

## **Interfacing of the SPV System with Off-grid Load by using Boost converter and Inverter**

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**Abstract**— This paper presents the interfacing of Solar Photovoltaic (SPV) system which consist Photovoltaic (PV) panels with the off-grid load. Two types of converters, namely a dc to dc converter and a dc to ac converter are used for the interfacing. A closed loop boost converter is designed using the controller and voltage-feedback technique. An error signal is generated by comparing the output voltage of the boost converter with reference voltage and this error signal is fed to controller. In response to error signal the controller generates the pulse width modulation (PWM) signal which is used to control the duty cycle of the boost converter so as output voltage can be maintained to a fixed level. Thus boost converter step up solar panel voltage to a stable value at output. The output voltage of the boost converter is fed to a sinusoidal pulse width modulation (SPWM) based inverter which converts the dc supply into the ac supply to feed any off-grid load. In this paper first design of boost converter and then relevant MATLAB simulations are presented.

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**Keywords** - Renewable Energy Source (RES), Photovoltaic (PV) Panel, Boost converter, Sinusoidal Pulse Width Modulation (SPWM) Inverter, Off-grid load.

### **I. INTRODUCTION**

Basically there are two ways by which electrical power is generated are Conventional way & non conventional way. In conventional way of the electrical power generation fossil fuels i.e. non renewable energy sources (NRES) are mainly used. While in case of non-conventional way of the electrical power generation, renewable energy sources (RES) are mainly used as the source of energy. At present, the main sources of electrical power generation are fossil fuels. Over the past few decades, the demand for renewable energy has increased significantly due to the disadvantages of fossil fuels and greenhouse effect. Among various types of renewable energy sources (RES), like solar energy and wind energy have become the most promising and attractive feature because of advancement in power electronic technique. The sun energy to the earth is approximately  $1.2 \times 10^5$  TW which is about 104 times of the rate at which human civilization currently produces and uses [2], [5]. Solar energy is promising solution for the energy and environmental challenges and the global warming. Solar energy is clean, reliable and environment friendly. Photovoltaic (PV) based electricity generation has become one of the main ways to use solar energy because of numbers of the advantages associated with it like maintenance and pollution free, adequate in amount, long life, advancement in technology leads to the higher efficiency of photovoltaic cell etc. Generated dc voltage from a solar panel is generally small in magnitude. Therefore a step up dc to dc converter called boost converter is required. Generated dc output from solar panel is not constant in magnitude due to variation in solar irradiation during morning to evening. It also depends upon the temperature and weather conditions. Therefore to make output voltage of dc-dc boost converter constant close loop control of dc-dc boost converter is required. After making constant voltage at the output of the dc to dc converter a dc to ac converter called an inverter is required to get the ac supply which is then given to the ac load.

## II. BLOCK DIAGRAM OF PROPOSED SCHEME

Figure 1 shows a basic schematic block diagram of the proposed scheme. A Solar panel basically contains Photovoltaic (PV) cells which convert the solar energy into electrical energy in dc form directly. But single PV panel gives dc output voltage of low magnitude. Therefore dc output voltage of a PV panel is required to step up. A boost converter directly connected to panel.

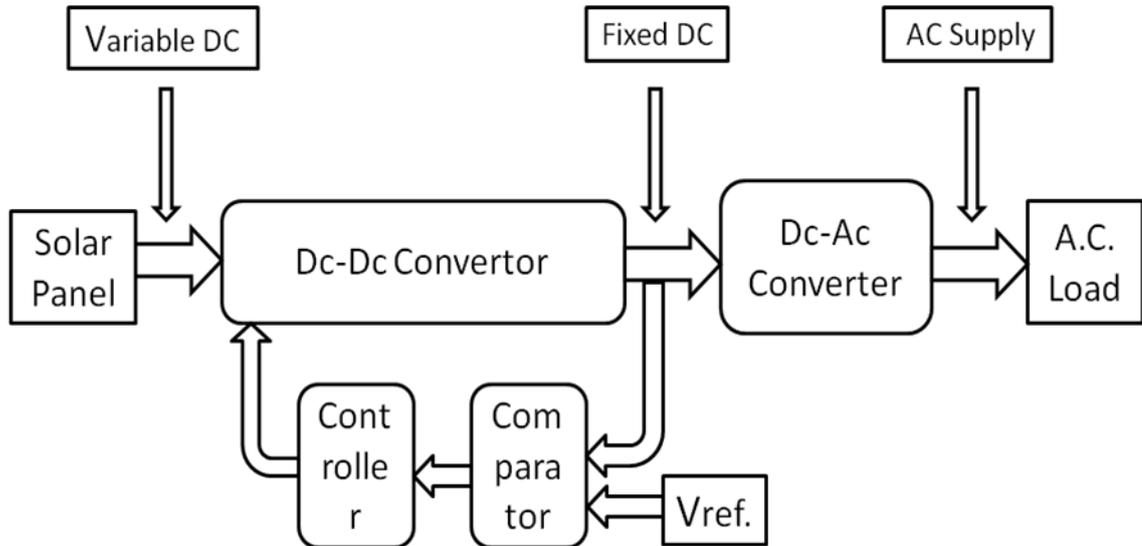


Figure1 . Circuit diagram of boost converter

As dc output voltage of a PV panel is vary with solar irradiation and weather condition. Therefore closed loop control of the boost converter is required to maintain the constant output voltage. This is done by introducing a voltage feedback loop as shown in figure. A reference voltage (desired voltage) is compared with actual output voltage of the boost converter with help of a comparator. The comparator generates an error signal. This error signal is given to the controller which controls the boost converter such that output voltage will be constant. An inverter (dc to ac converter) converts this dc voltage into ac voltage to supply the load.

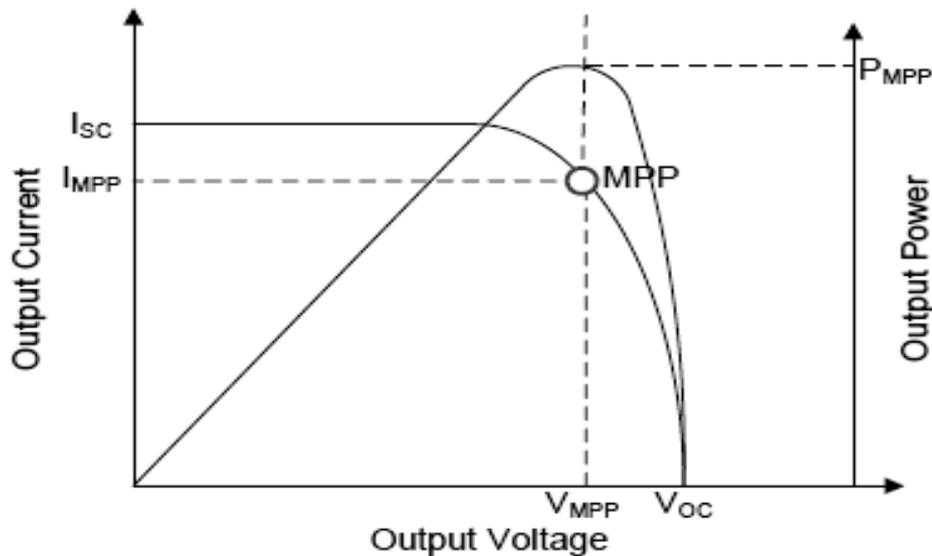
In this proposed scheme the boost converter operates in continues conduction mode and its output voltage is stabilized by voltage feedback control. This technique is quite simple compared to maximum power point tracking technique. Practically closed loop control of the boost converter can be implemented by using any suitable microcontroller say PIC16F876 or by using digital signal processor say TMS320C240 [6]. Controller or processor will produce the PWM signal to switch the power switch of the converter and the duty ratio of the PWM signal is varied with variation in the converter output [11]. Thus convert will produce the constant output voltage. The PWM based control technique is generally used due to advantages like easy to implement, less cost, not affected by temperature variation, good linearity, less power consumption. Sinusoidal pulse width modulation SPWM based two level inverter converts dc power to ac power. SPWM technique is used for the inverter because of it consists less number switches and so losses, simple control circuitry, easy to implement, good utilization of dc source and higher efficiency compared to other technique[6].

## III. CHARACTERISTIC OF PV PANEL

PV Panel consists of no. of solar cells. Solar cell is made by semiconducting material and is able to convert solar energy in the form of radiation into DC current. The output characteristic equation of the current equation of a solar panel can be expressed as

$$I = I_L - I_{RS} \left\{ \exp \left[ \frac{q}{AKT} (V + IR_S) - 1 \right] \right\} - \frac{V + IR_S}{R_{SH}} \quad (1)$$

Where  $I_{RS}$  is reverse saturation current,  $I_L$  is current generated by light,  $q$  is charge of the electron,  $K$  is constant of Boltzmann,  $A$  is factor which has no dimension,  $T$  is temperature in Kelvin,  $R_{SH}$  is the shunt resistance of a cell,  $R_S$  is series resistance of a cell. Figure 2 shows the V-I and V-P characteristic for the solar panel which shows the variation of the output.



**Figure 1. Voltage-current and voltage-power characteristic**

#### IV. BOOST CONVERTER

A boost converter or step-up converter is a dc to dc power converter with an average output voltage greater than its input voltage. It is a class of switched-mode power supply (SMPS) containing at least two semiconductor switches (a diode and a transistor) and at least one energy storage element (an inductor).

The key principle that drives the boost converter is the tendency of an inductor to resist changes in current. In a boost converter, the output voltage is always higher than the input voltage. A schematic of a boost converter is shown in figure 3. The operation of a boost converter can be divided into two modes. First when the switch is closed, current flows through the inductor in clockwise direction and the inductor stores the energy. Polarity of the left side of the inductor is positive.

Second when the switch is opened, current will be reduced as the impedance is higher. Therefore, change or reduction in current will be opposed by the inductor. Thus the polarity will be reversed (means left side of inductor will be negative now). As a result two sources will be in series causing a higher voltage to charge the capacitor through the diode D.

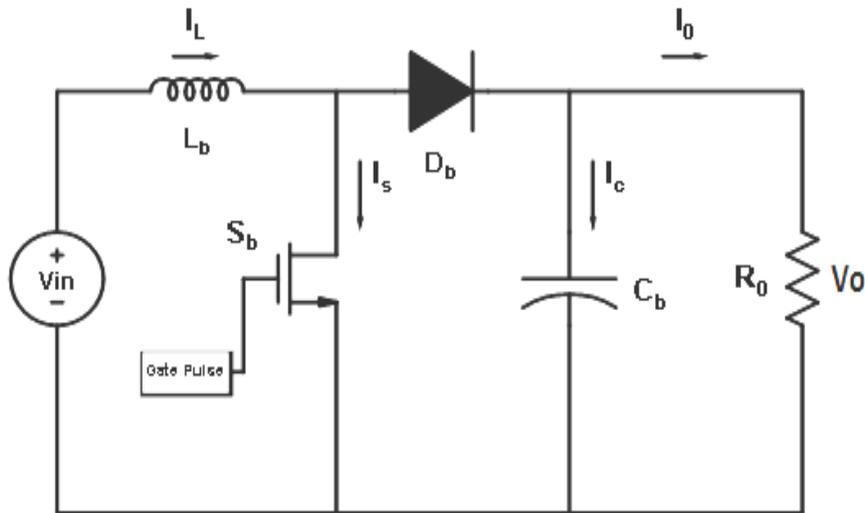


Figure 2. Circuit diagram of a boost converter

Using Faraday's law,

$$V_{in} k T = (V_o - V_{in})(1 - k) T \quad (2)$$

Where,  $V_{in}$  is the input voltage of the converter,  $V_o$  is the output voltage of the converter,  $k$  is the duty ratio,  $T$  is the time period. From the above equation, the output voltage equation is given by

$$V_o = \frac{V_{in}}{1 - k} \quad (3)$$

## V. DESIGN OF BOOST CONVERTER

For designing of boost converter following parameters design should be selected properly to get desired operation from boost converter [7]. Input voltage range (minimum & maximum voltage), required output voltage, maximum output current, load resistance and switching frequency of the converter. The values of these parameters depend on particular application. This is necessary, because if these parameters are known the calculation of the power stage can take place. Also design should be such that inductor ripple current should not be more than 10% and capacitor ripple voltage should be less than 3%.

### A. Calculation of Duty Ratio

The duty ratio or duty cycle is calculated from the equation (3). For example if input voltage is 25 volts and required output voltage is four times the input i.e. 100 volts, then from equation (3) the value of the duty ratio ( $k$ ) is 0.75.

### B. Selection of the Inductor

During selection of inductor one should keep in mind is higher the inductor value, the higher is the maximum output current because of the reduced ripple current. And also lower the inductor value, the smaller is the inductor size but may increases the ripple current. Note that the inductor must always have a higher current rating than the maximum current because the current increases with decreasing inductance which may leads to unstable operation of the converter. The value of the inductance should be choose based on allowable ripple current at minimum duty ratio  $k$ , at maximum input voltage [9]. For high value of the inductor increases the start-up time which results in to slow response, where as for small value of the inductor increases ripple current. Note that ferrite cored inductor should be used [8]. The value of the inductor can be determined by using expression given as

$$L_{min} = \frac{(1 - k)^2 kR}{2f} \quad (4)$$

Where,  $L_{min}$  is the minimum value of the inductance for continuous conduction mode,  $k$  is the duty ratio,  $R$  is the resistance of the load, and  $f$  is the switching frequency.

### C. Selection of the Capacitor

Two main factors are considered for choosing a capacitor viz. its capacitance value and equivalent series resistance (ESR) value [9]. The losses of capacitor depend on ESR value which affects the efficiency of the converter. Therefore capacitor with low value of ESR is preferable. Low ESR can be achieved by connecting capacitors in parallel. Voltage rating of the capacitor should be higher than converter output voltage and capacitor should be capable to carry the load current during the turn on period. Also capacitor ripple voltage should be less than 3%. The value of the capacitor can be determined by using expression given below.

$$C_{min} = \frac{kV_o}{Rf\Delta V_o} \quad (5)$$

Where,  $C_{min}$  is the minimum value of the capacitance for continuous conduction mode,  $\Delta V_o$  is the capacitor ripple voltage (output ripple voltage) and  $V_o$  is output voltage of the converter.

### D. Selection of the Diode

The main parameters to be considered for choosing a diode are its losses & switching time. To reduce losses, Schottky diode should be used which is also suitable for the high frequency application. Schottky diodes have a much higher peak current rating than average rating. Therefore the higher peak current in the system is not a problem Peak repetitive reverse voltage (blocking voltage) rating of the diode should be higher as it is reversed biased when switch is on and diode should be capable to carry the supply current when switch is off. The forward current rating needed is equal to the maximum output current.

$$I_F = I_{o(max)} \quad (6)$$

Where,  $I_F$  is the average forward current of the diode &  $I_{o(max)}$  is the maximum output current.

## VI. SIMULATION OF CLOSED BOOST CONVERTER

The values of the different parameters for the simulation of the boost converter are calculated by using the different equations as presented in section. These values of the different parameters for the simulation of the boost converter are tabulated in the table 1 and the simulation of the closed loop boost converter is done using MATLAB simulink. Figure 4 shows the simulation circuit in MATLAB.

*Table 1. Parameter's values used for the simulation*

| Parameter description | Parameter symbol | Value  |
|-----------------------|------------------|--------|
| Average panel         | Vin              | 24 V   |
| Switching frequency   | F                | 10 KHz |
| Duty ratio            | K                | 0.75   |

|                 |   |                |
|-----------------|---|----------------|
| Load resistance | R | 50 $\Omega$    |
| Inductance      | L | 0.41 mH        |
| Capacitance     | C | 153.13 $\mu$ F |

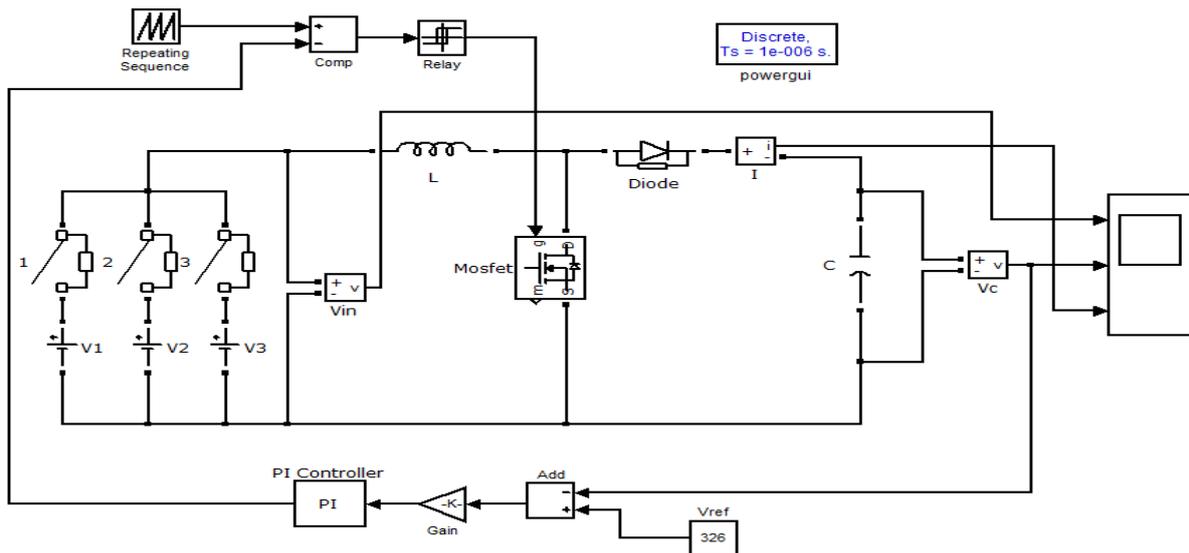


Figure 4. MATLAB model of open loop boost converter

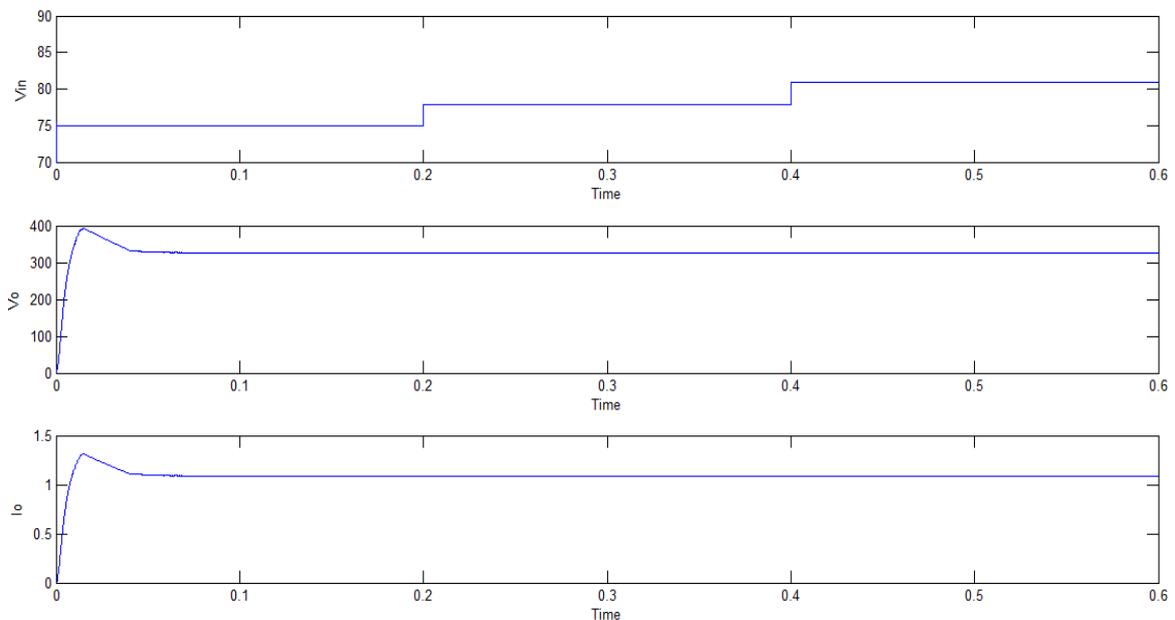


Figure 5. Output voltage waveforms for variable input voltage

Figure 5 shows the output voltage & current for variable input voltage. The same result along with the values of different parameter is tabulated in table 2.

Table 2. Parameter's values used for the simulation

| Vin volt | Time sec  | f KHz | L mH     | C $\mu$ F | R $\Omega$ | Vo Volt |
|----------|-----------|-------|----------|-----------|------------|---------|
| 75       | 0 - 0.2   | 10    | 0.4<br>1 | 153       | 50         | 325.5   |
| 78       | 0.2 - 0.4 |       |          |           |            |         |
| 81       | 0.4 - 0.6 |       |          |           |            |         |

The simulation result shows that closed loop boost converter is able to maintain the output voltage constant for variable input voltage supplied by the PV panel.

### VII. TWO LEVEL H-BRIDGE INVERTER WITH SPWM

Figure shows 6 MATLAB model of two level H-bridge inverter with SPWM and without any filter. Figure 7 shows output voltage & current waveform without filter.

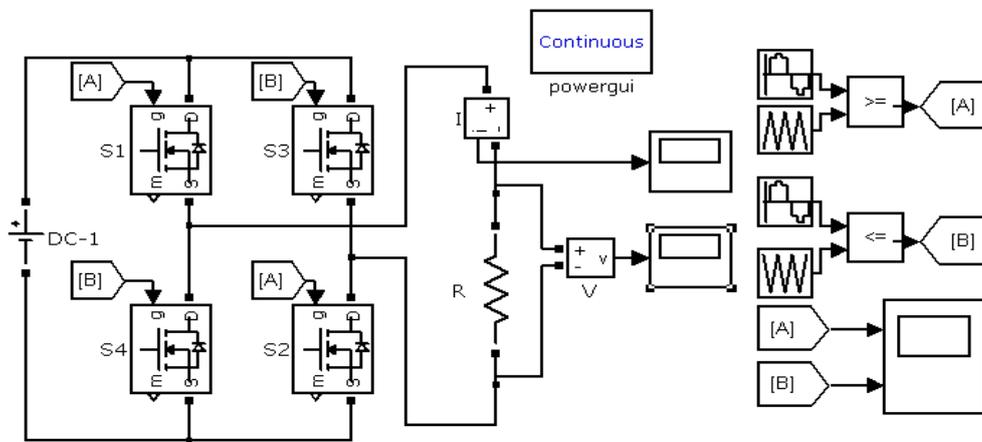


Figure 6. MATLAB model of two level H-bridge inverter with SPWM

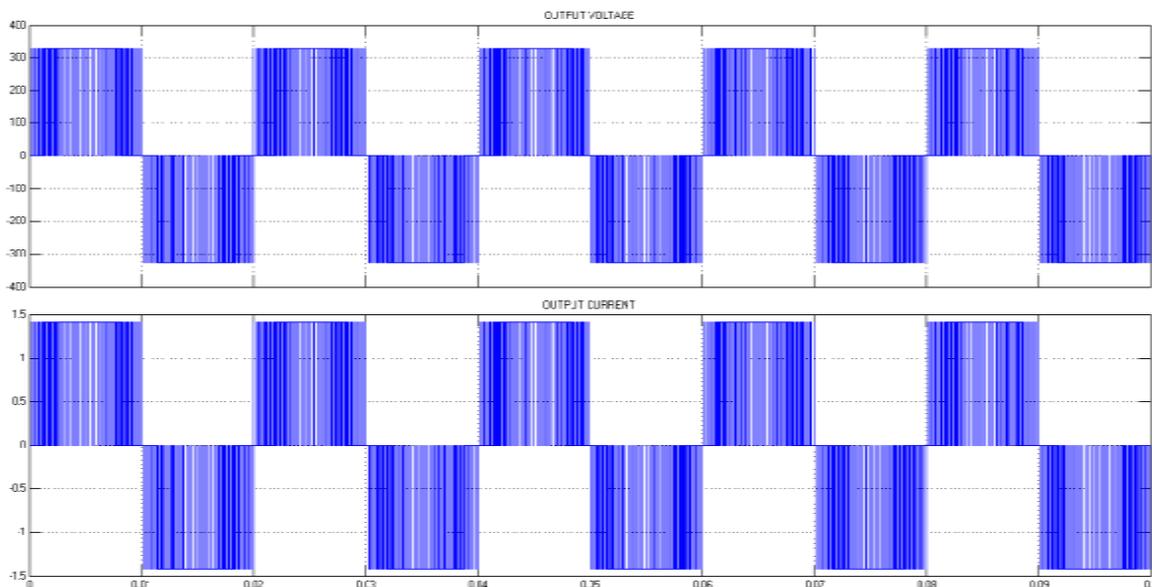


Figure 7. Output voltage and current of two level H-bridge inverter with SPWM

Figure shows 8 MATLAB model of two level H-bridge inverter with SPWM and with LC filter. Figure 9 shows output voltage & current waveform with LC filter.

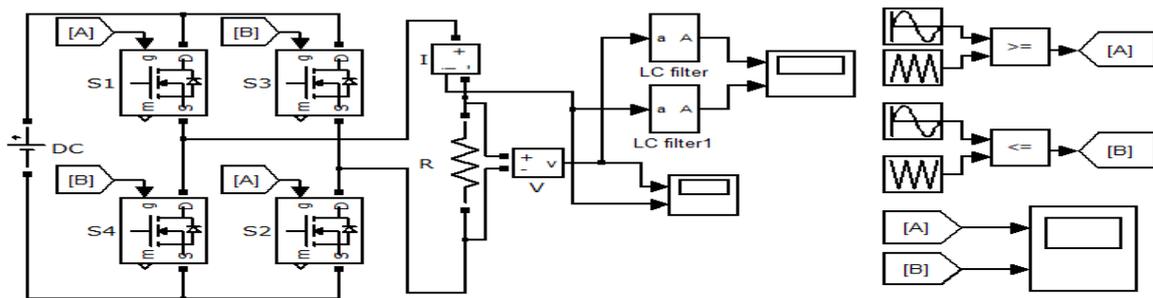


Figure 8. MATLAB model of two level H-bridge SPWM inverter with LC filter

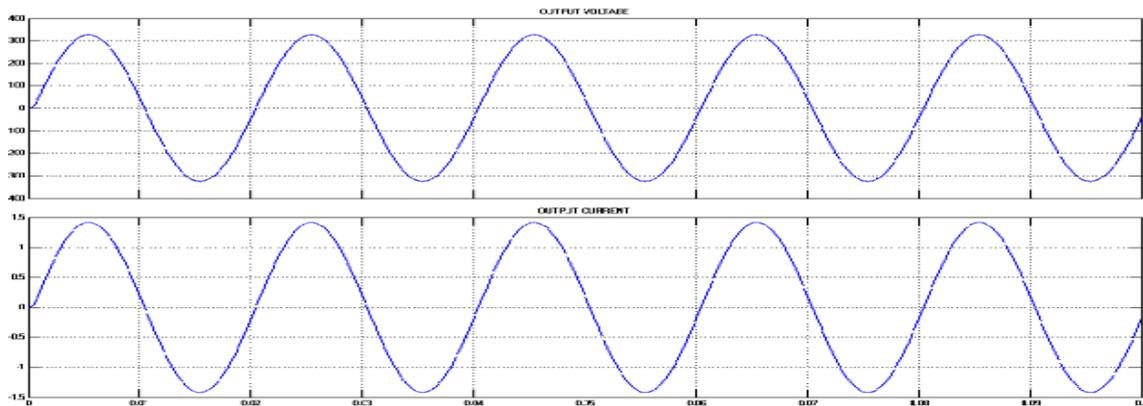


Figure 9. Output of two level H-bridge SPWM inverter with LC filter

Figure 10 shows MATLAB model of two level H-bridge inverter with SPWM and with LC filter supplied by the boost converter i.e. complete system and Figure11 shows output voltage & current waveform for the same.

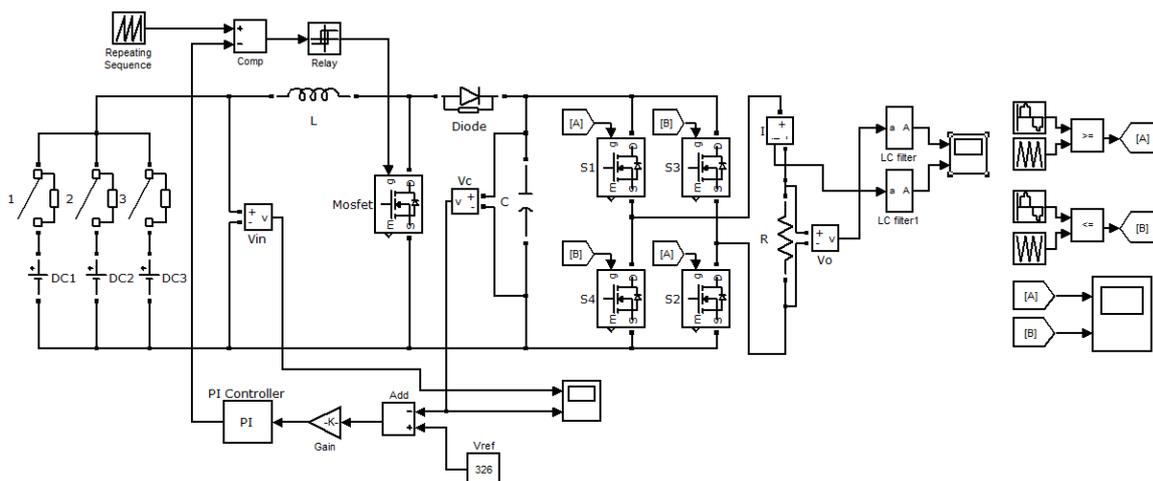
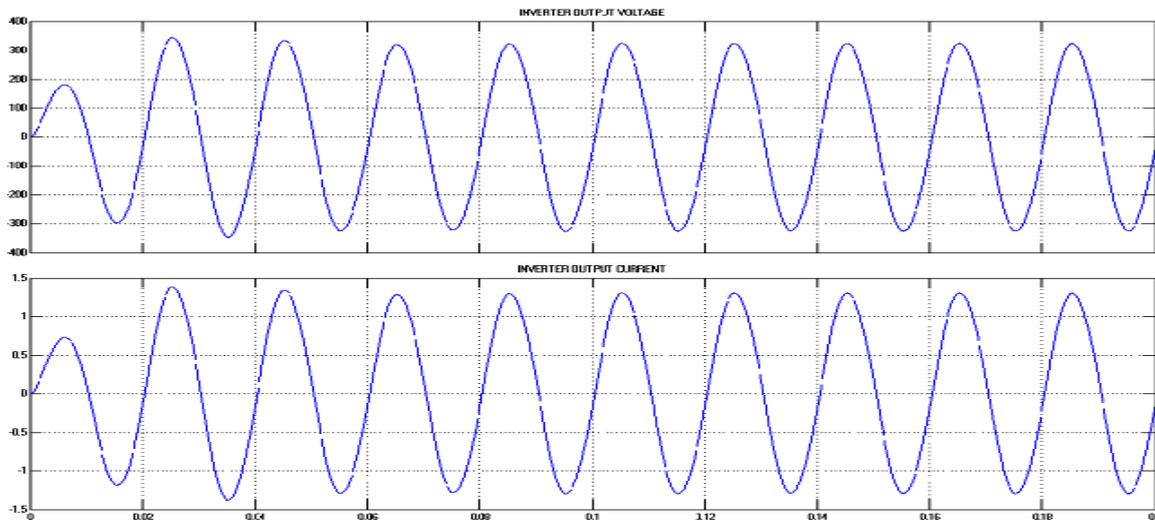


Figure 10. MATLAB model of H-bridge SPWM inverter fed by boost converter



**Figure 11. Output of H-bridge SPWM inverter fed by boost converter**

### VIII. CONCLUSION

From the simulation results using MATLAB simulink for two level SPWM inverter fed by the closed loop boost converter it can be concluded that output voltage does not vary with input voltage. The closed loop system using PWM technique is able to maintain constant voltage and therefore it is suitable to step up and regulate the output voltage of the PV panel. The converters used in the proposed scheme has advantages like good output voltage regulation and it can be implemented with reduced hardware using any suitable microcontroller leads to less cost and small size of the system.

### REFERENCES

- [1] Ned Mohan, Tore M. Undeland, William P. Robbins, "Power Electronics: Converters, Applications and Design", 2nd edition, John Wiley & Sons, pp. 172-178, 1989.
- [2] G.W. Crabtree and N.S. Lewis, "Solar energy conversion", Physics Today, vol. 60, pp. 37-75, 2007.
- [3] M. Nelson, B. Orlando, C. Ricardo, "Development of a Low Cost Induction Motor Drive System using a PVM, Boost Converter and Three-Phase Inverter", pp. 1348-1351, 2011.
- [4] Victor M. Caracas, Luis Felipe M. Teixeira, Guilherme de C. Farias, "Implementation of a High efficiency and low Cost Converter for a Photovoltaic Water Pumping System", pp. 2080-2086, 2012
- [5] Electronics for you, pp. 29-30, Feb.-2012.
- [6] Zhenyu Yu, Arefeen Mohammed, Issa Panahi, "A Review of Three PWM Techniques", Proceedings of the American Control Conference Albuquerque, New Mexico June 1997, pg no. 257-261 (1997).
- [7] Brigitte Hauke, "Basic Calculation of a Boost Converter's Power Stage" Texas instruments Application Report, SLVA372B–November 2009–Revised July 2010.
- [8] Pallavee Bhatnagar, R.K Nema, "Control Techniques Analysis of DC–DC Converter for Photovoltaic application using SIMSCAPE", pg. 978-983, 2012.
- [9] M. Veerachary, "PSIM circuit-oriented simulator model for the nonlinear photovoltaic sources", IEEE Trans. Aerosp. Electron Syst., vol. 42, no. 2, pp. 735–740, April 2006.
- [10] Doo-Yong Jung, Young-Hyok Ji, Sang-Hoon Park, Yong-Chae Jung, and Chung-Yuen Won, "Interleaved Soft-Switching Boost Converter for Photovoltaic Power-Generation System", IEEE transactions on power electronics, vol. 26, no. 4, pp. 1137-1145, April 2011.