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A Three Phase Grid Connected PV System using Fuzzy Logic Controller

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Abstract: This paper presents an intelligent control of the output power energy from the three-phase grid connected photovoltaic (PV) array, based on fuzzy logic controller the implementation of the voltage source inverter for the grid connected applications. Firstly, a simulation module based on the mathematical model of a PV panel is utilized to predict the maximum total power from PV arrays; the second one is a frequency regulation module used to compute a proper reference value for the output active power; and the last is a coordinated main controller for power-electronic converters and battery charger to deliver active power to the grid exactly according to the reference value computed beforehand. Especially in the frequency regulation module, a unique fuzzy logic controller (FLC) is designed. MATLAB/Simulink model is developed to illustrate the proposed system.

Keywords: Solar Photovoltaic; Voltage Source Inverter, Fuzzy Logic Controller.

I. INTRODUCTION

With weariness of normal assets and quickened interest of routine vitality, the issues of vitality lack and ecological contamination on the planet have happened to much significance that constrained the organizers and approach creators to search for option assets. The deregulation of power markets and prerequisite to diminish nursery gas outflow from the routine electric force era make the dispersed era (DG) renewable vitality frameworks pick up an awesome open door as another method for force era that take care of the quickened demand for electric energy[1]. Among all the different DG advancements, sun powered photovoltaic frameworks are quickly developing in power markets because of the declining expense of PV modules, expanding effectiveness of PV cells, fabricating innovation improvements and financial matters of scale [2- 3]. Be that as it may, the expanding infiltration levels of PV frameworks into the network have offered ascend to potential issues identifying with force quality (i.e. low power component, consonant mutilation, and so on.). Thus, a grid-connected inverter is usually needed to convert this dc power into the ac power, which is then fed into the electric grid for utilization. The two major types of inverters are voltage source inverters (VSIs). The control of the voltage source inverter, because VSI can balance the grid voltage fluctuations and it produces a predetermined value of current to the grid, thereby achieving a high power factor at the output voltage[4].

To control various nonlinear applications, fuzzy controller is the most appropriate solution. The response of the PI controller (input/output) is collected in the database manually. Fuzzy logic controller comprises of membership functions (input/output). The input response collected in the knowledge base is categorized into error „d" and change in error „de". Architecture of fuzzy logic controller In fuzzy, a single member function in error „d" is compared with all the membership functions in change in error „de" at a particular time instant. Thus, the time consumption of the fuzzy logic is very less compared to PI controller.

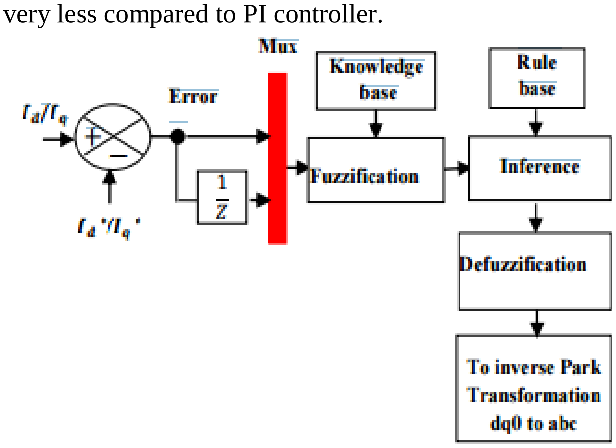

Fig.1. Architecture of fuzzy logic controller.

The membership functions of fuzzy logic controller are depicted in fig. 1, 2 and 3. The fig. 2 and 3 shows the change in error and input error respectively and fig. 4 describe the output of the fuzzy controller. NL –Negative Large; NM-Negative Medium; NS – Negative Small; Z – Zero: PS -Positive Large; PM – Positive Medium and PL – Positive Large

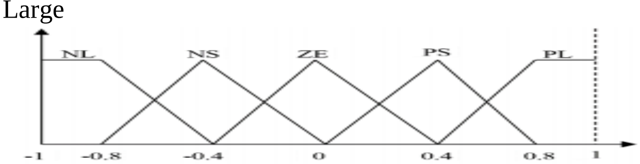

Fig. 2. Change in error (de).

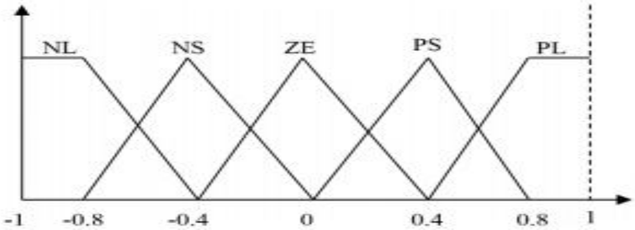

Fig. 3. Input in error (d).

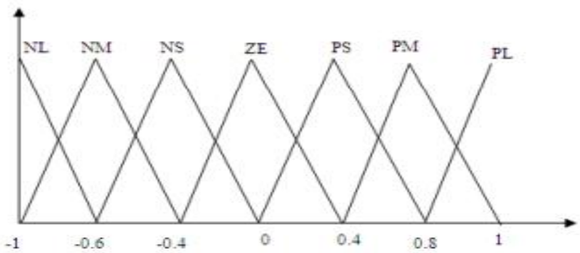

Fig. 4. Output of fuzzy controller.

TABLE I: Fuzzy Rules

		Error						
		NL	NM	NS	Z	PS	PM	PC
Rate of change of error	NL	NL	NL	NL	NL	NM	NS	Z
	NM	NL	NL	NL	NM	NS	Z	PS
	NS	NL	NM	NM	NS	Z	PS	PM
	Z	NL	NS	NS	Z	PS	PM	PL
	PS	NM	Z	Z	PS	PM	PL	PL
	PM	NS	PS	PS	PM	PL	PL	PL
	PL	Z	PM	PM	PL	PL	PL	PL

II. GRID CONNECTED SOLAR PVSYSTEM

The general grid connected SPV system is shown in Fig.5. First stage PV array or module is connected with the system which connects the input to the inverter. The 3-phase VSI is used to convert DC voltage to AC voltage and feeds the energy to the load and grid through LC filter circuit. The inverter has to be controlled in order to obtain harmonic less voltage to achieve good power quality. Various PWM techniques are used to switch the inverter circuit. A PLL is used for proper synchronization.

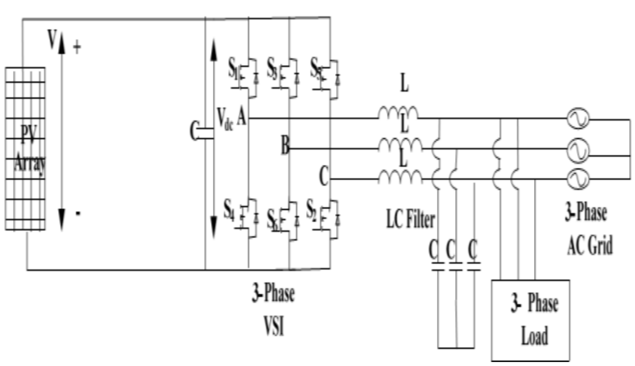

Fig.5. General Block Diagram of Grid Connected SPV system.

A. Modeling of Solar PV

The Solar-PV cells are used to produce electricity by directly converting solar energy to electrical energy. Each solar cell is basically a p-n diode. As sunlight strikes a solar cell, the incident energy is converted directly into electrical energy without any mechanical effort. The voltage and current levels are produced from PV cells are very less, thus these PV cells are connected in series and parallel called modules and arrays to produce required voltage and current levels. The solar PV array is modeled by considering the output characteristics of PV panel which directly have relation with power converters which exists in the system. The solar PV cell is a non linear device which can be represented by a current source connected parallel with diode as shown in Fig.6. The characteristics of equivalent solar cell circuit are given in (1).

$$I_{PV} = N_P * I_{Ph} - N_P * I_0[\exp\{\frac{q*(V_{PV} + I_{PV}R_s)}{N_s AkT}\} - 1] \quad \textbf{(1)}$$

Where I_{pv} is the PV array output current, V_{pv} is the PV array output voltage, I_p his module photo current, R s is the series resistance, k is the Boltzmann constant (138e-23 J/K), A is the ideal factor, N sis the series no of cells and N_p is parallel number of cells. T is the operating temperature [2]. The equation (1) is simulated using MATLAB/Simulink and P-V and I-V characteristics are obtained. The operating curves shows that solar PV output power is function of solar irradiation.

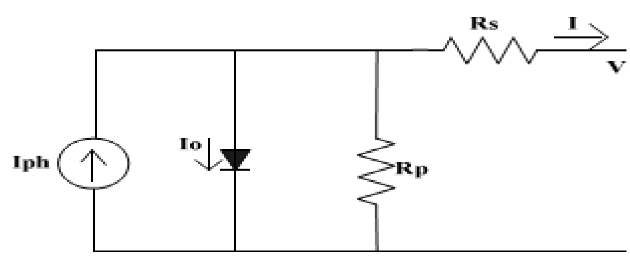

Fig.6. PV Module.

B. 3-Phase VSI and Filter

A 3-phase VSI is used to convert DC voltage into AC voltage and feeds power to consumer loads and utility grid. The 3-phase inverters are used in grid connected SPV systems. A 3-phase inverter is a six step bridge inverter. It uses a minimum of six devices. As stated earlier, the transistor family of devices is now very widely used in inverter circuits. Presently the use of IGBT in three-phase inverter is on the rise. A capacitor connected at the input terminals tends to make the the input dc voltage constant. This capacitor also suppresses the harmonics fed back to the source. In inverter terminology, a step is defined as a change in the firing from one IGBT to the next IGBT in proper sequence. For one cycle of 360, each step would be of 60 intervals for a six step inverter. This means that the IGBT would be gated at regular intervals of a six step inverter. There are two possible patterns of gating the switches. In one pattern, each switch conducts for 180 and in the other each switches conducts for 120. But in both these patterns gating signals are applied and removed at 60 intervals of the output voltage. A LC type filter is used to provide 50Hz frequency output to consumer loads and electric grid. There are various factors which decide the selection of filter capacitor and inductor. Generally in order to eliminate the higher order harmonics, the resonant frequency of the filter should be greater than 6 times of desired output frequency [4].

III. MATHEMATICAL MODEL OF LC FILTER

The mathematical model of LC filter circuit has been derived using state space analysis [5]. LC output filter circuit for voltage and current equations is shown in Fig.4. Kirchhoff's current law is applied to the nodes a, b, c shown in Fig.7.

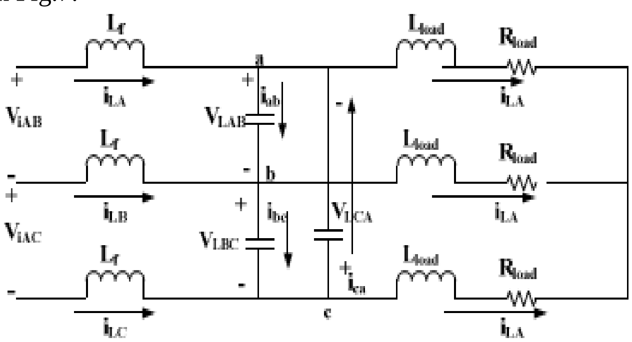

Fig.7. LC Filter Circuit.

At node a,

$$i_{iA}+i_{ca}=i_{ab}+i_{LA}\Rightarrow i_{iA}+C_f\frac{dV_{LCA}}{dt}=C_f\frac{dV_{LBC}}{dt}+i_{LB} \quad (2)$$

At node b,

$$i_{iB}+i_{ab}=i_{bc}+i_{LB}\Rightarrow i_{iB}+C_f\frac{dV_{LAB}}{dt}=C_f\frac{dV_{LBC}}{dt}+i_{LB} \quad (3)$$

At node c,

$$i_{iC}+i_{bc}=i_{ca}+i_{LC}\Rightarrow i_{iC}+C_f\frac{dV_{LBC}}{dt}=C_f\frac{dV_{LCA}}{dt}+i_{LC} \quad (4)$$

To make state equations, Kirchhoff's voltage law is applied to inverter side and load side and finally state space equation for LC filter circuit is given in (5).

$$\dot{X}(t)=AX(t)+Bu(t) \quad (5)$$

$$X=\begin{bmatrix}V_L\\ I_i\\ I_L\end{bmatrix}_{9\times1},\quad A=\begin{bmatrix}0_{3\times3} & \frac{1}{3C_f}I_{3\times3} & \frac{-1}{3C_f}I_{3\times3}\\ \frac{-1}{L_f}I_{3\times3} & 0_{3\times3} & 0_{3\times3}\\ \frac{1}{L_{load}}I_{3\times3} & 0_{3\times3} & \frac{-R_{load}}{L_{load}}I_{3\times3}\end{bmatrix}_{9\times9}$$

$$B=\begin{bmatrix}0_{3\times3}\\ \frac{1}{L_f}I_{3\times3}\\ 0_{3\times3}\end{bmatrix}_{9\times3},\quad u=[V_i]_{3\times1}$$

Where $V_L=[V_{LAB}\ V_{LBC}\ V_{LCA}]^T$, $Ii=[i_{iAB}\ i_{iBC}\ i_{iCA}]^T$, $Vi=[V_{iAB}\ V_{iBC}\ V_{iCA}]^T$, $I_L=[\ i_{LAB}\ i_{LBC}\ i_{LCA}\ ]^T$ (6)

IV. MATLAB/SIMULINK RESULTS

Simulation results of this paper is as shown in bellow Figs.8 to 21.

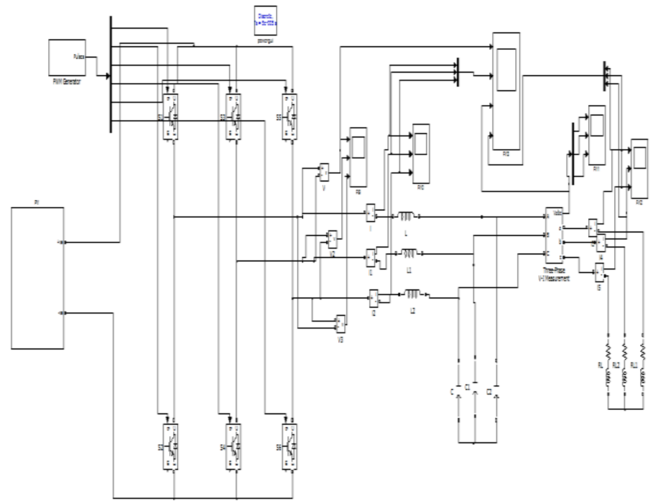

Fig. 8. Matlab/Simulink Circuit diagram Grid Connected SPV system.

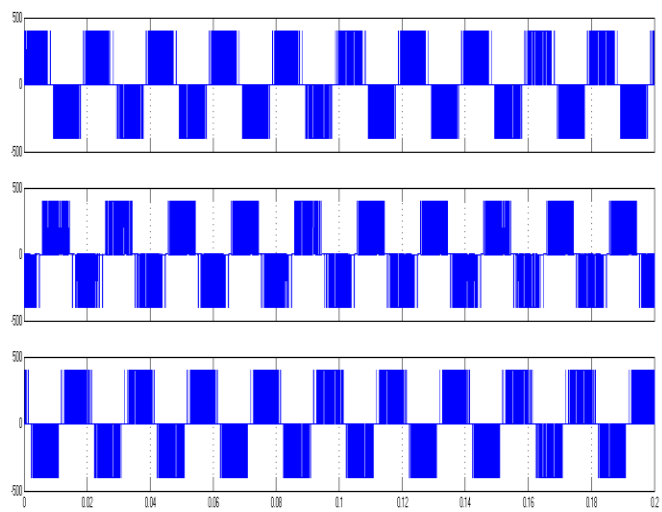

Fig.9. Inverter Output line to line Voltages (ViAB,ViBC,ViCA).

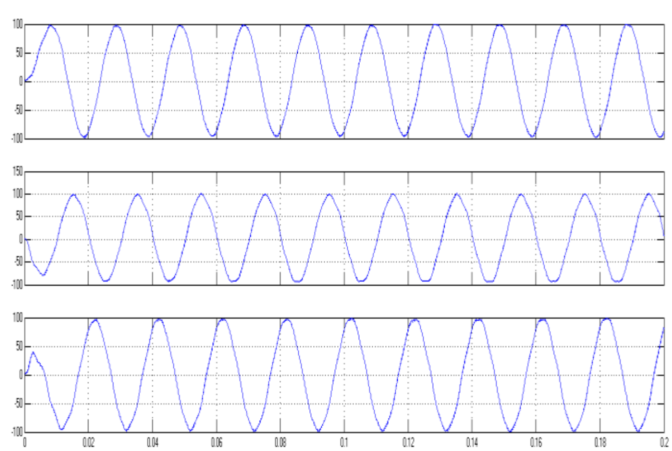

Fig. 10. Inverter Output Currents (iiA,iiB,iiC).

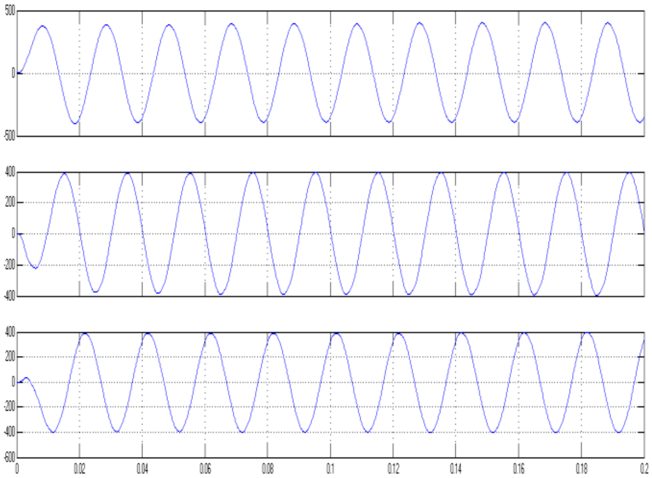

Fig. 11. Load line to line voltages (VLAB, VLBC, VLCA).

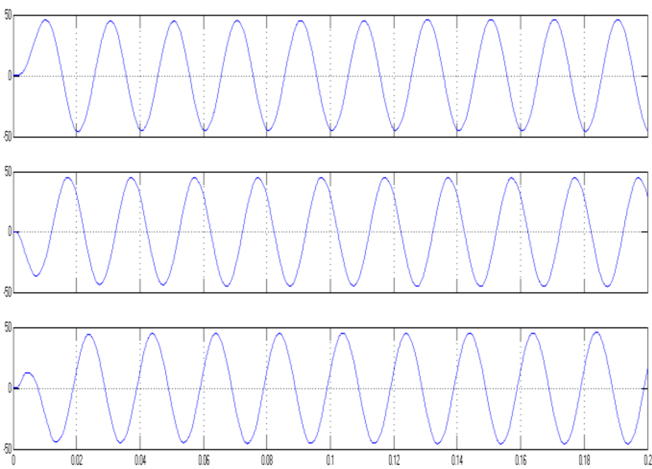

Fig. 12. Load Phase Currents (iLA,iLB,iLC).

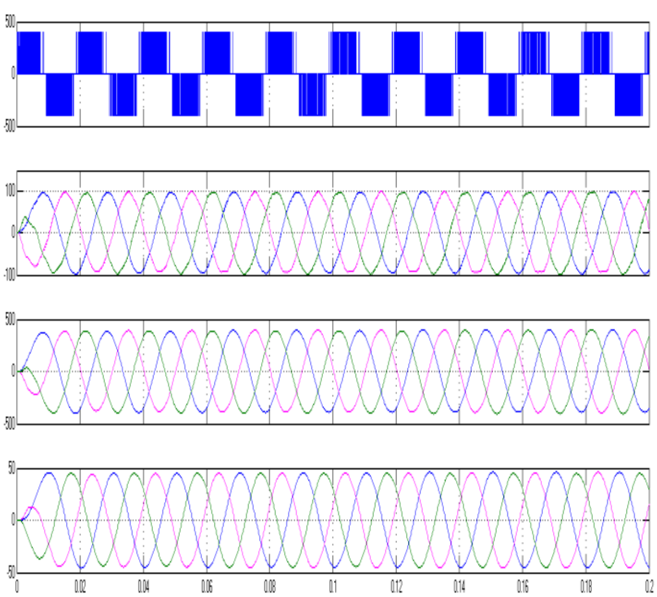

Fig.13. Inverter output line voltage, Inverter output current, Load line voltage, Load phase currents.

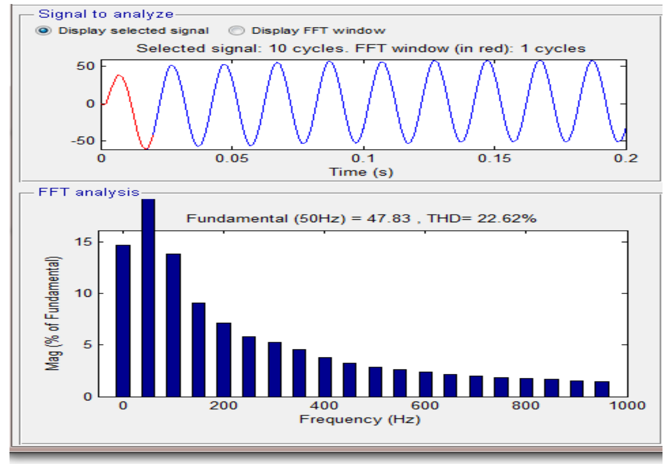

Fig.14. FFT analysis for Load phase current without fuzzy logic controller.

Inverter output line to line voltages are given in Fig. 9. The voltages are called as ViAB, ViBC, ViCA. Fig. 10 shows inverter output currents iiA, iiB, iiC. Load line to line voltages and load phase currents iLA, iLB, iLC are given in Fig. 11 and Fig 12. Inverter output line to line voltages (ViAB), Inverter output currents (iiABC), load line to line voltages (VLABC) and load phase currents (iLABC) are given in Fig.13.

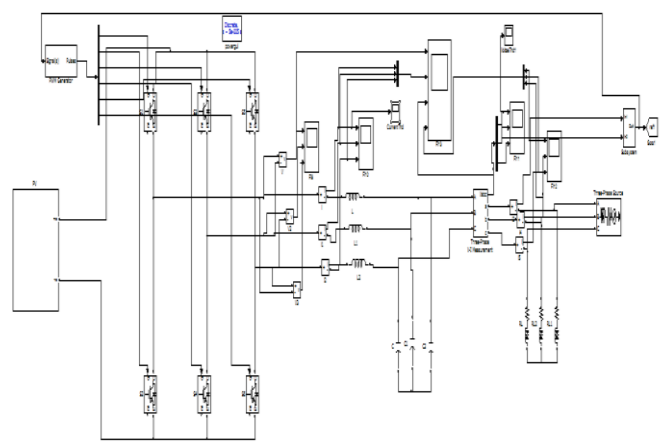

Fig.15.Matlab/Simulink Circuit diagram Grid Connected SPV system with fuzzy logic controller.

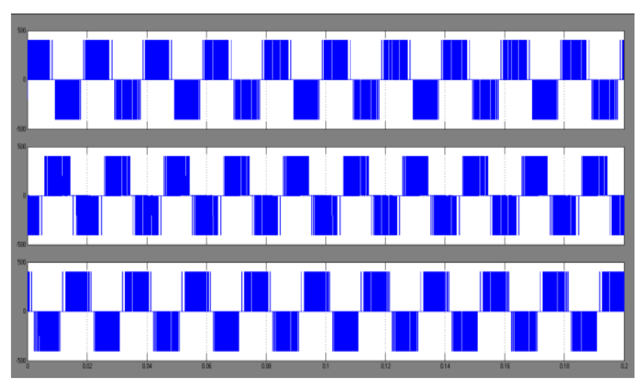

Fig.16. Inverter Output line to line Voltages (ViAB, ViBC, ViCA) with fuzzy logic controller.

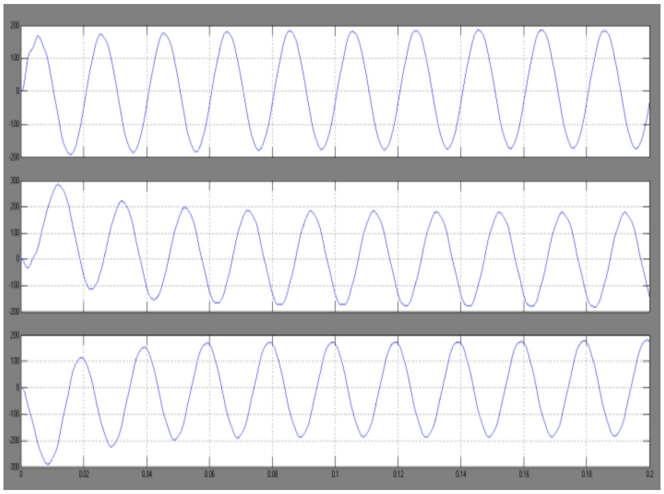

Fig.17. Inverter Output Currents (iiA,iiB,iiC)with fuzzy logic controller.

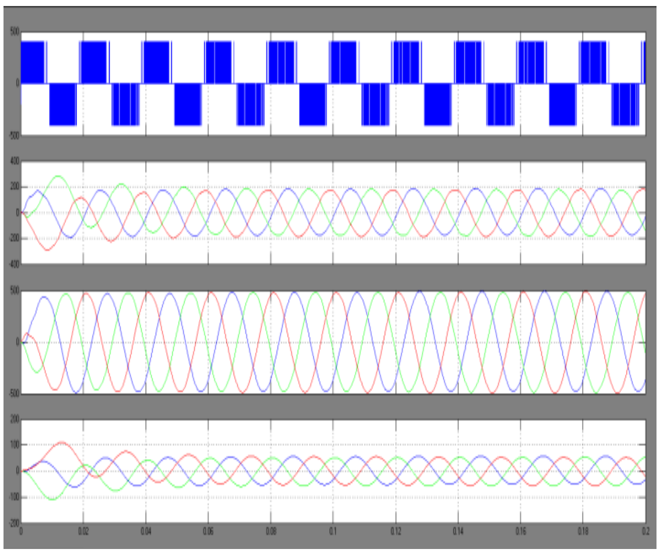

Fig.18. Inverter output line voltage, Inverter output current, Load line voltage, Load phase currents with fuzzy logic controller.

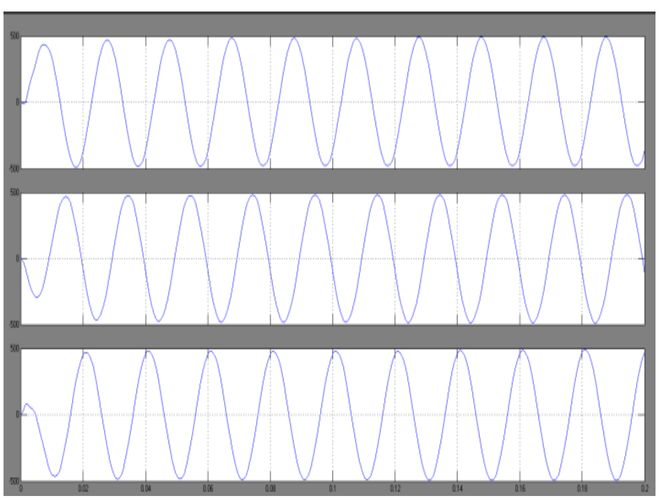

Fig.19. Load line to line voltages (VLAB, VLBC, VLCA).with fuzzy logic controller.

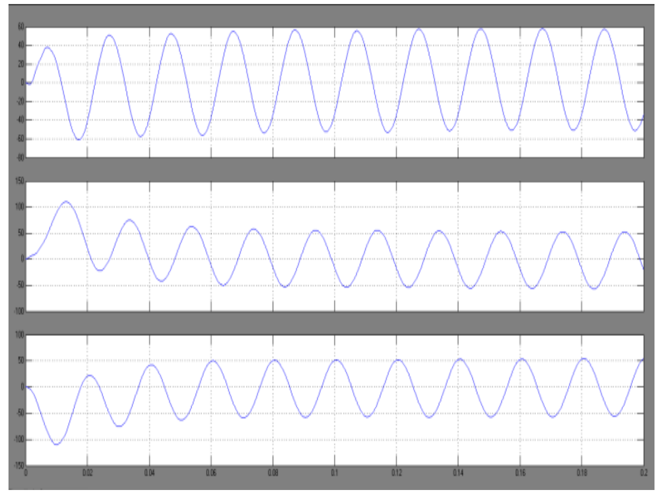

Fig.20. Load Phase Currents (iLA,iLB,iLC) with fuzzy logic controller.

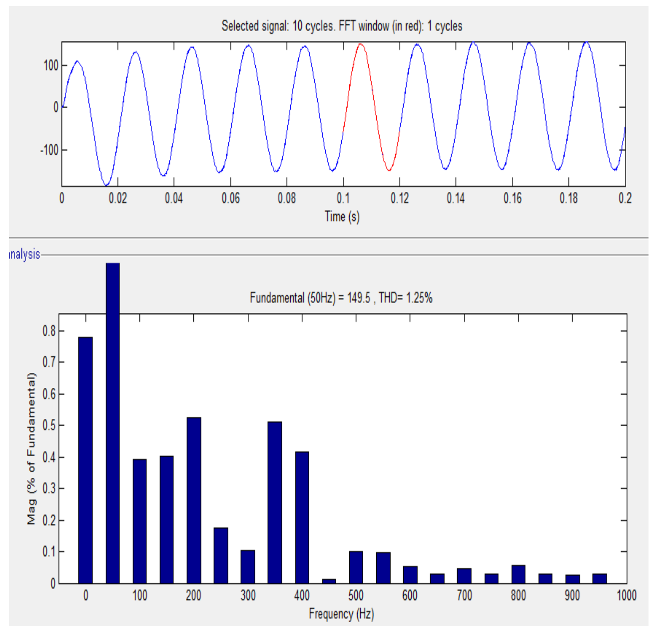

Fig.21.FFT analysis for Load phase current with fuzzy logic controller.

VI. CONCLUSION

Increasing demand on energy efficiency and power quality issues, grid connected solar PV systems is taking a good place. In this paper for 3-phase grid connected VSI The LC filter circuit is used in the proposed system. This filter circuit is mathematically modeled by using state space analysis and complete state space equation is obtained. The PWM technique is implemented and simulated on 3 phases VSI using state space model of the LC filter circuit for grid connected solar PV system. Simulation mode of the voltage source inverter using the Fuzzy logic controller is implemented. The results clearly show the output has very less THD and produces much lower switching losses. Thus the three phase grid connected solar pv system with Fuzzy logic controller has better performance compared with conventional methods.

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