Bridgeless Interleaved Boost PFC For High Power Applications

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Abstract- On increasing the efficiency of interleaved boost converter (IBC) applied for power factor correction (PFC) many researches are conducted by utilizing superior power physics devices and soft switching circuits, that is not useful to cut back hardware price and systematic complexity. An improved bridgeless interleaved boost power factor correction (PFC) rectifier is employed to enhance output power, efficiency and reduces the system complexity. The simulation is done in MATLAB/SIMULINK R2017 setting. The shift pulses for the feedback circuit is generated using PIC16F877A microcontroller. The switches are driven together with its driver TLP250H. A 20V input voltage, 36V output voltage and 26W output power model circuit is implemented and the performance is verified.

Keywords – Interleaved Topology, Power Factor Correction (PFC)), Pulse Width Modulation (PWM)

I. INTRODUCTION

In applications where high power output is required with low voltage ripple for a high power factor AC to DC converter, a modifed interleaved boost converter (MIBC) is having a lot of consideration due to its simple structure and its improved performance. However, since the traditional IBC has to endure a high voltage across the switch continuously, the high-voltage switch is required. For the applications of the high output voltage, conventional IBC has predominent power losses as well as high ripple. Thus the conversion effciency of such boost converter would be reduced signifcantly. Consequently, in order to overcome the demerits mentioned above, there are many improved boost converter topologies. That is an auxiliary coupled inductor is introduced in [2] to realize zero-voltage switching (ZVS) turn-on condition of MOSFET. An auxiliary device is added in [3] to realize zero-current-switching (ZCS) condition of IGBT. A snubber cell is introduced in [4] to realize soft switching condition of all devices. The above auxiliary circuits can reduce switching loss, but they simultaneously increase complexity and cost of hardware, which is not practical for industry.

To increase efficiency without adding any extra circuits, some researches aims at using high-performance power electronics devices are conducted. As is known to all, wide band gap (WBG) devices, such as SiC devices and GaN devices have better material properties compared with traditional Si devices, this allows WBG devices to operates at higher switching speed, higher voltage and higher temperature. However, their cost is much higher than Si devices, which is an obstacle to commercial applications. It is impossible to completely replace Si devices by WBG devices in a short term because of high cost, especially for industrial applications.

The interleaved boost converters are used with the goal of rising power density, boost inductors are optimized with considering shift loss, system volume, inductance power loss, operating temperature and magnetism noise in [6]-[7]. Integrated geophysics and paired inductance are accustomed scale back volume of boost inductors in [8]-[9]. A comprehensive improvement technique is conducted to optimize operation modes, EMI fillter and shift frequency with considering volume and losses of elements, time period of electrical device and price of IBC in [10]. A proportional shift strategy for reducing current ripple of DC-DC boost convertor is enforced [11], however, it is not appropriate for greenhouse emission application as a result of its input voltage is not curving undulation. Compared to the boost AC-DC PFC convertor, the bridgeless boost greenhouse emission topology avoids the requirement for the rectifer input bridge, nevertheless it maintains the classic boost topology. It is a gorgeous answer for applications at high power levels, wherever power density and effciency particularly essential. This topology solves the matter of warmth management within the input rectifier diode bridge.

In this work, a modified bridgeless interleaved boost converter with input passive filter is projected. The converter acts in continuous physical phenomenon mode. If the convertor operates in discontinuous physical phenomenon mode, all the elements suffer by current stress. Therefore conductin loss and core loss of the converter will be raised. Throughout steady state, the voltage stress across all the active switches before activate or when shut down is reduced. The conversion ratio, output current ripple, ripple in the inductor are lower. Modifed interleaved boost converter consists of 2 boost converters connected in parallel. Interleaved stages are for reducing the ripple currents by operating 2 or additional convertor circuits in parallel and to control the switches in various sub-circuit with a phase shift with respect to one another. The phase difference between the operations of the 2 switches ends up in the ripple currents of 1 of the sub-circuits cancelling the ripple currents of the opposite. This reduces the ripple current in both the input and also the output of the convertor. As compared to the boost AC–DC PFC converter, the bridgeless boost PFC topology avoids the necessity for the rectifier input bridge, nevertheless it maintains the classic boost topology. It is an attractive solutionfor applications at power levels larger than one kilowatt, wherever power density and efficiency particularly important.

II. TOPOLOGY OF INTERLEAVED BOOST PFC

The Interleaved technique accustomed improve power device performance in terms of potency, size, conducted magnetic attraction emission, and transient response. The advantages of interleaving are high power capability, modularity, and improved reliableness. IBC consists of input electro-magnetic interference (EMI) fillter, rectifier bridge, boost inductors, high-frequency power switches, freewheeling diodes and output capacitance etc. Power factor correction (PFC) shapes the input current of the facility offer to be in synchronization with the mains voltage, so as to maximise the real power drawn from the mains. In a very good PFC circuit, the input current follows the input voltage as would an equivalent resistor, with no additional input current harmonics. Projected topology of bridgeless single phase interleaved boost PFC is as shown in Figure.1.

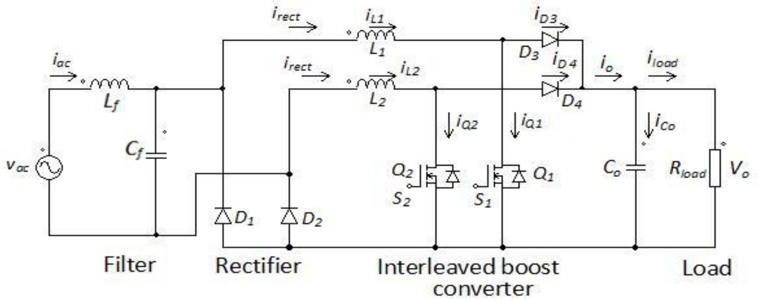


Figure 1. Proposed bridgeless boost converter

The single phase bridgeless interleaved boost converter consists of two switches S1 and S2, four diodes D1, D2, D3 and D4, two boost inductors L1, L2, one filter inductor Lf , one filter capacitor Cf and one output capacitor Co. Vac is the input voltage and output voltage is denoted as Vo. Figure.1 shows a circuit of typical arrangement of single phase bridgeless interleaved boost converter applied for power factor correction.

III. OPERATION PRINCIPLE

Generally typical boost converters are accustomed to acquire higher output voltage than the input voltage. Once these boost converters are operated for top ratios it ends up in high voltage and current stress on the switch. Thus associate interleaving technique of boost convertor has been conferred. This methodology of approach is utilized in high power applications to supply high voltage gain in comparison to the traditional boost convertor. The interleaved boost convertor consists of 2 stage parallel connected switches S1, S2; inductors L1, L2; diodes D3, D4 capacitor Co and load resistance Rload with common input source(Vac). The switches are controlled by phase shifted switching function called interleaving operation. Once Q1 is popping on, source voltage applies on L1 and iL1 rises linearly. Once Q1 is turned off, iL1 charges Co and provides power to Rload. Output capacitor Co is employed to filter output current ripple and stabilize output voltage. If Co is high enough, Vo can be seen as a constant value. Input LC filter is employed to filter input current harmonics. Diode rectifier converts Vac to a half-wave DC voltage.

Interleaved stages are for reducing the ripple currents by operating two or more converter circuits (sub-circuits) in parallel and to operate the switches in respective sub-circuit with a phase shift with respect to each other. The phase difference between the operations of the two switches results in the ripple currents of one of the sub-circuits cancelling the ripple current of the other. Bridgeless circuit will reduces diode loss and improves effciency. AC supply is used as the source voltage which initially passes through a filter to filter out input current ripple. Rectifier bridge converts vac to a full-wave DC voltage. Then it is fed to the interleaved boost converter to step up the input voltage to a DC voltage. The working of the circuit can be explained by 4 modes of operation. Operations are described as follows:

Mode 1[0 – t0] : In this mode, switch S2 is turned on but the switch S1 is turned off. At the same time, diode D1 is forward biased and diode D2 is reverse biased. Also, the input supply energy to the inductor L2 resulting in rise of the inductor current iL2. At the same time, inductor L1 supplies energy to the load resulting in decrease in inductor current iL1. Figure.2 (a) shows the equivalent circuit diagram of the converter and current paths for this mode is also shown. From Figure.2 (a), the rate of change of iL1 and iL2 can be written as follows.

$$\frac{di_{L1}}{dt} = \frac{V_{rect} - V_o}{L_1} \tag{1}$$

$$\frac{di_{L2}}{dt} = \frac{V_{rect}}{L_2} \tag{2}$$

Mode 2[t0 – t1] : In this mode, switches S1 and S2 are turned off. The diodes D1 and D2 are forward biased. The currents iL1 and iL2 freewheels through diodes D 1 and D2 respectively and supplies energy to the load. Figure.2 (b) shows the equivalent circuit diagram of the converter and current paths for this mode is also shown. From Figure.2 (b), the rate of change of iL1 and iL2 can be written as follows.

$$\frac{di_{L1}}{dt} = \frac{di_{L2}}{dt} = \frac{V_{rect} - V_o}{L} \tag{3}$$

Mode 3[t1 – t2] : In this mode, switch S1 is turned on but the switch S2 is turned off. At the same time diode D2 is forward biased and diode D1 is reverse biased. The currents iL2 freewheels through diodes D2. Inductor L2 discharging and supplying energy to the load resulting in fall of the inductor current iL2. At the same time, the input supplies energy to the inductor L1 resulting in increase in inductor current iL 1. Figure.2 (c) shows the equivalent circuit diagram of the converter and current paths for this mode is also shown. From Figure. 2(c), the rate of change of iL1 and iL2 can be written as follows.

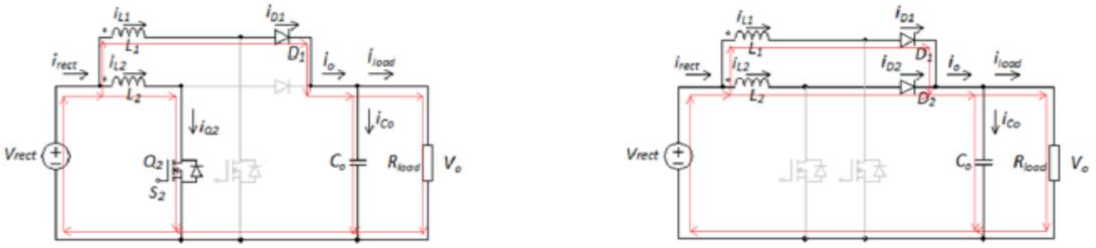
$$\frac{di_{L1}}{dt} = \frac{V_{rect}}{L_1} \tag{4}$$

$$\frac{di_{L2}}{dt} = \frac{V_{rect} - V_o}{L_2} \tag{5}$$

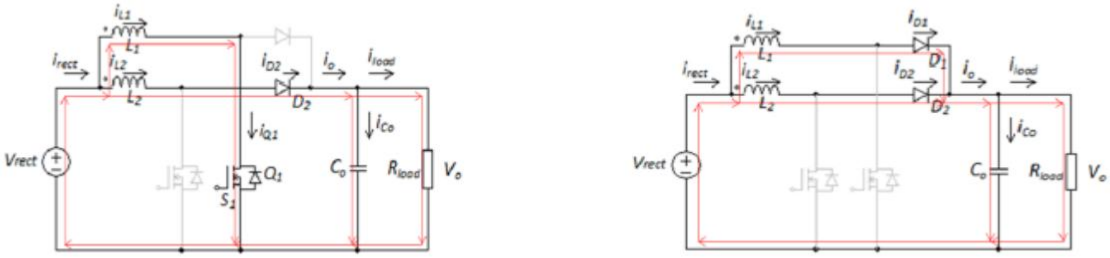
Mode 4[t2 – t3] : In this mode, switches S1 and S2 are turned off. The diodes D1 and D2 are forward biased. The currents iL1 and iL2 freewheels through diodes D1 and D2 respectively and supplies energy to the load. Figure.2(d) shows the equivalent circuit diagram of the converter and current paths for this mode is also shown. From Figure 2(d), the rate of change of iL1 and iL2 can be written as follows.

$$\frac{di_{L1}}{dt} = \frac{di_{L2}}{dt} = \frac{V_{rect} - V_o}{L} \tag{6}$$

Following are the different modes of operation of the proposed converter along with the curent flow path under steady state operation which is shown in the Figure.2.



(a) Mode 1 (0 – t0)   (b) Mode 2 (t0 – t1)



(c) Mode 3 (t1–t2)   (d) Mode 4 (t2–t3)

Figure 2. Modes of Operations

The theoretical waveform corresponding to each mode of operation can be represented as shown in Figure.3.

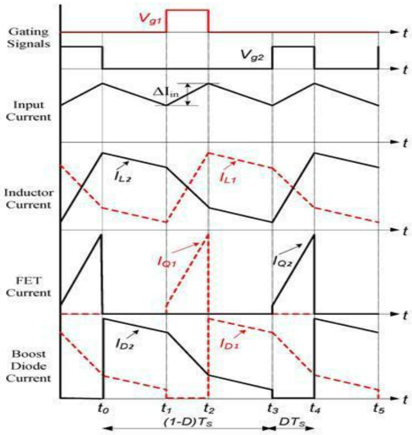


Figure 3. Theoretical Waveforms

IV. DESIGN CONSIDERATIONS

The input voltage is taken as 220 V. The design is done so as to get an output voltage of 400 V, high output power of 3300 W and high effciency. The pulses are switched at the rate of 80 kHz. Duty ratio of main switch and auxiliary switch is selected at 45% .

$$L = \frac{V_s * D * T_s}{\Delta I_L} = \frac{220 * 0.45 * 12.5 * 10^{-6}}{4.5} = 275\mu H \tag{7}$$

The value of inductor is set at 220 µH.

$$C_{o\ min} = \frac{I_o * D}{f_s * \Delta V_0} = \frac{8.25 * 0.45}{80 * 10^3 * 0.1725} = 269.02\mu F \tag{8}$$

To ensure minimum output voltage ripple and thereby a smooth output characteristics, the output capacitor is selected as 770 µ F which is greater than Co min.

Thus by using appropriate designs of the boost converter, components L and C are designed and suitable values of inductor L and capacitor C0 is set to as 220 µH and 770 µ F respectively.

V. SIMULATION RESULTS

The simulation parameters for the single phase bridgeless interleaved boost converter is given in Table 1. The parameters given in the table are corresponding to 20kHz switching frequency. An input voltage Vac of 220V gives an output voltage Vo of 400V for an output power Po of 3300W. The switches are MOSFET with constant switching frequency of 20 kHz. The duty cycle of switches is taken as D=0.45. Along with this simulation design a prototype can also be designed by taking input voltage is taken as 20V. The pulses are switched at the rate of 20kHz with a duty ratio of 0.45. The design is done so as to get a high output power, high efficiency and improved power factor.

Table -1 Simulation Parameters

Parameters	Specification
Input voltage Vd	220V
Switching frequency fs	20kHz
Output voltage V0	400V
Inductor L1, L2	1.1mH
Output capacitor C0	1mF
Load resistance	50Ω

The bridgeless interleaved boost converter is simulated in MATLAB/SIMULINK by choosing the parameters listed in TABLE 1 and the simulink model is shown in Figure. 4.

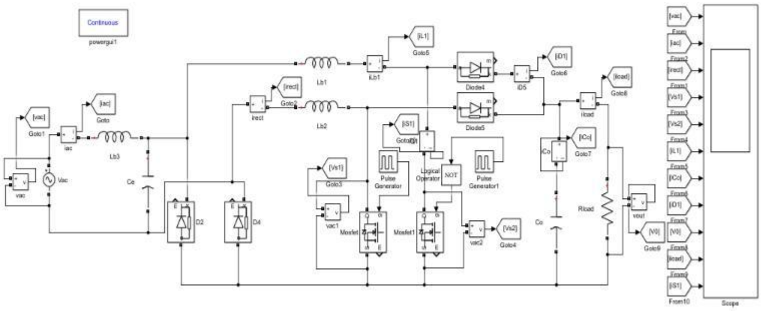


Figure 4. Simulink Model of Bridgeless Interleaved Boost Converter

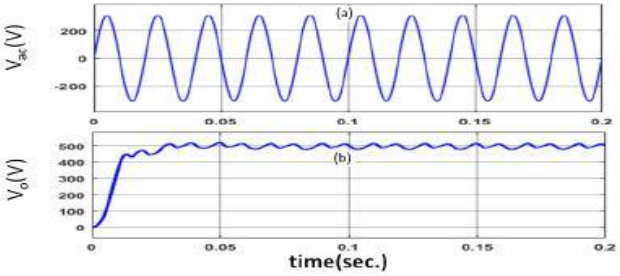


Figure 5. (a) Input Voltage (b) Output Voltage

Figure. 5 shows that input to this converter is purely sinusoidal and the output is obtained as DC with output voltage ripple of 0.04V. The input voltage Vin is 220V, 50Hz and the output voltage Vo is above 400 V respectively. This shows a high gain of single phase interleaved boost converter. The ouput voltage is DC with minimum ripples in it.

Figure. 6 shows the input current and output current of the converter. Input current is sinusoidal with a THD of 21.05 And its magnitude is around 30A. This AC current is rectified with two diode rectifiers and rectified current is obtained whose magnitude is also around 30 A. Output current is about 10 A with a low ripple of 0.05A. Inorder to reduce the harmonics content in the AC current LC filters are used.

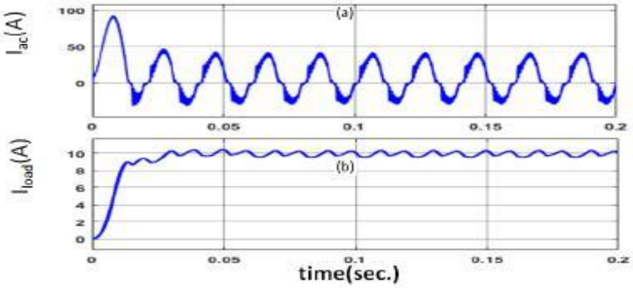


Figure 6. (a) Input Current (b) Output Current

Figure.7 shows the voltage across switches S1 and S2 respectively. From the figure it is clear that both the switches have a high value of voltage stress which is almost equal to the output voltage. But the switching stress is not experiencing continuously but in descrete manner.

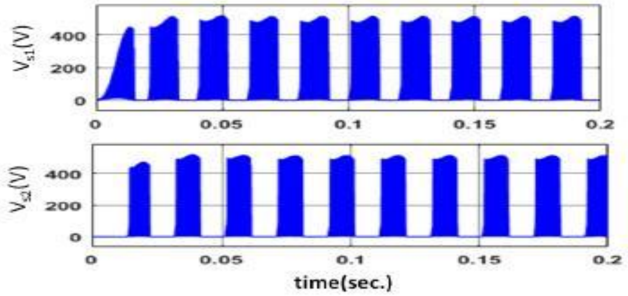


Figure 7. (a) S1 Stress (b) S2 Stress

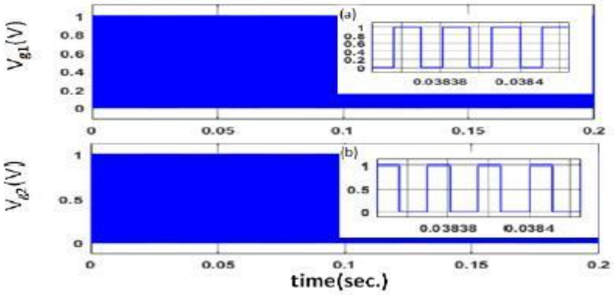


Figure 8. (a) S 1 Gate Pulse (b) S2 Gate Pulse

Figure. 8 shows the gate pulses for two switches of interleaved boost converter. These pulses are 180 degree phase shifted from each other. The switching frequency is chosen to be 80 kHz and the duty ratios of S1 and S2 is equal to 0.45.

VI. ANALYSIS

The analysis of single phase bridgeless interleaved boost converter is carried out by considering parameters like effciency, and power factor. Analysis is done by considering steady state condition and comparison between convensional and modified converter is also done.

6.1 Efficiency Curve

Efficiency of a power equipment is defned at any load as the ratio of the power output to the power input. The effciency tells us the fraction of the input power delivered to the load. A typical curve for the variation of efficiency as a function of output power is shown in Figure 9. The converter effciency is around 98% for 4kW output power for R load.

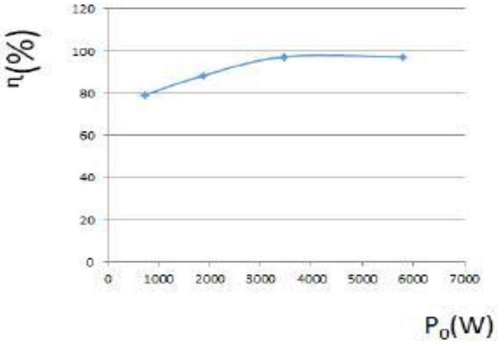


Figure 9. Efficiency Vs Output Power With R Load

6.2 Power Factor Curve

A typical curve for the variation of power factor as a function of output power is shown in Figure 10. Power factor is improved to 98% .

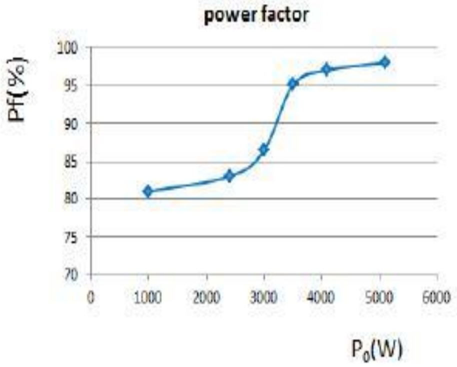


Figure 10. Power Factor Vs Output Power

6.3 Fft Analysis

The FFT analysis is shown in Figure 11. From that THD of the converter is obtained as 18.97% . It shows the total harmonic distortion in the input alternating current .

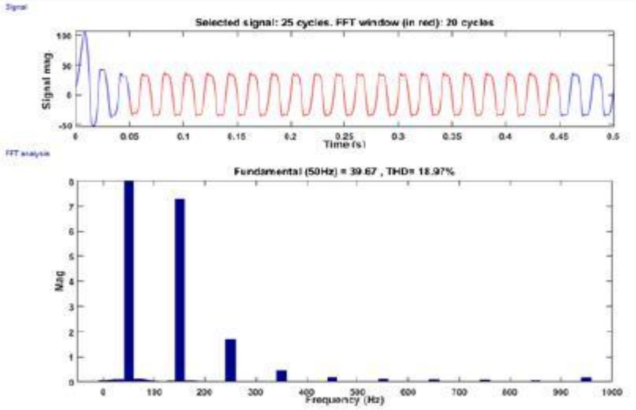
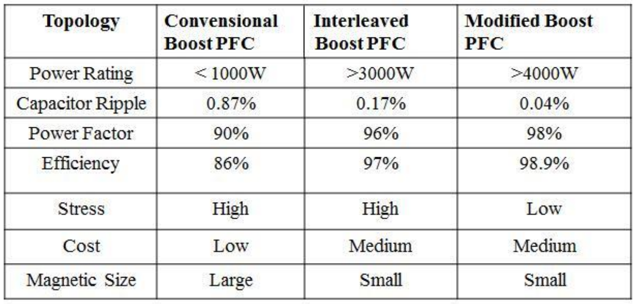


Figure 11. FFT Analysis

The comparison between conventional, interleaved and modified interleaved boost converters is given in Table 2.

Table -2 Comparison of the Steady State Characteristics



Topology	**Convensional Boost PFC**	**Interleaved Boost PFC**	**Modified Boost PFC**
Power Rating	< 1000W	>3000W	>4000W
Capacitor Ripple	0.87%	0.17%	0.04%
Power Factor	90%	96%	98%
Efficiency	86%	97%	98.9%
Stress	High	High	Low
Cost	Low	Medium	Medium
Magnetic Size	Large	Small	Small

It is observed from the above discussions that in bridgeless interleaved boost converters the high efficiency, high power output and high power factor operation can be achieved with this simplest circuit. That is power factor as well as efficiency can be increased without adding any hardware cost and software cost, then total loss and heat can be decreased, heatsink volume can be reduced.

VII. EXPERIMENTAL SETUP

The experimental setup of bridgeless interleaved boost converter is done through two stages. First the program is written in micro C for generating gate pulses for switching devices. The program is verifed and frequency is checked by simulating it in the Proteus software. The program is burned to the microcontroller(PIC16F877A) using the software micro programming suit for PIC. The switches used are MOSFET IRF540 along with its driver TLP250. A prototype of bridgeless interleaved boost converter with input voltage of 20V is implemented. The top view of the experimental setup is shown in Figure 12. It consists of control circuit, driver circuit and power circuit. Control circuit is composed of PIC microcontroller and its power supply. The control pulses for MOSFET switches are generated using PIC microcontroller. The pulses from microcontroller is amplifed by driver circuit which is composed of TLP250. It also provides isolation between control and power circuit. Power circuit forms the bridgeless interleaved boost.

Figure 12. Experimental Setup of Bridgeless Interleaved Boost Converter

VIII. CONCLUSION

The single phase bridgeless interleaved boost converter offers a high output power, high power factor, reduced effective voltage stress across switch and most simplest structure. It achieves an improved overall effciency and performance. The input voltage is 220 V and output voltage is 400 V. The converter has a peak effciency of 98.9% , power factor of 98% and output power near 5kW. A duty ratio of 0.45 and a high switching frequency of 80kHz is suitable for this converter so as to get maximum effciency. The prototype of interleaved boost converter with input voltage of 20V is built. The output voltage is 36V. It achieves an improved overall effciency of 98% . A duty ratio of upto 0.45 is suitable for this converter so as to keep the voltage stress across the switches and diodes to a safe limit. The converter can be used for applications with low input AC and high output DC voltage as well as with high output power, such as PV system, off line power supplies for computer and telecom applications, PHEV battery chargers, distributed power systems, DC leakage tester, 250 to 5000W PWM DC/AC 220V power inverter etc.

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