DESIGN AND SIMULATION OF SOLAR PV SYSTEM

Kartika Dubey
M.Tech in Electrical Power System
Institute of Technology, Nirma University
Ahmedabad, Gujrat, India.
dubey.kartika@gmail.com

M.T.Shah
Assistant Professor, Department of Electrical Engineering,
Institute of Technology, Nirma University
Ahmedabad, Gujrat, India.
manisha.shah@nirmauni.ac.in

Abstract— **The demand of the electrical power is increasing per day which is supplied by fossil fuels resulting into huge carbon emissions in the atmosphere, which leads the electrical engineers to generate the power by using the renewable energy sources. This paper is aimed at simulation and development of Solar PV system which is able to fulfil the power demand in the isolated locations or in standalone condition. The system consists of various components like PV solar panel, DC-DC converter (Step up converter) and two level inverter connected to load. The controlling of input loop of the solar PV system is shown with the help of PI controller for maintaining the dc link constant irrespective of changes in the input side and output side parameters resulting into the constant inverter output. The simulations are performed in the MATLAB SIMULINK software.**

Keywords—**Solar PV Power Generation, DC-DC Boost Converter, SPWM Technique, MPPT Techniques, Two level Inverter.**

I. INTRODUCTION

The conventional sources like fossil fuels are used to supply the energy demand in the world, which is the most basic cause of generating the carbon contents in the environment. These carbon contents are responsible for the unwanted change in the climate or for Global Warming.

Solar energy is the most efficient renewable energy source if it is efficiently harnessed by the modern technology [1]. In solar PV system, the sunlight is directly converted into the electrical energy. The energy that can be produced by a solar cell basically depends on the intrinsic properties of the cells and the amount of solar radiation which falls on the panel [2]. The typical size of the solar array as well as AC inverter required for solar PV applications depends on the type of loads connected. The energy from the panel can also be stored by using battery storage for later use.

The basic disadvantage of solar PV system is its lower efficiency as panels are hugely dependent on highly unpredictable atmospheric parameters, i.e., the solar radiation and temperature. So, it is bit difficult to extract the maximum power from the panel resulting into reduced efficiency of system. To increase the system efficiency and to extract maximum power from the panels, different MPPT (Maximum Power Point Tracking) techniques are used [3][4].

The power obtained from the PV panel is of fluctuating dc in nature. To convert this value into constant dc value, dc-dc converter (either step up or step down) is used. Other than the boost converter (Step up converter); buck converter (Step down converter), buck-boost converter, SEPIC converter and Cuk converter configurations can also be used. The duty cycle of the dc-dc converter is regulated to vary the load impedance as seen by the source, to match point of the maximum value of power of the source in order to transfer the maximum power of the panel to the load [4]. Thus, using MPPT techniques the PV array is made to operate on MPP (Maximum Power Point). There are many MPPT techniques used like: Perturb and Observe (P&O) method, Incremental Conductance (IC) method, Fuzzy Logic Method, Constant Voltage method, etc. [5]. The most simplest technique amongst them is P&O method which is used mostly, as it provides fast tracking of MPP and it have easy algorithm to implement [6][7][8]. But in this paper, in spite of using the MPPT technique to control the switching of boost converter, simple PI controller is used to maintain the constant dc link voltage by controlling the converter duty cycle.

The panel voltage and current obtained are dc quantity, which should be converted into ac quantity by means of inverters to feed the ac loads or for grid connection. The solar PV systems are of two types: Grid-connected system and Standalone-system. In the grid connected system, the solar PV system will supply the power to the connected grid along with the loads connected to it. The grid connected solar PV inverters used can have different configurations like: Central inverters, String inverters and Multi-String inverters. The central inverter configuration is the simplest one having main drawback that when different solar irradiation falls on the module then the strings of the panel will operate at different MPPs. The string inverters have advantage of operating at common MPP even for different irradiance value. The selection of inverter configuration is based on the cost, power requirement and the area of project. In the Standalone system, the solar PV system will feed the loads which are directly connected to it. Both of the systems are capable of feeding ac and dc both types of the load. The standalone systems are mostly preferred for household applications.

II. SOLAR PV SYSTEM

The technology of Solar PV is mostly used now-a-days. The characteristic of all solar panels depends on the two important

atmospheric parameters: Temperature and Solar irradiation. The I-V and P-V characteristic of solar array is shown in Fig. 1, having constant temperature of 25^0C and different solar irradiations of 1.2kW/m^2, 1kW/m^2 and 0.8kW/m^2. As the irradiance is increased the current across the panel is increasing significantly having almost insignificant change in the voltage, resulting into the increase in the power produced. Thus, more the solar irradiation more will be the power produced.
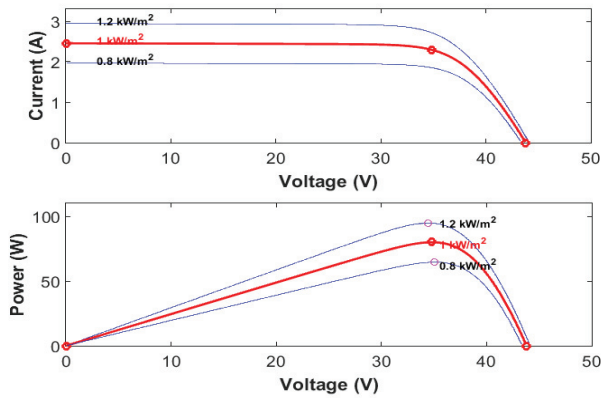

Fig 1: I-V and P-V characteristics of PV Array at constant temperature of 25^0C and varying solar irradiation

The I-V and P-V characteristics of solar array having changing temperatures and constant irradiation of 1000W/m^2 and different temperature of 65^0C, 45^0C and 25^0C is shown in the Fig. 2. The voltage reduces with the increase in the temperature having insignificant change in current, which reduces the power of the array. So, at very high temperature the array does not work efficiently and will not produce high power.
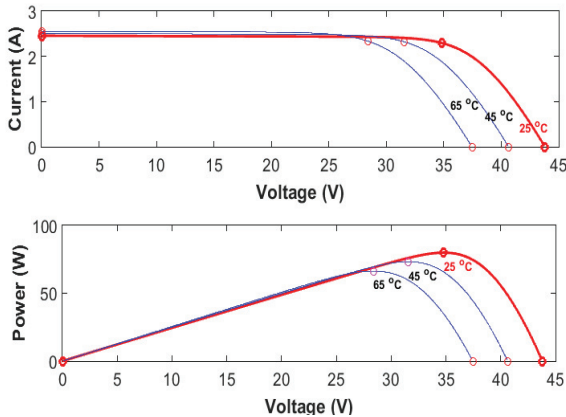

Fig 2: I-V and P-V Characteristics of PV array at constant solar irradiation of 1000W/m^2 and varying temperature

III. SYSTEM DESCRIPTION

The solar PV system consists of mainly two power electronic components: boost converter and inverter. The block diagram of close loop solar PV system having interconnected power electronic components is shown in Fig. 3, where boost converter will convert the fluctuating dc obtained from PV panel into constant dc value and the inverter will convert this

constant dc value into ac value which is compatible for the connected ac loads.

The system parameters like dc link voltage and inverter output voltage will change, as the output parameters (loads) as well as input parameters (solar radiation and temperature) are changed which is not required and accepted. To obtain the controlled system the switching of power electronic devices are changed and PI controllers are used. The entire system diagram for the close loop system is shown in the Fig. 4, for standalone system.
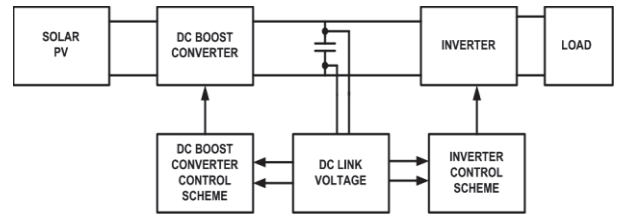

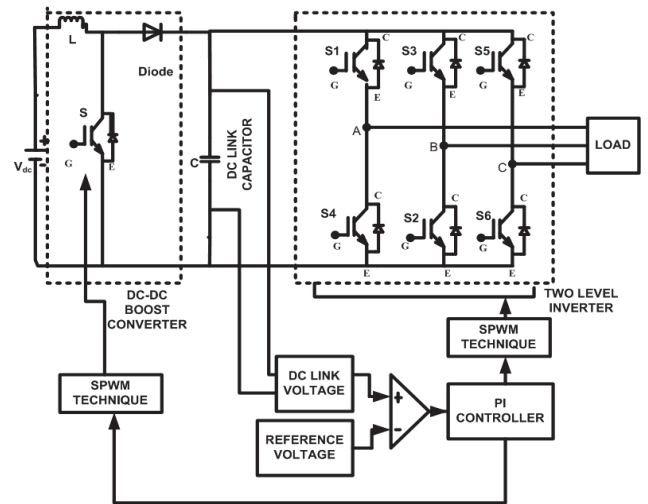Fig 3: Block diagram of close loop solar PV system

Fig 4: Entire block diagram of close loop solar PV system with system components.

A. Boost Converter

The important functions of various dc-dc converters are mentioned as follows:

- To convert the fluctuating input dc voltage into constant output dc voltage.
- To reduce the amount of voltage ripple in the output voltage.
- To regulate and maintain the dc output voltage against the variations or fluctuations in load and line.
- To isolate the input source and the load.

When the voltage at the input side is not sufficient then the value of output voltage is increased to the certain required level. For this purpose boost converters are used having

converter has an inductor, a switch (usually IGBT or MOSFET), diode and a capacitor. The Fig. 5 shows the basic diagram of dc to dc boost converter.
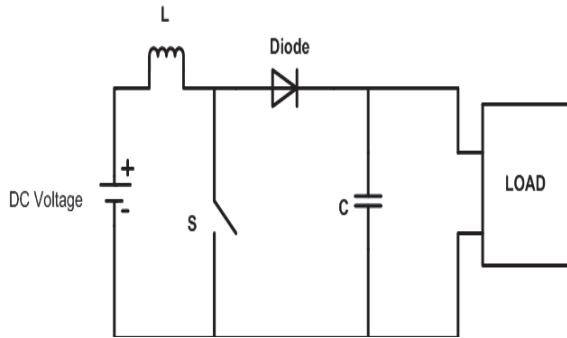

Fig 5: Boost converter

➢ **Calculation of Inductor Value:**

Given parameters:
      Panel Output Current, I_{panel} = 2A
      Input Voltage, V_{in} = 34V

Assume:
      Switching frequency, f_s = 20 kHz.
      Duty Ratio, D = 0.5
      Δi_L = 10% of I_{panel} = 0.2A

The voltage obtained at the output of the boost converter is calculated by using (1):

$$V_0 = \frac{V_i}{1-D} = 68V \qquad (1)$$

The inductor value is calculated by using (2):

$$L = \frac{V_{in} * D}{\Delta i_L * f_s} = 4.25mH \qquad (2)$$

The value for capacitor is taken as standard value equals to 4700µF. The capacitor value is decided so that the ripples in output voltage of boost converter are lesser in the desirable limit. The entire simulation is performed considering these values of inductor and capacitor.

B. Inverter

    The main function of voltage source inverter is to convert a fixed dc quantity into three phase ac voltage having variable magnitude and fixed frequency which are compatible for the ac load applications. The basic diagram of three phase voltage source inverter is shown in the Fig. 6. The IGBT's are used as switches. In this paper, the gate pulses given to the inverter switch are generated by using SPWM switching technique.
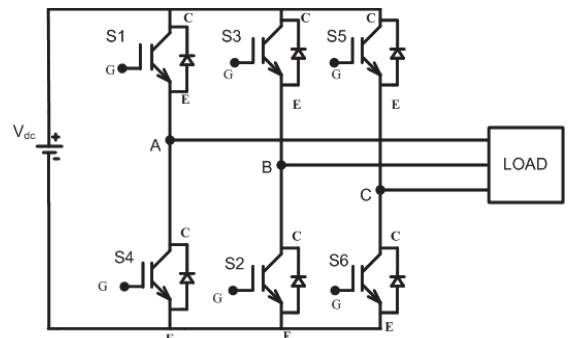

Fig 6: Three phase voltage source inverter

    The PWM techniques basically results into the reduced THD and controlled output voltage of the system. The SPWM switching technique allows controlling of magnitude and frequency of the output voltage. In SPWM scheme, triangular carrier wave having high frequency is compared with a sinusoidal modulating signal. The peak magnitude of the modulating signal is less than the peak magnitude of the carrier signal. The SPWM techniques have two operating modes: Unipolar and Bipolar. The unipolar operation is preferred because it gives less input ripple current. The pulses are obtained as the output of the comparator which is then applied to the gate of the IGBTs for driving IGBT switches [10][11]. The generation of pulses using SPWM technique is shown in Fig. 7. The parameters considered for SPWM pulse generation are: amplitude of reference sine wave and carrier wave is 0.8 and 1 respectively and the switching frequency of reference wave and carrier wave is 50 Hz and 1 kHz respectively. Thus, the amplitude modulation index is 0.8. The modulation index less than 1 provides better controlling of the output rms voltage.
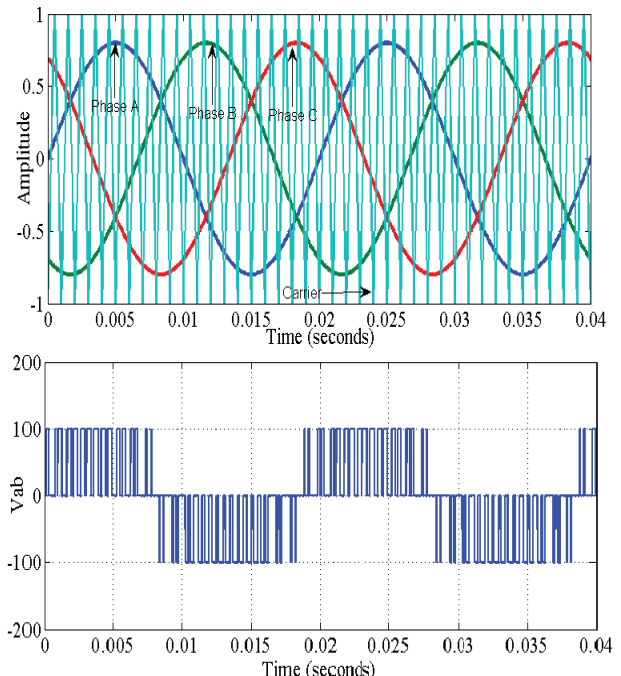

Fig 7: Unipolar sinusoidal pulse-width modulation (SPWM) technique and line-to-line Voltage (Vab)

C. Boost Converter Control Scheme

The changing input parameters tends to change the change of dc link voltage as shown in Fig. 12 and the inverter output voltage. The voltage across the dc link should remain constant for having controlled system and better result at the output side. The input side controlling of the system is done by using PI controller in the input loop by tuning the value of controller to maintain the dc link constant throughout the operation. Thus, other than the MPPT technique, the input loop can also be controlled by simply using PI controller at the input side. The control scheme of boost converter is shown in the Fig. 8.
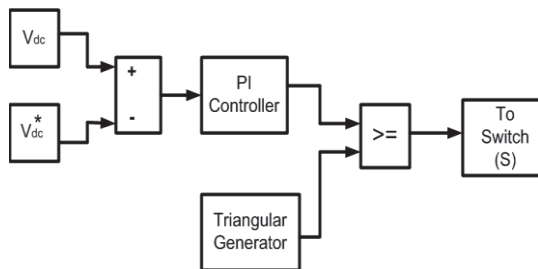

Fig 8: Boost converter control scheme

The actual dc link voltage is sensed and compared with reference value. The error is sent to the PI controller. The output obtained from PI controller is then compared with the triangular generator for generating the pulse which will then fed to the boost converter switch.

D. Inverter Control Scheme

The inverter output voltage is also affected by the variation in system parameters. Thus, the inverter output is also maintained to a constant value.
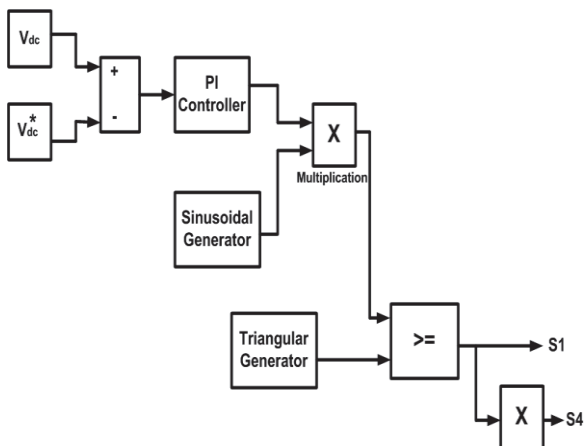

Fig 9: Inverter control scheme

Fig. 9 shows the control scheme for one leg of inverter to control the output side of the system. The voltage across the dc link is sensed and compared with the reference value. The error produced is sent to PI controller. The PI output obtained will be a dc quantity. This dc quantity is multiplied by the sinusoidal value to convert it into ac value which is then compared with the triangular wave for producing pulses for inverter switches.

Similarly, we can implement this scheme for the other two legs of inverter.

IV. SIMULATION RESULTS

The simulation is performed in order to analyze the behavior of the solar PV system having changes at its input and output side. The entire simulation is performed in the MATLAB Simulink software and the results are shown below. The open loop system, when operated on constant input and output parameters produces the output voltage across boost converter and inverter as shown in Fig. 10 and Fig. 11. The open loop offers no controlling of the system output with respect to change in input and output parameters.
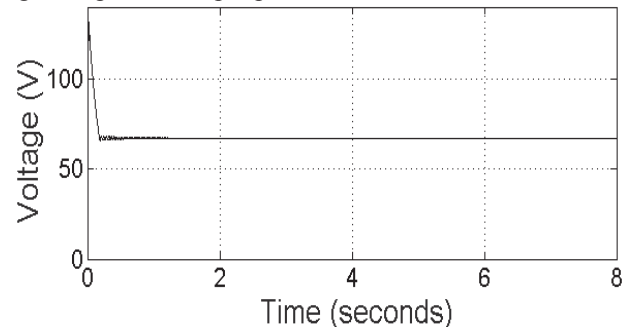

Fig 10: Output voltage of boost converter with constant load
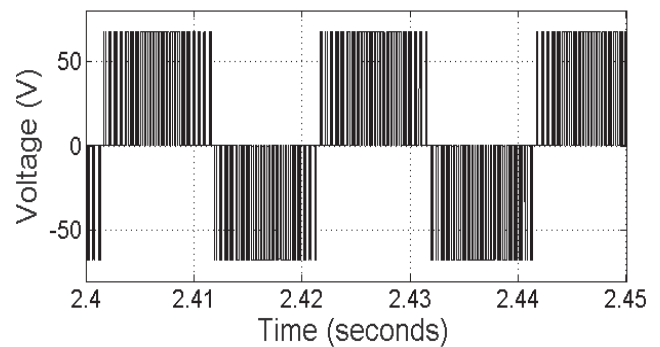

Fig 11: Output voltage of inverter with constant load

When the load is changed in the system with no close loop feedback at 2 and 4 seconds then the dc link voltage will change as shown in Fig. 12, which results into unwanted change in the inverter output voltage. Fig. 13 shows the change in load current with change in load, as the load is increased in parallel in the system the load current is increasing.
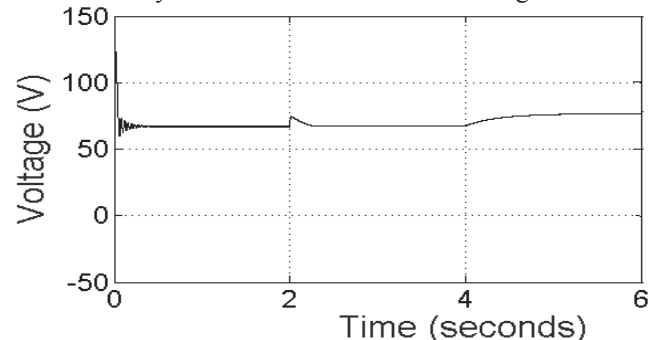

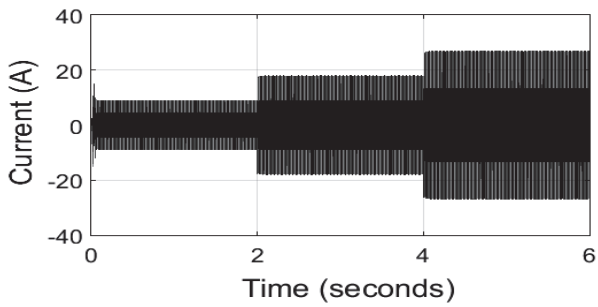**Fig 12: Change in DC link voltage with change in load without PI controller**

Fig 13: Output load current with change in load at 2sec and 4sec without PI controller

The entire close loop system as shown in Fig. 4, shows the controlling of system from both the sides. It is seen that as the input and output parameters of the solar PV system are changed, the dc link voltage and the inverter output current changes. In order to have the controlled system the different switching control schemes for input loop and output loop are used as shown in Fig. 8 and Fig. 9.

The output side controlling is required to make system output voltage constant irrespective of the load change and the controlling is done by using the inverter control scheme as shown in Fig. 9. After implementation of the close loop the dc link voltage obtained is now constant as shown in Fig. 14 and the inverter output voltage is shown in Fig. 15. The simulation is performed for R-load and load is changed at 2 and 4 seconds respectively.
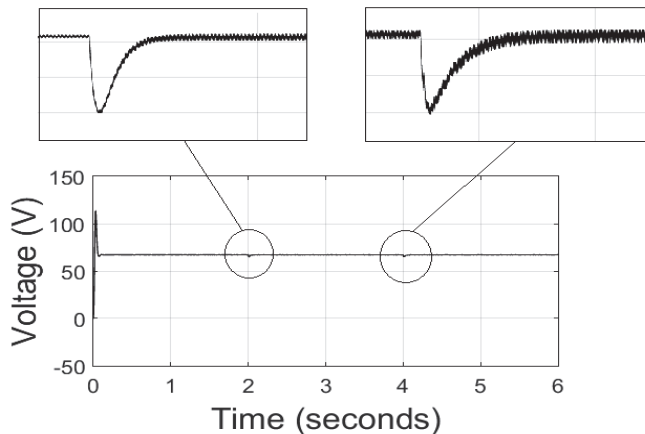

Fig 14: DC link voltage with load change (2sec and 4sec) with PI controller at output side
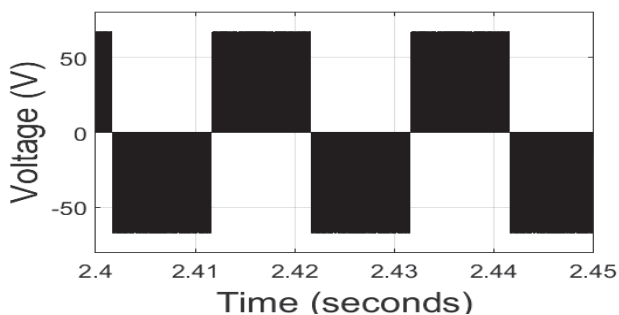

Fig 15: Inverter output voltage with change in load with PI controller at output side

The input side controlling is required to have system dc link constant irrespective of the change in input parameter and the controlling is done by using the boost converter control scheme as shown in Fig. 8. Considering the RL-load in the system with no load change, the following results are obtained after controlling the input side. The constant dc link voltage is obtained giving constant inverter output voltage as shown in Fig. 16 and Fig. 17.
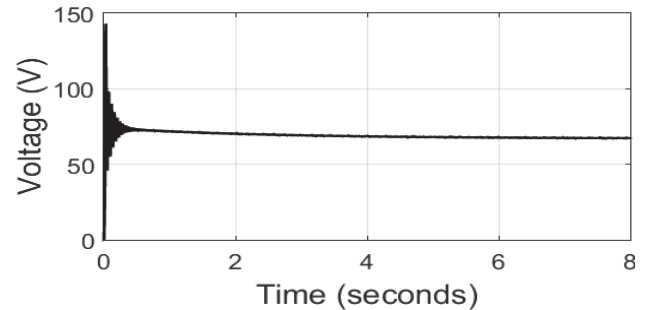

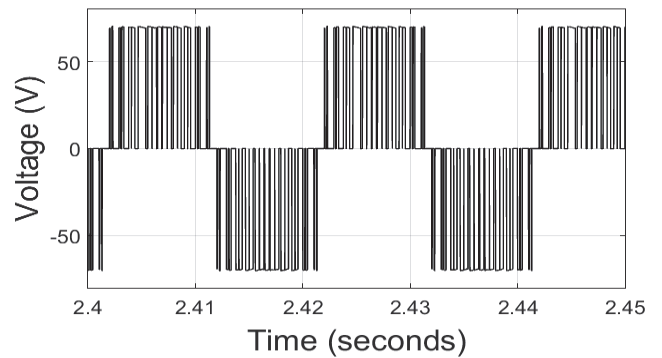**Fig 16: DC link voltage waveform with PI controller at input side**

Fig 17: Output voltage waveforms of the inverter with PI controller at input side

The output current obtained is also sinusoidal in nature which is compatible for the ac loads, as shown in Fig. 18.
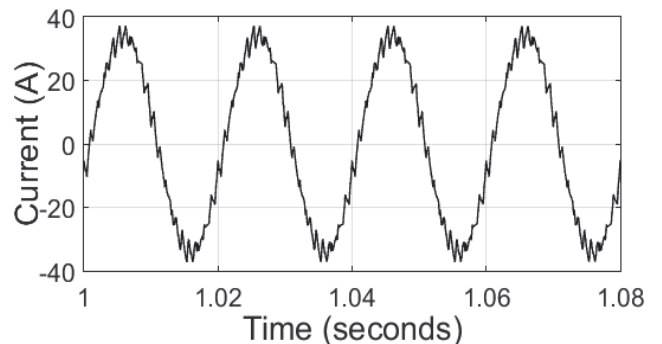

Fig 18: Output load current waveform of inverter having RL-load with PI controller at input side

The change in input parameters of the system is considered by varying the input voltage of the boost converter. The simulation results obtained for the inverter output voltage and load current is obtained almost same as that shown in Fig. 17 and Fig. 18 above. The variation in dc link voltage will occur when the input voltage will be changed which is shown in

Table. 1. The reference voltage is 34 V and the variation taken is of 8 V, considering step size of two units. The result obtained shows that the change in dc link voltage is only in between the ripple of 3 V, for the range of variation in the input voltage of about 8 V.

TABLE I. VARIATION IN DC LINK VOLTAGE WITH RESPECT TO THE VARYING INPUT VOLTAGE

S.No.	INPUT VOLTAGE (in Volts)	DC LINK VOLTAGE (in Volts)
1	30	64.67
2	32	65.98
3	34	67.34
4	36	68.88
5	38	69.24

The above results were for the loops operating individually. Now both the loops are combined for the controlled solar PV system. The R-load is considered and the load is allowed to change at the 2 and 6 seconds. The results obtained are shown in Fig. 19 and Fig. 20.
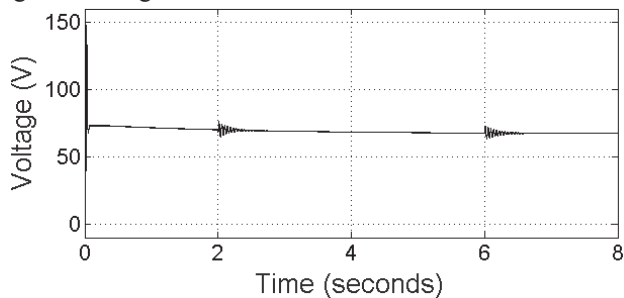

Fig 19: DC link voltage of entire system with change in load at 2sec and 6sec with PI controller

The inverter output voltage will also fluctuate at 2 sec and 6 sec due to the fluctuation in dc link voltage because of load change. But after the implementation of PI controller the entire system produces the constant voltage at the output with some of the mild fluctuations occurring at time instant when the load changes as shown in Fig. 20 below.
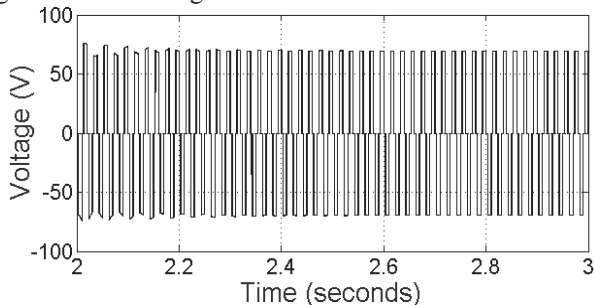

Fig 20: Inverter output voltage of entire system with change in load with PI controller

CONCLUSION

Power generated by solar PV panel always fluctuates due to the fluctuation in panel voltage and current which mainly occurs because of the changes occurred in load, resulting into unwanted system behavior. In this paper, the simulation results of the uncontrolled solar PV system and the controlled solar PV system have been discussed. The proposed control technique having PI controller in both the input and output control loops gives utmost stability as compared to an uncontrolled PV system. Also, the proposed system is much simpler to understand and easy to implement, when compared with the other input loop controlling techniques. The simulation results verify the system stability, with change in the load as well as input parameters. For load variations, constant value of dc link voltage is obtained having ripple of 1 V within 0.6 sec. It has been concluded from the table that the variation in the input parameters also leads to the constant dc link voltage. Thus, the results shown above, gives the required dc link voltage as well as the output voltage, which can be further used to feed various ac and dc loads.

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