A Noel Soft-Switching AC-DC Converter using L^2SC

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ABSTRACT

In this paper, proposes a novel AC-DC converter of high power factor and high efficiency by partial resonant method. The input current waveform in proposed circuit is got to be a discontinuous sinusoidal form in proportion to magnitude of ac input voltage under the constant duty cycle switching. Thereupon, the input power factor is nearly unity and the control circuit is simple. Also the switching devices in a proposed circuit are operated with soft switching by the partial resonant method. The result is that the switching loss is very low and the efficiency of system is high. The partial resonant circuit makes use of a inductor using step up and L^2SC (Loss-Less Snubber Condenser). The switching control technique of the converter is simplified for switches to drive in constant duty cycle.

Some simulative results and experimental results are included to confirm the validity of the analytical results.

1. INTRODUCTION

The efficiency correction of AC-DC converters for high power applications has undergone great development during recent years. It is serious that an input current drawn by the phase controller or diode rectifiers creates a number of problems for the power distribution network and for other electrical systems. To improve the input current waveform and to control the power factor of it unity at the same time.

There are two control modes for the chopper of this usage. One is continuous current mode and another is discontinuous it.

In continuous conduction mode (CCM), input ac voltage and current are detected and input current is formed to be sinusoidal waveform by using pulse width modulation (PWM). The control circuit for this mode is complicated one.

In discontinuous conduction mode (DCM), the input ac current is nearly sinusoidal waveform with the constant duty cycle switching. The control circuit for the discontinuous mode is simple. The discontinuous mode converter eliminates the complicated circuit control requirement, reduces the number of components, and reduces the filter reactive components size.

When the switching device turned on, it becomes a zero-current -switching. But the device must be switched off at a maximum inductor current and a certain level of voltage in one cycle of the carrier frequency, that is, hard switching operation.

It causes the large current stress of the switching device and electromagnetic interference (EMI). Being increased switching frequency, the discontinuous mode converter has the disadvantage of increasing the switching power losses and the switching stresses of the switching devices in comparison with the conventional continuous mode converter.

Generally, the power conversion system must be increased switching frequency in order to achieve a small size, a lightweight and a low noise.

As a result of those, the power system brings on a low efficiency. To improved these, a large number of soft switching topologies, that is, zero current switching(ZCS) and zero voltage switching(ZVS) included a resonant circuit have been proposed. But these circuits increase the number of switch in circuit, complicate sequence of switching operation and increase stresses of components in the resonant circuit.

Therefore authors propose that a new AC-DC converter of high power factor and high efficiency by a partial resonant type using a L^2SC.

2. CIRCUIT CONFIGURATION

Figure 1 shows a new AC-DC converter of high power factor and high efficiency by partial resonant type using a loss-less snubber condenser.

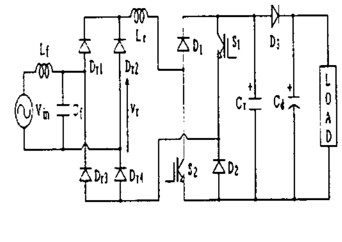


Fig. 1 Proposed Circuit

The partial resonant operation makes zero voltage switching for turn-off of the control switches with the discontinuous mode. The current flowing through the inductor L_r is controlled to be discontinuous, and then turn-on operation of switching device S_1 and S_2 becomes to be ZCS.

It results in not only decreasing switching power losses in the devices drastically, but also improving input ac current waveform distortion and power factor. Also the circuit has a merit, which is taken to increase of efficiency and to improve of harmonics distortion factor, as it makes to regeneration at input source of accumulated energy in snubber condenser without loss of snubber circuit

3. OPERATIING PRINCIPLE

If the inductor of the output side is bigger than the inductor using resonant, the load side can consider with a constant current source during one cycle of the carrier frequency. Fig. 2 shows equivalent circuits for operation of switching modes in a cycle.

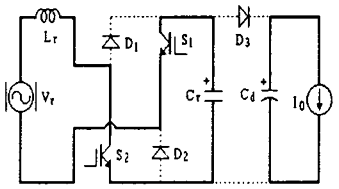


Fig. 2(a). Mode 1

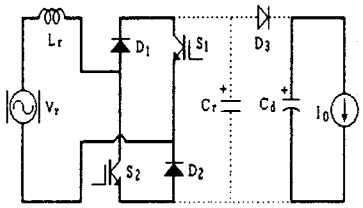


Fig. 2(b). Mode 2

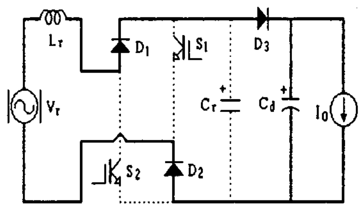


Fig. 2(c). Mode 3

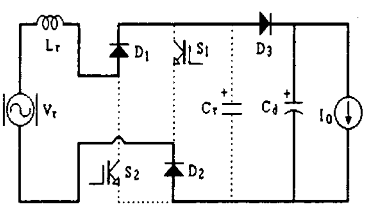


Fig. 2(b). Mode 2

Fig. 2 Equivalent circuits of switching modes in a cycle

At initial condition, the current flowing through the inductor L_r is zero.

Switch S_1 and S_2 are off-state and condenser C_r is charged at the same voltage of dc output voltage V_{cd}. Also the AC input voltage V_{in} and output voltage of full bridge rectifier V_r is expressed as like eq. (1) and eq. (2).

$$v_{in} = V_m \sin \omega_s t \tag{1}$$

$$v_r = |v_{in}| = |V_m \sin \omega_s t| \tag{2}$$

MODE 1 : T_1, $t_0 \le t < t_1$

Mode 1 begins by turning on both S_1 and S_2 at the same time. The output voltage of rectifier V_r and the voltage of condenser V_{cr} are added and applied to the inductor L_r. Then this mode takes form of a series LC resonance circuit. The condenser C_r discharges its electric charge through the inductor L_r. Turn-on of the switching device occurs in zero current state. Hence this is ZCS.

The condenser voltage v_{cr} is expressed in eq. (3) and the current flowing inductor i_{Lr} increases as like eq. (4).

$$v_{cr} = (v_r + V_{cd})\cos\omega_r t - v_r \tag{3}$$

$$i_{Lr} = \frac{v_r + V_{cd}}{X} \sin \omega_r t \tag{4}$$

here, $\omega_r = \frac{1}{\sqrt{L_r C_r}}$, $\quad X = \sqrt{\frac{L_r}{C_r}}$

This mode ends when $v_{cr}=0$. Time duration of this mode T_1 is evaluated as follows

$$T_1 = \sqrt{L_r C_r} \cos^{-1}\left(\frac{v_r}{v_r + V_{cd}}\right) \tag{5}$$

and the inductor current I_1 at the end of the mode is given by

$$I_1 = \frac{1}{X}\sqrt{v_{cr}^2 + 2 v_r V_{cd}} \tag{6}$$

MODE 2 : T_2, $t_1 \le t < t_2$

Mode 2 begins when the voltage of across C_r achieves zero. Then diodes D_1 and D_2 start conduction. The inductor current is divided into two paths of S_1-D_2 and S_2-D_1. The inductor current is linearly increased while the switches are turned off as follows

$$i_{Lr} = \frac{v_r}{L_r} t + I_1 \tag{7}$$

This mode ends when both switch S_1 and S_2 are turned off. Using the time duration of on-state of S_1 and S_2, T_{on}, time duration of this mode T_2 can be obtain as follows

$$T_2 = T_{on} + T_1 \tag{8}$$

and the inductor current I_2 at the end of the mode is given by

$$I_2 = \frac{v_r}{L_r} T_2 + I_1 \qquad (9)$$

In Mode 1 and Mode 2, ac input current increase and inductor L_r stores the energy.

MODE 3 : T_3, $t_2 \leq t < t_3$

Mode 3 begins by turning off both S_1 and S_2 at the same time. The ac current flowing through L_r takes a route of D_1-C_r-D_2 and charges C_r. Then this mode takes form of a series LC resonance circuit. Turn-off of S_1 and S_2 occurs in ZVS, because the voltage of C_r is zero voltage.

In this mode, the voltage of C_r and the current of L_r are evaluated as follows

$$v_{cr} = v_r + \sqrt{\frac{L_r}{C_r}}\, I_a \sin(\omega_t + \theta) \qquad (10)$$

$$i_{Lr} = I_a I_a \cos(\omega_t + \theta) \qquad (11)$$

here,

$$I_a = \sqrt{\frac{C_r}{L_r} v_r^2 + I_2^2}$$

$$\theta = \sin^{-1}\left(- \frac{v_r}{\sqrt{v_r^2 + \frac{L_r}{C_r} I_2^2}} \right)$$

$V_{cr} = V_{cd}$ is achieved and the diode D_3 begins to conduct, then this mode ends. Time duration of this mode T_3 is expressed as follows

$$T_3 = \sqrt{L_r C_r} \left\{ \sin^{-1}\left(\frac{V_{cd} - v_r}{\sqrt{v_r^2 + \frac{L_r}{C_r} I_2^2}} - \theta \right) \right\} \qquad (12)$$

and the inductor current I_3 at the end of the mode is given by

$$I_3 = I_2 \cos \omega_r T_3 + \sqrt{\frac{C_r}{L_r}}\, v_r \sin \omega_t T_3 \qquad (13)$$

MODE 4 : T_4, $t_3 \leq t < t_4$

Mode 4 begins when the voltage of across C_r achieves output voltage V_{cd}.

The inductor current flowing through L_r flows into the load. Since output dc voltage is higher than input dc voltage, the inductor current is decreased and achieves to zero at the end of mode 4. When the diode D_3 begins to conduct, the inductor current is decreased linearly as following to the next equation.

$$i_{Lr} = \frac{v_r - V_{cd}}{L_r} t + I_3 \qquad (14)$$

This mode ends when $i_{Lr}=0$. Time duration of this mode T_4 is expressed as follows

$$T_4 = \frac{L_r}{V_{cd} - v_r} I_3 \qquad (15)$$

4. SIMULATION RESULTS

The proposed circuit was analyzed by Pspice. Fig. 3 show waveforms of each part in a cycle switching in order to certify partial resonant operation and soft switching operation of control devices. In Fig. 3, the controlled switches are turned on at t_0 and C_r begins to discharge. v_{cr} achieves to zero at t_1. At t_2, the controlled switches are turned off and C_r is charged with i_{Lr} and achieves to V_{cd} at t_3. At t_4, i_{Lr} achieves to zero and the controlled switches are kept off till the next cycle. Tc is one period of a cycle of switching operation As the current flowing switches is zero at t_0, the controlled switches are turned on with ZCS. Also, as the voltage being across switches is zero at t_2, the switches are turned off with ZVS.

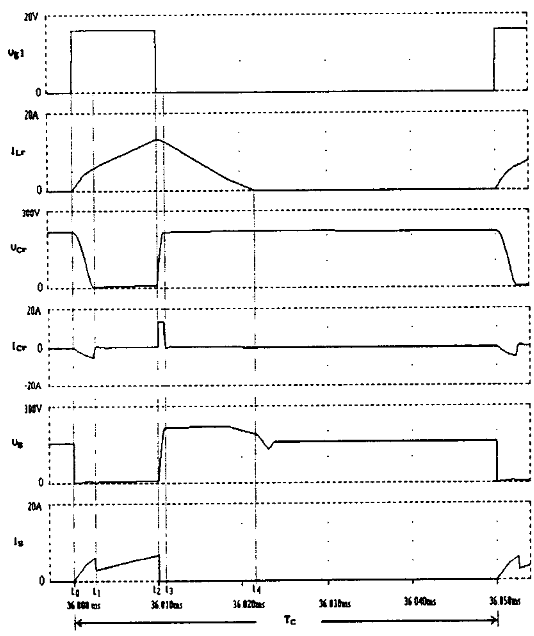
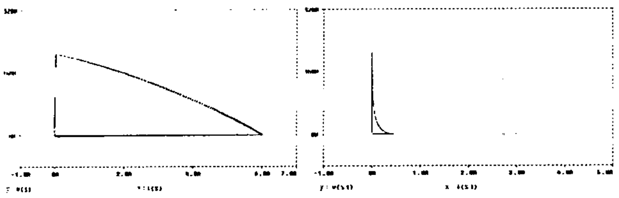


Fig. 3 Simulated waveform of each part in a cycle switching

The simulated results are confirmed the validity of the analytical results for each mode as previously stated.

Voltage-current locus (V-I locus) of the controlled switching devices in the conventional hard switching circuit is shown in Fig. 4(a). The V-I locus of the proposed soft switching circuit is shown in Fig. 4(b). For the hard switching circuit, The V-I characteristic of the controlled switching devices has a large area.

The area surrounded by the switching loci is proportional to switching loss of the device. For the proposed soft switching circuit, V-I characteristics of these have only a small area. It shows that ZCS and ZVS are achieved at switching of the devices, and drastic reductions of the switching loss of the devices are also achieved.



(a) hard-switching (b) soft-switching

Fig. 4 V-I locus of switching device

Fig. 5 shows input voltage and current with main filter. The proposed boost converter is more similar to a sinusoidal waveform because input current boost up around the zero cross point which discharged current of the resonant snubber condenser C_r regenerated to source. Hence the current has quite a little of the third harmonic component. Fig. 6 shows FFT of the input current.

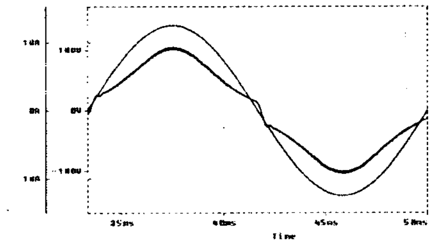


Fig. 5 Waveform of input voltage and current

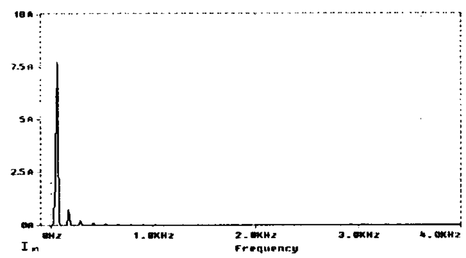
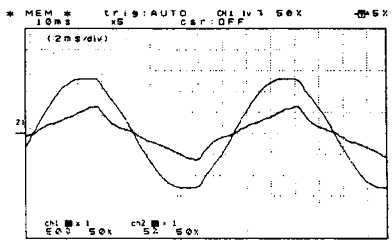


Fig. 6 Frequency spectrum of input current

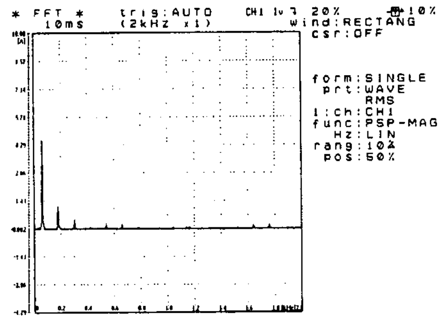
5. EXPERIMENTAL RESULT

In order to confirm the feasibility, the proposed converter is experimented with power capacitor of 0.5kW. The experimental circuit is regulated at 200V output with AC 100V input.

In order to analyze the input current, Fig. 7 show waveform and frequency spectrum of input voltage, current through input low pass filter with duty cycle 20[%]. Waveform and frequency spectrum of input voltage, current with duty cycle 30[%], 40[%] is shown in Fig. 8, Fig. 9 respectively. The fundamental component of input current is on the increase following increment of duty cycle.

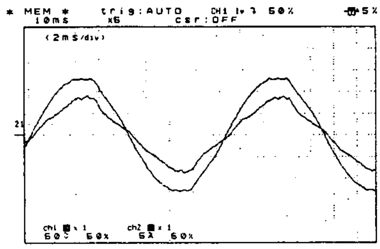


(a) Waveform of input voltage and current

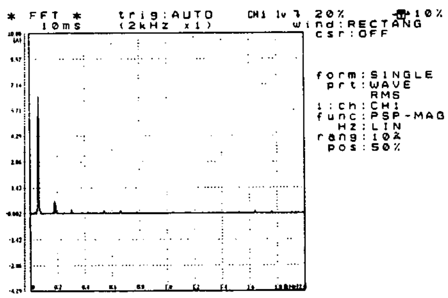


(b) Frequency spectrum of input current

Fig. 7 Input voltage, current and frequency spectrum(D_c=20[%])

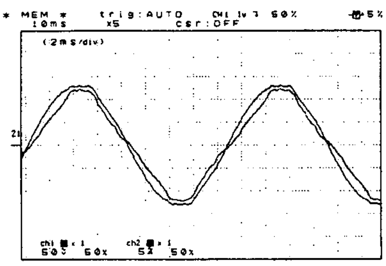


(a) Waveform of input voltage and current

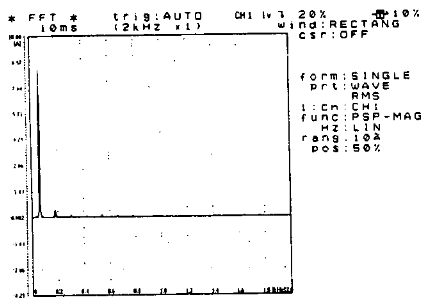


(b) Frequency spectrum of input current

Fig. 8 Input voltage, current and frequency spectrum(D_c=30[%])



(a) Waveform of input voltage and current



(b) Frequency spectrum of input current

Fig. 9 Input voltage, current and frequency spectrum (D_c=40[%])

Fig. 10 shows the relation between power factor PF and duty cycle D_c. The proposed soft-switched converter maintains high power factor in wide operational range.

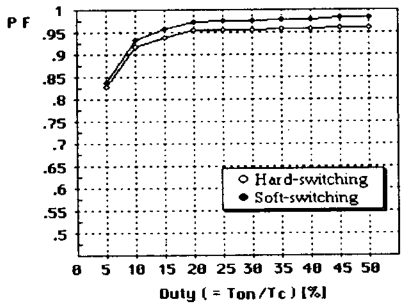


Fig. 10 Relationship between input power factor and duty cycle

Fig. 11 shows the relation between the efficiency and output power. The efficiency of the soft-switching is increased more than that of the conventional hard switching.

To make the same power, the duty cycle of soft switching operation is smaller than that of hard switching operation, because it makes to a regeneration at input source of accumulated energy in snubber condenser

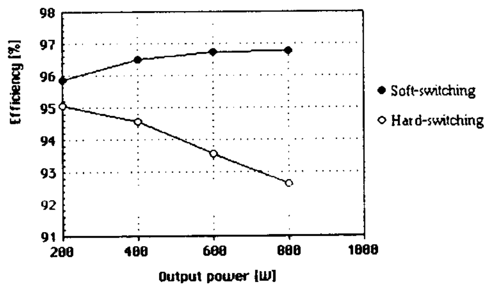


Fig.11 Relationship between efficiency and output power

6. CONCLUSIONS

A novel soft switching AC-DC converter of high power factor and high efficiency has been presented in this paper.

To achieve ZVS and ZCS, the proposed circuit is applied a partial resonant technique which is used an inductor of step up and a condenser of the loss-less snubber. The result is that switching loss is very low and efficiency of system is high. The switching control technique of the converter is simplified for switches to drive in constant duty cycle.

Also its input current is got to be discontinuous sinusoidal form in proportion to magnitude of ac input voltage under the constant duty cycle switching. Thereupon, the input power factor is nearly unity.

The circuit has merit which taken to increase of efficiency and to reduce of the harmonics of input current, as it makes to a regeneration at input source of accumulated energy in snubber condenser without loss of snubber in conventional circuit.

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7. REFERENCES

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