PRACTICAL IMPLEMENTATION AND COMPARISON OF AN EMBEDDED CONTROLLED INTERLEAVED BOOST CONVERTER WITH CONVENTIONAL BOOST CONVERTER FOR SOLAR INSTALLATION SYSTEM

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ABSTRACT

This paper proposes a practical implementation of two stage interleaved boost converter for solar installation system. The topology study of open loop and closed loop systems with step-up conversion and step increase in input voltage are proposed. The proposed converter is modeled and simulated using matlab/Simulink and it is implemented using embedded controller. The performance of the converter is compared with the conventional boost converter. This comparison reveals that the present converter system has the advantages of high efficiency and reduced switching stress.

Keywords: Closed loop, Embedded control, Interleaved boost converter, Matlab, Simulation, Solar.

I. INTRODUCTION

Lot of research work has been conducted in the area of generation of electricity using PV cells. Photovoltaic is the technology that uses solar cells to convert solar light directly into electricity. The power produced by the array depends directly on the factors that are not controlled by the human being such as the cell's temperature and solar irradiance. Usually the energy generated by these solar cells is used to provide electricity to a load and the remaining energy is saved in batteries. Photovoltaic cells have a single operating point where the values of the current and voltage result in maximum power output. These values correspond to a particular resistance which is equal to the division of the maximum voltage and maximum current. By connecting the PV cell directly to a load or a battery, the output power can be severely reduced due to load mismatching. Since this operating point depends on factors like temperature, solar irradiance and load impedance, a device capable of tracking the maximum power operating point and force the photovoltaic module to operate at that maximum point is required. A maximum power point tracker is a device capable of searching the maximum power point and, using DC-DC converters, extracts the maximum power available by the cell. By controlling the duty cycle ratio and converter switching frequency, we can change the equivalent voltage of the PV cell and its equivalent resistance into one in which the photovoltaic module is in the maximum power operating point.

The DC-DC converter designs are being investigated as they form major parts of uninterrupted power supplies (UPS), renewable energy systems, communication systems and industrial operations [1]-[3]. DC-DC converters are used in renewable energy systems to step up the low battery voltage or electric storage devices voltage to high voltage levels required by the loads. To raise the conversion efficiency, many modified boost converter topologies have been investigated by several researchers [14],[16]. Some of the main factors to be considered while designing DC converters for solar energy systems are the voltage gain, output power and the ease of design.

The conventional boost converters cannot provide the required gains even with maximum duty cycles [4]. Other topologies such as flyback converters can be suggested. However, they can't be used in energy systems as they have low power ratings below 100 watt [5]. As a result, modified boost designs such as the half and full bridge converters can be used. Looking at the disadvantages of these converters, due to the use of transformer it delivers lower efficiency [6]-[11].

The above literatures do not deal with embedded implementation of interleaved boost converter system for solar installation. The present work is modeling and simulation of two stage interleaved DC to DC boost converter. All switching converters draw a source current with small amount of superimposed ripple. The amplitude of the ripple can be reduced by operating the converter at high switching frequency but, when switching frequency is increased, it will increase the switching losses. In order to maintain the efficiency at satisfactory levels, several modifications, such as interleaved boost configuration have been proposed. The main advantage is that the ripple of the input can be greatly reduced without resorting to high frequency switching, as long as the gating signal to the individual switches are properly turned on and off. This work makes an attempt to implement the interleaved boost converter using 89C2051 controller.

A. Photovoltaic Cell

Photons of light with energy higher than the band-gap energy of PV material can make electrons in the material break free from atoms that hold them and create hole-electron pairs. These electrons, however, will soon fall back into holes causing charge carriers to disappear. If a nearby electric field is provided, those in the conduction band can be continuously swept away from holes toward a metallic contact where they will emerge as an electric current. The electric field within the semiconductor itself at the junction between two regions of crystals of different type, called a p-n junction [12-13]. The PV cell has electrical contacts on its top and bottom to capture the electrons. When the PV cell delivers power to the load, the electrons flow out of the n-side into the connecting wire, through the load, and back to the p-side where they recombine with holes [13]. Note that the conventional current flows in the opposite direction from electrons.

B. Modeling of PV Cell

In the past, there have been different types of models to estimate the non-linear equations of the photovoltaic module. Some of these models are the Anderson's, Bleasser and, the most common, the one diode model. All these models present a good approach into estimating the solar cell voltage and currents, but most of them need too much computational power or need information not available in the manufacturer's sheet. A more suitable model to simulate a PV module is proposed by [14]-[15]. The equivalent circuit of simplest model of a PV cell is shown in Fig 1. It has parallel connected ideal current source with an ideal diode. The current generated by photons is representing by the current source I_{LG} or I_{ph} and its output is constant under constant incident radiation of light and constant temperature. To characterize a PV cell two key parameters are frequently used. Shorting together the terminals of the PV cell, as shown in fig. 1, the photon generated current I_{LG} or I_{ph} will flow out of the cell as a short-circuit current (I_{sc}). Thus, $I_{ph} = I_{sc}$. As shown in fig. 1, when there is no connection to the PV cell (open-circuit), the current generated by the PV cell is shunted internally by the intrinsic p-n junction diode. It results the open circuit voltage (V_{oc}).

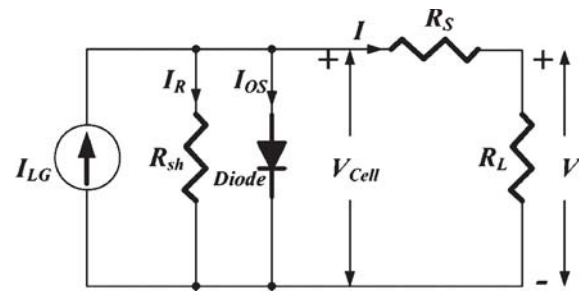

Fig. 1. Model of PV cell

Under illumination, the cell may be represented by an equivalent circuit, based on a single-diode model, as shown in fig. 1. It is described as a current source in parallel with the junction as shown in equation (1):

$$I = I_{LG} - I_{OS}\{\exp[q(V + I_n R_s)/AkT - 1\} - (V + I_n R_s)/R_{sh} \quad (1)$$

$$I_{LG} = [I_{SCR} + K_I\ (T - T_r)]\ \lambda\ /\ 1000 \quad (2)$$

$$I_{OS} = I_{OR}\ [T/T_r]^3 \exp\ [qE_{GO}\ (1/T_r - 1/T)/BK] \quad (3)$$

where I and V are cell output current and voltage. I_{os} is cell reverse saturation current, T is cell temperature in ^{0}C, k is Boltzmann's constant, q is electronic charge, K_1 (= 0.0017) short-circuit current temperature coefficient at I_{SCR}, A is solar irradiation in W/m^2, I_{SCR} is short-circuit current at 25^{0}C and 1000 W/mi, I_{LG} is light-generated current, E_{GO} is band gap for silicon. B = A (= 19.2) are the ideality factors, T_r *(= 301.180 K)* is reference temperature, I_{OR} is cell saturation current at *T,* R_{sh} is shunt resistance and R is series resistance.

The PV output voltage is mainly affect by the temperature change, while the he PV output current is mainly affect by the irradiation changes. The operating point of the PV cell is determine by intersection of the load-line with the PV module I-V characteristic, for a given temperature and irradiation. The maximum power production point P_{max} is based on the load-line adjustment under varying atmospheric conditions. Switch mode DC to DC converters are used to match a PV generator output to a variable load. A practical photovoltaic energy conversion system block diagram is shown in Fig. 2.

C. Design Analysis

The equations used in the interleaved boost converter are as follows:

An expression used to calculate the inductor values can be obtained by performing an energy-balance analysis.

The current ripple $\Delta I_L = V_{pv} (V_o\text{-}V_{pv}) / f_s * L * V_o$ (4)

where $L_1 = L_2 = L$.

The inductor $L = V_{pv} * D / \Delta I_L * f_s$ (5)

The capacitor $C = I_o * D/f_s * \Delta V_c$ (6)

The input current delivered by the PV cells at full power

$I_{pv} = P_o / V_{pv} * \eta$ (7)

The average current I_{SAVE} through each switch in two interleaved stages $I_{SAVE} = I_{pv} * (1\text{-}D) / P_o$ (8)

where V_{pv} is the input voltage, L is the inductance and f_s is the switching frequency and D is the duty cycle of the interleaved boost converter.

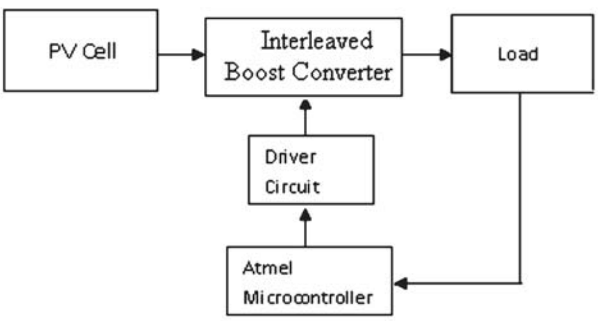

Fig. 2. Block Diagram of PV Installation system

II. INTERLEAVED BOOST CONVERTER

A boost converter draws an almost constant current from the source, without requiring further stages. The magnitude of the current with ripple at the switching frequency *fs*, can be greatly minimized by using the interleaved configuration shown in Fig. 3. The switches are turned on and off with 180° phase shift between each other for proper operation of the boost converter. The supply current is divided equally between the paralleled stages. Therefore, for the same output power, an interleaved boost converter requires devices with a lower current rating than the conventional boost converter.

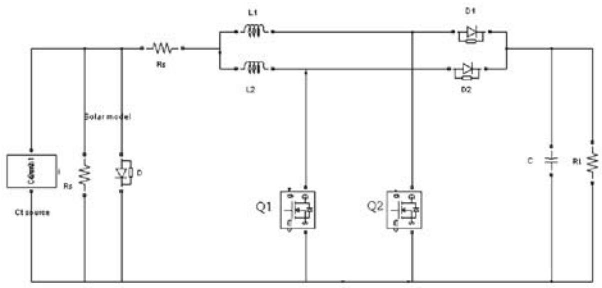

Fig. 3. Interleaved boost converter

III. SIMULATION RESULTS

The Simulink model of an interleaved DC to DC boost converter for solar installation system is shown in Fig. 4. Simulation of the interleaved boost converter was carried out with the following parameters. V_{in} = 12 V to 17 V, Vo = 60 V, L = 25% H, C = 3.6 μ F and R_L = 100 Ω.

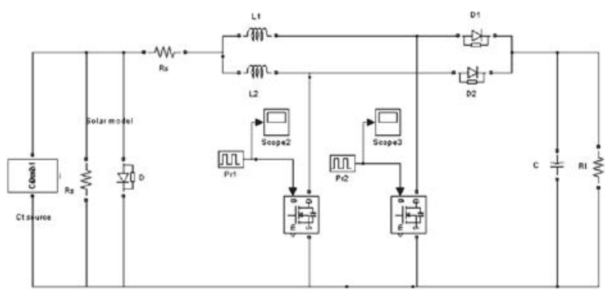

Fig. 4. Interleaved DC to DC boost converter

V_{in} of 12 volts is applied as input voltage in normal condition which is shown in Fig. 5. and V_{in} of 17 volts is applied as input while assuming external disturbance in the PV panel.

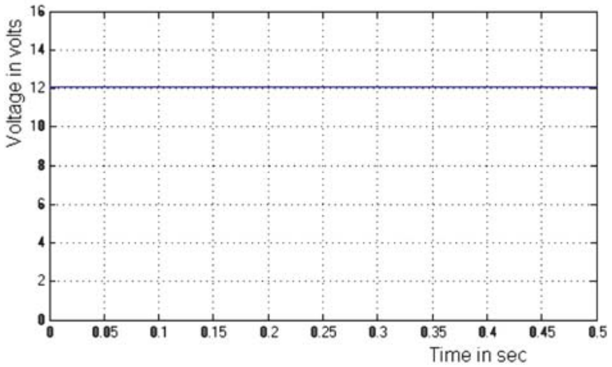

Fig. 5. Input voltage

The driving pulses of the MOSFETs are shown in Fig. 6. The pulse applied to the switch is 180° out of phase.

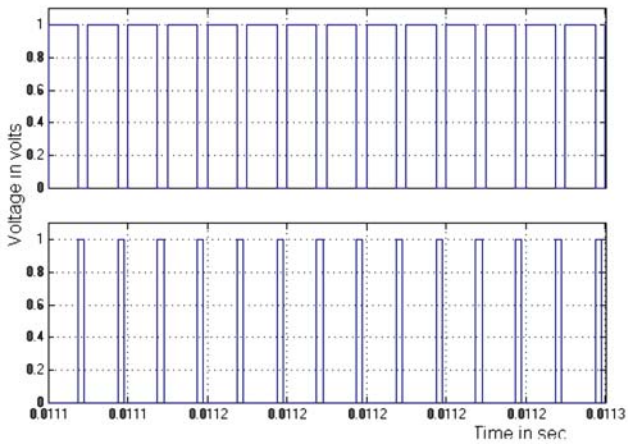

Fig. 6. Driving pulses for switches

The input current flow through the circuit is shown in Fig. 7. which average value is 2.85 A.

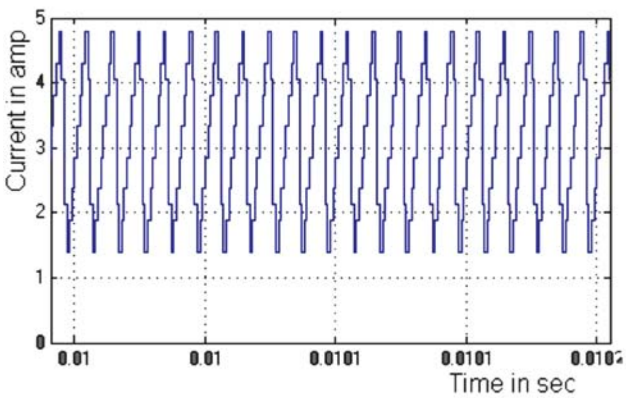

Fig. 7. Input current

The output current is shown in Fig. 2.(e) which is 0.6 A. The output current reaches its steady state value at 1 msec. The rise time of the current is 0.56 msec.

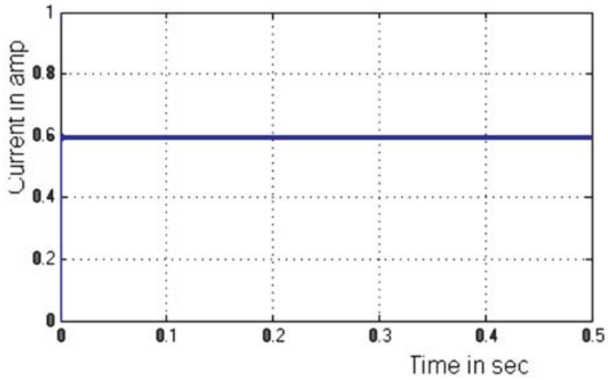

Fig. 8. Output current

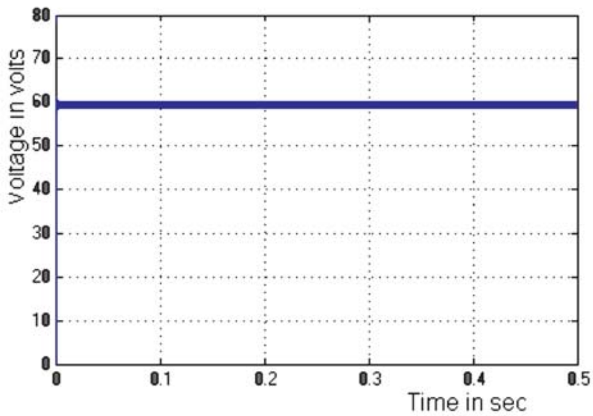

Fig. 9. DC Output voltage

The DC output voltage is shown in Fig 9. Steady state value of output voltage is 60 V.

A. Time Response Analysis

The time response specifications of the output voltage are analyzed.

Rise time is 0.56 msec, peak time is 0.61 msec, and settling time is 2 msec. There is no delay in the output voltage.

The open loop system with disturbance is shown in Fig. 10. In this open loop system an external disturbance of 5 V is applied with the input voltage at 0.2 sec.

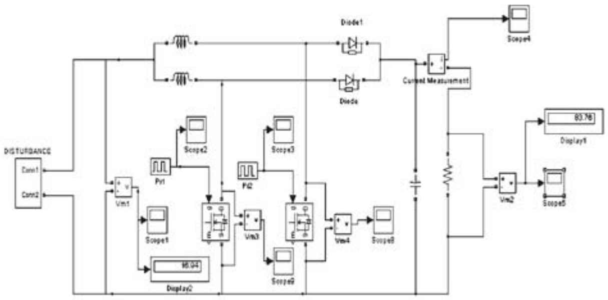

Fig. 10. Open loop Improved DC to DC boost converter with external disturbance

The input and output voltages of the open loop system with disturbances are shown in Figs. 11 and 12 respectively. 12 V is applied as input till 0.2 sec so the converter produces an output voltage of 60 V. At 0.2 sec with the 12 V input voltage, 5 V is added as disturbance in the input side. At 0.2 sec, the output voltage increases from 60 V to 83.76 V for the 17 V input.

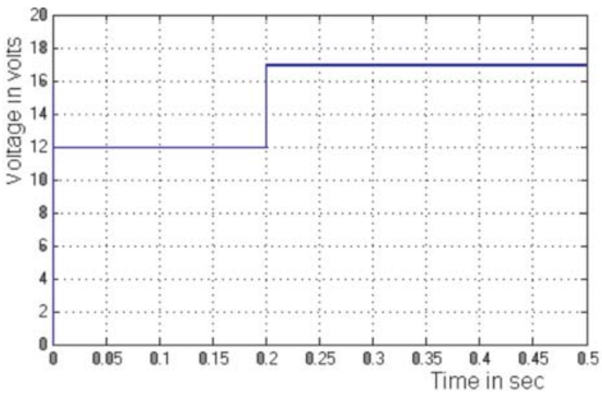

Fig. 11. Input voltage with disturbance of open loop system

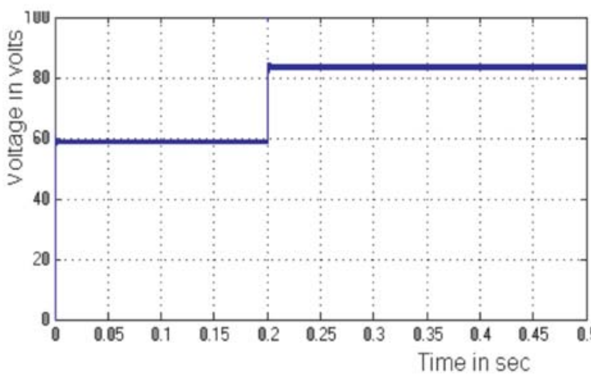

Fig. 12. Output voltage with disturbance of open loop system

The closed loop system with disturbance is shown in Fig. 13. The closed loop system is designed to provide constant output voltage for a step change in output voltage.

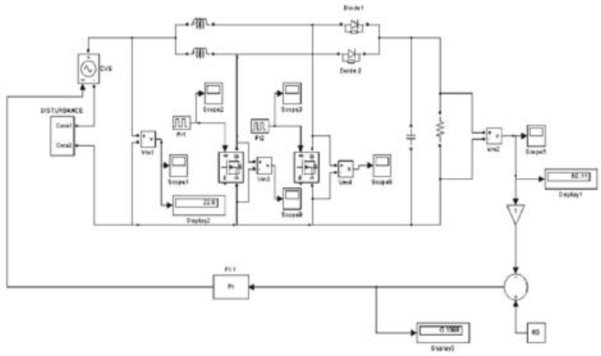

Fig. 13. Closed loop Interleaved DC to DC boost converter with external disturbance.

The input and output voltages with disturbance of the closed loop converter are shown in Figs. 14 and 15 respectively. Till 0.2 sec the output voltage of the converter is 60 V for the input of 12 V. At 0.2 sec the input voltage increases from 12 V to 17 V due to the external disturbance. Hence the output voltage increases from 60 V to 83.76 V. Output voltage is sensed and it is compared with a reference voltage. Then the error is processed by a PI controller. The output of PI controller adjusts the pulse width to maintain the constant output voltage of 60 V. Thus the output voltage reduces and reaches the steady state set value of 60 V at 0.3 sec.

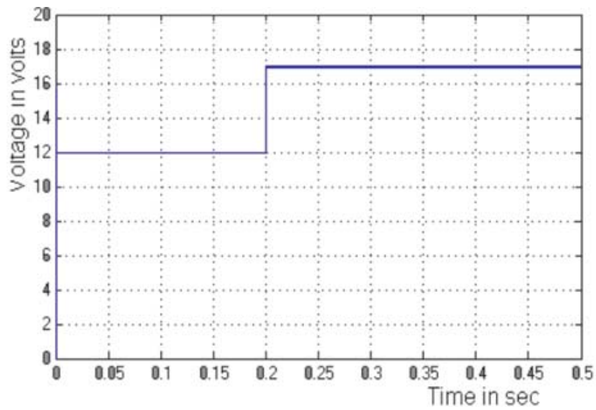

Fig. 14. Input voltage with disturbance

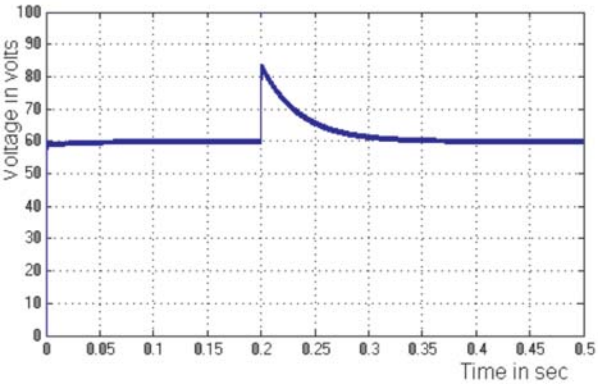

Fig. 15. Output voltage with disturbance of closed loop system

B. Performance Comparison Analysis

The performance of the proposed boost converter is compared with the performance of the conventional boost converter and the comparison is presented in table I. The proposed and conventional converter performances in open loop system are analysed for different input voltages.

Table I Performance Analysis

Input voltage (V)	Output voltage (V)		Efficiency (%)	
	Conventional converter	Interleaved boost converter	Conventional converter	Interleaved boost converter
10	24.84	49.66	69.51	89.07
12	28.99	60.11	69.69	89.6
14	33.82	69.64	71.01	89.56
16	38.19	79.17	70.88	89.70
18	43.26	90.14	71.09	89.8

The input verses output voltage comparison of the proposed and conventional boost converter is shown in Fig. 16. For the input of 12 V the conventional boost converter can produce 28.99 V but the proposed converter produces 60.11 V. This voltage is much higher than the output of conventional boost converter. However, in closed loop system, the proposed interleaved boost converter maintains constant output voltage for a step change in input voltage.

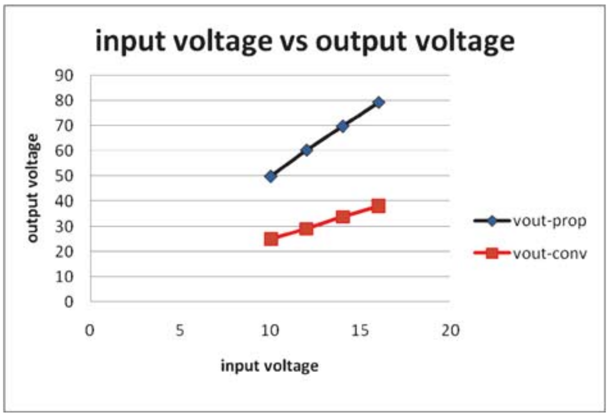

Fig 16. Input Vs Output voltage

The input voltage verses output power comparison is shown in Fig. 17. and input voltage verses efficiency comparison is shown in Fig 18. For the input of 12 V, the conventional boost converter can deliver an output power of 8.28 W but the proposed converter can deliver an output power of 35.4 W. For the same input of 12 V the efficiency of the conventional boost converter is 69.69% only but the proposed boost converter can give an efficiency of 89.6%. This is almost 20% higher than the conventional boost converter efficiency.

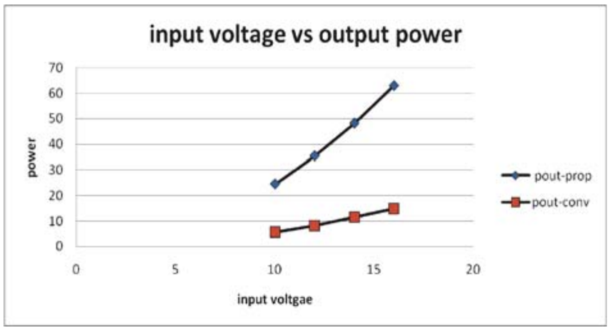

Fig. 17. Input voltage Vs Output power

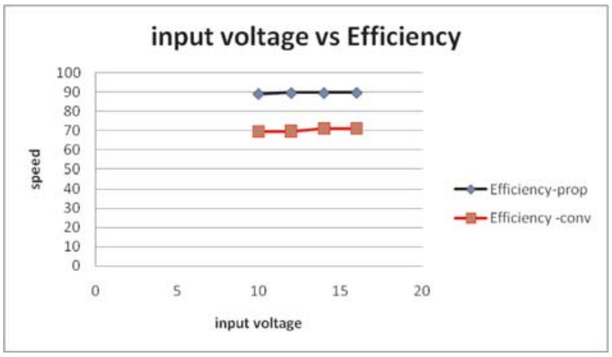

Fig. 18. Input voltage Vs Efficiency

The output power verses efficiency comparison is shown in Fig. 19. The conventional boost converter gives efficiency in the range of 70% but the proposed converter can give an efficiency of 90%.

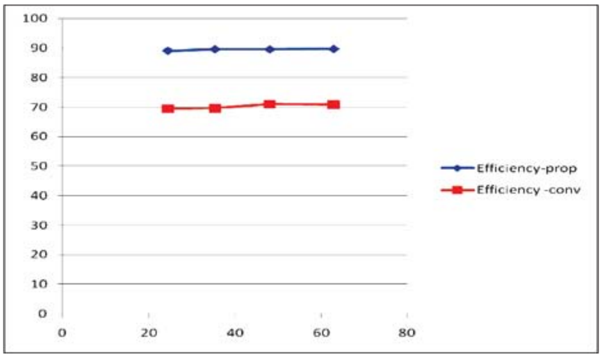

Fig. 19. Output power Vs Efficiency

The above results confirm that the interleaved boost converter has better performance efficiency than conventional boost converter.

IV. EXPERIMENTAL RESULTS

In order to verify the circuit operation and confirm the simulation results, a prototype is built and tested in laboratory. The hardware implementation is shown fig. 20. The solar panel input is applied to the converter circuit. The switches are turned on and off by the pulse driver circuit.

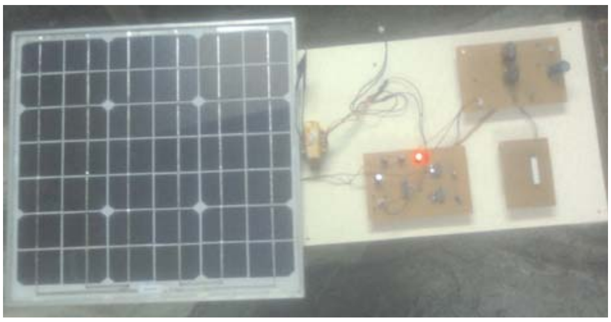

Fig. 20. Hardware Circuit

The Embedded controller based driver circuit is shown in fig. 21. The output pulse from the controller is amplified using the driver chip IR 2110.

The driving pulses applied to the MOSFETs are shown in Fig. 22. From the Figures 6. and 22, it can be seen that the experimental results are almost similar to the simulation results.

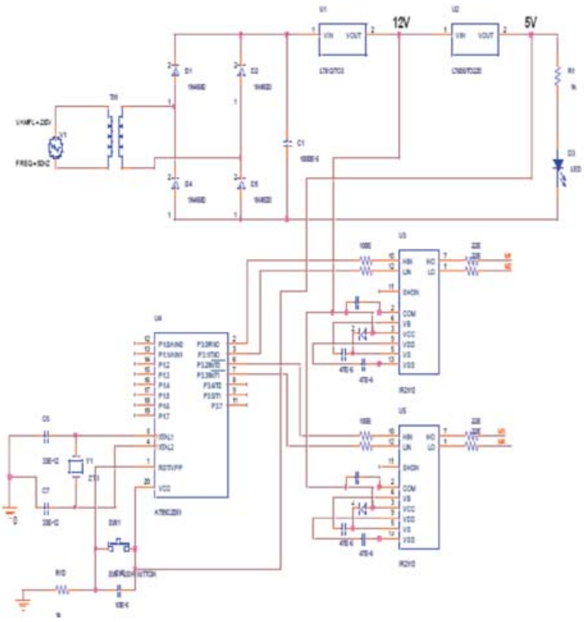

Fig. 21. Control circuit

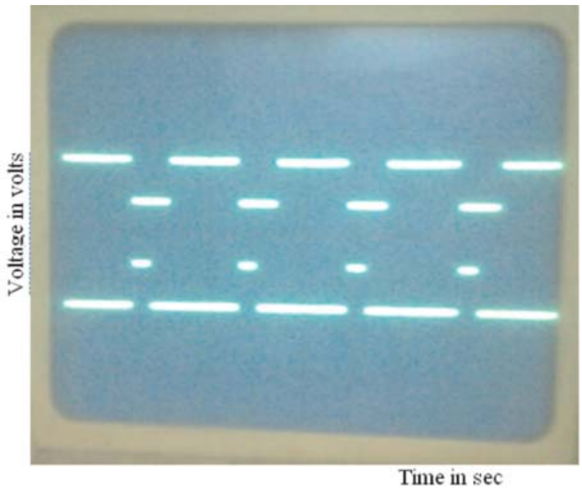

Fig. 22. Driving pulses

The input voltage applied to the converter is shown in Fig. 23.

The oscillogram of input voltage is shown in Fig. 24. Display of output voltage is shown in Fig. 25. The output voltage of the interleaved boost converter is 58.1 V which is closely in line with the simulation result. The output is free from ripple.

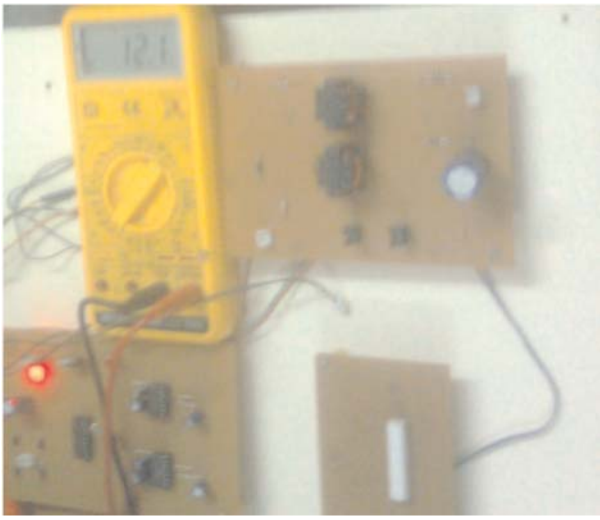

Fig. 23. Display of the input voltage

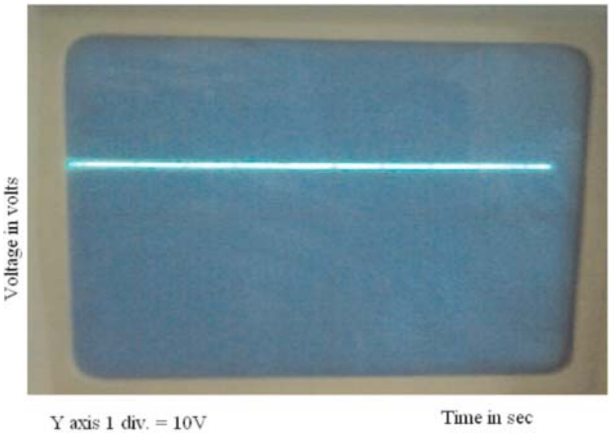

Fig. 24. Input voltage

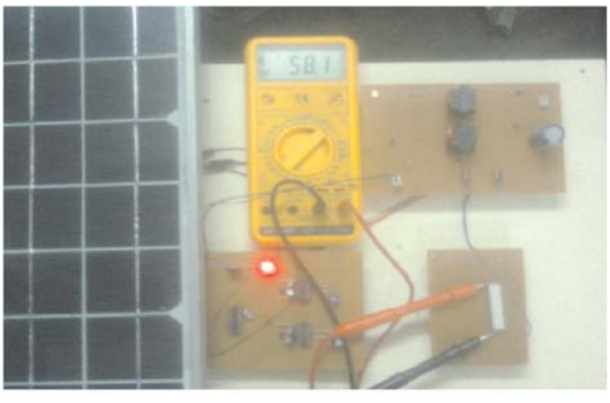

Fig. 25. Display of the output voltage

V. CONCLUSION

The practical implementation of two-stage interleaved boost converter for solar installation system was proposed in this paper. The modified two-stage interleaved DC to DC boost converter was modeled and simulated using matlab/Simulink and it was implemented using embedded controller and lab tested. The simulation and experimental results of this system are compared with the conventional boost converter. Also its time response analysis was made. It was observed that the proposed two-stage interleaved boost converter system has the advantages of fast response, low ripple content and reduced switching stress. The experimental results confirmed that the interleaved DC to DC boost converter gives better performance efficiency than conventional boost converter.

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