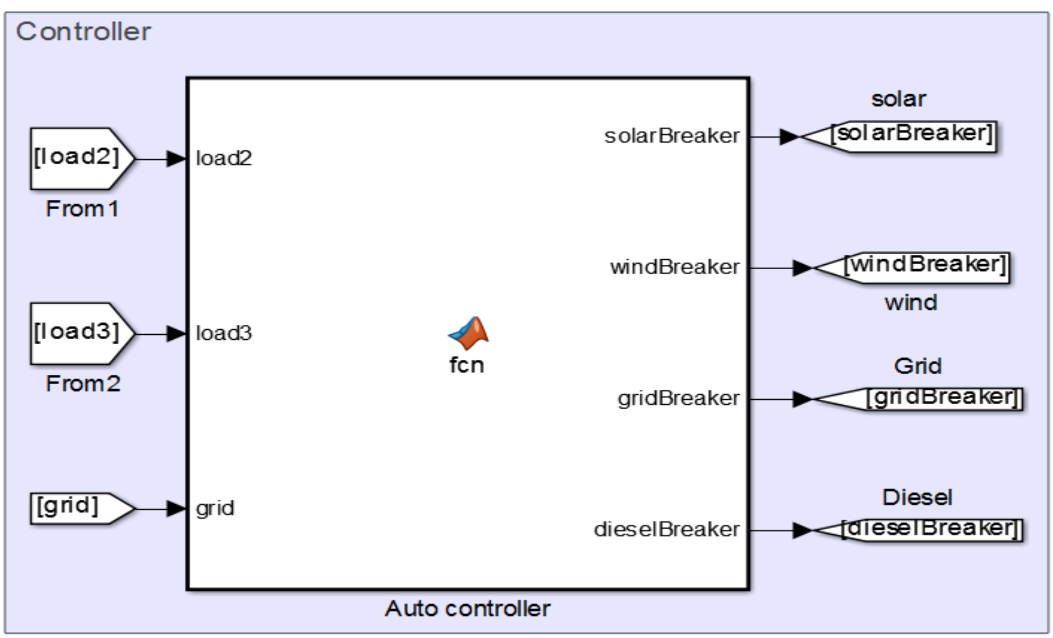

Figure 4.20 Block control strategy

A simple load based control strategy is adopted for studying this model is shown in Figure 4.20. Based on the switching the loads, power supply sources are automated. The model has the flexibility to make grid supply on or off. Out of three loads, load 2 and load 3 can be switched on or off manually. Based on the load switching selection, the control algorithm will decide the power sources to be used to meet the load demand. It is noted that, power produced by solar PV and wind turbine are considered to be available all the time. Figure 4.21 shows the user operation and power sources status panel of the model. Table 4.8 represents supply control strategy and energy management, Flowchart of simulation hybrid power system sources HPSS is shown in Figure 4.22.

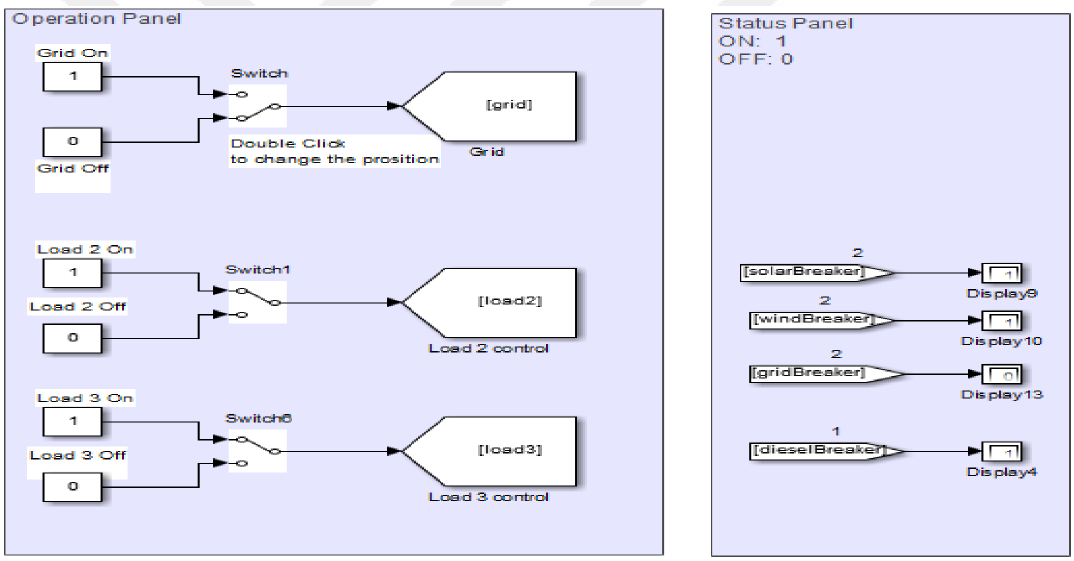

Figure 4.21 User operation and power sources status panel

Table 4.8 supply control strategy and energy management

Only one Load(50Kw)	Load (50+100)Kw	Load (50Kw+100Kw+3.125Mw)	
		Grid available	
		Yes	NO
Solar ON Wind OFF Grid OFF Diesel OFF	Solar ON Wind ON Grid OFF Diesel OFF	Solar ON Wind ON Grid ON Diesel OFF	Solar ON Wind ON Grid OFF Diesel ON

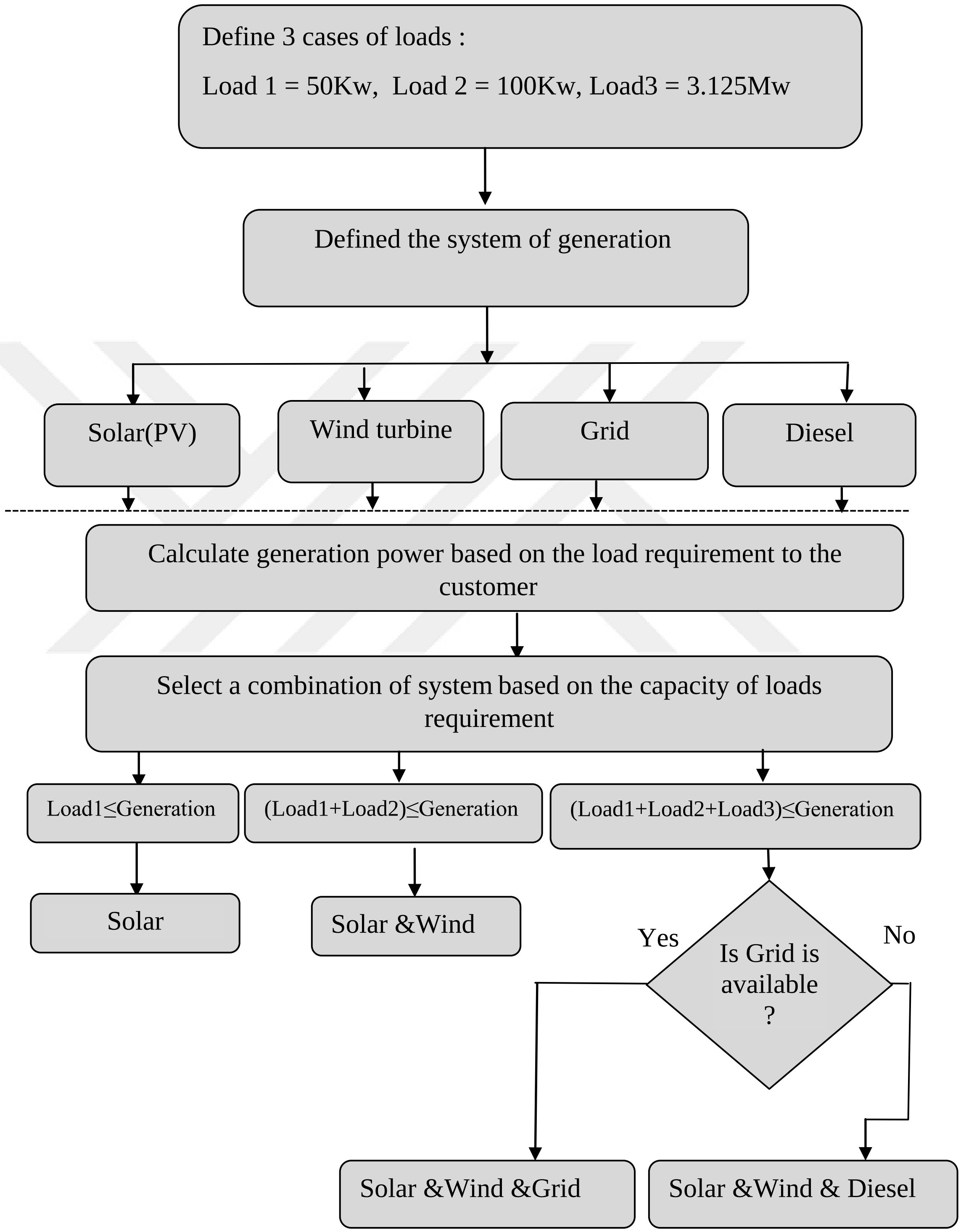

Figure 4.22 Flowchart of simulation hybrid power system sources HPSS

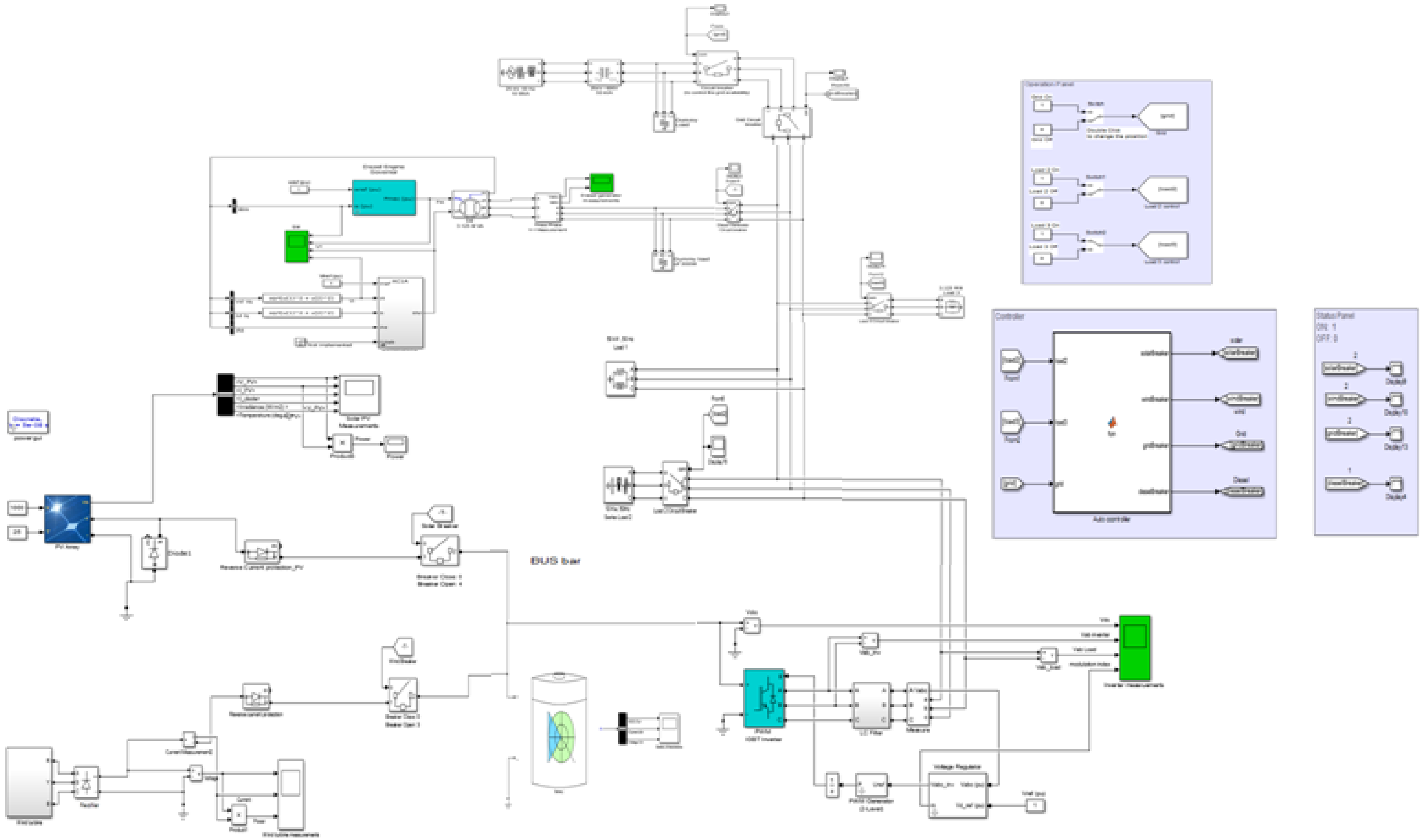

Figure 4.23 Simulation model hybrid power system sources

4.11 Results and Discussions

In this section 3 cases of phase load variation are studied and considered according to usage of sources, then the control algorithm will determine the power sources that need to be applied to meet the load demand. The simulation results of the three cases are obtained and explained in the following cases.

A. Case Study One

In the first case study only one load as (50Kw) is connected to the solar system, and wind are available. The generated power by solar is sufficient to supply the load demand and the power produced by wind generation is being used in charging the battery.

B. Case Study Two

In the second case study a 100Kw local AC load is applied to the system to the load of (50Kw).These loads are supplied by both the sources of solar and wind turbine.

C. Case Study Three

In a third case three loads of (50Kw,100Kw and 3.125Mw) are connected to the system. In this case solar and wind generation are not sufficient to supply the load demand, so the system need to one more power source as a gird or diesel. The diesel is more costly compared to the grid. Control Algorithm checks the status that the grid supply is available or not.

- If the grid is available sufficient to supply the power to the load, in this case three systems (Solar, Wind and Grid) have to run together and offer a stable system to supply the load.
- If the grid supply is not available, then diesel power system is being used as the emergency backup in system, in this case three systems (Solar, Wind and Diesel) have to run together and sufficient to provide the required power to the load.

Simulation Results

The solar power generated is presented in Figure 4.24, the model is tested at 25^0C degree, irradiance is fixed in of 1000 W/m2.

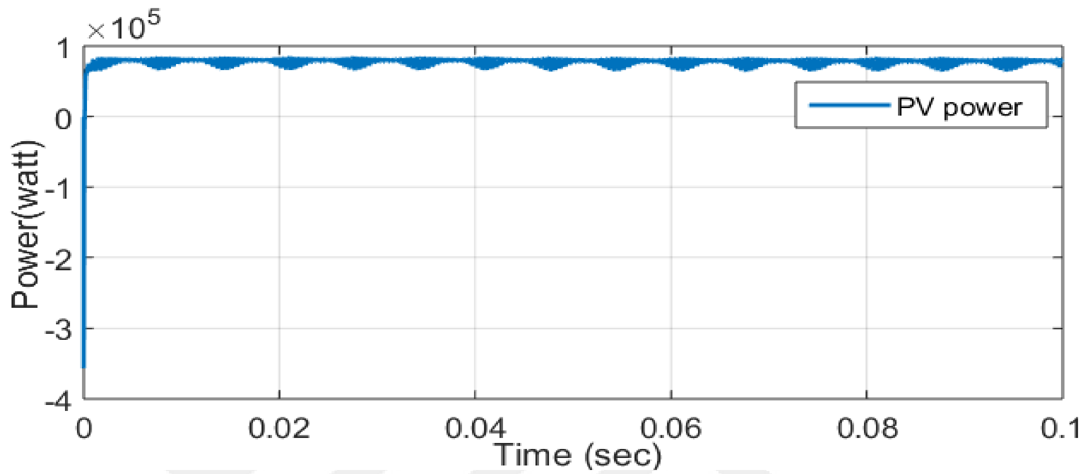

Figure 4.24 Solar output power

The power generation of wind turbine is shown in Figure 4.25 the speed of the wind starts to increase then the wind turbine begins to rotate and the PMSG begins to generate electrical power, with increasing the speed of the wind the generated electrical power is gradually increased, the wind speed reaches and stops increasing, soon after that the system comes to the steady state.

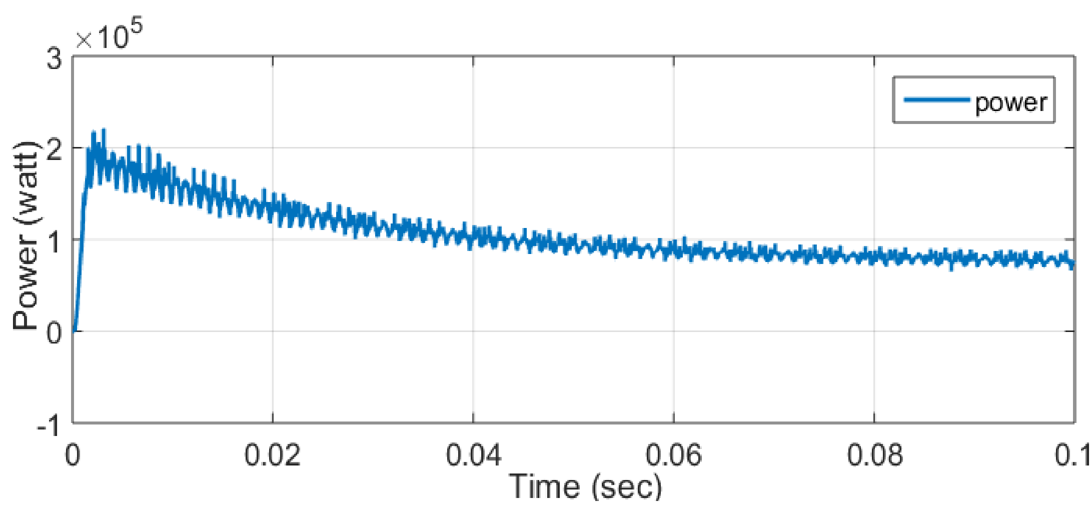

Figure 4.25 Wind output power

The Inverter outputs are shown in Figure 4.26 and 4.27 (inverter output with LC Filter and inverter output without LC Filter).

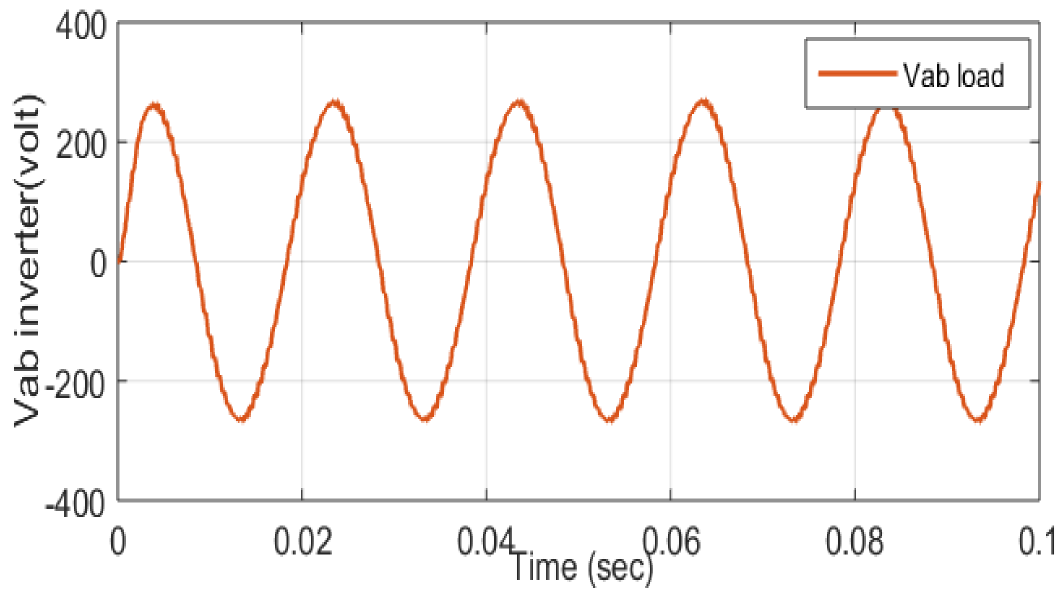

Figure 4.26 Output Inverter with Filter LC

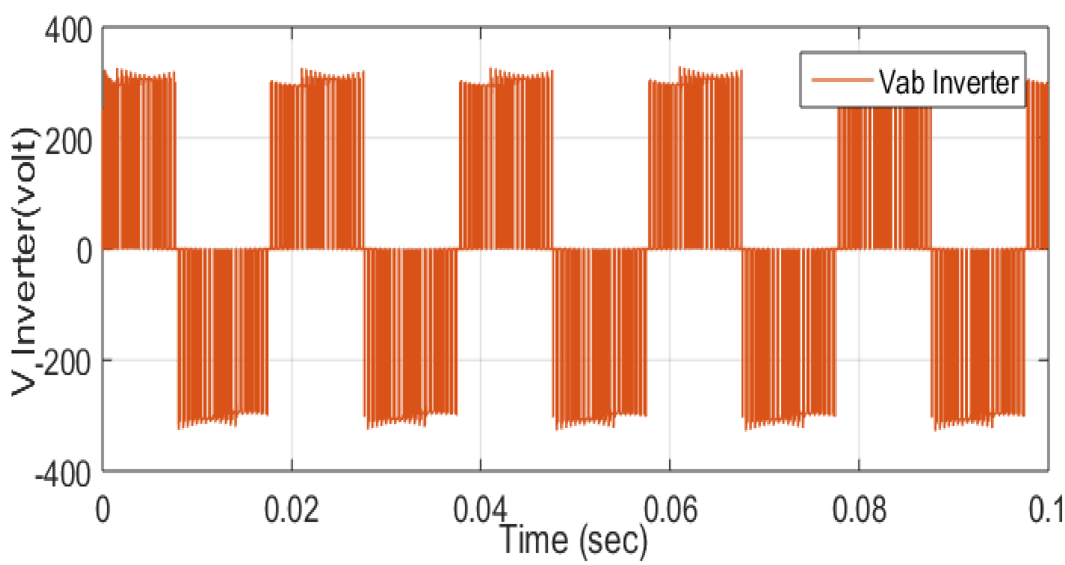

Figure 4.27 Output Inverter without Filter LC

Three phase line outputs of voltage and current diesel generator are shown in Figures (4.28 - 4.30)

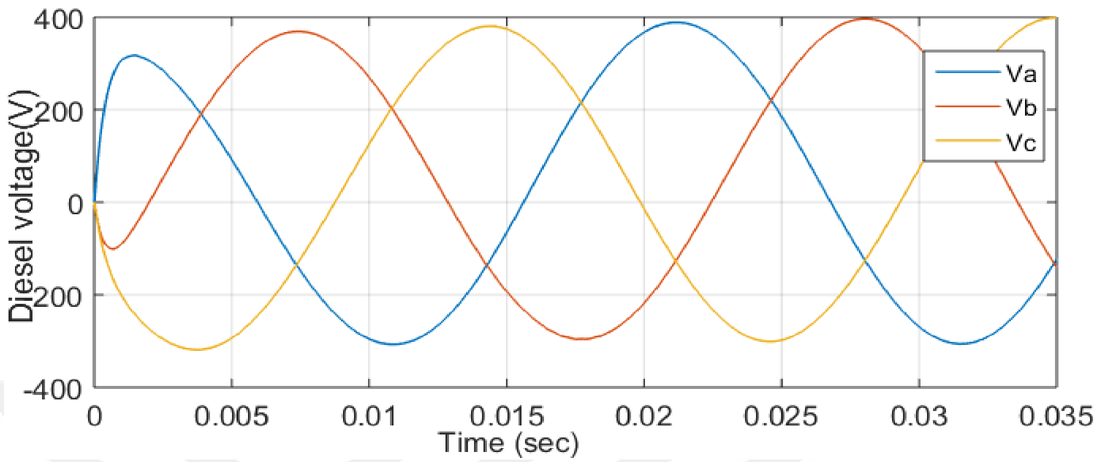

Figure 4.28 Three phase line output of voltage diesel generator

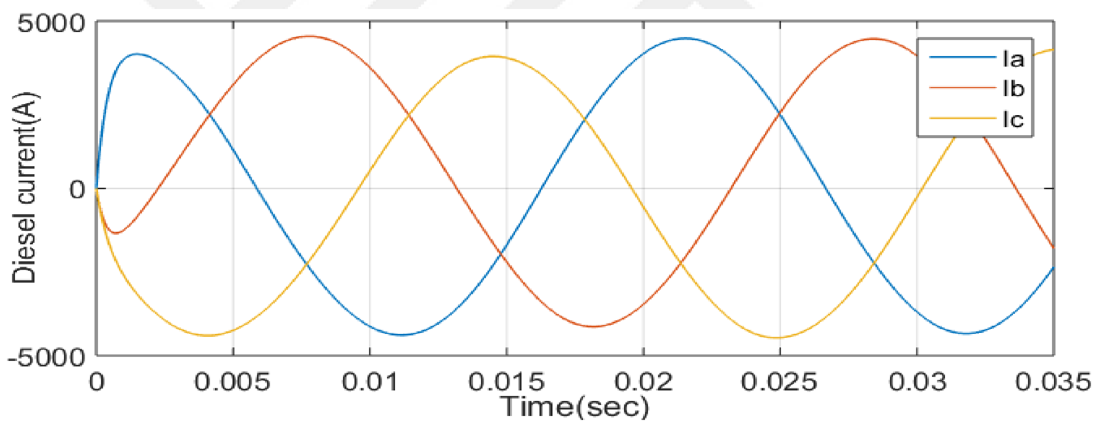

Figure 4.29 Three phase line output of current diesel generator

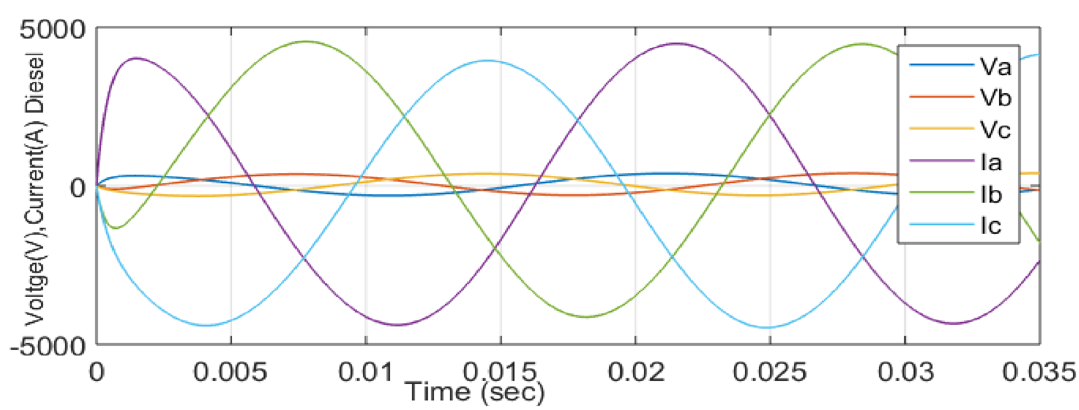

Figure 4.30 Three phase line output of voltage and current diesel generator

Results of Charging battery

Figure 4.31 shows characteristics of battery during charging, the surplus power is being used in charging the battery system and the state of charge (SOC) of battery is increasing which signifies that battery is getting charged. This can be confirmed by the current value which is negative.

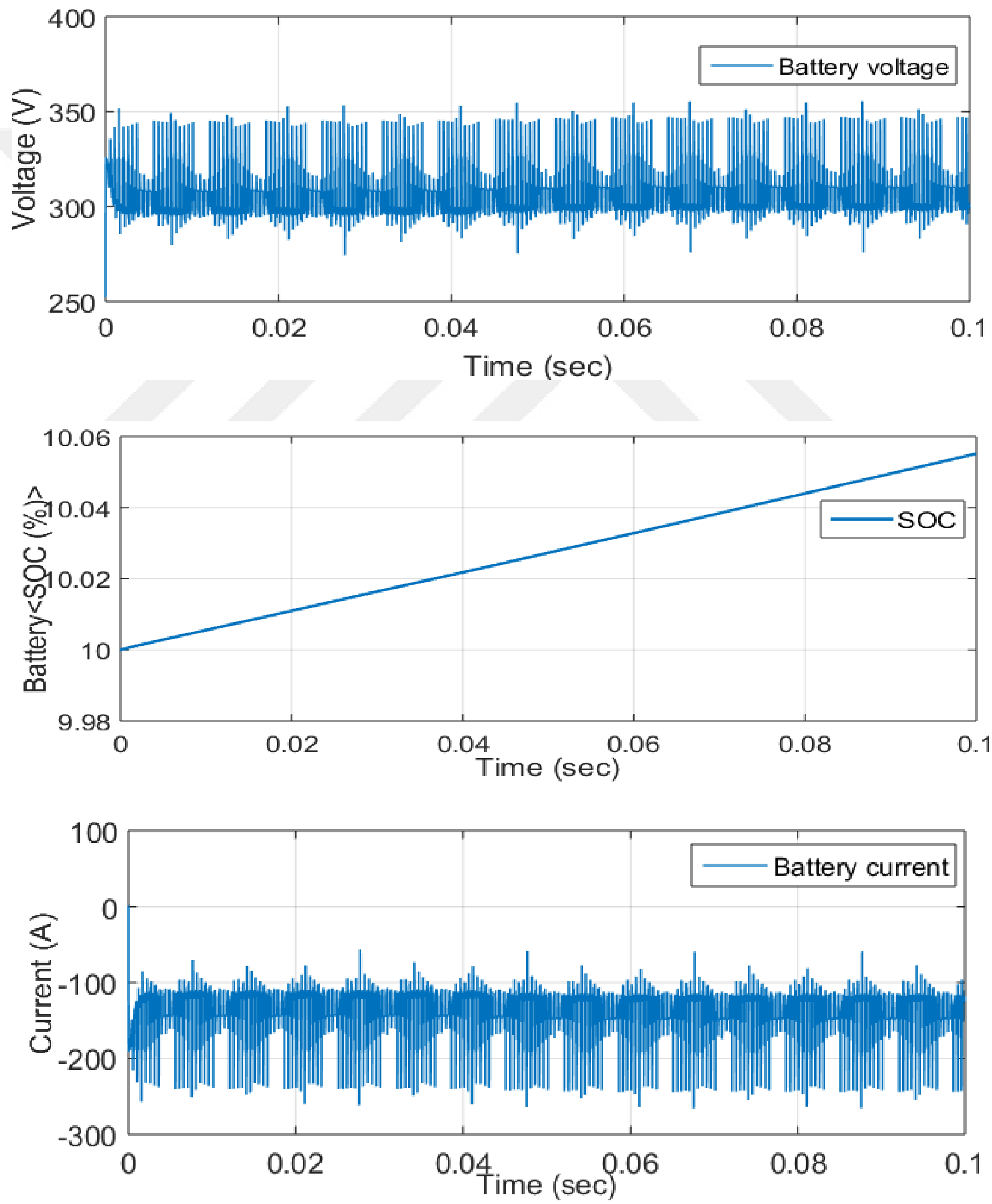

Figure 4.31 charging characteristics of battery

results of discharging battery

Figure 4.32 shows characteristics of battery during discharging, the battery starts to supply constant voltage and state of charge(SOC) is decreasing also the current become positive which is supplying the power to the load.

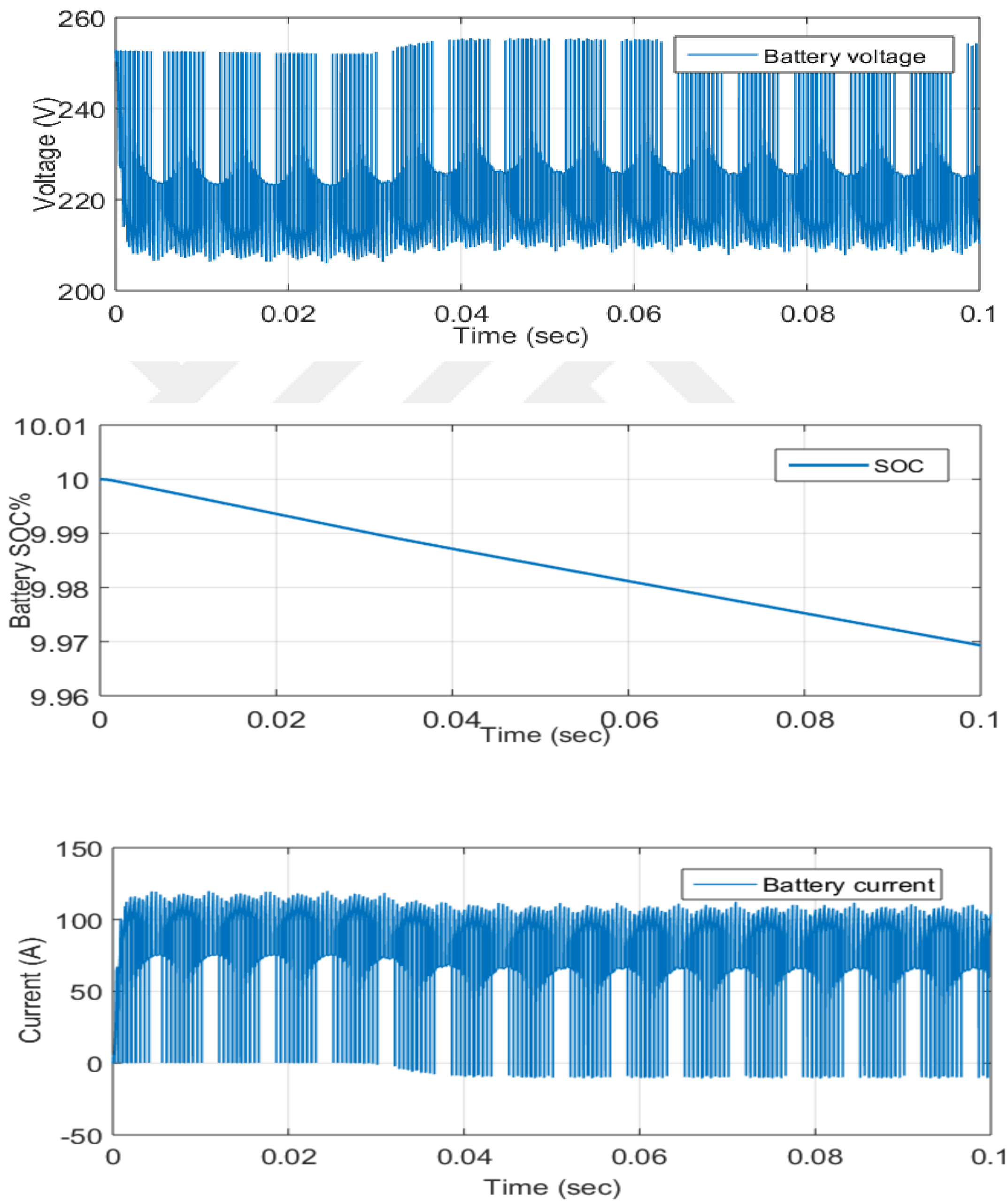

Figure 4.32 Discharging characteristics of battery

CHAPTER 5

CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORKS

5.1 Introduction

This chapter reviews the significant results obtained from proposed model of the hybrid power system sources with the grid connected and to make recommendations and suggestions for future research.

5.2 Conclusion

- This project investigated the model of hybrid power system sources by connecting different generation systems that consist of renewable energy (photovoltaic (PV), wind turbine based permanent synchronous generator (PMSG), Battery, Diesel generation set power system and the grid which were generated energy for an AC and continuous electric power production to supply the load requirement.

- The components of the hybrid power systems have been modeled and implemented using Software Simulink and the results obtained from the simulation was presented and discussed.

- A control strategy was adopted for studying this model of hybrid power systems. The proposed management system was used in order to satisfy the load requirements basis of low cost of kWh energy, maximum availability and to improve the reliability of hybrid operation.

- This work dealt with the operation and control of a diesel and grid connected hybrid power system as auxiliary sources with the wind, solar energy (PV). If the solar PV and wind generation were not sufficient to supply the load demand, so the system need to connect one power source as a gird or diesel.

- Additionally, the control strategy was used for studying this model for energy management and to choose the sources at minimum energy cost to meet the load demand. Once the grid was available with the renewable energy system, the grid was applied as an auxiliary source instead of the diesel generator to supply the load because of diesel generator was the most costly source compared to the grid. Otherwise, when the grid supply was not available, then the diesel power system was used as the emergency or backup source to provide the sufficient required power to the load.

- Photovoltaic (PV) and wind turbine from the renewable energy systems were used to charge a battery through using bi-directional. The battery was used as a storage energy system and the charging/discharging of the battery was controlled between the upper and lower limits.

- Three cases of phase load variation were studied and considered according to usage of sources, then the control algorithm determined the power sources that need to be applied to meet the load demand.

- Also the thesis presented an insight of the various entry and exit conditions of each zone or (quantity of the loads) of operation, thereby it can efficiently switch (by auto control) between different type generating units to meet the demand efficiently

- This system was operated to show the performance of the system with any variations from the load demand.

5.3 Future Work

- Expanding the model by using other renewable sources to get more energy from nature and increasing generating to supply the load demand.
- Improving and developing the control strategy of the system by applying advanced control techniques like fuzzy logic control.
- Implementing advanced control techniques on the system to study and improve the performance of the system by improving the energy management.
- Develop a specific controller with the grid connected hybrid system models to make the balance in the average power, the grid supplied the load in case of power deficit

and when the renewable energy system produced the energy greater than load demand the excess energy goes into the grid.

- Considering the software of the Hybrid Optimization Model for Electric Renewable (HOMER) to calculate the cost of Per kWh to find out the most cost effective system and to minimize the cost of the hybrid system.

REFERENCES

[1] Ortjohann, E., Mohd, A., Schmelter, A., Hamsic, N., & Lingemann, M. (2007). Simulation and implementation of an expandable hybrid power system. In *2007 IEEE International Symposium on Industrial Electronics*(pp. 377-382). IEEE.

[2] Khare, V., Nema, S., & Baredar, P. (2016). Solar–wind hybrid renewable energy system: A review. *Renewable and Sustainable Energy Reviews*, 58, 23-33.

[3] Bhandari, B., Poudel, S. R., Lee, K. T., & Ahn, S. H. (2014). Mathematical modeling of hybrid renewable energy system: A review on small hydro-solar-wind power generation. *international journal of precision engineering and manufacturing-green technology*, 1(2), 157-173.

[4] Kumar, S. (2014). Modeling and simulation of hybrid Wind/Photovoltaic Stand- alone generation system (Doctoral dissertation).

[5] Bahta, S. T. (2013). Design and Analyzing of an Off-Grid Hybrid Renewable Energy System to Supply Electricity for Rural Areas: Case Study: Atsbi District, North Ethiopia.

[6] Sun, H. (2014). Research on a new hybrid wind turbine system (Doctoral dissertation, University of Birmingham).

[7] Friedel, V. (2009). Modeling and simulation of a hybrid wind-diesel micro grid. Master of Science Thesis.

[8] Udayakanthi, G. (2015). Design of a Wind-Solar Hybrid Power Generation System in Sri Lanka.

[9] Borowy, B. S., & Salameh, Z. M. (1996). Methodology for optimally sizing the combination of a battery bank and PV array in a wind/PV hybrid system. *IEEE transactions on energy conversion*, *11*(2), 367-375.

[10] Ashari, M., & Nayar, C. V. (1999). An optimum dispatch strategy using set points for a photovoltaic (PV)–diesel–battery hybrid power system. *Solar Energy*, 66(1), 1-9.

[11] Yang, H. X., Lu, L., & Burnett, J. (2003). Weather data and probability analysis of hybrid photovoltaic–wind power generation systems in Hong Kong. *Renewable Energy*, 28(11), 1813-1824.

[12] Jeon, J., Kim, S., Cho, C., Ahn, J., & Kim, J. (2007). Power control of a grid-connected hybrid generation system with photovoltaic/wind turbine/battery sources. *In Power Electronics, 2007. ICPE'07. 7th Internatonal Conference on* (pp. 506-510). IEEE.

[13] Karasavvas, K. C. (2008). Modular simulation of a hybrid power system with diesel, photovoltaic inverter and wind turbine generation. *Journal of Engineering Science and Technology Review*, 1, 38-40.

[14] Deshmukh, M. K., & Deshmukh, S. S. (2008). Modeling of hybrid renewable energy systems. *Renewable and Sustainable Energy Reviews*, 12(1), 235-249.

[15] Saheb-Koussa, D., Haddadi, M., & Belhamel, M. (2009). Economic and technical study of a hybrid system (wind–photovoltaic–diesel) for rural electrification in Algeria. *Applied Energy*, 86(7), 1024-1030.

[16] Nagaraj, R. (2012, December). Renewable energy based small hybrid power system for desalination applications in remote locations. In *2012 IEEE 5th India international conference on power electronics (IICPE)* (pp. 1-5). IEEE.

[17] Saib, S., & Gherbi, A. (2013). Modeling and simulation of hybrid systems (PV/wind/battery) connected to the grid. *In International Conference on Electrical Engineering and Automatic Contro*l.

[18] Kazem, H. A., & Khatib, T. (2013). A novel numerical algorithm for optimal sizing of a photovoltaic/wind/diesel generator/battery microgrid using loss of load probability index. *International Journal of Photoenergy*, 2013.

[19] Nair, N. R., & Ebenezer, M. (2014). Operation and control of grid connected wind—PV hybrid system. In Advances in Green Energy (ICAGE), 2014 *International Conference* on (pp. 197-203). IEEE.

[20] Pachori, A., & Suhane, P. (2014). Modeling and simulation of photovoltaic/wind/diesel/battery hybrid power generation system.*International Journal of Electrical, Electronics and Computer Engineering*,3(1), 122.

[21] Athulya, J. V., Lakshman Rao, S. P., Kurian, C. P., & Singh, B. K. (2014). Design and simulation of wind and solar hybrid system under isolated mode of operation. *International Journal of Industrial Electronics and Electrical Engineering*, 2(3), 23-27.

[22] Chowdhury, M. S. F., & Mannan, M. A. Simulating Solar and Wind Based Hybrid Systems Synchronized and Segmented for Grid Connectivity.

[23] Pachori, A., & Suhane, P. (2014). Design and Modelling of Standalone Hybrid Power System with Matlab/Simulink. *International Journal of Scientific Research and Management Studies IJSRMS, ISSN*, 2349-3771.

[24] Venkobarao, V., & Chinnagounder, C. (2013). Design Modeling and Simulation of Supervisor Control for Hybrid Power System. *In Artificial Intelligence, Modelling and Simulation (AIMS), 2013 1st International Conference on* (pp. 179-183). IEEE.

[25] Gan, L. K., Shek, J. K., & Mueller, M. A. (2015). Hybrid wind–photovoltaic–diesel–battery system sizing tool development using empirical approach, life-cycle cost and performance analysis: A case study in Scotland. *Energy Conversion and Management*, 106, 479-494.

[26] Etamaly, A. M., Mohamed, M. A., & Alolah, A. I. (2015). A smart technique for optimization and simulation of hybrid photovoltaic/wind/diesel/battery energy systems. In *Smart Energy Grid Engineering (SEGE), 2015 IEEE International Conference on* (pp. 1-6). IEEE.

[27] Prema, V., Datta, S., & Rao, U. (2015, November). An effective dispatch strategy for hybrid power management. In *TENCON 2015-2015 IEEE Region 10 Conference* (pp. 1-5). IEEE. Region Conference (pp 1-5). IEEE.

[28] Charfi, S., Atieh, A., & Chaabene, M. (2016). Modeling and cost analysis for different PV/battery/diesel operating options driving a load in Tunisia, Jordan and KSA. *Sustainable Cities and Society*, *25*, 49-56.

[29] Khare, V., Nema, S., & Baredar, P. (2016). Solar–wind hybrid renewable energy system: A review. Renewable and Sustainable Energy Reviews, 58, 23-33.

[30] Aribisala, H. A. (2013). Improving the efficiency of solar photovoltaic power system.

[31] http://www.alternative-energy-tutorials.com/solar-power/photovoltaics.html.

[32] http://www.alternative-energy-tutorials.com/solar-power/photovoltaics.html.

[33] http://www.dupont.com/products-and-services/solar-photovoltaic-materials/what-makes-up-solar-panel.html.

[34] Weldemariam, L. E. (2010). Genset-solar-wind hybrid power system of off-grid power station for rural applications (Doctoral dissertation, TU Delft, Delft University of Technology).

[35] Kumar, S. (2014). Modeling and simulation of hybrid Wind/Photovoltaic Stand-alone generation system (Doctoral dissertation).

[36] Bahta, S. T. (2013). Design and Analyzing of an Off-Grid Hybrid Renewable Energy System to Supply Electricity for Rural Areas: Case Study: Atsbi District, North Ethiopia.

[37] Islam, M. (2014). Power management and control for solar-wind-diesel stand-alone hybrid energy systems.

[38] Chowdhury, M. M. (2014). Modelling and control of direct drive variable speed wind turbine with Interior Permanent Magnet Synchronous Generator(Doctoral dissertation, University of Tasmania).

[39] http://www.plainswindeis.anl.gov/guide/basics/index.cfm.

[40] http://www.small-windturbine.com/Vertical-Wind-Turbine-Power-

[41] https://en.wikipedia.org/wiki/Wind_turbine

[42] https://kalyan07.files.wordpress.com/2014/01/pmsg.jpg

[43] Saiju, M. S. E. R. (2008). Hybrid Power System Modelling-Simulation and Energy Management Unit Development (Doctoral dissertation, Universität Kassel).

[44] Sumathi, S., Kumar, L. A., & Surekha, P. (2015). Application of MATLAB/SIMULINK in Solar PV Systems. In Solar PV and Wind Energy Conversion Systems (pp. 59-143). Springer International Publishing.

[45] Bhandari, B., Poudel, S. R., Lee, K. T., & Ahn, S. H. (2014). Mathematical modeling of hybrid renewable energy system: A review on small hydro-solar-wind power generation. *international journal of precision engineering and manufacturing-green technology*, 1(2), 157-173.

[46] http://www.mpoweruk.com/nimh.htmy

[47] Pachori, A., & Suhane, P. (2014). Design and Modelling of Standalone Hybrid Power System with Matlab/Simulink. *International Journal of Scientific Research and Management Studies IJSRMS, ISSN*, 2349-3771.

[48] Kjellander, M., & Tengvall, A. (2014). Design of a small scale hybrid photovoltaic and wind energy system.

[49] Amin, M. (2012). Efficiency and Power Density Improvement of Grid-Connected Hybrid Renewable Energy Systems utilizing High Frequency-Based Power Converters.

[50] https://en.wikipedia.org/wiki/Electrical_grid

[51] http://sputniknews.com/asia/20150124/1017291523.html / Sputnik_ Russia and DPRK May Develop $20-30 Billion Power Grid Project _ Sputnik International _ 2012_ What's the 'real' truth_

[52] Toliyat, A. (2011). Modeling and Simulation of Distribution System Components in Anticipation of a Smarter Electric Power Grid (Doctoral dissertation, University of Texas).

[53] Matlab®/ Simulink®, SimPower Systems, Examples, 2015b

[54] http://www.mathworks.com/matlabcentral/fileexchange/36116-pmsg-based-wind-power-generation-system?s_tid=srchtitle

[55] Tremblay, O., & Dessaint, L. A. (2009). Experimental validation of a battery dynamic model for EV applications. *World Electric Vehicle Journal*, 3(1), 1-10.

[56] Tudorache, T., & Roman, C. (2010). The numerical modeling of transient regimes of Diesel generator sets. *Acta Polytechnica Hungarica*, 7(2), 39-53.