Adaptive Frequency Control Strategy for Piezoelectric Transformer in AC/DC Adapter Applications using Phase-Detector

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Abstract -- An adaptive frequency control method for AC/DC adapters using a piezoelectric transformer (PT) is proposed. It combined the conventional frequency method and frequency tracking for the PT such that the main frequency control loop to regulate the output voltage is compensated by the phase loop in order to adaptively change the operating frequency range. This method provides PT gain peak tracking to tackle the resonant frequency drift problems common in the PT according to the temperature changes and sample variations, and consequently makes more efficient and stable driving of the PT possible, thus improving the overall productivity. The validity of the proposed algorithm is verified by a constructed 40W AC/DC adapter hardware using a PT.

I. Introduction

To miniaturize AC/DC adapters, employment of piezoelectric transformers (PT), rather than the classical magnetic transformers is being investigated [1-2]. As for the adapters for labtop computer with input power more than 50W, distortion of the supply current waveform drawn by the ac mains is limited by international standards, IEC61000-3-2. To meet the requirement, a power factor correcting(PFC) pre-regulator is placed in front of the main power stage. Therefore, the input voltage of the main power stage is maintained around 400V.

In this situation, a frequency control method with symmetric duty waveform provides more efficient driving of the PT and alleviates the switch stress problem in the PWM method [2]. In order to regulate the output voltage according to the input and load variations, the operating frequency is adjusted by the output voltage loop, and either the left-hand region or the right-hand region of the voltage gain peak point can be used as in Fig.1. For the half-bridge topology, the right-hand region is preferred for the zero-voltage-switching condition and the minimum frequency is set near the resonant frequency. However, the resonant frequency changes according to the operating temperature and tolerances in the device manufacturing process of the PT. A slight drift in the resonant frequency from the initial design value could allow the operating point to slip to the left-side region of the gain curve which may result in the instability in the gain control of the PT as in Fig. 2.

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To avoid above mentioned possibility, choosing a minimum frequency requires a certain margin such that the minimum frequency is slightly higher than all possible peak frequency deviations, which results in losses both in the voltage gain and in the efficiency of the PT, which is very sensitive for the PT with an inherent high resonant quality factor of more than 100. The decreasing tendency in the efficiency of the PT according to the deviation from the resonant frequency is shown in Fig. 3. Moreover, timing resistor and capacitor values in voltage-controlled oscillator generally have tolerances, which require additional design margin in selecting the minimum operating frequency.

Past researches have presented phase-locked-loop techniques to tackle this problem[3-8]. In these papers, the operating frequency is automatically tuned to a point which has a fixed phase-difference between the input voltage and output voltage of the PT[6], or the zero phase difference (phase-locking) between the input voltage and input current of the PT[7,8]. In [3], pulse-width-modulation (PWM) control was added to the phase-locking scheme, which in general utilizes an asymmetric duty cycle control and it causes higher circulating harmonics for the PT.

In this paper, a new control strategy which combines the frequency control and the frequency tracking is proposed, where the main frequency control loop regulating the output voltage is compensated by the phase loop in order to adaptively change the operating frequency range. With this method, automatic frequency tracking according to temperature changes and sample variations is achieved with the frequency control.

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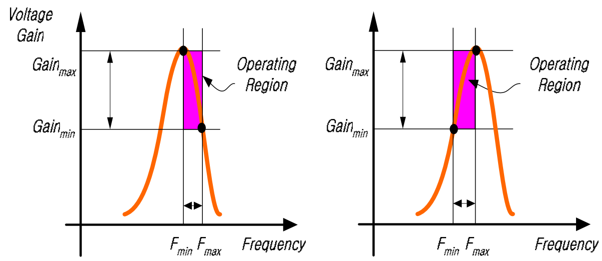


(a) right-slope control (b) left-slope control

Fig. 1 Conventional frequency control for the PT gain curve

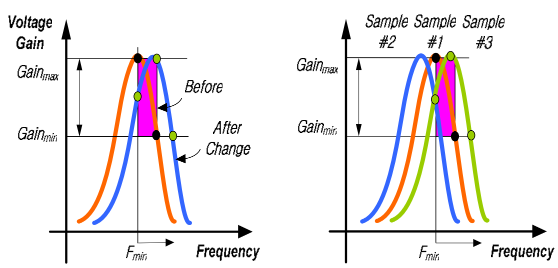


Fig. 2 Possible instability problems in the conventional frequency control caused by (a) temperature changes and (b) sample differences.

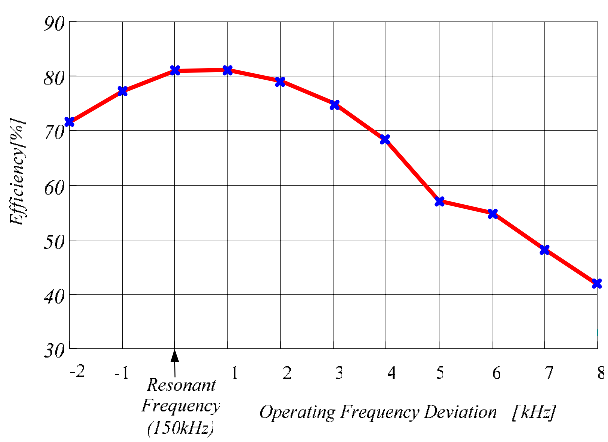


Fig. 3 Efficiency vs. operating frequency of a disk-type PT sample(Experimental data obtained by symmetric trapezoidal waveform voltage driving. The PT was terminated by 100[Ω] load and the output power was held constant to be 5W.)

II. Proposed Adaptive Frequency Control Strategy For PTs

A. Basic Concept

Figure 4 shows the magnitude and phase angle of the input to output voltage transfer function of the PT, which presents the basic concept of the proposed control strategy. Because the phase curve also shifts together with the gain curve, auto-tracking and frequency control is performed at the same time in this control scheme. The phase difference information between the input and output ac voltage of the PT is used to limit the frequency range instead of the VCO control voltage. Even if there is a change in resonant frequency, the operating frequency control range is automatically tracked.

B. Control Block Diagram and Implementation

The control block diagram of the proposed method is depicted in Fig. 5. The main outer voltage loop generates a phase-reference command to the inner phase loop, and current sensed phase-difference signal is compared with this reference signal to generate a VCO control signal in order to regulate the output voltage through the operating frequency change of the PT.

Figure 6 shows an implementation of the method. The phase-difference information between the input and output ac voltage of the PT is continuously monitored using a Phase Detector circuit, and is used to limit the frequency range based on the minimum and maximum phase value in the Phase Reference Generator, which consists of OpAmp's and limiter logics.

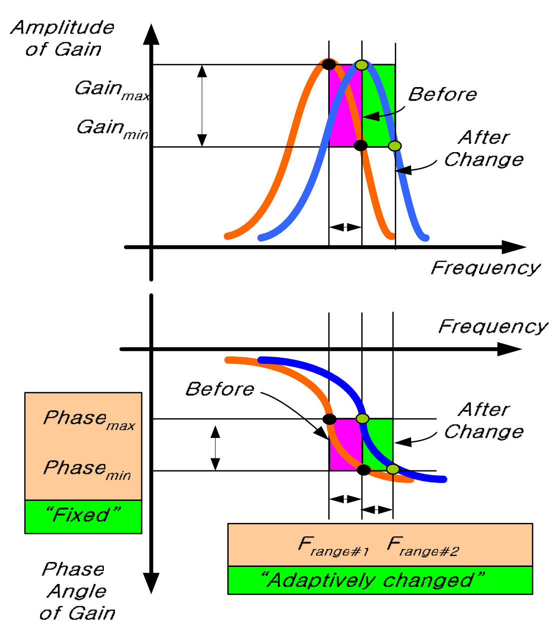


Fig. 4 Basic concept of the proposed strategy – the proposed adaptive frequency control can track the resonant frequency deviation automatically.

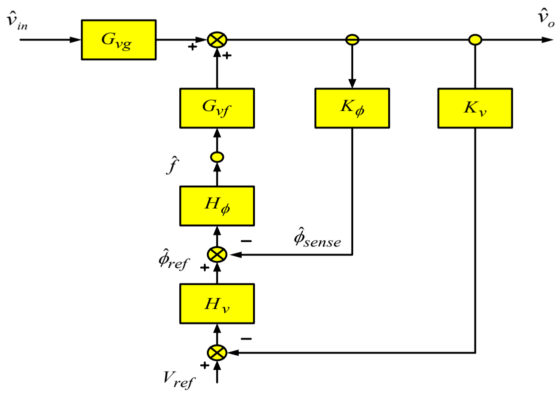


Fig. 5 Control Block Diagram

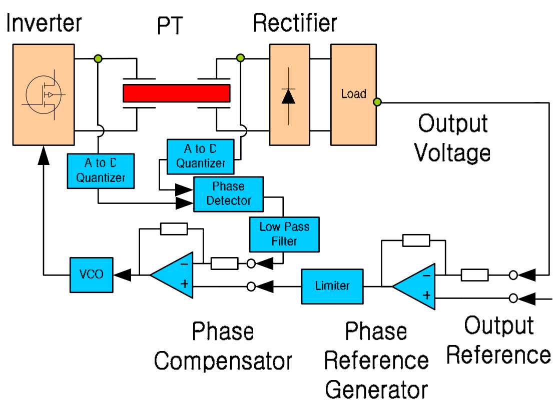


Fig. 6 Implementation of the proposed method

III. Hardware Experimental Results

A prototype 40W AC/DC adapter for labtop computers was constructed as in Fig. 7, and the proposed control method was implemented with this hardware. It consists of a boost pre-regulator which provides a dc-link voltage, a frequency-controlled half-bridge topology [9] used to drive the PT and to regulate the output voltage, and a current-doubler rectifier to obtain the DC output voltage from the PT. The PT sample used in this paper is a disk-shaped radial mode type, which was analyzed in [10]. The specifications of the target system are :

- AC input voltage : 85~265 [V_{rms}] / 60Hz
- DC-link voltage : 360 ~ 420 [V]
- Regulated output voltage : 20 V
- Maximum output current : 2 A

By adopting the proposed method, the output voltage is regulated to 20V as in Fig. 8(a) and the operating frequency range is automatically tracked according to the temperature change or sample deviation as shown in Fig. 8(b). The results provide verification that the proposed method is valid for the PT, especially in power converter applications.

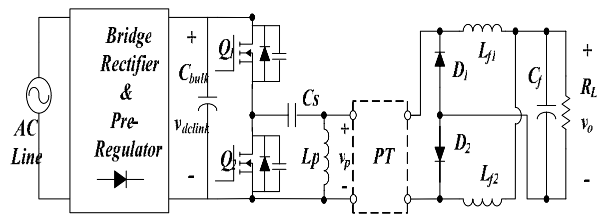
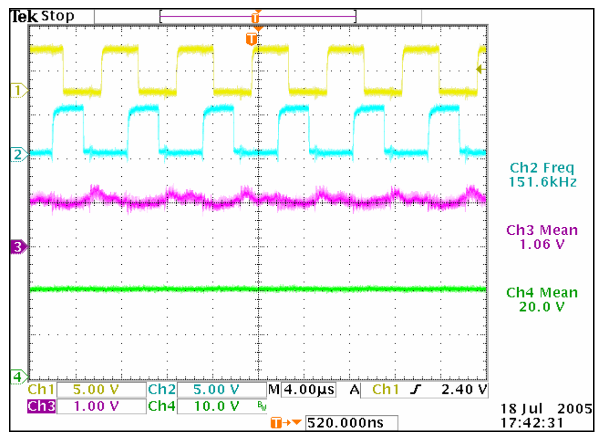
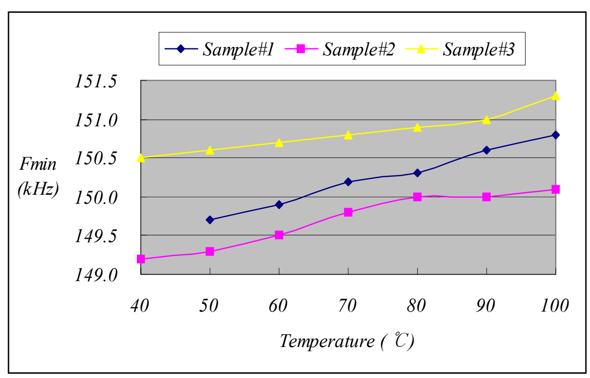


Fig. 7 A prototype of 40W AC/DC adapter using Cs-Lp topology with the PT sample. The proposed control algorithm was incorporated into this hardware.



(a)



(b)

Fig. 8. (a) Hardware waveforms (CH1: quantized PT input voltage, CH2: quantized PT output voltage, CH3: phase-reference voltage, CH4: regulated output voltage) (b) Frequency(F_{min}) tracking results according to temperature changes and sample differences

Ⅳ. Conclusions

An adaptive frequency control method for AC/DC adapters using a PT is proposed. It provides PT resonant peak tracking to tackle the resonant frequency drift problems common in PT's, consequently making more efficient and stable driving of the PT possible. The proposed method combined the conventional frequency method and the frequency tracking for the PT, thus overcoming the disadvantages from adopting other control algorithms, such as duty control, to regulate the output. Constructed hardware tests have been presented to verify the validity of the method.

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