Soft-Switching Two-Switch Resonant Ac-Dc Converter

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Abstract - *In AC to DC converters, power factor has significant importance. Most power converters and equipments are developed to have power factor correction technology to improve their performance. A soft-switching two-switch resonant AC-DC converter with high power factor is presented. In this converter, a boost PFC circuit is integrated with a soft-switching resonant converter in order to achieve high power factor. This topology provide low component stress, high frequency operation, zero voltage switching, and applicability under a wide range of input and output conditions. The voltage across the main switches is confined to the dc-link voltage and the energy of the transformer leakage inductance is also recycled. Soft-switching operation of main switches and output diodes is achieved in a resonant manner and the switching losses are significantly reduced. Thus, the overall efficiency is improved.*

***Key Words*: Power factor correction(PFC), Soft switching, Resonant converter, 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]. Examples of such effects are, distortion of input current/voltage, input voltage dip due to the presence of bulk capacitors and electromagnetic interference (EMI) due to high frequency switching.

2. SOFT-SWITCHING TWO-SWITCH RESONANT AC-DC CONVERTER

Soft-switching two-switch resonant AC-DC converter with high power factor merges a boost converter and a two switch resonant converter. The circuit diagram of the converter is shown in figure 1. The boost PFC circuit is designed to operate in discontinuous conduction mode (DCM) 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 are 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 a boost inductor L_b, reverse-blocking diode 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 S_1, S_2, and the primary winding. The operation of the converter in one switching period T_S can be divided into six modes.

3. OPERATION OF 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.

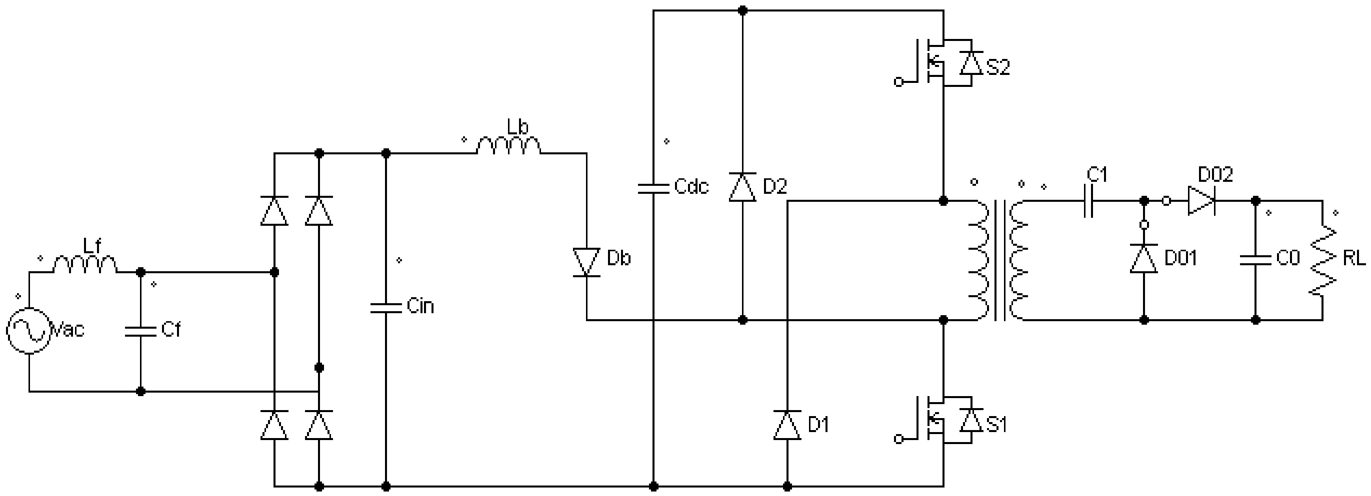

Fig-1: Soft-switching two-switch resonant AC-DC converter

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 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.

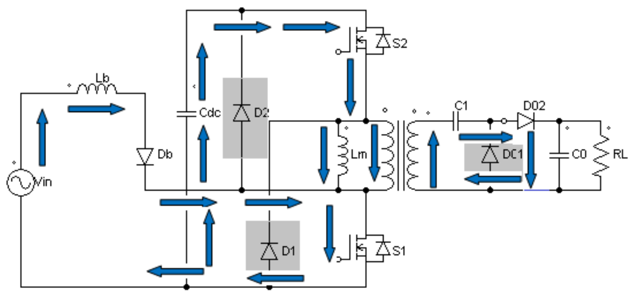

Fig- 2(a) Mode 1

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.

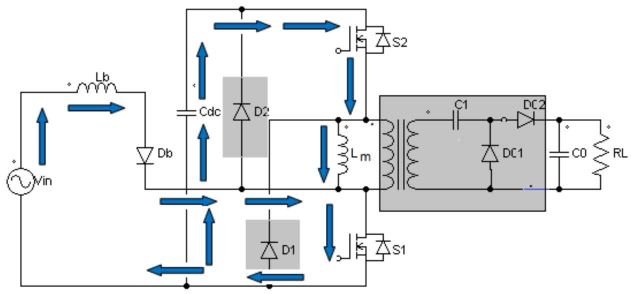

Fig-2(b) Mode 2

.**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}.

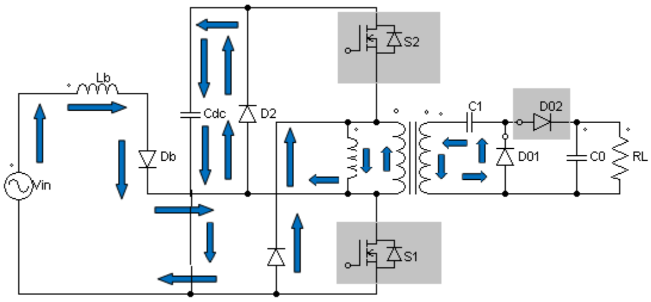

Fig-2(c) Mode 3

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.

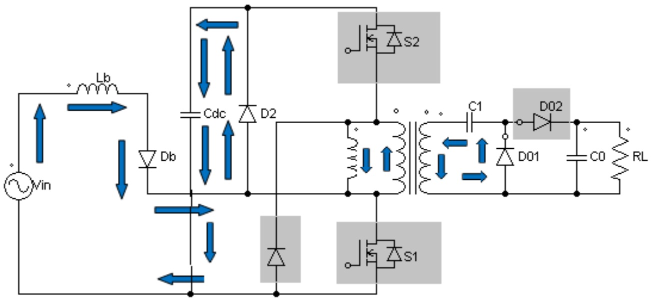

Fig-2(d) Mode 4

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

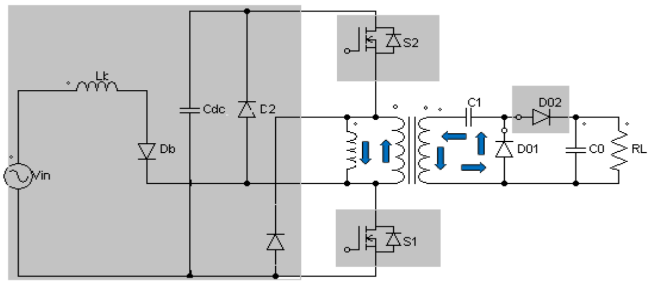

Fig-2(e) Mode 5

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.

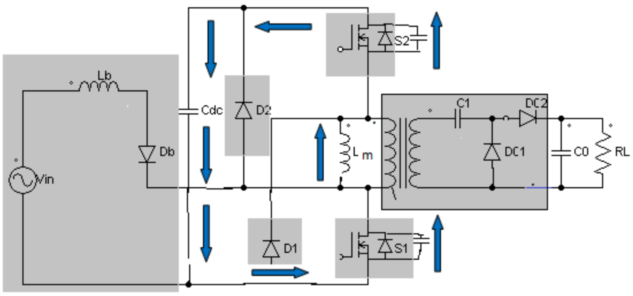

Fig-2(f) Mode 6

4. SIMULATION MODELS AND RESULTS

In this simulation work, Soft-Switching Two-Switch Resonant AC-DC Converter with PFC circuit is done by using Psim. In the two-switch resonant DC-DC module, the transformer T_1 is modeled 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 Four phase interleaved buck converter are shown in table.3.1.

Figure 3 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 two MOSFETS 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. Figure 4 shows the simulated waveforms of the input voltage and input current, power factor respectively. The measured input voltage is 130 V and the output voltage is about 44.5 V. The measured power factor is about 0.9. Figure 5 shows input voltage, rectified voltage and voltage across capacitor.

Table 1 Simulation Parameters

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

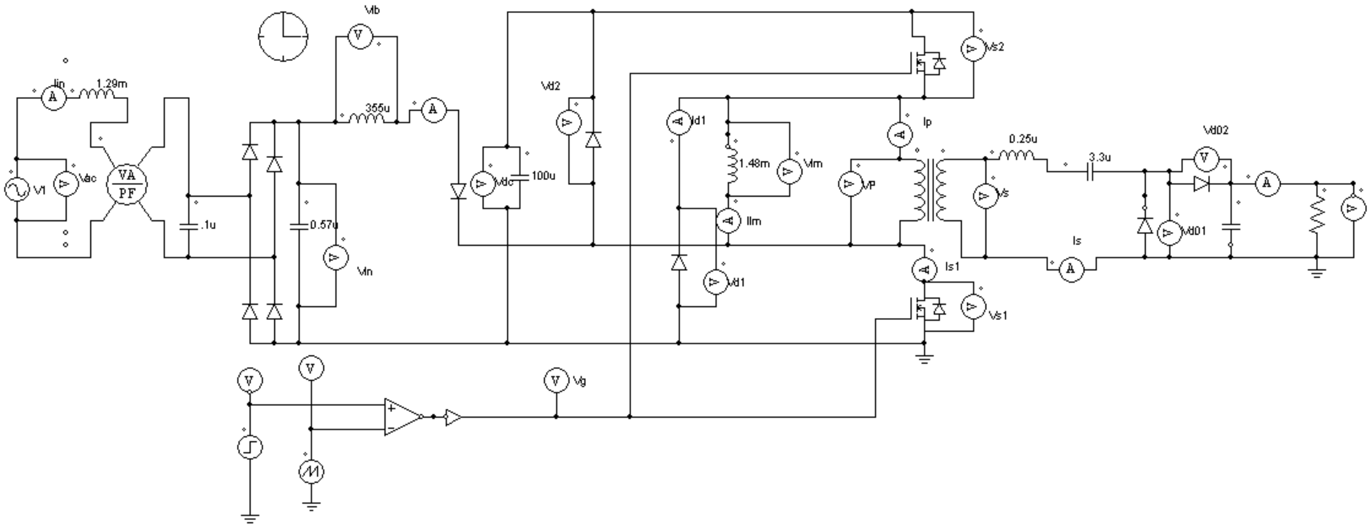

Fig-3 Psim Model of two switch Resonant converter

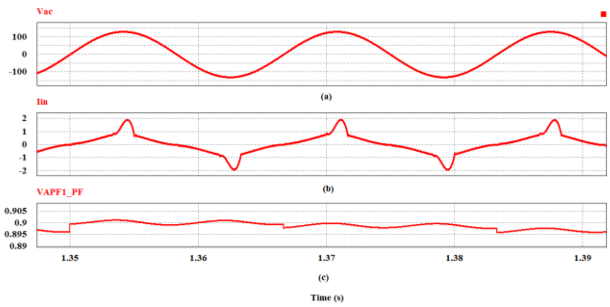

Fig-4 (a) Input Voltage, (b) Input Current and

(c) Power Factor

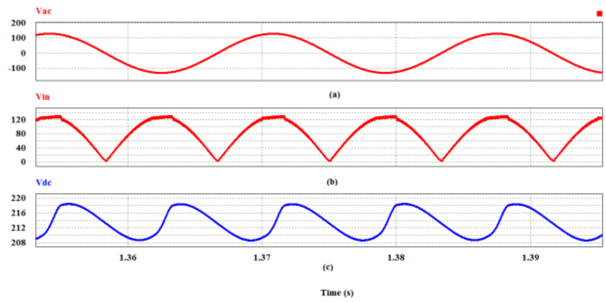

Fig-5 (a) Vac, (b) Vin and (c) Vdc

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 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 6. Figure 7 indicate corresponding voltage stress of main MOSFETs. Figure 10 shows the simulated waveforms of i_{Lb} and V_{Lb} under 60W load conditions at 130 V ac. Since the phase of the input current is similar to that of the input line voltage, a high power factor is achieved.

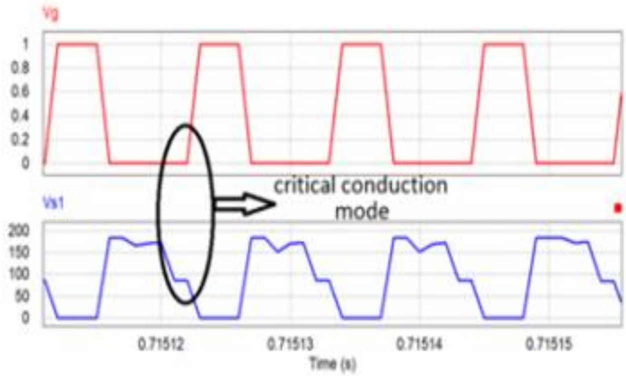

Fig-6 Critical conduction mode operation

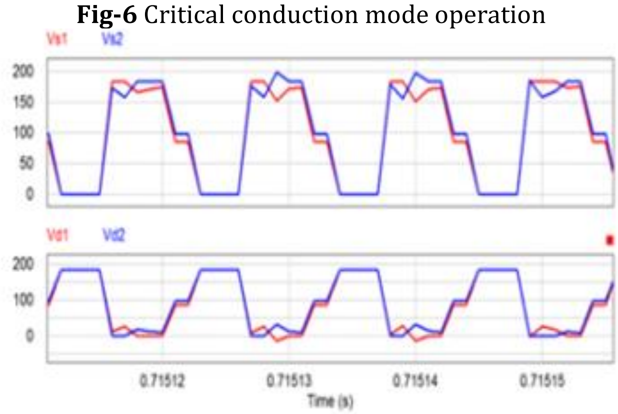

Fig-7 Voltage across switches and diodes

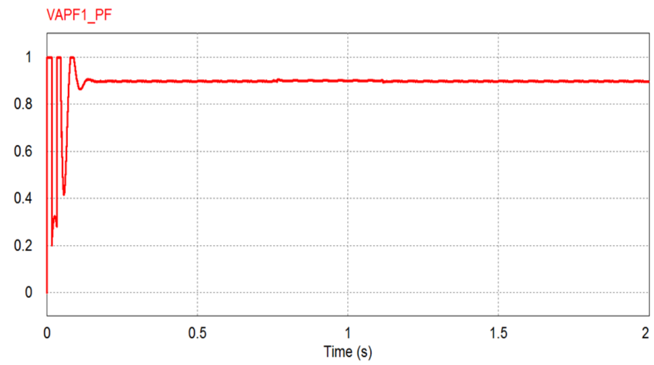

Fig-8 Power Factor

Figure 9 shows the soft-switching waveforms of D_{01} and D_{02}. Current circulating through secondary output diode D_{o1}, naturally decreases to zero; the secondary output diode D_{o1} 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. In figure 9, it can be seen that output diodes D_{01} and D_{02} operate in ZCS. The resonance between L_k and C_1 ends before the turn-on of D_{01}. Since voltage V_{D01} is maintained at zero after current i_{D02} arrives at zero, the turn-off loss of output diode D_{02} is almost zero, and the ZCS operation of D_{02} is achieved. After the current of output diode D_{01} reaches zero, the output diode D_{01} is turned off. Hence, the turn-off loss of output diode D_{01} is seen to be almost zero, and ZCS operation of D_{01} is achieved. In addition, the reverse recovery of output diodes D_{01} and D_{02} is significantly alleviated.

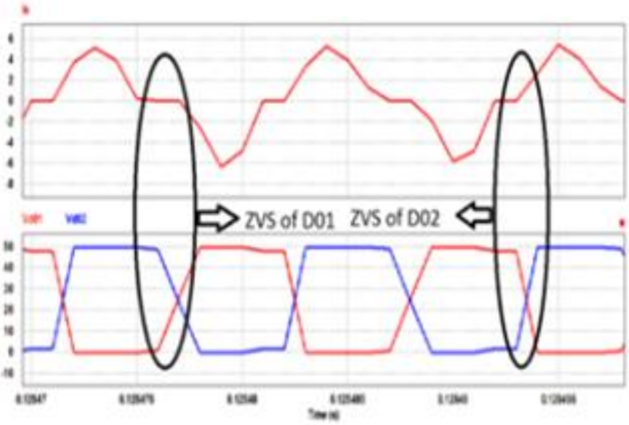

Fig-9 ZCS operation of diodes

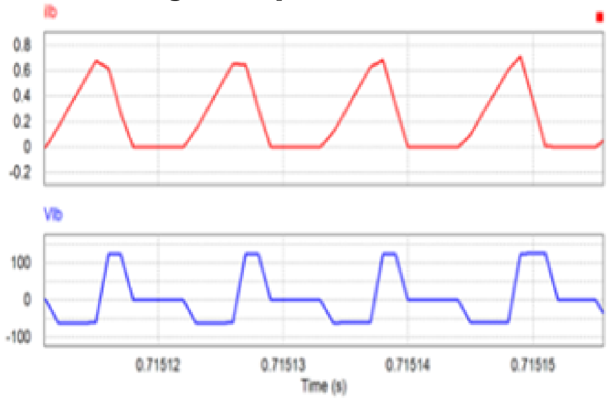

Fig-10 Current through L_b and Voltage across L_b

It can be seen that resonance between L_k and C_1 occurs, and the resonant current flows through output diode D_{02} during turn-on of the main switches S_1 and S_2. Main switch voltage V_{S1} is well clamped around V_{dc}.

5. CONCLUSIONS

In the switching two-switch resonant AC-DC converter with PFC circuit, the 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 0.91.

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