PARALLEL-RESONANT CONVERTER WITH ZVS-PWM CONTROL

Tamotsu NINOMIYA*, Takayoshi HASHIMOTO*, Hidekazu TANAKA*,
Masahito SYOYAMA*, and Richard P. TYMERSKI**

* Dept. of Elect. and Electro. Syst. Eng., Kyushu University, Fukuoka, 812-8581 JAPAN
** Dept. of Electrical Engineering, Portland State University, Portland, Oregon 97207 USA

ABSTRACT - A parallel-resonant converter with zero-voltage-switching, pulse-width-modulation (ZVS-PWM) control is proposed. Similar to the previously proposed series-resonant counterpart, *it has a simple structure and can be* controlled at a constant switching frequency using an active-clamp technique. The nearly constant current output characteristic of the parallel-resonant converter lends itself beneficially to precisely controlled constant current power supply applications. An experimental breadboard featured an accuracy of ±1% for an output current of 2A, with an efficiency of 75%.

1. INTRODUCTION

Many resonant converters have been proposed [1,2]. Generally, variable frequency control is used to control the output voltage or current of such converters. Consequently, the output filter is designed for the lowest switching frequency, and so the size reduction of the converter is compromised. Constant–switching-frequency operation is highly desired for optimum design of the output smoothing filters and noise filters. Recently, resonant converter topologies with constant-switching-frequency operation and PWM control have been proposed[3-5], but their circuit configurations are complicated.

A novel series-resonant converter with ZVS-PWM (zero-voltage-switching, pulse-width-modulation) control was proposed in [6-8]. This converter has a simple structure, and constant-switching-frequency operation can be achieved by an active-clamp technique[9].

In this paper, a parallel-resonant version with *ZVS-PWM control is proposed.* When the converter operates at a switching frequency higher than its resonant frequency, it can maintain ZVS operation, and the output voltage or current can be controlled by the PWM method at a constant switching frequency. The output characteristics of this converter are of a constant current source. Therefore, using PWM control of an active-clamp circuit results in a precisely controlled constant-current power supply. *An accuracy of ±1%* deviations for an output current of 2A and an efficiency of 75% have been obtained with an experimental breadboard.

2. CIRCUIT TOPOLOGY

The circuit topology of the ZVS-PWM-controlled parallel-resonant converter is shown in Fig.1, where the output current is regulated through the feedback loop. The inverter with an active-clamp circuit is composed of a main switch S1, auxiliary switch S2, clamp capacitor Ca, and inductor La. This inverter yields an ac voltage with an amplitude-modulated quasi-square waveform. The parallel-resonant circuit composed of Lr and Cr is connected to the above inverter. The output side consists of a center-tapped rectifying circuit and an LC filter.

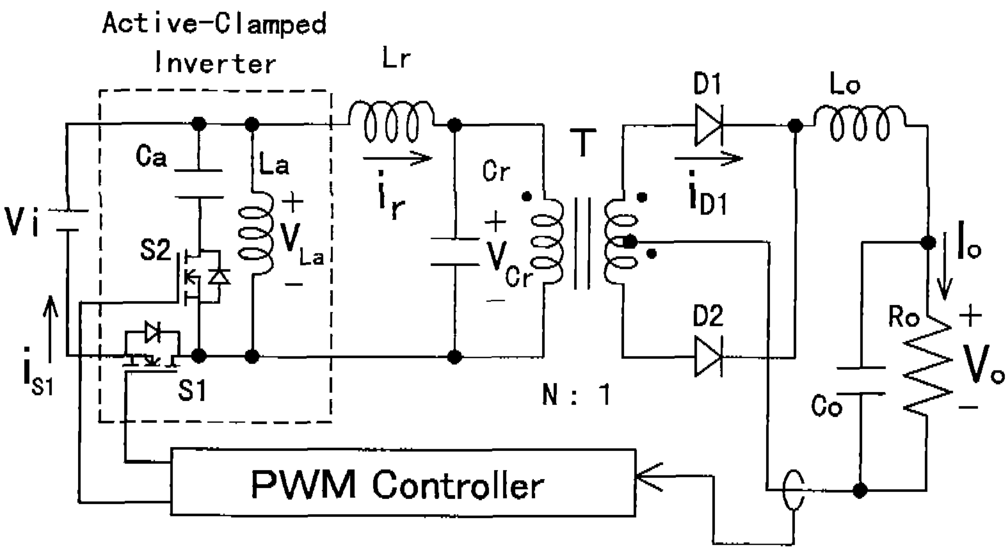


Fig.1. ZVS-PWM-controlled parallel-resonant converter for a constant-current power supply

3. OPERATION AND ANALYSIS

The switching frequency of this resonant converter is set to be slightly higher than resonant frequency so that the phase of the resonant current **ir** lags behind the voltage across the inductor La. Furthermore, switches S1 and S2 are turned on and off alternately with a short dead time. During this dead-time interval, the output capacitance of the main switch S1 is discharged by the phase-lagging current **ir** . As a result, ZVS operation of the main switch is achieved. Figure 2 shows key converter waveforms, where neglecting the short dead times, one switching cycle is divided into four states. A precise analysis can be performed using these four states, but its process is too complicated to obtain any analytical expressions. Here, we consider a simple procedure to describe the PWM control mechanism and to obtain some analytical expressions for the output characteristics.

First, denoting the duty ratio of S1 by D, the voltage VLa is derived to be a quasi-square waveform with peak-to-peak amplitude of Vin/(1-D) as shown in Fig.2. Then, this quasi-square waveform is expanded in Fourier Series as follows:

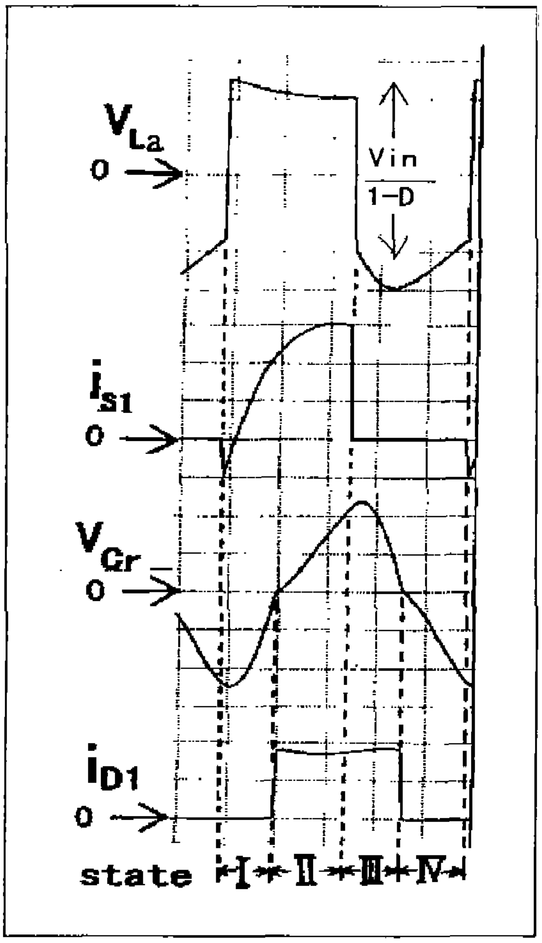


Fig. 2 . Key converter waveforms and Operating states

$$V_{La}(t)=\frac{V_{in}}{1-D}\cdot\frac{2}{\pi}\cdot\sum_{k=1}^{\infty}\left\{\frac{1}{k}\sin(kD\pi)\sin(k\omega_s t-\Phi_k)\right\} \tag{1}$$

where

$$\omega_s = 2\pi f_s \, , \qquad \phi = \tan\left\{\frac{\sin(2\pi kD)}{1-\cos(2\pi kD)}\right\} \tag{2}$$

Considering that this voltage is applied to the resonant circuit and its fundamental frequency component only is transferred to the output side due to the strong resonance, the amplitude of the ac input voltage of the resonant circuit is equivalently given by

$$V_{LA}(1)=\frac{V_{in}}{1-D}\cdot\frac{2}{\pi}\cdot\sin(D\pi) \tag{3}$$

The normalized quantity VLa(1)/Vin versus D is shown in Fig.3. It is evident that the output voltage or current can be controlled by the duty ratio D over a wide range. Namely, PWM control of this resonant converter is achieved at a constant switching frequency.

Second, connecting the above equivalent input voltage to the parallel-resonant circuit, the transformer, and the output stage, an equivalent circuit for analysis is obtained as shown in Fig.4, where Rs is a parasitic resistance associated with the inductor Lr, and Rac represents an equivalent ac resistance for a full-wave rectifier and an inductor-input smoothing filter[10], and is expressed as

$$Rac = \frac{\pi^2}{8} Ro \tag{4}$$

As a result, the output current Io is derived from this linear circuit composed of Lr, Cr, Rs, and Rac as follows:

$$Io = \frac{4}{\pi^2} * \frac{Vin}{1-D} * \frac{\sin(D\pi)}{N\ Ro} * \frac{1}{\sqrt{\left(1+\frac{Rs}{N^2Rac}-\omega^2 CrLr\right)^2+\left(\omega CrRs+\frac{\omega Lr}{N^2Rac}\right)^2}} \tag{5}$$

Third, calculating (5) with some parameter values, the load characteristics are obtained as shown in Fig.5. Evidently, the output dc current is precisely controlled by the PWM method.

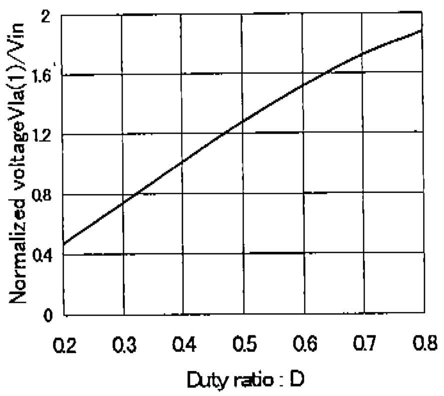


Fig.3. |VLa(1)|/Vin vs. D

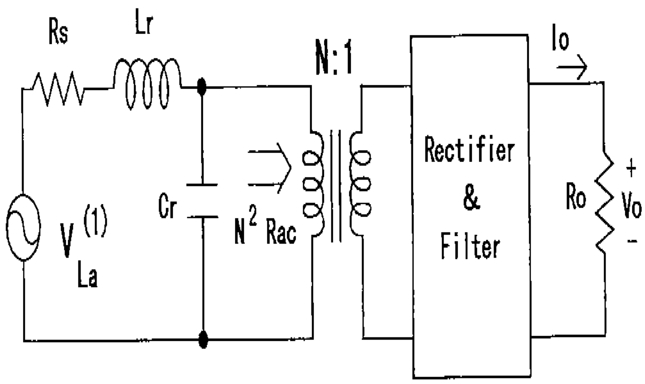


Fig.4. Equivalent circuit for analysis

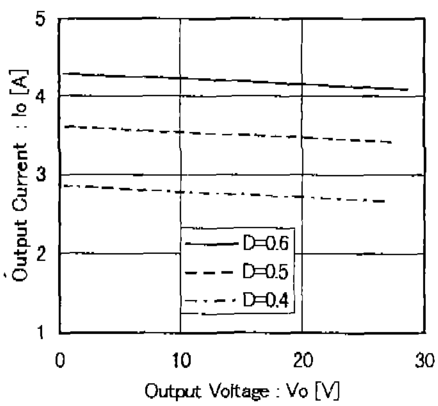


Fig.5. Calculated result of load characteristics (Vin=50V)

4. EXPERIMENTAL RESULTS

To confirm the operation of this converter, a breadboard was built for a constant-current power supply with the output current set at about 2A. The circuit parameters are as follows: Input voltage Vin=50V, La=63 μ H, Ca=0.1 μ F, Lr=14.0 μ H, Cr=44.8nF, transformer's turns ratio N=1, Lo=43 μ H, Co=1200 μ F, and switching frequency fs=220kHz. Figure 6 shows the load characteristics of this converter. We see a nearly constant current characteristic. Furthermore, the output current can be varied by the duty ratio D of the main switch. Therefore, under feedback control with a current sensor, the output current can be precisely regulated at a predetermined value. Figure 7 shows the experimental results of the regulation characteristics, for the variation of the input voltage Vin in Fig.7(a), and for the load variation in Fig.7(b). As seen from these figures, a high accuracy of ±1% is achieved.

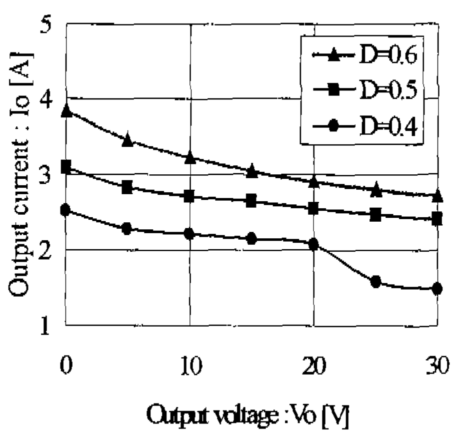
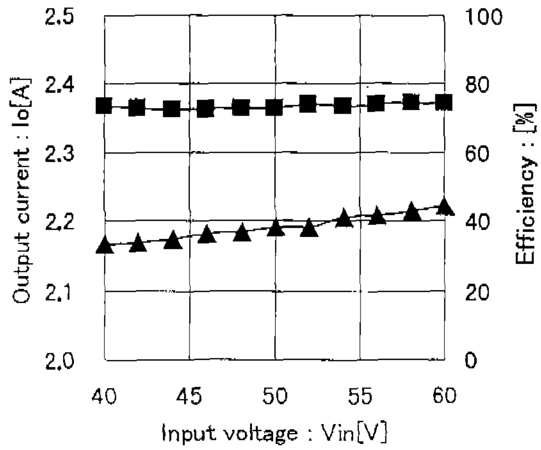
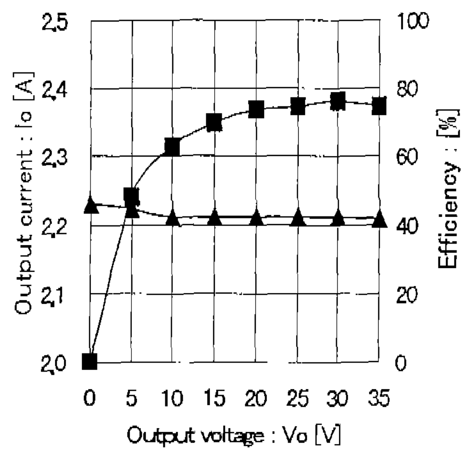


Fig.6. Experimental result of load characteristics (Vin=50V)



(a) For input-voltage variation (Ro=9.1Ω)



(b) For load variation (Vin=50V)

Fig.7. Output-current regulation

Furthermore, these figures show the experimental results of power conversion efficiency, and we see that a maximum efficiency of 75% is achieved. In the case of a higher output voltage, a higher efficiency may be obtained.

Figure 8 shows some experimental current and voltage waveforms which confirm normal operation. Finally, Figure 9 shows noise characteristics of the output current and voltage.

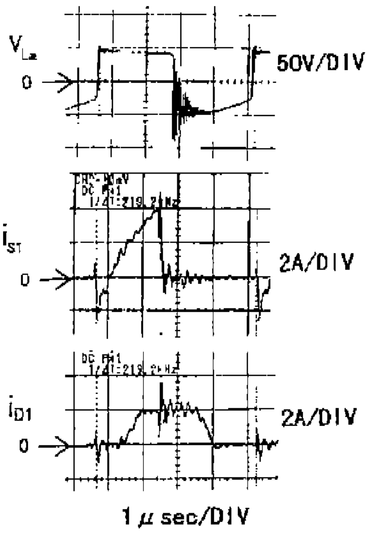


Fig.8. Experimental key waveforms

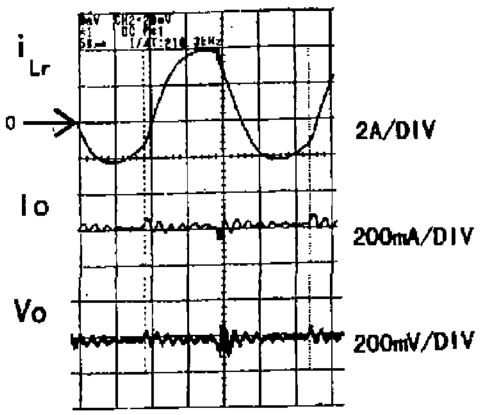


Fig.9. Noise ripples of output current and voltage (Io=2.2A, Vo=25V)

5. CONCLUSIONS

A ZVS-PWM-controlled parallel resonant converter using an active-clamp technique has been proposed and its steady-state characteristics have been examined by experiment. It was found that the output current of this converter can be regulated precisely by means of a PWM control scheme at a constant switching frequency. An experimental circuit operating at 220kHz was constructed and yielded a maximum efficiency of 75% at an output current of 2A.

The proposed converter circuit shows promise as a power supply for an optical fiber communication system[11] due to its accurate constant current property.

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