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Resonant AC-DC Converter with Interleaved Boost PFC

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Abstract: **AC-DC soft-switching resonant converter with interleaved boost power factor corrector (PFC) is presented. In this converter, an interleaved boost PFC circuit is integrated with a soft-switching resonant converter. High power factor is achieved by the interleaved boost PFC circuit. The input current can be shared among the inductors so that high reliability, power factor and efficiency in power system can be obtained and ripples are also reduced. Another advantage of interleaved technique is reduction of THD. Thus the converter performance can be improved. The voltage across the main switches is confined to the dc-link voltage. Soft-switching operation of main switches and output diodes is achieved. Hence the switching losses are reduced significantly. Therefore, the overall efficiency is improved. Circuit is simulated with 110V AC input voltage and 45V DC output voltage is verified. Performance parameters such as voltage stress and output ripple are also analyzed. The simulation is done in PSIM. Power factor of 0.96 is achieved with this converter. For the hardware, dsPIC30F2010 is used for generating PWM pulse with switching frequency 90 kHz.**

Keywords: **Power factor correction (PFC), Soft switching, Resonant converter, Interleaved Boost converter.**

1. INTRODUCTION

The power supply unit is an essential circuit block in all electronic equipment. It is the interface between the AC mains and the rest of the functional circuits of the equipment. These functional circuits usually need power at one or more fixed dc voltage levels. Switched mode power supplies (SMPS) are most commonly used for powering electronic equipment since they provide an economical, efficient and high power density solution compared to linear regulators. In order to conserve energy, high overall power conversion efficiency is required. However, conventional AC/DC switched mode power supplies introduce some adverse effects on the AC side [1]. There comes the importance of resonant converter.

With the tightening requirements of power quality, offline power supplies are required to operate at high power factor.

Any power electronic converter circuit is characterized by certain parameters that are used to ascertain its performance. Important performance parameters are Total Harmonic Distortion (THD), Distortion Factor (K_p), Displacement Factor (K_d) and Power Factor (PF).

2. RESONANT AC-DC CONVERTER WITH INTERLEAVED BOOST PFC

The interleaved boost converter is an improvement over the conventional boost converter in that a number of boost converters are connected in parallel. The number of such boost converters denotes the phase number of the interleaved boost converter topology. All the boost converters involved have the same switching frequency and phase shift. The converter consists of the two phase IBC topology. Conventionally, active power factor correction circuits involve only the

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boost converter topology. But the IBC topology has significant advantages over the conventional boost converter. Some of these are as listed under:

1. Minimization of ripple content in input current

2. Lower switching and conduction losses

3. Reduced size, improved efficiency and transient response

4. Higher power capability

5. Higher reliability and modularity

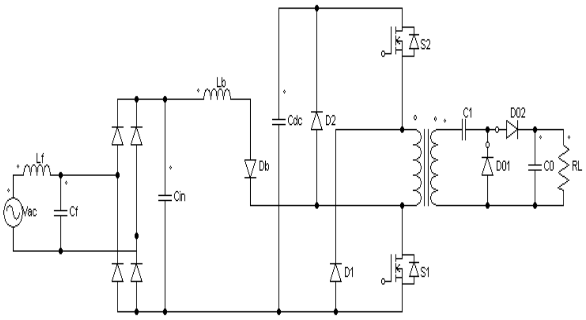

Fig. 1: Soft-switching two switch resonant converter

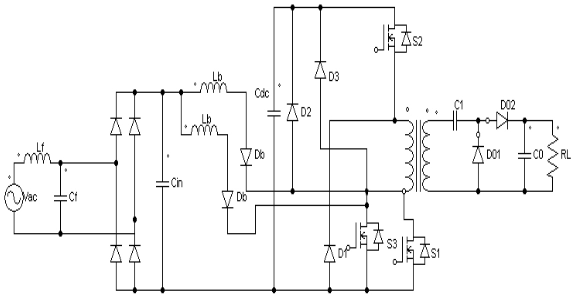

Fig. 2: Resonant AC-DC converter with interleaved boost PFC

The proposed converter consists of interleaved boost and resonant converter. The difference of this one from soft switching resonant converter is in the interleaved portion. The circuit diagram of the proposed converter is shown in figure 2. Resonant AC-DC Converter with Interleaved Boost PFC merges interleaved boost converter and a two switch resonant converter. The circuit diagram of the soft switching two switch resonant converter is shown in figure 1. The boost PFC circuit which is designed to operate in discontinuous conduction mode (DCM) is replaced by interleaved boost to achieve a high power factor. The maximum voltages across main switches and clamping diodes are confined to the dc-link voltage V_{dc}. The secondary side consists of an output capacitor and a voltage doubler with a resonant tank. The voltage of output diodes is clamped to V_o and so it has no high spike voltage due to voltage doubler topology. Soft-switching operation of main switches and output diodes is achieved due to resonance between transformer leakage inductance and a resonant capacitor and critical conduction mode (CRM) operation of a two switch resonant converter. CRM operation reduces switching losses of main switches at their turn-on and zero-current switching (ZCS) of the output diodes reduces the switching losses and alleviates reverse recovery problem of output diodes.

In addition, the energy stored in leakage inductance and magnetizing inductance of the transformer is recycled. The boost PFC cell is composed of boost inductors L_b, reverse-blocking diodes D_b, and a main switch S_1. In the two-switch resonant DC-DC module, the transformer T_1 is modeled as the magnetizing inductance Lm, the leakage inductance L_k, and an ideal transformer with a turns ratio of n:1. To simplify the total transformer leakage inductance, L_k is referred to the secondary side. The capacitor C_{dc} is a DC bus capacitor. The snubber diodes D_1 and D_2 are cross-connected across the main switches and the primary winding.

Here the importance is that S_1, S_3 has half the duty of S_2. When S_1 turns off S_3 turns on. There will not be major change in the working of proposed one and two switch resonant converter. Instead of single S_1 turn on of conventional circuit here there will be periodic turn on of S_1 and S_3.The operation can be explained with help of that of soft switching two switch resonant converter.

Prior to Mode 1, main switches S_1, S_2 and diodes D_1, D_2, and D_{02} are off. Diode D_{01} is conducting. Inductor currents i_{Lm} and is approach zero at t_0.

Mode: 1 At t_0, when voltage V_{S1} is a minimum value, both switches S_1 and S_2 are turned on at the same time. This is called near zero-voltage switching (ZVS), and it minimizes the power dissipation at turn-on. Since the boost inductor voltage V_{Lb} is Vin, the boost inductor current i_{Lb} increases linearly. Snubber diodes D_1 and D_2 are reverse-biased as $V_{D1} = V_{D2} = V_{dc}$. Since the voltage V_{Lm} across the inductor L_m is V_{dc}, the inductor current i_{Lm} increases linearly. In the secondary

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of T_1, with the turn-on of S_1 and S_2, output diode D_{02} starts to conduct, and resonance occurs between the leakage inductance L_k and the capacitor C_1. Output diode D_{01} is reverse-biased as V_0.

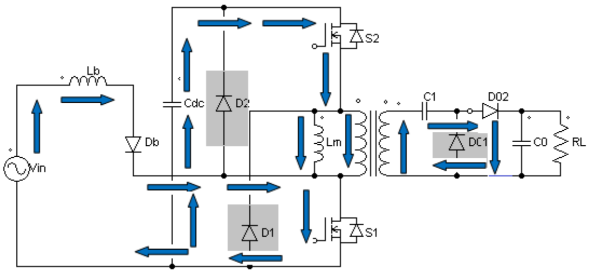

Fig. 3: Mode 1

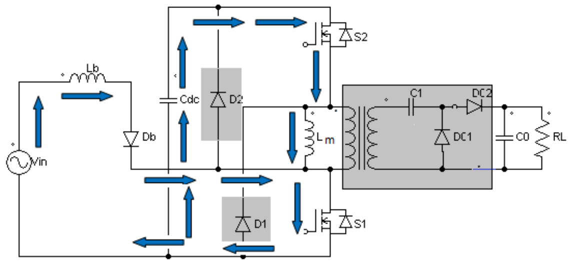

Fig. 4: Mode 2

Mode: 2 At t_1, when the leakage inductance current i_{Lk} reaches zero by resonance between L_k and C_1, this mode begins. Zero-current turn-off of diode D_{02} is achieved. The inductance current i_{Lm} increases linearly from i_1. At the end of this mode, the inductor currents i_{Lm} arrive at their maximum value. In the Secondary of the transformer T_1, the leakage inductance current i_{Lk} is zero. Hence, output diodes D_{01} and D_{02} are turned off. Output diode D_{01} is reverse-biased and output diode D_{02} is reverse biased.

.**Mode: 3** At t_2, both switches S_1 and S_2 are turned o_ at the same time. Since there is leakage inductance at the primary of the transformer T_1, snubber diodes D_1 and D_2 are turned on by the current in the leakage inductance. Hence, the voltage V_{Lm} across the inductor L_m is V_{dc}. The inductor current i_{Lm} decreases linearly from i_1 .Output diode D_{01} is turned on by the voltage of the secondary of the transformer T_1. The inductor current i_{Lk} decreases linearly. At the end of this mode, snubber diode D_1 arrives at zero, and inductor current i_{Lm} arrives at the value i_2. Since snubber diodes D_1 and D_2 are turned on, main switch voltages V_{S1} and V_{S2} are clamped to V_{dc}.

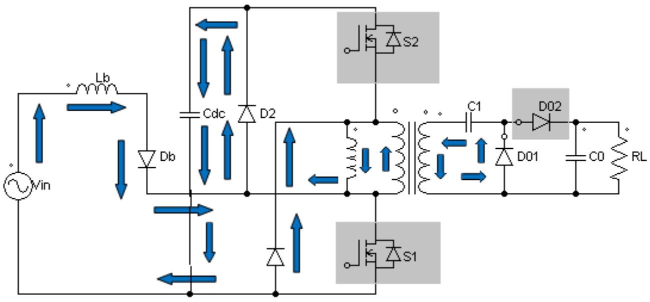

Fig. 5: Mode 3

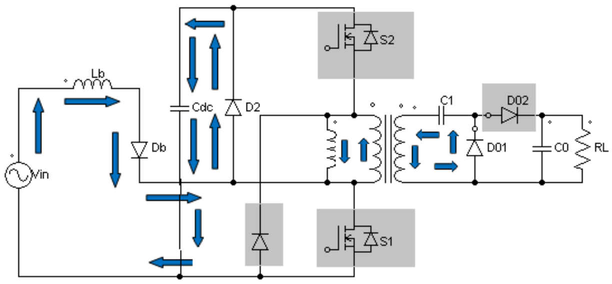

Fig. 6: Mode 4

Mode: 4 At t_3, when the snubber diode current i_{D1} reaches zero, this mode begins. However, snubber diode

D_2 is not turned off by the reverse-blocking diode D_b. Therefore, main switch voltages V_{S1} is V_{dc}. At the end of this mode, boost inductor current i_{Lb} arrives at zero. The voltage V_{Lm} across inductor L_m is reflected the voltage of the secondary of the transformer T_1.

Mode: 5 At t4, when the boost inductor currents reach zero, this mode begins. Snubber diodes D_1 and D_2 are turned off.

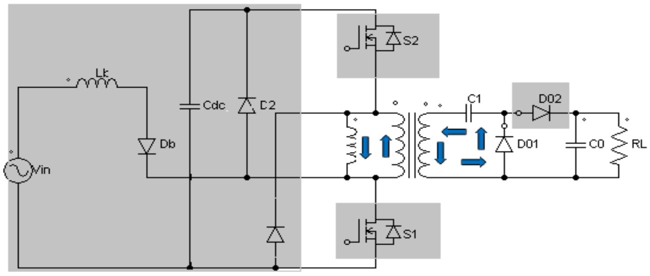

Fig. 7: Mode 5

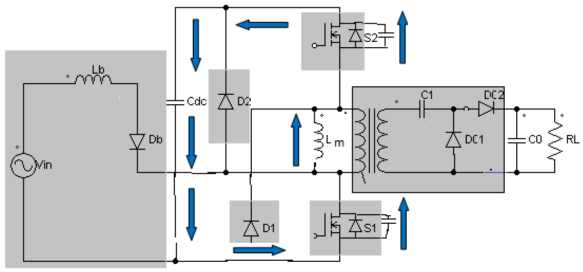

Fig. 8: Mode 6

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Mode: 6 At t_5, the magnetizing inductance current i_{Lm} falls to zero, and output diode D_{01} is turned off under the ZCS condition. Then the voltages of main switches V_{S1} and V_{S2} decrease non linearly.

The only difference of proposed converter's working is that above cycles complete with S1 first. After that S1 turns off and S3 turns on. So now these cycles repeat with S3.

3. SIMULATION MODELS AND RESULTS

In this simulation work, Resonant AC-DC converter with interleaved boost PFC circuit is done by using Psim. In the two-switch resonant DC-DC module, the transformer T_1 is modelled as the magnetizing inductance L_m, the leakage inductance L_k, and an ideal transformer with a turn ratio of n:1. Simulation parameters of two phase interleaved buck converter are shown in table 1.

Figure 9 shows the Psim model of the Soft-Switching Two-Switch Resonant AC-DC Converter with High Power Factor. 130V AC input is provided to the circuit and three MOSFET are used. The gate signals to the MOSFETS are generated using PWM technique. Gate pulse for the switch can be generated by comparing a sawtooth and a constant. In Psim sawtooth of required frequency, 90 kHz is compared with a constant using a relational operator. Whenever repeating sequence is less than the constant, it will output a high value and if constant is smaller, it will output a low value. By varying the value of constant, duty ratio of MOSFET can be controlled. Switching pulses generated is applied to the switches of the converter. Gate pulses are shown in figure 10. Figure 11 shows the simulated waveforms of the input voltage and output voltage. The measured input voltage is 130 V and the output voltage is about 44.5 V. The measured power factor is about 0.9. Soft-switching operation of main switches and output diodes is achieved due to resonance between transformer leakage inductance and a resonant capacitor and critical conduction mode (CRM) operation of a two switch resonant converter.

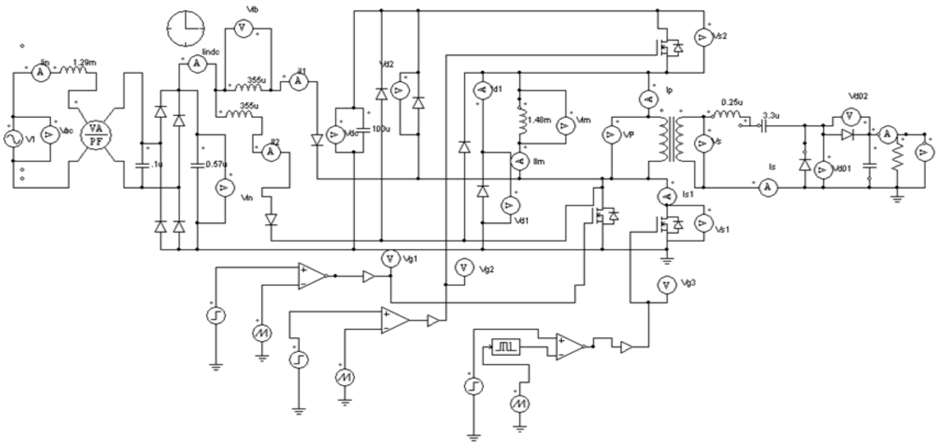

Fig. 9: Psim Model of two switch Resonant converter

TABLE 1: Simulation Parameter

PARAMETERS	VALUES
Supply Voltage	130 v
Output Power	60W
Switching Frequency	90KHz
Inductor L_f	1.29mH
Capacitor C_{in}	0.57 µF
Inductor L_b	355 µH
Capacitor C_{dc}	100µF
Capacitor C_f	0.1 µF
Transformer	L_m = 1.48mH L_k = 0.25 µH 9:1
Capacitor C_1	3.3 µF

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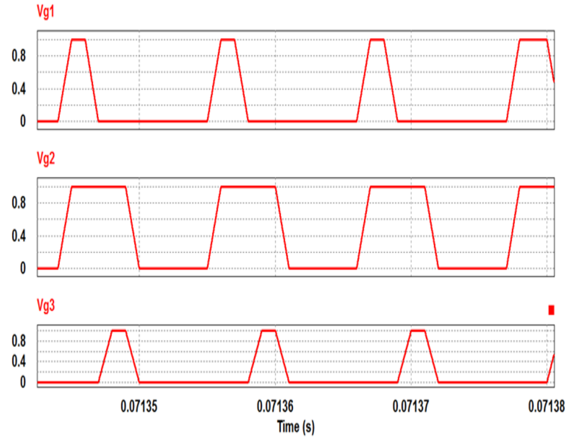
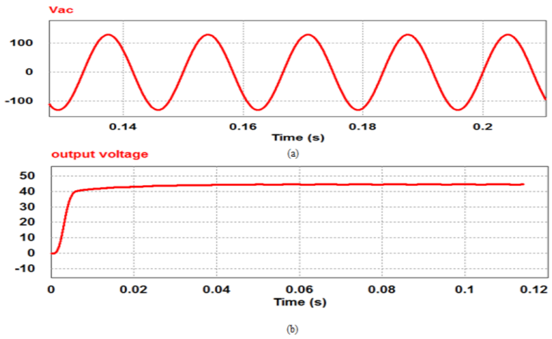


Fig. 10: Gate pulse



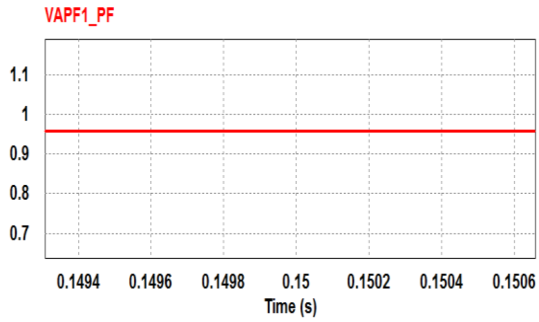


Fig. 11: (a) Input Voltage, (b) Output Voltage **Fig. 12: Power Factor**

CRM operation reduces switching losses of main switches at turn-on of them and zero-current switching (ZCS) of the output diodes reduces also switching losses and alleviates reverse recovery problem of output diodes. It is shown in figure 13 and figure 14 respectively. Since the phase of the input current is similar to that of the input line voltage, a high power factor is achieved.

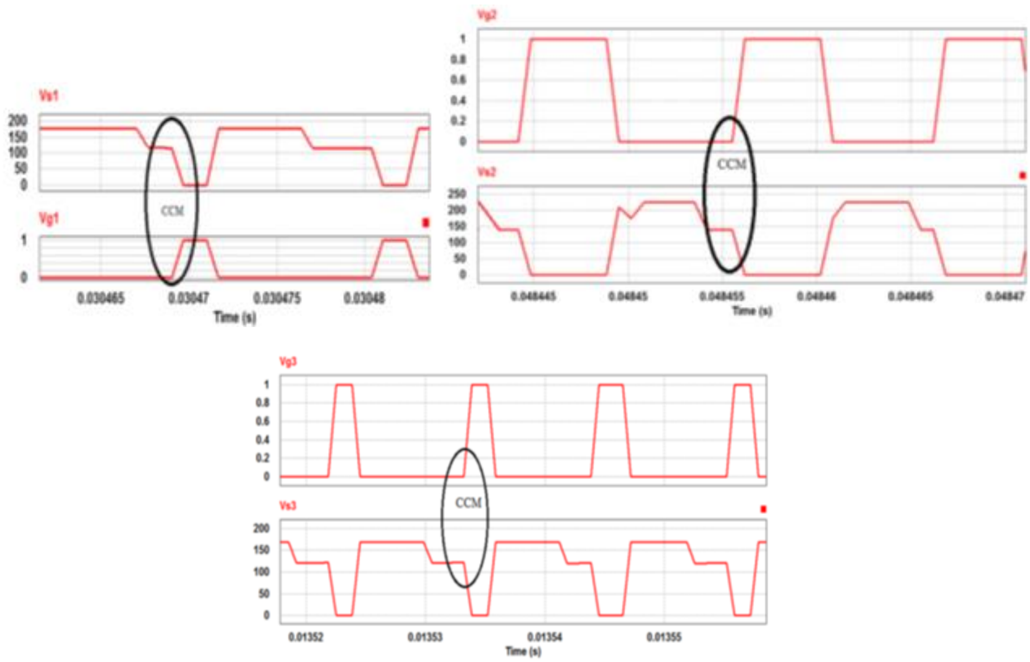


Fig. 13: Critical conduction mode operation

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Figure 14 shows the soft-switching waveforms of D01 and D02. Current circulating through secondary output diode Do1, naturally decreases to zero; the secondary output diode Do1 turns off under condition of zero current, and reverse recovery does not occur. The proposed converter obtains full range ZCS operations at heavy load condition. The resonance between Lk and C1 ends before the turn-on of D01. Since voltage VD01 is maintained at zero after current iD02 arrives at zero, the turn-off loss of output diode D02 is almost zero, and the ZCS operation of D02 is achieved. After the current of output diode D01 reaches zero, the output diode D01 is turned off. Hence, the turn-off loss of output diode D01 is seen to be almost zero, and ZCS operation of D01 is achieved. In addition, the reverse recovery of output diodes D01 and D02 is significantly alleviated.

TABLE 2: Comparative study

PARAMETER	CONVENTIONAL CONVERTER	PROPOSED CONVERTER
THD	48.63%	35.08%
Distortion factor, K_p	0.89	0.943
Power Factor	0.895	0.96
No. of switch	2	3
No. of Diodes	5	7
No. of Inductor	1	2
Duty Ratio	0.4 for all	0.4,0.2,0.2

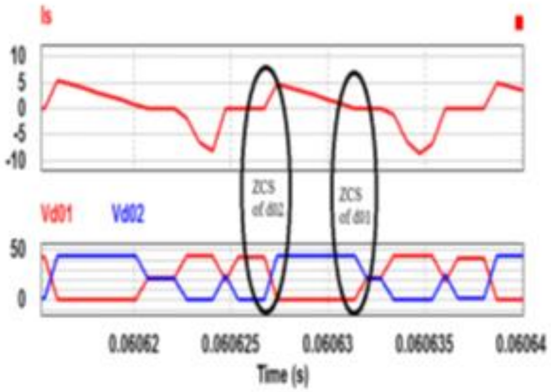
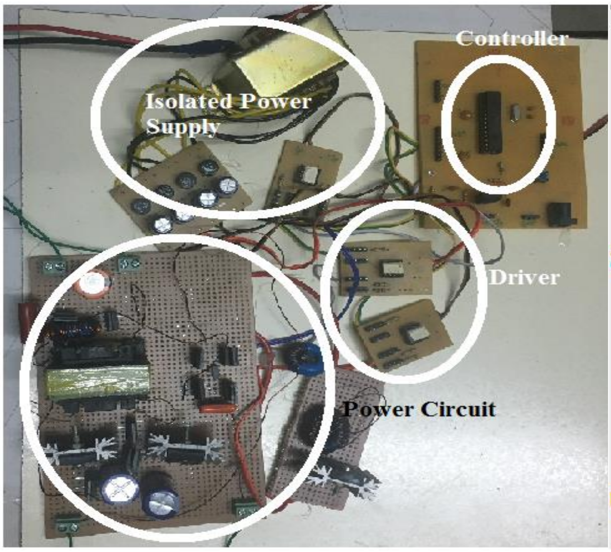


Fig. 14: ZCS operation of diodes

The total harmonic distortion or THD is a measurement of the harmonic distortion present in a signal and is defined as the ratio of the square root of the sum of the squares of all harmonic components to the fundamental frequency component. The distortion factor describes how the harmonic distortion of a load current decreases the average power transferred to the load. Table 2 shows the comparative study between resonant converter with boost PFC and resonant converter with interleaved boost PFC. Even though there is slight increase in number of components, losses are minimum due to soft switching operations. An experimental prototype was built to verify the operation of the proposed converter. A photo of the prototype is provided in figure 15. Hardware setup is done in a Printed Circuit Board(PCB). Control circuit and power circuit are implemented in one PCB. A DSpic dsPIC30F2010 which provides a high level of computational performance and programming exibility is used as control circuit.



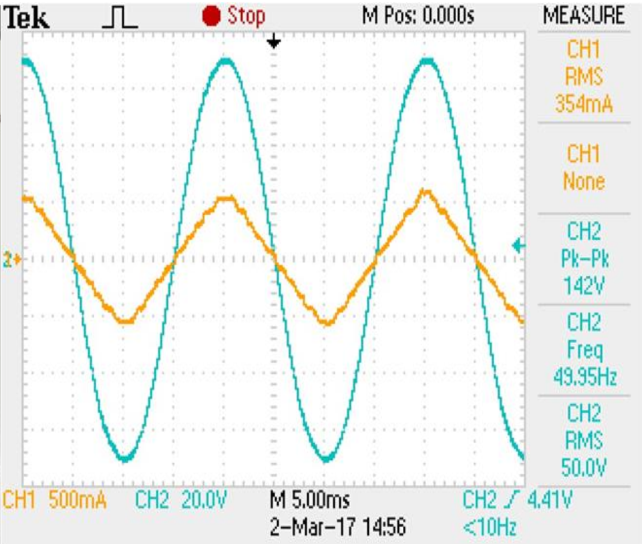


Fig. 15: Experimental set up

Fig. 16: input voltage and current

4. CONCLUSIONS

In the switching two-switch resonant AC-DC converter with interleaved PFC circuit, the interleaved boost PFC circuit operates in DCM. So a high power factor is achieved. Also the control circuit for the converter is simple. Voltage stress of main switches and diodes is reduced by utilizing two-switch structure and the voltage doubler of output stage. Moreover, the absorbed energy from the leakage inductor is reprocessed by the DC-DC module. Due to CRM operations of DC-DC module, switching losses of main switches are significantly reduced. Also, ZCS operation of output diodes is achieved by resonance manner. Therefore, the proposed converter alleviates the reverse-recovery losses of the output diodes. Hence, the converter provides high efficiency. Two switch resonant AC-DC converter with PFC circuit achieves high power factor about 0.96. THD is reduced by 27%.

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