International Journal of Power Electronics and Drive System (IJPEDS)
Vol. 7, No. 2, June 2016, pp. 543~550
ISSN: 2088-8694 ❒ 543

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

M. Venkatesan[1], R. Rajeshwari[2], N. Deverajan[3], M. Kaliyamoorthy[4]
[1]Department of Electrical & Electronics Engineering, Karpagm Academy of Higher Edu., Coimbatore, India
[2,3]Department of Electrical Engineering, GCT, Coimbatore, India
[4]Department of Electrical & Electronics Engineering, Karpagam College Engg., Coimbatore, India

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

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.

Corresponding Author:

M. Venkatesan
Assistant Professor, Department of Electrical & Electronics Engineering,
Karapagm Academy of Higher Education,
Coimbatore.
Email: venkatesangct@gmail.com

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 sinusodial 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 calculatation. 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 advatages 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.

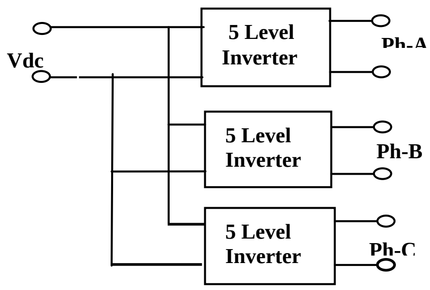

Figure 1. Three phase PV inverter topology

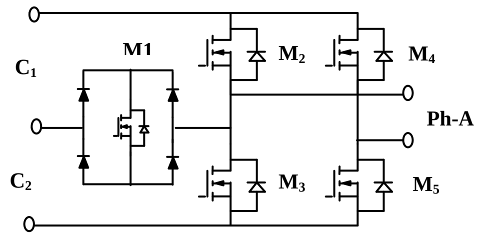

Figure 2. Single five level phase inverter

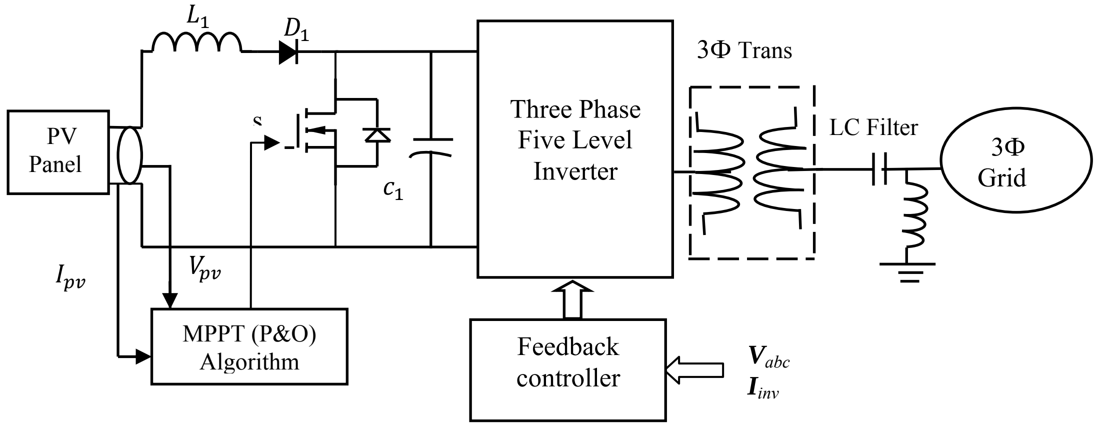

Figure 3. Single line diagram of three phase PV inverter topology

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 shoud 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 inveretr 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 achive the steady state is difficult and consumes more time. These limitations can be overcome by fuzzy controller [17].

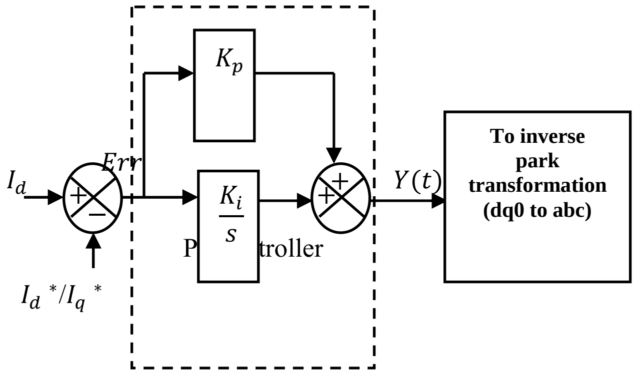

Figure 4. Block diagram of PI controller

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.

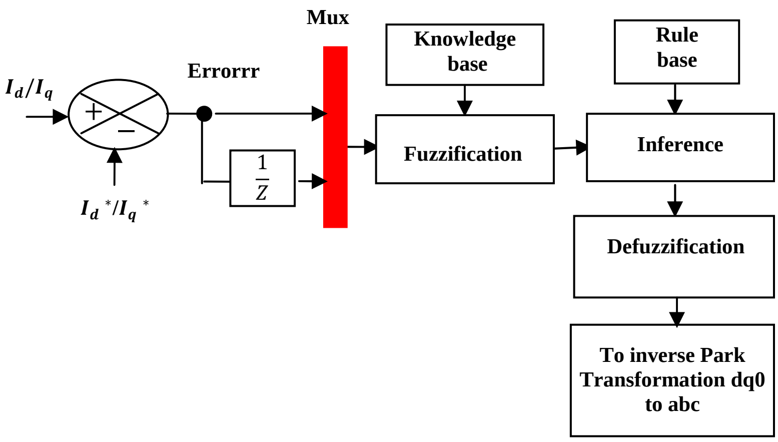

Figure 5. Block diagram of fuzzy logic controller

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 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 voltgage 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.

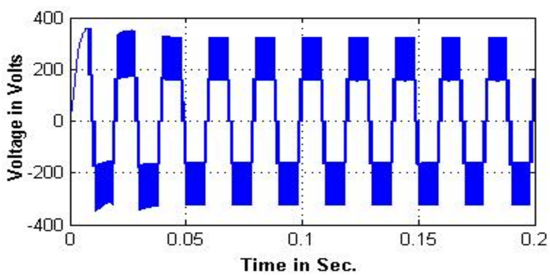

Figure 6. Five level output voltage –Phase A

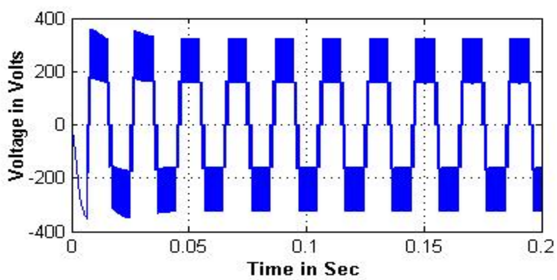

Figure 7. Five level output voltage –Phase B

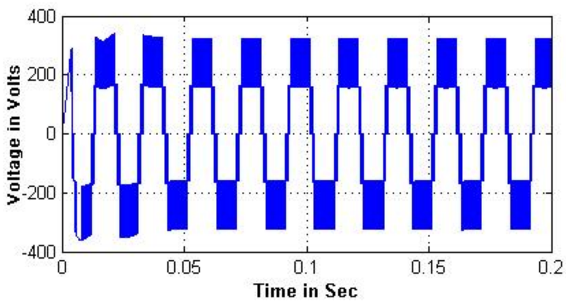

Figure 8. Five level output voltage –Phase C

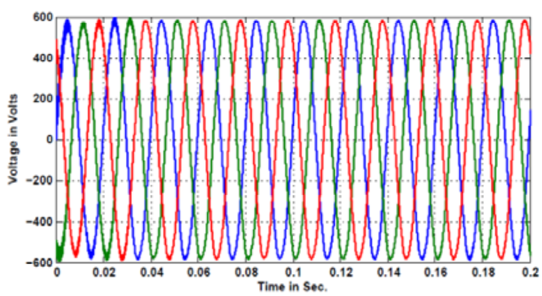

Figure 9. Three phase voltage

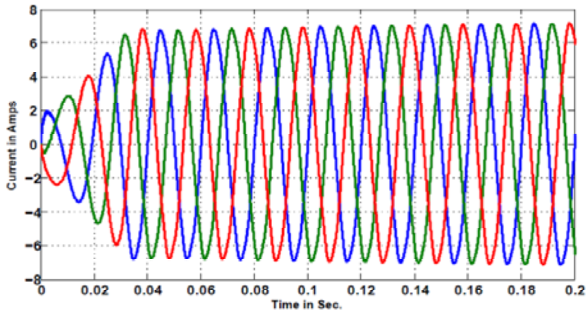

Figure 10. Three phase current

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 setlling 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 considerabley 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:

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

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.

$$P_{SW\_LOSS} \ \alpha \quad V_{DC} f_s \tag{2}$$

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:

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

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:

$$P_{closs} = 6R_{ON} I^2 \tag{4}$$

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. Finaly 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 Version8.3R2014a 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.

REFERENCES

[1] D.V.N Ananth and G.V. Nageshkumar, "Design of Solar PV Cell Based Inverter for Unbalanced and Distorted Industrial Loads", *Indonesian journal of Electrical Engineering and Informatics,* Vol. 3, No. 2, pp. 70-77, 2015.

[2] K.S. Srikant, "A Three Phase Multi Level Converter for grid Connected PV System", *International Journal of Power Electronics and Drive System,* Vol. 5, No. 1, pp. 71-75, July 2014.

[3] N. Deverajan and A. Reena, "Reduction of Switches and DC Sources in Cascaded Multilevel Inverter", *Bulletin of Electrical Engineering and Informatics,* Vol. 4, No. 3, pp. 186-195, Sep 2015.

[4] Chetanya, et al., "Harmonic Analysis of Seven and Nine Level Cascade Multilevel Inverter Using Multi-Carrier PWM Technique", *International Journal of Power Electronics and Drive System,* Vol. 5, No. 1, pp. 76-82, July 2014.

[5] M. Valan Rajkumar and P.S. Manoharan, "FPGA Based Multilevel Cascaded Inverters with MSVPWM Algorithm for Photovoltaic System", *Solar Energy,* 87, pp. 229–245, 2013.

[6] Y. Suresh and A.K. Panda, "Research on Cascade Multilevel Inverter By Employing Three Phase Transformer", *IET Power Electronics,* vol. 5, pp. 561-51, 2012.

[7] Sung Geun Song, Feel Soon Kang, Sung-Jun Park, "Cascade Multilevel Inverter Employing Three Phase Transformer and Single DC Input", *IEEE Transactions on Industrial Electronics,* vol. 56, No. 6, pp. 2005–2014, 2009.

[8] Nguyen Gia Minh Thao and Kenko Uchida, "Active and Reactive Power Control Techniques Based on Feedback Linearization and Fuzzy Logic for Three-Phase Grid-Connected Photovoltaic Inverters", *Asian Journal of Control,* vol. 17, No. 5, pp. 1–25, Sep 2015.

[9] Kumar Subash, and V. Gopalakrishnan, "Design of Synchronous Reference Frame Based Harmonic Detection and Space Vector Pulse Width Modulation Based Switching of Shunt Active Filter", *Australian Journal of Electrical & Electronics Engineering,* vol. 10, No.3, pp. 362, Nov. 2015.
[10] J. Raju and M. Kowshree alya, "Varying Vector Pluse Width Modulation for Three Phase Inverter", *Bulletin of Electrical Engineering and Informatics,* vol. 3, No. 2, pp. 91-100, June 2014.
[11] A. Soetedjo et al, "Modeling of Maximum Power Point Tracking Controller for Solar Power System", *Telkomnika,* vol. 10, No.3, pp. 419-430, Sep. 2012.
[12] M. Kaliamoorthy, et al., "Single-Phase Fifteen-Level Grid-Connected Inverter for Photovoltaic System with Evolutionary Programming Based MPPT Algorithm", *Solar Energy,* 105 pp.314–329, 2014.
[13] Nasrudin A. Rahim and Jeyraj S, "Multistring Five Level Inverter with Novel PWM Control Scheme for PV Application", *IEEE Transactions on Industrial Electronics,* vol. 57, pp. 2111–2123, 2010.
[14] Agelidis V. G, et al., "A Multilevel PWM Inverter Topology for Photovoltaic Applications", *in Proc. the IEEE International Symposium on Ind. Electronics,* pp. 589-594, 1997.
[15] Peng Mao, et al., "A Review of Current Control Strategy for Single Phase Grid Connected Inverter", *Telkomnika,* vol. 12, No. 3, pp. 563-580, Sep. 2014.
[16] K. Vinothkumar, et al., "Simulation and Comparison of SPWM and SVPWM control for three phase inverter", *ARPN Journal of Engg. and Applied Sciences,* vol. 5, No.7, pp. 61-74, 2010.
[17] N. Ammasai Gounden, et al., "Fuzzy logic controller with MPPT using Line Commutated Inverter for Three-Phase Grid Connected Photovoltaic Systems", *Renewable Energy,* vol. 34, pp. 909-915, 2009.
[18] Mohammed shoeb Mohiuddin, Performance comparision of Conventional Controller with Fuzzy Logic Controller using Chopper circuit and Fuzzy Tuned PID Controller", *Indonesian ournal of Electrical Engineering and Informatics,* vol. 2, No 4, pp. 189-200, Dec. 2015.
[19] M. Venkatesan et al., "A Fuzzy Logic Based Three phase Inverter with Single DC Source for Grid Connected PV System Employing Three Phase Transformer", *International Journal of Renewable Energy Research,* vol. 05, no. 3, pp. 739-745, 2015.
[20] Venkatachalam Kumar Chinnaiyan, et al., "An Experimental Investigation on a Multilevel Inverter for Solar Energy Applications", *International Journal of Electrical Power & Energy Systems,* Volume 47, pp. 157–167, May 2013.
[21] M. Kaliamoorthy, et al., "Experimental Validation of a Cascaded Single Phase H-Bridge Inverter with a Simplified Switching Algorithm", *Journal of Power Electronics,* vol. 14, No. 3, pp. 507-518, May 2014.
[22] M.Kaliamoorthy, et al., "Generalised Hybrid Switching Topology for a Single-Phase Modular Multilevel Inverter", *IET Power Electronics,* vol. 7, No.10, pp. 2472-2485, July 2014.

BIOGRAPHIES OF AUTHORS

Venkatesan M was received his B.E., in Electronics and Communication Engineering from Anna University, Chennai, Tamil Nadu, India, in 2008, and his M.E. in Power Electronics and Drives from Government college of Technology, Coimbatore, Tamil Nadu, India, in 2010. He is currently working towards to his Ph.D and also working as an Assistant Professor in the Department of Electrical and Electronics Engineering, Faculty of Engineering, Karpagam Academy of Higher Education, Coimbatore, Tamil Nadu, India. His current research interests include Power electronics, DC-DC converter, Multilevel inverter, PV based system design.

Rajeswari R
She received her B.E., in Electrical and Electronics Engineering and M.E. in Power Systems Engineering from Thiagarajar College of Engineering, Madurai Kamarajar University, Madurai, Tamil Nadu, India, in 1995 and 1998 respectively. She was completed her Ph.D in Power Systems Engineeing in 2009, Anna Uinversity, Chennai, Tamilnadu, India. She is currently working as an Assistant Professor (Senior Grade) in the Department of Electrical and Electronics Engineering, Government College of Technology, Coimbatore, Tamil Nadu, India. More than Ten scholars are pursuing research under her Guidence. Her current research interests include Smart Grid, Power system protection, operation and control and intelligent techniques.

Deverajan N was received his B.E., in Electrical and Electronics Engineering from Madras Uinversity, Tamil Nadu, India, in 1982. and his M.E. in power systems Engineering from Bharathiyar University, Coimbatore, Tamil Nadu, India, in 1989. He was completed his Ph.D in Control system from Bharathiyar University, Coimbatore, Tamil Nadu, India, in 2000. He is currently working as a Professor & Head in the Department of Electrical and Electronics Engineering, Government College of Technology, Coimbatore, Tamil Nadu, India. More than 30 scholars has completed Ph.D under his guidence. His current research interests include control sytem, power system, PV based system design. He is life member of the Institution of Engineers (India) and ISTE.

Kaliamoorthy Mylsamy received his B E in Electrical and Electronics Engineering at Madras University, Chennai, India, in 1999, and his M.Tech degree in Electrical Drives and Control from Pondicherry University, Puducherry, India, in 2006. He was a gold medalist for the academic years 2004-2006. He has one decade of teaching experience for under graduate and post graduate students of electrical and electronics engineering. He is presently working as a Professor in the Department of Electrical and Electronics Engineering, Karpagam College of Engineering, Coimbatore, Tamil Nadu, India. His current research interests include alternative energy sources, fuel cells, energy conversion, multilevel inverters, analysis and control of power electronics devices, power quality and active harmonic analysis. For further details please visit www.kaliasgoldmedal.yolasite.com