Design and Implementation of Single Phase Cascaded Multilevel Grid Connected Inverter with Reduced Switches Using Photovoltaic Systems

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ABSTARCT

This paper objective is to propose a modern cascaded nine level inverter topology for a nearly sinusoidal output voltage and reduce total harmonic distortion. This topology is designed based on novel PWM technique and one voltage source is desired. This structure is quiet and easy to extended higher level but also its gate driver circuits are required because the number of active switches is reduced. The modified inverter is efficient of generating nine level of output-voltage levels ($V_{dc}, 3V_{dc}/4, V_{dc}/2, V_{dc}/4, 0, -V_{dc}, -3V_{dc}/4, -V_{dc}/2, -V_{dc}/4$) from the DC supply voltage. Finally the performance of the proposed system is evaluated through simulation MATLAB/SIMULINK, PROTEUS Software and experimental results.

Key words: Cascaded multilevel inverter, photovoltaic System, Pulse Width Modulation (PWM), Fuzzy Rule base System, Maximum Power Point Tracking (MPPT), Total Harmonic Distortion (THD).

1. INTRODUCTION

Energy is necessary knowledge in the process of financial, civil along with technical and improvement. Energy usage is growing appropriate rapidly. Fossil fuels supply will be depreciated in few hundred years and energy shortage problem will be created in the world. Therefore nonconventional energy resources are desired to develop for energy requirements. Inexhaustible energy generation schemes, particular kind of system is photovoltaic (S. B. Kjaer, 2005). Similarly a scheme reproduces electric power from modifying sunshine into electric power. Solar photovoltaic systems can be issued energy to loads over multilevel inverter (P. Lezana, 2009). A single phase nine level Inverter is mostly used for domestic and portable power applications.

The nine level inverters can gratify conditions through its very high switching, but it could also unfortunately increase switching losses, acoustic noise, and level of interference to other materials (S. Vazquez, 2009; S. Alepuz, 2009;P. Lezana, 2009; G. Ceglia, 2006; Y. Cheng, 2006). Developing its output waveform decreases its harmonic content , size of the filter used and the level of electromagnetic interference (EMI) generated by the inverter's switching operation (E. Ozdemir, 2009). Cascaded H – Bridge Multilevel inverters are promising, they have virtually sinusoidal output-voltage waveforms, output current with better harmonic profile, less feature of electronic components owing to decreased voltages, switching losses that are lower than those of conventional inverters, a smaller filter size, and lower EMI, all of which them cheaper, lighter, and more compact (K. A. Corzine, 2004) Different topologies for multilevel inverters have been exposed over the years. Common ones are diode-clamped, flying capacitor or multi cell, cascaded H-bridge, and altered H-bridge multilevel (E. Villanueva, 2009)

This paper recounts the development of an innovative H-bridge single-phase multilevel inverter that has two diode embedded bidirectional switches and a novel pulse width modulated (PWM) technique (C. Cecati, 2010). The topography was enforced to a grid-connected photovoltaic system with attention for a maximum-power-point tracker (MPPT) (G. Ceglia, 2006).

2. PROPOSED TOPOLOGY

The proposed single-phase nine-level inverter was grownup from the seven-level inverter. It composes a single-phase conventional H-bridge inverter, three bidirectional switches and a capacitor voltage divider formed by C_1, C_2, C_3, and C_4 as shown in Fig. 1. The cascaded H-bridge topology is advantages of less power switches, power diodes and less capacitor than the conventional inverters. The Boost converter (DC – DC) is interconnection between photovoltaic (PV) and grid.

The generated power by the inverter is to be dispatched to the power network, so the utility grid, rather than a load was used. The DC–DC boost converter was required because of the PV arrays had a low voltage than the grid voltage. High DC voltages are needed to assure that power flows from the PV arrays to the grid. A filter was used to filtering the current is injected in to grid using inductance (L_f) and practically obtained total harmonic distortion from simulation results as given in Table Proper switching of the inverter can generate nine output voltage levels ($V_{dc}, 3V_{dc}/4, V_{dc}/2, V_{dc}/4, 0, -V_{dc}, -3V_{dc}/4, -V_{dc}/2, -V_{dc}/4$)from the DC supply.

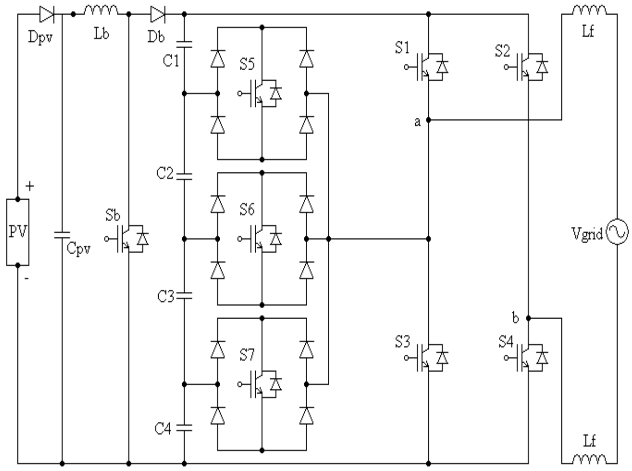


Fig.1.Proposed single phase nine-level grid-connected inverter for Photovoltaic System

3. SYSTEM DESCRIPTION AND OPERATION

The Implementation of photo voltaic system in a single phase as shown in Fig. 2. The boost converter offers the flexibilities of MPPT and active power control, and extends the operational time of the PV inverter when the solar irradiance level is very low. The PV inverter can be transformer less to sustain a high efficiency. A hybrid control scheme of MPPT control allows further to increase the penetration level.

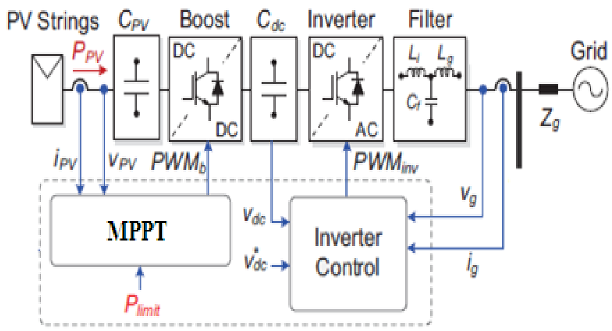
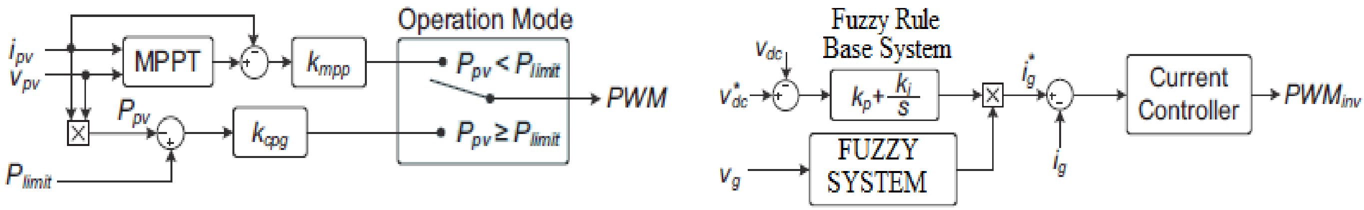


Fig.2.A two stage single phase PV system with MPPT

The MPPT algorithm is adopted in this paper for the single-phase PV systems due to its simplicity in nature. The control structure of a two-stage PV system as shown in Fig. 3. The operation principle of a PV system with MPPT control schemecan be described as follows. When the available PV output power P_{pv} exceeds the power limitation P_{limit} and the system goes into the Constant Power Generation mode of the PV strings which is controlled by a fuzzy controller (k_{cpg}). When $P_{PV} \leq P_{limit}$, The PV system operates in MPPT mode with a peak power delivered to the grid from the PV strings. A fuzzy rule based k_{mpp} is used to controlled power in PV system. The future scope of current controller, reduce the total harmonic distortion and maintain power quality in grid system by fuzzy rule base system through fuzzy controller.



(a) (b)

Fig.3.Control diagram of a single-phase PV system with MPPT Controller: (a) MPPT boost controller and (b) PV inverter control system

4. MODES OF OPERATION

It composes a single-phase conventional H-bridge inverter, three bidirectional switches and a capacitor voltage divider formed by C_1, C_2, C_3 and C_4 as shown in Fig. 4. The altered H-bridge topology is significantly auspicious over other topologies, i.e., less power switches, less diodes and less capacitor for inverters of the same number of levels. Photovoltaic (PV) arrays were connected to the inverter via a dc–dc boost converter.

The power produced by the inverter is to be delivered to grid. The DC–DC boost converter was needed because the PV arrays had a voltage that was lesser than the single-phase voltage. High DC bus voltages are needed to provide that power flows from the PV arrays to loads. The filter is designed using L and C to get pure sine wave and is given to AC loads. The proposed inverter's operation can be divided into nine switching states.

The inverter generates nine output voltagelevels ($V_{dc}, 3V_{dc}/4, V_{dc}/2, V_{dc}/4, 0, -V_{dc}, -3V_{dc}/4, -V_{dc}/2, -V_{dc}/4$) from the dc supply voltage. The new topology of theinverters operation can be divided into nine switching states as shown in Fig. 5(a) to (k), Fig. 5(d), (e), (k) shows a conventional inverters operational states in sequence, while Fig. 5(a), (b), (c), (d), (f), (g), (h), (i), (j) shows additional states in the proposed inverter synthesizing one and three - fourth levels of the dc voltage.

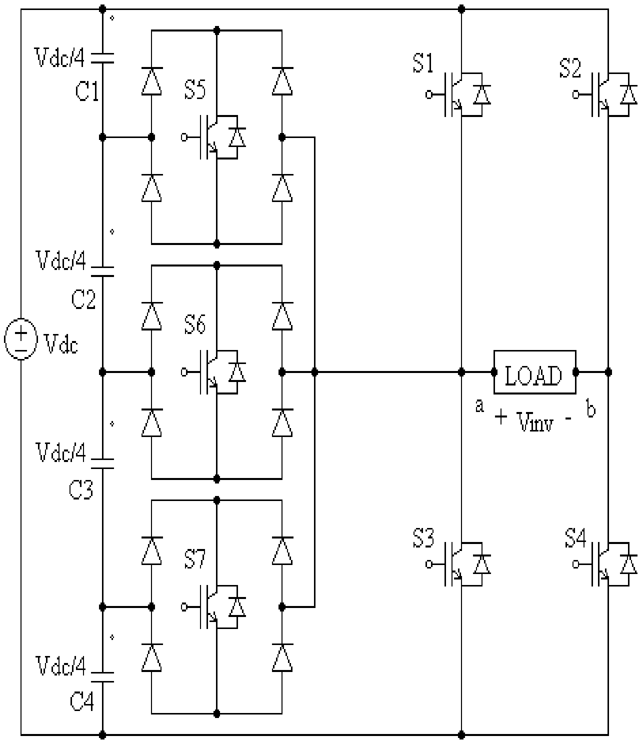


Fig.4.Nine Level Inverter for Switching Operation

(a) Maximum positive output Voltage (V_{dc}):S_1 is towards joined the load positive fatal through V_{dc} and S_4 is towards joined the load negative fatal through ground. Entire another controlled switch is absent. The voltage activated through the load fatal isV_{dc}. Fig. 5(a) views the current direction that is operating on the indicated point.

(b) Three-fourth positive output Voltage ($3V_{dc}/4$): The bidirectional switch S_5 is ON, towards joined the load positive fatal through V_{dc} and S_4 is ON, towards joined the load negative fatal through ground. Entire another controlled switch is absent. The voltage activated through the load fatal is ($3V_{dc}/4$) Fig. 5(b) views the current direction that is operating on the indicated point.

(c) Half of the positive output Voltage ($V_{dc}/2$): The bidirectional switch S_6 is towards joined the load positive fatal through V_{dc} and S_4 is ON, towards joined the load negative fatal through ground. Entire another controlled switch is absent. The voltage activated through the load fatal is $V_{dc}/2$. Fig. 5(c) views the current direction that is operating on the indicated point.

(d)One-fourth of the positive output Voltage ($V_{dc}/4$): The bidirectional switch S_7 is ON, towards joined the load positive fatal and S_4 is ON, towards joined the load negative fatal to ground. All other controlled switches are OFF; the voltage applied to the load terminals is $V_{dc}/4$. Fig. 5(d) views the current direction that is operating on the indicated point.

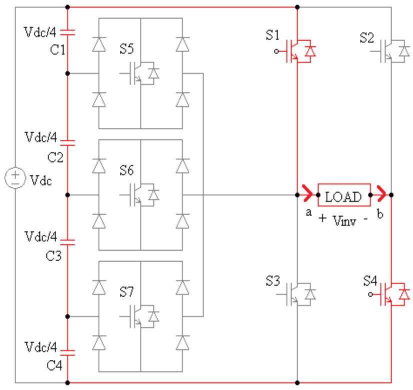
(e) Zero output Voltage (0 & 0*):The indicated level can be formed by two switching sequences. Switches S_3 and S_4 are ON (or) S_1 and S_2 are ON and all another controlled switch is absent. The fatal ab is short circuit and the voltage activated to the load fatal is zero. Fig. 5(e) & (f) views the current directions that are operating on the indicated point.

(f) One-fourth negative output Voltage ($-V_{dc}/4$): The bidirectional switch S_5 is ON, connecting the load positive fatal, and S_2 is ON, towards the load negative fatal to Vdc. All other controlled switches are OFF; the voltage applied to the load fatal is $-V_{dc}/4$.Fig. 5(g) views the current direction that is operating on the indicated point.

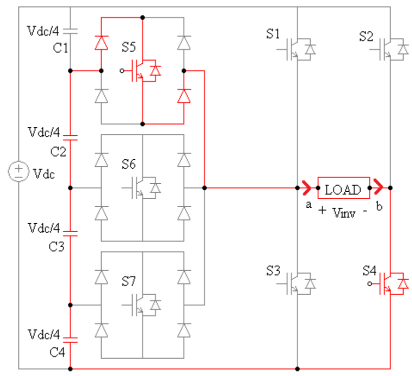
(g) Half of the negative output Voltage ($-V_{dc}/2$): The switch S_2 is ON, towards joined the load positive fatal through V_{dc} and the bidirectional switch S_6 is ON, towards joined the load negative fatal through ground. Entire another controlled switch is absent. The voltage activated through the load is $-V_{dc}/2$.Fig. 5(h) views the current directions that are operating on the indicated point.

(h)Three-fourth negative output Voltage ($-3V_{dc}/4$): The bidirectional switch S_7 is ON, connecting the load positive fatal and S2 is ON, connecting the load negative fatal to ground. All other controlled switches are OFF, the voltage applied to the load terminals is $-3V_{dc}/4$. Fig. 5(i) views the current directions that are operating on the indicated point.

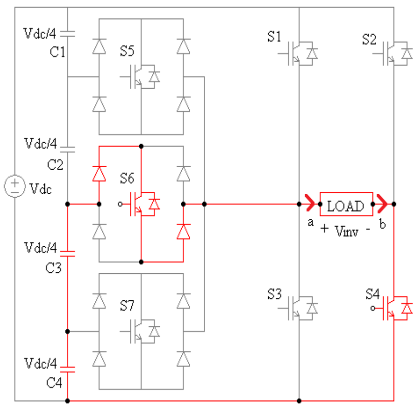
(i) Maximum negative output Voltage($-V_{dc}$)**:** S_2 is ON, connecting the load negative fatal to V_{dc} and S_3 is ON, connecting the load positive terminal to ground. All other controlled switches are OFF, the voltage applied to the load terminals is $-V_{dc}$. Fig. 5(j) views the current directions that are operating on the indicated point.



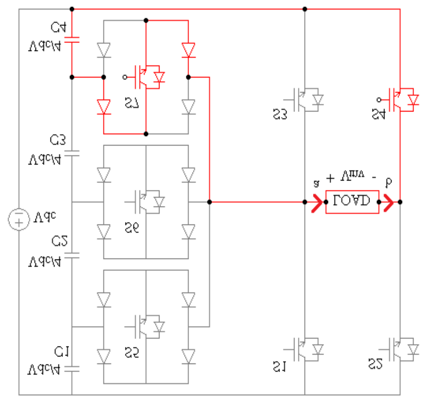
(a)



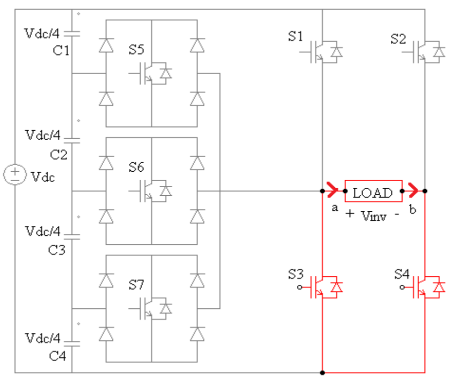
(b)



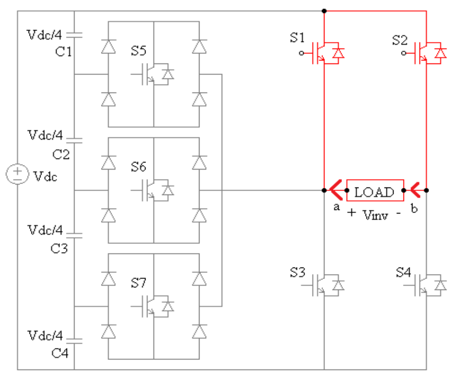
(c)



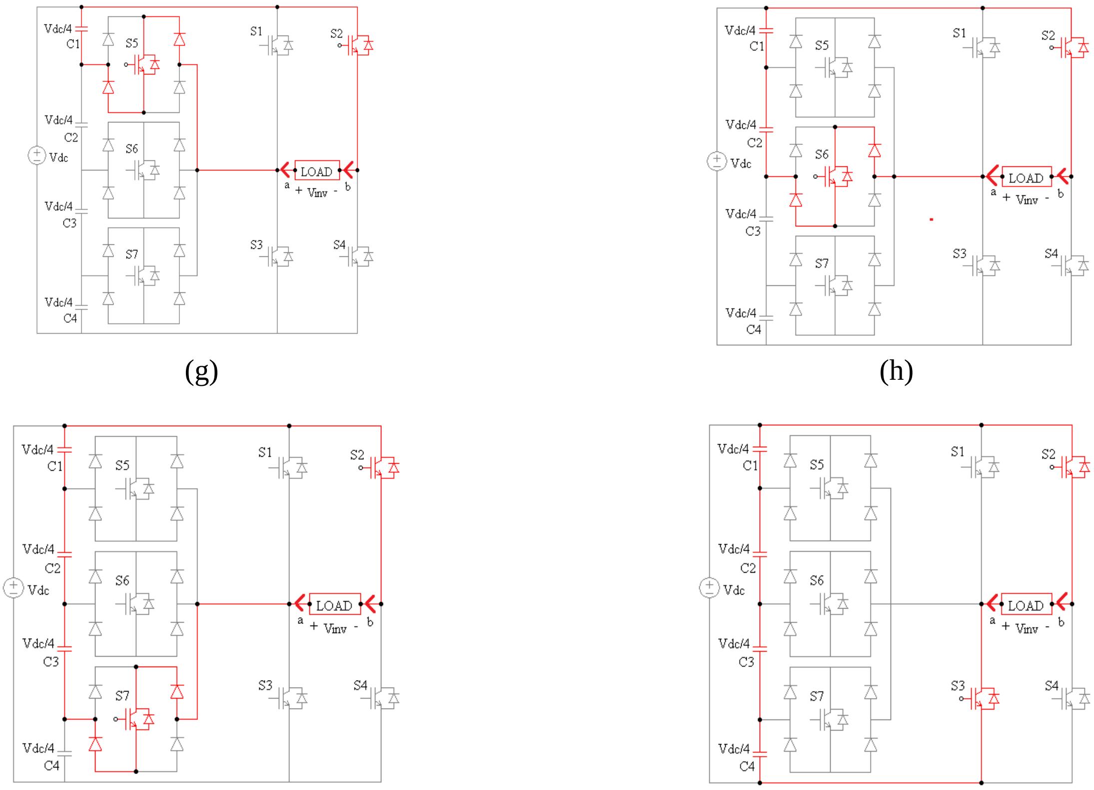
(d)



(e)



(f)



(g) (h)

(i) (j)

Fig.5.Switch Combination required to generate the output voltage (V_{ab})

(a) $V_{ab} = V_{dc}$ (b) $V_{ab} = \frac{3V_{dc}}{4}$ (c) $V_{ab} = \frac{V_{dc}}{2}$ (d) $V_{ab} = \frac{V_{dc}}{4}$ (e) $V_{ab} = 0$ (f) $V_{ab} = 0^*$ (g) $V_{ab} = \frac{-V_{dc}}{4}$ (h) $V_{ab} = \frac{-V_{dc}}{2}$ (i) $V_{ab} = \frac{-3V_{dc}}{4}$ (j) $V_{ab} = -V_{dc}$

Table.1.Output Voltage According to the Switches ON – OFF Condition

V_0	S_1	S_2	S_3	S_4	S_5	S_6	S_7
V_{dc}	1	0	0	1	0	0	0
$3V_{dc}/4$	0	0	0	1	1	0	0
$V_{dc}/2$	0	0	0	1	0	1	0
$V_{dc}/4$	0	0	0	1	0	0	1
0	0	0	1	1	0	0	0
0^*	1	1	0	0	0	0	0
$-V_{dc}/4$	0	1	0	0	1	0	0
$-V_{dc}/2$	0	1	0	0	0	1	0
$-3V_{dc}/4$	0	1	0	0	0	0	1
$-V_{dc}$	0	1	1	0	0	0	0

Table I Shows the switching combinations that generated the nine output voltage levels ($V_{dc}, \frac{3V_{dc}}{4}, \frac{V_{dc}}{2}, \frac{V_{dc}}{4}, 0, \frac{-V_{dc}}{4}, \frac{-V_{dc}}{2}, \frac{-3V_{dc}}{4}, -V_{dc}$) with switching pattern for single phase nine level inverter as shown in Fig. 6.

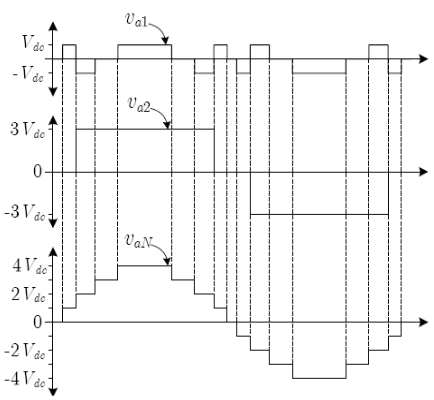


Fig.6.Switching Pattern for Single Phase Nine Level Inverter

5. CLOSED LOOP CONTROL SYSTEM

The control system composes MPPT Controller, DC voltage controller and inverter controller as shown in Fig. 7. The objective of this system is extract the maximum amount of power collected from photovoltaic system to grid with reduce total harmonic distortion.

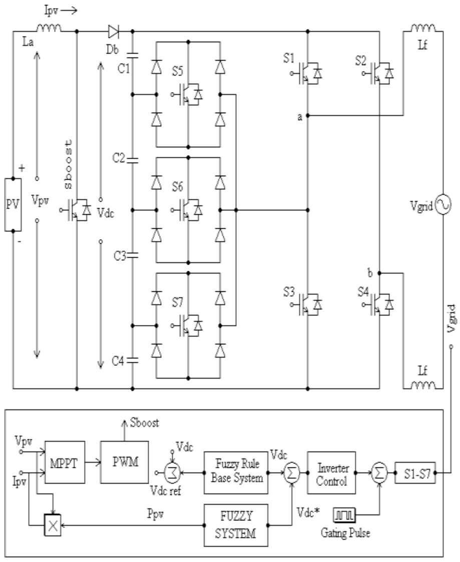


Fig.7.Nine Level Inverter with Closed – Loop Control algorithm

Fuzzy rule base system for applying in MPPT Technique to its quite structure. It periodically fuzzy rule viewer system (Increment or decrement) as shown in Fig. 8. The photovoltaic terminal voltage and output power compares with that previous fuzzy rule base algorithm. If the power is increasingP_{limit}, the operating mode goes to $P_{pv} \geq P_{limit}$ than fuzzy rule base system continuous in the same direction. Other wise in next cycle, $P_{pv} < P_{limit}$ the direction will be reversed.

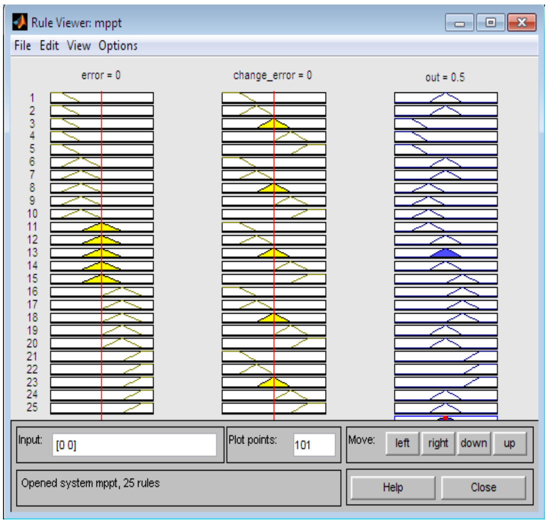


Fig.8.Fuzzy Rule Viewer for closed loop system

Fuzzy rule base system used in DC – DC boost converter. To extract the maximum output power of MPPT is operating based on duty cycle function. As the DC voltage $V_{dc}$was regulated in nine level inverter and the output voltage of PV changes based on duty cycle changes.

Photovoltaic connected DC – DC boost converter and grid through surge diverters for protection of entire system. The input sources of Photovoltaic (I_{pv}, V_{pv}) is given to MPPT with PWM boost converter. The input supply V_{dc} &V_{dcref} given to fuzzy rule based system. Comparing the output voltages of PV and MPPT using trial and error method. Finally the output voltage V_{dc} &V_{dc}^{*} given to inverter control through gating pulses of switches ($S_1 - S_7$) with fed to grid through filter.

6. RESULTS

Simulation Result: The proposed method has been tested and simulation results are shown Fig. 9. This model has been implemented using MATLAB/SIMULINK environment with SIMPOWER system toolbox.

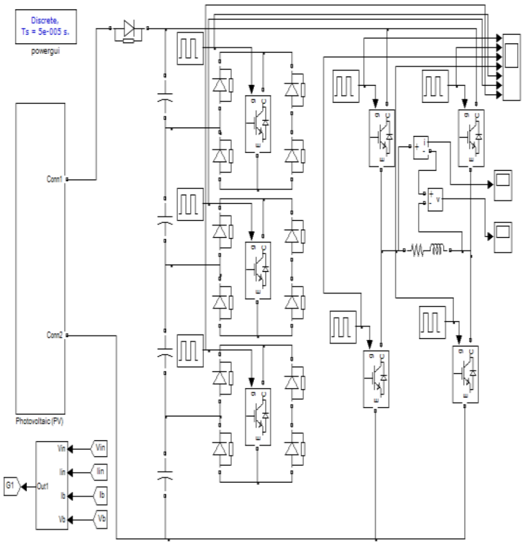


Fig.9.Simulation Circuit for Cascaded Nine Level Inverter

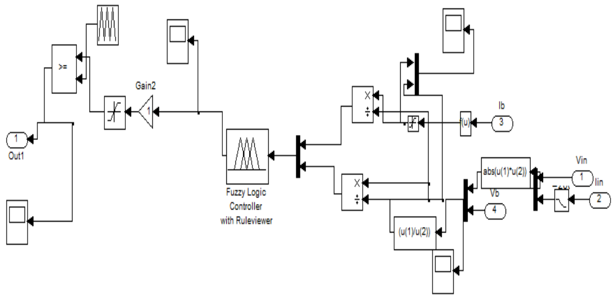


Fig.10.Sub circuit for fuzzy rule base System

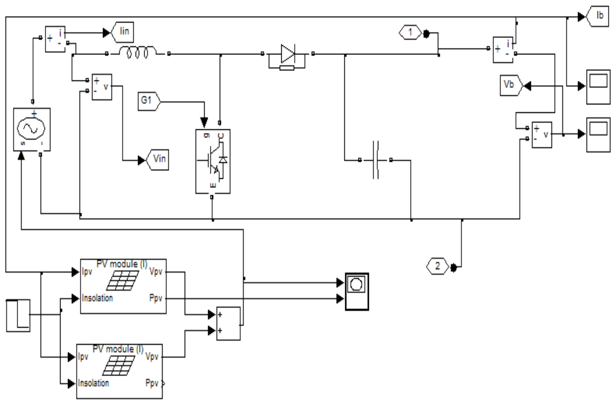


Fig.11.Sub Circuit for MPPT Boost Controller

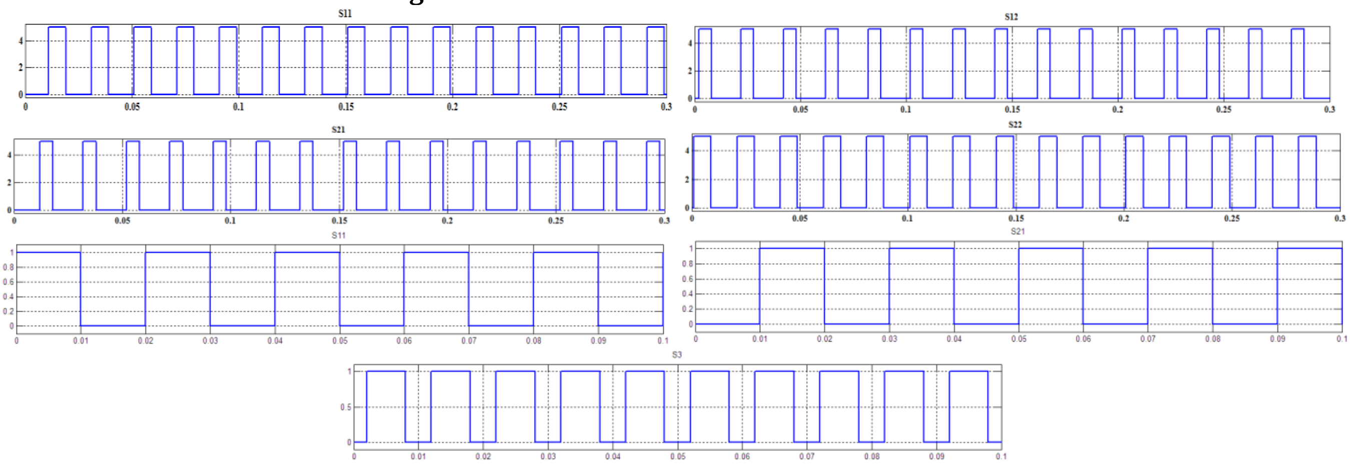


Fig.12.PWM Signal for Cascaded Nine Level Inverter

ISSN: 0974-2115
Journal of Chemical and Pharmaceutical Sciences

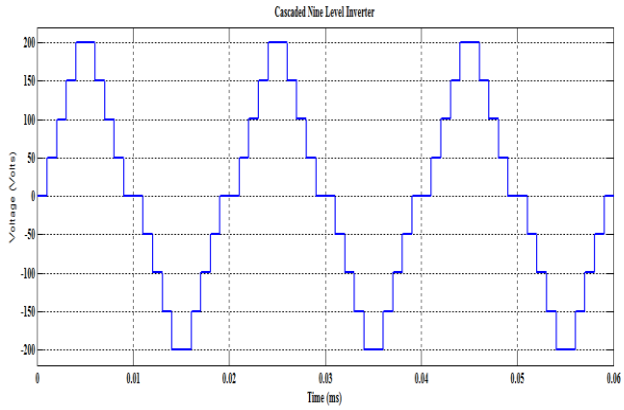


Fig.13.Output Voltage for Cascaded Nine Level Inverter

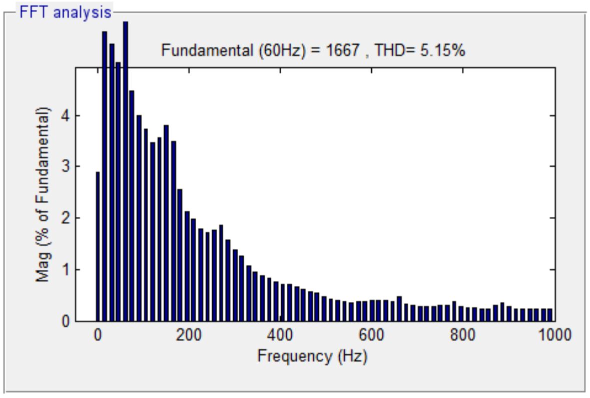


Fig.14.THD for Cascaded Nine Level Inverter

Proteus model: Proteus is one of the most famous simulators. It can be used to simulate almost every circuit on electric fields. It is easy to use because of the Graphical User Interface (GUI) that is very similar to the real prototype board. Moreover, it can be used to design printed circuit board (PCB).

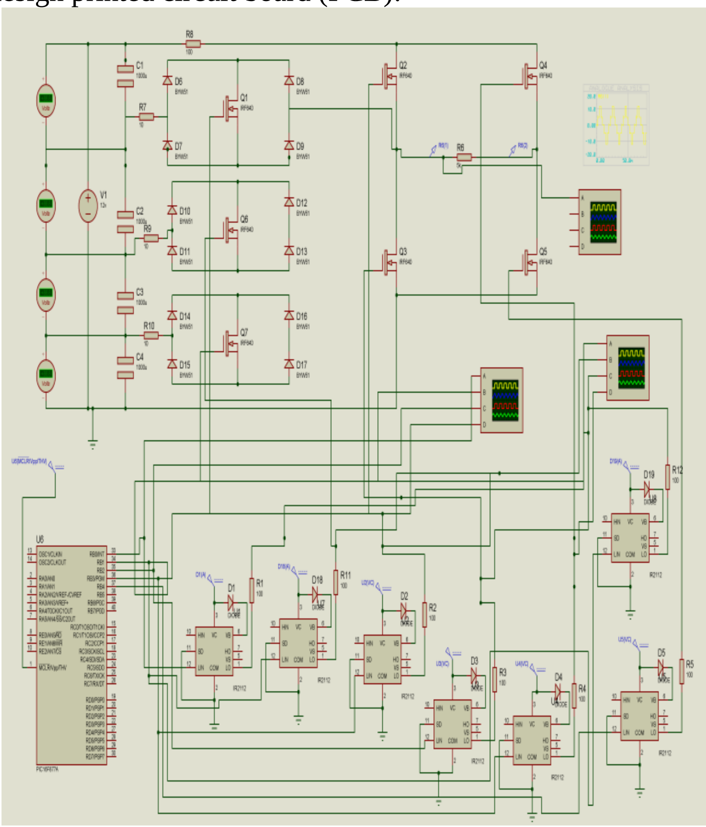


Fig.15.Development of Nine Level Inverter in PROTEUS Software

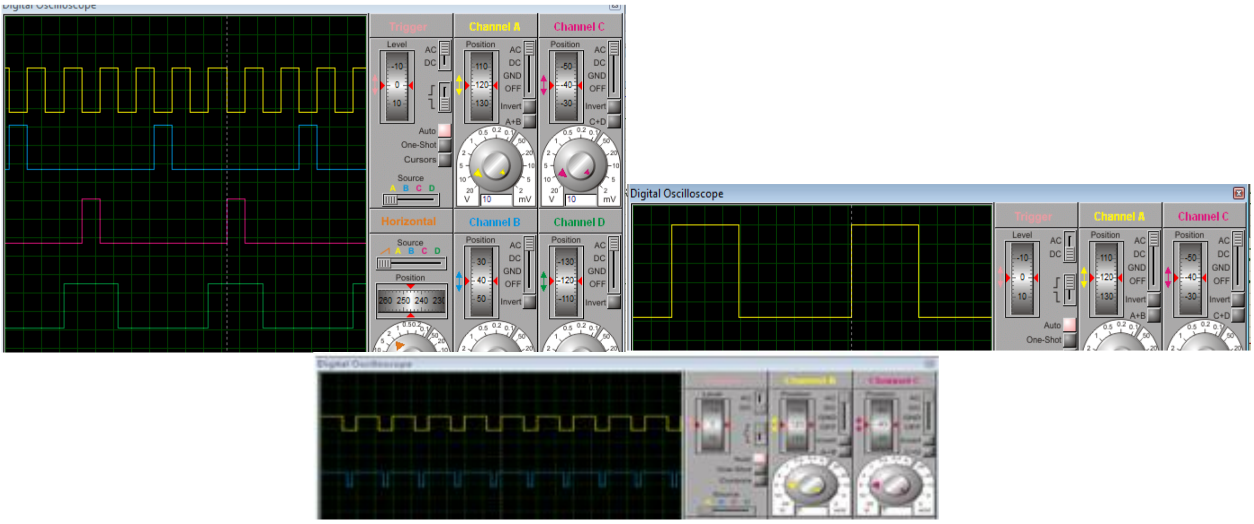


Fig.16.Output Pulse for Cascaded Nine Level Inverter

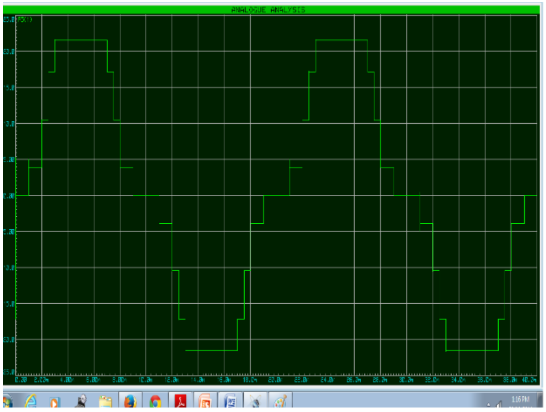


Fig.17.Output Voltage for Cascaded Nine Level Inverter

Hardware Model:

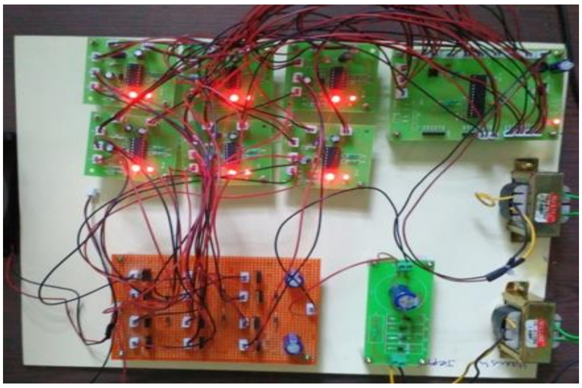


Fig.18.Experimental Setup for Nine Level Cascaded Inverter

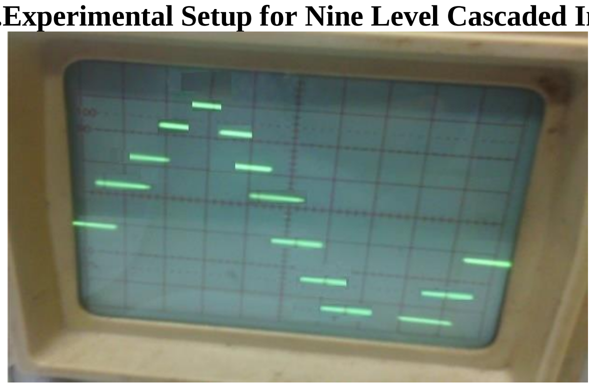


Fig.19.Cascaded Nine Level Output Voltage

Table.2.Comparison between Cascaded Multilevel Inverter

Voltage Levels	No. of Switches required	% THD	No. of Phases
5	5	11.93	1
7	6	7.32	1
9	7	5.15	1

7. CONCLUSION

Multilevel inverter provides quality output waveforms and lesser Total Harmonic Distortion (THD). This paper has presented cascaded nine level inverter with new PWM switching technique towards nearly sinusoidal output using less number of power switches, bidirectional switches and power diodes. Total harmonic distortion in the nine level inverter compared with that in the seven level and five level inverters is an attractive solution for grid connected photovoltaic inverters as given in Table II. Finally the proposed system results are verified through MATLAB/SIMULINK, PROTEUS Software and prototype model.

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