Adaptive Link Voltage Variation (ALVV) Control for High Efficiency in High Power Density Adapter

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Abstract

In designing a LLC resonant converter, the ratio of magnetizing inductance (L_M) to resonant inductance (L_R), the inductor ratio (K) is usually considered. In high power density adapter, both adapter size and efficiency are important factors. Considering the size of adapter, high K design can be more attractive. But, wide frequency variation of high K design results in design difficulty of magnetic elements and decrease in efficiency. To solve these drawbacks, an adaptive link voltage variation (ALVV) control is proposed. With the proposed control method, the LLC resonant converter can be operated at the resonant frequency despite the output voltage variation. The control strategy and schematics are presented, and verified experimentally.

1. Introduction

With the trend of reducing weight and size reduction of laptop computer adapters, increasing power consumption of laptop computer requires laptop computer adapter to have high power rating. Higher power density and efficiency of adapter are required to meet this increase in power rating. Normally, adapters can be considered of two configurations: single-stage and two-stage. For power levels above approximately 80W, the applications are required to satisfy harmonic limits imposed by international standards like the IEC-61000-3-2 [1]. To satisfy these demands, the two-stage approach, shown in Fig. 1, is a suitable candidate because of good power factor correction (PFC) and high efficiency [2].

In this approach, there are two independent power stages. The first stage is the PFC stage. As shown in Fig. 1, the boost converter is most popular for this stage because it has a number of advantages including direct control of line current and low input current ripple [3]-[4]. The second stage is the DC/DC stage to tightly regulate output voltage. Many converters can be used as the DC/DC stage. Among these converters, the LLC resonant converter, shown in Fig. 1, is preferable due to high efficiency, high switching frequency and high power density [5]-[6].

Recently, laptop computers use mobile microprocessors, and their power consumption has increased dramatically. In order to supply power to these microprocessors effectively, output voltage variation according to load current, shown in Fig. 1, has been required. The output voltage variation according to load current causes the gain value of the LLC resonant converter to change. To adjust the changing gain, the operating frequency of the LLC resonant converter needs to be varied widely. This results in design difficulty of passive elements and decreases efficiency [7]-[9].

In this paper, in order to overcome these drawbacks, an ALVV control is proposed. The gain characteristics of the LLC resonant converter are investigated, and the relation between efficiency and operating frequency is analyzed. Operational principle of proposed control is given. Finally, the validity of the proposed control method is verified with an 85W AC/DC adapter prototype

2. Design Considerations of LLC resonant Converter with conventional control

The parameters in power stage can be designed. L_M, L_R, C_R and n are key design parameters in the proposed converter. The optimal operating point of the LLC resonant converter is when switching frequency equals to the resonant frequency of L_R and C_R [7]-[9]. At this point, the voltage gain of the LLC resonant converter is 1. In normal operating conditions, the input voltage of the LLC resonant converter, which is generated by PFC stage, is regulated at 400V. With the regulated input voltage and unity gain at f1, n can be chosen base on the following equation:

$$n = \frac{V_L}{2V_O}. \qquad (4)$$

Here, V_O is the output voltage and V_L is the link voltage. After the n is selected, the resonant tank (L_M, L_R and C_R) can be designed.

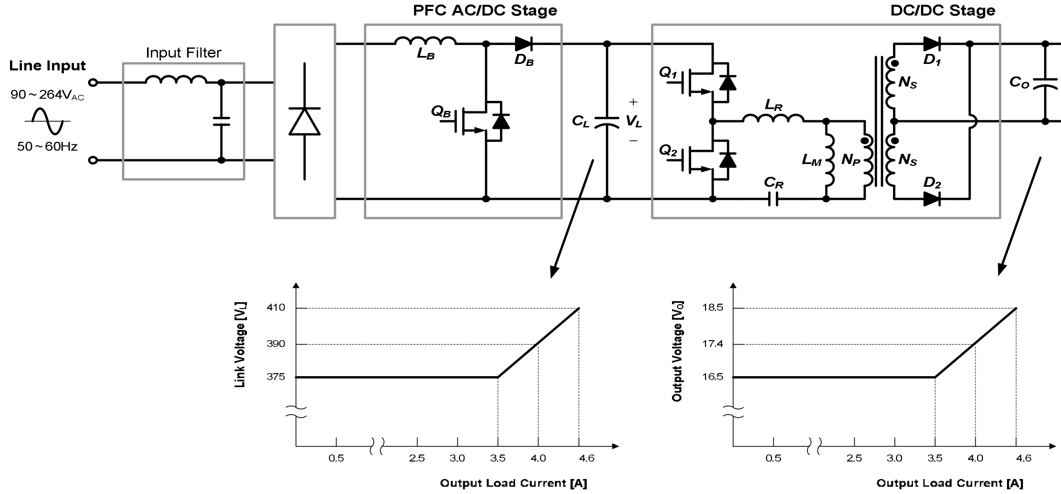
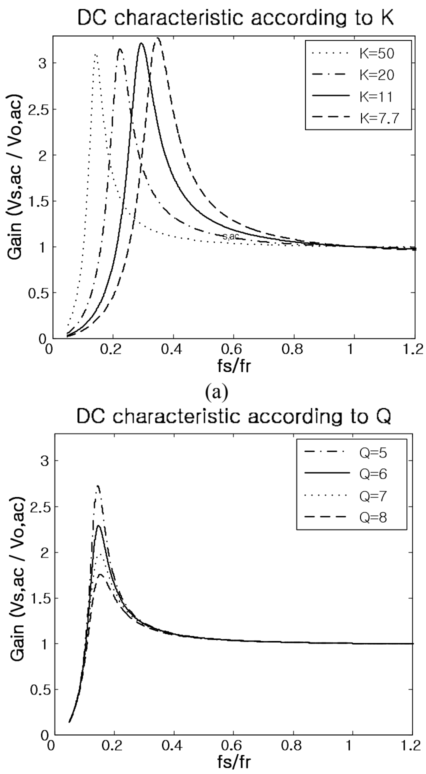


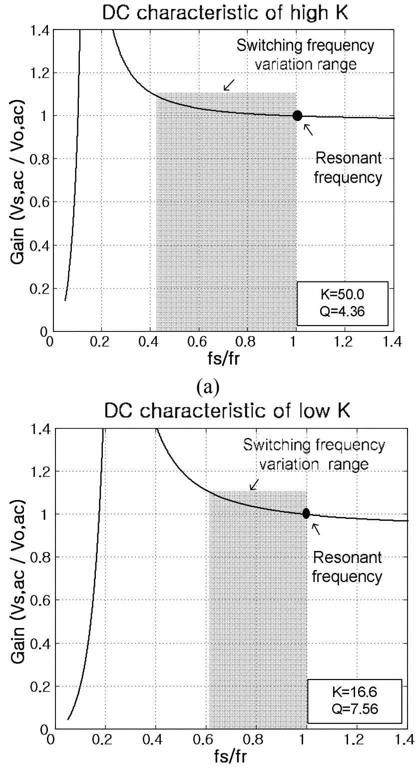
Figure 1. Two stage adapter approach and The Proposed Control Strategy.



(a)

(b)

Figure 2. DC characteristic of the LLC resonant converter. (a) according to K and (b) according to Q.



(a)

(b)

Figure 3. The switching frequency variation range according to (a) high K and (b) low K.

The resonant tank can be selected from the DC gain characteristics curve. The DC gain curve is characterized by K, Q and F_O. As K gets lower, lower resonant frequency will shift to higher frequency, as shown in Fig 2(a). As it move to higher frequency, switching frequency range to regulate the output voltage will decrease. From the above characteristics, operating frequency range can be decided by K. The quality factor Q shows the relation between load and gain, as shown in Fig. 2(b). As the load gets heavier, the peak gain at lower resonant frequency will decrease. With this relation, the peak gain can be determined by Q. From above analysis, the operating frequency and peak gain can be chosen by K and Q.

Generally, F_S can be determined from the size of magnetic elements. L_M is determined by switching frequency, switching turn off loss and conduction loss of converter. A 100 kHz switching frequency and an 1mH magnetizing inductance is chosen as an example.

In high power density adapter applications, the output voltage is required to vary according to load current, as shown in Fig. 1. In the output voltage variation, the LLC resonant converter is operating at switching frequency far from the resonant frequency, as shown in Fig. 3(a). This results in complex design of passive elements and decreases in efficiency. Therefore, K is required to be as low as possible in order to reduce the switching frequency range, which requires a large L_R, as shown in Fig. 3(b). However, choosing a large L_R increases the adapter size.

Consequently, efficiency and converter size of adapter should be properly selected according to the application. In high power density adapter application, efficiency and size are the major factors. To fulfill these requirements, the LLC resonant converter should be designed in higher K with respect to size, and in resonant frequency with respect to efficiency. However, high K LLC resonant converter has wide frequency variation, as shown in Fig. 3(a). In order to reduce the wide frequency range, the adaptive link voltage variation control method is proposed.

3. The Proposed Adaptive Link Voltage Variation Control Schematic

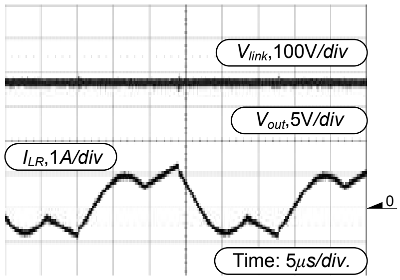
The proposed ALVV is a control method to optimize the efficiency, by varying the link voltage proportional to the output voltage variation. In order to achieve high efficiency, the LLC resonant converter should be operated at resonant frequency to lower conduction loss. Gain at resonant frequency is always unity independent of the change in load. To continue operating at its resonant frequency, the gain of the LLC resonant converter should be unity apart from the output voltage variation. Fig. 1 shows the control strategy of the two-stage adapter. For the second stage, to increase the power conversion ratio, the output voltage variation according to load current is required. For the first stage, to maintain resonant frequency operating at output voltage variation section, the link voltage is modified with the load current information. ALVV is the control that regulates link voltage variation proportional to the output voltage variation to maintain unity dc gain of the LLC resonant converter.

TABLE I. DESIGN SPECIFICATIONS FOR HIGH POWER DENSITY ADAPTER.

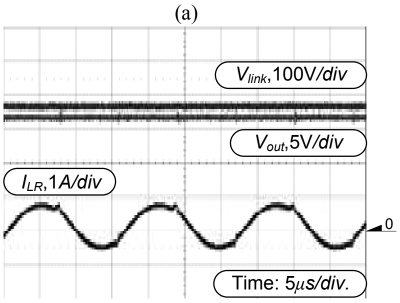
Input Voltage, V_S	365V ~ 410V
Output Voltage, V_O	16.5V ~ 18.5V
Maximum Output Power, $P_{O,max}$	85W
Switching Frequency, F_S	62kHz

TABLE II. CIRCUIT PARAMETERS FOR HIGH POWER DENSITY ADAPTER.

T_1	$N_P : N_S$	54 : 5
	L_M	1mH
	L_R	50μH
C_R		100nF/400V

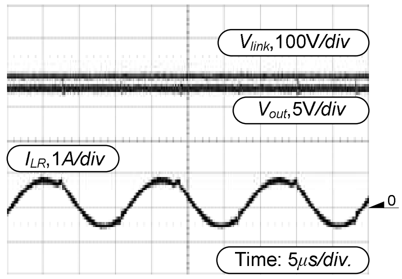


(a)

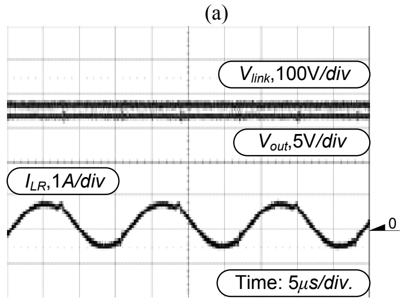


(b)

Figure 4. Experimental waveforms of V_{link}, V_{out} and i_{LR} according to the load variation in conventional method. (a) 100% V_{link}=365V, V_O=18.5V and I_O=4.6A) load. (b) 70% (V_{link}=365V V_O=16.5V, I_O=3.6A) load.



(a)



(b)

Figure 5. Experimental waveforms of V_{link}, V_{out} and i_{LR} according to the load variation in proposed method. (a) 100% V_{link}=408V, V_O=18.5V and I_O=4.6A) load. (b)70% (V_{link}=365V V_O=16.5V, I_O=3.6A) load.

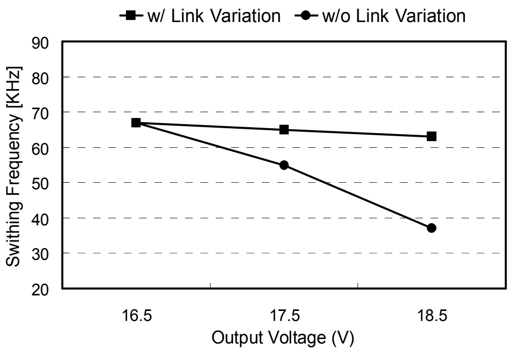


Figure 6. Comparison switching frequency variation range of conventional and proposed control method.

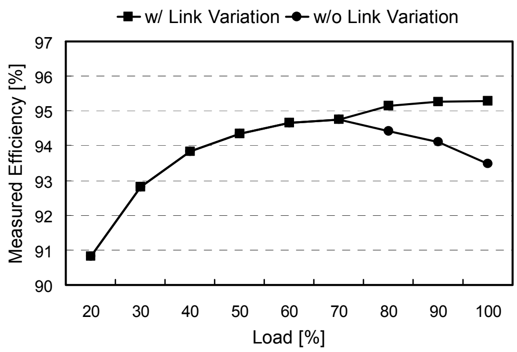


Figure 7. Comparison efficiency of conventional and proposed control method.

4. Experimental Results

To verify the validity of the proposed control method, an 85W adapter prototype has been implemented. The design specifications and circuit parameters of this prototype are the same as presented in Table I and Table II, respectively. Fig. 4 shows the experimental link voltage, output voltage and resonant current waveforms of the second stage without the proposed control method. As the load decreases from full load, the switching frequency is driven further away from the resonant frequency. Employing the proposed control method, the switching frequency is the same at full load, but it can keep up with the resonant frequency operating with adaptive link voltage, as can be seen in Fig. 5.

From Fig. 6 and Fig. 7, the proposed control method is shows narrow frequency range and high efficiency at the output voltage variation section. The adaptive link voltage variation increases efficiency from 93.5% to 95.4% at full load.

5. Conclusion

In this paper, ALVV control method is proposed to increase efficiency of an adapter with output voltage variation. The proposed control method increases efficiency as the output voltage increases. The design method is derived based on the characteristics of the LLC resonant converter. The operational principle of the proposed control method is verified with an 85W adapter prototype with output voltage variation. The variation of switching frequency is greatly reduced from 30kHz to 3kHz and the measured efficiency of the LLC resonant converter is improved from 93.5% to 95.4% at full load. Consequently, the PFC LLC resonant converter with the proposed control method features small size, high efficiency, and is very promising for high power density adapters.

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