Analysis of a partial resonant AC-DC converter for high power and power factor

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ABSTRACT

This paper proposed that an Analysis of a partial resonant AC-DC converter for high power and power factor operates with four choppers connecting to a number of parallel circuit. To improve these, a large number of soft switching topologies included a resonant circuit have been proposed. And, some simulative results on computer are included to confirm the validity of the analytical results. The partial resonant circuit makes use of an inductor using step-down and a condenser of lose-less snubber. The result is that the switching loss is very low and the efficiency of system is high. And the snubber condenser used in a partial resonant circuit makes charging energy regenerated at input power source for resonant operation.

The proposed conversion system is deemed the most suitable for high power applications where the power switching devices are used.

1. INTRODUCTION

Generally, an input type commutative circuit is often used for a commutative circuit in a power conversion device in order to converter AC to DC. Input current in the circuit is flowing at a pick point of input voltage with a type of pulse, making lower input power factor and affecting a power system badly because it has lots of harmonic elements. In order to solve these problems, "Analysis of a partial resonant AC-DC converter for high power and power factor" is proposed in this paper. The came out converter operates with current discontinuous mode by static duty factor control. Thus, it operates with a high power converter and increases factor of the converter by making soft switching for turn-on and turn-off operating of switching.

This paper is described basic feature of the proposed circuit; the partial-resonant AC-DC converter circuit for high power that is connected to several parallel types of four choppers, by analysis and simulation.

2. STRUCTURE OF THE CIRCUIT

According to the composition of the proposed partial resonant circuit the resonant inductor can be changed to an energy charge inductor that is used commonly in a boost-down converter, and instead of the resonant condenser, a snubber condenser can be used which is in a snubber circuit of a switching mode power converter. Thus, this paper proposes topology of the circuit composition which has those merits Fig.1 indicates a common hard switching circuit.

Fig. 2 shows the main circuit of the partial resonant AC-DC converter for high power and power factor. The structure of the circuit consists of a connected partial resonant circuit part between input and a load which does switching and boosting.

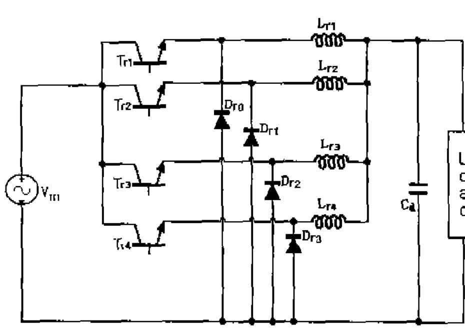


Fig.1 AC-DC Converter of Hard switching mode

The partial resonant circuit part consists of control elements, inductors for resonance, and a loss less snubber condenser. Energy that is charged in the condensers has a regenerated mode to a power device when switches are turned on. Turning on of the switches that are S_1 and S_2 makes zero current switching because current of the inductor is controlled discontinuously. On the other hand, turning off of the switches makes zero voltage switching because it operates when voltage of the condenser is zero.

The inductor(L_F) and the condenser(C_F) at a input part are filter in order to eliminate harmonics of the input current.

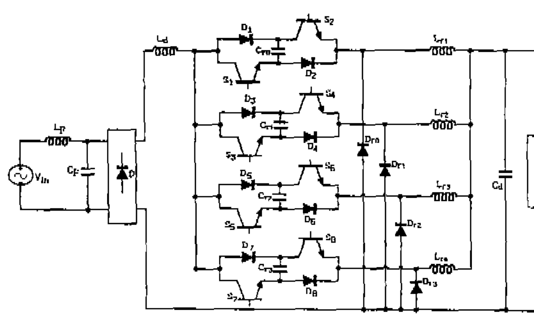


Fig.2 AC-DC Converter of High power factor with soft switching mode

3. OPERATION PRINCIPLE

When input inductance is compared with inductance at a output load part, if it is assumed that the input inductance is large enough, the load can be a constant current source, I_o, during a period of resonance. Initial conditions for this part of partial resonant circuit are that 1) switches, S_1 and S_2, are off, 2) a capacitor C_{21} for resonance is charged by voltage V_{c2} of a smoothing condenser C_2 at the output part. Besides, the alternative input voltage V_{in} and output voltage V_r of a diode bridge full-wave rectifier are showed blew equations.

$$V_{in} = V_m \sin \omega_s t \quad (1)$$

$$Vr = | V_{in} | = | V_m \sin \omega_s t | \quad (2)$$

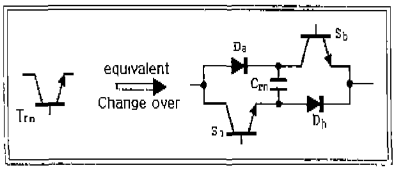
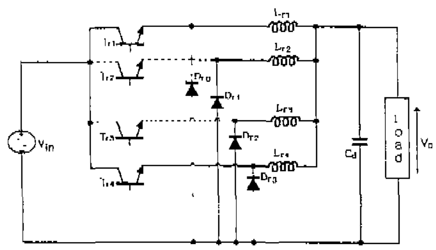
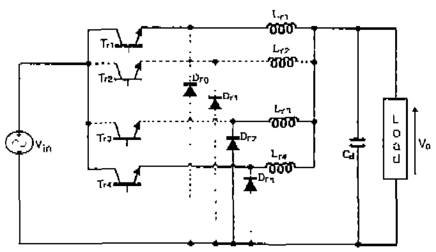


Fig.3 Modified equivalent circuit of T_{rn}

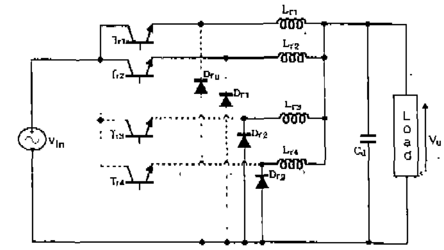
Fig. 3 shows an equivalent T_{rn} of the circuit in order to explain the mode simply whose composition is two diodes, loss less snubber condenser, two soft switches. Fig.4 shows equal circuits by the operation modes. During a period, total modes are able to be divided into 12 modes, but, in this paper, several modes are explained.



Mode Ⅰ



Mode Ⅱ



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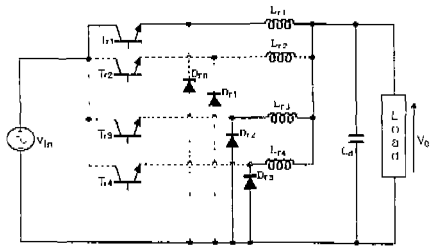
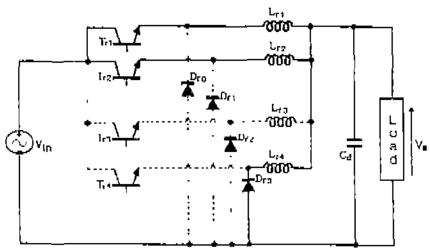
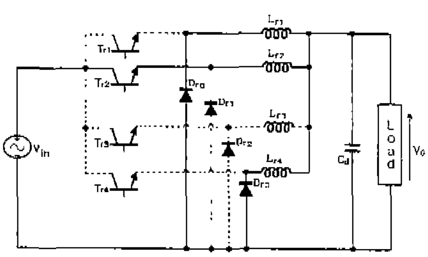


Mode Ⅳ



Mode Ⅴ



Mode Ⅵ

Fig.4 Equivalent circuit operating mode

※ Mode Analysis

Mode I : Being turn-on the switches Tr_1 and Tr_4, the current of L_{r1}, and L_{r4} increases linearly. This mode occurrences under the condition and shows that the current L_{r2}, and L_{r3} decreases and flows to the load simultaneously.

Mode II: When the switches Tr_1, and Tr_4 repeat turn-on, this mode is that the current of L_{r2} is zero and the current L_{r3} flywheel.

Mode III: The switch Tr_1 is turn-on , the current of L_{r2} becomes zero, and the current of L_{r4} starts to flywheel.

Mode IV: When the switch Tr_2 is turn-on under turn-on of the switch Tr_1, L_{r1} and L_{r2} have flowing of current, and L_{r3}, and L_{r4} flywheel to the load.

Mode V: Under such a condition which the switch Tr_3 is turn-off, the current to L_{r3} is zero and L_{r4} flywheel only.

Mode VI: Under such a condition which the switch Tr_3 and Tr_4 is turn-off, the switch Tr_2 is turn-on, the current of L_{r2} increases linearly, and the current of L_{r3} becomes zero.

4. RESULTS OF SIMULATION AND INVESTIGATION

Parameters for PSpice simulation are regarded as that a control switch is a variable resistor, and other elements are ideal. Fig. 5 indicates simulation waveforms of each part over a period of switching in order to examine the partial resonant AC-DC converter and subordinate operation of the converter's soft switching by 20[kHz] for switching frequency and 40[%] for duty factor.

Table 1 Parameters of simulated circuit

Source Voltage	Vin = 100 [Vrms] f = 60 [Hz]
Switching	f = 20 [kHz] D.F = 40 [%]
Inductor	C_d = 40 [uH]
Capacitor	Lr = 1000 [μF]
Filter Inductor	L_F = 80 [uH]
Filter Capacitor	C_F = 100 [μF]
Snubber Capacitor	Cr = 100 [nF]
Load	1 [Ω]

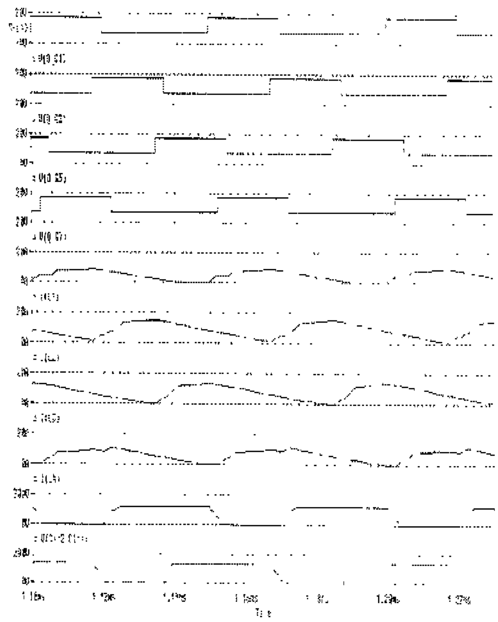


Fig.5 Simulation waveforms of each part in one cycle switching

From the simulation waveforms at the fig. 5, the partial resonant circuit is not continuous over a resonance period. Also, partial resonant operation is shown when the switch is turned on and off. By the operation, shared capacity and stress of resonant elements are reduced and loss of the resonance is decreased when output current is increased. In addition, the fig. 5 shows intervals of each modes. When the switches S_1 and S_2 are turned on, a condenser C_r in a part of serial resonant circuit starts to discharge and a inductor L_r starts to charge energy at t_0. At this point, current i_s through the switches S_1 and S_2 are the same as the inductor current i_{Lr} that makes the switches operate zero current switching. When the voltage of the condenser is zero at t_1, the control switches make short circuit, and the current of inductor L_r, thus, increases linearly and charges energy.

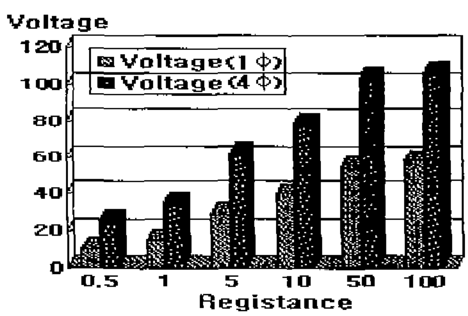


Fig.6 Relationship between output voltage and resistance ($D_c(=T_{on}/T_c)$)

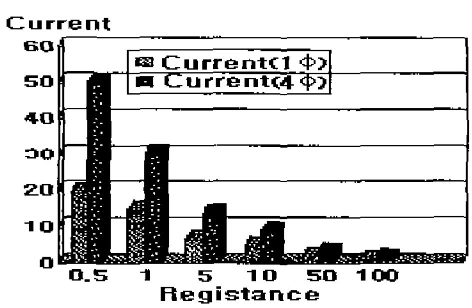


Fig.7 Relationship between output current and resistance ($D_c(=T_{on}/T_c)$)

Fig. 6 and 7 show change of the output voltage and current in regard to resistance by the results of the simulations when duty factor $D_c(=T_{on}/T_c)$is constant. Other parameters which are used in the simulations are based by the table 1. Fig8, 9 show charge of efficiency and quantity of output according the duty factor. Compared with a common hard switching and a boosting type converter, the proposed partial resonant soft switching converter has merits, those are the proposed converter can make the same output under lower duty factor in switching and the same electric energy.

It is due to the charged energy in a loss less snubber condenser, which is used for partial resonance by turning on of a switch, re-operates toward the input part then assigns to the inductor

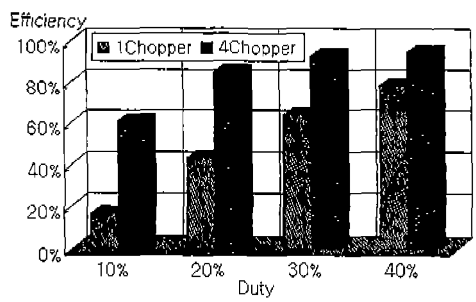


Fig.8 Relationship between efficiency and duty cycle ($D_c(=T_{on}/T_c)$)

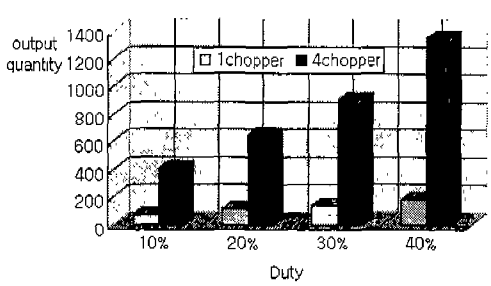


Fig.9 Relationship between output quantity and duty cycle ($D_c(=T_{on}/T_c)$)

Waveform of input voltage and current of a common hard switching AC-DC boost-down converter is shown at Fig. 10.

Fig. 11 shows a simulation waveform about the input voltage and current by the parameters of the proposed partial resonant AC-DC converter for high power. Because the discharged current of the partial resonant snubber condenser re-operates toward the power device then boosts around zero of the input current, the wave form is much similar to sinusoid. Hence, this method features that distortion factor is improved by decreasing of low level harmonics elements. By using the complex-double Fourier Series for analysing harmonics elements of the input current, the input current I_{in} appears below equations.

$$I_{in} = \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} K_{mn} \, e^{j(mx+ny)} \qquad (3)$$

$$K_{mn} = \frac{1}{(2\pi)^2} \int_0^{2\pi} \int_0^{2\pi} i_{Lr}(x,y) \cdot e^{-j(mx+ny)} \, d_x \, d_y \qquad (4)$$

In the equations, the i_{Lr} is the current of the inductor L_r, x = $\omega_c t$, y = $\omega_c t$, the ω_c is switching angular frequency, and the ω_s is angular frequency of an alternative input power source.

Fig. 12 and Fig. 13 are frequency spectrum results for analysing harmonics elements of input current about a common hard switching method and the proposed soft switching method

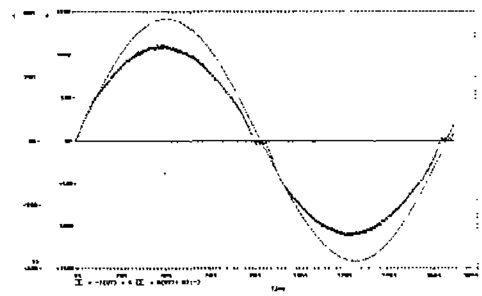


Fig.10 Simulation waveform with input voltage and current of conventional hard switching circuit

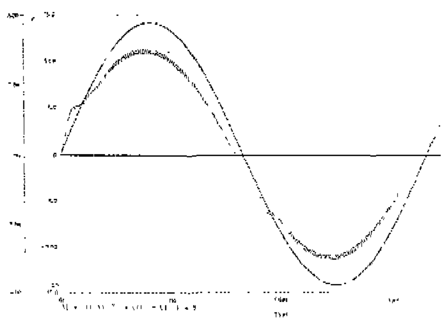


Fig.11 Simulation waveform with input voltage and current of proposed soft switching circuit

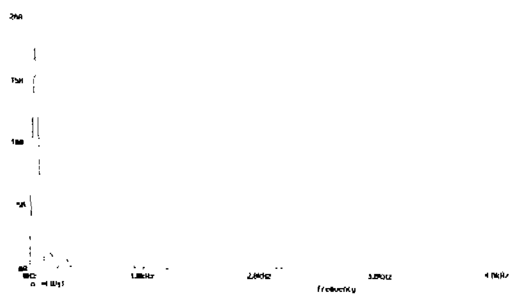


Fig.12 waveforms and frequency spectra of current of conventional hard switching circuit

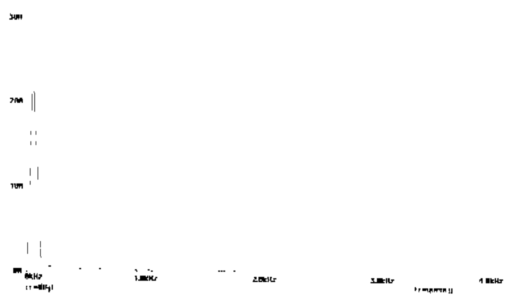


Fig.13 waveforms and frequency spectra of input current of proposed soft switching circuit

5. CONCLUSION

Commonly, a partial resonant converter circuit has lots of problems because of an increase in capacity share of a partial resonant element by repeated resonance, in peak voltage and current, and in circulating current of semiconductor device for power. It has a problem which makes control mode of switching complicated as well.

This paper has proposed the Analysis of a partial resonant AC-DC converter for high power and power factor which makes partial improvement in those problems. The switches that are used by the partial resonant soft switching mode(PRSSM) make a reduction in switching loss and the part of the resonant circuit takes a decrease in resonant loss and in the stress of resonant elements. Thus, the transducer operates with high power and efficiency. Analysis of a partial resonant AC-DC converter for high power and power factor features that the distortion factor is more improved due to canceling out the third harmonics elements by the re-generation of the snubber condensers energy than a common AC-DC converter. Besides, the converters input power factor is as good as unit power factor because the input current becomes certain current on discontinuous sinusoidal pulse in proportion to the size of the sinusoidal input voltage by static duty factor control.

Efficiency and validity of this paper are supported by computer simulation and experiment. In the long run, the AC-DC converter will have higher power, power factor, and efficiency when the most adaptable filter and load current.

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