POWER SYSTEM STUDY OF 25kW SOLAR AND DIESEL GENERATOR BASED MICROGRID

Major Project Report

Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Technology

In

Electrical Engineering

(Electrical Power Systems)

By

Nirankush Prasad
(13MEEE12)

Department of Electrical Engineering
Institute of Technology
NIRMA UNIVERSITY
AHMEDABAD 382 481

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CERTIFICATE

This is to certify that the Major Project Report entitled **'Power System Study Of 25kW Solar and Diesel Generator Based Microgrid"** submitted by **Ms. Nirankush Prasad (13MEEE12)**, towards the partial fulfillment of the requirements for the award of degree in **Master of Technology (Electrical Engineering)** in the field of **Electrical Power System** of Nirma University is the record of work carried out by him under our supervision and guidance. The work submitted has reached a level required for being accepted for examination. The results embodied in this major project to the best of my knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

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Statement of Originality

I, **Nirankush Prasad**, Roll. No. **13MEEE12**, give undertaking that the Major Project entitled "**Power System Study Of 25kW Solar and Diesel Generator Based Microgrid**" submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in **Electrical Power System** of Institute of Technology, Nirma University, Ahmedabad, contains no material that has been awarded for any degree or diploma in any university or school in any territory to the best of my knowledge. It is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. It contains no material that is previously published or written, except where reference has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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Abstract

In recent years, there has been a worldwide growth in the exploitation of renewable energy considering its capacity of generating safe and clean energy. India is also taking renewable energy resources as alternative for future energy needs either grid interacted or as stand-alone system. Among the available renewable resources the most promising and reliable distributed generation is photovoltaic due to excess amount of presence of solar radiation in various parts of India, absence of moving parts in the generation system, less maintenance requirement and possibility of installation using utilized space on rooftops and wastelands around buildings. The thesis consisting the power system studies of the 25kW Solar system with battery storage system and diesel generator which are connected to make DC grid maintained at 500± 1%Vdc. The DC grid is connected to an inverter which was synchronised with the Utility grid maintained at 415 Vac. The simulations performed contains the control strategy and algorithm for load sharing between the photovoltaic, battery storage, diesel generator and Utility Grid for varying weather conditions , and load fluctuations for deciding the power intake from the distributed energy resources(DER). In case of the failure of the Solar system and the battery storage, if it is unable to satisfy the load the diesel generator can be used as a backup to feed the load in standalone grid. In grid connected system the utility grid was used to feed the load in the case failure of all distributed Energy resources. The thesis represents Standalone DC microgird as well as Grid interactive.The coordinated control of AC-DC Hybrid grid has been presented. Harmonics Analysis has been done at Point of common coupling accordingly filter has been designed for harmonics compensation.

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Abbreviations

AC . . . ALTERNATING CURRENT
BS . . . BATTERY STORAGE
DC . . . DIRECT CURRENT
DQ . . . DIRECT-QUADRATURE AXIS
DER . . . DISTRIBUTED ENERGY RESOURCES
DG . . . DIESEL GENERATOR
FFT . . . FAST FORIUER TRANSFORMATION
IC . . . INCREMENTAL CONDUTACNE
PV . . . PHOTOVOLTAIC
SOC . . . STATE OF CHARGE
PCC . . . POINT OF COMMON COUPLING
PLL . . . PHASE LOCKED LOOP
VSC . . . VOLTAGE SOURCE CONVERTER

Contents

Chapter 1

Introduction

1.1 Microgrid

1.1.1 Definition:

A Microgrid comprises of two or more than two energy resources connected with local loads. The distributed resources can be operated autonomously or grid connected to satisfy the desired load demand and mitigation from grid disturbances with islanding. Microgrids now a days are very useful for the electrification of the remote areas or villages. Now a days microgrids are playing important role in the power systems. Various Distributed Energy Resources(DER), loads and energy storage can be integrated with the utility grid at the point of common coupling(PCC) and also can be used as stand-alone systems. Microgrid considered as a small grid based on distributed energy resources. The distributed energy resources may be of few kilowatts or few megawatts.The distributed energy resources available are:

a. Diesel Generator

b. Solar Energy

c. Wind Energy

d. Battery Storage

e. Hydro

f. Biomass

All of the above distributed energy resources are coming more into picture because of their several advantages and disadvantages which are discussed in the next section.

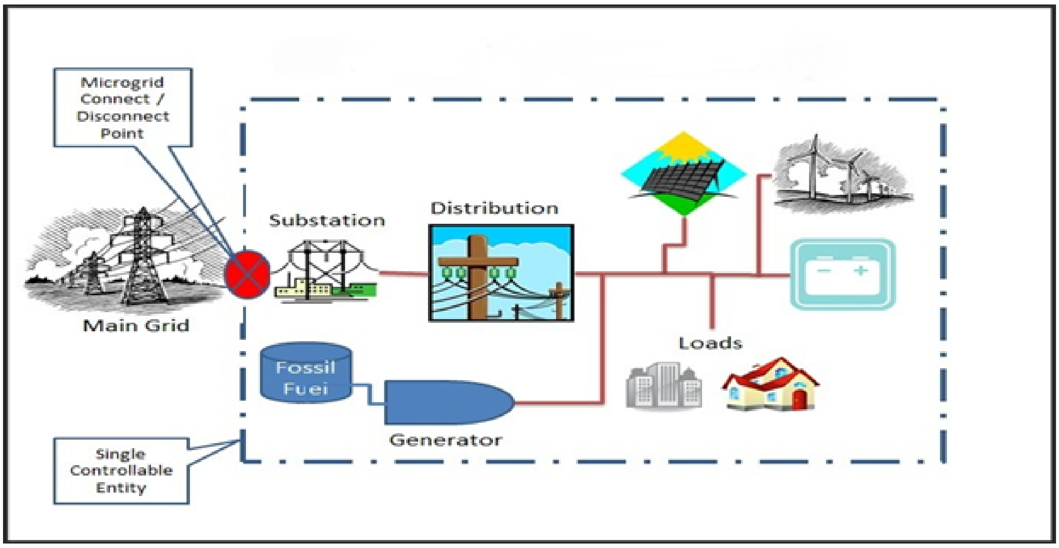


Figure 1.1: Schematic diagram of microgrid

1.1.2 Advantages of Microgrid:

The Microgrid, though it does not replaces the utility grid but have some of the following advantages:

a. Usage of renewable energy resources makes the microgrid more eco-friendly with low carbon emission

b. Lower financial budget

c. Can rely on automation

d. Can be isolated from grid disturbances

e. Easy installations and less maintenance

1.1.3 Disadvantages of Microgrid

a. Increase in the energy demand requires integration of more resources to it , which is a complicated task

b. High level of monitoring and controlling of the microgrid is required where the generating resources and capacity are more

c. For efficient utilisation of microgrid capacity,energy storages are required

1.1.4 Classifications Of Microgrid

a. Microgrid are basically classified in four categories:

b. Remote grids:Because of the geographical locations we have to built the remote grids , places like islands where the energy demand cannot be fulfilled with the national grids.

c. Commercial and industrial grids:The microgrids at the industries can be formed with the help of energy recovered from biomass ,waste heat.

d. Military and security grids: In order to keep data secured in case of failure of utility grid,the militaries are now days adapting the concept of microgrids.

e. Community grids:To meet the energy demand for a smaller region community can implement their own microgrids.

1.2 Motivation

a. The power system studies of microgrid can lead us to some new concepts not only for us but also globally. Because of the involvement of renewable energy resources.It helps to serve the world with more safe, clean, eco-friendly and reliable energy generation.

b. The analysis of the microgrid will help to make it 100% renewable sources based i.e. solar,wind , hydro etc.

c. Power system studies of microgrid have wide area in the field of Research and Development(R& D) like:

    (1) Integration of renewable to the grid
    (2) Synchronisation of various distributed energy resources
    (3) Protection and controlling of distributed resources
    (4) Battery storages systems(BSS)
    (5) Islanding
    (6) Power quality
    (7) Power management

1.3 Thesis Objective

The power system studies of microgrid comprises of 25kW Solar system, battery storage and Diesel generator. The following things will be studied and analyzed :

a. Introduction to microgrid i.e. integration of photovoltaic, battery storage system and diesel generator stand-alone system as well grid interactive

b. Simulation of the individual DC Microgrid components

c. Integration of DC microgrid

d. Response of individual systems in DC standalone grid due to load variations and Varying weather (For PV Systems)

e. Development of control schemes and algorithms for the efficient power sharing between the DC energy resources

f. Involvement of various converter like boost converter for PV system, bidirectional converter for battery, rectifier for Diesel generator

g. Coordinated controlling of AC/DC Microgird

h. Common inverter of DC Grid for AC grid synchronisation

i. Harmonic analysis at Point of Common Coupling(PCC)

j. Filter design for harmonics analysis

1.4 Power system Studies

Power systems studies analyses the power flow from generation to the loads under the controlled actions and protection ; various scenarios were observed during normal and contingency conditions. Network behaviour is captured under the different time of frame from nano seconds to several hours with the help of mathematical models. The power system studies are of the following types:

a. Static

b. Dynamic

c. Transient

The power system studies have the following objectives:

a. Planning & designing of system

b. Controlling and protection of system

c. Technical innovations for the development of new technologies

d. Feasibility studies

e. Best suggested solutions for the problems faced during operating systems

f. Modernization of the existing techniques

1.5 Literature Review

a. **Udaykumar R Yaragatti and Ra jesh P Mandi** [1] The paper entitled Integration of renewable energy systems solar with diesel generator .This paper describes the sizing of solar PV, DG set and battery bank Hybrid Power Systems(HPS) for different configuration for share of diesel & solar power. Different configurations for the integration of solar and PV with diesel Systems.

b. **W. W. L. Keerthipala, Chemmangot V. Nayar and Mochamad Ashari** [2] The paper entitled A Grid-Interactive Photovoltaic Uninterruptible Power Supply System Using Battery Storage and a Back Up Diesel Generator. This paper describes the practical implementation of solar PV systems with the battery storage and using diesel generator as a backup. The laboratory setups are used to analyze the effect of various systems during running conditions. The system incorporates 2.5kW photovoltaic system with 10kVA power conditioning unit and a 300Ah battery.

c. **Ashish Solanki , Qiang Fu and Luis F. Montoya**[3]. The paper entitled Microgrid Generation Capacity Design With Renewables and Energy Storage Addressing Power Quality and Surety. The describes about the IEEE 34 bus distribution feeder system in which the various distributed resources are added .The modelling is done with the help of the PSCAD/EMTDC software.

d. **Eduardo Alegria,Tim Brow, Robert H.Lasseter and Rin Minear** [4] The paper entitled CERTS Microgrid Demonstration With Large-Scale Energy Storage and Renewable Generation. In this paper CERTS Microgrid concepts have been demonstrated at the Alameda County Santa Rita Jail in California. The existing system included a 1-MW fuel cell, 1.2 MW of solar photovoltaic, and two 1.2-MW diesel generators. Adding a 2-MW, 4-MWh storage system, a fast static switch, and a power factor correcting capacitor bank enabled microgrid operation.

e. **Thoshita T. gamage, Xin qui and Tu A. Nguyen**[5] The paper entitled Microgrid application with computer models and power management integrated using power management using PSCAD/EMTDC. This paper consisting of the the computer model based simulations in PSCAD/EMDTC.

f. **Abdulrahman Y. Kalbat**[6] The paper entitled PSCAD Simulation of Grid-Tied Photovoltaic Systems and Total Harmonic Distortion Analysis. The paper explains about the PV-system connected to the grid and modeled in the PSCAD/EMTDC. The model involves all the required components for the AC generation and the trigger of the inverter, six-pulse inverter is used for the inverter process. The paper also investigates about the effect of variation of the temperature on the Photovoltaic system and the power generation.

g. **Indrani Maity and Shrisha Rao** [7].The paper named Simulation and Pricing Mechanism Analysis of a Solar-Powered Electrical Microgrid. This paper explains about the coordination of the solar energy and the battery storage and the about the storage capacity of the battery. The simulation also explains about the pricing mechanism required of electrical microgrid.

h. **Kai Strunz, Ehsan Abbasi, and Duc Nguyen Huu** [8] The paper entitled DC Microgrid for Wind and Solar Power Integration. This paper explains Operational controls are designed to support the integration of wind and solar power within microgrids. An aggregated model of renewable wind and solar power generation forecast is proposed to support the quantication of the operational reserve for day-ahead and real-time scheduling.

Chapter 2

25kW Photovoltaic system

2.1 Introduction

2.1.1 Solar panel

The solar cell is made up of the pn-junction diode which is used for the conversion of light into electricity. The collection of the solar cells forms the Arrays and arrays are electrically coupled to form and solar panel. Solar panels consisting of solar cell connected in series or in parallel for higher voltage, current and power. In the recent years highly sustainable and reliable solar panel were developed due to increase in the interest of the renewable energy resources. Crystalline solar cell have open circuit voltage. The photovoltaic system which is to be analyzed in the thesis work will be of 25kWp. The analysis will be performed in such a way that it can be implemented practically.

2.2 Mathematical Model of PV Module:

The mathematical modelling of the PV array is show in the figure below where, Equivalent circuit for PV module showing the diode and ground leakage currents. where,
I_{ph} = Cell photocurrent,
R_s=intrinsic series resistance
Ideally,

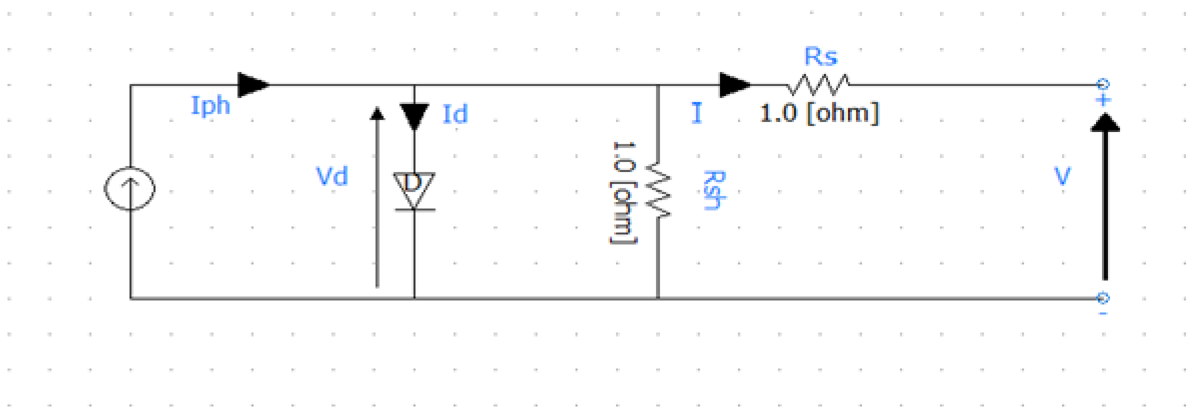


Figure 2.1: Mathematical Model of PV panel

Ideally $R_s = 0$ (no series resistance) and $R_{sh} = \infty$ (no leakage to ground) Practically R_s varies between 0.05 and 0.01 Ω and R_{sh} varies between 200-300 Ω

The open circuit voltage of the PV cell is given as:

$$V_{oc} = V + IR_{sh} \tag{2.1}$$

The diode current is given as:

$$I_d = I_D[e^{\frac{QV_{oc}}{AkT}} - 1] \tag{2.2}$$

Where,
I_D = the saturation current of the diode;
Q = electron charge = $1.6 * 10^{-19}C$
K= Boltzmann constant= $1.38 * 10^{-23}J/^oK$
PV cell are grouped in a large units which are known as PV module and they are further interconnected in a series parallel pattern to form PV array.The photovoltaic panel can be modelled mathematically by equation as:
Module photo current:

$$I_{ph} = [I_{scr} + K_i(T - 298)] * \lambda/1000 \tag{2.3}$$

Module reverse saturation current:

$$I_{rs} = I_{scr}/[exp(qV_{oc}/N_s kAT) - 1] \tag{2.4}$$

The module saturation current I_0 varies with the cell temperature, which is given by

$$I_0 = I_{rs}[\frac{T}{T_r}]^3 exp[\frac{Q * E_{go}}{Bk}(\frac{1}{T_r} - \frac{1}{T})] \tag{2.5}$$

The current output of PV module is:

$$I_{pv} = N_p * I_{ph} - N_p * I_0[exp(\frac{Q * (V_{pv} + I_{pv}R_s)}{N_s kAR}) - 1] \tag{2.6}$$

where,

I_{pv} = output current of a PV module (A)

V_{pv} = output voltage of a PV module (V)

T = the module operating temperature in Kelvin

T_r = the reference temperature = 298 K

I_{ph} = the light generated current in a PV module (A)

I_0 is the PV module saturation current (A)

Q is Electron charge = $1.6 * 10^{-19}$ C

A = B is an ideality factor = 1.6

k is Boltzman constant = $1.3805 * 10^{-23}$ J/K

R_s = the series resistance of a PV module

I_{scr} = the PV module short-circuit current at $25^o C$ and $1000 W/m^2$ = 2.55A

Ki = the short-circuit current temperature co-efficient at

I_{scr} = 0.0017A / $^o C$

λ = the PV module illumination (W/m^2)= $1000 W/m^2$

Ego is the band gap for silicon = 1.1 eV

Ns = the number of cells connected in series

Np = the number of cells connected in parallel

2.3 Maximum Power Point Tracking

Due to varying weather conditions like temperature, irradiance, cloud transients the PV system have irregular V-I characteristics and have a unique maximum power point. With respect to the changing weather conditions we need to track the maximum power output by an PV array. Various algorithms are present for Tracking the Maximum power namely :

a. Incremental conductance

b. Perturb and observe

c. Hill Climbing

Irradiance and temperature are the two main factors for deciding the maximum power point, which depends on the weather conditions. The MPPT algorithms may differ from each other in respect to cost, efficiency ,complexity and types and various sensors required. In the thesis the incremental conductance method has been used because of its less complexity and maximum efficiency in our thesis Incremental Conductance is used because of its efficient response

2.3.1 Incremental Conductance

The Incremental Conductance (IC) algorithm was implemented to overcome the drawbacks of other tracking algorithms method and its maximum efficiency as it acts more faster than other algorithms was proposed in order to overcome the drawbacks of the PO algorithm when subject in varying weather conditions .It measures the volatge and current and sets conductance I/V and incremental conductance dI/dV and decides the left or right operating point of the MPP respectively.

2.3.2 Working Principle

Principle of the Incremental conductance algorithm depends on MPPT depends on the power curve. The of the IC method relies on the fact that the slope of the PV panel power curve is negative on the right of the MPP, zero at the MPP and positive on the left of the MPP as follows:

a. $dP/dV > 0$ Left of MPP (V<VMPP)

b. $dP/dV = 0$ at MPP (V=VMPP)

c. $dP/dV < 0$ Right of MPP (V>VMPP)

d. $dI/dV < - I/V$ Right of MPP

e. $dI/dV > - I/V$ Left of MPP

f. $dI/dV = - I/V$ At MPP

The IC provides enough information for locating the Maximum power point and is made possible by respective comparison and measurement of dI/dV and I/V and VMPP is the set-point reference voltage corresponding to the MPP at which the PV module is required to operate. The detailed working principle of the IC algorithm can be understood by means of the following flowchart.

2.3.3 Advantages of IC Algorithm

The benefits of the IC method can be summarized as follows:

a. It is more efficient than other algorithms at varying solar irradiation

b. Requires only voltage and current measurement devices, for comparing the change in voltage and current because of the varying weather conditions

2.3.4 Disadvantages of IC Algorithm

The drawbacks of the IC method are as follows:

a. Complexity of IC algorithm is more as comparison with the other algorithms.

b. Compulsory measurement of PV voltage and current is required.

c. When the fixed step increment is decreased to improve the accuracy of tracking, dynamic performance suffers because the system slows.

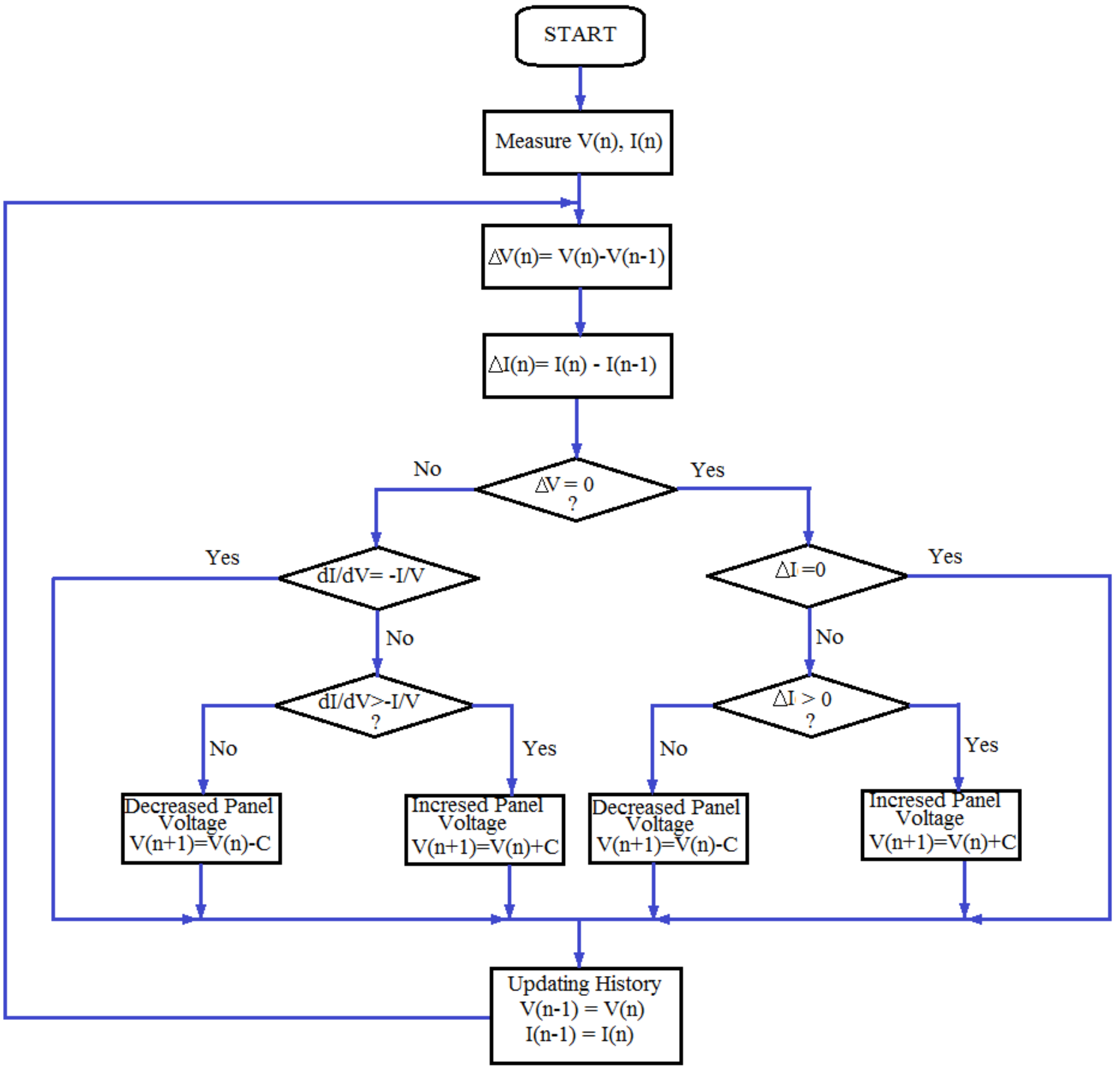


Figure 2.2: Incremental Conductance Algorithm

2.4 Boost Converter

Generally the output of PV panel is very low and it changes according to the atmospheric condition. So in order to make DC link voltage Vdc constant irrespective of the change in input from PV panel an additional stage is used i.e. Boost converter is used to boost up the voltage at a constant level irrespective of the change in input. Fig. below shows the circuit diagram of boost converter. A proper design and selection of each component is done.

Boost Mode

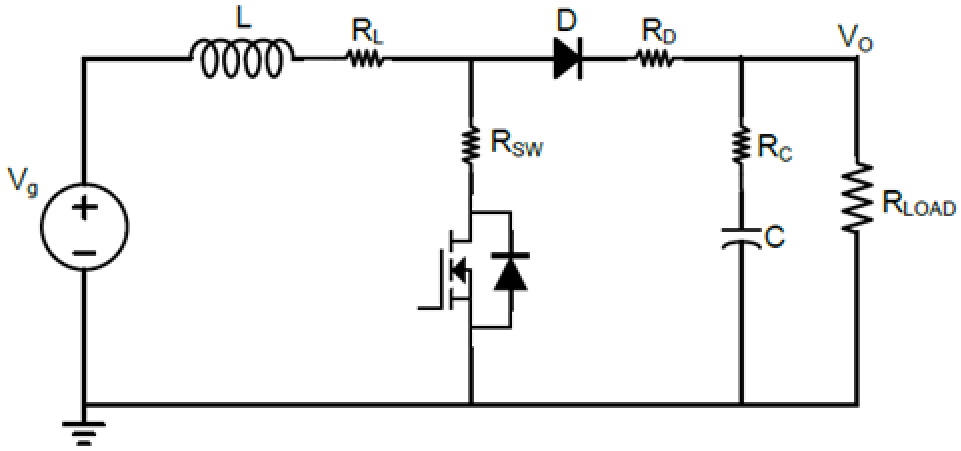


Figure 2.3: Circuit Diagram Of Boost Converter

a. Power output, $P_{(out)} = 25$KW

b. Output Voltage, $V_{(out)} = 500$V

c. Input Voltage, $V_{(int)} = 307$V

d. Load Current, $I_o = 50$A

e. Load Resistance, $R_o = 10$ ohm

f. Voltage ripple V_r= 1V %

g. Switching frequency = 5 KHz(Fs)

$$dutycycle = 1 - \frac{V_{input}}{V_{output}} \tag{2.7}$$

$$= 1 - \frac{307}{500} \tag{2.8}$$

$$D = 0.3860 \tag{2.9}$$

Inductor Design

$$L_s = \frac{R_1(1-D)^2}{2 * f_s} \tag{2.10}$$

$$L_s = 3.770010^{-6} H \tag{2.11}$$

Capacitor Design

$$C = \frac{D}{V_{out}} * \frac{V_r}{R_{load}} \tag{2.12}$$

$$C = 1.816 * 10^{-6} F \tag{2.13}$$

2.5 Simulation Results

The parameter for the 25kw solar panel has been taken from TATA POWER-TS 250, 100 panels were connected 10 panel in series and 10 in parallel.

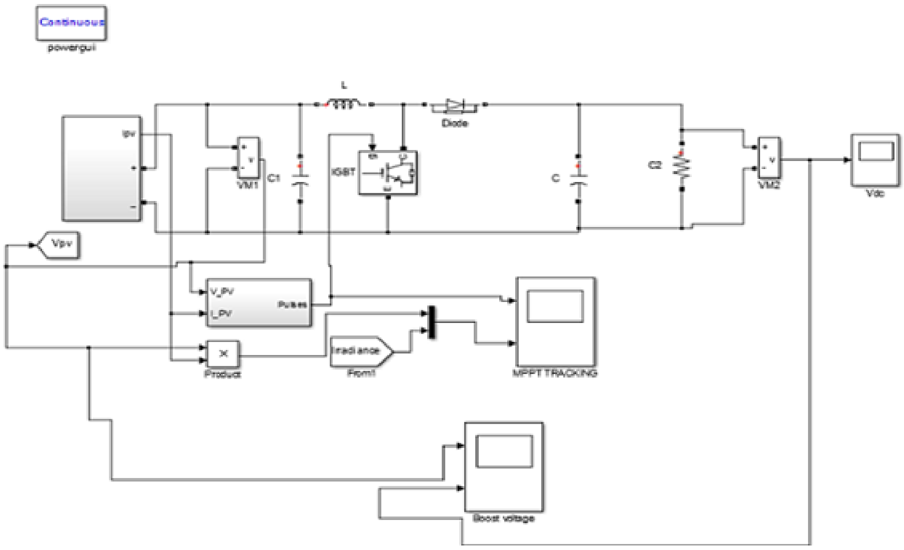


Figure 2.4: Simulation block of 25kW Solar Panel

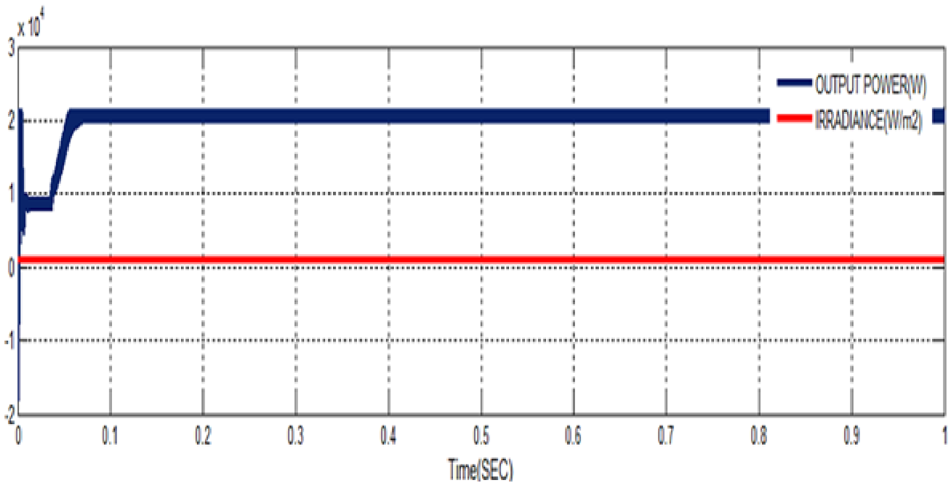


Figure 2.5: Power output of Solar Panel

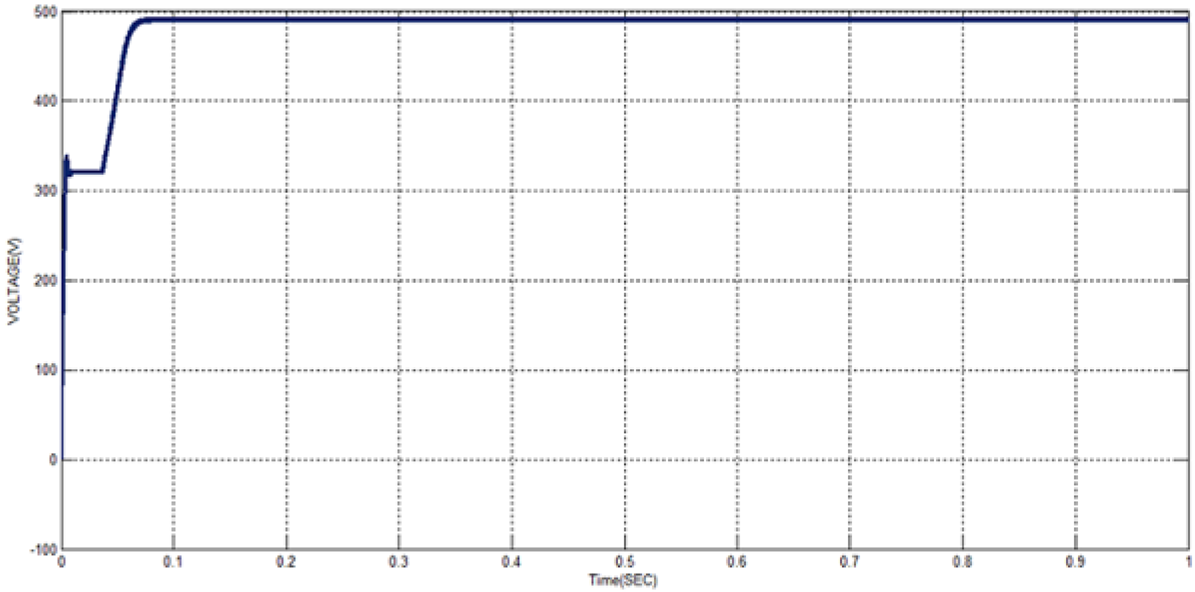


Figure 2.6: Dc grid voltage after PV MPP Tracking

Table 2.1: 25kW PV panel parameters

Number of modules connected in series	10
Number of modules in parallel	10
Reference irradiation	1000
Reference cell temperature	25
Voltage at Pmax Vmpp (V)	307
Open-circuit voltage VOC (V)	381
Short-circuit current ISC (A)	85.8
Current at Pmax Impp (A)	81.6
Diode ideality factor	1.5
Band gap energy	1.103

2.6 Summary

The simulation of 25kW Solar system has been carried out in MATLAB Simulink Environment. Voltage of the PV panel has been maintained at 500 Vdc after the voltage boost up using Incremental Conductance Algorithm.

Chapter 3

Battery storage

3.1 Introduction

Battery storage plays a important role to satisfy the load demand at the consumer end , for storing immediately the electric energy battery storage are used by electrical engineers. There are four rechargeable batteries were present in the MATLAB library namely : Nickel-Cadmium(Ni-Cd) , Lithium ion(Li-Ion) ,lead acid and metal hydride(Ni-MH). The efficiency of rechargeable batteries are around 90-95 %. Important terminologies related to the battery are as follows:

a. **State of charge (SOC):** It express the present percentage of maximum capacity.

b. **Rated capacity (Ah):** It is defined as how much Fully charge battery can deliver in terms of ampere-hours.

c. **Nominal Voltage (V):** Under normal operating conditions the voltage that a battery have.

d. **Charing rate (C rate) :** In one hour the amount of current that battery can deliver.

e. **Internal resistance (ohm) :** Thevenin Resistance of battery.

3.1.1 Need for battery Storage

The battery storage system has been needed for the following purposes

a. Uninterruptable Power Supplies UPS)

b. Battery Energy Storage System (BESS) to be installed in power grids for the purpose of compensating reactive power.

c. For storing the Renewable energy of the PV panel which can be further utilised.

d. Batteries are the main energy source of electric vehicles.

e. Mitigating the load demand whenever the PV is unable to supply power according to the load .

f. Energy storage for future needs

g. Clean Energy

3.2 Mathematical modelling

The basic equivalent battery circuit is represented by shepherds equations as: The voltage at the battery terminal is calculated as :

$$E_{bat} = E_0 - K^{\frac{1-soc}{soc}} * Q + Ae^{(1-soc)*Q} \tag{3.1}$$

$$V_{bat} = E_{bat} - I_{bat} * R_{bat} \tag{3.2}$$

where,

E_{bat}: Internal Voltage(V) E_0: Battery Voltage constant(V) V_{bat}: Terminal Voltage SOC: State of charge Polarisation Constant (V/Ah) I_{bat}(A): Battery current A (V): Exponential Amplitude B (1/Ah): Exponential Time constant inverse Q: Battery Capacity

3.3 Bidirectional converter

The bidirectional converter consisting of two mode

a. **Boost Mode**

   The Voltage of the battery is 96V hence we need to boost up the voltage around 500Vdc according to our need , it has been performed using the boost converter.

b. **Buck Mode**

   The buck mode is used for voltage set down for the charging purpose ,When the load demand is low the PV system will be used for battery storage charging.

The boost mode is used for voltage boost up as our battery is of 96 V and we need to boost it up to 500Vdc .The boost mode is used for mitigating load demand whenever the PV system is unable to supply the load and the buck mode is when the load demand is low the PV will charge the battery.[9]

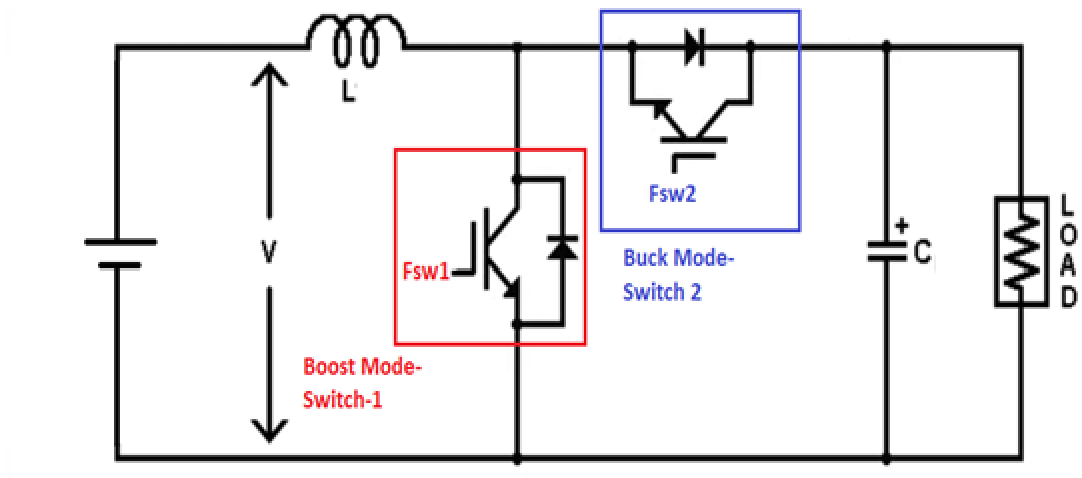


Figure 3.1: DC-DC Bidirectional Converter

Note : In Boost mode Switch-1 will be closed for battery discharging and in Buck mode Switch-2 will be closed for battery discharging.

3.3.1 Boost Mode

a. Power output, $P_{(out))}$ = 25kW

b. Output Voltage, $V_{(out))}$ = 500V

c. Input Voltage, $V_{(int))}$ = 96V

d. Load Current, I_o = 50A

e. Load Resistance, R_o = 10 ohm

f. Voltage ripple = 1V

g. Switching frequency = 5 kHz(Fs)

$$Dutycycle = 1 - \frac{Vinput}{output} \tag{3.3}$$

$$= 1 - \frac{96}{500} \tag{3.4}$$

$$D = 0.808 \tag{3.5}$$

Inductor Design

$$L_s = \frac{R_1(1-D)^2}{2 * f_s} \tag{3.6}$$

$$L_s = 3.6864 * 10^{-5} H \tag{3.7}$$

Capacitor Design

$$C = \frac{D}{V_{out}} * \frac{R_e}{R_{load}} \tag{3.8}$$

$$C = 1.816 * 10^{-6} F \tag{3.9}$$

3.3.2 Buck Mode

a. Source Voltage,V_s = 500V

b. Output Voltage, V_o= 96V

c. Load Current, I_o=50A

d. Switching frequency = 5kHz,Fs

e. Voltage ripple = 1V

f. Load resistance = R_o

$$R_o = \frac{V_o}{I_o} = 1.92 DutyCycle, D = \frac{V_o}{V_0 + V_s} = \frac{96}{96 + 500} = 0.1610 \tag{3.10}$$

Inductor Design

$$L_1 = \frac{10 * (1 - D)^2}{2 * f_s} = \frac{10 * (1 - 0.1610)^2}{2 * 5000} \tag{3.11}$$

$$L_s = 1.355 * 10^(- 4x) H \tag{3.12}$$

Capacitor Design

$$C = \frac{D}{V_{out}} * \frac{R_e}{R_{load}} \tag{3.13}$$

$$C = 1.616 * 10^(- 6) F \tag{3.14}$$

Note: From above both calculation of buck and boost,highest value of inductor and capacitor are selected.

3.4 Simulation results

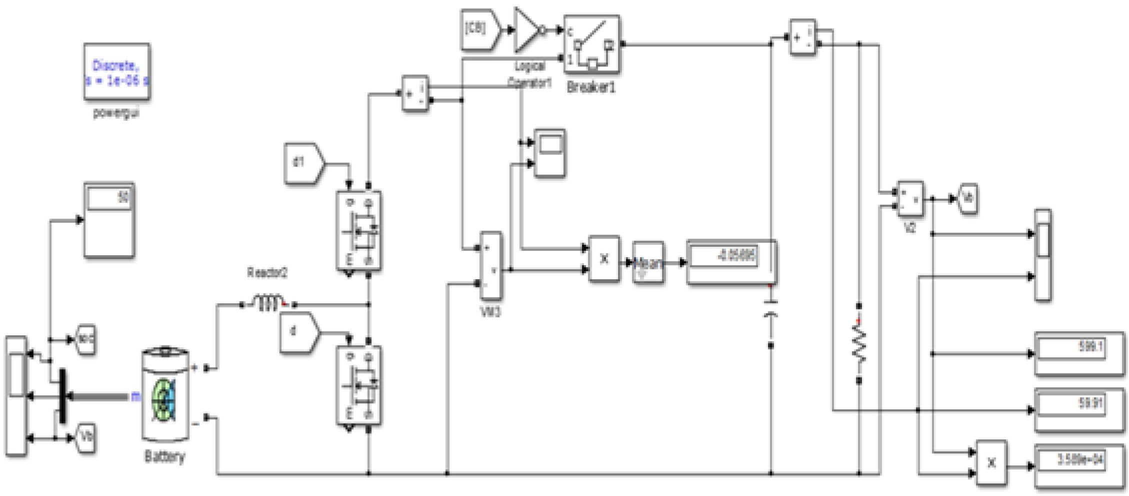


Figure 3.2: Battery simulation block

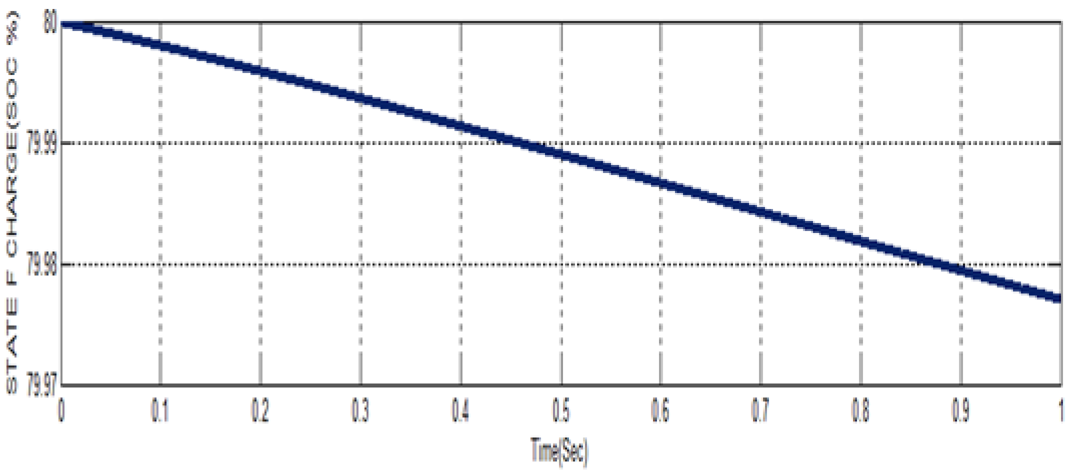


Figure 3.3: Battery State of charge

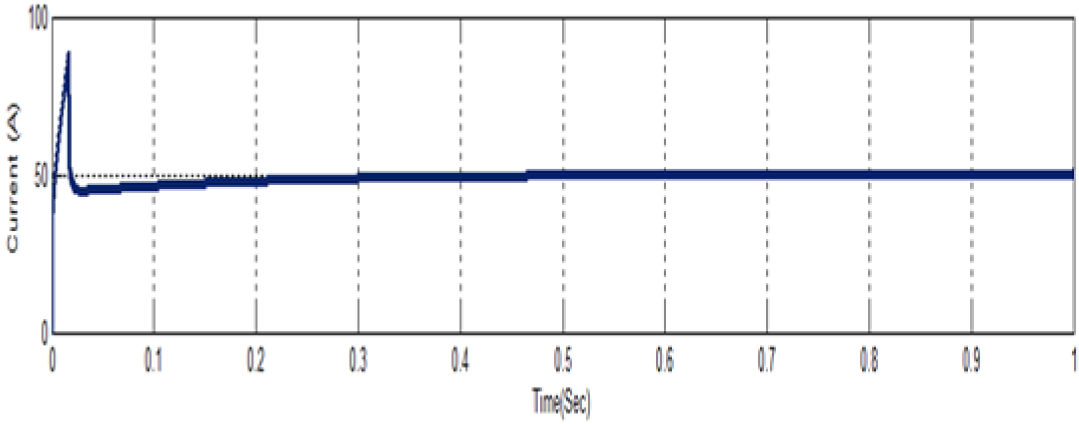


Figure 3.4: Battery output current at load end

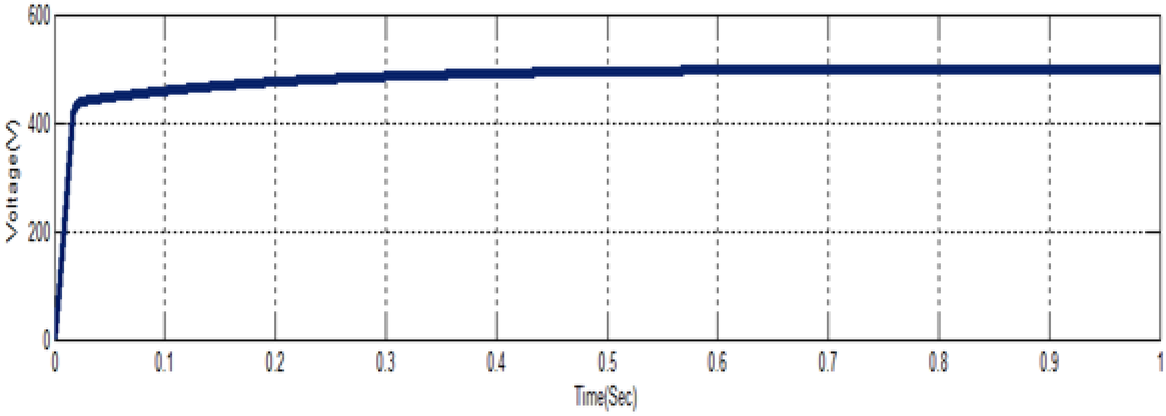


Figure 3.5: DC link Voltage after boost up

Table 3.1: Battery Parameters

Battery Type	Lithium Ion
Nominal Voltage(V)	96
Rated Capacity(Ah)	262
Initial SOC(%)	80
Maximum Capacity (Ah)	262
Fully Charged Voltage (V)	111.7428
Nominal Discharge Current (A)	113.913
Internal Resistance (Ohms)	0.0013
Capacity (Ah) at Nominal Voltage	236.9391
Exponential [Voltage (V)]	103.717
Exponential [Capacity (Ah)]	12.87217

3.5 Summary

The battery storage has been simulated for 260Ah,96V in the MATLAB software and bidirectional converter has been built for the battery charging and discharging. The bidirectional converter worked in both boost as well as buck mode. The battery is satisfactorily maintaining the 500 Vdc at the load end.

Chapter 4

Diesel generator

4.1 Introduction

A diesel generator is a combination of two components:

a. Engine (The Driver)

b. Alternator (The Driven)

The diesel generator comprises of the following things as shown in the figure below.

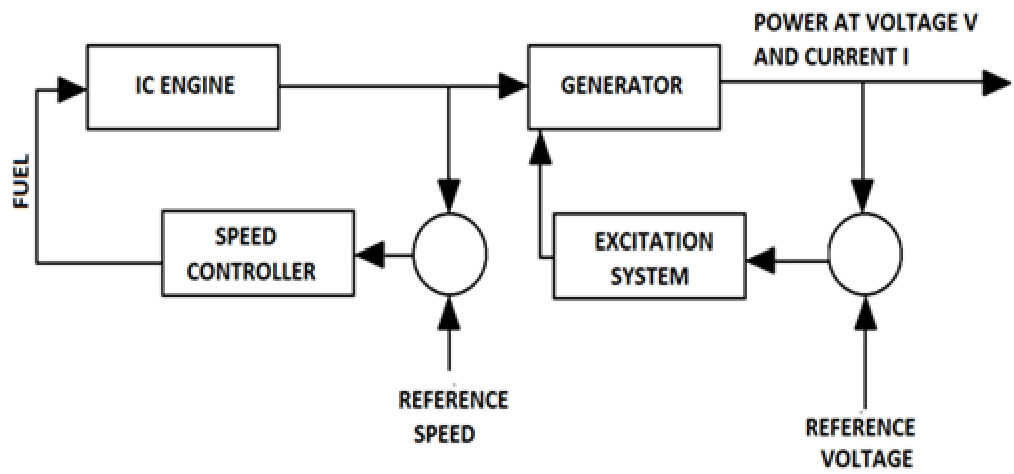
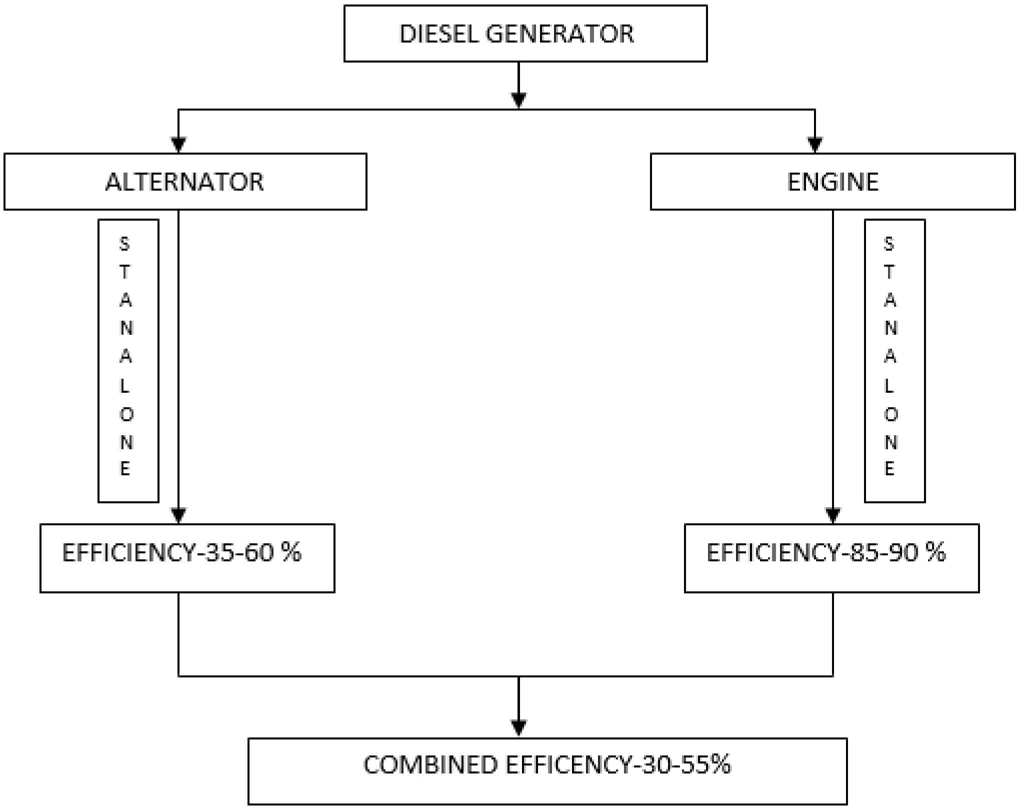


Figure 4.1: Components and control of diesel generator

Among distributed Energy Resources for remote location , the Diesel engines are one of the most promising Source. There are two types of diesel generators are involved these days:

a. Otto cycle engine

b. Diesel cycle engine



The efficiency mainly depends on the

a. Design

b. Size

c. Mechanism

d. Capacity

e. Cooling mechanism

f. Construction material

The efficiency may deviate during operation because of the following reason:

a. Loading Conditions

b. Ambient Conditions

c. Maintenance and Operation

4.2 Components

4.2.1 Synchronous generator

Commonly used alternators are synchronous machines in power systems. the alternators are used to convert mechanical energy into electrical energy supplied by prime mover. The synchronous generator data has been taken according to the Eliiott Magnetek-model- 25 RD,25kW

4.2.2 Diesel Engine and governor System

The diesel engine and the governor system are available MATALB library with Typical Parameters are selected for Diesel engine and governor system. The diesel engine is supposed to provide the power to the generator and the speed is controlled by the means of governor system consisting of output of the Diesel engine is the mechanical torque and take as fuel input and shaft speed as input.

4.2.3 Excitation system

The Excitation system is the combination of regulator and exciter .As the manufactures does not provides the parameters most of the typical values are used as described in [9] parameters are not necessary.AC5A has been used in the simulation work..The excitation system have the following components,

a. Exciter

b. Voltage regulator

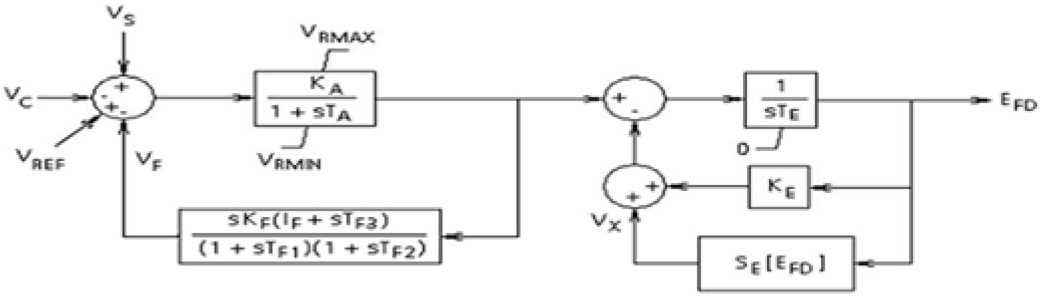


Figure 4.2: Transfer function model of the AC5A

Table 4.1: AC 5A Excitation Parameters

Parameter	Value
Exciter time constant,Te	0.8(s)
Regulator amplier time constant, Ta	0.02 (s)
Regulator stabilizing circuit time constant(Tf1,Tf2,Tf3)	(1 , 0 , 0) (pu)
Regulator gain	400 (pu)
Regulator stabilizing circuit gain, Kf	0.03 (pu)
Exciter constant related to self-excited eld,Ke	1.0 (pu)
Saturation at EFD1	0.86 (pu)
Saturation at EFD2	0.5 (pu)
Excitation voltage for SE1	5.6 (pu)
Excitation voltage for SE2	4.2 (pu)
Maximum regulator output	7.3 (pu)
Minimum regulator output	-7.3 (pu)

4.2.4 Rectifier

The diesel generator is a 3-phase AC voltage source which has been connected to an rectifier for converting the AC to DC. The rectifier consisting of 3 leg with 2 diodes in each leg. Uncontrolled rectifier has been used. The DC voltage converted will be approx 1.35 times to the AC input voltage. The diesel generator Output AC is converted to DC because it will be easier to integrate with PV and Battery DC link.

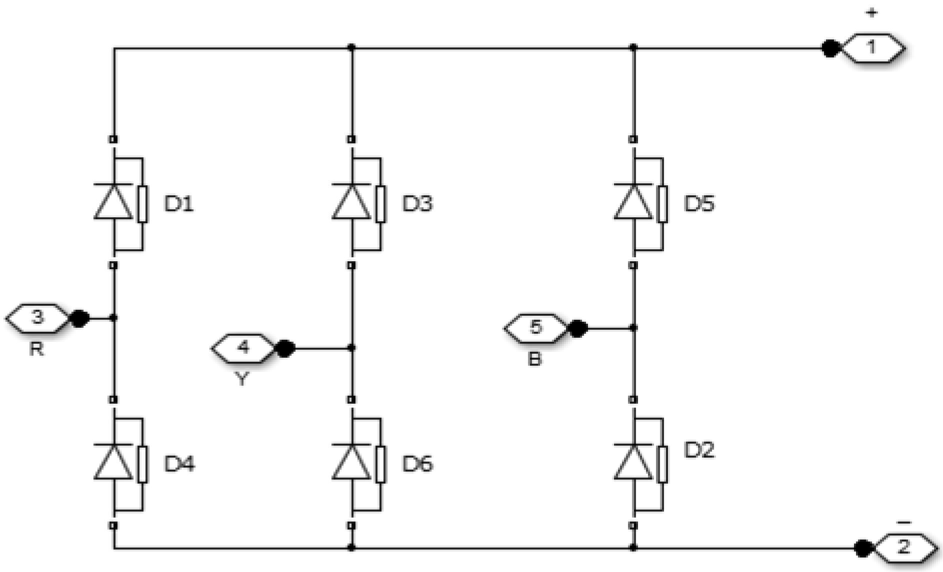


Figure 4.3: Rectifier

4.3 Simulation Results

For the simulation of the 25kW diesel generator,the parameter are taken from Eliiott Magnetek-model- 25 RD,25kW.

Table 4.2: Diesel Generator Parameters

Nominal power, line-to-line voltage (P)	25kW
line-to-line voltage(V)	400Vrms
Frequency (Hz)	50Hz
D-Synchronous Reactance Xd (pu)	3.772
D-Transient Reactance Xd'(pu)	0.286
D-Sub Transient Reactance Xd'(pu)	0.222
Q-Synchronous Reactance Xq'(pu)	1.06
Q-Transient Reactance Xq' (pu)	0.177
leakage reactance Xl (pu)	0.052
short-circuit time (Td')	3.7
d-axis transient open-circuit (Td")	0.05
d-axis subtransient open-circuit (Tqo")	0.05

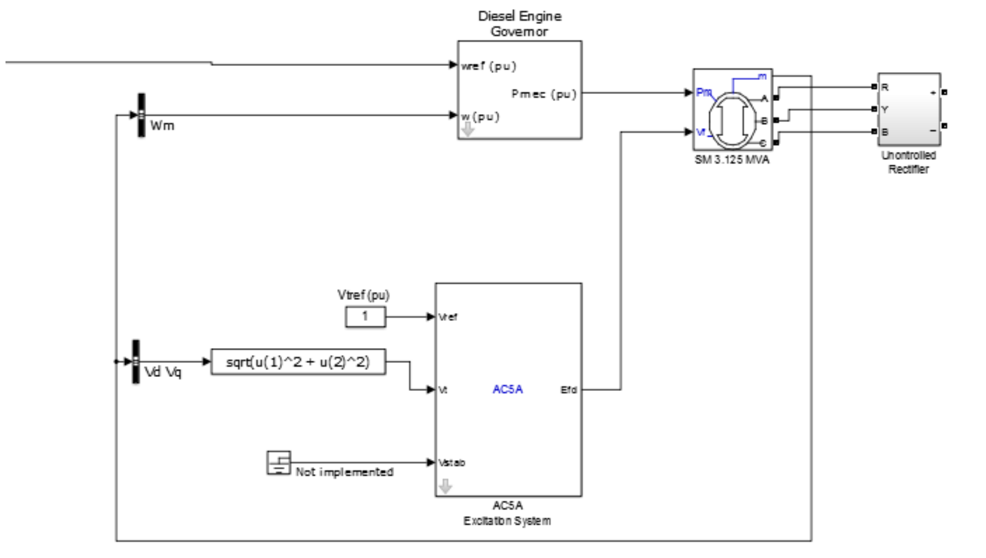


Figure 4.4: Simulation block of Diesel Generator

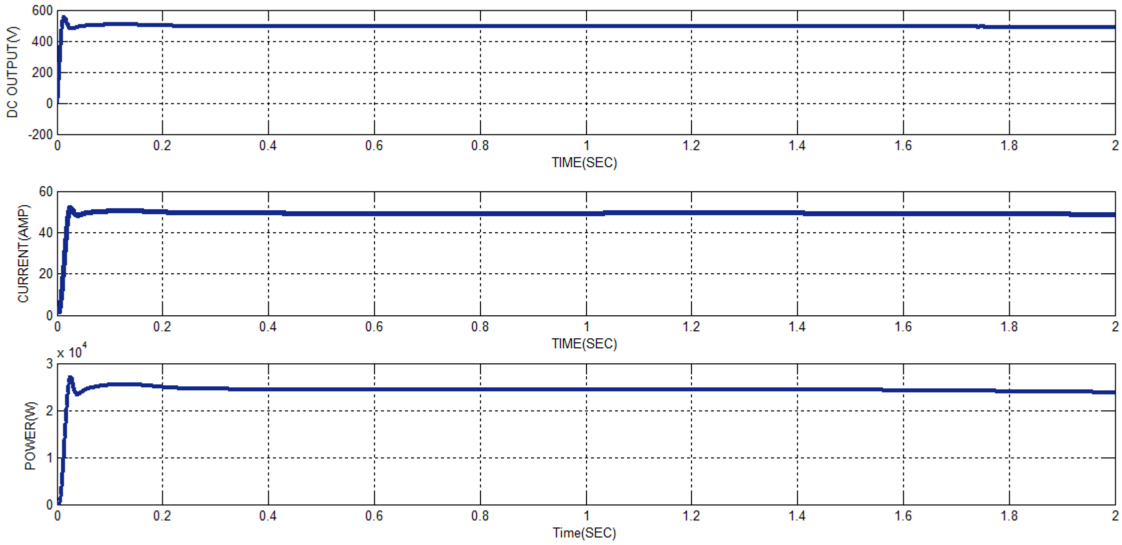


Figure 4.5: Diesel Generator Output

4.4 Summary

The diesel generator has been simulated in MATLAB according to the datasheet of 25kW.The Rectification of the AC to DC has been done with the help of rectifier. The role of the diesel generator is to run in back up after the PV system and battery storage failure.

Chapter 5

DC Standalone Microgrid

5.1 Introduction

The DC grid made in previous simulation was maintained at $500 \pm 1\%$ Vdc. In DC microgrid, the integration of the distributed resources are easier than AC Grid as in AC grid we need to take care all parameters like phase angle, phase sequence and frequency for integration and synchronisation.

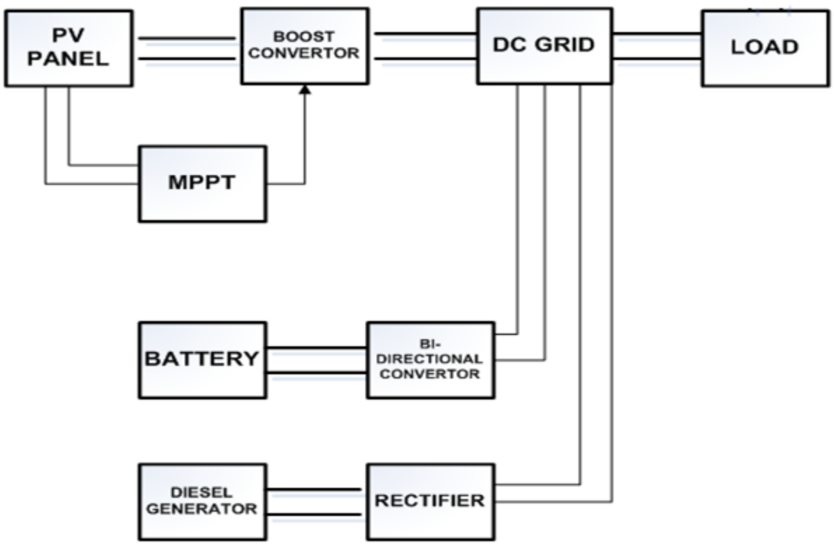


Figure 5.1: DC Standalone Microgrid

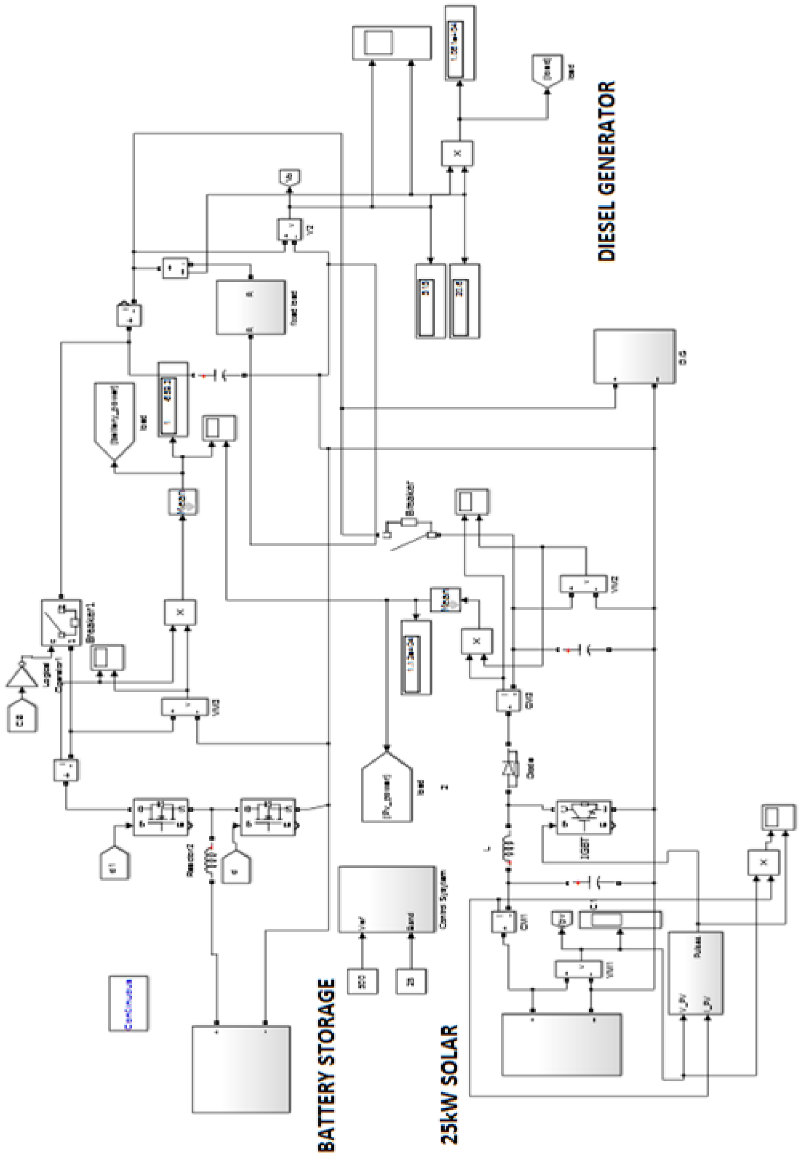


Figure 5.2: Standalone Microgrid

5.2 Controlling scheme and algorithm

Control strategies has been implemented in our simulation for the load sharing among the distributed energy resources i.e. PV system , battery and diesel Generator. Two types of controlling has been used for the PV and Battery Storage and Circuit Breaker Controlling for diesel generator has been implemented.

5.2.1 Hysteresis band

The hysteresis band used in our simulation is having band gap from 500 ± 1 % Vdc, The band gap allowed for the DC link Voltage is ± 1% Vdc, The range for the simulation purpose is taken from 495 to 505 Vdc. It is used for setting up a range for the voltage fluctuations.

5.2.2 Constant Voltage Control

The constant Voltage Control used for keeping the DC link voltage within the hysteresis band at constant voltage accordingly the charge and the discharge of the battery will be decided.

5.3 Control Algorithms

5.3.1 Algorithm for PV and Battery (For Case-1 & Case-2)

a. **Step-1:**DC source taken-PV and battery

b. **Step-2:** Desired DC Grid Voltage- 500Vdc

c. **Step-3:** Assumed Voltage/ Reference voltage- 500Vdc

d. **Step-4:** Take voltage ripple or band gap = ± 1%V

e. **Step-5:** Compare DC link voltage with band gap

f. **Step-6:** The constant voltage control will be used to sense the DC link voltage

g. **Step-7:** If the DC link voltage > Limit, The battery will charge from PV system(buck mode)

h. **Step-8:** If DC link voltage < Limit , The battery will Discharge(Boost mode)

i. **Step-9:** The DC link Voltage is maintained within the limits

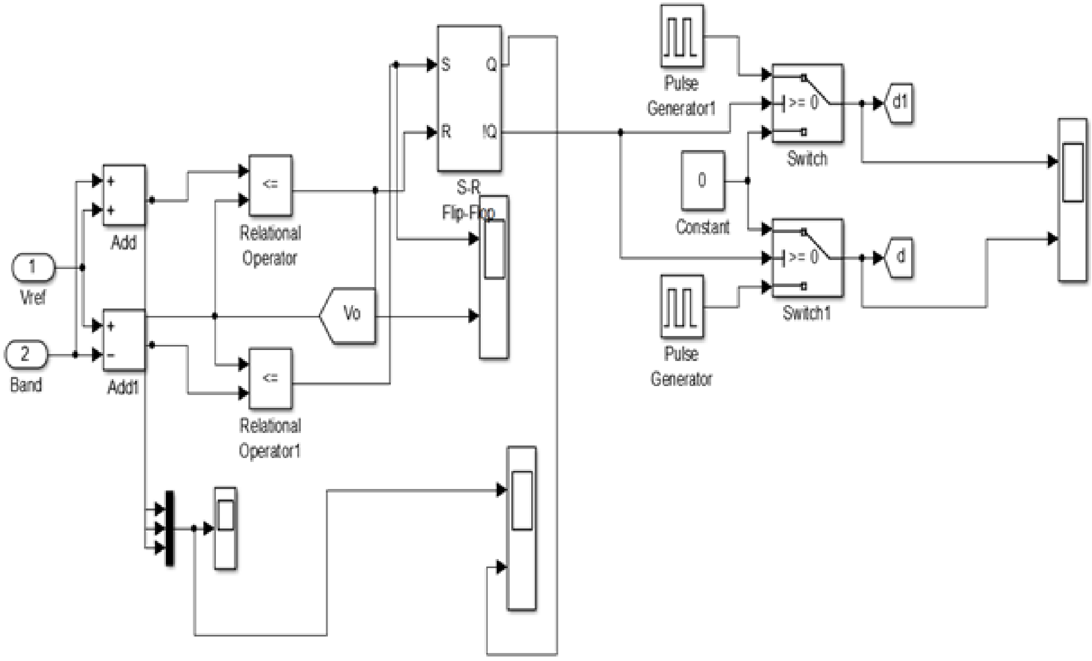


Figure 5.3: Control System For PV and BATTERY

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5.3.2 Algorithm for diesel generator as as back-up (Case-3)

The control system used for the diesel generator will sense the Voltage of the PV System and SOC limit of the battery. In this simulation the State of Charge (SOC) limit is taken 0.004% because we need to analyse affect of diesel generator after PV and battery system failure whether the diesel generator able to mitigate the desired load demand . Algorithm for the Diesel generator as a back-up is shown below:

Algorithm

a. **Step-1)** Take PV Output Voltage and State of Charge of battery

b. **Step-2)** PV voltage limit=0V(irradiance=0)

c. **Step-3)** State of charge of battery < desired limit.

d. **Step-4)** When both the above steps are satisfied the Circuit breaker will turn on to supply load

e. **Step 5)** DC link voltage is maintained with diesel generator operation also.

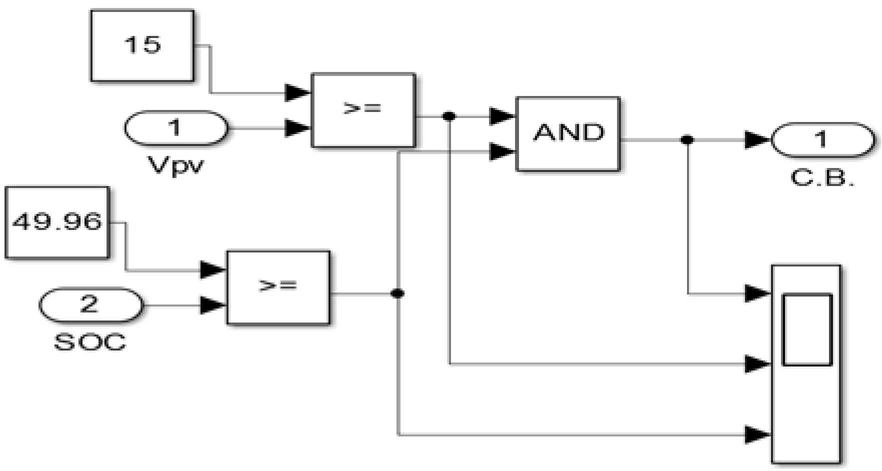


Figure 5.4: control system for battery

Note: Diesel generator will not charge the battery as it is used for storing the renewable energy from the PV system.

5.4 Simulation results

The simulation of the DC-standalone is performed in 3 cases.

case-1) PV and battery Storage load sharing under variable loading conditions

case-2) PV and battery Storage load sharing under variable Irradiance

Case-3) Diesel generator as a back-up

Case-1) PV and battery Storage load sharing under variable loading conditions

The simulation is performed for the pv and battery storage load sharing

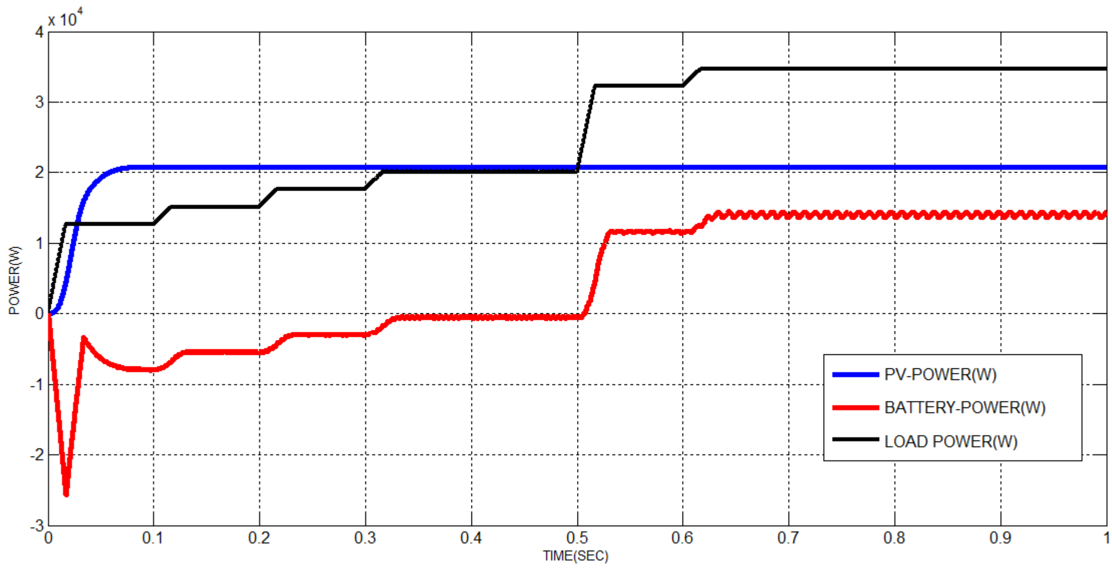


Figure 5.5: Load Sharing by PV and Battery under varying load

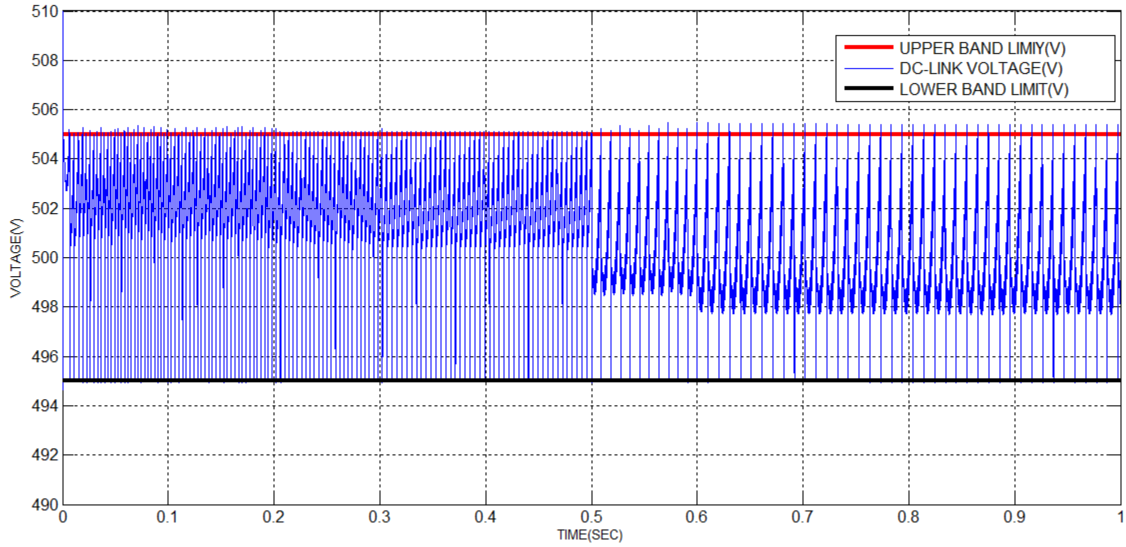


Figure 5.6: Hysteresis Band for Case 1

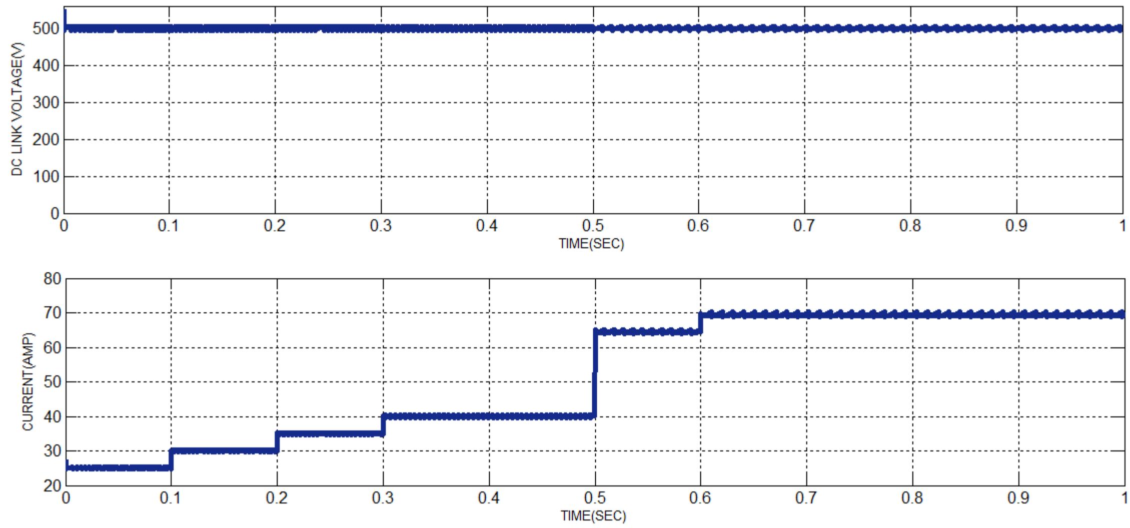


Figure 5.7: DC Link output

Table 5.1: PV and Battery Response during variable load

Time (Sec)	Irradiance (W/m^2)	PV power (kW)	Battery power (kW)	Diesel Generator Power(kW)	Load Power (kW)	DC Link (Voltage Vdc)
0.1-0.2	1000	21	-6	0	15	500
0.2-0.3	1000	21	-3	0	18	500
0.3-0.5	1000	21	-1	0	20	500
0.5-0.6	1000	21	11	0	32	500
0.6-1	1000	21	14	0	35	500

Case-2) PV and battery Storage load sharing under variable irradinace

The simulation is performed for the pv and battery storage load sharing

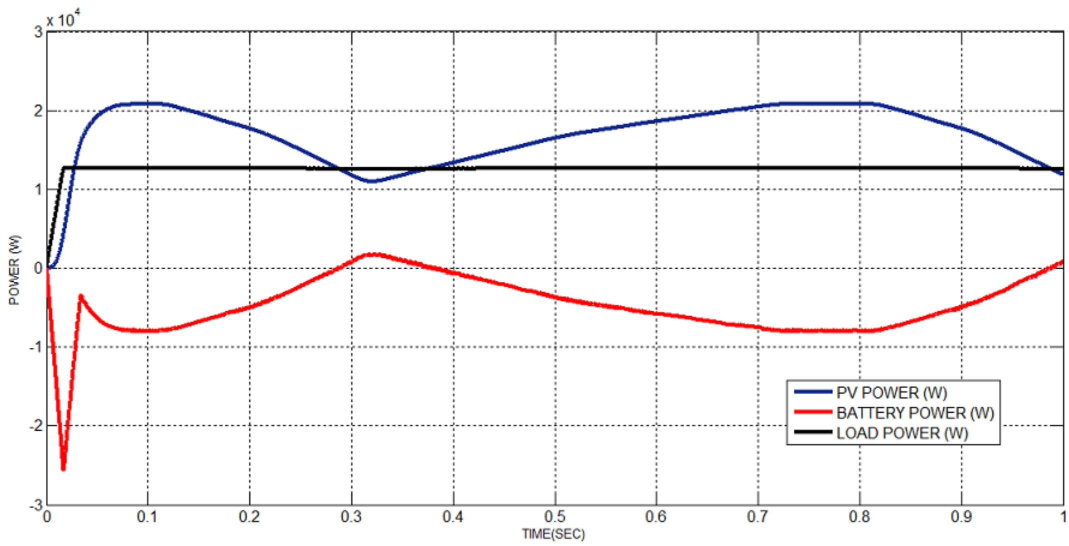


Figure 5.8: Load share by PV and battery under variable Irradiance

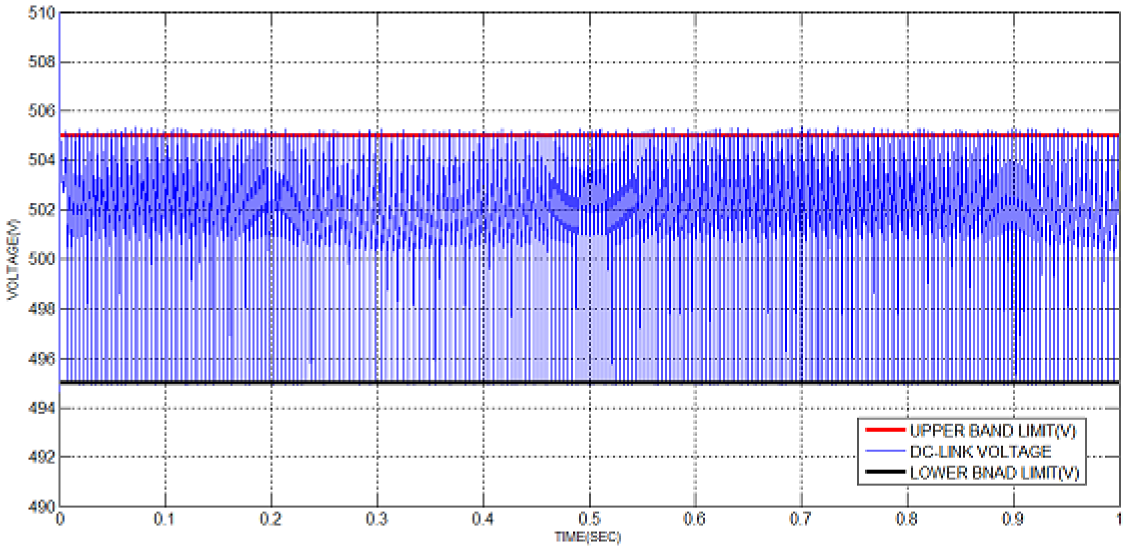


Figure 5.9: Hysteresis band

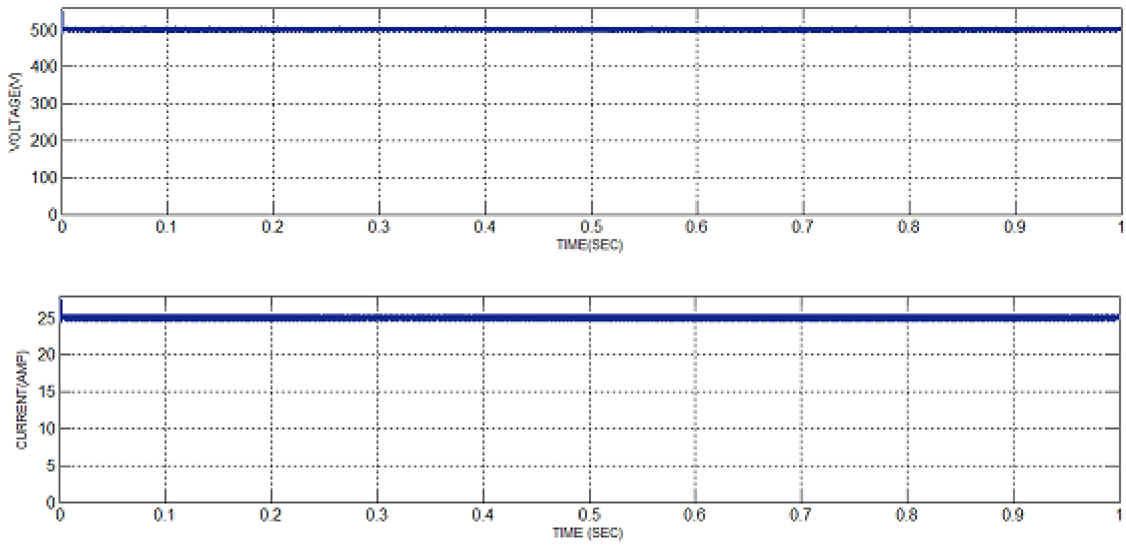


Figure 5.10: DC link output

Table 5.2: PV and Battery Response during variable load and irradiance

Time (Sec)	Irradiance (W/m^2)	PV power (kW)	Battery power (kW)	Diesel Generator Power(kW)	Load Power (kW)	DC Link (Voltage Vdc)
0.1-0.2	1000	21	-9	0	12	500
0.2-0.3	800	18	-6	0	12	500
0.3-0.5	500	11	1	0	12	500
0.5-0.7	800	18	-6	0	12	500
0.7-0.8	1000	21	6	0	12	500

5.4.1 Case-3 Diesel generator supplying load after PV and battery failure

PV Power in kW	Irradiance	Battery (Initial) SOC limit =0.04%	Diesel Generator	DC (Power in kW)	Diesel generator on Time	DC Link Voltage
0	0(0.2-2 Sec)	0	25	25	from 0.2sec	500 DC

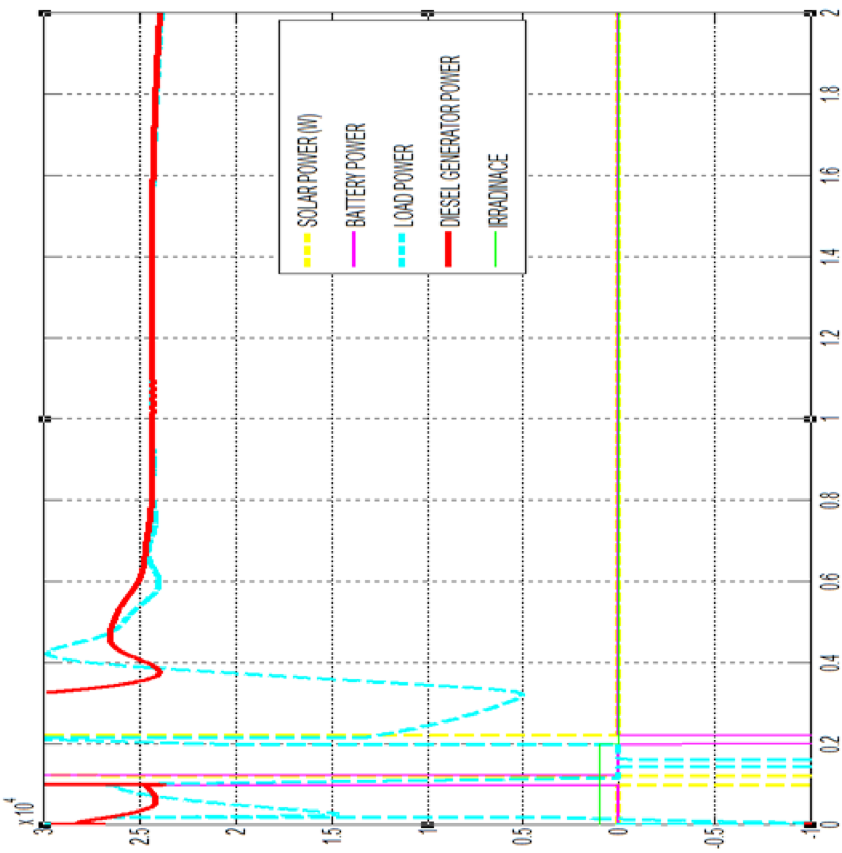


Figure 5.11: Diesel Generator supplying load when PV and battery fails

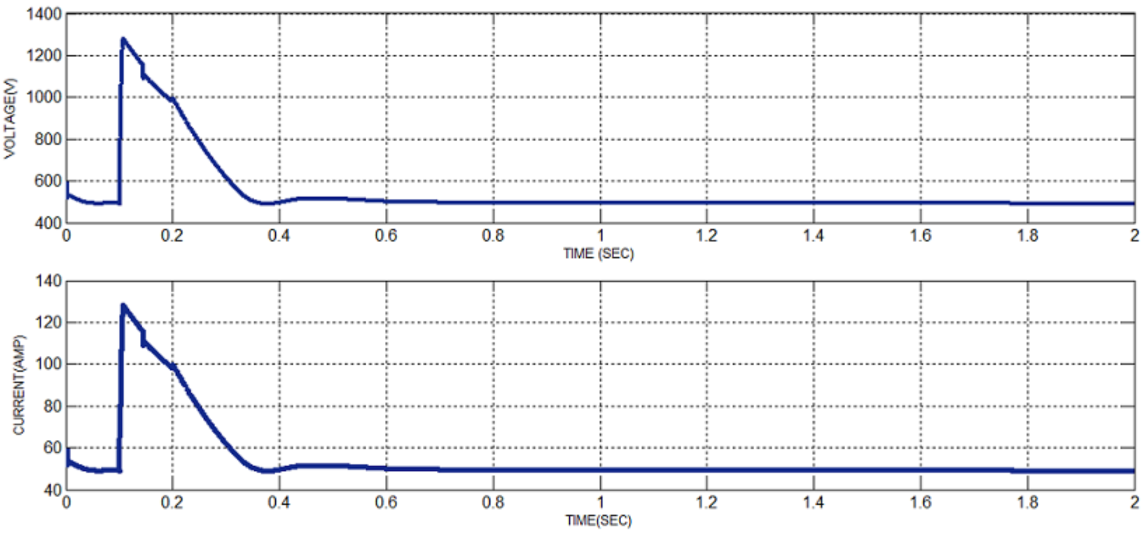


Figure 5.12: DC Link Output

5.5 Summary

The chapter showed the detailed simulation and results for the DC Standalone Microgrid. It includes the various controlling schemes under varying conditions and load. Development of Various converter like Boost converter for PV Systems, Bidirectional Converter for battery storage, Rectifier for Diesel Generator. The Whole DC standalone Microgrid is satisfactorily maintained at Desired $500\pm1\%$Vdc.

Chapter 6

DC/AC Hybrid Microgrid

6.1 Introduction

In this chapter the simulation of the DC microgrid connected to an AC grid through inverter has been shown. The task is performed using various components like PLL(phase locked loop), ABC-DQ0 and vice versa transformation, Inverter, Coupling transformer for synchronisation of inverter with utility grid . For synchronisation we need to take care of the following things for the inverter and utility grid that they should have:

a. Similar voltage profile

b. Same Frequency

c. Same Phase angle

d. Same Phase sequence

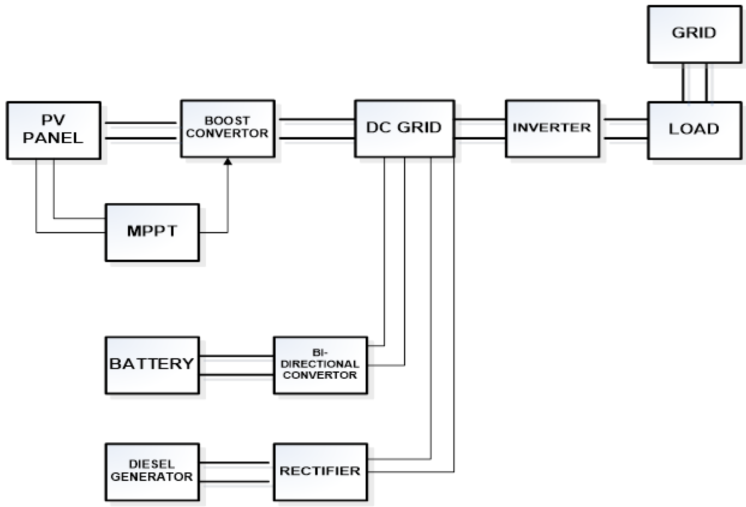


Figure 6.1: Implementation of AC/DC Hybrid Grid

6.2 Components for Synchronisation

The DC side connected Inverter will be synchronized with the utility grid, The synchronisation of the inverter is performed to compensate the voltage Sag in the utility grid and feed the load demand connected on the AC side.

6.2.1 Voltage Sources

a. **Utility Grid**

   The main Voltage source is the Utility gird at 415V AC , 50Hz

b. **Reference Voltage Source**

   The reference voltage source is taken is of same rating 415V AC 50Hz.

6.2.2 Inverter

3-Phase inverter is used for converting the DC link voltage to the AC and for synchronisation with the utility gird.

6.2.3 Transformer

The transformer will be used for coupling of the inverter and the utility Grid.

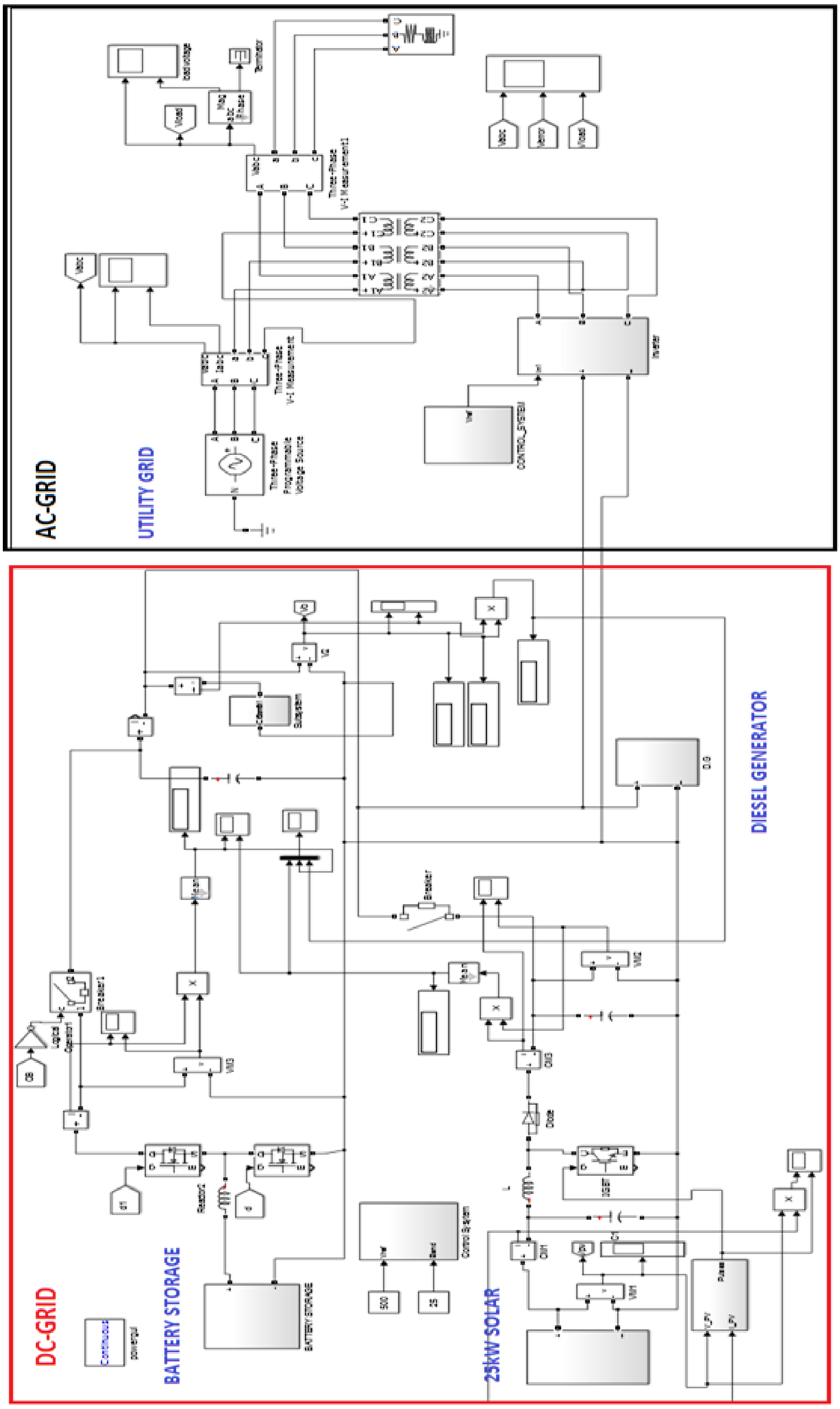


Figure 6.2: Simulation block of DC/AC Hybrid Grid

6.2.4 PLL

The PLL technique is used for locking the grid phase and frequency.It will vary according to the changing conditions in the utility grid.The Phase locked loop is most commonly used for grid side connected converters to lock the phase and frequency of the grid in order to synchronise the converter with the utility grid and tries to maintain the output of inverter in phase with grid voltage[11]. Novel concept has been given for grid synchronisation in [12].

6.2.5 ABC-DQ0 Transformation

The ABC-DQ0 voltage has been used for simplification as it will be easier to resolve two phases rather than three phases calculations

6.2.6 Error generation

The error will be generated by the comparing the utility voltage sag and the reference voltage source it will helps us to know what amount of voltage we need to feed in the grid.

6.2.7 Filter

The filters are necessary for the harmonics compensation at the PCC(Point Of common coupling) , In the simulation passive L & C filter is designed.

6.3 Implementation of Synchronisation

The synchronisation will be performed in the following pattern:

a. Take Voltage source (Grid) of 415 Va.c, 50HZ and a reference voltage source of same rating

b. The Phase locked loop(PLL) will sense the phase angle of the Utility Grid and will be used for DQ0-ABC and vice versa and we need to keep the system in phase with the inverter.

c. DQ0 transformation will be performed for the Utility Grid and reference Voltage Source using the phase of the utility grid.

d. DQ0 transformation of both the Grid and reference voltage source with be added to detect the error or voltage sag in the utility grid.(In our case we have taken the voltage sag between 0.2 to 0.4 of 0.8(P.U)) of the amplitude. The dQ0 transformation is performed for reducing the complexity of the 3-phase voltage measurement hence we convert it in D-Q i.e. direct and quadrature Axis.

e. DQ0 to ABC Transformation will be performed for the error generated and sent to the SPWM inverter to decide the power intake from the DC grid.

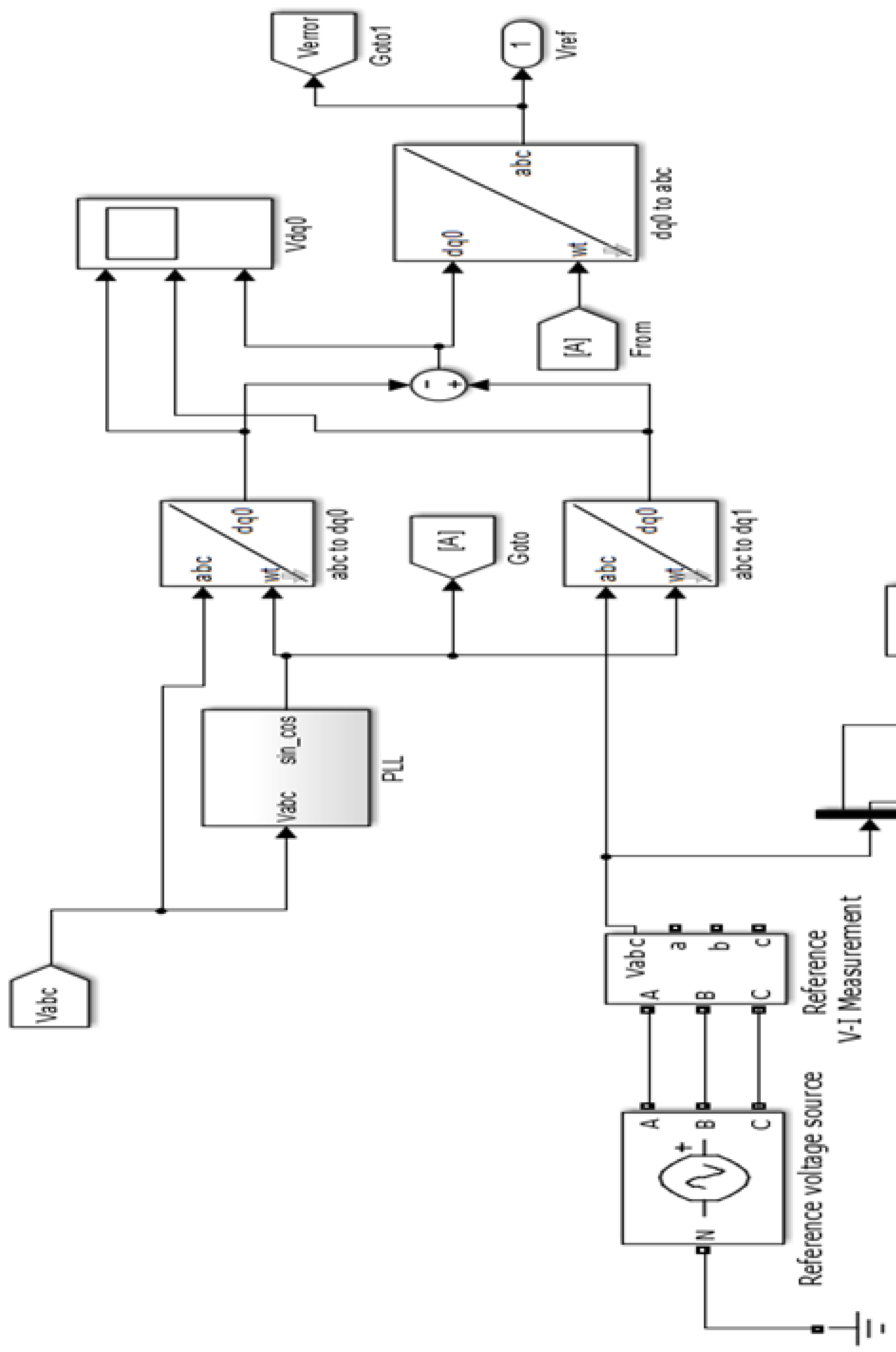


Figure 6.3: Synchronisation Block

6.4 Simulation Results

6.4.1 Inverter

The main objective of this converter is to DC to AC conversion. Three leg two level converters are used in our work, consisting six IGBT's semiconductor switches supposed to be turned Off/On in a complementary manner to avoid the short circuit condition at the Terminal. SPWM(Sinusoidal Pulse width modulation) technique has been used for providing the gating pulse.

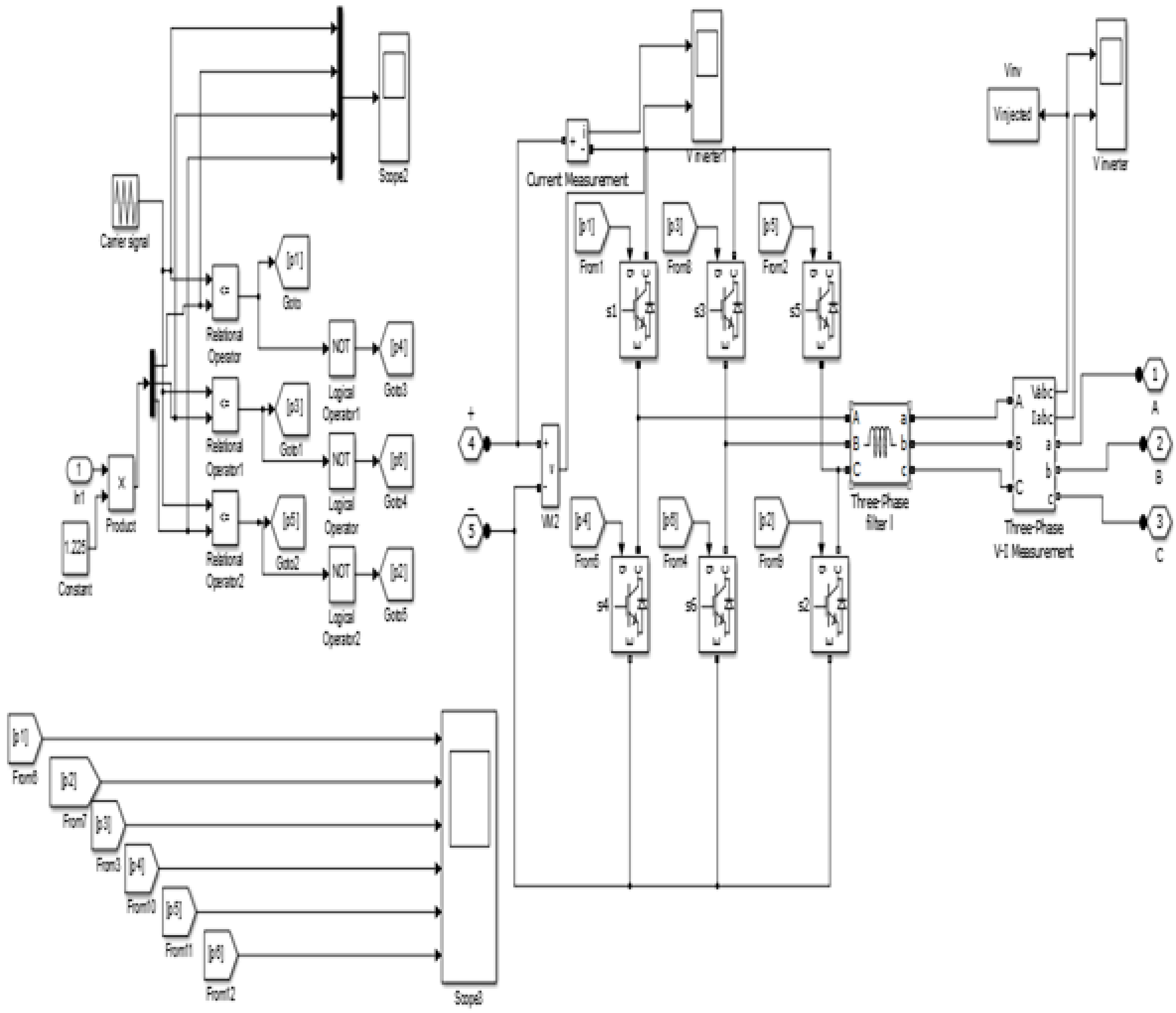


Figure 6.4: Inverter

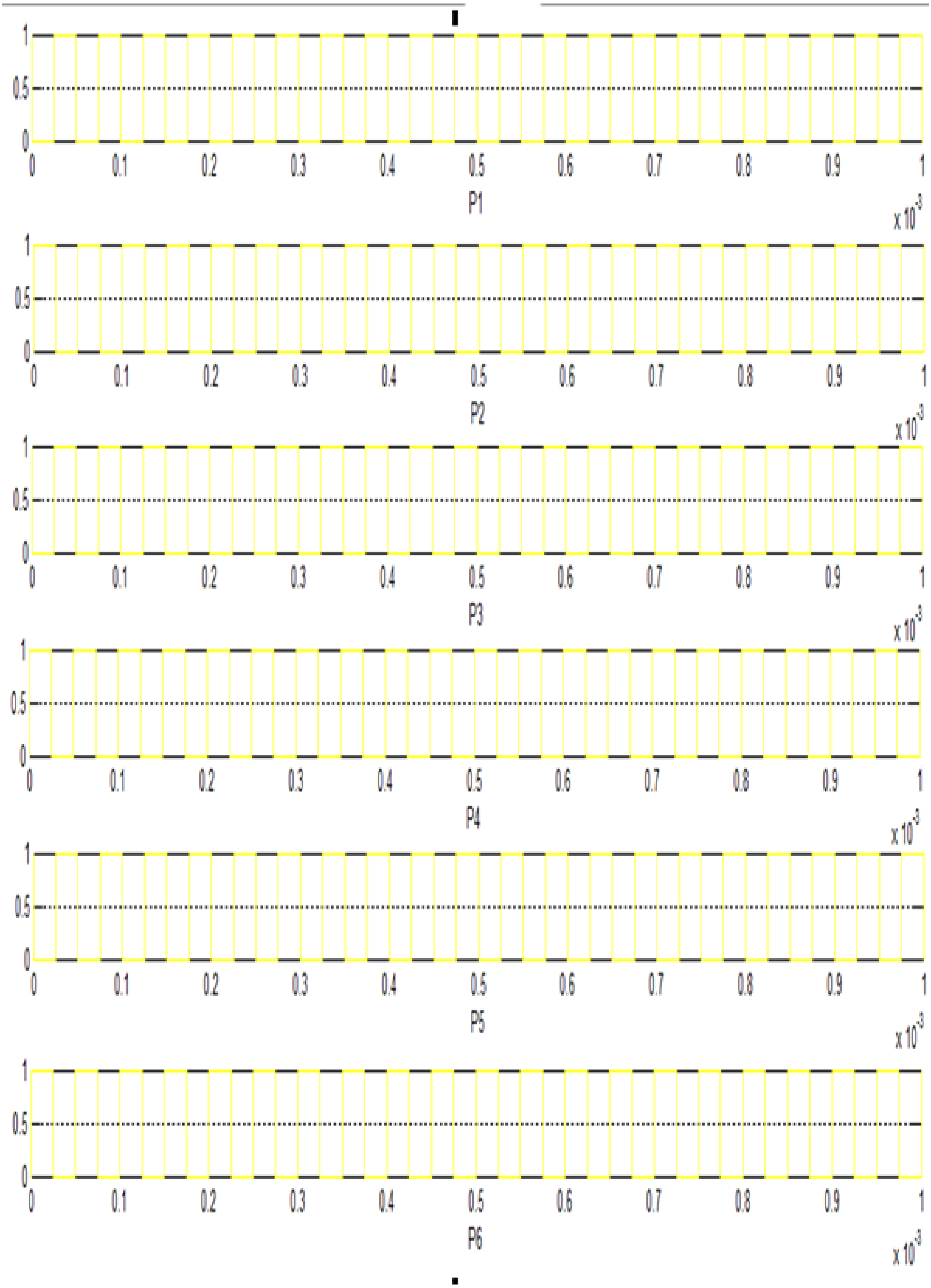


Figure 6.5: Gating pulse for inverter

6.4.2 PLL

The Phase locked loop is most commonly used for grid side connected converters to lock the phase and frequency of the grid in order to synchronise the converter with the utility grid and tries to maintain the output of inverter in phase with grid voltage[11]. Novel concept has been given for grid synchronisation in[12].

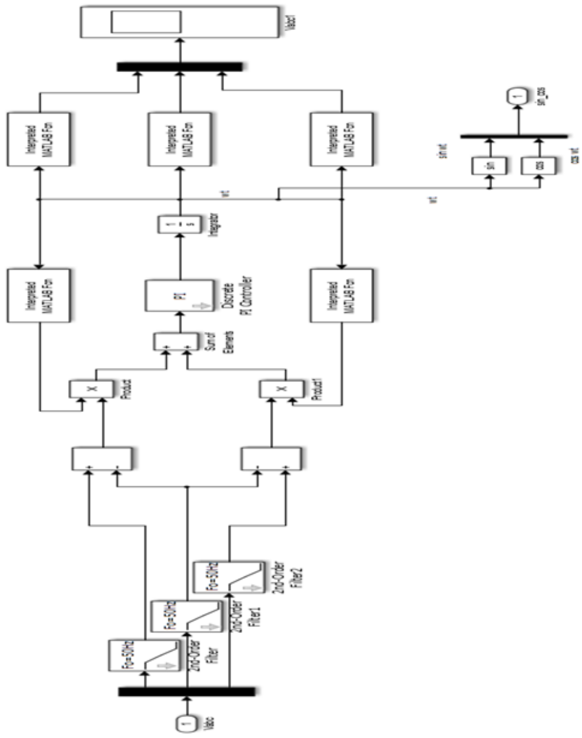


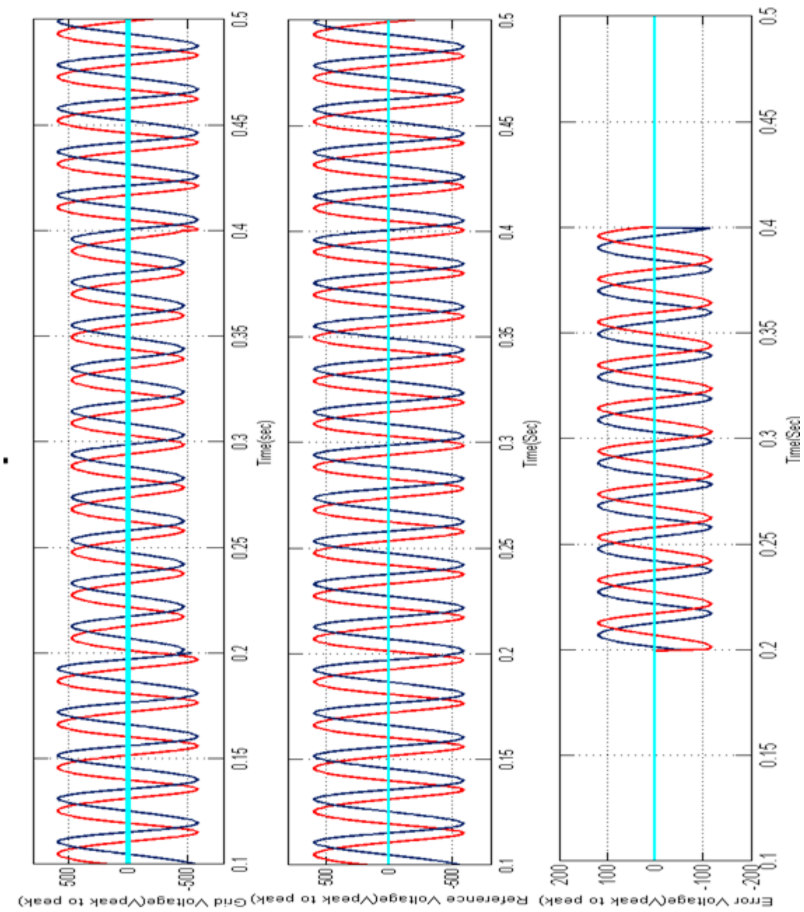
Figure 6.6: Block diagram of PLL

Proportional gain	0.1
Integral gain	0.11
Base Frequency	50Hz
Upper Tracking Limit	1e6
Lower Tracking Limit	1e-6

6.4.3 ABC TO DQ0 TRANSFORMATION

Park transformation is performed for ABC TO DQ0 block performs in a rotating reference frame. For performing this task the ABC to DQ0 block has been used present in the MATLAB Simulink Library. The transformation is performed from the following equations.

$$\begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \sin(\theta) & 1 \\ \cos(\theta - \frac{2\pi}{3}) & \sin(\theta - \frac{2\pi}{3}) & 1 \\ cos(\theta + \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) & 1 \end{bmatrix} \cdot \begin{bmatrix} d \\ q \\ 0 \end{bmatrix}$$



6.4.4 DQ0-ABC Transformation

For performing this task the ABC to DQ0 block has been used present in the MATLAB Simulink Library. The DQ0-ABC transformation is performed From the following equations

$$\begin{bmatrix} d \\ q \\ 0 \end{bmatrix} = \frac{2}{3} \cdot \begin{bmatrix} \cos(\theta) & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \sin(\theta) & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \cdot \begin{bmatrix} a \\ b \\ c \end{bmatrix}$$

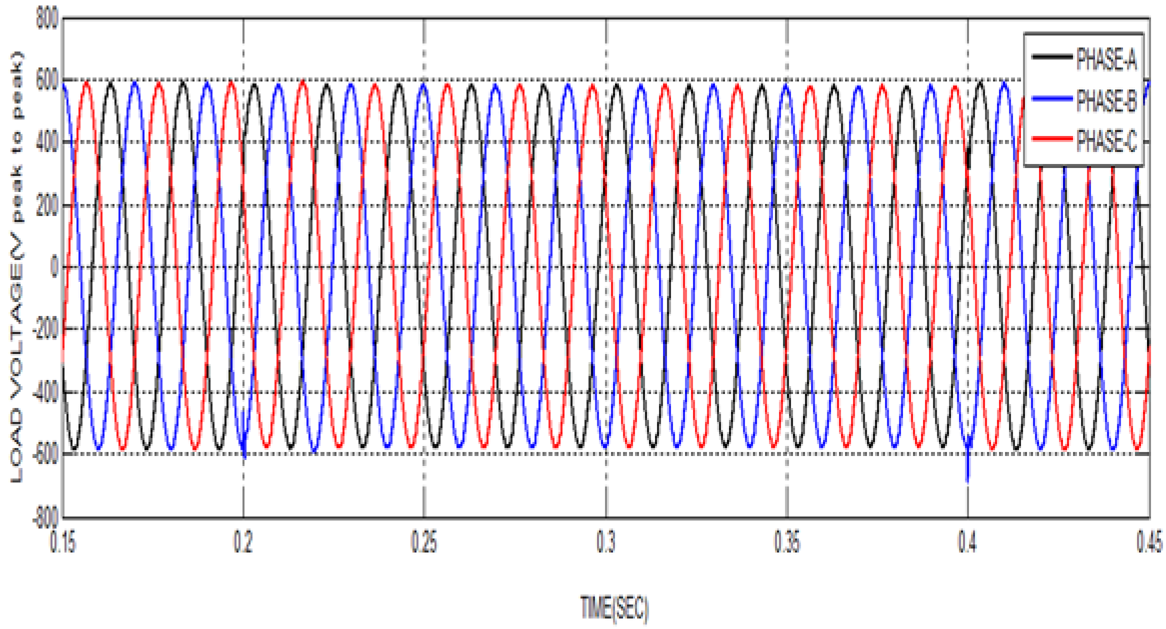


Figure 6.7: VDQ0-ABC TRANSFORMATION

6.4.5 Error Generation

The voltage sag has been created from 0.2 to 0.4 sec in the utility grid of 0.8(pu) in Amplitude of the grid voltage. The sag has been created to know the proper synchronisation of the DC/AC Grids and whether the DC grid is able to inject in the Grid for the voltage Sag.

DQ0 transformation of the error generated is shown in the following figure:-

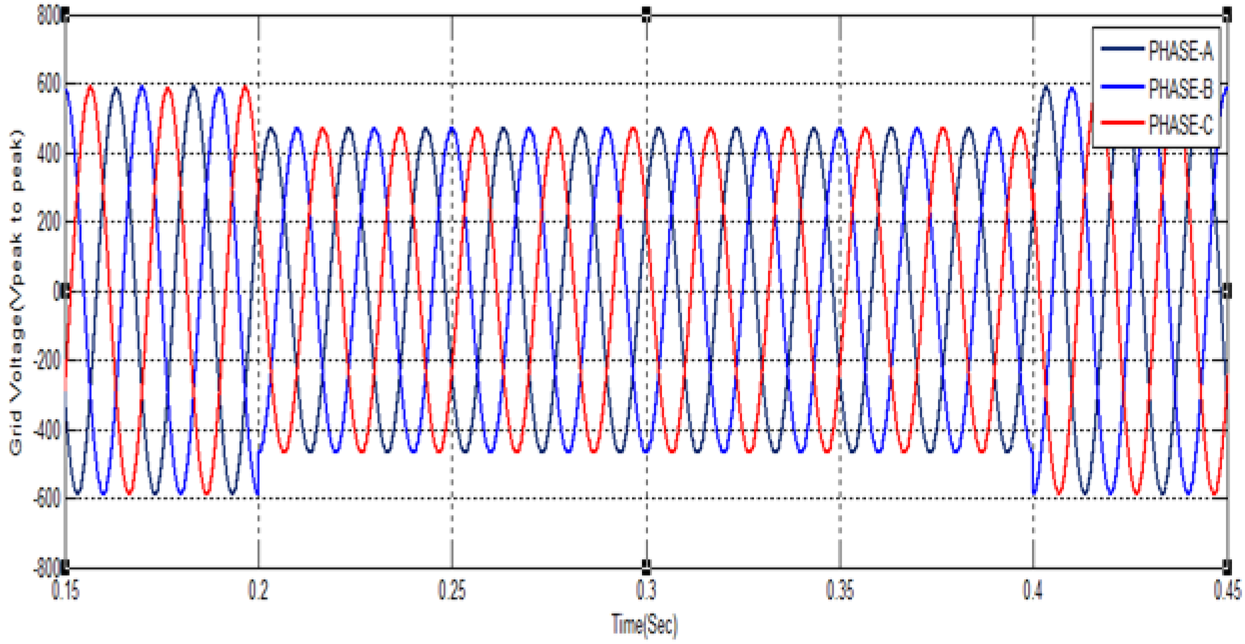


Figure 6.8: Error in Generated at time 0.2 to 0.4 Second voltage graph

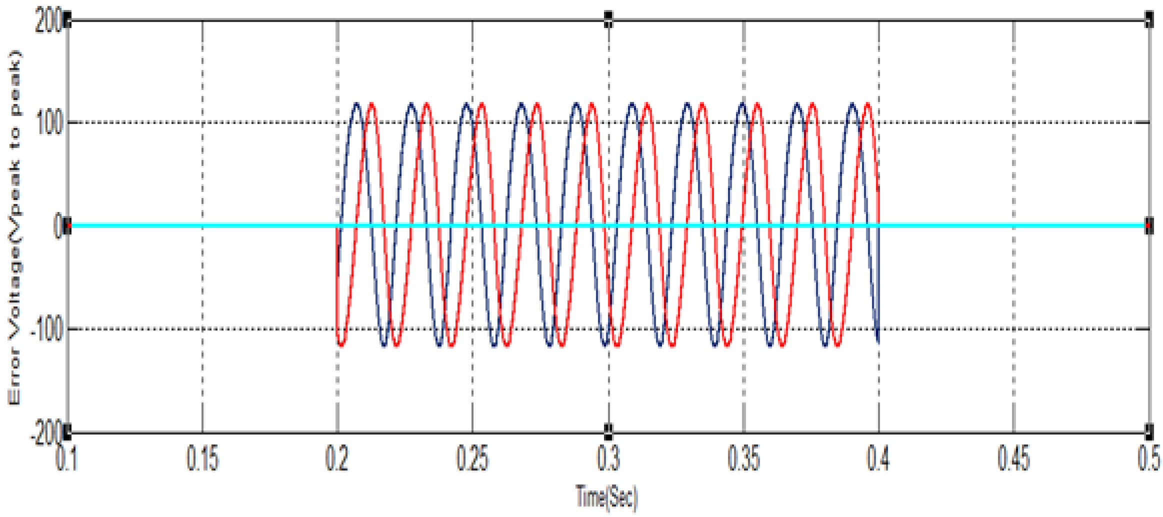
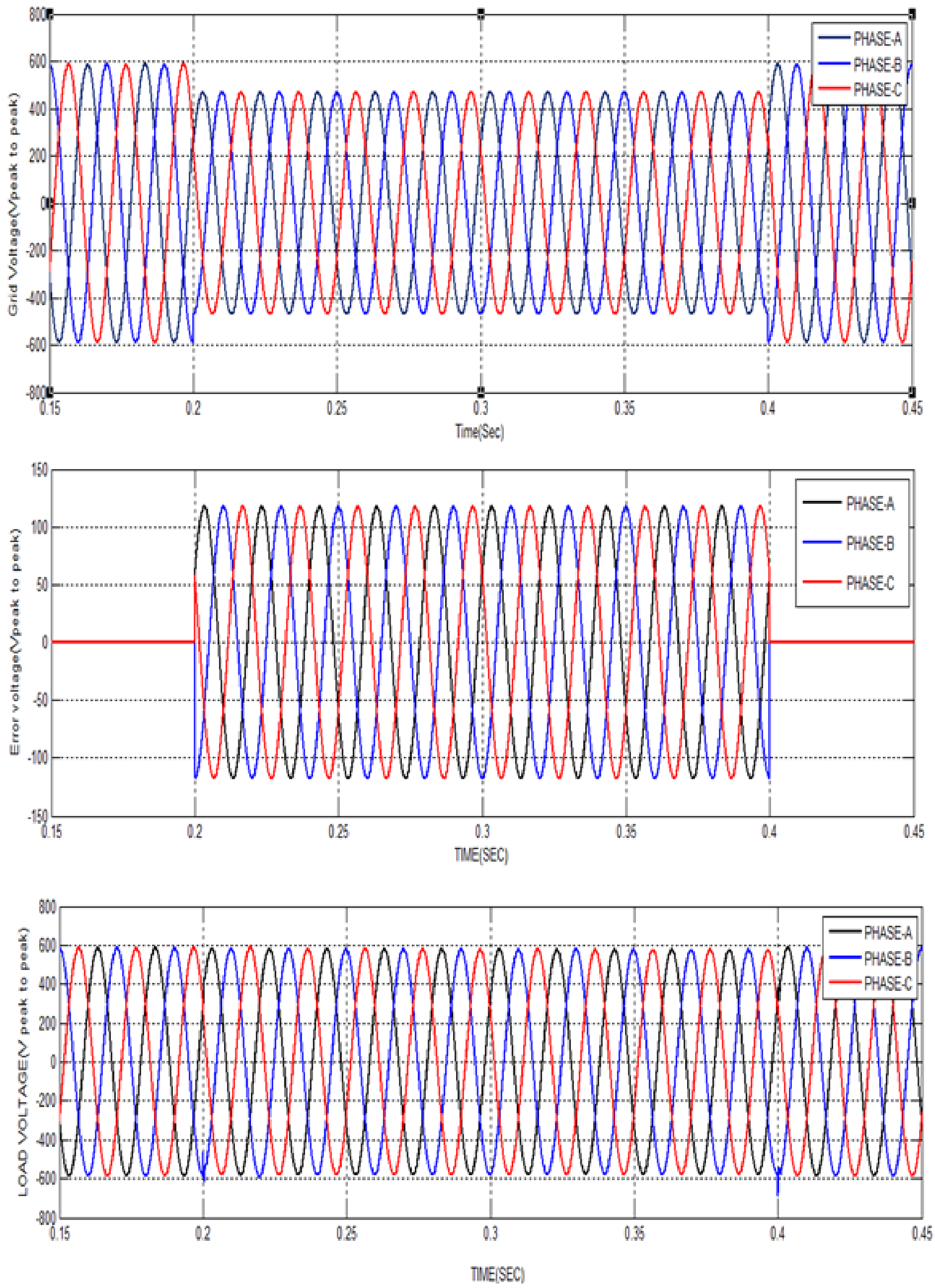


Figure 6.9: Dqo transformation of Error Voltage.

6.4.6 Sag Compensation



6.4.7 Harmonics Analysis

The FFT Analysis is done at the PCC(Point of coupling) for analysing the harmonics presence.The following results shows the harmonics presence and hence accordingly the filter has been designed.

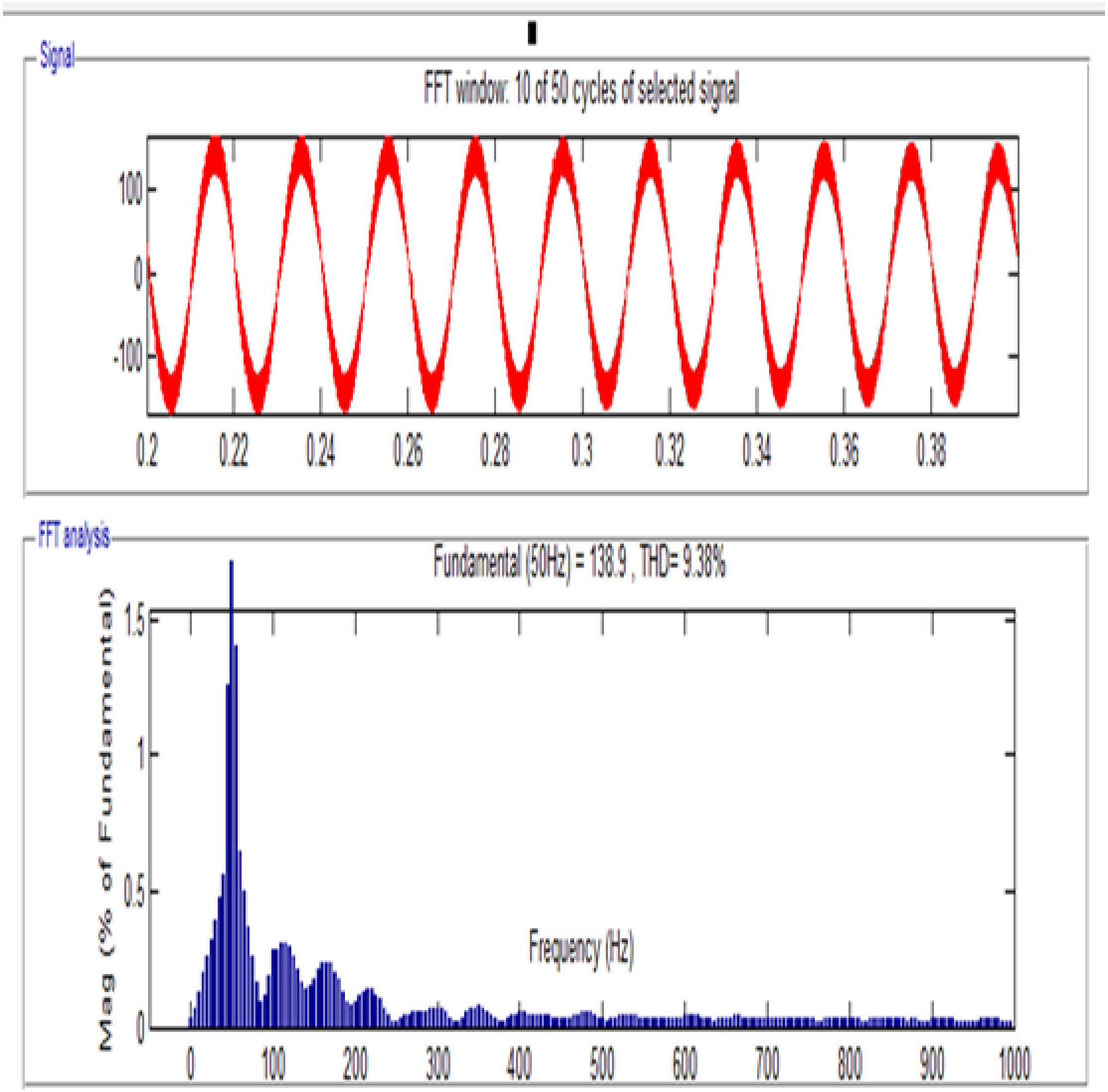


Figure 6.10: Harmonics at PCC without filter

6.4.8 Filter design

The filter has been designed according to IEEE 519 as mentioned in [10].The filter has been designed for the harmonics compensation at the Point of common coupling(PCC)[15].The FFT analysis has been performed at PCC showing 9.35% THD. Passive LC filter is designed for most dominating harmonic.The calculations for the filter design has been shown as follows:
We know that,

$$X_L = X_C W_L = 1/W_C 2F_L = 1/2F_C \tag{6.1}$$

The Filter will be designed for most dominating harmonics order i.e. 5th order harmonics. Assume C=1e-6

Now from above equation we have: 2*3.14*50(5)*L= 1/3.14*250*1e-6

We get L= 40 mH

Similarly we get C= 10mF

After FFT analysis the results shows the harmonics has been reduced upto 2.33%. at PCC after designed filter implementation.

6.4.9 Load

The load taken at the utility grid is of 25kW A.C at 415AC, 50Hz.

6.5 Summary

The 500V DC grid has been synchronised with the AC utility grid using dq0 transformation. Voltage sag and harmonics are eliminated.Harmonics analysis has been done.Filter is designed to maintain the harmonics limit according to IEEE519.

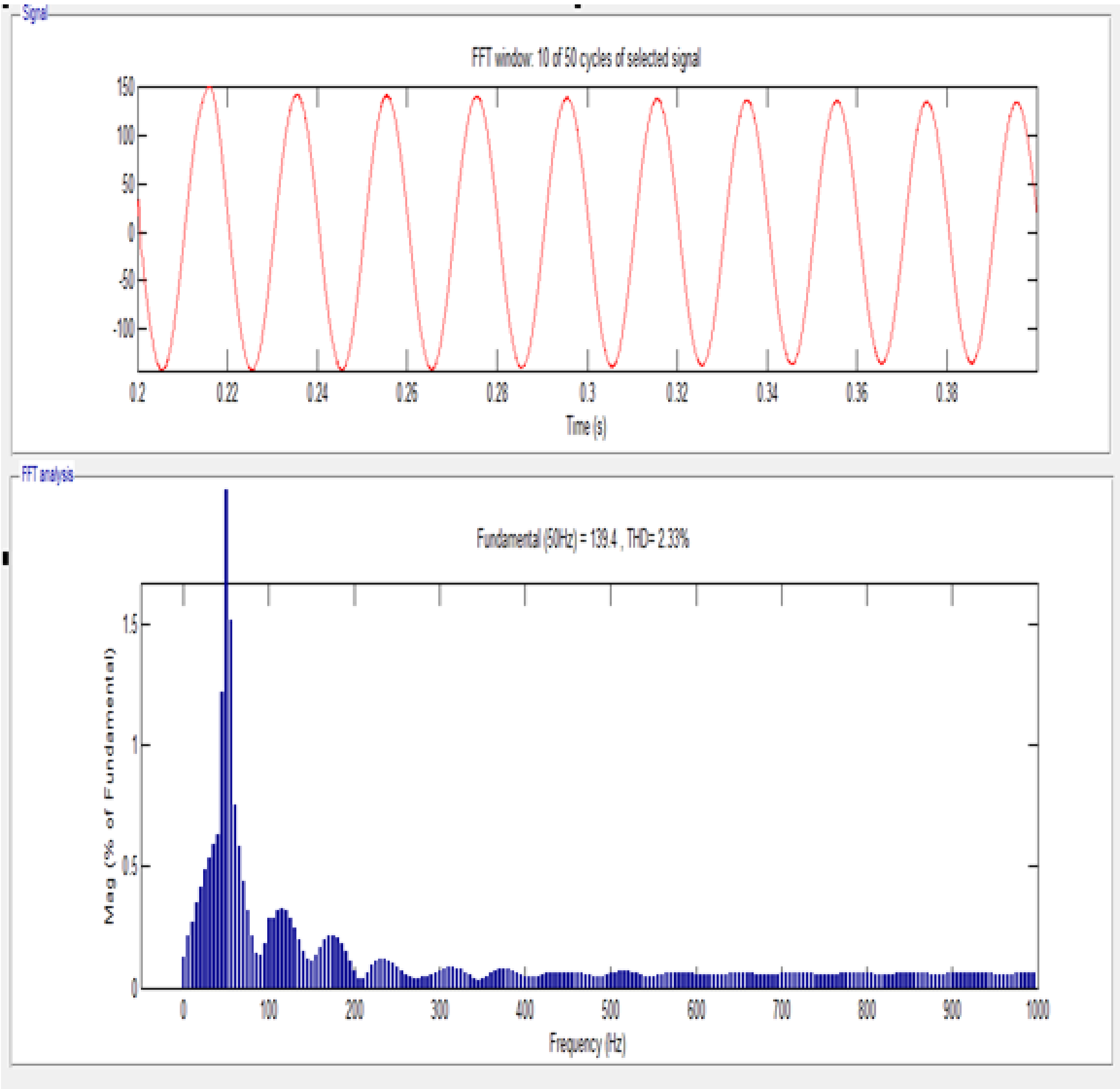


Figure 6.11: Harmonics at PCC with filter

Chapter 7

Conclusion and Future Work

7.1 Conclusion

a. Literature Survey of the microgrid

b. Integration of the various distributed energy resources like PV, Battery, Diesel generator

c. DC microgrid has been maintained at 500±1%Vdc for PV system, battery storage and diesel generator, it worked as a standalone microgrid.

d. Coordinated control scheme has been developed for load sharing in the DC within Distributed Energy resources.

e. The DC microgrid was connected to a common inverter for feeding AC variable load

f. The inverter has been synchronised with the utility grid using PLL and DQ0 transformation

g. Voltage dip in the utility grid has been compensated From DC Microgrid

h. Coordinated AC-DC hybrid Grid has been developed

i. Harmonics analysis has been done at Point of common coupling

j. Filter has been designed for harmonics elimination

7.2 Future Scope

a. Integration of various renewable distributed energy sources like fuel cell, wind energy,hydro etc .

b. Development of advanced control strategies for load sharing at AC side.

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