# "Modeling and Performance Analysis of a standalone renewable based Hybrid System for DC Micro Grid "

Major Project Report

Submitted in Partial Fulfillment of the Requirements for the Degree of

MASTER OF TECHNOLOGY
IN
ELECTRICAL ENGINEERING
(Electrical Power Systems )

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# Certificate

This is to certify that the Major Project Report entitled "Modeling and Performance Analysis of a standalone renewable based Hybrid System for DC Micro Grid" submitted by Mr. Abhishek Harit (13MEEE01) towards the partial fulfillment of the requirements for Semester-III of Master of Technology (Electrical Engineering) in the field of Electrical Power Systems of Nirma University is the record of work carried out by him under our supervision and guidance. The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma. .

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# Nomenclature

| | |
|---|---|
| **AC** | Alternating Current |
| **DC** | Direct Current |
| **DER** | Distribution Energy Resource |
| **DG** | Diesel Generator Set |
| **D** | Duty ratio |
| **MPPT** | Maximum Peak Power Tracking |
| **P & O** | Perturb & Observe |
| **PAC** | Pitch Angle Control |
| **PMSG** | Permanent Magnet Synchronous Generator |
| **SOC** | State Of Charge |
| **SPV** | Solar Photo Voltaic |
| **SSG** | Simplified Synchronous Generator |
| **WECS** | Wind Energy Conversion System |

# Abstract

The Project has been carried out with the modeling and performance analysis of the renewable based standalone hybrid system for DC micro grid to supply data centres. Solar Photo voltaic (SPV) arrays, Wind Turbine, Diesel Generator and Storage Battery are the sources used as a DER in the hybrid system. Maximum power point tracker algorithm is used to increase the efficiency of Solar PV panel. DC-DC and AC-DC converter is used for Solar, and Wind Generation and DG set respectively.Buck and Boost converter are used to manipulate the voltage level. DC power is accumulated at a bus and fed to the micro grid. Whole system is considered as a standalone system, it means it is an isolated system. In order to examine the effectiveness of the proposed scheme, performance analysis of the characteristics of the hybrid system will be carried out for few of the normal conditions. Analytical part has been done for DC micro grid too. MATLAB is used as a simulation tool.

# Contents

# Chapter 1

# Introduction

## 1.1 Objective

Increasing demand and decreasing fossil fuels, and pollution generated by the generation of electricity takes the globe towards to generate electricity using renewables sources as distributed energy resources along with DC micro grid.
In the practical scenario of loads, some loads such as electronic equipment are work on DC supply. Data centres are similar kind of loads which just contain racks of servers only. As desktop or laptop these servers are also work on the DC supply. According to a survey, 34-35 % electricity is wasted in the form of heat due to the changing of AC power into DC power. This heat would definitely increase the temperature of the building, to maintain certain temperature air conditioning equipment is required, which again considered as a loss of power. Consequently, the company bears a huge loss of power and money.
To manage the existing energy resources, generating power effectively and supply intelligently to the data centres is an equally important agenda at the global level. Transmission losses of the system are also a big concern to resolve, to make the power cheaper.

The objective of the project is to design a standalone renewable base hybrid system containing multi resources as DER to accumulate power at DC micro grid, to supply the data centres. A single server is taken as a prototype of a data centre.

## 1.2 Photo Voltaic Effect

In 1983, this effect was first observed by the French physicist A. E. Becquerel. The photo-voltaic effect is the creation of voltage or electric current in a material upon exposure to light. It works when the sun rays or rays in other form, incident on the silicon material sheet. Electrons present in the valence band of the silicon absorb the energy provided by the light (rays) and jump to the conduction band. These electrons are free, highly excited in nature and thus the material sheet behaves as a p-n junction where electrons and holes make a depletion layer. By getting energy from the light these electrons generates electromotive force and if load is connected to the terminal ends, the electron starts flows through the load. In this way it can be say that light energy converts into electric energy.

### Photo voltaic cell :

Photovoltaic cell is an electrical device that converts the light energy into electricity by the photovoltaic effect. It is a form of photoelectric cell, defined as a device whose electrical characteristics, such as current, voltage, or resistance, vary when exposed to light. Solar cells are the building blocks of photovoltaic modules, otherwise known as solar panels. The operation of a photovoltaic (PV) cell requires 3 basic attributes:

- The absorption of light, generating either electron-hole pairs.
- The separation of charge carriers of opposite types.
- The separate extraction of those carriers to an external circuit.

## 1.3 Wind generation

Wind power can be used as the renewable energy source by converting wind energy to electrical energy. It can be used for the other functions like windmills to extract mechanical power. Wind turbines are used to generate the electrical power. Power generation through wind can be achieved by connecting large number of turbines on a site to produce adequate amount of power, such as wind farms, onshore wind turbines, off shore wind turbines, etc.
Generally, wind farms contain a large number of turbines connected at a same location to feed the power to grid. When wind turbines are connected at the seashore where availability of wind is high are called as onshore wind turbines. When same turbines are situated in the sea, almost 5 to 8 kilometres from the land having the maximum availability of wind is called off shore wind turbines. Out of the all of three off shore wind turbines are preferred most because they have less visual impact, winds are stronger than land, due to the sea noise is not a concern, and reliability is higher. Off shore wind turbines could be the most expensive because of its constructional cost and maintenance but the payback period is less because it generates more amount power to the grid.

## 1.4 Problem Identification

Renewable energy is not available throughout the year, natural obstacles like spring time (for solar), Tsunami for off shore wind turbine plants doesn't allow to generate power more effectively and efficiently. Although transmitting power to far end through lines also increases the losses in the system.[1]

Hybrid model could be the best solution to these problems, since it contains multi sources to generate power, along with the conventional source (Diesel Generator) helps to distribute DC power more economically and efficiently. This DC power can be given to the DC load (data centres). Data centre is a building having racks of servers. Servers are the electronic equipment that work on DC power.

## 1.5 Scope

Standalone Hybrid system at distribution side reduces the losses and generates power more economically, would definitely decreases the cost and increases the reliability as well as availability of the power. As per a survey report, 33%-34% energy supplied to data centre is wasted in the form of heat, because of the losses. Due to change of AC power to DC power, high voltage DC power to low voltage DC power. This loss of power can be saved if DC power is direct provided to the servers, and company can make a nice profit by saving power as well as money. At a large level, standalone hybrid system can be supply more than one data centre that again could save more power. Capital cost of the system may be high but its maintenance cost would be low and compensation of transmission losses would be seen.

# Chapter 2

# Literature Survey

## 2.1 Literature Survey

- Pothina Kartik, Harish Sesham - "Simulation and Performance Analysis of Renewable based Standalone System for Smart Mini Grid Applications"
- Aparna Pachauri, Payal Suhane – "Design and modelling of standalone hybrid power system with matlab/Simulink"
- Sandeep Kumar, Vijay Garg - "Hybrid system of pv solar / wind and fuel cell"
- R.Chedid, Akiki , Saifur Rehman- "A decision support technique for the design of hybrid solar-wind power system"
- Kai Strunz, Ehsan Abbasi, Duc Nguyen Huu - "DC Microgrid for Wind and Solar Power Integration"

Above papers are referred to understand the designing and modelling of hybrid system. Simulations and analysis has done using Simulink. Smart mini grid which is self-sustainable to manage the load demand according to the economic considerations.

- N. Pandiarajan – "Mathematical Modeling of Photo Voltaic Module in Simulink"
- N. Pandiarajan – "Application of Circuit Model for Photo Voltaic Energy Conversion System"
- Habbati Bellia, Ramdani Youcef – "A detailed modeling of photovoltaic module using MATLAB"
- Nahla Mohmed Abd AlrahimShannan - "Single-Diode Model and Two-Diode Model of PV Modules: A Comparison".
- Ernest Ruppert Filho – "Comprehensive Approach to Modeling and Simulation of Photo Voltaic Arrays"

Above papers are about non-linear I-V and P-V characteristics, mathematical modelling of Photo Voltaic module can be understood. Equivalent single diode model & double diode model of solar panel has studied to know about the accuracy and computational time between the two. Single diode model is used in the project due to the less complexity and less computational time.

- Hairul Nissah Zainudin - "Comparison Study of Maximum Power Point Tracker Techniques for PV Systems"
- Trishan Esram – "Comparison of Photo Voltaic Array Maximum Power Point Tracking Techniques"

Different type of algorithms for maximum power point tracking has studied with their accuracy, convergence, complexity and costing parameters. Perturb & Observe algorithm is used in the project for the mppt techniques.

- Suman Nath, Somnath Rana - "The Modeling and Simulation of Wind Energy Based Power System using MATLAB"
- Djohra Saheb-Koussa , Maiouf Belhamel , Mourad Haddadi , Seddik Hadji, Said Nouredine -"Modeling and simulation of wind generator with fixed speed wind turbine under Matlab-Simulink"
- Aparna Pachori , Payal Suhane-"Design and modelling of standalone hybrid power System with matlab/simulink"
- Caisheng Wang, and M. Hashem Nehrir-"Power Management of a Stand-Alone Wind/Photovoltaic/Fuel Cell Energy System "

Above papers are referred to understand, the modeling and simulation of the wind energy conversion system and analysis of the parameters of the wind turbine curve. Effects of Hybrid system on the grid, increasing the efficiency of the system. obstacles that can create problems and elimination of that problems.

- Le Luo, Lan Gao and Hehe Fu-"The Control and Modeling of Diesel Generator Set in Electric Propulsion Ship"
- Jiacheng Wang,Dewei (David) Xu, BinWu,and Zhenhan Luo-"A Low-Cost Rectifier Topology for Variable-Speed High-Power PMSG Wind Turbines"
- Jianzhong Zhang, Ming Cheng, Zhe Chen, Xiaofan Fu-"Pitch Angle Control for Variable Speed Wind Turbines "
- Sachin Khajuria, Jaspreet Kaur-"Implementation of Pitch Control Of wind Turbine Using Simulink"

Above papers are referred to understand, the modeling of the maximum power point tracking algorithm for wind turbine and different pitch angle control strategies and implementation of these startegies.

## 2.2 Equivalent Circuit of the solar panel

It is classified in two forms :[5]

1. Single diode model
2. Double diode model

Single diode model is used despite its less accuracy but due to its less complexity and less computation time. Sometimes three diode model is also can be seen in the research paper, but most preferred are the these two only. We are using Matlab as the simulation tool and taking the data sheet of the SOLKAR model of 36 watt panel , as the reference to get the I-V and P-V characteristics.[3]

**Single diode model**

As shown in the diagram, the equivalent circuit contains constant current source as the solar photo voltaic panel, single diode is connected across the current source, a shunt resistance ($R_{sh}$ or $R_p$) is connected in across this diode, and series resistance ($R_s$) connected with in series. Value of $R_p$ is the very high and value of Rs is very less, so the amount of current flowing through the resistor Rp is negligible, thus in the simulation this current is ignored.

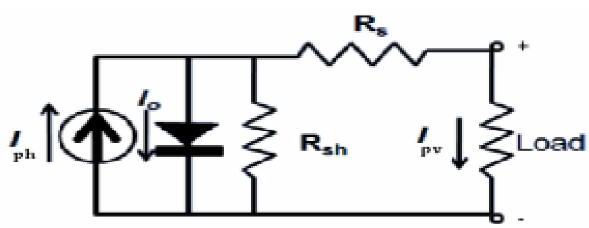


Figure 2.1: Equivalent Circuit Diagram of Solar PV cell

Varying insolation and temperature varies the output characteristics, insolation is directly proportional to the voltage and temperature is proportional to the current. Photo current $I_{ph}$, is given by-

$$I_{ph} = [I_{scr} + K_i(T_k - T_{ref})]\frac{\lambda}{1000}]$$

where,
$I_{scr}$= Short circuit current
$K_i$ = 0.0017 A/K
$T_k$= Actual Temperature in kelvin
$T_{ref}$= reference temperature in kelvin
W= Amount of irradiation ($1000\frac{w}{m}^2$)

Module reverse saturation current is the ”leakage” of carriers across the p-n junction in reverse bias, denoted by $I_{rs}$, which is given as –

$$I_{rs} = \frac{Iscr}{(exp(\frac{qVoc}{N_s KAT})-1)}$$

where,
q = charge of electrons
$V_{oc}$= Open circuit voltage of the panel
$N_s$ = no. of cells connected in series (to increase voltage)
K = Boltzman's constant
A = Ideality factor
T = operating temperature
Module Saturation current is the current flowing through the diode in the forward bias which is dependent on the reference as well operating temperature, denoted by $I_o$, and given as –

$$I_o = I_{rs}[\frac{T}{T_{ref}}]^2 exp[\frac{qE_{go}}{AK}(\frac{1}{T_r}-\frac{1}{T})]$$

Where ,
$E_{go}$ = band gap energy of semiconductor
Module output current , $I_{pv}$ is given as –

$$I_{pv} = N_p I_{ph} - N_p I_o[exp(q\frac{(V_{pv}+I_{pv}Rs)}{(N_s AKT)} - 1]$$

where, $N_p$ = Number of cells connected in parallel ( to increase current rating) $V_{pv}$ = Voc $R_s$ = Series connected resistance

# Chapter 3

# SPV Modeling

## 3.1 Modeling of Solar Photovoltaic Panel

Simulink is used to model the solar photo voltaic module. The subsystem contains all the modelled equations in a form of blocks. Different blocks are provided in the Simulink environment for different functions such as the addition, subtraction, division and product of the parameters. All kind of mathematical operations can be performed with the parameters and characteristics can be seen the according to the response of the function.[2]

### 3.1.1 Photon current

Equation is given by,

$$I_{ph} = [I_{scr} + K_i(T_k - T_{ref})]\frac{\lambda}{1000}]$$

The equation can be model in the follow way, as shown in fig. 3.1 Blocks can be found in different libraries of the Simulink. Here, Insolation, $T_{ak}$, $T_{rk}$ , $I_{scr}$ is provided at the subsystem level. Point here to be noted that $I_{scr}$ is the current provided by the manufacturer in the data sheet.

### 3.1.2 Reverse saturation current

Equation is given by ,

$$I_{rs} = \frac{Iscr}{(exp(\frac{qVoc}{N_sKAT})\text{–}1)}$$

The equation can be model in the following way, here $T_ref$ is the parameter that will be provide at the subsystem level. Yellow block is the function "Fcn" block , which is used to make the function of the parameters and reduce the complexity of the model.

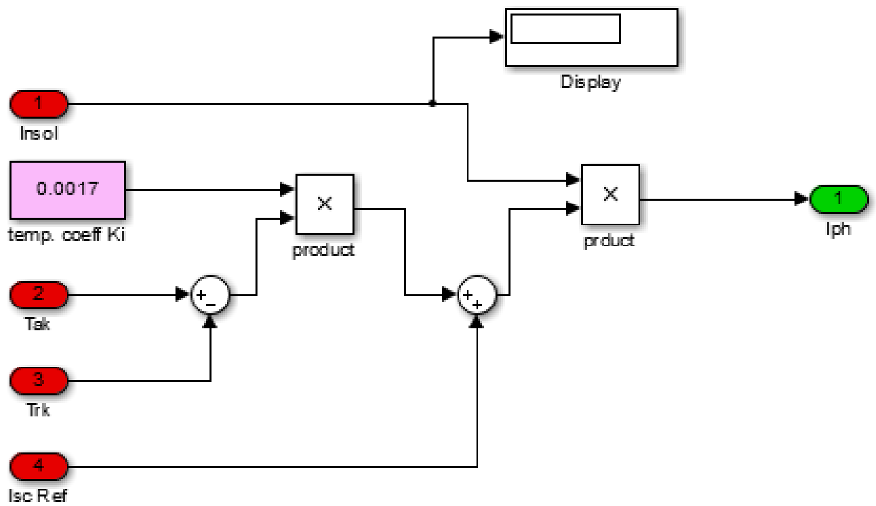


Figure 3.1: modeling of photon current$I_ph$

### 3.1.3 Module saturation current

Equation is given by,

$$I_o = I_{rs}[\frac{T}{T_{ref}}]^2 exp[\frac{qE_{go}}{AK}(\frac{1}{T_r} - \frac{1}{T})]$$

Equation can be model in the following way, $I_o$ current is depend on the both the reference temperature and operation temperature. In the latter, we would see that output current varies with the operating temperature.

### 3.1.4 Overall Output current

Equation is given by ,

$$I_{pv} = N_p I_{ph} - N_p I_o [exp(\frac{q(V_{pv} + I_{pv} Rs)}{(N_s AKT)} - 1]$$

After combining all the subsystems, final block visualise in the following way, Voc, Irradiation of sun $(1000w/m^2)$, temperature (25 degree) are the input to the block and outcome is the $I_{pv}$,

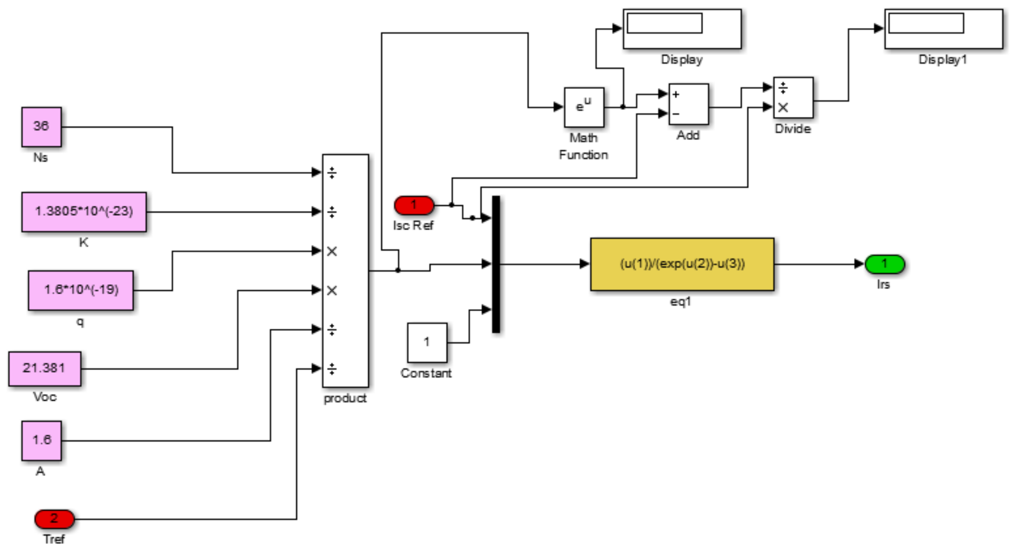


Figure 3.2: modeling of the reverse saturaiton current$I_r s$

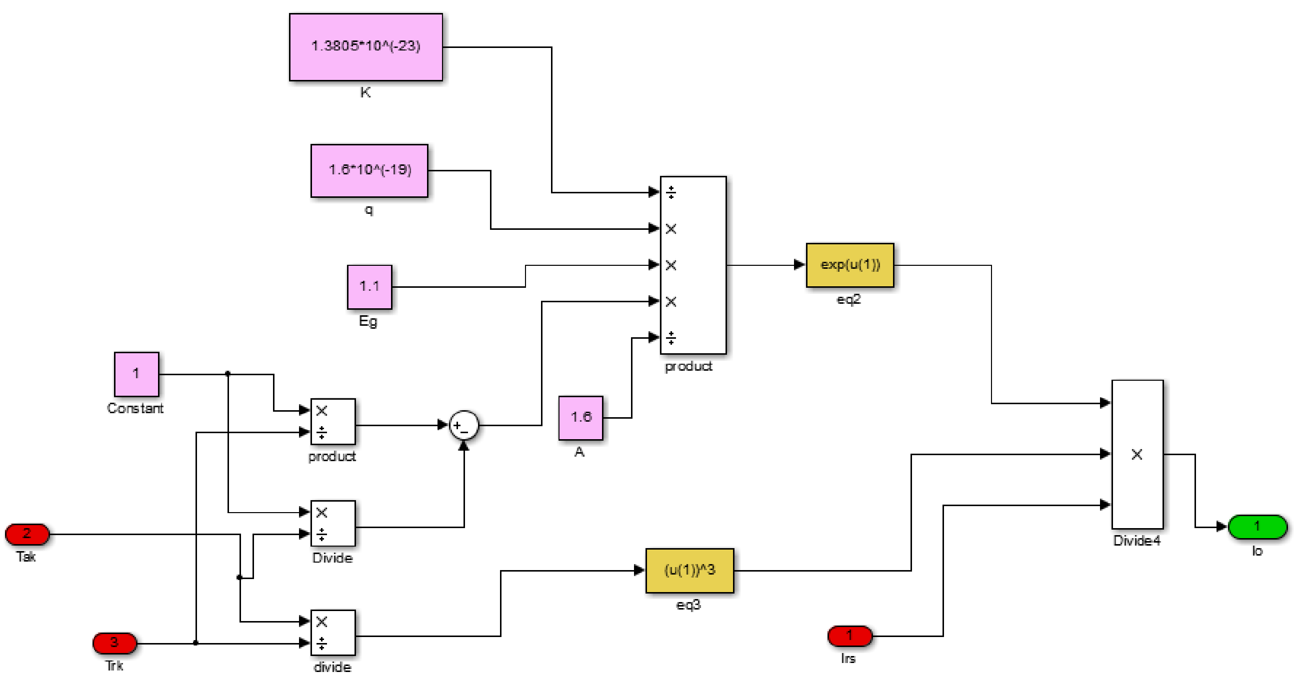


Figure 3.3: modeling of module saturation ccurrent,$I_o$

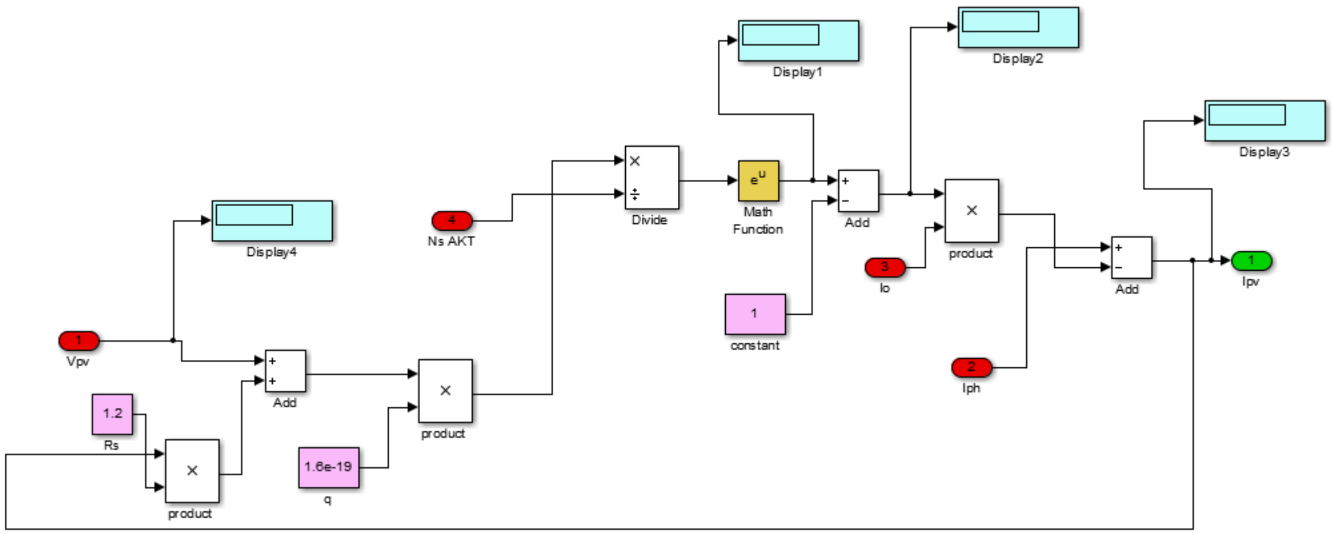


Figure 3.4: modeling of output current $I_{pv}$

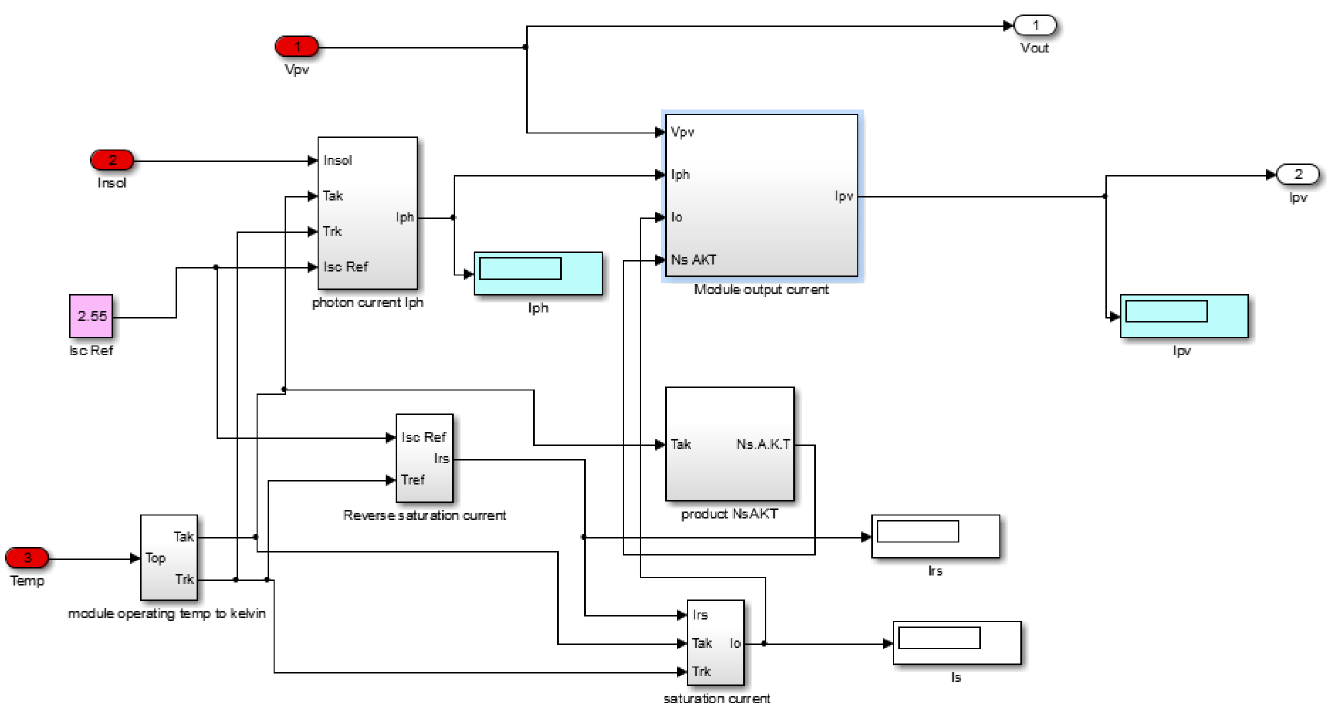


Figure 3.5: Overall diagram modeling of the solar panel

### 3.1.5 Simulation results

**P-V characteristics**

It can be seen with the increase in voltage power increases, but at a certain time (.68 sec) it begins to follow negative slope.

Fig.3.6 shows the P-V curve with time and fig.3.7 shows the X-Y plot of the curve where voltage is taken on x-axis and power is taken on y-axis.

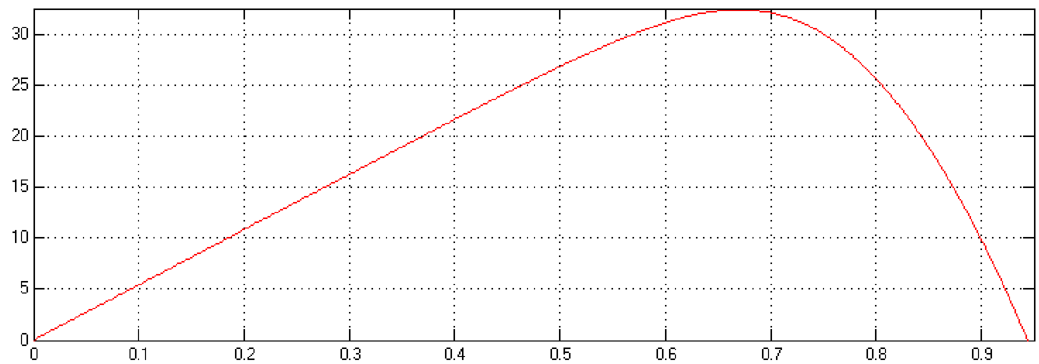


Figure 3.6: V-P curve on time scale

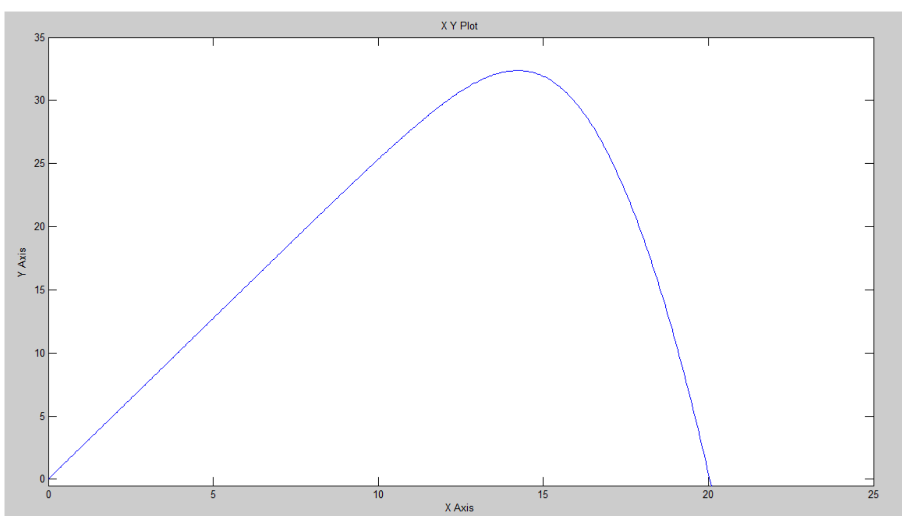


Figure 3.7: V-P curve on x-y plot

**I-V characteristics :**

In the I-V curve, current becomes constant with the increase in voltage but similarly to P-V curve at a certain time it gradually decreases to zero.
Fig. 3.8 shows the I-V curve with time and fig.3.9 shows the X-Y plot of the I-V curve where voltage is taken on x-axis and current is taken on y-axis.

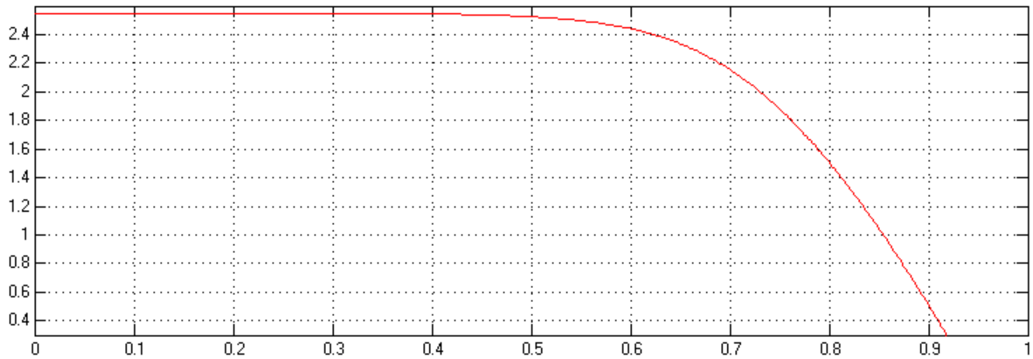


Figure 3.8: V-I curve on the time scale

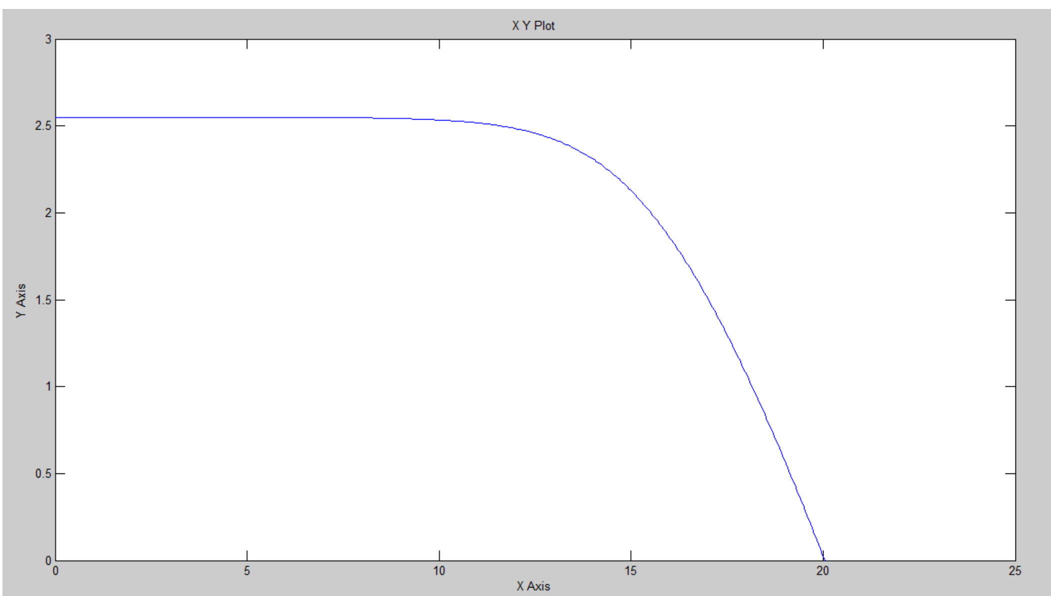


Figure 3.9: V-I curve on the x-y plot

## 3.2 Converter(dc to dc)

### 3.2.1 Requirement of the Converter

Converter is required to step up or step down the voltage level as per the desired value. It works similarly to the transformer in the case of alternating current. Mainly there are four type of converter :

1. Buck Converter
2. Boost converter
3. Buck-Boost Converter
4. Ćuk Converter

Buck converter is used to step down the voltage level, and boost converter is used to step up the voltage level. Buck boost converter increase or decrease the level as per the switching or gate pulse provided to the switch. Ćuk converter, converts in the same way as buck boost but its efficiency is higher than the other all converters.
In the case of solar photo voltaic system boost converter is generally used to charge the batteries or to produce desired voltage.

### 3.2.2 Working Principle

Boost converter is used to increase the voltage level. Converter circuit configuration can be set as given diagram. It converts the voltage of 14 V to the higher level as shown in the plotted curves.It works in two mode-

1. In first mode, when the switch is closed, current charges inductor through switch in the form of magnetic field.
2. In second mode, when the switch is opened, charged inductor discharges through the load.

Circuit diagram is shown by fig.3.10

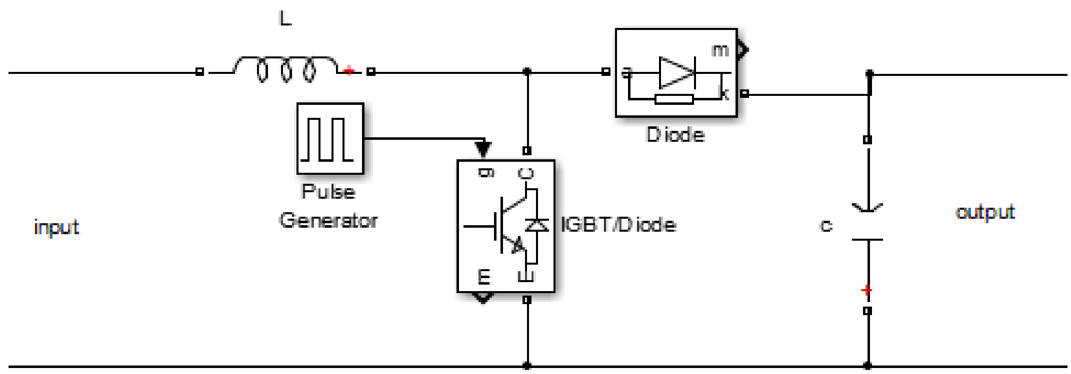


Figure 3.10: boost converter

## 3.3 Maximum Power Point Tracking

Mostly this technique is used to increase the efficiency of the solar photo voltaic panel.[7] In this technique, by using an algorithm a generated signal is supplied to the switching device and it conducts as per the algorithm and increase the efficiency of the converter and the solar panel.

**Types of Algorithm :**[8]

1. P&O algorithm
2. Incremental conductance
3. Fractional open circuit voltage
4. Fractional short circuit current
5. Fuzzy logic control
6. Neural network
7. Current sweep
8. DC link droop control
9. dP/dV & dP/dI feedback control

First two algorithms are mostly preferred by the researchers. P&O algorithm is easy to imply, can find local maximum value with less time, less complicated, easy to understand, and quite easy to model. Sometimes it can produce oscillations to the output, but that part can be eliminate by using filters.

At its peak, the output value of the converter is high as compared to the normal pulse converter.

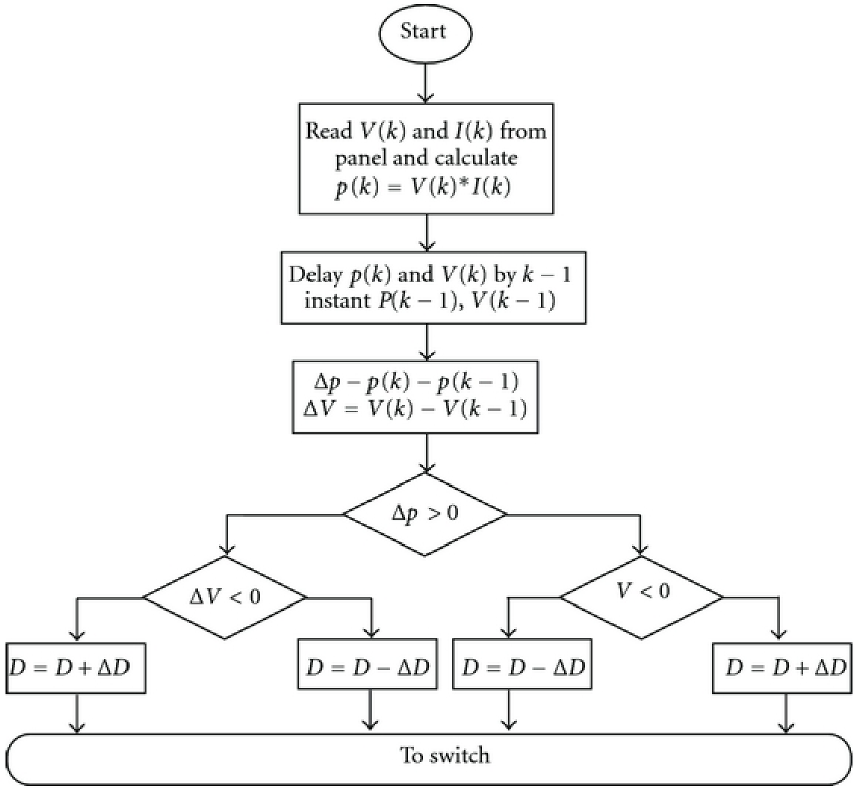


Figure 3.11: Flowchart of perturb & observe algorithm

## 3.4 Modeling of the Perturb&Observe Algorithm

Modeling of the P&O algorithm is given as below, the input is the power and voltage, and output is the signal generated pulse which is fed to the switching device. Important thing to notice here that duty cycle is plays a vital role in this algorithm.[3]

### 3.4.1 Curves

The waveform of the signal generated pulse and output voltage waveform of the converter is also given below :

Some oscillation is there in the starting but it damps out after some time, and constant voltage can be carried out as output .

### 3.4.2 Comparing of the Curve

As the I-V curve of the solar photo voltaic is non-linear in nature, current increases with the voltage but after certain time it gradually decreases to zero. Similarly P-V curve, increases gradually and at that

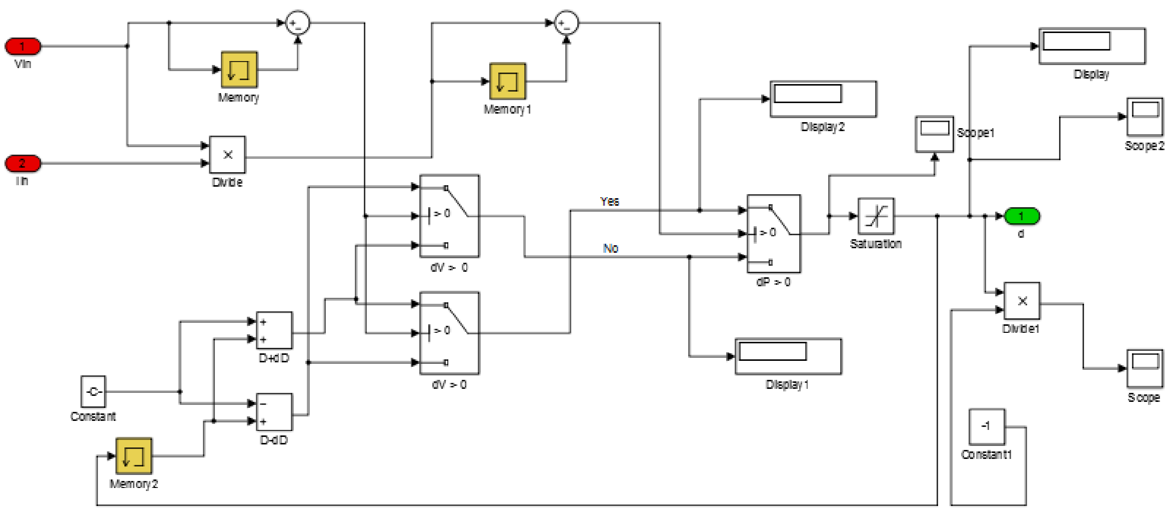


Figure 3.12: Modeling of perturb & observe algorithm

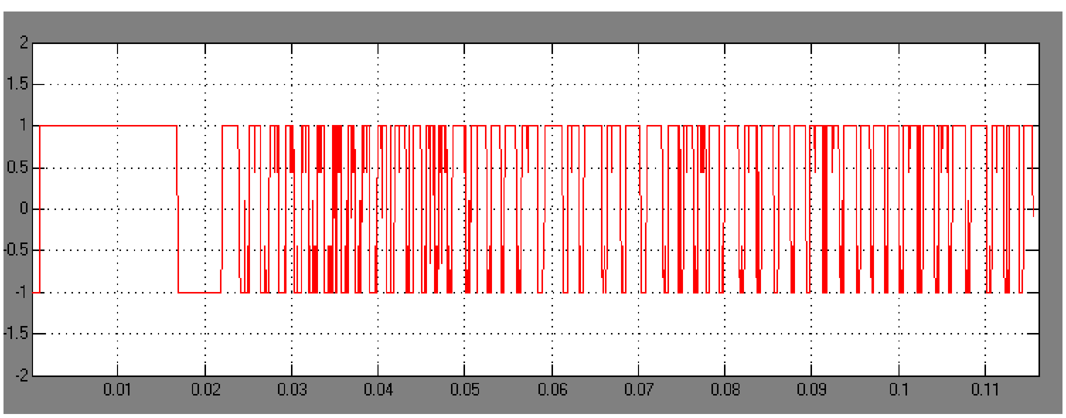


Figure 3.13: switching pulse generated for the IGBT(gate terminal) by the P&O

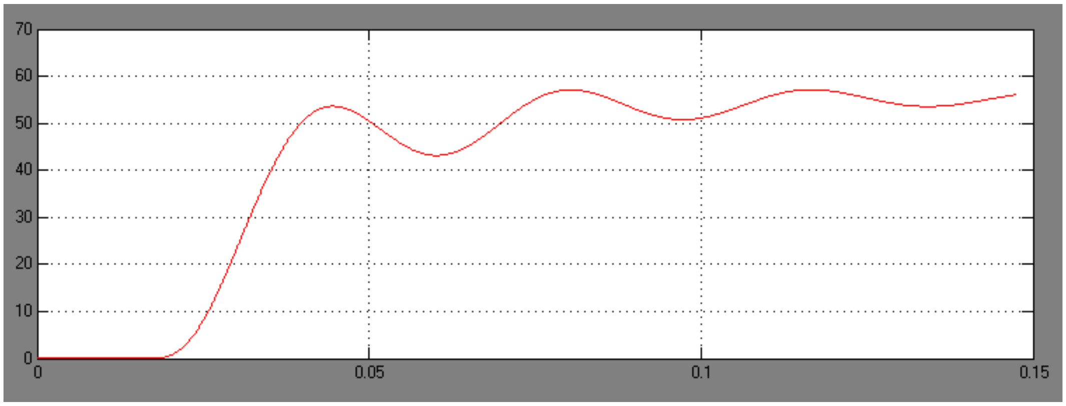


Figure 3.14: Output waveform of the converter

certain time it gradually decreases to zero. Thus, the output of the converter is reduced and efficiency of solar also reduces.
MPPT technique helps the output to hold position at the peak of the curve like Hill Climbing Algorithm.
**With and Without MPPT :** The difference between the output value of voltage can be seen by the waveforms. Without the MPPPT technique the voltage oscillates from 60volt to 30 volt and then limited by 37 volt .By using MPPT, oscillates same as in above case but it increases its value to the 57 volt and make it constant there.

Secondary increasing in voltage shows the MPPT algorithm in negative path (reverse to the peak), holds the peak at which we got the constant voltage output.

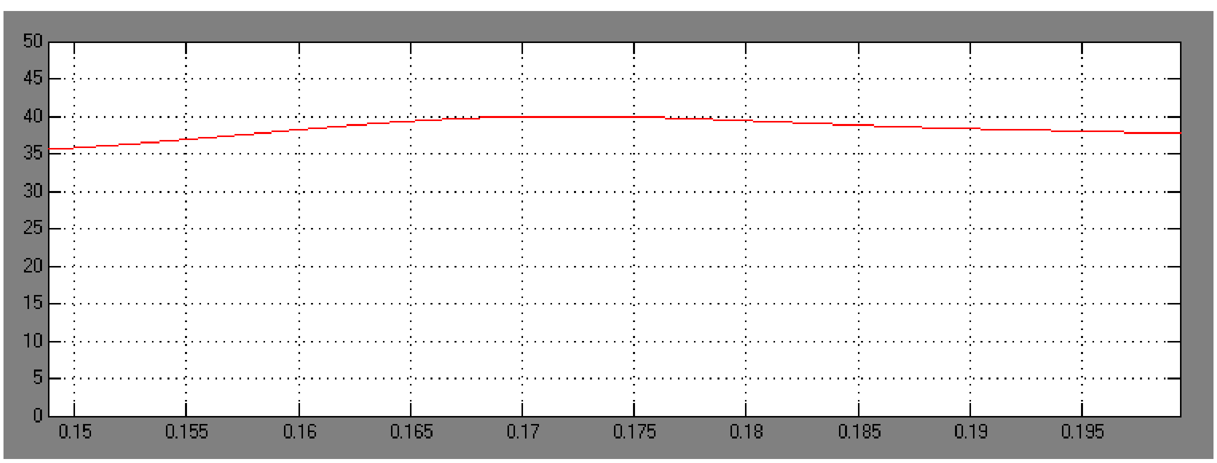


Figure 3.15: without mppt

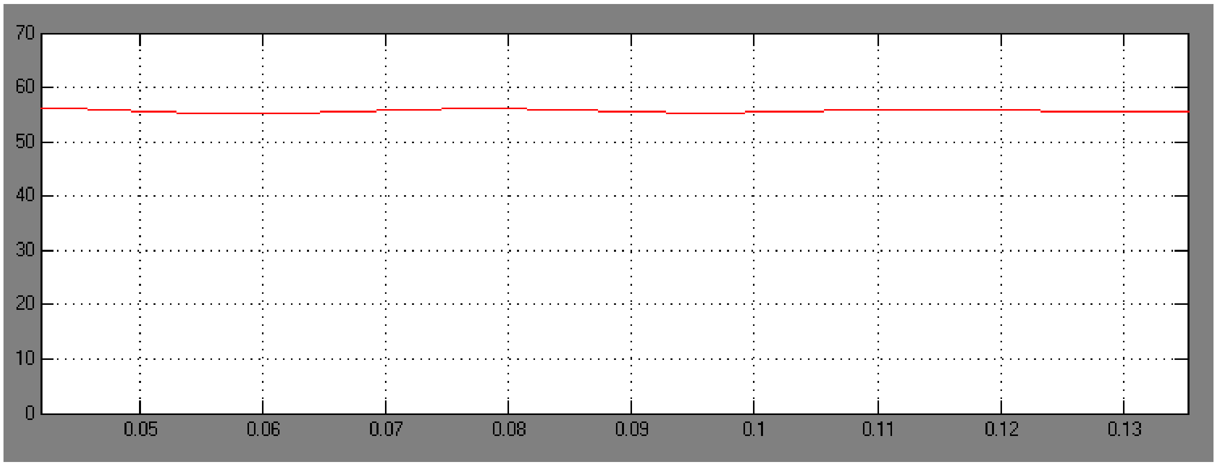


Figure 3.16: with mppt

## 3.5 Filters

Filters are mainly used to eliminate the ripples in the converted dc supply. These ripples can be making a severe damage to the circuit and decrease the efficiency of the system.

### 3.5.1 Types of Filters

Mainly there are three types of filters :

1. L filter
2. LC filter
3. Pie filter

Their circuit configurations can be shown as under,

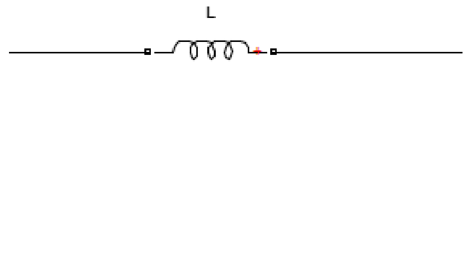


Figure 3.17: L filter

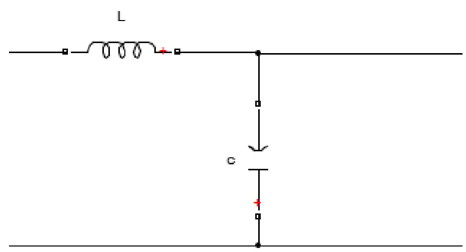


Figure 3.18: Waveform of the Voltage

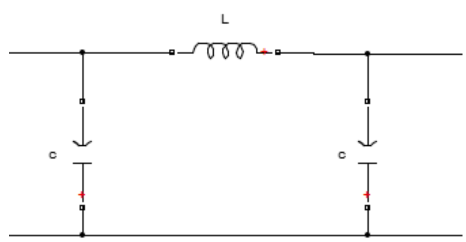


Figure 3.19: Pie filter with two shunt capacitors and one inductor

## 3.6 Practical Working of the MPPT

MPPT is designed to work for variable as well as constant conditions. In the practical conditions, both the irradiations and temperature are variable in nature.
As shwon below, the algorithm is working for the variable conditions. The varied irradiation and temperature signal is generated and given to the system.
The curves of the I-V plot and P-V plot can be shown as-

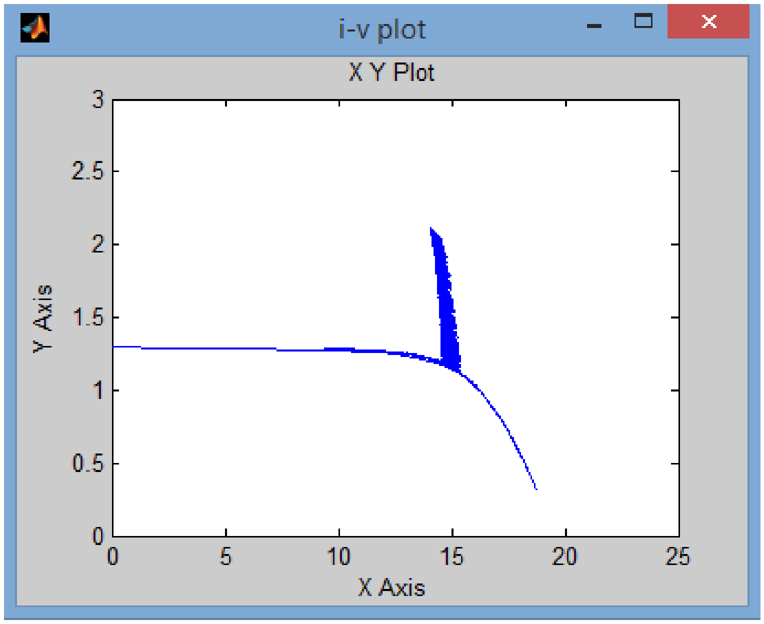


Figure 3.20: I-V plot of Solar in Varied Irradiation and Temperature

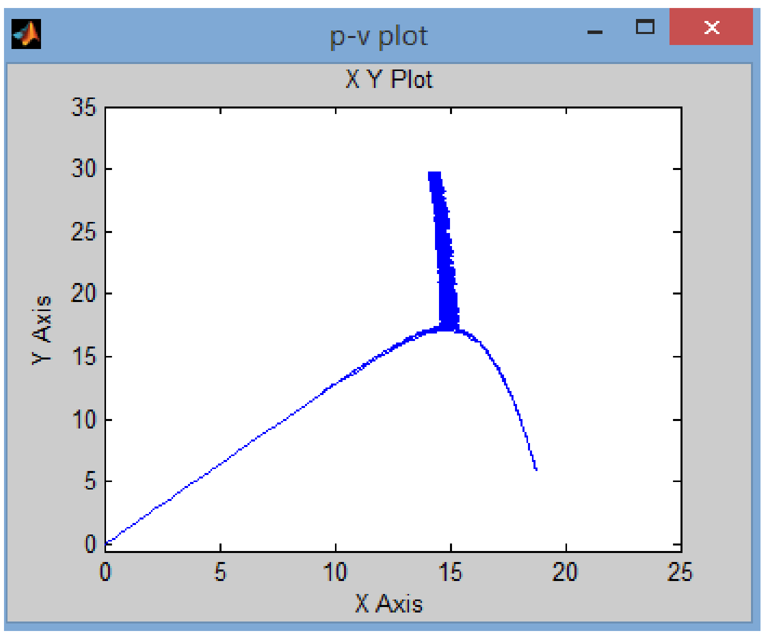


Figure 3.21: P-V plot of Solar in Varied Irradiation and Temperature

The Pertrub and Observe algorithm holds up the maximum power point and as the variaton, the algorithm makes the zigzag pattern to the maximum point.

# Chapter 4

# Wind Energy Conversion System

## 4.1 Wind as renewable source

Wind can be a very good option of renewable energy sources for the generation of electricity. Because of it is available throughout the year, at some place near sea shore or hilly areas and it could be a pollution free generation of power. Some countries are generating impressive part of their energy through wind only.

### 4.1.1 Countries Generating power through Wind Energy

In the area of the wind generation China is leading with the approx. 91000MW followed by US with 61000MW, Germany with 34250MW, Spain with 23000 MW.
India is 5th largest country as per the installation capacity of wind power in the world. Total capacity of India is 21264 MW, and it is estimated that 6000 MW of additional wind power capacity will be installed by 2014.

### 4.1.2 Wind Turbine & their types

**On the basis of structure, wind turbine are basic of two types :**

1. Horizontal Wind Turbine

2. Vertical Wind Turbine

1. **Horizontal Wind Turbine**
   It has the turbine in the horizontal direction i.e. direction of the facing wind. Blades have a special angle which helps to rotate it in the same direction without bothering the wind direction. This is mostly used because of its robust structure against heavy wind and efficiently operation. The gearbox and generator are connected on the top portion of the tower,so maintenance could be tough sometimes.

2. **Vertical Wind Turbine :**
   It has the shaft in the vertical direction and blades are arranged on the top of the tower, towards to the direction of the sky. This is used on the site where speed variation is a problem. In this scheme gearbox and generator are connected near the ground, thus easy to maintain it.

## 4.2 Parts of Wind Turbine

- **Tower:**
  It is foundation of the turbine. It is hollow from inside and have a stairs to the main turbine used for maintenance.

- **Rotor Parts:**
  Rotor parts contains blade, rotor bearing and rotor hub.

- **Main Shaft:**
  Main shaft connects the rotor blade to the gearbox.

- **Gearbox:**
  Gearbox plays a vital role in turbine. It converts the slow speed of the main shaft into the high speed rotor for the generator.

- **Generator:**
  Generator is used to produce electricity. It can be a synchronous generator or induction generator.

- **Yaw System:**
  It is mechanism which is placed at the connected point of tower and nacelle. It rotates the nacelle in the direction of the wind turbine.

- **Pitch System:**
  Similarly, this mechanism is used in the case of heavy winds, it changes the angle of the blades in the case of wind speed.

- **Nacelle:**
  Main shaft, gearbox, generator all are set up in a box called nacelle.

## 4.3 Manufacturers

Top manufacturers of wind turbine in the world are - Acciona, Alstom, Dongfang, Enercon, Gamesa, GE Energy, Goldwind, Nordex, Repower, Sinovel, Suzlon and Vestas.

## 4.4 Modeling of Wind Energy Conversion System

**Block Diagram of the wind energy conversion system :**

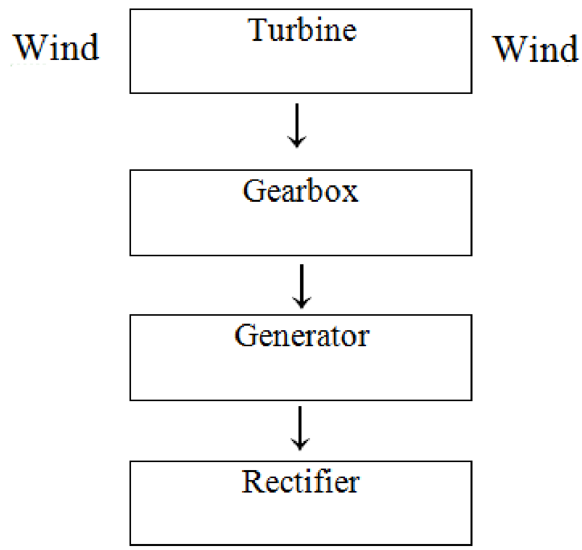


Figure 4.1: Block diagram of the WCES

Output power of Wind turbine can be given as,[9]

$$P_m = c_p(\lambda, \beta)\frac{\rho A}{2}v^3$$

Where,

$P_m$ = Output power
$c_p$ = Performance coefficient
$\rho$ = Density or wind
A = Swept area of blade
v = Wind speed
$\lambda$ = Tip speed ratio of the rotor blade
$\beta$ = Blade pitch angle

Term $c_p(\lambda, \beta)$ can be given as,

$$c_p(\lambda, \beta) = c_1(\frac{c_2}{\lambda_i} - c_3\beta - c_4)e^{\frac{c_5}{\lambda_i}} + c_6\lambda$$

&,

$$\frac{1}{\lambda_i} = \frac{1}{\lambda+0.08\beta} - \frac{0.035}{\beta^3-1}$$

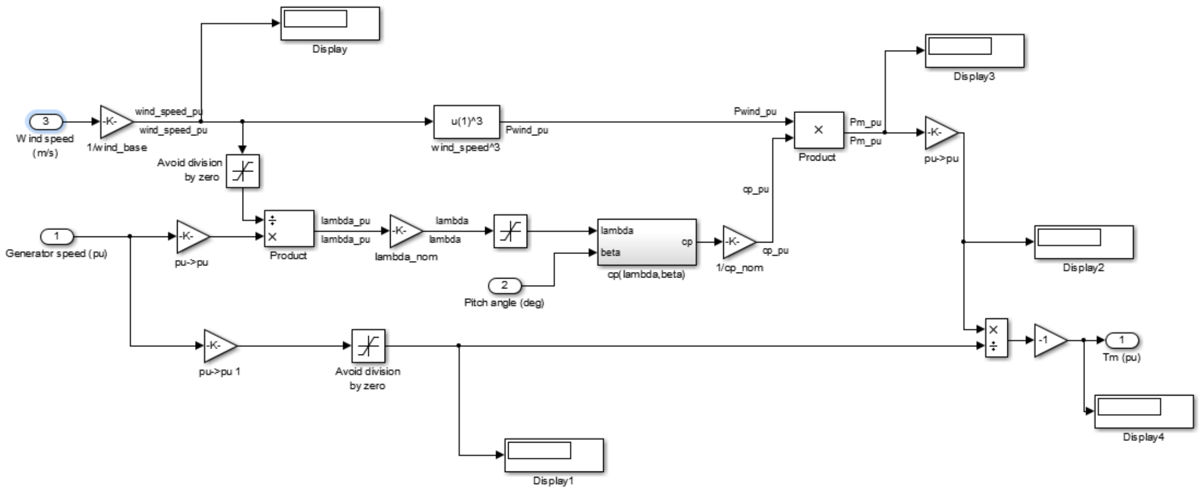


Figure 4.2: Modeling of output power($P_m$)

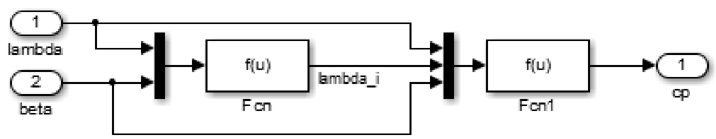


Figure 4.3: Modeling of performance coefficient $c_p$

### 4.4.1 Analysis using different Machines (generators)

Generated torque / power implied to different machine for analysis. Generated torque is fed to different machine such as Permanent Magnet Synchronous Generator(PMSG), Simplified Synchronous Generator(SSG).

**PMSG**

It can be considered as an expensive option. But no external circuitry is required for the excitation of generator. Wind turbine has three inputs speed of generator, pitch angle, and wind speed as input and torque as an output. Generator speed ($\omega$), wind speed is taken 12 m/sec, and pitch angle is taken as zero (generator has maximum efficiency at $\beta = 0$). This torque is given to the machine, since it is negative makes the machine to work as generator. Due to the permanent magnets the machine generates three phase AC power and m port is given to see the output waveforms.
This phase a,b,c is direct fed to the rectifier. For an simplicity, diode is used in the rectifier.

Capacitor is the connect to eliminate the ripples, and to get ripple free dc and resistor is connected as load. Output waveform would be shown in fig 4.5.

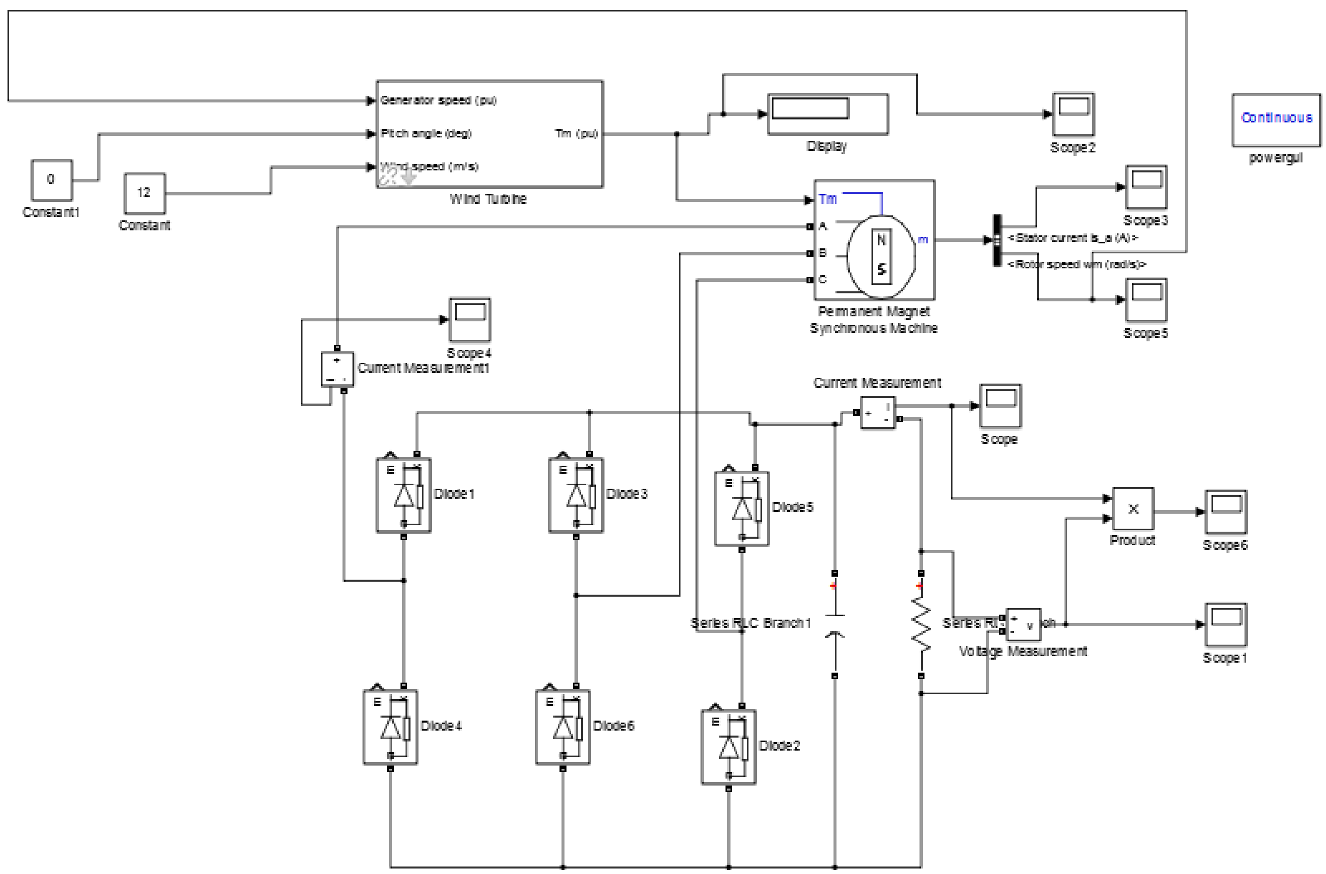


Figure 4.4: Modeling of Permanent Magnet Synchronous Generator

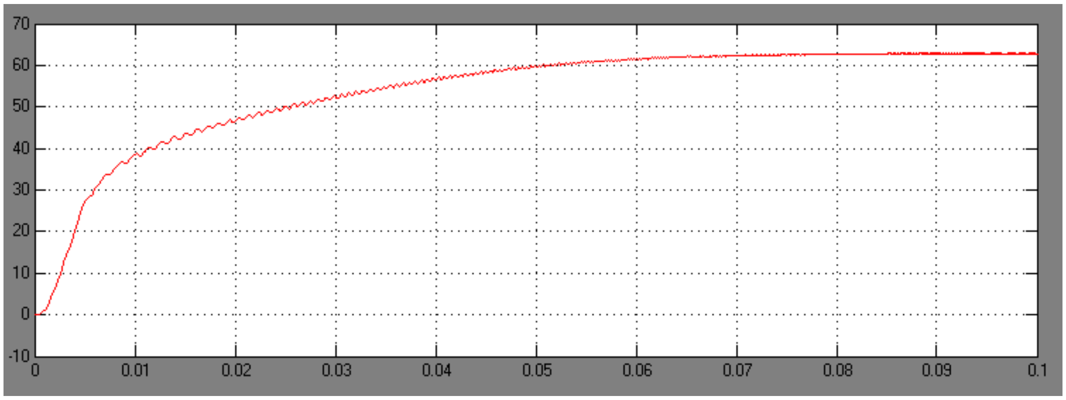


Figure 4.5: output voltage of Permanent Magnet Synchronous Generator

PMSG is preferred because it doesn't require additional DC excitation, excitation is provided by the permanent magnet. PMSG is more efficient, create less noise, mechanical stress is less,& there is no contribution to fault current than any other machine in the generating power through wind. Despite they are costly but maintenance is quite low as compared to the other generators. Due to elimination of the excitation circuit, circuit complicity is reduced.[13]

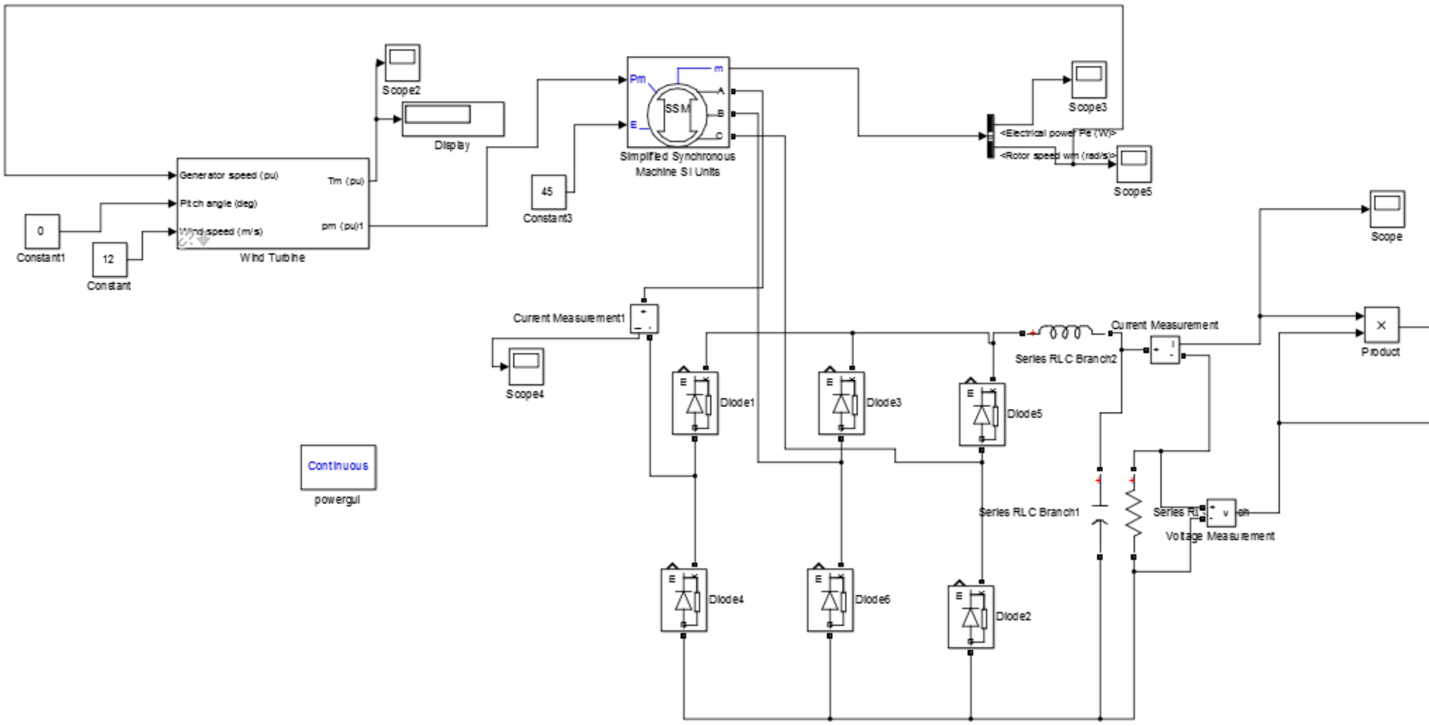


Figure 4.6: Modelling of Simplified Synchronous Generator

Output of the converter is given fig 4.7

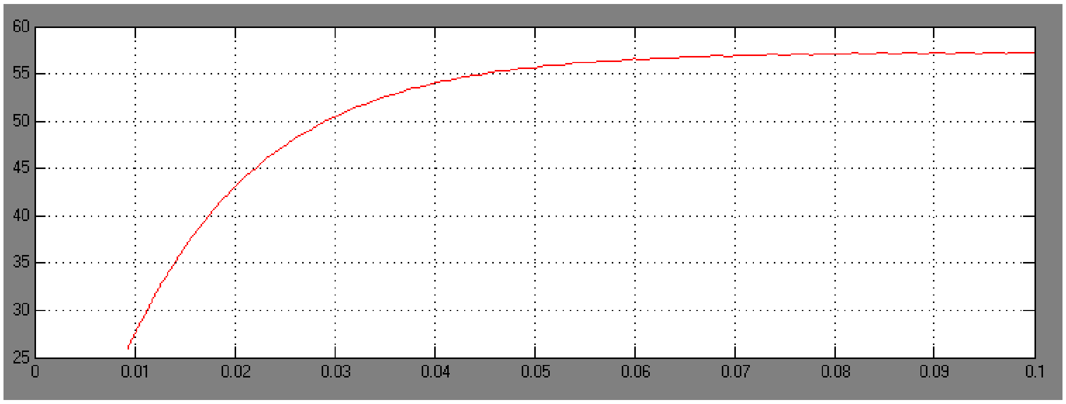


Figure 4.7: output voltage of Simplified Synchronous Generator

## 4.5 Wind Turbine with PMSG

Wind can't be flow constantly. Therefore, the output power will be consequently changing with the wind velocity. If velocity increases, it put more impact on the blades, so they will move with higher speed. Generator is directly connected to the blade's shaft (prime mover) rotates fast and generates more power.

In the case of very high velocity winds, the chances of wear and tear in the blades, shaft or the internal equipments in the nacelle. Most preferred survival velocity is 60 m/sec. So to make wind turbine withstand in very high velocity. Pitch angle controller ($\beta$) is required.

In the Pitch angle Control, the strip attached with the blade moves upward or downward, to increase or decrease the effective area of the blade where wind strikes. If wind velocity increases, the pitch angle increases and the strip go downwards to reduce the effective area of the blades, vice versa for the low velocity of wind.

Generally PI controller is being used for the Pitch angle Controller.Proportional controller can be used for the small variation in the winds.Since in this model, only Proportional controller is used.

### 4.5.1 Functioning of this controller

Basically this controller can be designed by three different control strategies :

1. Sensing change in Wind Velocity
2. Sensing change in Voltage
3. Sensing change in Power

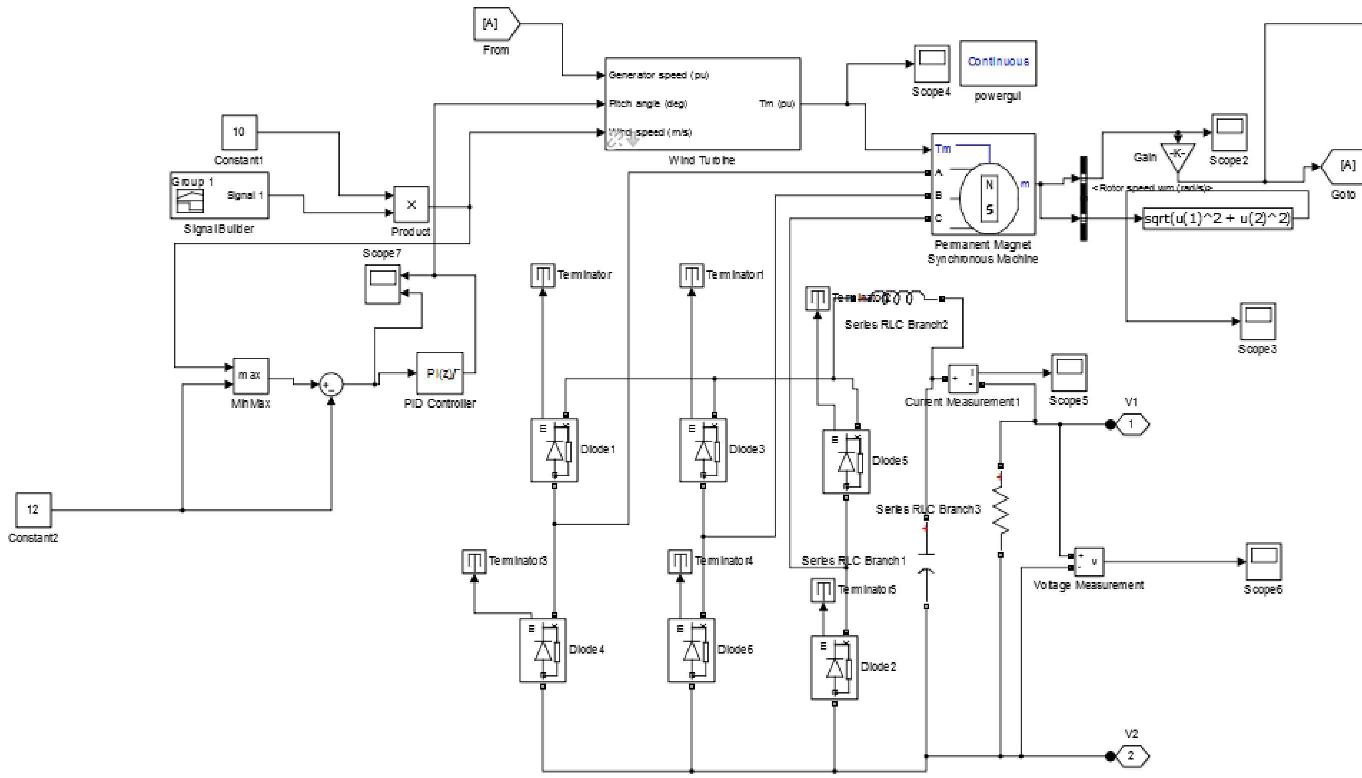


Figure 4.8: Modeling of the Wind Turbine Permanent Magnet Synchronous Generator

First strategy is more preferred than the other two. This is because of change in voltage or in power itself happens due to change in wind velocity, and first strategy is easy also to implementation and economically less expensive.
As shown in fig. 4.9 the error of the wind velocity is generated by the summing point having actual signal and reference signal. Reference signal is taken as 12m/sec. "Max" block provides the maximum value between actual and the reference value. The generated error is given to the P controller. In the P controller, it works according to the proportional gain $K_p$, and provides the pitch angle according to the variation or error generation.

In the testing of the controller,following results can be obtained. The wind is changing from 12 m/sec to 16 m/sec between $4^thto6^th$ seconds.First wave fig 4.10 form shows changing of output voltage to around 56 to 70 V on the instance of $4^th$ second and still increasing with low valued slope to 75 V. It is the consequence of changing just 2 m/sec in the wind velocity.The pitch angle remains zero during whole process.

The fig. 4.11 shows, with the P controller, at the instance of changing velocity the voltage is changed from 56 V (approx.)to 58 V. Since controller sets on discrete sample the slope increases positively for 1 second and then decreases for the another second. After $6^th$ second it remains as it was in initial stage. During $4^thto6^th$ controller increases the pitch angle, which maintains the output value of voltage constant.

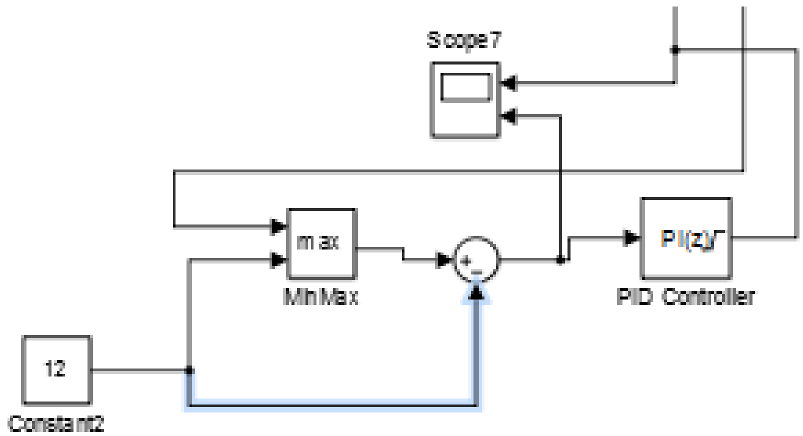


Figure 4.9: Modeling of the Pitch Angle Controller

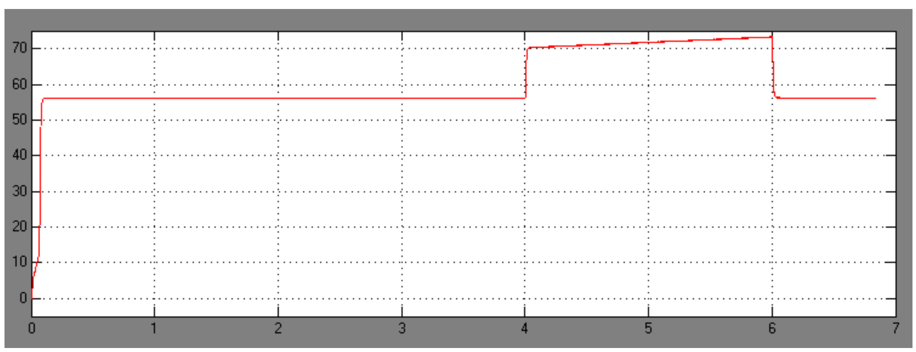

Figure 4.10: Output waveform of the voltage without Pitch Angle controller

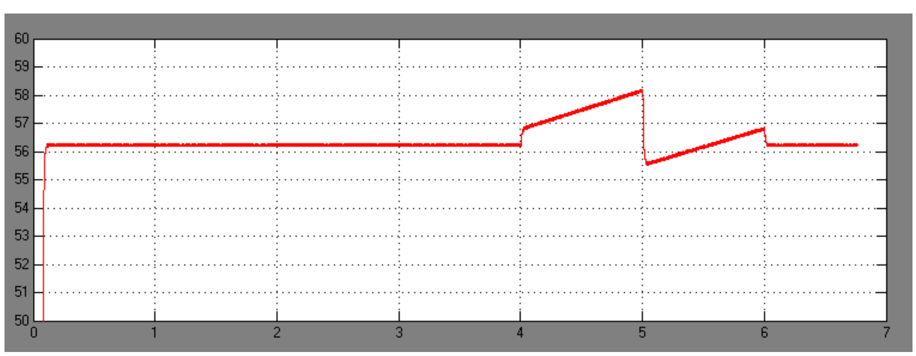

Figure 4.11: Output waveform of the voltage with Pitch Angle controller

# Chapter 5

# Diesel Generator Set

A conventional source must require increasing the reliability of the system. It can be helpful, when solar irradiation and wind both are not collected by the source is in adequate quantity. Diesel generator is used here as the conventional source. Battery could be used here as a conventional source but the problem associated to battery is, limited time to supply (2-3 hrs) and reliability as the source is less. For maintenance of the renewable source or for long duration fault sometimes third source is requires to work more than 6 hours or more than that.
Fuel cell can be used as a reliable source but problem associated with fuel cell is capital cost and the maintenance cost at the low voltage level. Therefore, Diesel generator set is the best conventional source that can be used as reliable source here. Battery is used as backup source.

## 5.1 DG set

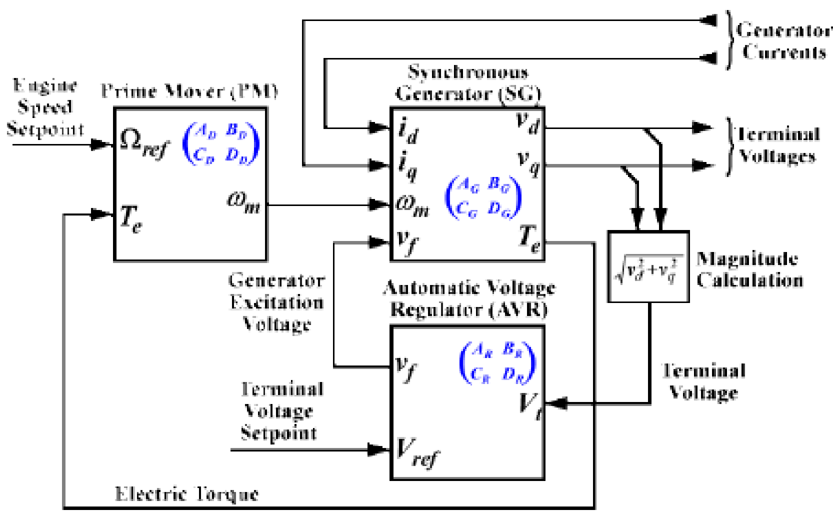


Figure 5.1: General diagram of diesel generator set

DG set converts mechanical energy into electrical energy by burning diesel as a fuel in IC engine. DG set contains with Prime mover, excitation system and synchronous machine. The block diagram of the diesel generator is shown in fig. 5.1.

## 5.2 Prime Mover

DG set doesn't contains any governor system with itself. So to make it more stable a prime mover or a governor system is required to be install with the DG set.This system should sense the actual speed and reference speed (i.e. 1 pu) to produce per unit rotational power $P_mech$, which would be feed to the synchronous machine. The block diagram of the prime mover and its modeling is shown below : In figure, $\omega_{ref}$(pu) is the per unit reference value, $\omega$(pu)is the per unit value of the actual speed of the

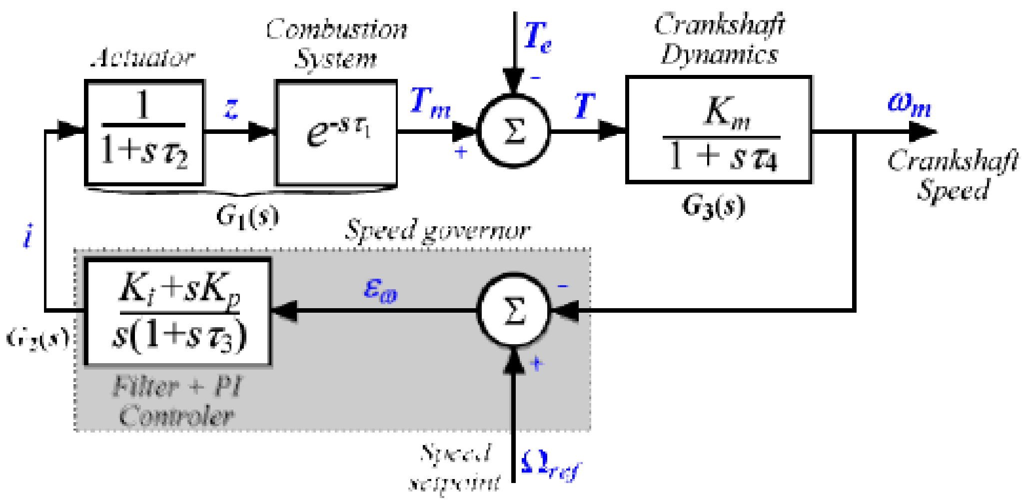


Figure 5.2: Block diagram of the Prime Mover

DG set. $P_{mech}$(pu)is per unit of diesel engine output power, feed to synchronous generator.The main unit contains the proportion, differential, second-order inertial link control unit, integral controller to generate torque for the generator.

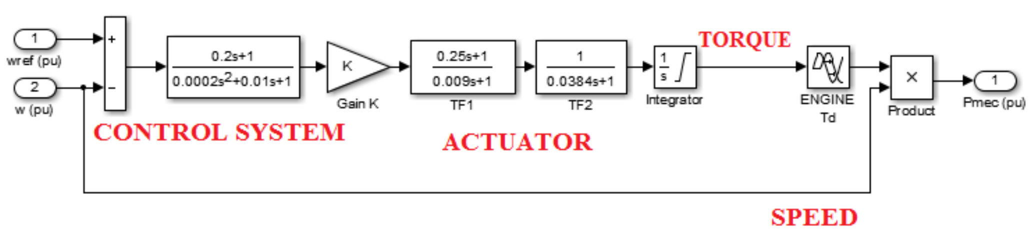


Figure 5.3: Modeling of the same system

Because diesel engine is a large time delay system, the torque first through delay unit then mechanical power multiplied the speed signal of multiplier to reach machinery power signal. The torque power drives generator give out power.

## 5.3 Synchronous machine

It converts the mechanical power produced by the primary mover into electrical power. The numerical models that can be used in the study of the synchronous generator can be classified into circuit models and field models, with the ones most used in electric drive systems being the circuit models. The Synchronous machine block operates in generator or motor modes. If $P-mech$ is positive it works as a generator or if it is negative as motor.[14] The model takes into account the dynamics of the stator, field, and damper windings. The equivalent circuit of the model is represented in the rotor reference frame (dq frame). All rotor parameters and electrical quantities are viewed from the stator.[14]

- d,q: d and q axis quantity
- R,s: Rotor and stator quantity
- l,m: Leakage and magnetizing inductance
- f,k: Field and damper winding quantity

The electrical model of the machine is

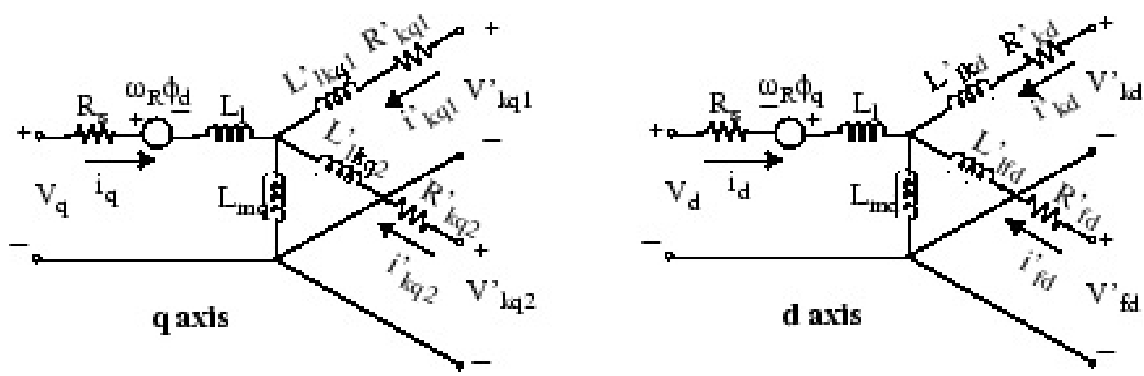


Figure 5.4: vector diagram of d-q axis[10]

with the following equations[10]- $V_d = R_s i_d + \frac{d\psi_d}{dt} - \omega_R \psi_q$

$V_q = R_s i_q + \frac{d\psi_q}{dt} - \omega_R \psi_d$
$V'_{fd} = R'_{fd} i'_{fd} + \frac{d\psi'_f d}{dt}$
$V'_{kd} = R'_{kd} i'_{kd} + \frac{d\psi'_k d}{dt}$
$V'_{kq1} = R'_{kq1} i'_{kq1} + \frac{d\psi'_k q1}{dt}$
$V'_{kq2} = R'_{kq2} i'_{kq2} + \frac{d\psi'_k q2}{dt}$
$\psi_d = L_d i_d + L_{md}(i'_f d + i'_k d)$

$\psi_q = L_q i_q + L_{mq} i'_{kq}$
$\psi'_{fd} = L'_{fd} i'_{fd} + L_{md}(i_d + i'_k d)$
$\psi'_{kd} = L'_{kd} i'_{kd} + L_{md}(i_d + i'_f d)$
$\psi'_{kq1} = L'_{kq1} i_{kq1} + L_{mq} i_q$
$\psi'_{kq2} = L'_{kq2} i'_{kq2} + L_{mq} i_q$

Mechanical characteristics of a simple synchronous machine. The electrical system for each phase consists of a voltage source in series with an RL impedance, which implements the internal impedance of the machine. The value of R can be zero but the value of L must be positive. The Simplified Synchronous Machine block implements the mechanical system described by $\Delta\omega(t) = \frac{1}{2H}\int_0^t (T_m - T_e)dt - K_d\Delta\omega(t)\ \omega(t) = \Delta\omega(t) + \omega_0$

where
Δω=Speed variation with respect to speed of operation H=constant of inertia

$T_m$ = mechanical torque
$T_e$ = electromagnetic torque
$K_d$ = damping factor representing the effect of damper windings
ω(t) = mechanical speed of the rotor
$\omega_o$= speed of operation (1 p.u.).
Although the parameters can be entered in either SI units or per unit in the dialog box, the internal calculations are done in per unit. The following block diagram illustrates how the mechanical part of the model is implemented. The model computes a deviation with respect to the speed of operation; not the absolute speed itself.[14]

## 5.4 Excitation system

In the above block diagram automatic voltage regulator plays a very important role in the system. Excitation system takes values of voltages and current. By referring the reference voltage which is set on 1pu, it varies the field voltage. Therefore, it helps generator to maintain a constant supply and provide stability to the system.

The type ST2A exciter model represents a compound source rectifier excitation system. The exciter power source is forms by phasor sum of main generator armature voltage and current. The regulator controls the exciter output through controlled saturation of the power transformer. The parameter Te represents the integration rate associated with control windings: $E_{fdmax}$ represents the limit on exciter output due to magnetic saturation. Block diagram and the modeling diagram is shown below. The excitation block is directly available in MATLAB for direct use.

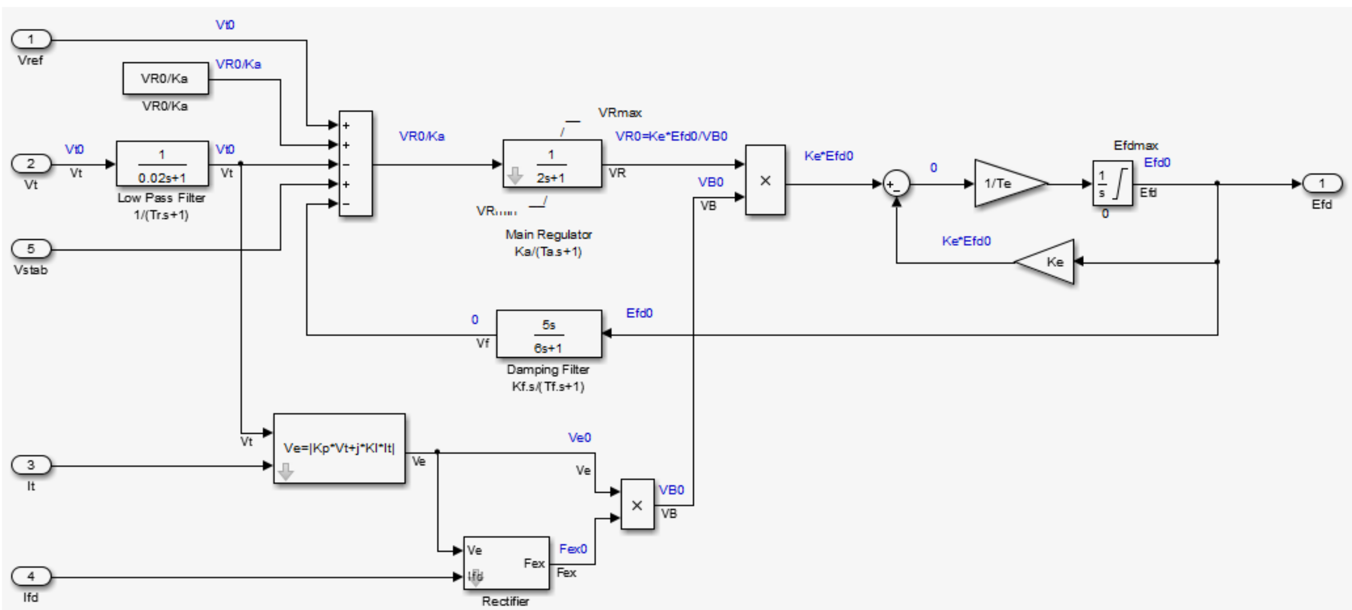


Figure 5.5: Modelling of the ST2A excitation system

# Chapter 6

# Modelling of DG set

Modeling of the diesel generator set along with governor and excitation system is shown below. 10 kilowatt resistive load is connected at receiving end. The sinusoidal waveform of the output waveform is shown below. The waveform of governor (constant), Efd's waveform which is a constant is shown below.

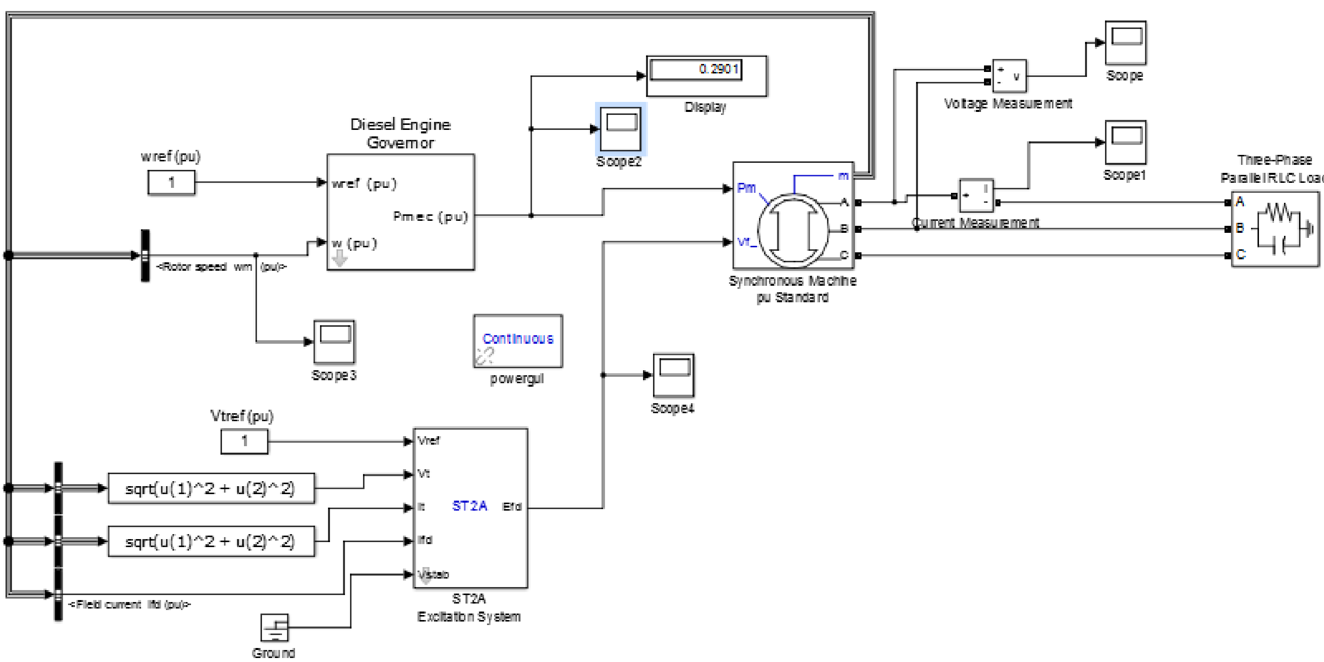


Figure 6.1: Modeling of the system including Excitation System, Diesel Governor System and Synchronous Generator

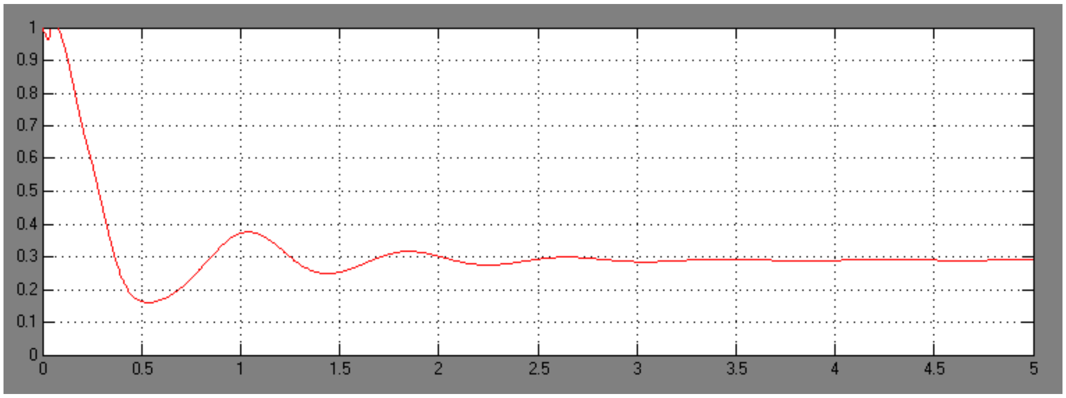


Figure 6.2: Waveform of Diesel Governor Model

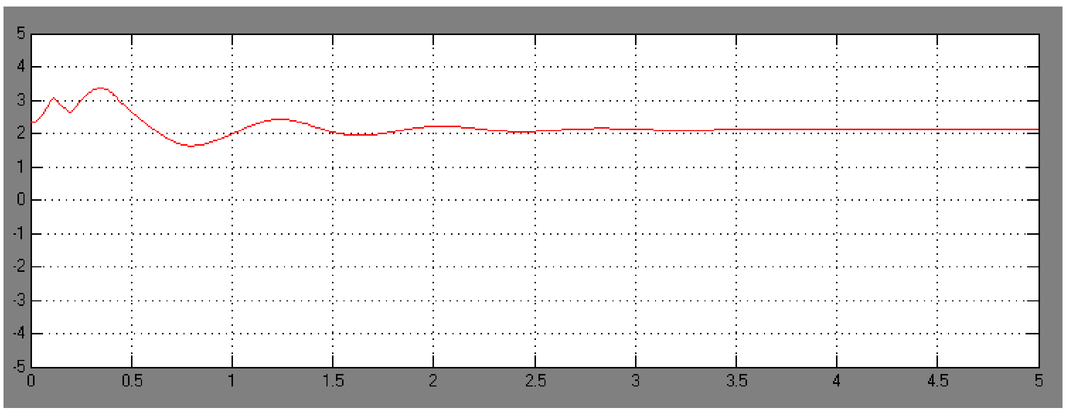


Figure 6.3: Waveform of Output of Excitation system

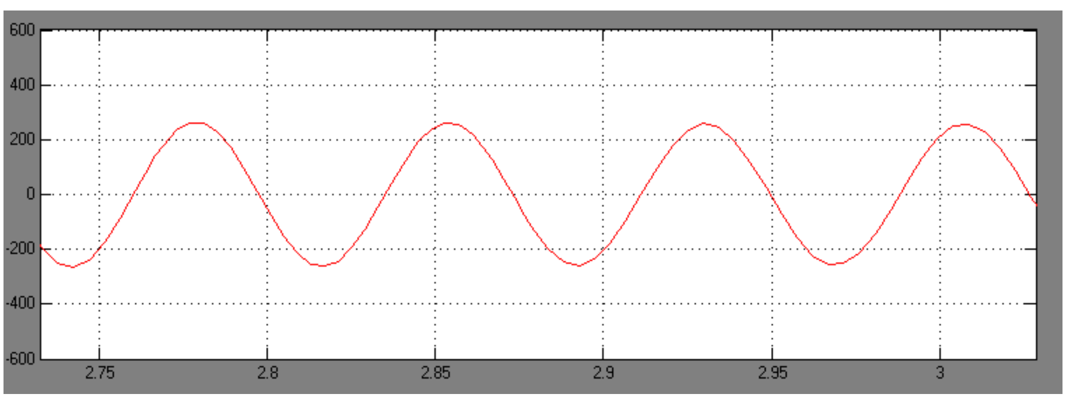


Figure 6.4: Sinusoidal Waveform of Output of Diesel Generator

## 6.1 Rectifier circuit with filter

Three phase uncontrolled rectifier is used to convert the three phase sinusoidal AC power into DC power. It contains six diodes connected in a specific manner as shown and pie filter is connected to rectify the ripples out of the output waveform. Filter contains a inductor (L1) and two capacitor (c1,c2) connected as shown-

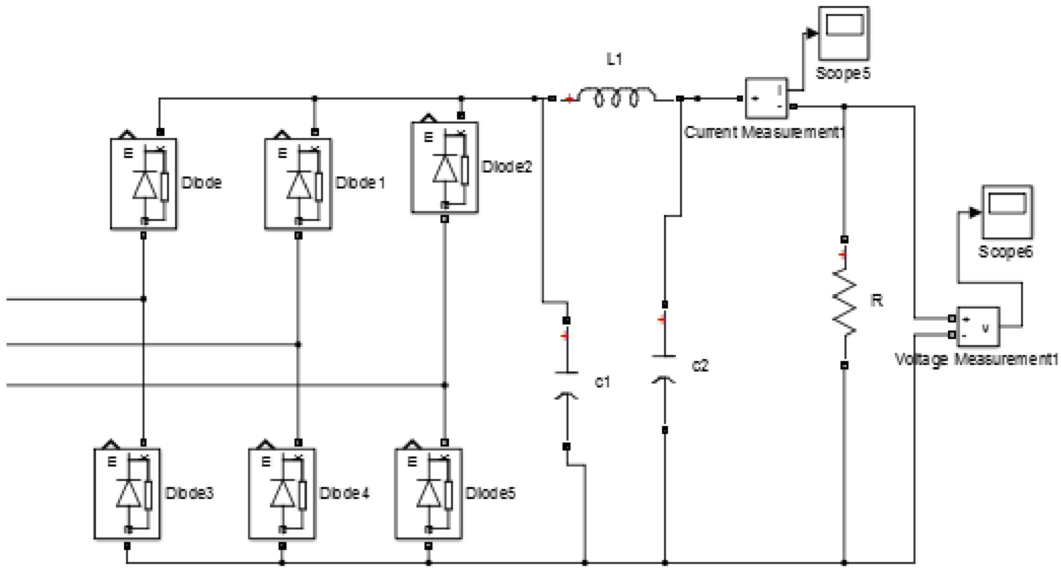


Figure 6.5: Rectifier circuit with pie filter

**Output waveform of the rectifier along with filter :**

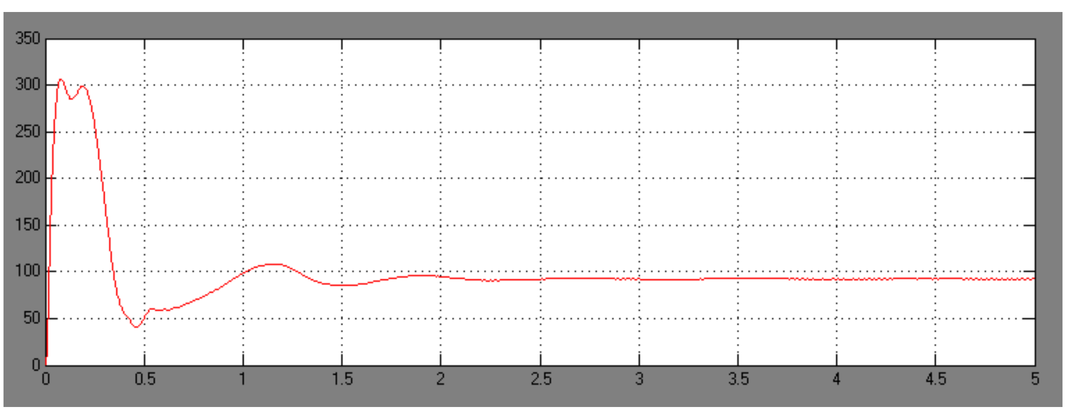


Figure 6.6: Waveform of the three phase rectifier(approx. 92 volt)

## 6.2 Buck Converter

Buck converter is used to step down the dc voltage. The simplest way to reduce the voltage of a DC supply is to use a linear regulator, but linear regulators waste energy as they operate by dissipating excess power as heat. It contains two stages. In the first stage, the switch IGBT switched on a voltage is supplied to the load through inductor L and capacitor C. Capacitor C is get charged through this stage. In later stage, switched get off and capacitor discharged through diode and inductor to load.

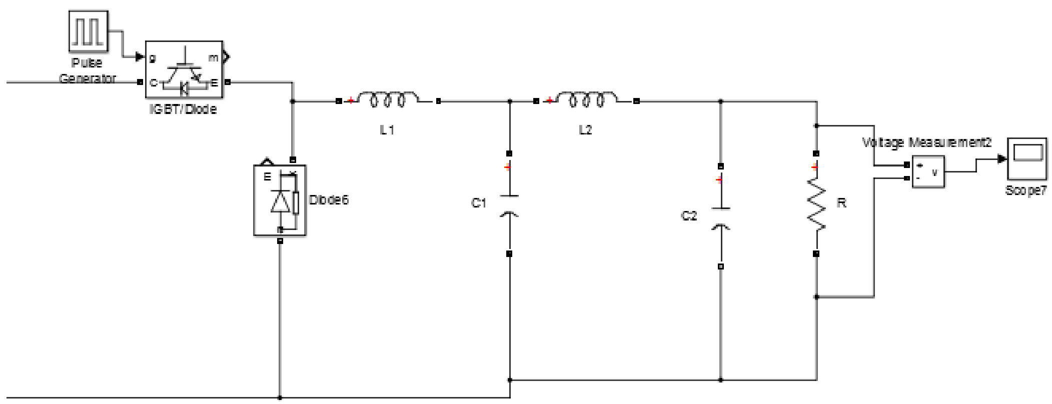


Figure 6.7: Modeling of Buck Converter

Here L2 and C2 is filter circuit is used to rectify the ripples through the waveform. These ripples are generated through the switching of the IGBT switch.
As shown above, the output value of the rectifier is 92(approx.) ,but desired voltage is 50volt. Therefore buck converter is used to decrease the voltcme level from 92 V to 50 V(approx.).

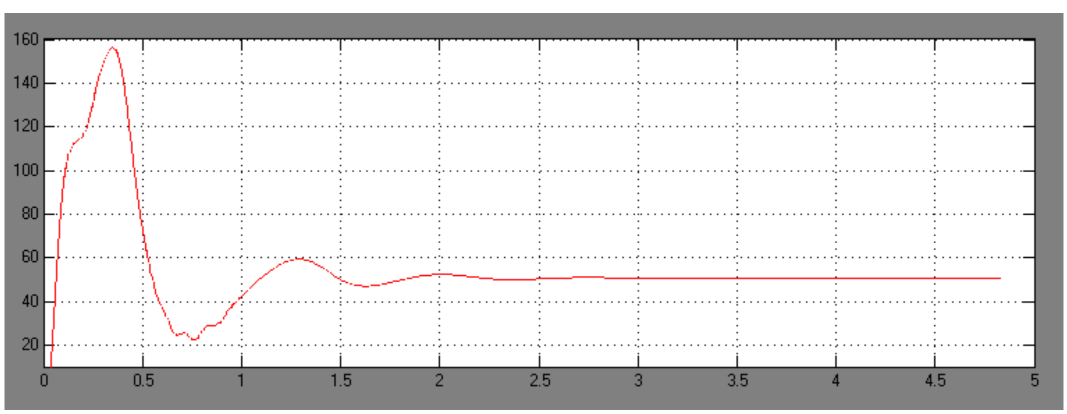


Figure 6.8: Output waveform of Buck Converter

# Chapter 7

# Battery Storage

Battery can be taken as a backup source, which can supply the power to the load in any emergency conditions. Limitations to the battery are the continuous availability of power for a long period. Since, it is available for a specific period until got discharged completely.

## 7.1 Modeling of Battery with Charging circuit

Model of Battery is already provided in the Simulink for direct use. All the parameters of the battery are predefined, and it can be change as per desired level. Four type of batteries are given in a block Li ion, Ni Cd, NiMH, lead acid. Parameters could be change automatically according to the battery and voltage rating.
There are three terminals provided, two are for connection and third is to take the output characteristics of the battery. Most important characteristics is SOC (state of charge).

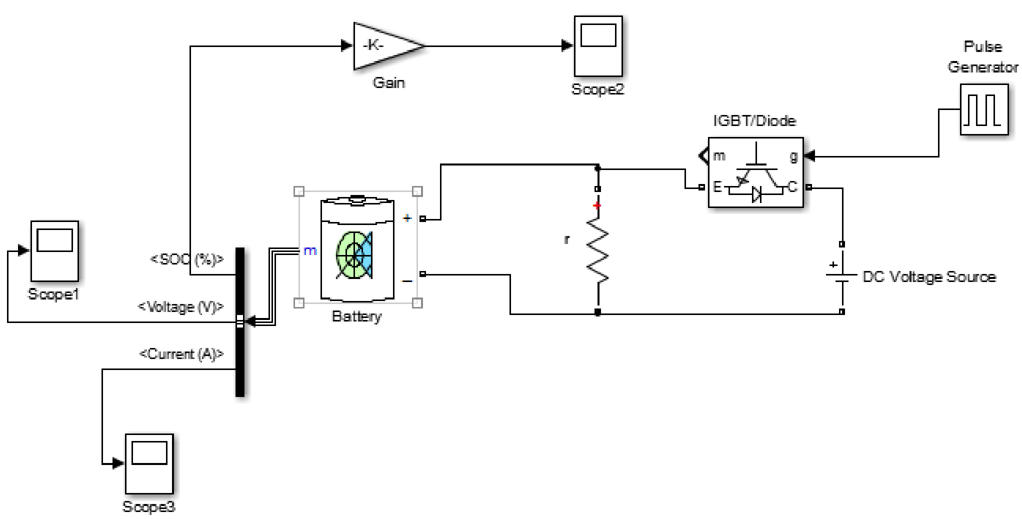


Figure 7.1: Modeling of the Battery Storage System

## 7.2 Functioning of the Charging Circuit

In the above circuit, a voltage source is connected across the battery and the load. It means which ever source is larger, will dominate the other one. Therefore, if dc source is slightly higher than the battery. It charge the battery and supply power to the load as well. IGBT switch is connected to check the charging and discharging. The waveform of SOC and voltage can be seen as –

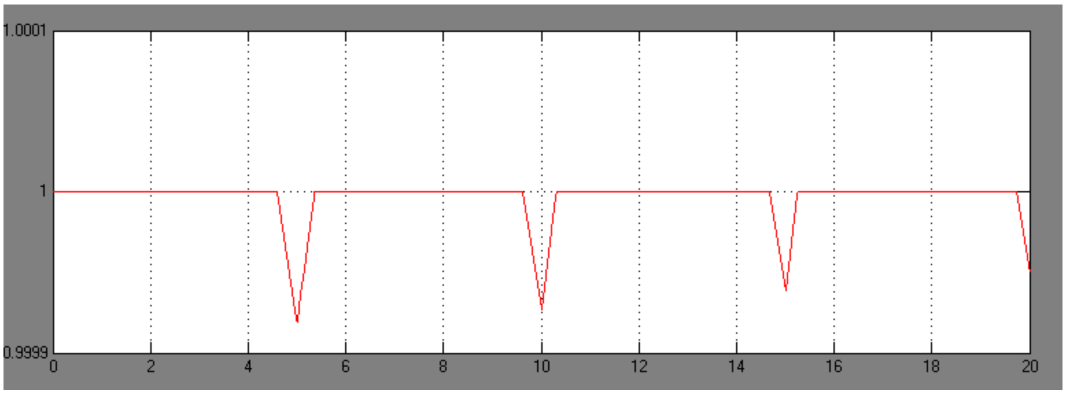


Figure 7.2: Output waveform of SOC characteristics

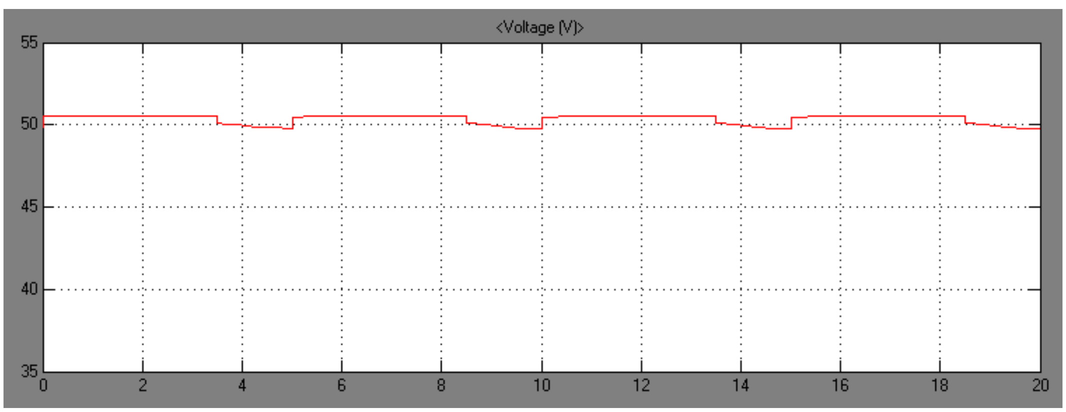


Figure 7.3: Waveform of the Voltage

The trenches in the SOC waveform is showing the discharging and charging of the battery, same trenches can be seen in the voltage waveform.

# Chapter 8

# Integration of sources:

Solar PV panel, Wind Generation, DG set and Battery, four sources have been modeled to supply the load. A single server is taken as load. Actual load is the data centre but the sources are designed to supply a prototype i.e. a single server. According to a site, a server is rated between 150 to 450 watt.

Absence of battery could introduce some serious issues in the system because DG set takes 2.5 seconds to settle down (to constant DC supply). Battery supplied a constant supply to the load, when low current is provided by the sources; battery will supply the current to the load. In case of high currents, battery gets charged at a certain level. The whole behaviour can be seen through the State of Charge characteristics. Trenches in SOC, is the discharging and charging behaviour of the battery. Current rating of the solar system can be increased by connecting same panel in parallel to each other. Similarly voltage rating of the system can be increased connecting panels in series.

## 8.1 Modeling of the integration of sources :

As shown in the modeled diagram, all the sources are connected in parallel, to supply the load. Two single phase circuit breaker are connected for switching purpose for wind turbine and diesel generator set. Initially Solar PV panel and battery would supply the load, and after certain instance wind generation system would supply. At 0.25 seconds DG set would start to supply the load.

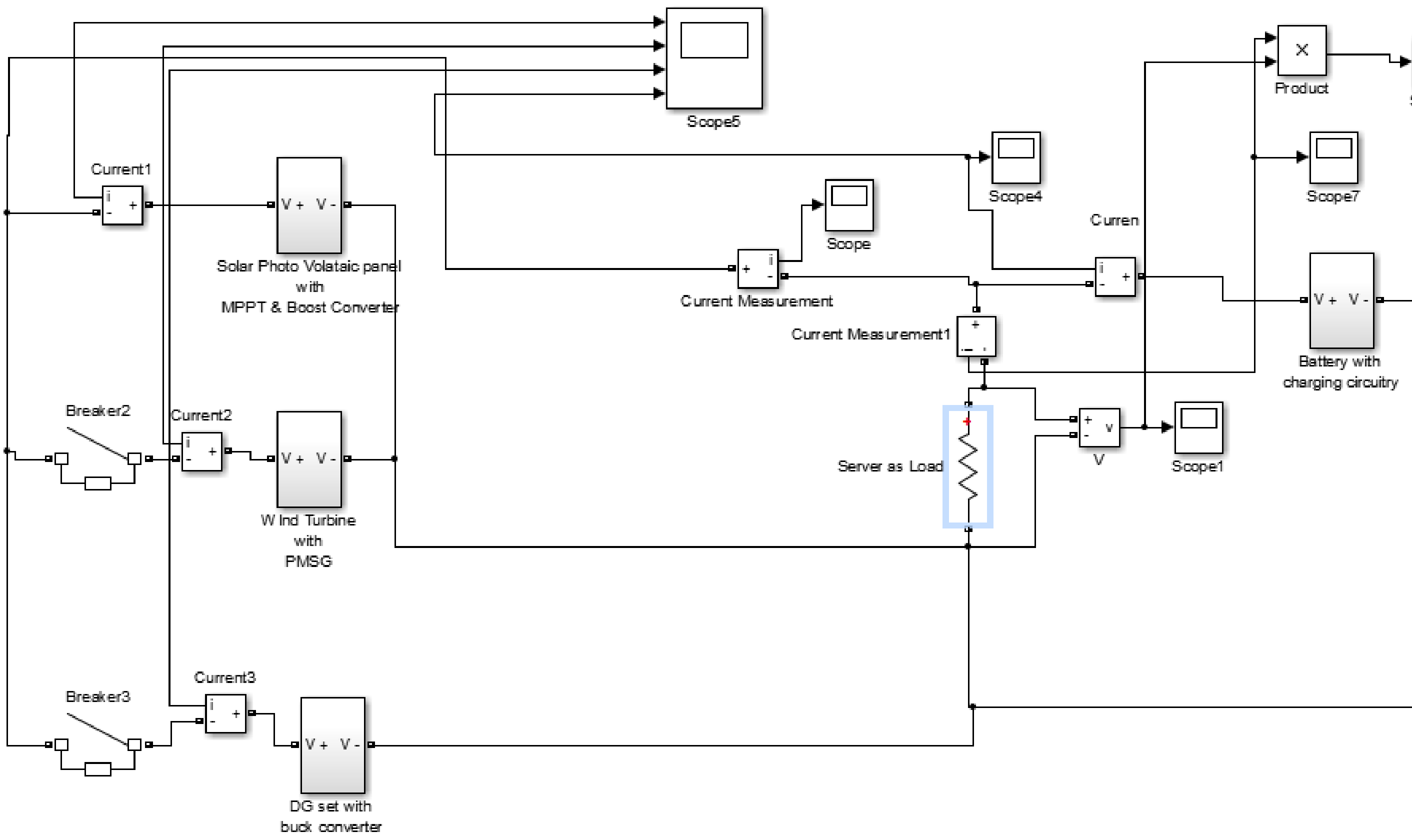


Figure 8.1: Modeled Circuit of Integrated Sources

### 8.1.1 Current Characteristics of the Sources

When the Wind and DG set triggered up, at that instance they introduce large amount of current in the circuit for few milliseconds. In the fig. 8.2, two peaks at 0.2 and 0.3 are due to triggering of the wind generation and DG set.

It can be seen, whenever the current of the battery goes to negative, it shows the charging of the battery and after the settling of the DG set and the Wind generation system, all the four sources supply the load together.

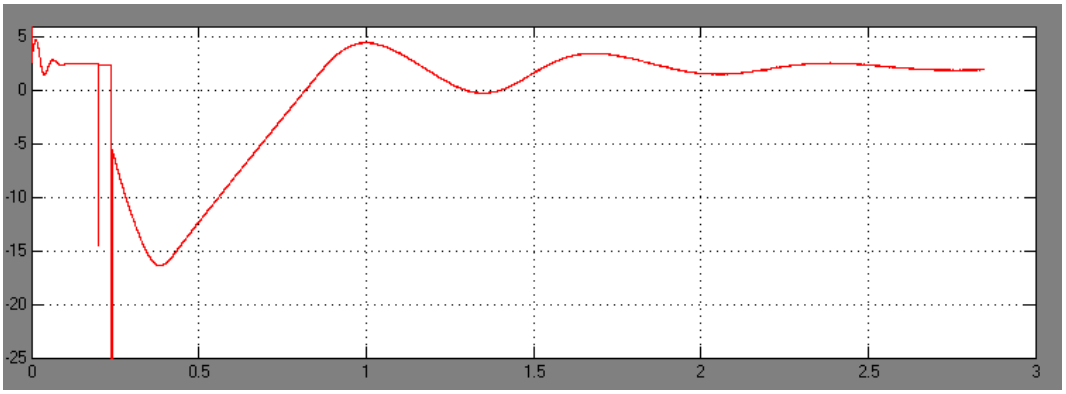


Figure 8.2: Waveform of the Current of Battery

### 8.1.2 SOC characteristics

When the high positive current introduce in the circuit due to the working of all the three sources (Solar, Wind and DG set). This positive current charges the battery. The charging characteristics can be seen by the State of Charge characteristics.
Following waveform shows the SOC of the battery, the trench that can be seen, the negative slope shows the discharging of the battery and positive slope shows charging characteristics.

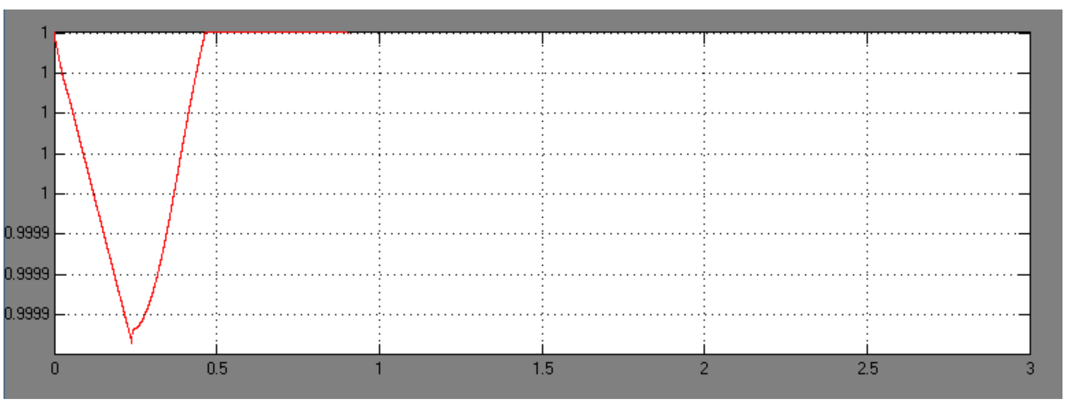


Figure 8.3: Waveform of the SOC

Voltage and current characteristics of the finally output is,

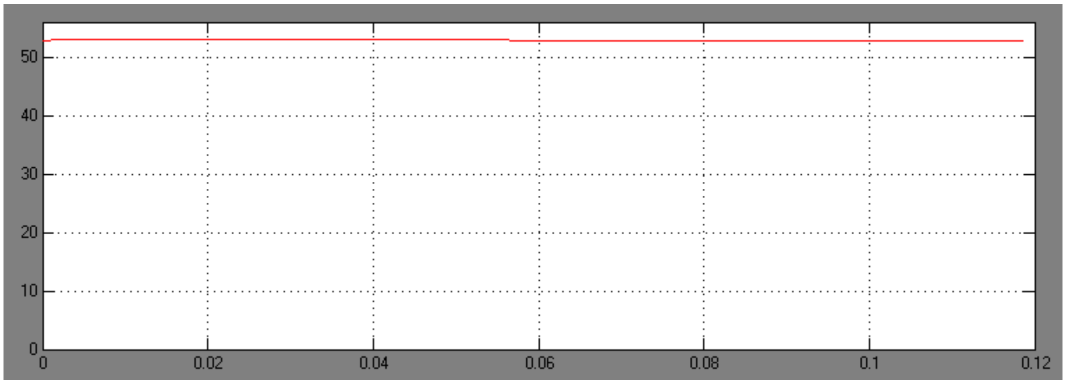


Figure 8.4: Waveform of the Voltage

Voltage is seen to be constant DC. The voltage initially rose to 52V, but it slightly down to 50 volt and be constant at this level. Similarly the value remains constant at 2.5 Amp. Current level is being increased according to the load. If high rating of server is connected then the current will raise i.e. for 250 watt server the current will be 3.5 Amp.

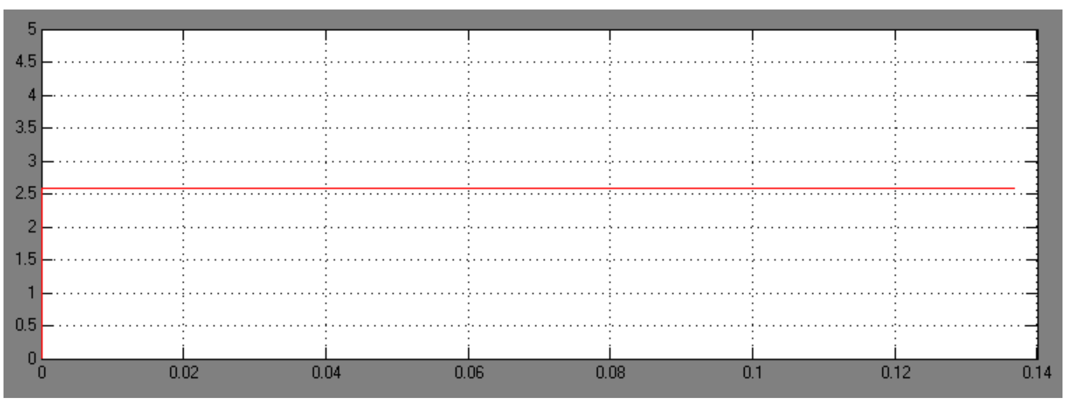


Figure 8.5: Waveform of the Current

# Chapter 9

# Conclusion

Solar PV panel is modeled along with the rectifier circuit and boost converter circuit to fetch a certain level of constant DC. To enhance the systems efficiency MPPT technique is preferred. Perturb & Observe algorithm is used as a MPPT technique, due to fast operation. Through the graph it can be seen that in varying condition of the solar irradiation and ambient temperature MPPT technique holds up the system to the maximum power point(by following a zigzag path).

Perturb & Observe algorithm increase the voltage is steps and check the power on the same step if it more than the previous step in further increased the voltage step. Similarly it follows same procedure to reach the peak and holds the curve there.

Performance analysis of wind turbine with different machine (generator) concludes that PMSG are more efficient, less noisy than others. No excitation or gear system is required for the PMSG. Diode rectifier along with filter is used to get constant DC supply. Uncontrolled rectifier is preferred due to simplicity in the design.

Pitch Angle Controller is designed to make the constant voltage at the generator terminals. It contains proportional controller (for the low rated load), which measures the error (between actual and reference wind speed), to generate the pitch angle $\beta$ of the blades. As the wind velocity changes, the pitch angle changes that makes the output constant, and stable operation in the heavy winds.

DG set with the Governor system (prime mover) is modeled as the third source. Governor system compares the actual speed with the reference speed and makes the system more reliable and stable. Synchronous machine is used as a the generator with the ST2A excitation system.ST2A is more convenient than the others system and helps to mitigate the oscillations of the system.

Battery with the charging circuit is used to maintain the supply for the load. Once the system gets its stability, the battery can operate as the source until its SOC reduced to a certain level (critical point). After that it behaves as a load and gets charged through the circuit. Another advantage of battery is, it maintains the continuation of the supply during maintenance and in the fault condition when any or all three main sources are cut off, immediate supply can be provide by the battery.

Individual circuit breaker is used near the every source that can isolate a particular source in the emergency or fault conditions. Therefore circuit breaker can help to improve the reliability. According to an analysis, in a 450 watt server, 33% of the total power consumed is wasted in the form of heat during conversion from AC to DC. Supplying DC directly to the server can save power as well as money.

# Future Scope

In the future scope, the mathematical stability analysis can be done to calculate the level of stability of the system. For this, transfer function of the whole system has to be determined. By using root locus method the stability of the system can be determined.

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