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Article in International Journal of Power Electronics and Drive Systems · June 2016

DOI: 10.11591/ijpeds.v7.i2.pp543-550

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## Comparative Study of Three Phase Grid Connected Photovoltaic Inverter Using PI and Fuzzy Logic Controller with Switching Losses Calculation

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### Article Info

#### Article history:

Received Sep 29, 2015

Revised Feb 10, 2016

Accepted Mar 3, 2016

#### Keyword:

Fuzzy Logic controller

PI controller

PV Inverter

SVPWM

Switching Losses

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### ABSTRACT

A comparative study of three phase grid connected photovoltaic (PV) inverter using Proportional-Integral (PI) controller and Fuzzy logic controller (FLC) is presented in this paper. Proposed three phase inverter with single DC source employing three phase transformer for grid connected PV system controlled by using space vector pulse width modulation (SVPWM) technique. PI and FLC are used as current controller for regulating the current. Perturb and observe maximum power point technique (MPPT) is used for tracking of maximum power from the PV panel. Finally total harmonic distortion (THD) comparison made between two controllers for validation of results. Furthermore swithing losses of inverter are also presented. The simulation results are obtained using MATLAB simulink.

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## 1. INTRODUCTION

In the modern scientific world ruled by science, the utilizing of electricity has increased rapidly due to growing of population of the world. Nowadays, most of the research works have focused on PV based power generation due to major reasons such as price of fossil fuel, green house effect and energy available in nature [1]. Actually, solar panel is directly converting solar irradiation in to electrical energy [2]. It is necessary to convert available DC voltage into AC voltage and the converted AC voltage should be sinusoidal with high quality output voltage. For this purpose, multilevel inverter (MLI) is the most suitable choice for converting DC into AC compared to the conventional two level inverters with minimum THD values. MLI's broadly categorised into three main types namely, diode clamped, flying capacitor and cascade [3]-[4]. Three phase MLI inverter using cascaded H-Bridge with independent DC source is presented in the literature review [5]. The above topology, each H bridge require separate DC sources with equal rating and separate DC sources make it system bulky and costlier [6]. Cascade H bridge inverter employing single phase and three phase transformers with single DC input is also presented [7]. This configuration use single DC input and require additional single and three phase transformers for higher voltage level. In accordance with the observation from the references [5]-[7], inverter topology requires more DC input, transformers and switches which result in increased complexity, system size and cost. For maintain grid current as pure sinusoidal Proportional-Integral (PI) controller and FLC controllers are used as feedback controller. The PI is maynot satisfactory in controlling various non linear control applications. Moreover the design of its control system is

also very complex and hence newly designed fuzzy logic controller is devoid of these drawbacks [8]. For the proper inverter operation, high quality the gating pulses to be generated to the inverter switches with the help of SVPWM technique [9]. This is a most famous control technique for three phase multilevel inverter [10]. This paper proposes comparative study of three phase PV inverter using PI and FLC with switching loss calculation. In order to increase the quality of power fed into the grid (in terms of THD), 5 level inverter used in this paper. Furthermore SVPWM is used to utilize the DC bus voltage effectively and PV cell is naturally an upcoming technology which is concentrated by most of the researchers. The performances both controllers are analysed interms of THD, fast response. Further more, it uses single DC input, one transformer, 15 switches, fast response and minimum THD are the remarkable advantages of the inverter.

## 2. PHOTOVOLTAIC SYSTEM DESIGN

The PV cell is a semiconductor device that directly converts solar irradiation into electrical energy is effect is called 'Photovoltaic Effect' [11]. The PV panel acts as input DC source for the inverter. The electrical power generated by a solar PV panel mainly depends on the operating conditions, solar irradiation, temperature, number of cells, and short circuit current ( $I_{sc}$ ), etc. In this proposed approach, in order to attain maximum power from the PV panel, P&O MPPT algorithm has been used. The DC output voltage of the PV panels is given to the boost converter. The boost converter increases input DC voltage level, which is based on the gating pulse given to the power MOSFET and time duration of gating pulses desired by duty ratio of switch. The duty ratio of the switch is not a fixed and it will change automatically during the tracking process [12]. The Power MOSFET is a high frequency switching device and it operates at higher frequency ranges of 10 kHz. This will reduce the size of the inductor and external noise.

## 3. THREE PHASE PV INVERTER TOPOLOGY AND PRINCIPLE OF OPERATION

The proposed inverter configuration consists of boost converter, DC bus ( $C_1$ ), three phase inverter, 12 terminal transformer, LC filter and three phase load. The Figure 1 and 2 show PV inverter topology and single phase five level inverter.

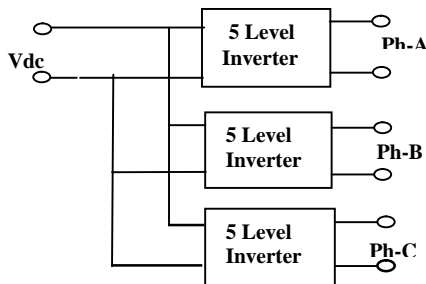


Figure 1. Three phase PV inverter topology

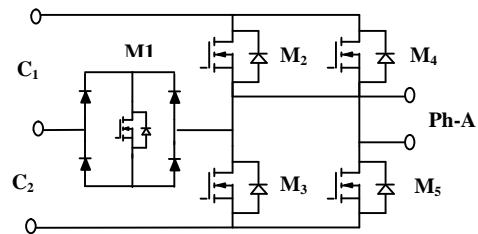


Figure 2. Single five level phase inverter

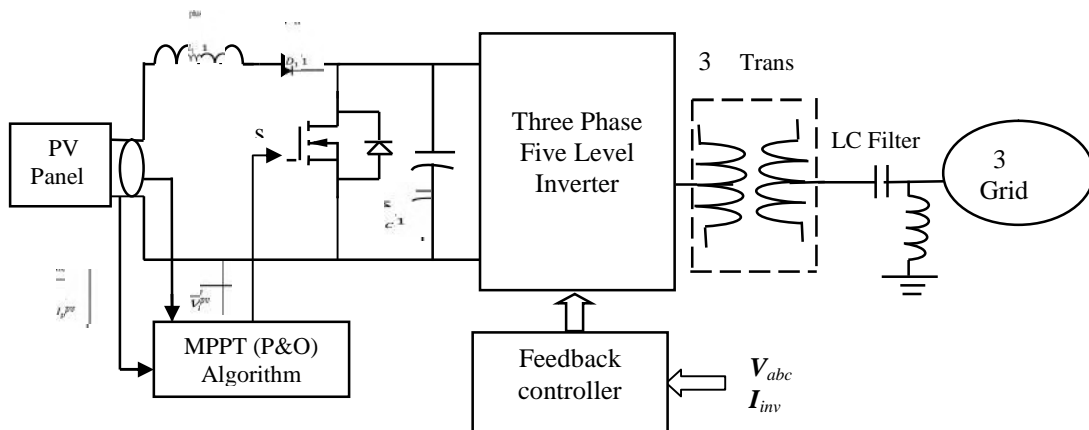


Figure 3. Single line diagram of three phase PV inverter topology

Figure 3 shows proposed single line diagram of three phase PV inverter topology, From the Figure 1 three single phase inverters connected in parallel with DC bus and each single phase inverter sharing voltage from the DC bus voltage. The DC bus consists of two capacitors with equal rating and value of the DC bus voltage should be higher than output voltage of inverter. The bus voltage around 330 V and this voltage can be realized in to five levels by each single phase inverter with phase shift of 120 degree. The output voltage of inverters is given to the primary winding of the 12 terminal transformer and all the neutral terminals are shorted. All the phase terminals are connected to the three phase LC filter. This LC filter is used to remove the harmonics present in the output of the inverter and filtered output voltage is given to the three phase grid. The proposed inverter is modified from the reference papers [13]-[14]

#### 4. CURRENT CONTROL SCHEME

The control system design plays a very important task in the PV inverter [15]. The control system consist a Phase lock loop (PLL), d-q reference frame, an inverse d-q reference frame and a controller. The purpose of the PLL is that, it synchronizes the output frequency and phase angle of the grid voltage with grid current. Use of the abc to d-q frame, which converts three variable quantities (i.e: three phase current and voltage) into two variable quantities (i.e: d-q values). In order to generate the five level output voltage, space vector pulse width modulation technique is used [16].

##### 4.1. PI Controller

The Proportional Integral (PI) is a conventional current controller which is used to maintain output current sinusoidal, to keep the power factor in near unity and easy to implement.  $K_p$  and  $K_i$  are the proportional and integral gains respectively, these gains depend on the system parameters. Err is the error signal, which is the difference between the instantaneous active current component  $I_d$  and reference instantaneous active current component  $I_d^*$ . Similarly, this Err, could also represent the difference between the instantaneous reactive current component  $I_q$  and reference instantaneous reactive current component  $I_q^*$ . The manual tuning of PI controller parameters to achieve the steady state is difficult and consumes more time. These limitations can be overcome by fuzzy controller [17].

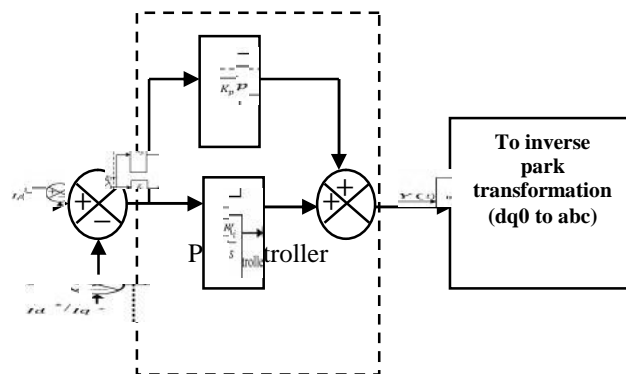


Figure 4. Block diagram of PI controller

##### 4.2. Fuzzy Controller

A FLC can be defined as the nonlinear mapping of an input data set to a scalar output data. A FLC consists of four major parts that is fuzzifier, rules, inference engine and defuzzifier. In most of the non linear application conventional controller may not perform well. Hence the fuzzy logic controller has been an appropriate solution to various nonlinear applications [18]. 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'. 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. The Figure 5 shows block diagram of fuzzy logic controller.

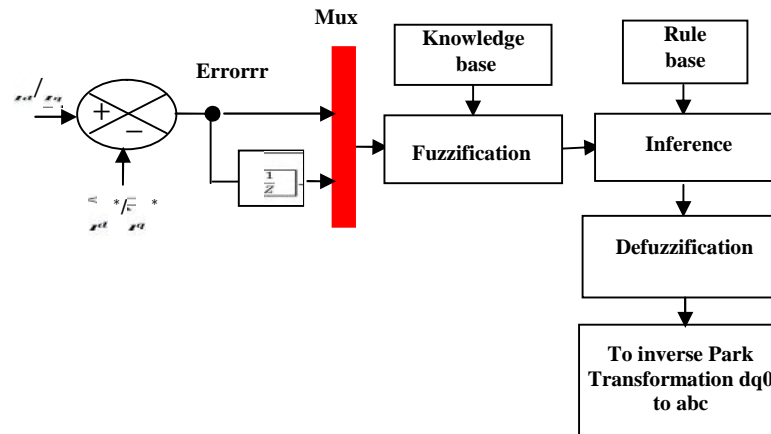


Figure 5. Block diagram of fuzzy logic controller

## 5. SIMULATION RESULTS

The three phase grid connected PV inverter using PI and fuzzy logic controller is simulated with help of MATLAB Simulink environment. In the simulation, all the PV panels are assumed to be operating 1000 irradiance  $\text{w/m}^2$  and Perturb and observe MPPT algorithms is used extract maximum power from the PV panel at all the climatic conditions. The 180 Watts PV panel parameter is chosen for the simulation study and output voltage of the PV panel is given to the DC-DC boost converter. The step up conversion is carried out by applying gating pulses to MOSFET. The output of the boost converter is given to the input of the five level three phase inverter and outputs are fed to three phase 12 terminal transformer. The Figure 6, 7 and 8 five level output voltage of the inverter Phase –A, B & C respectively, which is approximately equal to 330 V (Peak Value). The filtered three phase voltage and current is shown in Figure 9 and 10.

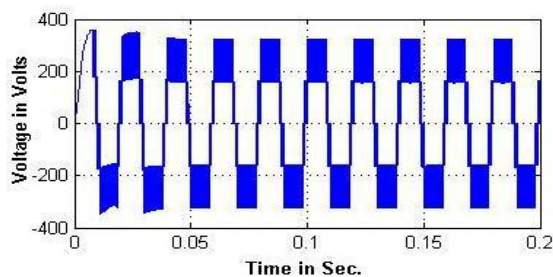


Figure 6. Five level output voltage –Phase A

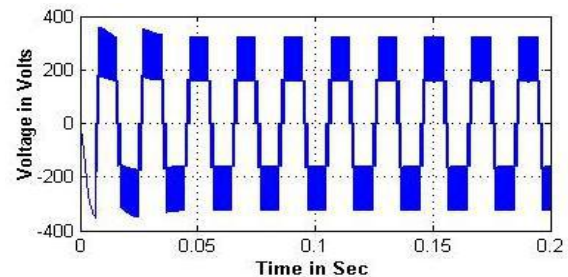


Figure 7. Five level output voltage –Phase B

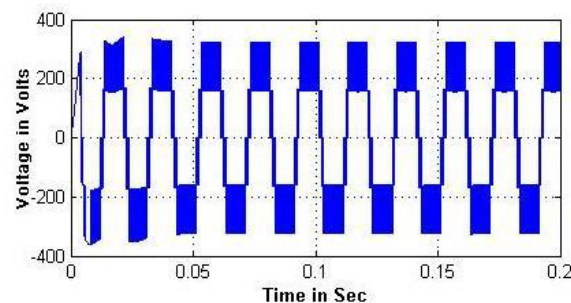


Figure 8. Five level output voltage –Phase C

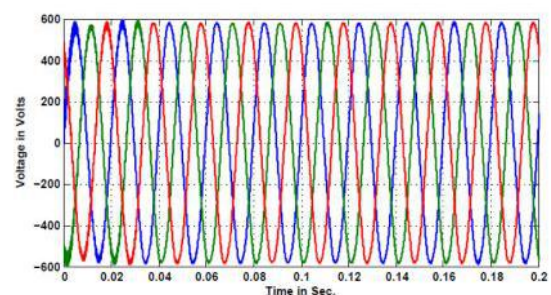


Figure 9. Three phase voltage

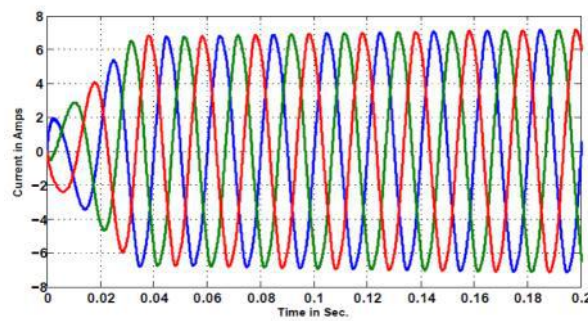


Figure 10. Three phase current

### 5.1. Performance Analysis of PI and Fuzzy Logic Controller

In this section, a deal with performances analysis of PI and FLC has been made interms of THD, rise time and settling time. It is noted that, the fuzzy controller shows best minimized THD of about 1.3% and THD generated by PI control about 1.71%. Thus, it is observed that the proposed fuzzy controller performs better when compared to conventional PI Controller [19]. Table 1 shows THD profile of exiting work.

Table 1. Comparison of THD Profile

Exiting works	Year of Publication	Topology Configuration	Levels	Modulation Technique	% of THD
References [ 5 ]	2013	Three Phase	5 Levels	SVPWM	5.68%
References [20]	2013	Three Phase	5Levels	SVPWM	9.0%

### 5.2. Device Utility Comparison

Table 2 shows the comparison of a number of power devices used in the proposed approach with two existing approaches inferred in [5] and [7].

Table 2. Power Device Utility Comparison

Parameters	Proposed Work	Existing work[5]	Existing work[7]
Switches	15	24	24
I/P DC source	1	6	1
Transformer	1	-	2

In the proposed work the numbers of switches are reduced to fifteen when compared to 24 in [5, 7]. Reducing the number of switches decrease the stress across the switches and the power loss is considerably reduced by means of the proposed approach. In addition the DC source used in the input is reduced to one whereas it is 6 in [5]. Similarly three transformers were used in [7] whereas in the proposed work only one transformer is used. Usage of lesser components results in reduced cost and reduced complexity of the system.

### 5.3. Switching Losses Calculation

Cascaded Single Phase H-Bridge Inverter with converter losses presented [21]-[22]. The average switching power loss  $P_{SW\_LOSS}$  in the switch during the transition of switch is given by:

$$P_{SW\_LOSS} = \frac{1}{2} V_{DC} I_{DC} f_s (T_{c(ON)} + T_{c(OFF)}) \quad (1)$$

Where  $T_{c(ON)}$  and  $T_{c(OFF)}$  are the turn on and turn off cross over intervals.  $V_{DC}$  is the voltage across the switch and  $I_{DC}$  is the current which flows through the switch. For the sake of clarity, the proposed topology with 5 levels is compared with familiar, similar topologies. For simplification, the proposed topology and the well-known inverter topologies are assumed to operate at the same turn-on and turn-off

crossover intervals and at the same  $I_{DC}$ . Then, the average switching power loss  $P_{SW\_LOSS}$  is proportional to  $V_{DC}$  and  $f_s$ .

$$P_{SW\_LOSS} \propto V_{DC} f_s \quad (2)$$

The number of power semiconductor devices imperative for generating 5 levels (three phase) in the proposed inverter is 15 and the voltage appear across these switches is  $V_{DC}$ . The one leg in each inverter (i.e. two switches) switches operated at fundamental frequency ( $f_m$ ) and remaining three switches in H bridge inverter switches operated at high frequency (i.e. switching frequency,  $f_s$ ). Totally nine switches switch at high frequency ( $f_s$ ) and six switches switch at fundamental frequency ( $f_m$ ). Therefore, the switching losses of the proposed inverter can be written as:

$$P_{SW\_LOSS} = 9V_{DC}f_s + 6V_{DC}f_m \quad (3)$$

In the proposed inverter, at any point in time, the number of switches in conduction is only 6 (2 switches for each phase). Therefore, the conduction losses  $P_{closs}$  of the proposed inverter are:

$$P_{closs} = 6R_{ON}I^2 \quad (4)$$

Where  $R_{ON}$  is the internal resistance of the switching device and  $I$  is the current flowing into the devices.

## 6. CONCLUSION

The comparative study of three phase grid connected PV inverter is effectively controlled by using PI and Fuzzy logic controller is presented in this paper. The current harmonics of the system are effectively minimized through SVPWM technique with the utilization of fuzzy logic controllers. Finally total harmonics distortion (THD) comparison is made between PI and Fuzzy Logic Controller. Thus the proposed fuzzy logic controller meets the requirement of fast response and minimum THD than conventional PI controller. This inverter topology is built using only fifteen power semiconductor switches and hence switching losses also minimized. The performance of proposed inverter is validated through MATLAB simulink.

## ACKNOWLEDGEMENTS

The authors thank Department of Electrical Engineering, Govt. College of Technology, Coimbatore, Tamilnadu, India for providing us the Licensed Software-MATLAB Version 8.3R2014a which was procured under TEQIP (Technical Education Quality Improvement Program)-Phase-II-Sub Module-Center of Excellence-Alternate Energy Research and also authors thank to Management of Karpagam Academy of Higher Education for providing the necessary facilities.

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