Maximum-Efficiency Tracking Scheme for Piezoelectric-Transformer Inverter with Dimming Control

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Abstract

This paper provides a solution for the problem of efficiency decrease caused by load variation. A novel control scheme of tracking the PT's operation frequency for the maximum efficiency is proposed. As a result, a high efficiency over 80% has been achieved even under the output-current decrease down to 10% of the full load current.

keywords: PT inverter, CCFL, dimming, phase-shift control, maximum-efficiency tracking

1. Introduction

In recent years, piezoelectric transformers(PTs) have been widely used as electronic ballasts for cold cathode fluorescent lamps(CCFLs) in liquid crystal displays for portable electronic equipments. The application of PT yielded the development of low-profile and energy-saving electronic equipments. Concerning the dimming control of a CCFL, the conventional method is to vary the operating frequency of PT to control the output current of the electronic ballast[1]. However, the power efficiency of PT depends on the operating frequency, and so the large frequency deviation from its resonant frequency causes the efficiency deterioration. In the previous paper[2], the electronic ballast with dimming control at a fixed-frequency operation has been reported, and the high power efficiency has been confirmed even for a deep dimming level. However, the power efficiency decreases due to a large deviation from the resonant frequency caused by load variation and environmental temperature changes.

This paper provides a solution for the above-mentioned problem, and presents the more improvement of efficiency by a novel control scheme. Namely, for tracking of the maximum efficiency, a method of controlling the PT's operation frequency is proposed. As a result, in the experiment, a high efficiency over 80% has been achieved for the output current decreased down to 10% of the full load.

2. Circuit and control operation

Figures 1 and 2 show the inverter circuit configuration, and waveforms to describe the mechanism of the phase-shift control in a full-bridge inverter. As seen from the time chart of gate signals for four switches, the input voltage Vr of the parallel-resonant circuit equals +Vi while both the switches S1 and S4 are kept ON. The voltage Vr becomes zero while both the switches S2 and S4 are ON. Therefore, the duration

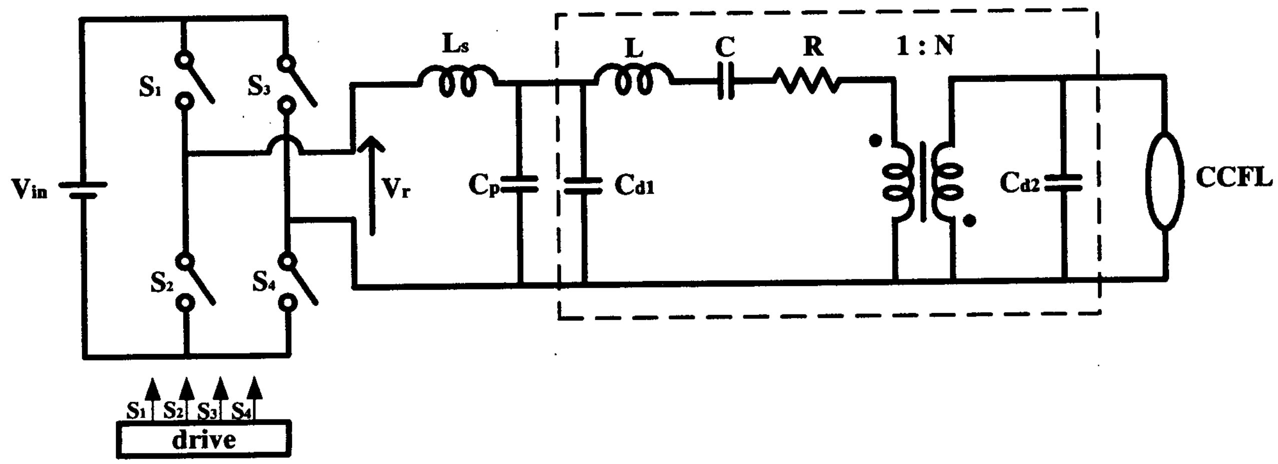


Fig.1. Piezoelectric-Transformer Inverter using Full-Bridge Circuit.

of voltage occurrence for Vr decreases oppositely when the phase difference ϕ between S1 and S4 increases. During the negative half-cycle, the duration when the voltage Vr keeps -Vi decreases with the increase in the phase difference ϕ between S2 and S3. Consequently, the pulse width of the voltage Vr varies with the phase difference of these switches. As a result, the input voltage of PT can be varied, and then the lamp current can be controlled. In another matter, a PT has the resonance peak in the frequency response of voltage boost ratio and efficiency. Therefore, our previous paper[2] presented the scheme of shifting the above phase difference at a fixed switching frequency near the resonance peak in order to improve the efficiency for dimming.

However, these resonant characteristics depend on the load impedance and the temperature change[3]. When the lamp is dimmed, the equivalent impedance of CCFL becomes larger than at the full-load condition, and therefore the PT's resonant frequency increases. As seen from Fig.3 where the simulated frequency characteristics of the PT inverter efficiency are shown for three values of load impedance, the switching frequency where the maximum efficiency is obtained shifts to the higher side as shown by black circles on the curves. Furthermore, the phase difference between input and output voltages of the PT is also shown in Fig 3. As seen from this result, the switching frequency where the phase difference is about 110 degrees also moves to the higher side. Therefore, by varying the switching frequency so as to keep the phase difference constant, the tracking control for a higher efficiency can be obtained, though it does not completely coincide with the maximum efficiency.

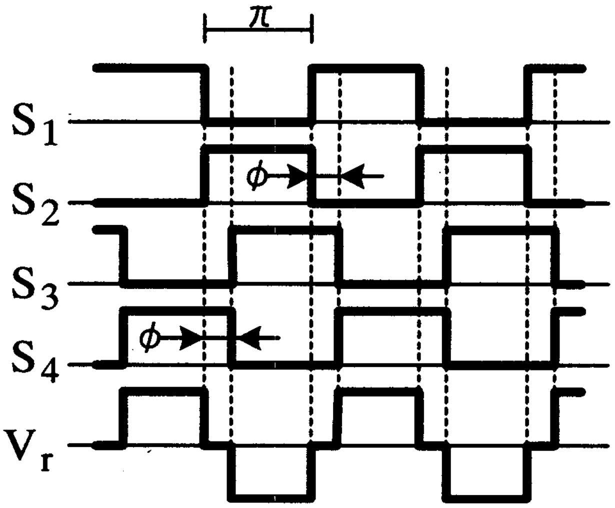


Fig.2. Time chart of gate-driving signals for phase-shift control.

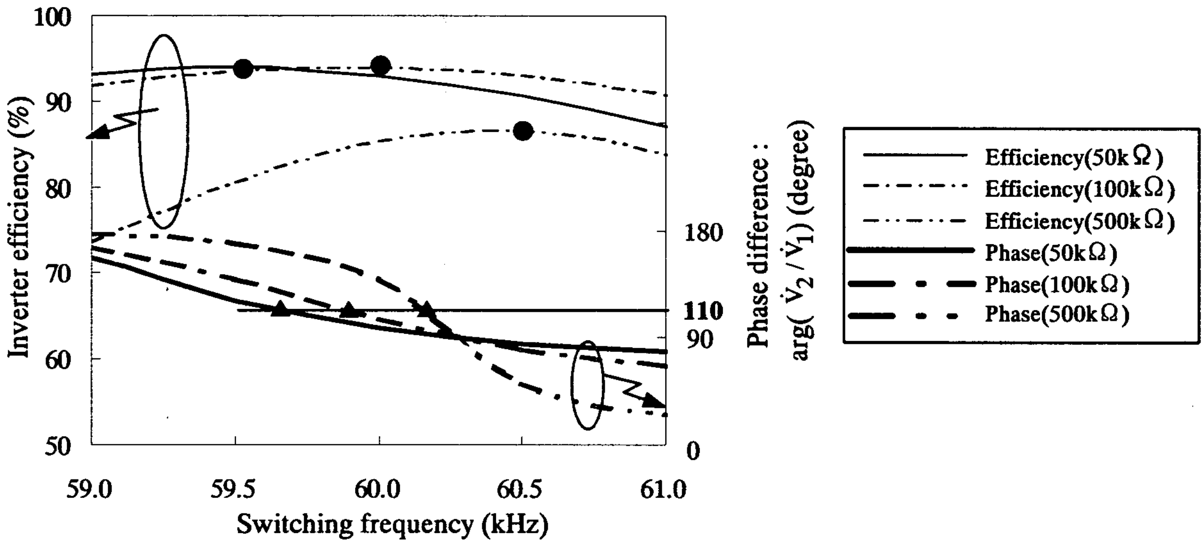
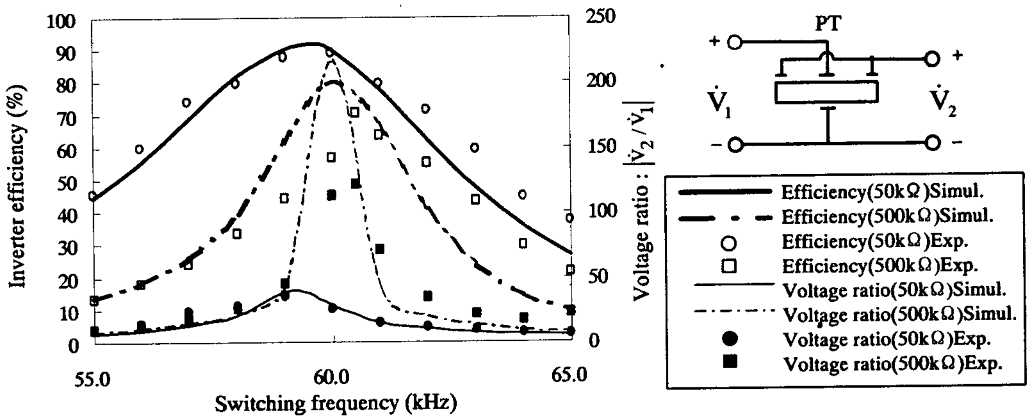


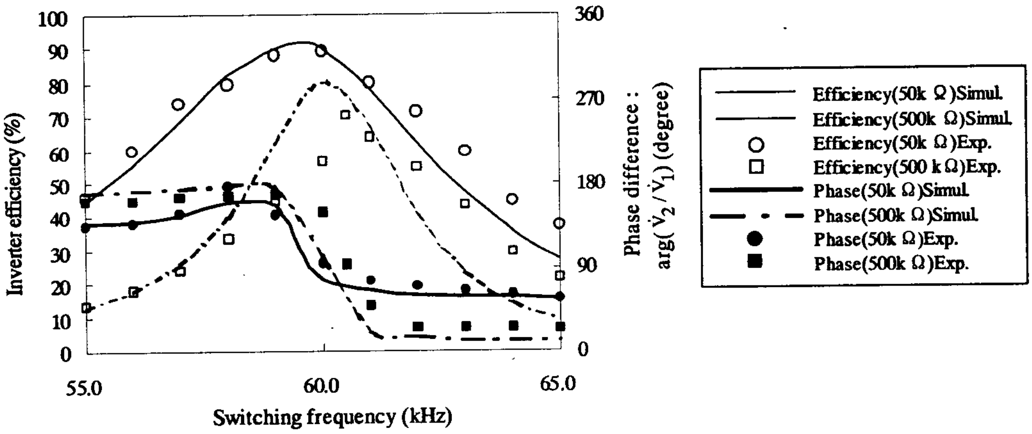
Fig.3. Frequency response of phase difference and inverter efficiency by simulation

Figure 4 shows the experimental frequency responses of voltage ratio, efficiency, and PT's phase difference, and compares them with the simulated results. It is evident from these results that the higher-efficiency tracking can be obtained by keeping the PT's phase difference to be 110 degrees.

Based on the above discussion, a block diagram of the quasi-maximum-efficiency tracking controller is proposed as shown in Fig.5. The input and output voltages of PT are detected, and the phase difference of them is converted to voltage signal. The minor feedback loop of frequency control by VCO maintains the PT's phase difference of 110 degrees. Hence, the switching frequency is shifted at the frequency near the resonance peak. The dimming control is achieved by the phase-shift control of the full-bridge inverter. Consequently, the quasi-maximum efficiency can be obtained at any conditions.



(a)Frequency response of voltage boost ratio and inverter efficiency



(b)Frequency response of phase difference and inverter efficiency

Fig.4. Resonant characteristics of PT inverter

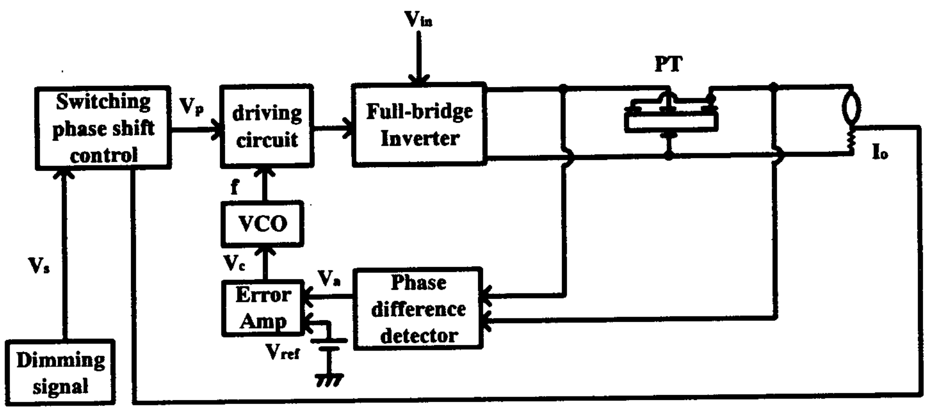


Fig.5. Block diagram of controller for dimming and maximum-efficiency tracking

3. Experimental results

In the experiment, a CCFL (3W rated) made in Matsushita, Inc., Japan, a PT (3W rated) made in Hitachi Metals, Inc., Japan, were used. In this case, a full-load lighting state was achieved at the output current of 10mA, and the power efficiency of the PT inverter was 88%. Figure 6 shows the efficiency characteristics for output-current variation, i.e. dimming control. It is evident from this result that a higher efficiency around 80% was maintained over a wide range of 10% to 100% of the maximum rating, and that it was about 6% higher at the dimming condition of 10% than the fixed-frequency operation reported previously.

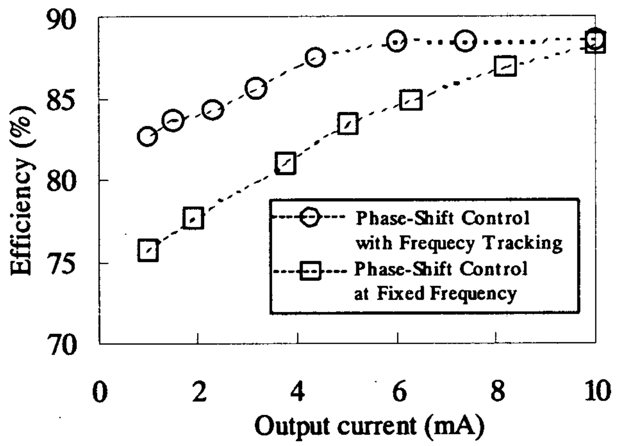


Fig.6. Efficiency for dimming control operation

4. Conclusion

A tracking control system has been proposed for achieving the maximum efficiency of the PT inverter, and the experimental conformation has been shown. This control system varies the inverter's switching frequency with the variation of PT's resonant frequency for the load change.

As a result, in case of an inverter composed of a 3W-rated PT and a load of a 3W-rated CCFL, a high efficiency over 80% was achieved over a wide range of the load variation of 10% to full load. This proposed inverter has a higher efficiency than the fixed-frequency inverter reported before.
The tracking scheme for environmental temperature variation is under examination.

References

[1] M.Shoyama, K.Horikoshi, T.Ninomiya, T.Zaitsu, Y.Sasaki : "Steady-State Characteristics of the Push-Pull Piezoelectric Inverter," IEICE Transactions, Vol.E82-B, No.8, pp.1318-1325, Aug.1999.

[2] T.Ishii, H.Kakehashi, H.Ogasawara, T.Ninomiya : "Piezoelectric-Transformer Inverter with Phase-Shift Control in a Full-Bridge Circuit," IPEC'2000 Record, pp.1051-1055, Apr 2000.

[3] H.Fukunage, H.Kakehashi, H.Ogasawara, Y.Ohta : "Effect of Dimension on Characteristics of Rosen-Type Piezoelectric Transformer," PESC'98 Record, pp.1504-1510, May 1998.