

# Microgrid Controlling in Grid Connected Mode Using Fuzzy Logic Controller with Optimization of Der's

Bhavya Bansal

**Abstract:** As the price of fuel is rising and GHG emission affecting environment adversely, we need to switch to renewable energy resources. To integrate all Renewable energy sources Microgrid came into existence. This paper presents a simulation and mathematical model of Microgrid in grid connected mode. This proposed system consists of two renewable sources i.e. solar energy and fuel cell energy. Modeling of solar PV system and fuel cell stack system with boost converter is explained. Main focus area of this paper is controlling of Microgrid in grid connected mode using fuzzy logic controller which enhances the power quality of system while feeding nonlinear load. Optimization of DER'S is done to utilize the resources at most keeping the cost in mind.

**Index Terms:** Microgrid, Solar PV system, Fuzzy controller, Nonlinear load, Grid connected mode and Boost converter.

## I. INTRODUCTION

To reduce CO2 emission, main cause of Global warming, we need to switch to renewable energy sources from conventional sources. Microgrid is the main focus area and need of hour due to increase in global temperature and climate change. A Microgrid can be defined as a low voltage distribution system to which small modular generating systems are to be connected. It can be installed in a village or town. MG is intended to operate in the following two operating modes.

- **GRID CONNECTED MODE:** In this mode of operation MG is connected to main utility grid through a point of common coupling (PCC) switch. MG feeds the load connected to it. Here Microgrid can receive energy from main grid through PCC. If the power generated by Microgrid is in excess compared to the local loads connected to it, then it can send excess power to main grid through PCC. Here this mode of operation has been explained in detail.
- **AUTONOMOUS MODE:** The MG operates autonomously, means whenever there is fault or black out condition occurs in main grid then MG is disconnected from main grid and MG alone feeds the local loads.

## II. MODELING OF ENERGY SOURCES

DER'S used in Microgrid are Solar PV system and fuel cell system with BESS. Modelling of each component of Microgrid is explained in detail.

### 2.1. PV system modelling

The equivalent circuit of PV cell is shown in figure 1.

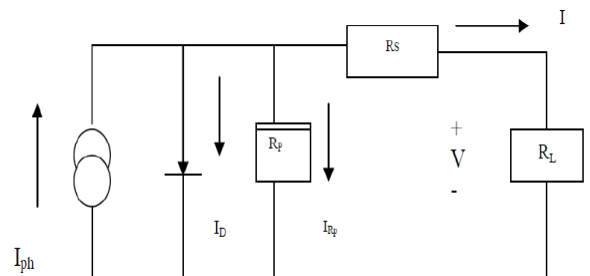


Fig.2.1.PV cell equivalent circuit

Applying Kirchoff's current law (KCL), we get:

$$I_{ph} = I_D + I_{Rp} + I \quad (1)$$

By rearranging the following equation we get photovoltaic current:

$$I = I_{ph} - I_{Rp} - I_D \quad (2)$$

$$I = I_{ph} - I_0 \left[ \exp \left( \frac{V + I \cdot R_s}{V_T} \right) - 1 \right] - \left[ \frac{V + I \cdot R_s}{R_p} \right] \quad (3)$$

Here  $I_{ph}$ - Insolation current

$I$  - Cell current

$I_0$ - Reverse saturation current

$V$ - Cell voltage

$R_s$ - Series resistance

$R_p$ - Parallel resistance

$V_T$ - Thermal voltage

$k$ - Boltzmann constant

$T$ - Temperature in kelvin

$q$ - Charge of electron (C)

Simulation block of solar cell and its parameters are shown in figure 2 and figure 3 respectively.

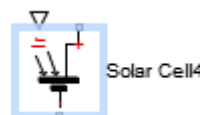


Fig.2.2.Simulation block of solar cell

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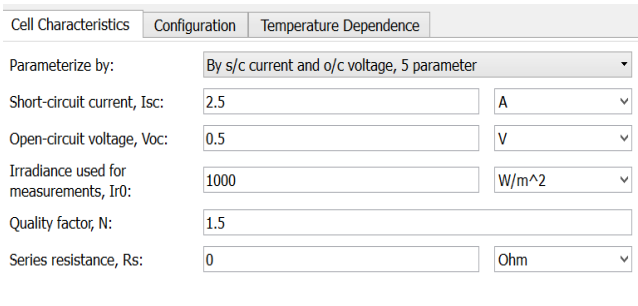


Fig.2.3.Solar cell parameters

As one solar cell voltage is 0.5 V. Here each cell has 10 solar cells in built in it giving voltage of 5V. By connecting such 3 cells in series we will get 15V voltage. It can be understood by looking in figure 2.4.

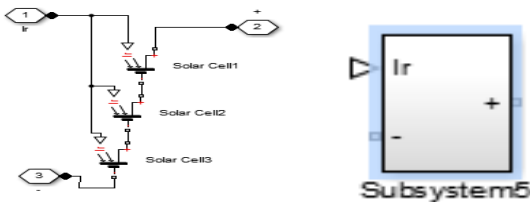


Fig.2.4.Series connection of solar cell in equivalent subsystem in Matlab

Now four subsystems are connected in series giving voltage of 60V as shown in figure 5.. To increase voltage rating we connect subsystem in series and to get higher current rating we connect subsystem in parallel.

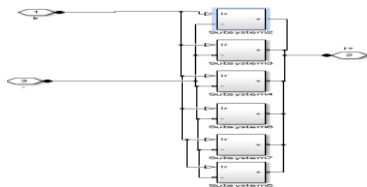


Fig.2.5.Series combination of solar subsystems

Simulation model of solar PV system can be obtained in Matlab simulation using the subsystem of solar cell which is shown in figure.2.4.

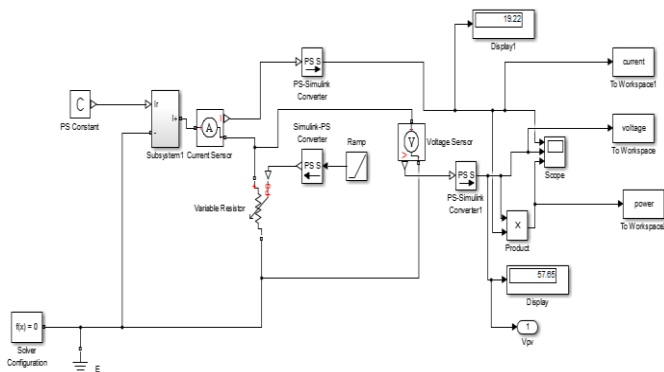


Fig.2.6.Simulation model of solar system

Now simulating this model in Matlab will give desired voltage, current and power waveform which are shown below.

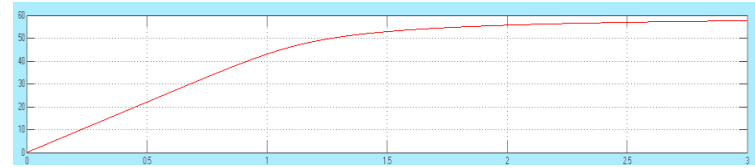


Fig.2.7.Voltage waveform of solar panel

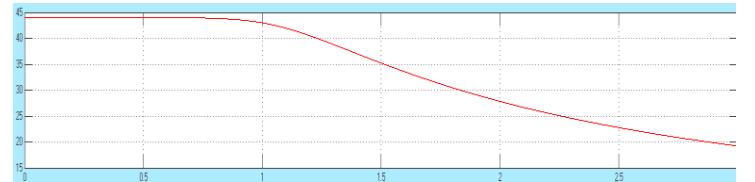


Fig.2.8.Current waveform of solar panel

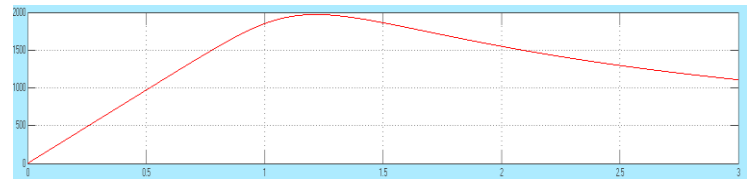


Fig2.9.Power waveform of solar panel

P-V And V-I characteristics of solar system is shown in figure 2.10 and figure 2.11 respectively.

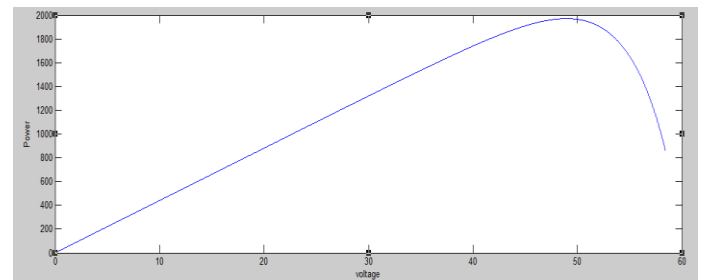


Fig.2.10.P-V characteristics of solar panel

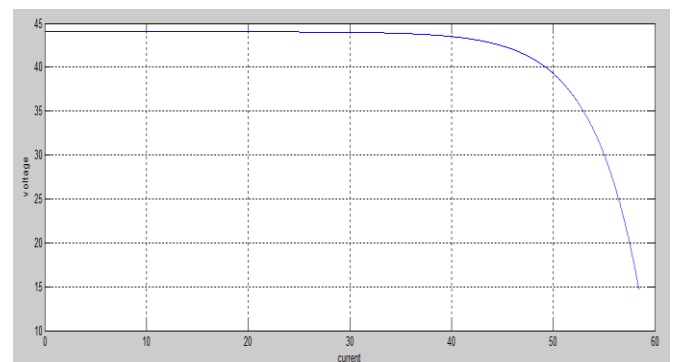


Fig.2.11.V-I characteristics of solar panel

## 2.2. FUEL SYSTEM MODELLING:

A fuel cell is an electrochemical device which converts chemical energy into electrical energy. It takes energy from a fuel and produce water and heat. It combines hydrogen and oxygen without any type of combustion.



**SIMULATION MODEL OF FUEL CELL:**

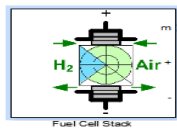


Fig.2.12. Fuel Cell simulation block

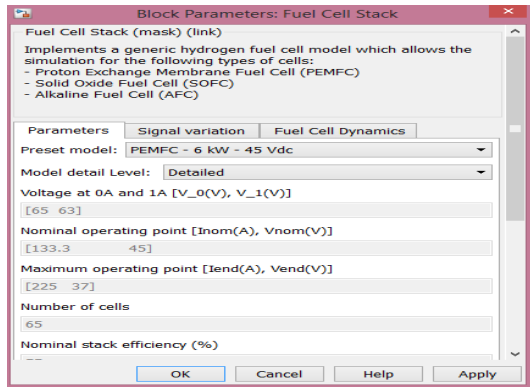


Fig.2.13. Fuel cell parameters

**2.3. BOOST CONVERTER MODELLING:**

It is a step up or PWM boost converter. It comprises of a Dc voltage source  $V_g$ , Boost inductor  $L$ , Diode  $D$ , a controlled switch  $S$ , Filter capacitor  $C$  and the load resistance  $R$ .

- When switch  $S$  is closed (ON STATE) current starts flowing through inductor and increase linearly. Diode  $D$  is reverse biased .
- When switch  $S$  is open (OFF STATE), The energy which is being stored in inductor during on state, get released to the output RC circuit through diode or we can say  $L$  is discharged through  $D$ .

**SIMULATION MODEL OF BOOST CONVERTER:**

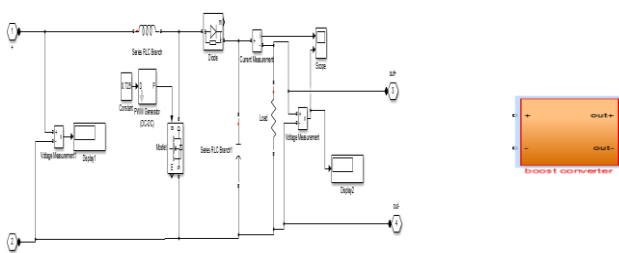


Fig.2.14. Internal diagram of boost converter and subsystem of boost converter

**VALUES OF DIFFERENT PARAMETERS IN BOOST CONVERTER:**

Inductor L	100mh
Capacitor C	100µF

**Duty cycle of MOSFET**

0.725

**2.4. INTERCONNECTION OF DER'S WITH BOOST CONVERTER AND BATTERY::**

As we know here we are using two renewable energy resources that are solar pv system and fuel cell system. We have connected them with boost converter to have increased voltage level. Both the sources are generating voltage of 220V. Now these sources along with boost converter and battery will be connected in parallel to power local loads and nonlinear loads.

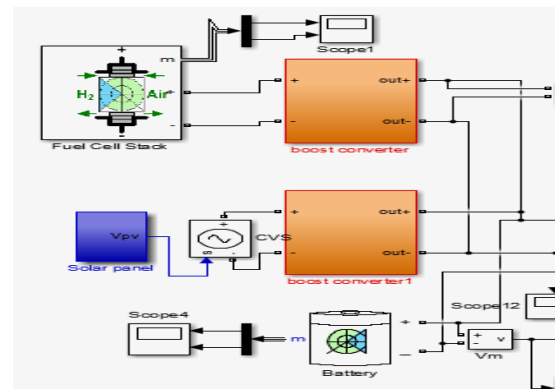


Fig.2.15. Interfacing of DER'S with boost boost converter and Battery

**III. OPTIMIZATION OF DISTRIBUTED ENERGY SOURCES**

Designing of Microgrid is a very important phase as we have to consider cost of every component used in system. So to get optimised value of power of each source we have assumed cost of each source. It can be changed depending upon market values.

As the cost of 1 KW of solar panel is between Rs. 55000 to 60000 .

Fuel cell stack cost is Rs. 10,000 per KW.

Battery cost around Rs. 7600 for 1 KW .

Depending upon these cost value of sources , a constraint equation can be formed. Let us assume power generated by solar panel is  $x$  KW, Fuel cell generate  $y$  KW power and power generated by battery is  $z$  KW.

Total load we are taking is 10 KW. So we need to generate 10 KW of power. As cost of solar panel is very high so minimum power generated by it is taken as 2 KW . The limit of fuel cell is 10 kw and that of battery is 2 kw. The equations finally formed are:

$$C = 57.5 x + 10 y + 7.6 z; \tag{3.1}$$

$$x + y + z = 10; \tag{3.2}$$

$$2 \leq x \leq 10; 0 \leq y \leq 10; 0 \leq z \leq 2. \tag{3.3}$$

By solving these linear equations in MATLAB we get optimum value of all the resources which is as follows:

$$X = 2.0$$

$$Y = 6.0$$

$$Z = 2.0$$

It states that solar panel should produce 2.0 kw of power. Fuel



cell should produce 6.0 kw of power and battery should give 2.0 kw of power. So we will put these values in our model to have optimum utilization of resources.

**IV. CONTROLLING OF MICROGRID IN GRID CONNECTED MODE**

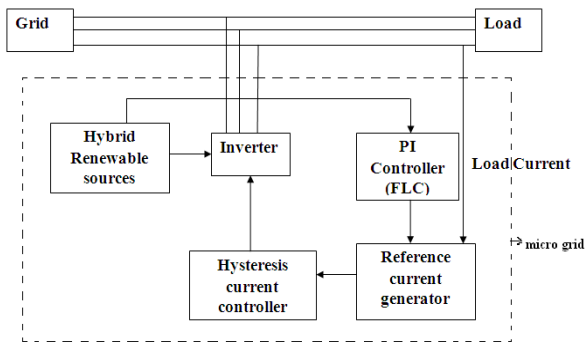


Fig.4.1. Block Diagram of Microgrid controlling

**4.1. CONTROL METHOD**

**4.1.1 SIMULINK MODEL OF COMPENSATION CURRENT REFERENCE ESTIMATOR USING d-q-0 THEORY**

In this Paper, synchronous frame theory is used to find compensation current reference signal, as it works with dc quantities and having instantaneous computation. Fig.4.2 shows the design of model of synchronous reference frame theory which is used here.

The control strategy uses a discrete PLL block which generates sinusoidal reference currents, for Park's and Inverse Parks transformation for which abc to dq0 and dq0 to abc transformation block is used respectively. To find fundamental components from load currents two digital second order low pass filter blocks are employed.

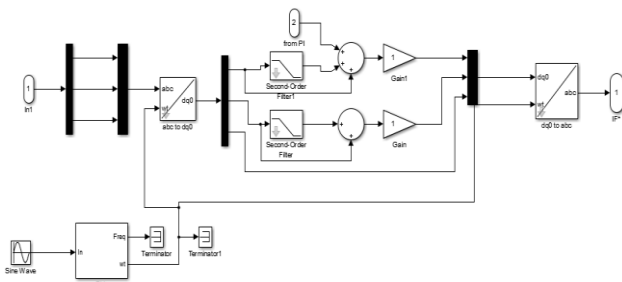


Fig.4.2. Simulink model of d-q-0 theory based reference current estimator

- Discrete PLL block is selected from “Sim Power System/ Discrete Control Blocks” library & its parameters are set and shown in fig.4.3.

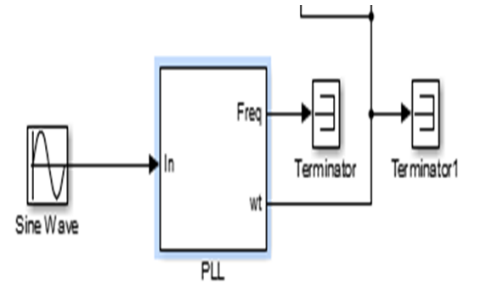


Fig.4.3. Block of PLL used in Simulink model

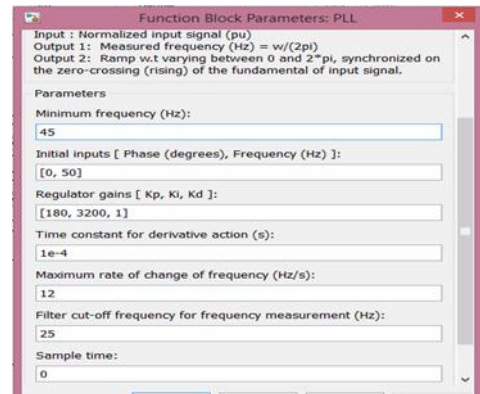


Fig.4.4. Block parameters of PLL

- “The abc to dq0 Transformation block” converts abc reference current into dq0 reference frame current which are then applied to second order LPF for noise filter. It has been taken from “Sim Power Systems/ Discrete Control Blocks” library for noise filtering.
- Here, we are using two 2<sup>nd</sup> order LPF known as Butterworth LPF. Design parameters of filter are  $T = 0.707$ ,  $f_{LPF} = 75$  Hz and  $F_s = 40$  KHz.
- Here in this fig.4.5, we can see fundamental component which is obtained from LPF is subtracted from the signal which is not filtered and then summed to current signal which is produced from DC.
- Then, we use inverse Park's transformation and get abc reference through dq0 to abc transformation block.

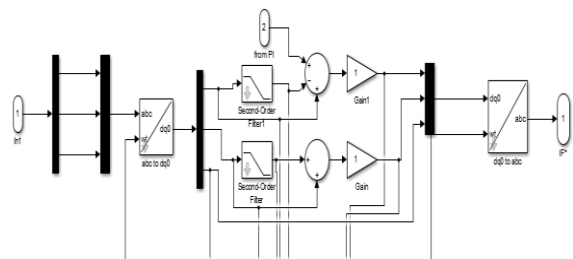


Fig.4.5 Showing conversion from abc to dq0 and dq0 to abc



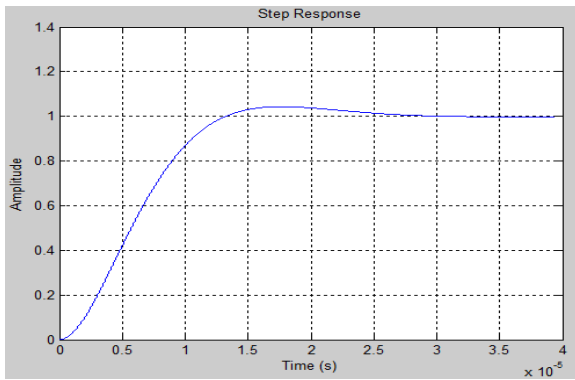


Fig.4.6. Response of butter worth Low pass filter

#### 4.1.2 SIMULINK MODEL OF HYSTERESIS CURRENT CONTROLLED SWITCHING SIGNAL GENERATOR

Here Hysteresis band current controller is employed for producing signals for Transistor of VSI. The technique mentioned here uses a bang bang type instantaneous control which forces the compensation current to follow its estimated reference. The actual Compensation Current is then subtracted from its estimated reference. We pass the output of subtractor to Hysteresis Controller input and we get appropriate gating signal. Hysteresis band chosen here is 0.1A with 0.5 as upper limit & -0.05 as lower limit. The Fig.4.7 shows a Hysteresis Controller which is generated by using “Relay” Block which has taken from “Simulink/Discontinuous” library.

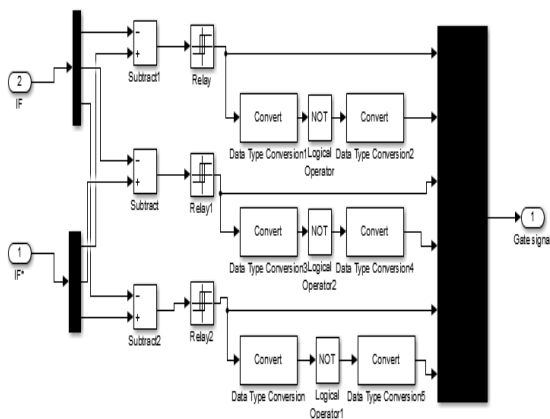


Fig.4.7.Simulation model of Hysteresis controller

#### 4.2.3 SIMULINK MODEL OF FUZZY LOGIC BASED DC-BUS VOLTAGE CONTROLLER

For regulating the DC bus voltage constant so that it can match to a reference value, Fuzzy Logic Controller (FLC) is used in this simulation model. The details of the “Fuzzy logic controller” block are mentioned in Fig.4.8.

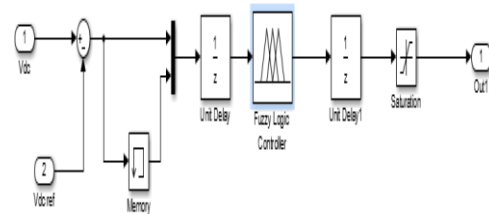


Fig.4.8.Simulink model of Fuzzy logic controller

First the DC-bus voltage is observed and then saturation compared with DC reference voltage. Finally error signal is produced. We apply error signal and its derivative to fuzzy logic controller. Error signal is fed to “Memory” block and its output is subtracted from the error signal to obtain derivative of error signal as shown in the Fig.4.8.

#### 4.2.3.1. FUZZY LOGIC CONTROLLER

A Fuzzy Control System is a scientific and mathematical system. It takes input in the analog form that are in terms of logical variables and has continuous values in the range of 0 and 1. This control system depends on fuzzy logic.

Fuzzy logic is used in various applications and in that vastly used in machine control. The phrase Fuzzy “partially true” in place of “true” or false. Genetic Algorithm and Neural networks both can perform like fuzzy logic in several studies but fuzzy logic has the benefit over these is that it can face the issue which can be understood by a human operator, that’s why it can be used in the design of controller. This special feature makes it convenient for Human usage.

#### 4.2.3.2. FUZZY LOGIC CONTROLLER IN MATLAB

A Fuzzy Control System is a mathematical system which takes analog input values in terms of logical variables having continuous values between 0 and 1. It is a control system based on fuzzy logic.

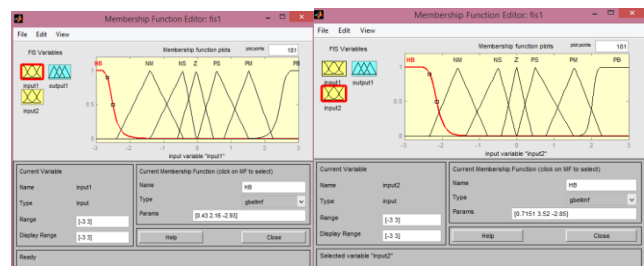


Fig.4.9.Inputs of fuzzy controller in Simulink

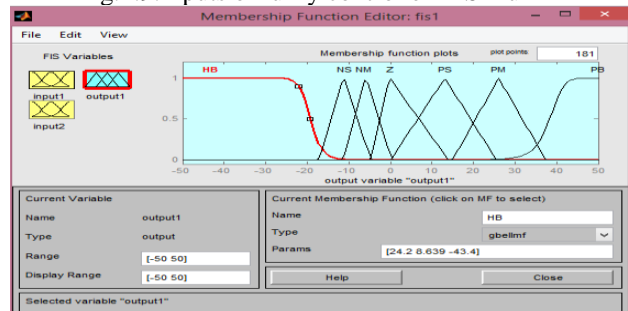


Fig.4.10.Output of fuzzy logic controller



E de	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NM	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PM	PB
PB	ZE	PS	PM	PB	PB	PB	PB

Fig.4.11.Rules of fuzzy logic controller

Inputs are fed to controller which maps then into their corresponding membership functions and truth values. These mapping are fed into rules. If the rule says an AND relation between the mapping functions then minimum of the two is used as the combined truth value. If rule says an OR relation between the two then maximum of two is used. Then output state is selected and a membership value at the truth level is assigned. Defuzzification of the truth value takes place and the desired output is obtained.

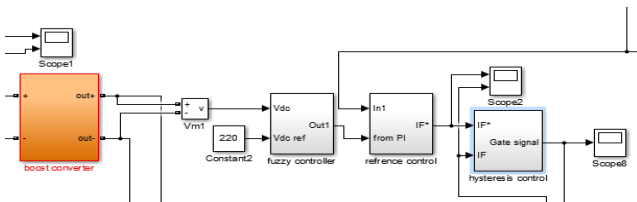


Fig.4.12.Simulation model of fuzzy controller

4.2 GATE PULSES GIVEN TO INVERTER

The output of controller fed to the inverter gate input to generate gate signals which will control output of inverter depending on load and grid voltage. Here the figure shows the gate signal of inverter which will turn on power electronic device like IGBT in inverter.

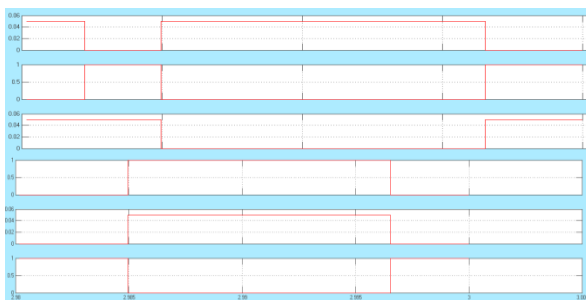


Fig.4.13.Gate pulses given to six IGBT'S

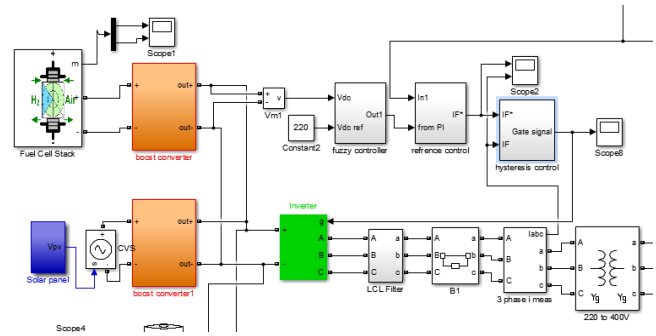


Fig.4.14. Controlling of Microgrid using Simulink

V. SIMULATION MODEL OF MICROGRID IN GRID CONNECTED MODE AND IN ISLAND MODE

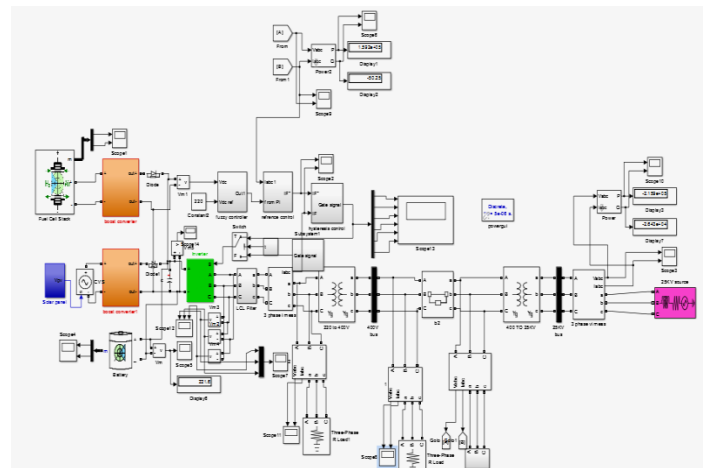


Fig.5.1.Simulation model of Microgrid connected to main grid

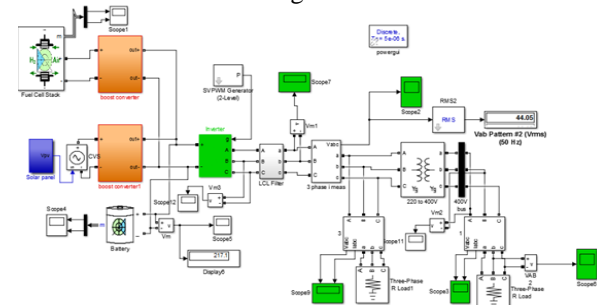


Fig.5.2.Simulation model of Microgrid in island mode

5.1 MODES OF OPERATION

5.1.1 Grid connected mode

In this mode a Microgrid is connected to main grid. The MG can take totally or partially energy from main grid. If there is excess power in micro grid then that power can be sent to main grid. Here from 0 to 0.02 sec grid is connected to Microgrid and from 0.12 sec to till simulation time again switch to grid connected mode.

5.1.2 Island mode

Whenever there is fault or internal disturbance in main grid then Microgrid is disconnected from the main grid and said to be working in autonomous mode. To isolate



Microgrid from main grid we have used here circuit breaker. Initially the circuit breaker is kept closed. We have assumed that fault occurs in main grid at 0.02 sec and it will disconnect main grid from Microgrid. Now Microgrid will work independently

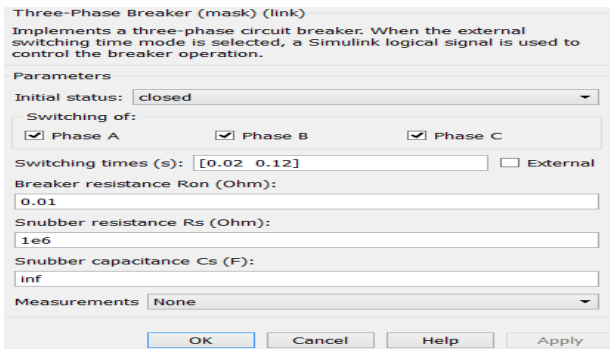


Fig.5.3.Circuit breaker which disconnect Microgrid from Main grid

Here we have used a timing circuit for switching of gate signals of inverter during grid connected mode and island mode.

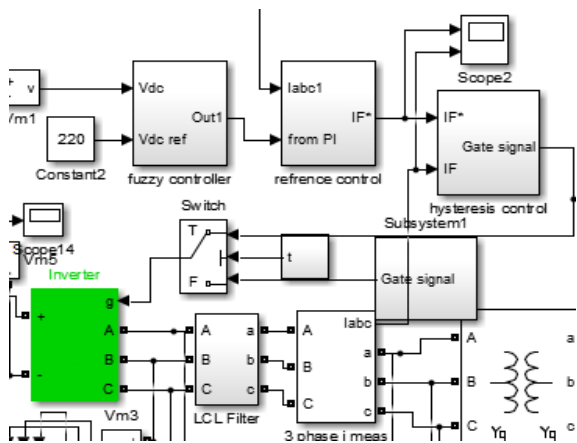


Fig.5.4 controlling of inverter

- 0 to 0.02 sec - Inverter is controlled by fuzzy controller (grid connected mode)
- 0.02 sec to 0.12 sec – inverter is controlled by SVPWM controller (island mode)
- 0.12 sec to till simulation time – Again fuzzy controller (grid connected mode)

## VI. SIMULATION RESULTS

### 6.1 VOLTAGE AND CURRENT WAVEFORM OF NONLINEAR LOAD IN GRID CONNECTED MODE

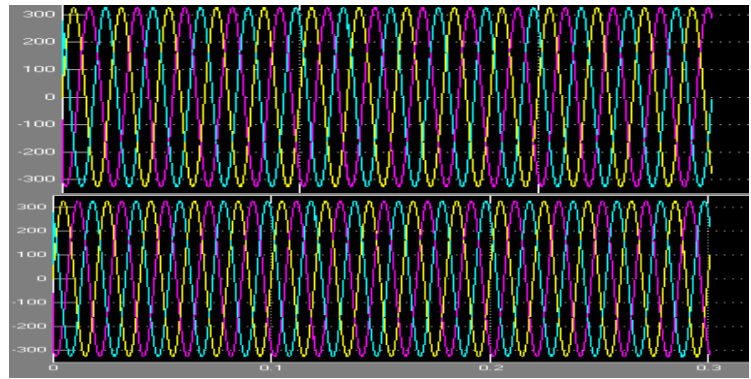


Fig.6.1. Voltage and current waveform of nonlinear load in grid connected mode

### 6.2 VOLTAGE AND CURRENT WAVEFORM OF R LOAD OF 5KW IN GRID CONNECTED MODE

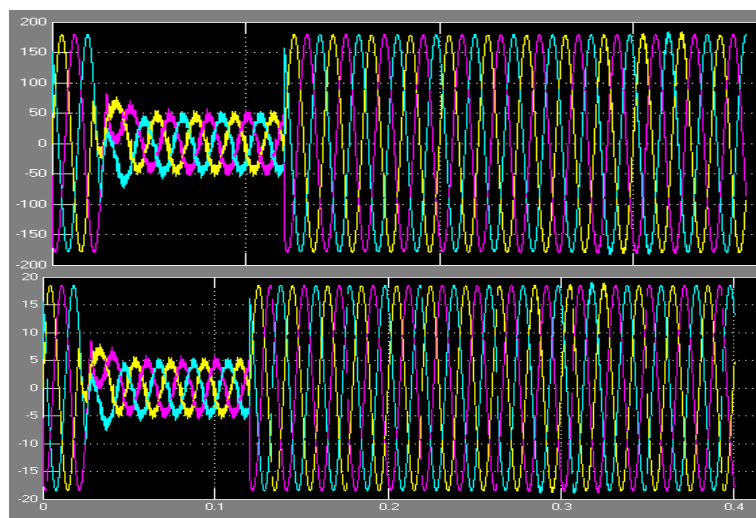


Fig.6.2. Voltage and Current waveform of Rload of 5KW in both mode

### 6.2. VOLTAGE AND CURRENT WAVEFORM OF R AND R1 LOAD DURING ISLANDING

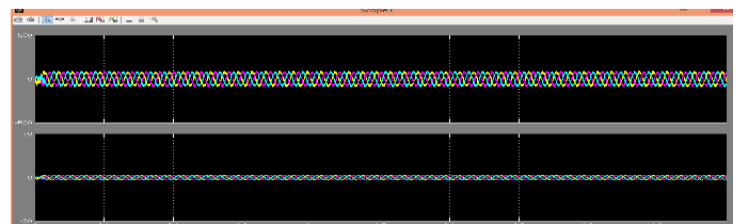


Fig.6.3. Voltage and current waveform of R load

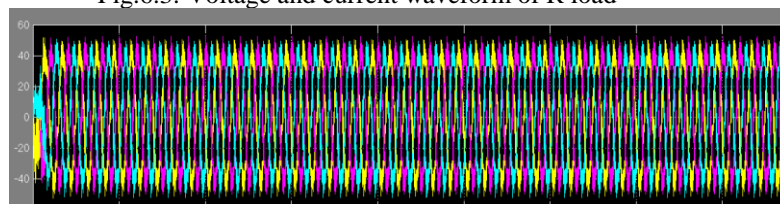


Fig.6.4.Voltage waveform of R load1

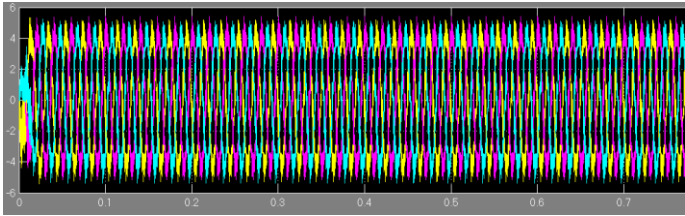


Fig.6.5.Current waveform of R load1

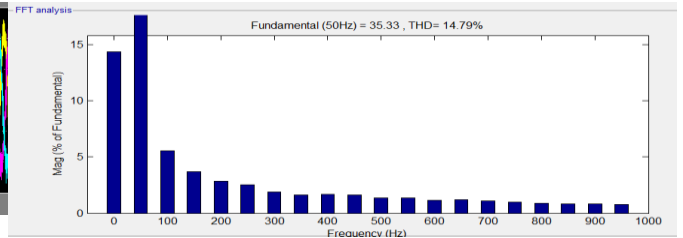


Fig.6.9.THD of R load1 using SVPWM

6.3 THD ANALYSIS IN GRID CONNECTED MODE

• THD OF NONLINEAR LOAD

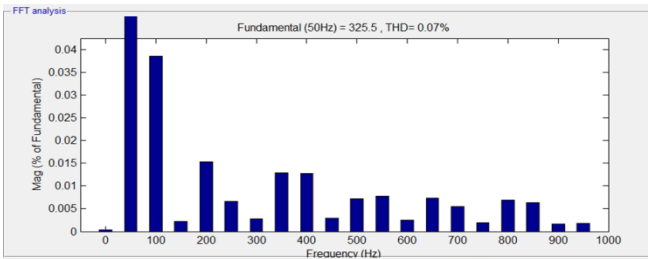


Fig.6.6. Total harmonic distortion of nonlinear load

• THD OF R LOAD

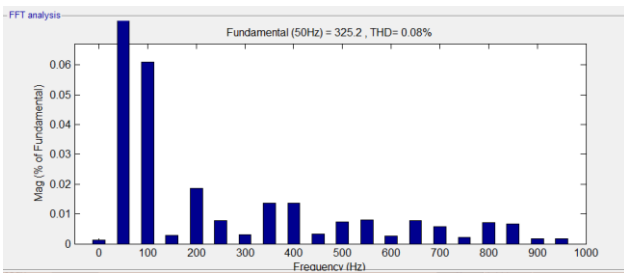


Fig.6.7. Total harmonic distortion of resistive load

As we can see from above figures we are getting very less THD in grid connected mode.

6.3 THD ANALYSIS IN AUTONOMOUS MODE

• THD OF R LOAD USING SPWM

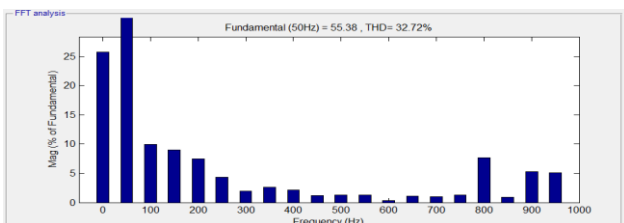


Fig.6.8. THD of Rload using SPWM

• THD OF R LOAD USING SVPWM

VII. CONCLUSION

Here, A MG system supplying power to a non-linear load is studied. In this Paper, a controller system is used which consists of Fuzzy controller, Hysteresis controller and PI controller which controls the pulses of inverter switches and improves the power quality by giving THD around 0.07%. Simulating the model in island mode it was observed that the THD during SPWM is around 32.72% and with SVPWM it reduces to 14.79%. So it is preferred to use SVPWM over SPWM for controlling of output voltage of inverter. Optimization of DER's for both Grid connected & island mode is studied and power for each RES & Battery is calculated in such a way that each DER is utilized to the most and system remains cost effective.

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