IMPLEMENTATION OF INTERLEAVED BOOST CONVERTER USING SIC DIODES IN RESIDENTIAL PV PRE-REGULATOR APPLICATION

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ABSTRACT

This paper composed of interleaved boost converter using SIC diodes for PV applications is proposed. The converter consists of two switching cells sharing the PV panel output current. Their switching patterns are synchronized with 180◦ phase shift. Each switching cell has a SIC Schottky diode and a Cool MOS switching device. The SIC diodes provides small reverse recovery current and voltage drop is also greatly reduced .Such an advantage from the SIC diodes enables higher efficiency and higher power density of the converter system by reducing the requirement of the cooling system. Additionally the MPPT controller is used in our proposed system to efficiently draw the power from the solar panel. Simulation and experimental results are presented to verify the proposed system. This paper presents a practical design and implementation procedure for an interleaved boost converter (IBC) using SIC Schottky diodes in a residential PV pre regulator application. It must be noted that this represents an example of the use of the method and procedure. It can be extended to optimize the dc–ac inverter. The design goal is to maximize the efficiency in the system and the design criteria with the typical specification of single-phase PV inverters.

KEYWORDS: *SIC, MPPT and cool MOS.*

I. INTRODUCTION

The power diode is the first device to adopt the Silicon carbide (SIC). The main advantage of SIC is high-breakdown voltage and the small reverse-recovery current. The SIC Schottky diode has the superior characteristics when compared to the Silicon based diode in device characteristics. The residential Photovoltaic (PV) inverter applications are gaining more and more attention nowadays. But however, a typical solar panel converts only 30 to 40 percent of the incident solar irradiation into Electrical energy depending on the characteristics of the PV panels, due to different temperature, irradiation conditions, and shading and clouding effects. Maximum power point tracking technique is used to improve the efficiency of the solar panel. The perturbation and observation MPPT algorithm is used to obtain the maximum power from the solar panel.

The market for residential photovoltaic (PV) inverters is becoming highly competitive. PV manufacturers are competing to increase the efficiency for every 0.1%. From the Maximum power point tracking (MPPT) algorithm point of view, the existing methods, such as perturbation and observation (P&O) and incremental conductance, can track the maximum power point properly and the dynamic response is good enough to deal with changes in temperature and irradiation From the hardware point of view, there are 2 DoFs in an inverter design used to improve the efficiency, namely semiconductor and topology. As the topology is limited by the issue of common mode voltage, the options of transformerless topologies are limited .With regard to the semiconductor, high voltage and low current ratings for residential PV inverters are required. The commercialized SIC diodes are acceptable in this particular application from the electrical performance point of view. However, it is well known that SIC increases the overall cost of components. Moreover, a single diode replacement without any optimization cannot effectively improve the system efficiency. Instead it may prolong the payback time from electricity savings to compensate for the cost of the PV inverter. Thus, the right selection of topology and peripheral devices, such as switches, passive devices, and cooling systems, is important in order to maximize the benefits of using SIC diodes in a power electronics. The interleaved boost converter will act as a power factor correction circuit. The power generated by the solar panel is fed to the interleaved boost for the power factor correction and it will be converted in to AC voltage using the inverter. The paper proposes implementation of an interleaved boost converter(IBC) using SIC diodes for photovoltaic (PV) applications is presented .The MPPT Controller is used to obtain the maximum power and efficiency from the PV panel .The converter consists of two switching cells sharing the PV panel output current. Each switching cell has a SIC Schottky diode and a Cool MOS switching device. The SIC diodes provide zero reverse - recovery current ideally, which reduces the commutation losses of the switches. Such an advantage from the SIC diodes enables higher efficiency and higher power density of the converter system by reducing the requirement of the cooling system. This paper presents also an optimization study of the size and efficiency of the IBC.

II. LITERATURE REVIEW

- Implementation procedure of an interleaved boost converter using SIC diode.

This paper presents a practical design and implementation procedure for an interleaved boost converter (IBC) using SIC Schottky diodes in a residential PV pre regulator application. It must be noted that this represents an example of the use of the method and procedure. It can be extended to optimize the dc–ac inverter. The design goal is to maximize the efficiency in the system and the design criteria are in agreement with the typical specification of single-phase PV inverters in. The design procedure is based on the SIC analysis of the steady-state characteristics of the topology and the semiconductor switching behavior. The further optimization for the passive devices and cooling system can be obtained based on the previously analyzed results shows the flow chart of the design steps. Experimental results in a 2.5 kW IBC prototype using SIC diodes are provided to show the performance of the optimized prototype By using this circuit structure and modulation scheme , the advantage of anti phase ripple cancellation of both inductors can be achieved. The amplitude of the input current ripple is smaller compared to a single boost converter.

- Performance Evaluation of a Schottky SIC Power Diode in a Boost PFC Application.

This paper discusses the results of the comparative evaluation of a 4 A, 600 V SIC Schottky diode (Infineon SDP04S60) and of two ultra-fast soft-recovery diodes (RURD460 and STTH5R06D) with the same ratings. The key application for this type of rectifiers is the boost power factor corrector (PFC). We developed a 300 W, universal input range boost PFC and evaluated its performance with the different diodes, measuring overall efficiency, switch and diode losses, and conducted EMI noise .The significant reduction of the peak reverse recovery current typical of this type of diode with respect to Si diodes. However, recently introduced Si diodes, as the one 5 considered here, offer a performance level very close to that of the SIC diode, both for the efficiency and the EMI generation, at least for usual switching frequencies (below 100 kHz). It is worth nothing, however, that a considerable advantage could be implied by the use of SIC diodes, in case their superior performance in terms of recovery current is exploited to increase the switching frequency, because this could allow a significant increase of the converter power density.

III. BASIC PRINCIPLES OF OPERATION

Interleaving is good for Boost Converters too. As power densities continue to rise, interleaved boost designs become a powerful tool to keep input currents manageable increase efficiency, while still maintaining good power density. With mandates on energy savings more common, interleaved construction may be the only way to achieve design objectives .The benefits of this approach are demonstrated by a two-phase boost converter design built around the LM5032 pulse-width modulation (PWM) controller.

3.1 Circuit Diagram:

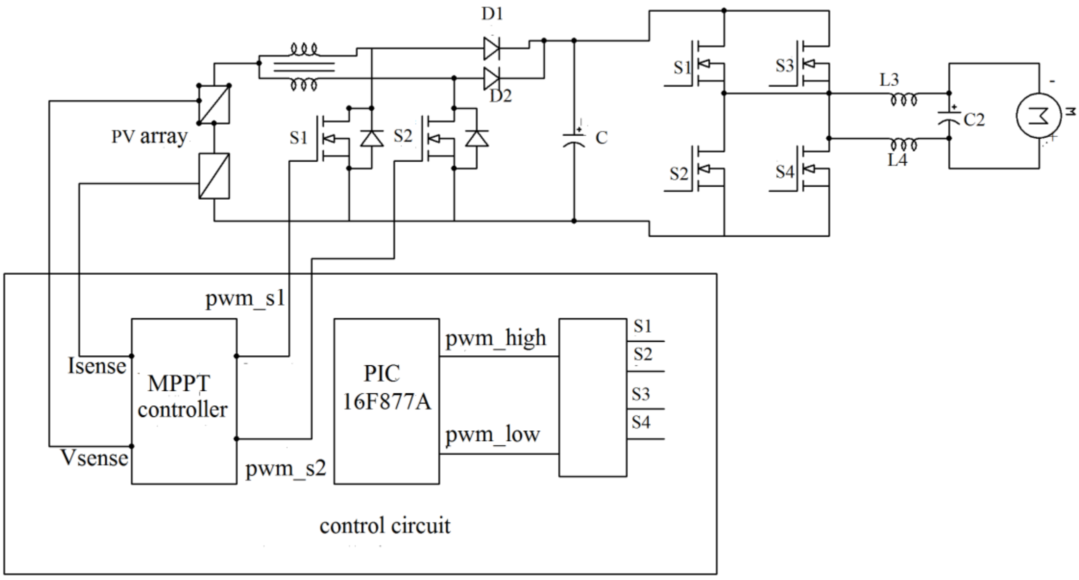

Fig1 Interleaved Boost Converter with MPPT Controller

3.2 Two-Phase Operation

In a two-phase converter, there are two output stages that are driven 180 degrees out of phase. By splitting the current into two power paths, conduction (I2R) losses can be reduced, increasing overall efficiency compared to a single phase converter. Because the two phases are combined at the output capacitor, effective ripple frequency is doubled, making ripple voltage reduction much easier. Likewise, power pulses drawn from the input capacitor are staggered, Reducing ripple current requirements. As in the buck counterpart, the designer has the choice of achieving higher efficiency by using the same rated components as in an equivalent single-phase converter, by reducing component sizes to lower costs or by using some combination of these two approaches .In the example described here, a boost converter is needed to generate a 48-V supply with high efficiency for a telecom application. The converter must be able to operate over a wide input-voltage range to accommodate a variety of input sources including batteries. Because of the wide input range, the converter also must be able to operate with a wide input-voltage to output-voltage ratio. Here, the boost MOSFETs and inductors are sized for 12 A of input current. The output capacitors are chosen to limit output-voltage ripple to 500 mV (1%) or less. Overall, the goal is to push the efficiency to a high-enough level to allow 15 peration at room temperature with no airflow, while still meeting all the other requirements. When Q1 turns on, current ramps up in L1 with a slope depending on the input voltage, storing energy in L1. D1 is off during this time since the output voltage is greater than the input voltage. Once Q1 turns off, D1 conducts delivering part of its stored energy to the load and the output capacitor. Current in L1 ramps down with a slope dependent on the difference between the input and output voltage. One half of a switching period later, Q2 also turns on completing the same cycle of events. Since both the power channels are combined at the output capacitor, the effective ripple frequency is twice that of a conventional single channel boost regulator. The component with the maximum temperature is Q2, which is operating at a case temperature the Q2 is hotter than Q1 since it is directly opposite D2, which also dissipates of Considerable heat. Since the junction-to-case thermal resistance of Q2 is 1°C/W, and since Q2 dissipates about 4 W maximum, its junction temperature is about 81°C. The ambient temperature is 25°C. Q2 is the hottest component on the board, and is well within its thermal rating. Refer to the board photos. Input and output ripple reduction are some of the benefits of an interleaved converter. Since the output ripple is double the frequency of the individual phases and at a lower root – mean square (rms) current value, the designer has the choice of using smaller output capacitors with the same ripple as a single-phase converter or using larger capacitors to achieve even lower output ripple. Effective ripple is a function of duty cycle. Using data from the actual prototype, illustrate the input and output ripple currents versus duty-cycle relationships.

Ripple reduction is a function of duty cycle, as the degree of ripple overlap is a function of duty cycle. There is near perfect cancellation of ripple at 50% duty cycle. This opens the intriguing of possibility of building a converter with little to no output ripple if the designer can limit VIN the proper value for 50% duty cycle. In the more general case, ripple is reduced by as much as 50% compared to an equivalent-power single-phase converter.

Likewise, inductor selection is flexible with the two-phase design. One – half the single-phase inductor value can be chosen, which will make each inductor smaller, but which results in the same ripple currents as the single-phase design. Or the inductors can remain the same value as in the single-phase design, reducing the ripple by one-half. The proper tradeoffs will depend on the overall design goal. Attention to ESR requirements will keep capacitors within temperature ratings and the output voltage ripple with in specifications.

IV. NECESSARY PARAMETERS OF THE POWER STAGE

Table 1 Necessary Parameters of Power Stages

Peak inductor current	i_{pk}
Min inductor current	i_o
Ripple Current	$\Delta i \equiv (i_{pk} - i_o)$
Ripple Current Ratio to Average Current	$r \equiv \Delta i / i_{ave}$
Duty Cycle	$D \equiv T_{on}/T$
Switch On Time	$T_{on} = D/f$
Average and Load Current	$i_{ave} \equiv \Delta i/2 \equiv i_{load}$
RMS Current for a Triangular Wave	$i_{rms} = \sqrt{i_o^2 + (\Delta i)^2}$,

4.1 Design Value for Inductor

Step 1. Calculate the Duty Cycle:

•Vo= output voltage
•Vi = Max input voltage
D = 1 - (Vi / Vo)

Step 2. Calculating the voltage across the inductance
•V1 = Vi (Switch on)

•V1 = Vo – Vi (Switch off)

Step 3. Calculating the required inductance

•L = Vl.dt/di

$$L = \frac{(V_{out} - V_{in} + V_D)(1 - D)}{\min(i_{load})f}$$

$$D = \frac{V_{out} - V_D}{(V_{in} - V_{Trans} - V_D)}$$

Vin = Input voltage

Vout = Output voltage
Vd = Voltage drop

Boost Converter Voltage Ripple

$\Delta Vo/Vo$

$\Delta Vo=\Delta Q/C$

$\Delta Q=((T)(\Delta iL))/(Imax)$

V. TECHNICAL EFFECTS OF PROPOSED SYSTEM USING MPPT TECHNIQUES

Various algorithms may perform MPPT. Important factors to consider when choosing a technique to perform MPPT are the ability of an algorithm to detect output.
The irradiance levels at different points on a solar panel's surface tend to vary. This variation leads to multiple local maxima power points in one system. The efficiency and complexity of an algorithm determine if the true maximum power point or a local maximum power point is calculated. In the later case, the maximum electrical power is not extracted from the solar panel. The type of hardware used to monitor and control the MPPT system affect the cost of implementing it. The type of algorithm used largely determines the resources required to build an MPPT system. For a high-performance MPPT system, the time taken to converge to the required operating voltage or current should be low. Depending on how fast this convergence needs to occur and your tracking system requirements, the system requires an algorithm (and hardware) of suitable capability.
The choice of the algorithm depends on the time complexity the algorithm takes to track the MPPT, implementation cost and the ease of implementation. For this application here we use petrub and observe algorithm the purpose of using this algorithm is simple to implement and thus can be implemented quickly. The major drawbacks of the P&O method are that the power obtained oscillates around the maximum power point in steady state operation, it can track in the wrong direction under rapidly varying irradiance levels and load levels, and the step size (the magnitude of the change in the operating voltage) determines both the speed of convergence to the MPPT and the range of oscillation around the MPPT at steady state operation.

5.1 Perturb and Observe Algorithm

The concept behind the "perturb and observe" (P&O) method is to modify the operating voltage or current of the photovoltaic panel until you obtain maximum power from it. For continues increasing the operating voltage until the power output begins to decrease. Once this happens, the voltage is decreased to get back towards the maximum power point. The system continues increasing the operating voltage until the power output begins to decrease. Once this happens, the voltage is decreased to get back towards the maximum power point. This pertubulance continues indefinitely. Thus, the power output value oscillates around a maximum power point and never stabilizes.

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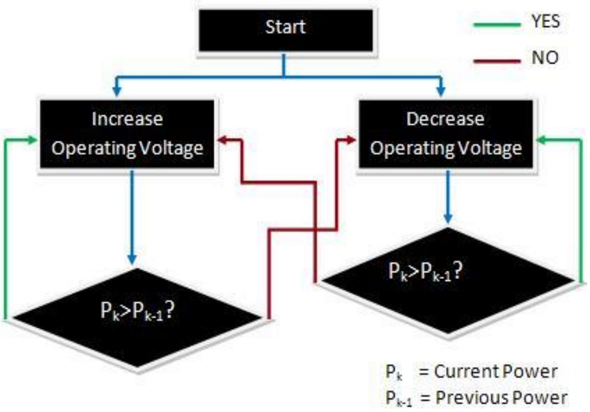


Fig. 2 petrub & observe algorithm

VI. Simulation of Proposed Circuit

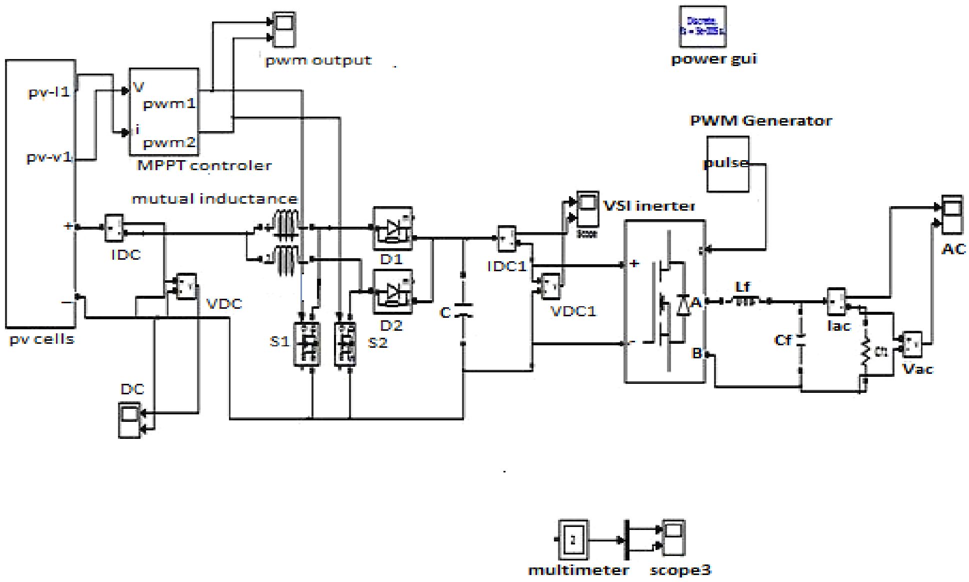


Fig.3 Simulation Circuit of Proposed System

The above figure shows the simulation circuit of proposed circuit in interleaved boost converter. In this proposed circuit using SIC, COOL MOSFET and MPPT are available.

6.1 PV Output

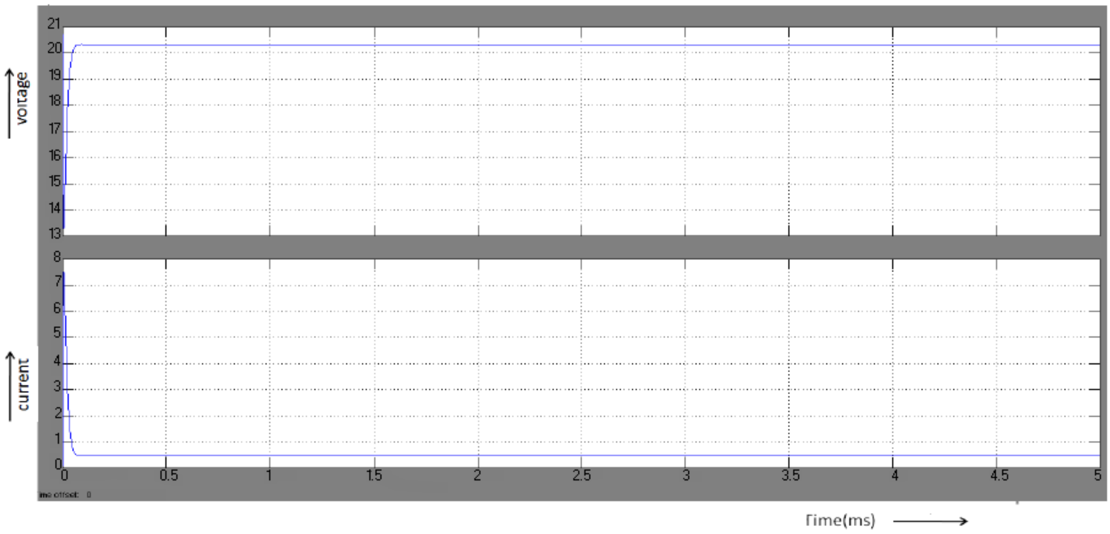


Fig. 4 PV Output

From above Fig 4 shows the PV output of voltage & current with the function of time , the output voltage is 20v & output current is 0.49 A .

6.2 PWM Output

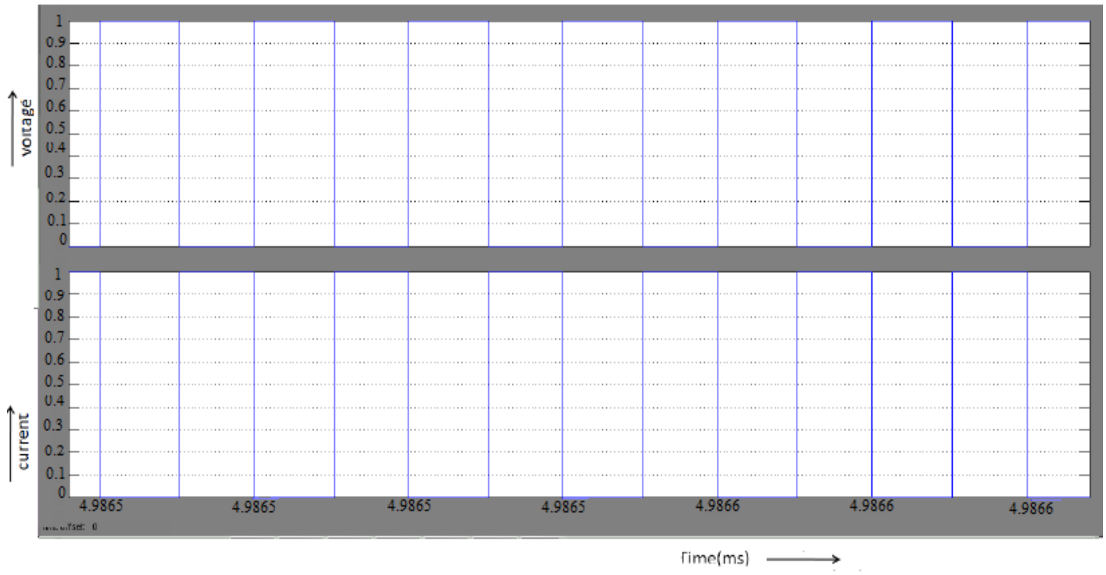


Fig.5 PWM Output

6.3 Interleaved Boost Converter Output

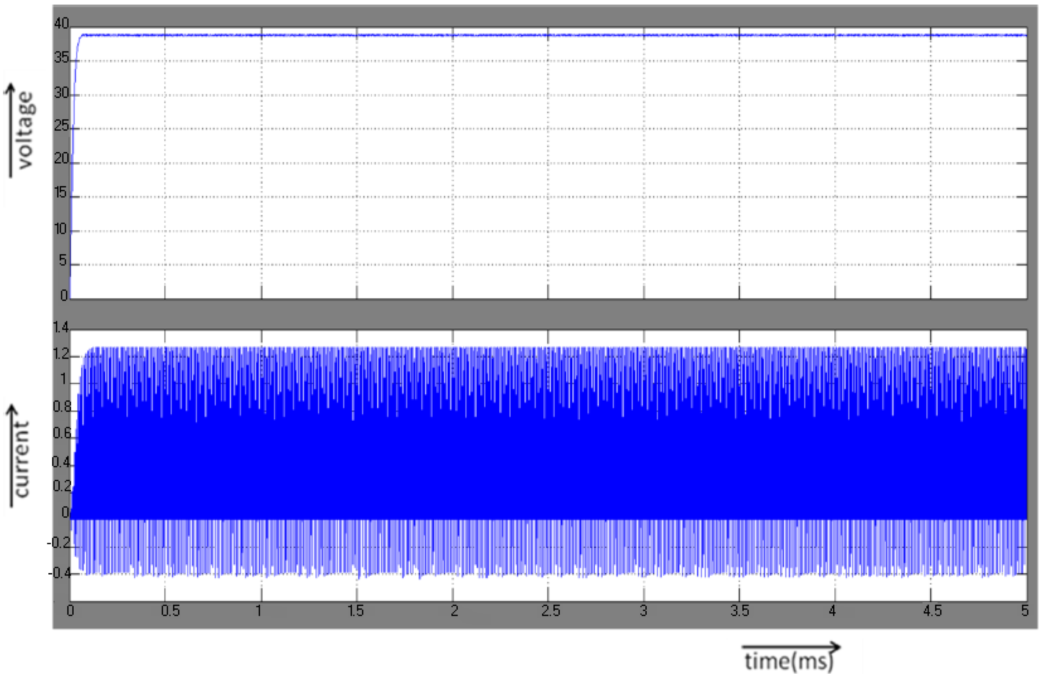


Fig. 6 Interleaved Boost Converter Output

From above Fig 6 shows the interleaved boost converter outputs of voltage & current with the function of time ,the output voltage is 39v & output current is 1.2 A .

6.4 Inverter Output

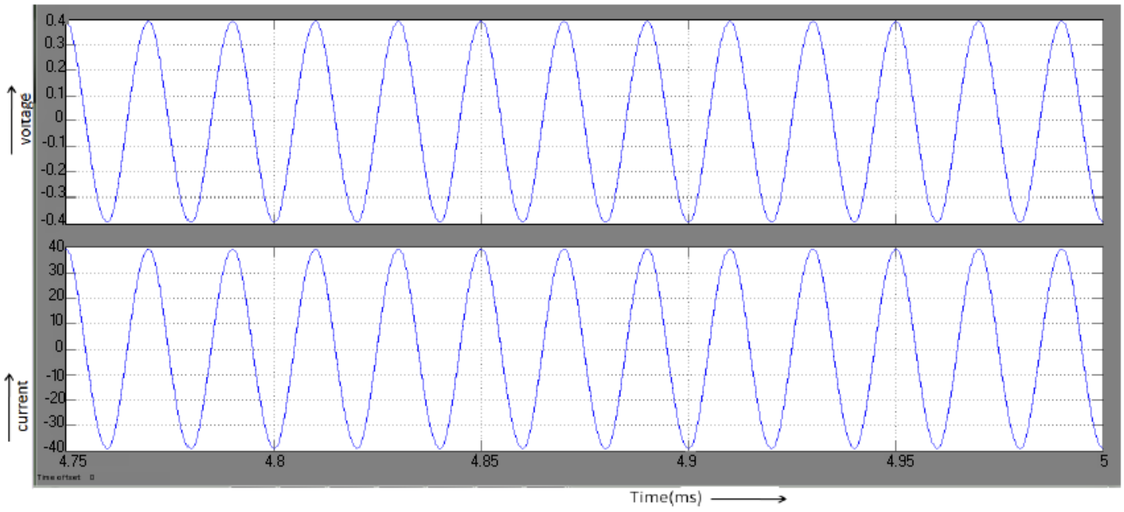


Fig. 7 Inverter Output

From above Fig 7 shows the inverter outputs of voltage & current with the function of time, the output voltage is 40v & output current is 0.4 A

6.5 Current Ripple

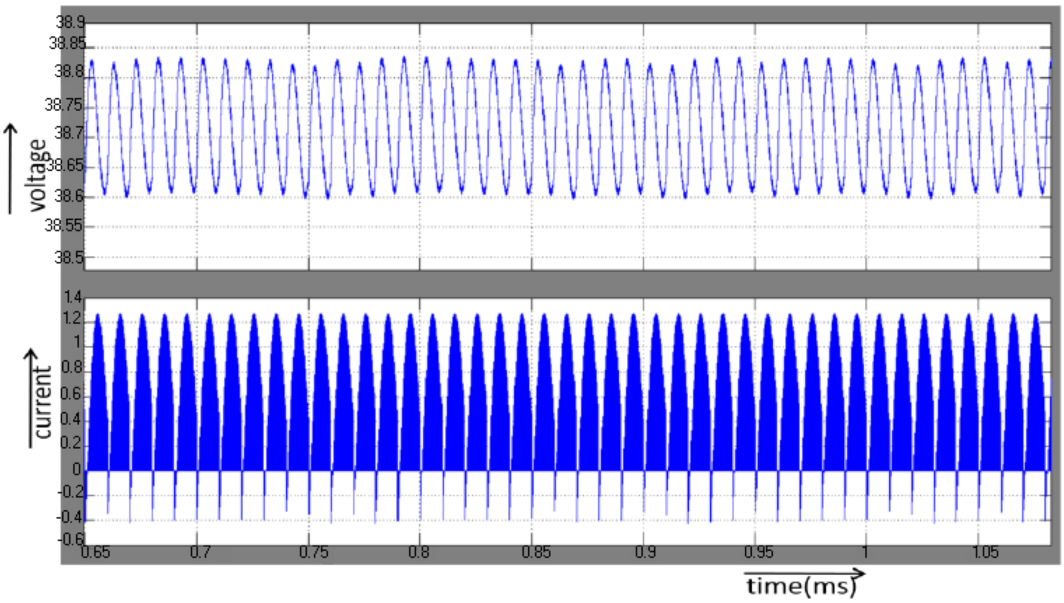


Fig.8 current ripple

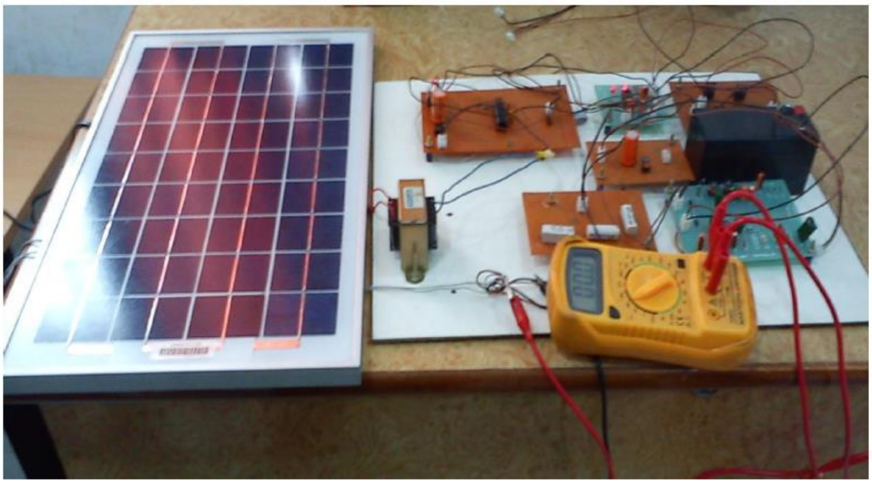
From above Fig.8 shows the current ripple as 0.02A & voltage ripple as 0.00018V

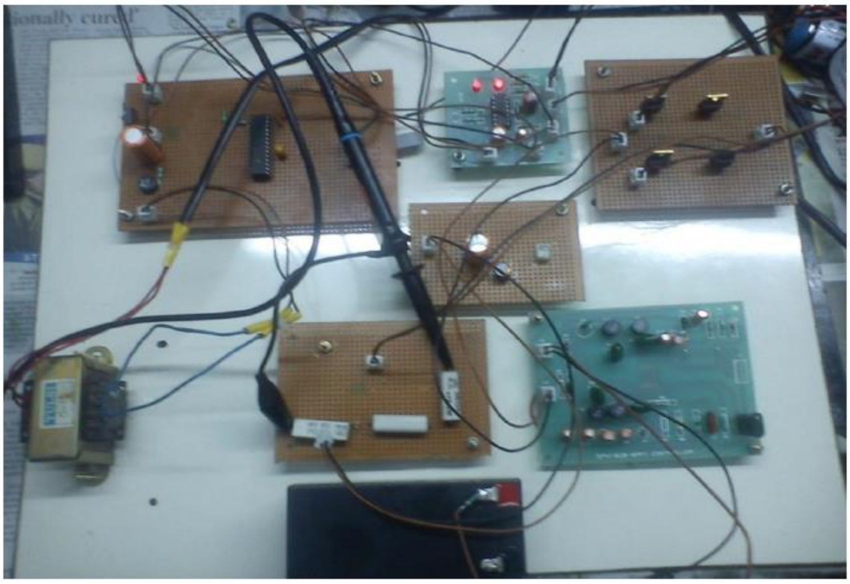
VII. Simulation Results

Table 2 simulation result

PV output	20V
Interleaved boost –converter output	39V
Inverter output	40V
Ripple current	0.02A
Voltage ripple	0.00018v

VIII. HARDWARE IMPLEMENTATION





8.1 PV Output

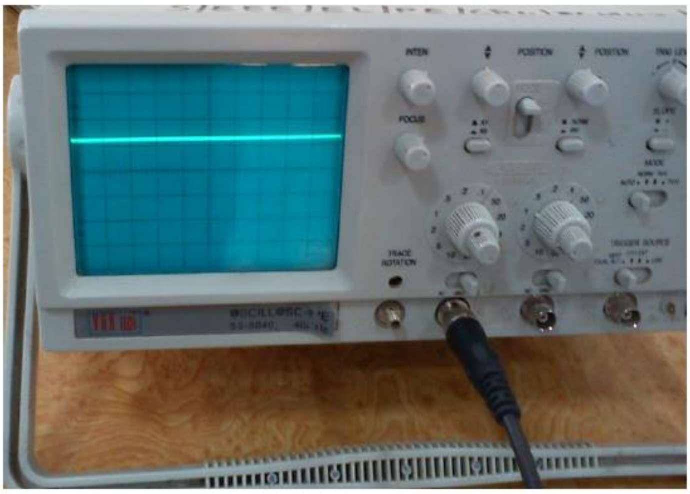


Fig 9 PV Output

The above figure 9 shows the PV output voltage as 17V

8.2 Interleaved Boost Converter Output

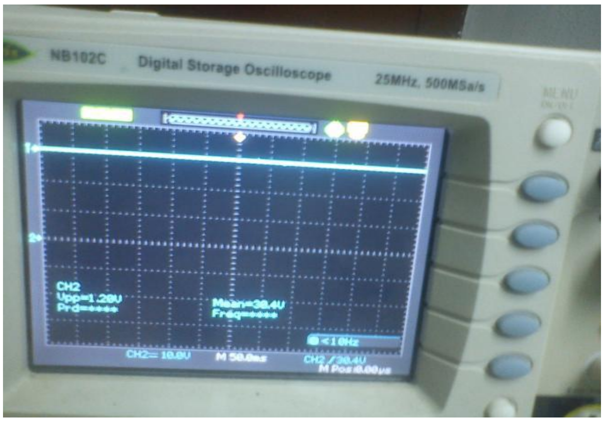


Fig 10 Interleaved Boost Converter Output

The above fig .10 shows the output voltage of interleaved boost converter as 36.4V

8.3 Inverter Output

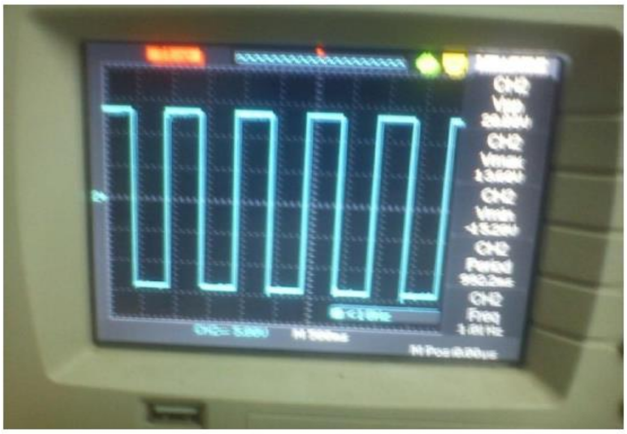


Fig 11 Inverter Output

The above fig 11 shows the output voltage of inverter as 37.5v

IX. HARDWARE RESULTS

Table 3 Hardware result

PV output	17v
Interleaved boost converter output	36.4v
Inverter output	37.5v

X. CONCLUSION

This paper has presented a complete design and implementation procedure for the IBC prototype using SIC diodes. The design criteria were based on four aspects: topology, semiconductors, magnetic devices, and cooling system. The steady-state characteristics of the IBC have been studied and the semiconductor losses have been experimentally obtained. Based on this, the optimized cooling system was designed to dissipate effectively the semiconductor losses. Moreover, the loss model of the magnetic devices was determined, thus the overall system's size and efficiency could be further optimized. The experimental results were similar to the simulated results in terms of junction temperature and efficiency. In conclusion, the converter with CoolMOS devices and SIC diodes is very suitable for PV preregulator applications because of the minimized system loss and size reductions.

10.1 Discussion

This work has presented a complete design and implementation procedure for the IBC prototype using SIC diodes. The experimental results were similar to the simulated results in terms of junction temperature and efficiency. In conclusion, the converter with CoolMOS devices and SIC diodes is very suitable for PV preregulator applications because of the minimized system loss and size reductions.

10.2 Extension of Interleaved Boost Converter for Other Applications

Batteries are widely used as the energy storage component for mobile applications. The battery charger/discharger is normally needed as the interface between the equipment and the battery. The boost converter is one of the simplest and most widely used topologies for the battery charger/discharger converter when isolation is not required. For example, the boost converter is used as the battery charger/discharger in the Hybrid Electric Vehicles (HEVs) applications for other application the interleaved boost converter extended up to three stage of operation.

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