A Fuzzy Logic Based Three phase Inverter with Single DC Source for Grid Connected PV System Employing Three Phase Transformer

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Abstract-A fuzzy based three phase inverter with single DC source for grid connected photo voltaic (PV) system employing three phase transformer is presented in this paper. Space Vector Pulse Width Modulation (SVPWM) control scheme is effectively used to generate the appropriate switching sequences to the inverter switches. The intend of the fuzzy logic approach is to meet high quality output, minimum THD,fast response and high robustness. Finally Total Harmonics Distortion (THD) generated by the inverter is compared with conventional proportional Integral controls (PI). The results are verified with the help of MATLAB Simulink.

Keywords: Fuzzy logic controller, Single DC source, Space Vector Pulse Width Modulation, THD.

1. Introduction

In this modern world ruled by science, the demand of electrical power increases for every year due to growing industries, commercial and domestic applications, etc. To meet the demand,the renewable energy systems have been designed instead of conventional systems of electric power generation. Out of the available renewable energy sources, solar PV based system design plays a vital role for the generation of electrical power as it is pollution free, noiseless and has abundant energy [1-3]. For these reasons, PV has been used as the input source for the proposed inverter topology and Perturb and Observe (P&O), Maximum Power Point Tracking (MPPT) algorithm is used to extract maximum power from the solar PV panel because it is simple, cost effective and easy to implement [4-5]. The major issue lies in converting the available dc sources into ac sources with better power quality aspects such as THD, power factor, etc. For better power quality aspects, Multi Level Inverter (MLI) is the most suitable choice for reducing the THD when compared to the conventional voltage source inverter. MLI's can be commonly classified into three topologies such as diode clamped, flying capacitor and H-bridge type with independent DC sources [6]. H-bridge inverter employing separate DC sources is presented [7]. Cascade MLI's employing three phase transformer with single DC input is proposed in the literature [8-9]. Observed from the references [6-9], inverter topology requires more input DC sources, transformers and switches which results in increased complexity, system size and cost. Proportional Integral (PI) controller is used to maintain the output current sinusoidal and the method to get dynamic performance of different operating conditions of PV panel is presented [10]. The PI controller sometimes may not be suitable for nonlinear control applications because it's gain is fixed , manual tuning of PI controller parameters to eliminate the steady state is difficult, and also it has slow response, large overshoot, very complex to solving mathematical equations [11-12]. In order to overcome the above crisis, the fuzzy logic controller based three phase inverter is introduced in the paper.

The main impetus of the inverter has not only been designed to meet minimumTHD, fast response, flexibility of design and **but also** it uses only 15 switches for generation of three phase powerusing three phase transformer.

The paper is organized follows, the first section of the paper is dealingwith a PV system design. The second section explains three phase PV inverter configuration and it is an operation and the third part discusses with the proposed fuzzy logic controller. The fourth portion deals with SVPWM techniques and the final fragment discusses with result and discussion of the proposed system.

2. PV System Design

2.1 Photovoltaic array and Boost Converter

The PV panel acts as the input DC source for the three phase inverter. The main aspects of the PV modeling are the solar irradiation, temperature, number of cells, short circuit current (I_{sc}), etc. The voltage and current relations for single diode model array can be given as

$$I = I_L - I_0\,(exp\left[\left(\frac{q}{\gamma k T_c}\right)x(V + IR_s)\right] \qquad (1)$$

Where, I_L - Photon current, I_0- Reverse saturation current, q - Electron charge (1.6 x10^{-19}C), k - Boltzmann constant, T_c- Cell temperature in °C. The PV voltage and current are sensed from the solar panel. The sensed voltage and current are given to the P&O based MPPT algorithm for the computation. The output of the P&O based MPPT is compared with a carrier signal with the help of comparator. The output of the comparator is given as an input pulse to the MOSFET switch. The proposed approach uses the boost converter to boost up the input DC voltage to feed the inverter. The boost converter comprises of a smoothing inductorL_1, high speed power semiconductor switches and DC bus. The DC bus has two capacitors with equal values (C_1 , C_2). The step up conversion is carried out through injecting the gate pulses to the switchS_1.

3. Three Phase PV Inverter Configuration

Fig. 1 shows the inverter (one Phase) configuration of the proposed system which consists of conventional H-bridge inverter and one auxiliary inverter along with four power diodes. The power switches M1, M2 and M3 operated at higher frequencies (i.e 20Khz) and M4, M5 operated at nominal frequencies (i.e. 50Hz).

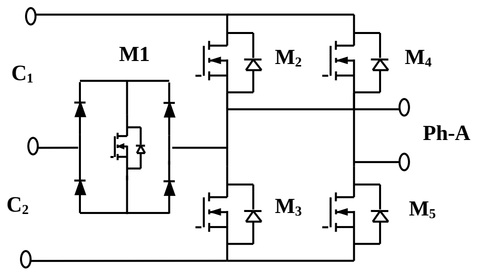

Fig. 1. Five level inverter circuit (One Phase)

In this proposed configuration, three phase inverter consists of three single phase five level inverter namely, phase A, phase B, and phase C is shown in fig. 2. The output voltage each single phase inverter synthesized from the DC bus voltage. DC bus voltage should be higher than grid voltage.

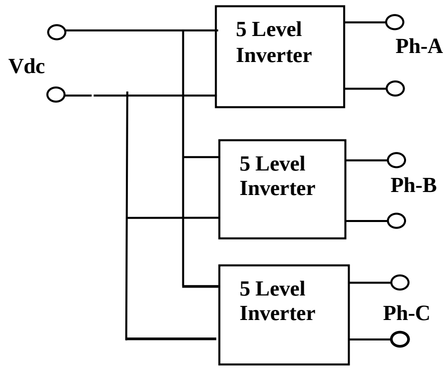

Fig. 2. Topology configuration of three phase ınverter with single DC source

Fig. 3 shows the overall schematic diagram of proposed fuzzy logic based three phase PV inverter configurations, which consists of DC-DC converter in front end, three phase 12 terminal transformer, LC filter and then followed by three phase grid. In this proposed configuration, The three phase inverter consists of three single phase five level inverter namely, phase A, phase B, and phase C . Each phase consists of a conventional H bridge inverter along with auxiliary circuit. The auxiliary circuit configuration using four power diodes (D_1, D_2, D_3, D_4) along with single power switch (M_1). The phase and neutral outputs of the each inverter are given to the primary terminals of the transformer. Similarly, phase B and phase C are connected to the respective primary terminals of the transformer. All the neutral points of the transformer are shorted and all the phases are connected to three phase LC filter. For the proper inverter operation, space vectorpulse width modulation technique is used to generate the appropriate gating pulses to the inverter. The harmonics generated by the inverter are filtered by three phase LC filter. The filtered sinusoidal output from the inverter is fed to the 1:1isolation transformer and the filtered power are injected into the grid. The three phase inverter is modified from reference paper [10, 13] and in order to control above inverter, fuzzy logic based approach is introduced in this paper. The based three phase inverter circuit synthesizes the five level output voltage from the DC bus voltage and it will be operated based on the following switching conditions:

i. If M_2& M_5 = 1 (High), the output voltage of the inverter (V_0) is equal to V_s.
ii. If M_1& M_5 = 1, the output voltage of the inverter (V_0) is equal to ($^{V_s}/_2$).
iii. If M_1& M_4 = 1 (High), the output voltage of the inverter (V_0) is equal to ($-\,^{V_s}/_2$).
iv. If M_3& M_4 = 1 (High), the output voltage of the inverter (V_0) is equal to $-V_s$.
v. If M_1 =0 (low), M_2 = 1 or 0, M_3 = 0 or 1, M_4 = 1 or 0, M_5 = 0 or 1, then output voltage V_o = 0.

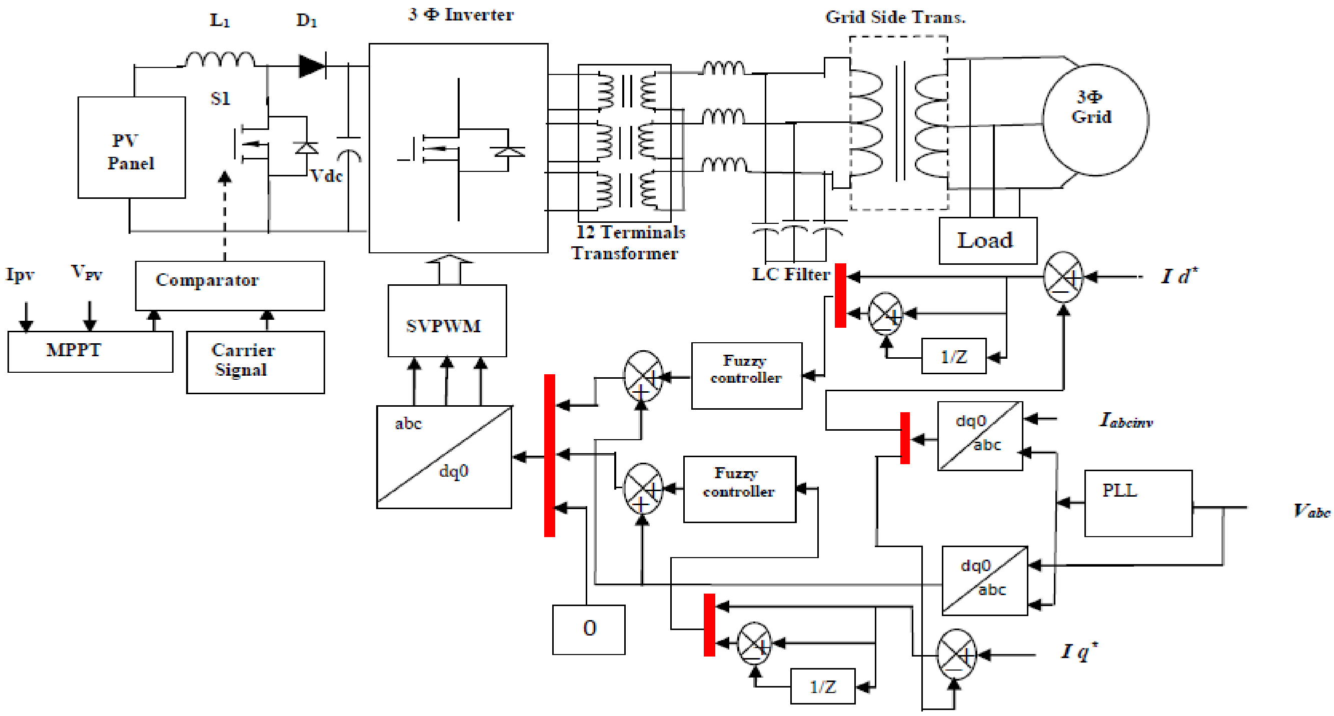

Fig. 3. Schematic diagram of proposed fuzzy logic based three phase inverter with single DC source for grid connected PV system employing three phase transformer

4. Proposed Fuzzy Logic Controller

Fuzzy logic controller architecture is shown in fig.4. In this proposed approach, fuzzy logic based current controller has been designed. 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'.

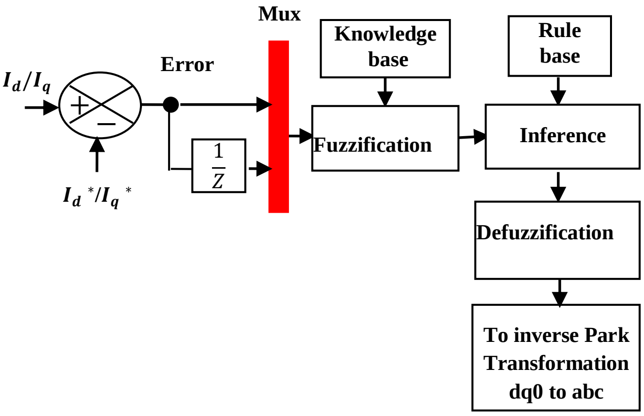

Fig. 4. Architecture of fuzzy logic controller

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. The membership functions of fuzzy logic controller are depicted in fig. 5, 6 and 7. The fig. 5 and 6 shows the change in error and input error respectively and fig. 7 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

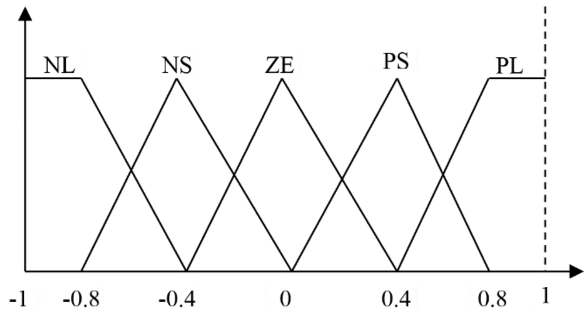

Fig. 5. Change in error (de)

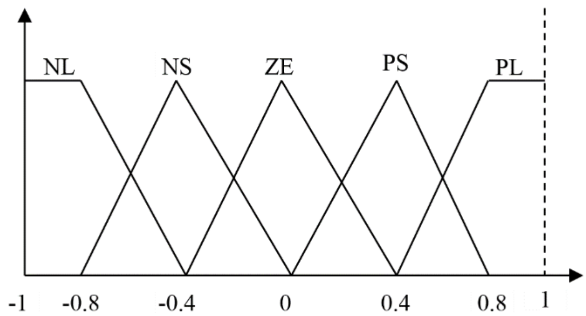

Fig. 6. Input in error (d)

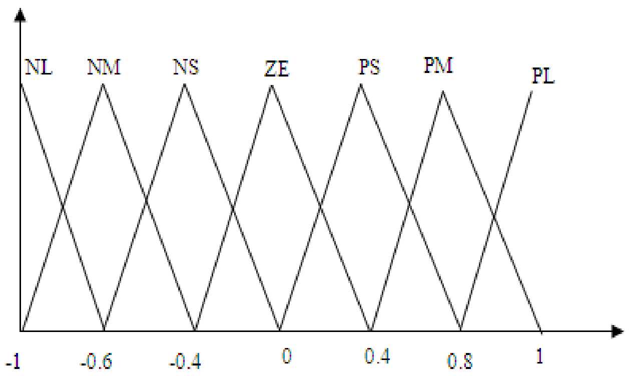

Fig. 7. Output of fuzzy controller

The Table 1 shows the fuzzy rules of the proposed system. This fuzzy rules generated based on the error (d/de). From the table 1'd' indicated as error and 'de' indicated as change in error.

Table 1. Fuzzy rules

d \ de	NL	NS	Z	PS	PL
NL	NL	NL	NM	NS	Z
NS	NL	NM	NS	Z	PS
Z	NM	NS	Z	PS	PM
PS	NS	Z	PS	PM	PL
PL	Z	PS	PM	PL	PL

5. Space Vector Pulse Width Modulation

PWM controls the inverter output voltage and minimizes the THD considerably. Moreover, filters such as LC, LCL, etc may not eliminate the lower order harmonics and hence, PWM has been used for the reduction of such lower order harmonics. But, there are some drawbacks in PWM such as Lower order harmonics may not be eliminated effectively, The higher PWM frequencywould increase the power losses along the switches[14]. Due to the above limitations of the PWM approaches, SVPWM techniques have become an attractive research solution. In this research work, Space Vector PWM (SVPWM) has been used. SVPWM receive reference sine wave as the input from the current controller. From the grid voltage, instantaneous active voltage component (V_d) and instantaneous reactive voltage component (V_q) are separated using Transformations. The magnitude estimation of V_d and V_q is given by $|V_{ref}|$. Then, the angle is extracted from the active and the reactive voltage component. The attained angle is compared with the angles and the appropriate sector for that angle is identified. Now, each sector represents 60^0.The adjacent vectors in each sector of SVPWM need to be averaged. Two adjacent vectors and zero vectors are combined to generate the appropriate PWM signals.

Fig. 8 shows the reference wave generator, which compares reference signal 1 and reference signal 2 compared with high frequency carrier signal and generates appropriate gating signals to the inverter switches.

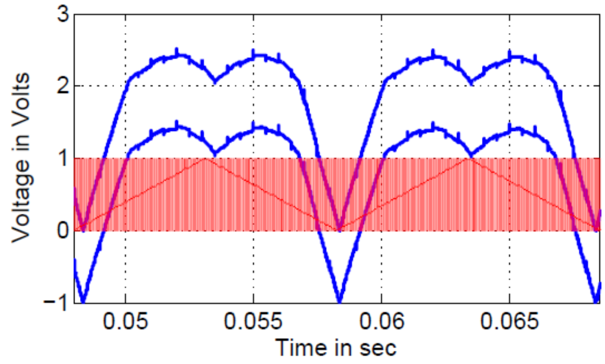

Fig. 8. Reference wave generator

5.1 Time duration calculation

$$T_1 = k \times \left(sin\left(\frac{\pi}{3} - \theta + \frac{n-1}{3}\pi\right)\right),$$

$$T_2 = k \times \left(sin\left(\theta - \frac{n-1}{3}\pi\right)\right)$$

$$T_0 = T_z - (T_1 + T_2)$$

Where, Modulation index 'k'

$$k = \frac{\sqrt{3} \times T_z \times V_{ref}}{V_{dc}}$$

$T_z = \frac{1}{f_s}$; f_s =Switching frequency

6. Simulation Results and Discussion

The proposed fuzzy logic based three phase inverter with single DC source for grid connected PV system employing three phase transformer is simulated and verified using MATLAB Simulink. . All the PV panel assumed to be operated in at 1000 W/m^2. The fig. 10 shows, PV panel operates at a different irradiances level, such as 200 W/m^2, 400 W/m^2, 600 W/m^2, 800 W/m^2, 1000 W/m^2 and it ensures that the power generated from the PV panel is maximum at 1000 W/m^2.

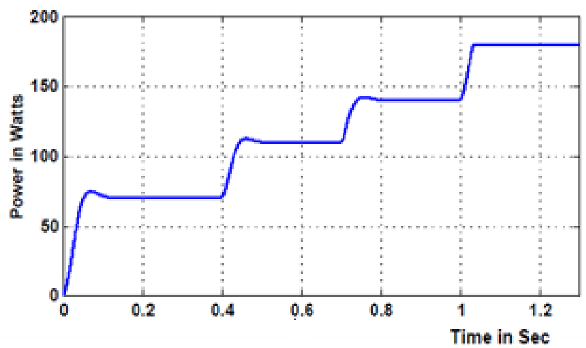

Fig. 9. PV Power Vs voltage (Single PV Panel)

The fig. 9 depicted step change in irradiance in W/m^2 verses time and fig. 10 shows corresponding power generated from the PV panel for step change in irradiancere. . Fig 11 &12 show that the maximum power is obtained from PV panel at 1000 W/m^2, Fig.12 shows maximum output power verses time.

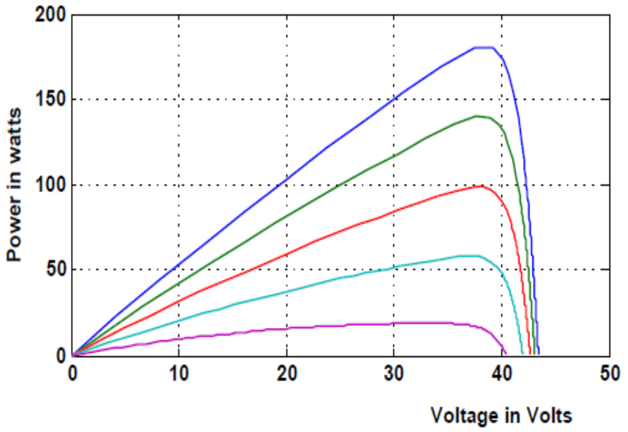

Fig. 10. Step change in the irradiance Vs time

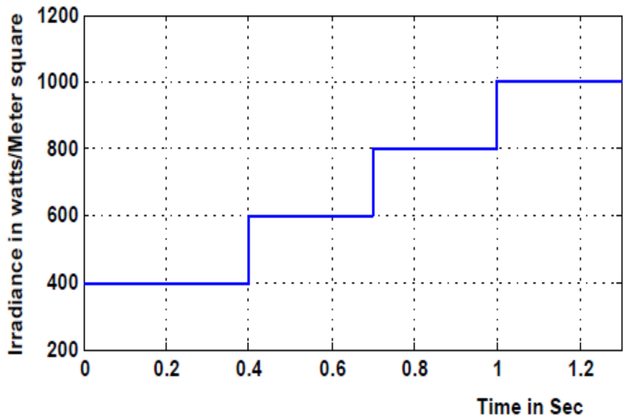

Fig. 11. Maximum PV power Vs time

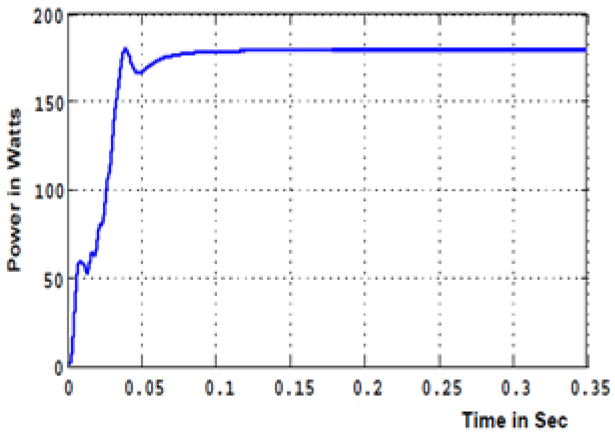

Fig. 12. PV output power Vs time

The proposed fuzzy logic controller based three phase inverter consists of a solar panel, boost converter, three phase inverter topology along with 1:1 ratio 12 terminal three phase transformer, three phase LC filter and grid side transformer. At the front end of the proposed system, dc- dc boost is used to increase input DC voltage to the required level and it is given to the five level inverter. The DC bus voltage approximately set to 330 V. This voltage shared by the inverter and five level voltage synthesized from DC bus voltage. Each single phase inverter generates 230V AC and it is fed to 12 terminal transformers. The Grid voltage of the proposed system is given in the fig. 13 and peak value of the grid voltage is approximately equal to 570 V Peak value AC (400V RMS). Fig. 14 shows inverter current of the proposed model, which is approximately equal to 7.7A Peak value (5.5 A RMS value). These output voltages are given to the three phase LC filter. This is used to filter out the harmonics presented with output of the inverter and filtered output voltage and current fed to the grid. MATLAB simulink model of the proposed system id depicted in the fig. 15.

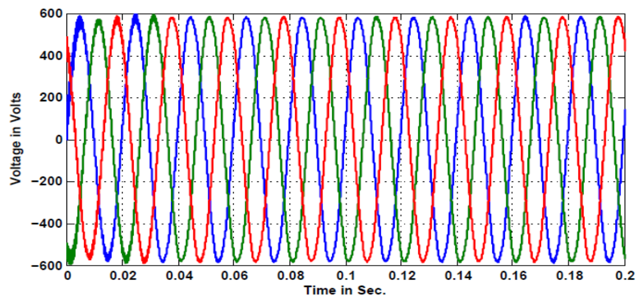

Fig. 13. Simulated three phase voltage

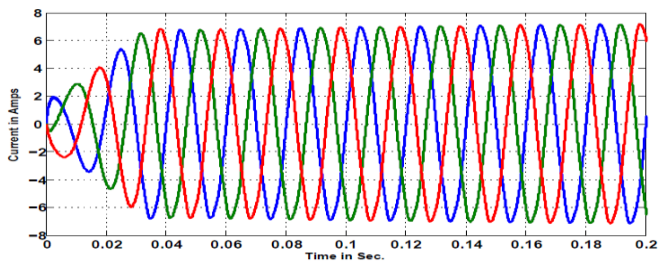

Fig.14. Simulated three phase current

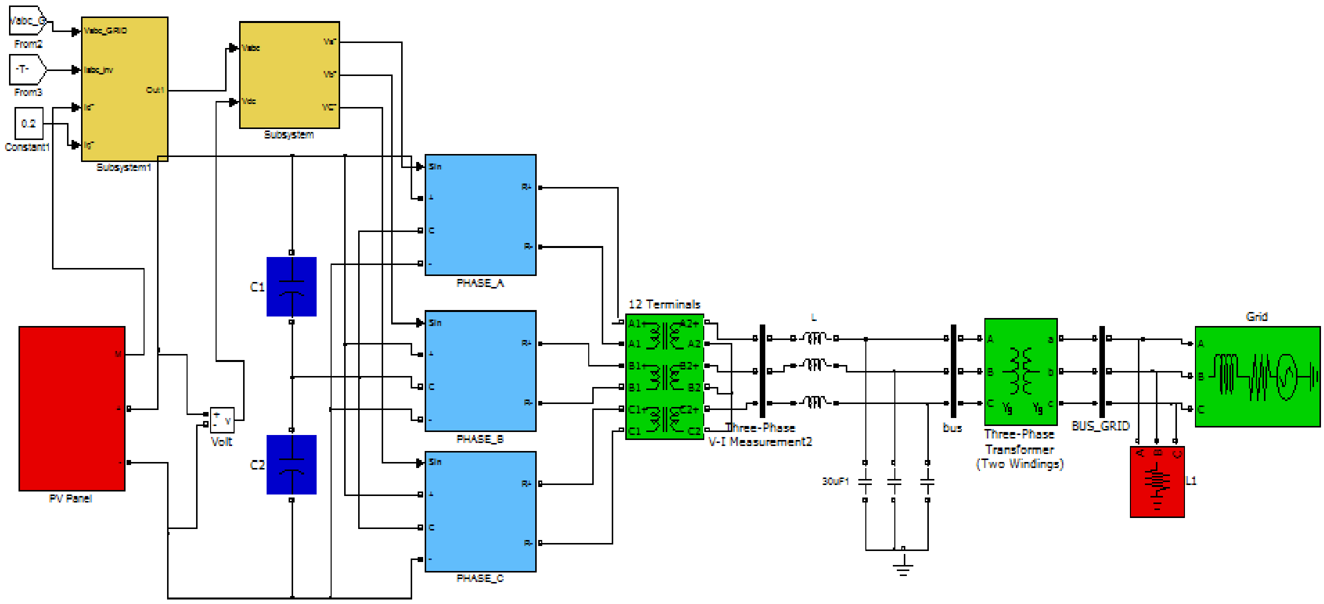

Fig. 15. Simulink model of the proposed fuzzy logic based three phase ınverter with single dc source for grid connected pv system empolying three phase transformer

6.1Performances, analysis of PI and Fuzzy Logic Controller

From the fig 16 and 17,It is observed that, the fuzzy controller shows best minimized THD of about 1.30% and THD generated by PI control about 1.71%. Thus, it is observed that the proposed fuzzy controller performs better when compared to PI Controller

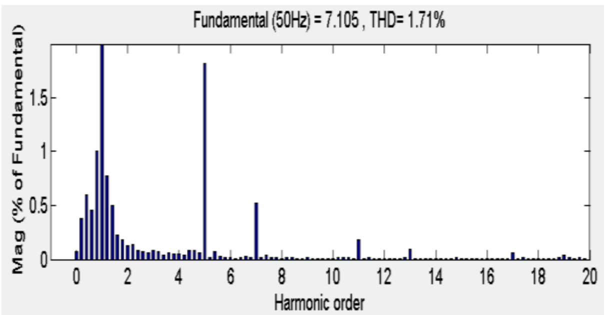

Fig. 16. THD Performances of PI controller

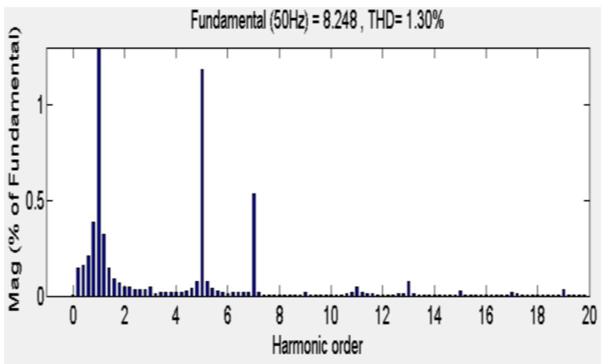

Fig. 17. THD Performances of fuzzy controller

Fig. 18 clearly shows the current response of the conventional PI controller is given in red line and Fuzzy controller is shown in blue. Thus, the performance of fuzzy logic controller as observed in the current waveform of the two controllers is found that fuzzy has lesser settling time when compared to the conventional PI controller.

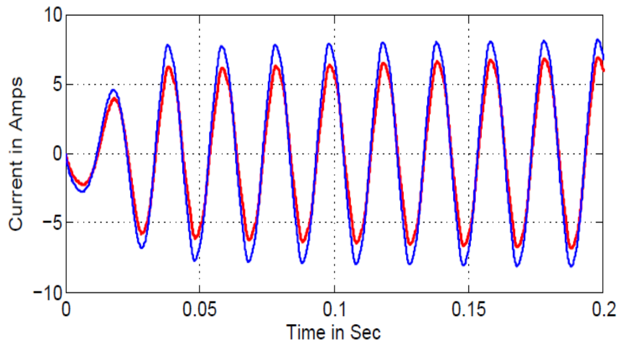

Fig. 18. Comparison of the two controller

The PV panel and system specifications are tabulated in the table 2 and 3.

Table 2. System Specifications

Specifications	Rating
Grid voltage	400V RMS
Inverter current	5.5A RMS
Transformer Ratio	1:1
Frequency	50Hz
Transformer winding connection	Star connected

Table 3. PV Panel Specifications

Specifications	**Rating**
Short circuit Current (I_{sc})	5.48A
Open circuit voltage (V_{oc})	43.6V
MPP voltage (V_{mp})	35.8V
MPP current (I_{mp})	5.03A
Series resistance (Rs)	0.1133Ω
Irradiance @ standard test conditions	1000 W/m^2
Cell temperature @ standard test conditions	25°C
Maximum PV power	180W

Conclusion

This paper has presented fuzzy based three phase inverter using single DC source employing three phase transformer for grid connected PV system.The P&O based MPPT algorithmis used for tracking maximum power from the PV panel. Current harmonics of the system are effectively minimized through SVPWM technique with the utilization of fuzzy logic controllers compared to conventional of PI controller. Thus the proposed fuzzy logic controller meet the fast response and minimum THD. The simulation results were validated using MATLAB Simulink.

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