

Cascaded Multilevel Inverter for PV Cell Application Using PIC Microcontroller

V. Srimaheswaran, R. Uthirasamy

Abstract— The PV power generation have low efficiency due to the various constrains. This paper gives a new proposed method to improve the performance of the PV system. The PV cell is connected to boost chopper and Multi-Level Inverter (MLI). In order to improve the efficiency and for making the power generation available to the grid MLI is employed. MLI have emerged as attractive high power medium voltage converter to reduce harmonic component in the output current due to filter. In the proposed MLI there are 2-H bridge inverters to achieve the 5-level output voltage. A SPWM technique is used to generate the PWM signal for boost chopper inverter switches. Boost chopper is connected between the PV array and MLI. The purpose of boost chopper is to step-up the voltage and to produce continuous current to MLI. The simulation results are validated for the improvement in the PV cell system. The hardware is implemented with boost chopper and multilevel inverter. The PIC microcontroller is used to generate the PWM signal for boost chopper and inverter switches. Boost chopper output is fed to multilevel inverter and the stepped wave is obtained. The results obtained through simulation are verified with hardware results obtained.

Key words — PV Array, Boost Chopper, and Multi Level Inverter.

I. INTRODUCTION

The demand for renewable energy has increased significantly over the years because of shortage of fossil fuels and greenhouse effect. Among various types of renewable energy sources, solar energy and wind energy have become very popular and demanding due to advancement in power electronics techniques. Photo-Voltaic (PV) sources are used today in many applications as they have the advantages of being maintenance and pollution free. Solar-electric-energy demand has grown consistently by 20%–25% per annum over the past 20 years, which is mainly due to the decreasing costs and prices. This decline has been driven by the following factors: 1) an increasing efficiency of solar cells 2) manufacturing technology improvements and 3) economics of scale [1]. Multilevel inverter, which is the heart of a PV system, is used to convert dc power obtained from PV modules into ac power to be fed into the grid. Improving the output waveform of the inverter reduces its respective harmonic content and, hence, the size of the filter used and the level of electromagnetic interference (EMI) generated by switching operation of the inverter. In recent years, multilevel inverters have become more attractive for researchers and manufacturers due to their advantages over conventional three-level inverters.

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They offer improved output waveforms, smaller filter size, lower EMI and lower total harmonic distortion (THD) [2].

II. MODELING OF THE SOLAR CELL

Thus the simplest equivalent circuit of a solar cell is a current in parallel with a diode. The output of the current source is directly proportional to the light falling on the cell. During darkness, the solar cell is not an active device; it works as a diode, i.e. a P-N junction. It produces neither a current nor a voltage. However, if it is connected to an external supply (large voltage) it generates a current I_d , called diode current or dark current. The diode determines the V-I characteristics of the cell.

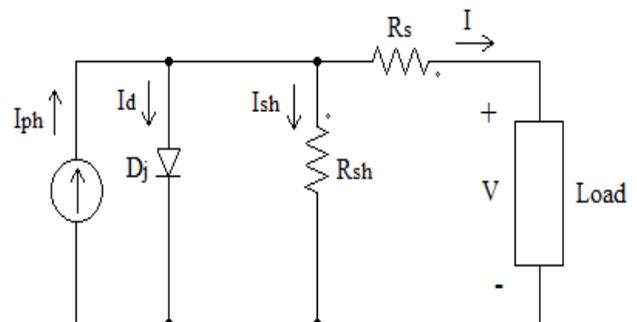


Fig. 1. Equivalent Circuit of a Solar Cell

Fig. 1 shows the equivalent circuit of a solar cell, where, R_s is the very small series resistance and R_{sh} is the quite large shunt resistance. D_j is the ideal P-N diode, I_{ph} expresses as the photocurrent source generated proportionally by the surface temperature and insolation. V and I represent the output voltage and output current of the solar cell, respectively. According to the physical property of the P-N semiconductor, the I-V characteristics of PV module could be expressed.

$$I \left(1 + \frac{R_s}{R_{sh}} \right) = n_p I_{ph} - n_p I_{sat} \left[\exp \left\{ \left(\frac{q}{kA T} \right) \left(\frac{V}{n_s + I R_s} \right) \right\} - 1 \right] - \frac{(V - n_s)}{R_{sh}} \quad (1)$$

In addition, the modules reverse saturation current I_{sat} .

$$I_{sat} = I_{rr} \left(\frac{T}{T_r} \right)^3 \exp \left\{ \frac{q E_{gap}}{kA} \left(\frac{1}{T_r} - \frac{1}{T} \right) \right\} \quad (2)$$

The I_{ph} is expressed in (3) represents the photocurrent proportionally produced to the level of cell surface temperature and radiation, where I_{SSO} is the short-circuit current, K_i is the short-circuit current temperature coefficient, and S_i is the solar radiation in W/m^2 [3].

$$I_{ph} = \{ I_{SSO} + k_i (T - T_r) \} \frac{S_i}{1000} \quad (3)$$

2.1. Psim-Based Photovoltaic Module Modeling

In order to exhibit the influence of insolation and temperature, the tested scheme of SIMENS SP75 PV module developed from the PSIM software package is constructed as shown in Fig. 2.



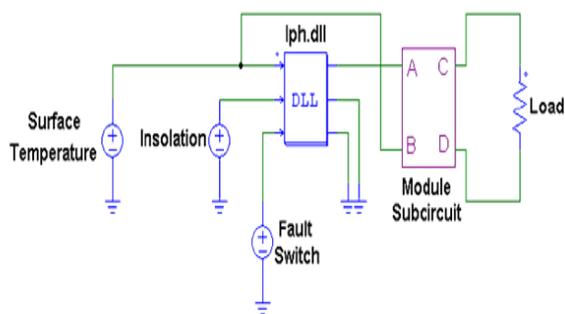


Fig. 2. Scheme Diagram of PV Module using PSIM

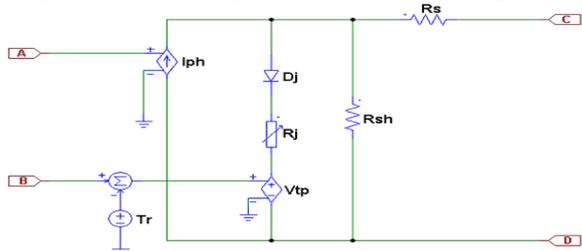


Fig. 3. PSIM model of PV cell

Fig. 3 shows the inner circuit of the proposed PV module, the photovoltaic current is a function of itself, causing an algebraic loop problem. To solve this problem, the series resistance is always neglected in the conventional mathematical model to form a simple equation. Its results show that the proposed PSIM model can be significantly more accurate than the conventional model in simulating the PV module characteristics [4].

2.2 V-I CHARACTERISTICS of PV CELL

Each solar cell has its own voltage-current (V-I) characteristic. Fig. 4 shows the V-I & P-V characteristic of a typical photovoltaic cell. The problem with extracting the most possible power from a solar panel is due to nonlinearity of the characteristic curve. The characteristic shows two curves, one shows the behavior of the current with respect to increasing voltage. The other curve is the power-voltage curve and is obtained by the equation $(P=I*V)$.

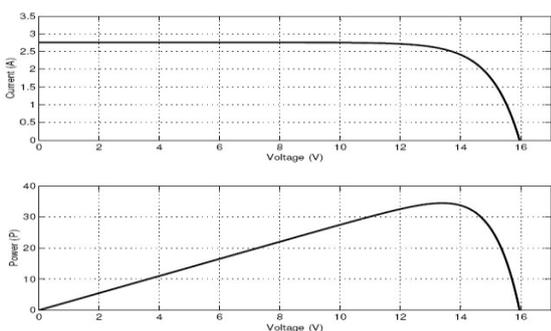


Fig. 4. Solar Panel V-I Characteristic and Power Curve

When the P-V curve of the module is observed, one can locate single maxima of power where the solar panel operates at its optimum. In other words, there is a peak power that corresponds to a particular voltage and current. Obtaining this peak power requires the solar panel to be operated at or very near the point where the P-V curve is at the maximum [3].

III. DC-DC BOOST CONVERTER

The boost converter will represent one of the most significant portions to the overall design of the MPPT. Ideally, the maximum power will be taken from the solar panels. In order to do so, the panels must operate at their optimum power point. The output of the solar panel will be either shorted or open circuited through the opening or closing of a switch.

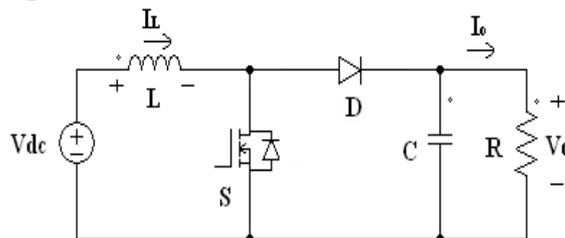


Fig. 5. Step-Up (Boost) DC-DC converter

In the design, the switch will actually be a MOSFET, which will be controlled by the digital controller. For better understanding of the converter, the model of the overall design can be made with the MOSFET as a simple, ideal switch. The switch will open and close to control the voltage across the inductor, essentially operating the panels at their optimum power level.

Fig. 5 shows the basic design of a step-up converter. As the name implies, the output voltage is always greater than the input voltage. The operation of the converter depends on the state of the switch. For better understanding the operation of the converter, the operation of the switch is examined circuit when the switch is opened or closed.

Mode 1

When the switch is on as shown in Fig. 6 the diode becomes reversed biased and the output stage is isolated. At this point, the input is supplying energy to the inductor [5].

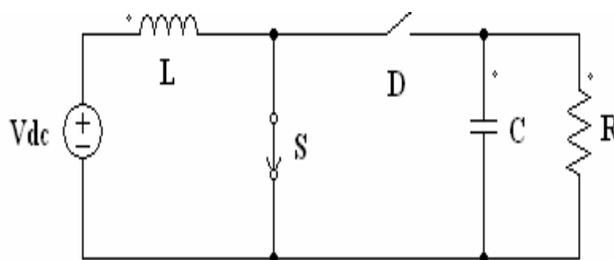


Fig. 6. Boost Converter Switch ON

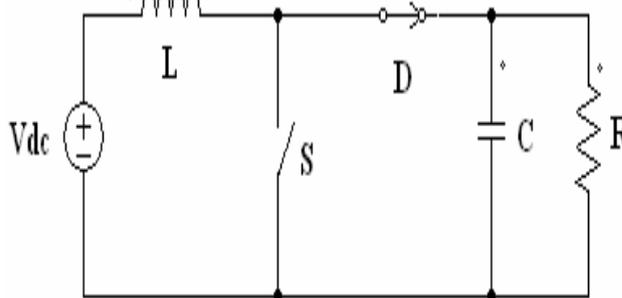


Fig. 7. Boost Converter Switch OFF

Mode 2

When the switch is off as shown in Fig. 7 the output stage receives energy from the inductor as well as from the input. In the steady-state analysis, the output filter capacitor is assumed to be very large to ensure a constant output voltage $v_o(t) = V_o$.

Fig. 8 shows the switch state, voltage and current waveforms. When the dc-dc converter operates in continuous conduction mode, the inductor current flows continuously when $[i_L(t) > 0]$.

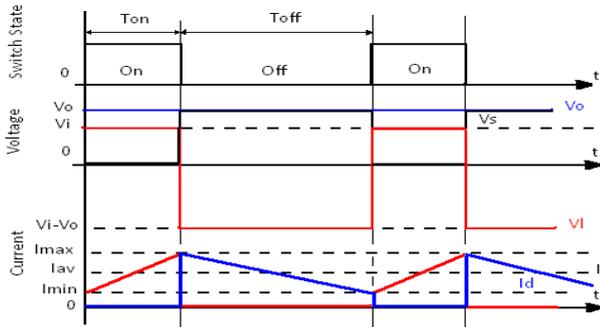


Fig. 8. Boost DC-DC Converter Switch State and Voltage and Current Waveforms

In steady state, the time integral of the inductor voltage over one time period must be zero.

Thus

$$V_d t_{on} + (V_d - V_o)t_{off} = 0 \tag{6}$$

Dividing both sides by the switching time, T_s , and rearranging terms, the equation obtained describes the relationship between the input and output voltages, switching time and duty cycle.

$$\frac{V_o}{V_d} = \frac{T_s}{T_{off}} = \frac{1}{(1-D)} \tag{7}$$

The equation [7] confirms that the output voltage is always higher than the input voltage. Assuming a lossless circuit, $P_d = P_o$, also have

$$\frac{I_o}{I_d} = (1 - D) \tag{8}$$

IV. MULTILEVEL INVERTER

A cascaded multilevel inverter consists of a series of H-bridge inverter units. The work of multilevel inverter is to synthesize a desired voltage from Several Separate DC Source. Fig.9 shows the basic structure of a SDCS. Each SDCS is connected to an H-bridge inverter. The ac terminal voltages of different level inverters are connected in series. Unlike the diode-clamp or flying capacitor inverter, the cascaded inverter does not require any voltage clamping diodes or voltage balancing capacitors. The numbering order of the switches is S1, S2, S3, S4, S5, S6, S7 and S8. The numbering is immaterial as long as the switches are turned on and off in the right sequence to produce the desired output waveform.

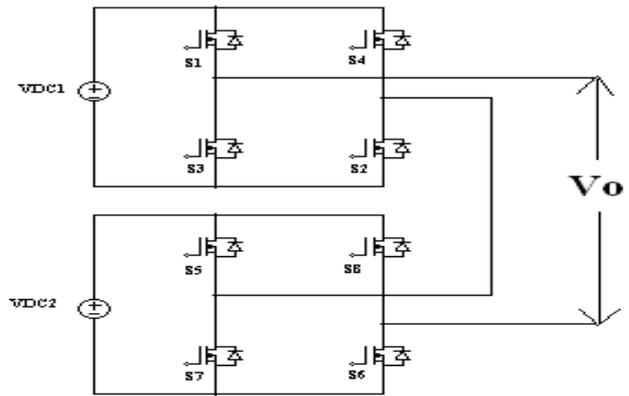


Fig. 9. Cascaded Multilevel Inverter

Number of bridges to be used = $(m-1)/2$ (9)

The five-level inverter is considered to produce stepped output voltage. The DC rail 0 is the reference point of the output phase voltage. The steps to synthesize the seven-level voltages are as follows:

1. For an output voltage level $V_o = V_{dc}$, S1 S2 & S5 S6 are turned on.
2. For an output voltage level $V_o = V_{dc} / 2$, S1 and S2 are turned on.
3. For an output voltage level $V_o = 0$, all switches are turn off.
4. For an output voltage level $V_o = - V_{dc} / 2$, S3 and S4 are turned on.
5. For an output voltage level $V_o = - V_{dc}$, S3 S4 & S7 S8 are turned on.

Table: 1 Switching Table for Five-Level Inverter

Output(V_o)	S1	S2	S3	S4	S5	S6	S7	S8
$V_o = V_{dc}$	1	1	0	0	1	1	0	0
$V_o = V_{dc}/2$	1	1	0	0	0	0	0	0
$V_o = 0$	0	0	0	0	0	0	0	0
$V_o = - V_{dc}/2$	0	0	1	1	0	0	0	0
$V_o = - V_{dc}$	0	0	1	1	0	0	1	1

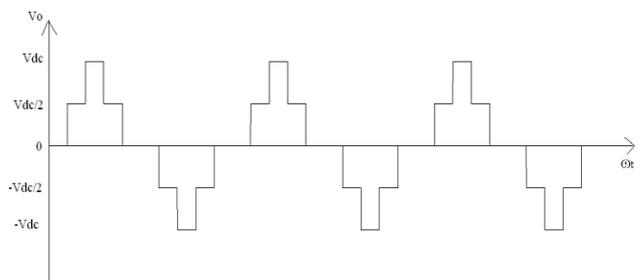


Fig. 10. Output Voltage (phase) Waveform of 5-Level Inverter

V. SIMULATION MODEL & RESULTS

PSIM is simulation software specifically designed for power electronics and motor drives. With fast simulation and friendly user interface, PSIM provides a powerful simulation environment for power electronics, analog and digital control, magnetic and motor drive system studies.

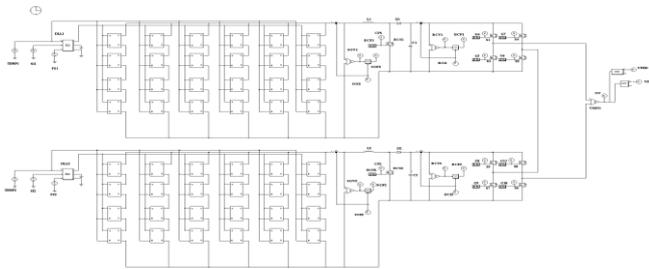


Fig. 11. Simulation Model of PV Cell with Boost Chopper and 5-Level Multilevel Inverter without Filter at No-Load Condition.

Input of the PV cell is temperature and solar insolation are given to the dynamic link library block. In this photovoltaic array model 4 series and 6 parallel cells are connected as shown and boost chopper and 5-Level multilevel inverter without filter at no-load condition Fig. 11. This PV system operates at a 25°C & 1000W/m². It gives the output voltage as 522V with a five stepped wave.

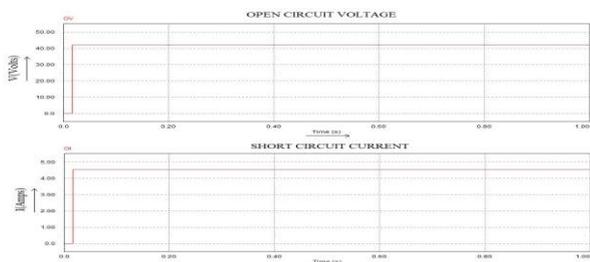


Fig. 12. Output Waveforms of PV Cell

Fig. 12 shows the output waveform of a PV cell. It shows the voltage and current characteristic with respect to time for a PV system. From the obtained results it is found that the average value of open circuit voltage is 41.38V and short circuit current is 4.43A.

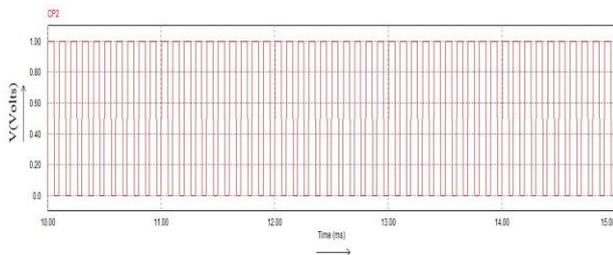


Fig. 13. Switching Pulses for Boost chopper

Fig. 13 shows the switching pulses for boost chopper that are generated using single pulse width modulation. The pulse is given to the chopper switch is turned on at a correct sequence to obtain the boosted output.

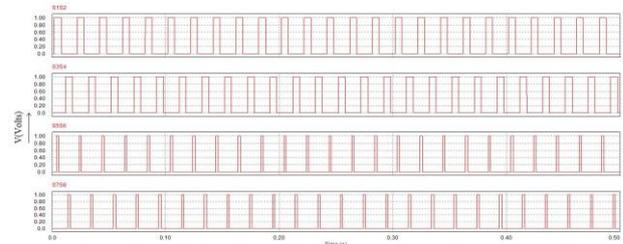


Fig. 14. Switching Pulses for Inverter

Fig. 14 shows the switching pulses for inverter that are generated using single pulse width modulation. The pulses are given to multilevel inverter switches at a correct sequence to obtain the five stepped wave.

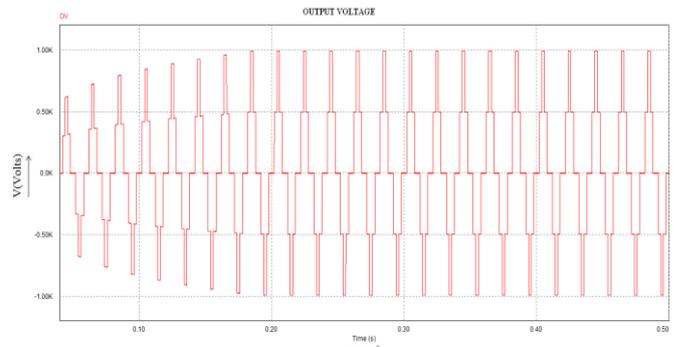


Fig. 15. Output Waveform of five-Level Multilevel Inverter without Filter at No-Load Condition

Fig. 15 shows the output waveform of five-level multilevel inverter without filter at No-Load Condition. From the obtained result it is viewed that the rms output voltage of multilevel inverter is 522V.

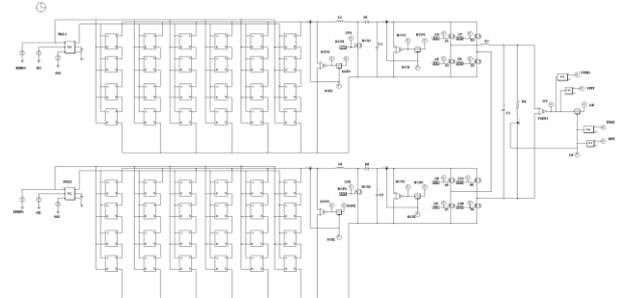


Fig. 16. Simulation Model of PV Cell with Boost Chopper and Multilevel Inverter with Filter at Load Condition Model of PV cell with boost chopper and multilevel inverter with filter at load condition is given in Fig. 16. Here LC filter is used to obtain the pure sinusoidal output waveform.

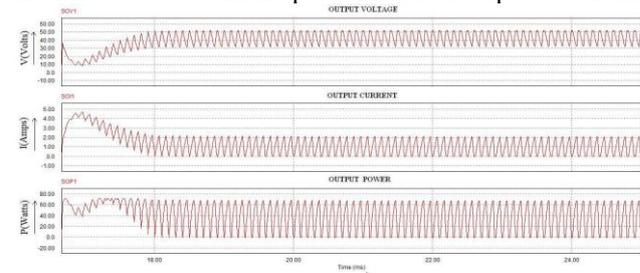


Fig. 17. Output Waveforms of PV Cell

Fig. 17 shows the output waveform of a PV cell. It shows the voltage, current and power characteristic with respect to time for a PV system. From the obtained results it is found that the average value of voltage is 40.47V, current is 1.12A and power is 44W.

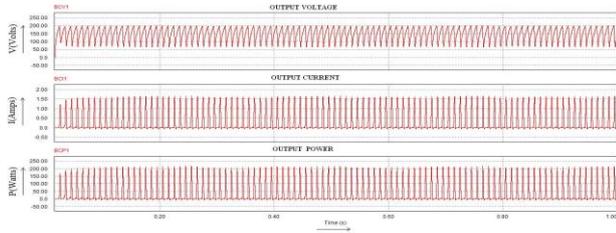


Fig. 18. Output Waveforms of Boost Chopper

Fig. 18 shows the output waveform of boost chopper. The input given to the boost chopper is 40.47V and boosted to an average output of 143V. The boost chopper output is given to the multilevel inverter. From the obtained results it is found that the output current is 0.3A and output power is 44W.

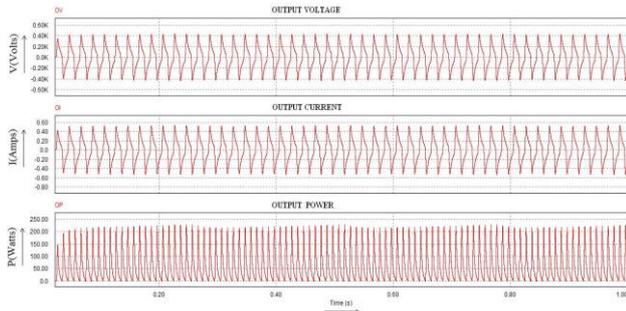


Fig. 19. Output Waveform of Multilevel Inverter with Filter at Load Condition

Fig. 19 shows the output waveform of multilevel inverter with filter at Load condition. The boost chopper output is fed to the MLI. The obtained output voltage, output current and output power from Fig 4.14 of multilevel inverter is 230V, 0.27A and power 60W.

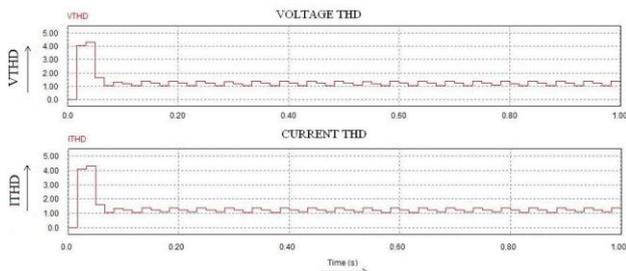


Fig. 20. THD of Output Voltage and Current Waveforms

Fig. 20 shows the output waveform of voltage THD and Current THD. From the obtained results it is found that the voltage and current THD are 1.43%.

VI. EXPERIMENTAL ANALYSIS

The hardware of cascaded multilevel inverter with boost chopper is implemented and the output is fed to the load. The DC supply is given to the boost chopper. The boosted voltage is given to the cascaded multilevel inverter. The cascaded multilevel inverter is used to reduce the harmonics. The DC link voltage is given as input to the PIC microcontroller. The microcontroller is used to produce

control signals based on single pulse width modulation technique for the gates of the MOSFET. The hardware results are pulses and voltage. These results are measured using Digital Storage Oscilloscope (DSO).

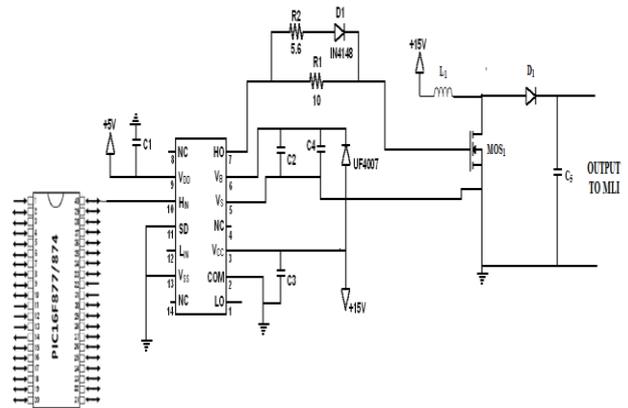


Fig. 21. Hardware Circuit for Boost Chopper

Fig. 21 shows the hardware circuit for boost chopper. The gate pulses for boost chopper are generated using PIC microcontroller. The output of boost chopper is given to multilevel inverter.

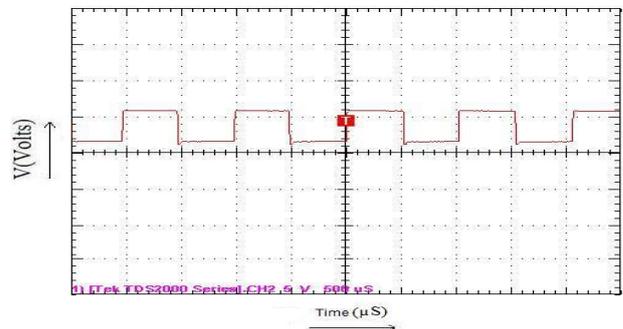


Fig. 22. Switching Pulse for Boost Chopper

Fig. 22 shows the switching pulse for boost chopper. The pulses are generated using the PIC Microcontroller & given to the boost chopper switch.

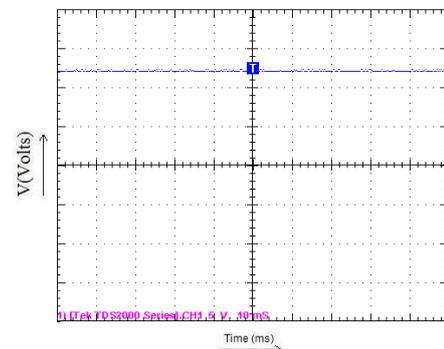


Fig. 23. Input Voltage Waveform

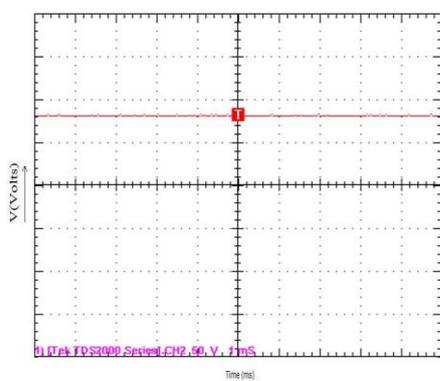


Fig. 24. Output Voltage for BC

The Fig. 23 shows the input voltage of 12V which is given to boost chopper. Fig. 24 shows the boost chopper output voltage of 80V. The input 12V is boosted to 80V.

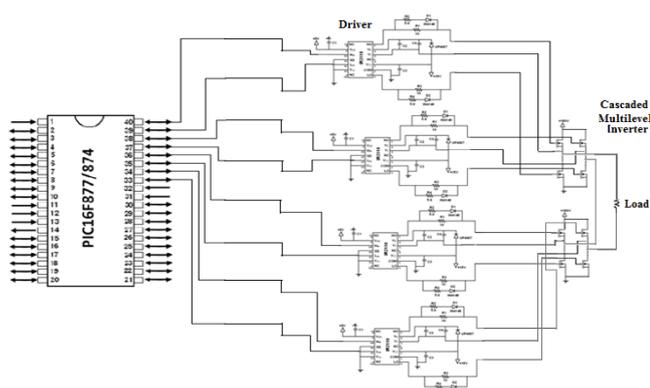


Fig. 25. Driver Circuit for Cascaded Multilevel Inverter

Fig. 25 shows the driver circuit for cascaded multilevel inverter. Multilevel inverter works based on the driver circuit. The inverter consists of 2-H bridge inverter. The pulses are generated using the PIC Microcontroller and given to the inverter switches.

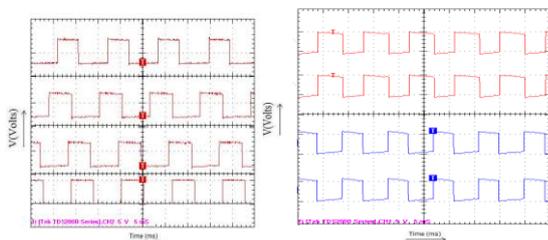


Fig. 26. Switching Pulse for Upper and Lower Arm of the H Bridge Inverter

Fig. 26 shows the switching pulse for upper and lower arm of the inverter. The pulses generated using the PIC Microcontroller and given to the inverter switches. The pulses supplied from the PIC have amplitude of 5V which is not enough to drive the MOSFET switches and therefore driver IC's are employed. The input supply to the driver board is 12V DC from the regulator. The switches S1, S2, S3 and S4 are turned on. The switches S5, S6, S7 and S8 are turned on.

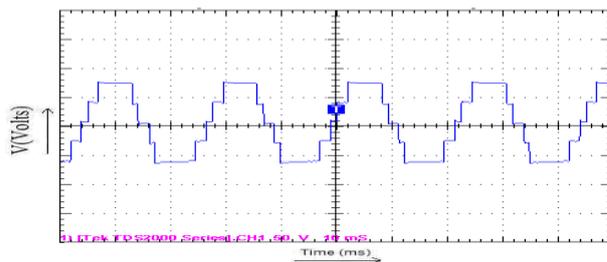


Fig. 27. Output Voltage for 5-Level Multilevel Inverter

Fig. 27. shows the output voltage for multilevel inverter. The output voltage is 5-level stepped waveform. The output voltage is 160Vols (peak-peak).

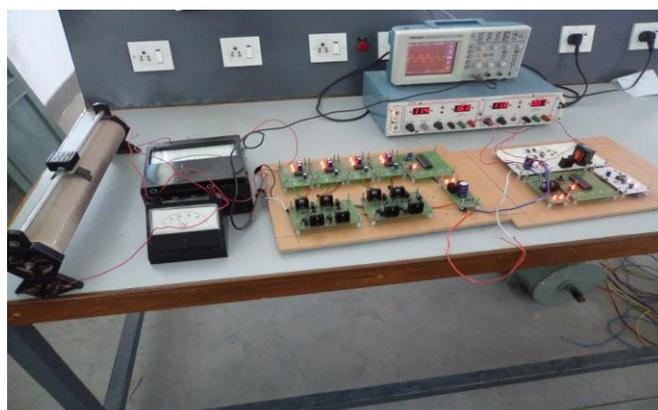


Fig. 28. Experimental Set up

VII. CONCLUSION

This paper gives the clear idea about the cascaded multilevel inverter topology for PV cell. The voltage level of the PV panel is improved using boost chopper and multilevel inverter. The proposed multilevel inverter is to reduce both voltage & current THD of the inverter. The circuit topology, modulation law and operational principle of the proposed inverter are analyzed in detail. The performance of the PV system is increased with in solar insolation and surface temperature. Simulation results indicate that the THD of the five-level inverter is much lesser than that of the conventional three-level inverter. As the level increases, the THD value reduces but the complexity of the system increases. Thus the hardware is implemented with five levels. The hardware is implemented with boost chopper with multilevel inverter. Boost chopper is used to boost the voltage, without that the input voltage drawn from the source by the multilevel inverter is high. The pulses are generated by the gate driver circuit and it is given to the switches of the multilevel. The output voltage waveform of the multilevel inverter is a stepped wave with five levels. In the proposed MLI there are Two H Bridge inverters to achieve the five level output voltage. Compared to the conventional three-level inverter, the harmonics are reduced in the five level inverter.



REFERENCES

1. Juan Manuel Carrasco, Leopoldo Garcia Franquelo, "Power-Electronic Systems for the Grid Integration of Renewable Energy Sources: A Survey", *IEEE Transactions on Power Electronics*, Vol.53, No.4, pp 1002-1016, Aug 2006.
2. Jeyraj Selvaraj and Nasrudin Rahim A, "Multilevel Inverter for Grid-Connected PV System Employing Digital PI Controller", *IEEE Transactions on Power Electronics*, Vol.56, No.1, pp 149-158, Jan 2009.
3. Kuei-Hsiang Chao, Ching-Ju Li and Sheng-HanHo, "Modeling and Fault Simulation of Photovoltaic Generation Systems Using Circuit Based Model", in *proceedings on IEEE-ICSET Annual Meeting*, Taichung, Taiwan, 2008, pp 290-294.
4. *SIEMENS Solar Module SP75 Specifications*, Siemens Solar Industries, 2002.
5. M.H.Rashid, *Power Electronics: Circuits, Devices, and Applications*, 3rd ed. Englewood Cliffs, NJ: Prentice- Hall, 2004.
6. X. Kou, K. Corzine and M. Wieleski, "Over distention Operation of Cascaded Multilevel Inverters", *IEEE Transactions on Industrial Applications*, Vol.42, No.3, pp 817-824, June 2006.
7. Martina Calais, Agelidis V.G, "A Transformer less Five Level Cascaded Inverter Based Single Phase Photovoltaic System ", in *proceedings on IEEE-PESC Annual Meeting*, Perth, Australia, 2001, Vol.3, pp 1173-1178.
8. Park S. J, Kang F. S, Lee M. H and Kim C. U, "A New Single-Phase Five Level PWM Inverter Employing a Deadbeat Control Scheme", *IEEE Transactions on Power Electronics*, Vol.18, No.18, pp 831-843, May 2003.
9. ESRAM T and Chapman P. L, "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques", *IEEE Transactions on Energy Conversion*, Vol.22, No.2, pp 439-449, June 2007.

BIOGRAPHY



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