Link Voltage Adjustment Converter Employing Load Power Estimator for Notebook Computer Adaptor

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Abstract

A link voltage adjustment converter employing load power estimator for notebook computer adaptor is proposed. It is consisted of the boost converter as a power factor correction stage and the LLC resonant converter as a DC/DC conversion stage with a newly introduced link voltage adjustment method employing load power estimator, which helps to reduce the transformer size and peak of output voltage ripple, maintaining high efficiency over all the load condition. Experimental results with 85W converter are given to verify the validity of the proposed circuit.

1. Introduction

The ever-present trend of reducing the size and weight of the portable data-processing equipment has created new challenges to the design of their power systems. Among these power systems, adaptors, which are devices that convert incoming high voltage AC power from wall outlets into low voltage dc power, are required to have high power density in excess of 5W/in^3 and average efficiency in the 84~87% range as many consumers prefer small-size devices and some countries make energy efficiency regulation such as energy star program to save money and protect environment. Moreover, an adaptor for notebook computer application is recently demanded to output voltage variation specification according to the load power in order to supply power to notebook computer effectively as shown in Fig. 1.

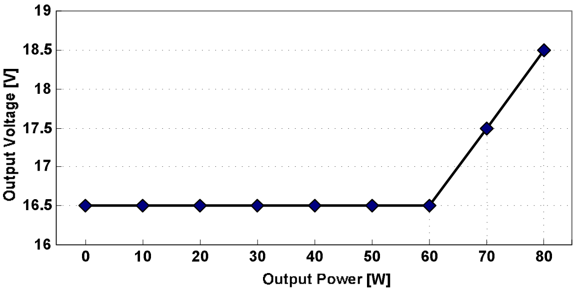


Fig. 1 Example of output voltage variation specification according to the load power for notebook computer adaptor

At the high power level above 80W, conventional adaptors have been developed based on two stage configuration to obtain lower value and smaller size of passive component as well as high efficiency and to satisfy the IEC 1000-3-2 harmonic regulation. This two-stage configuration is normally consisted of boost converter as a front-end power factor correction stage and half-bridge (HB) topology as a back-end DC/DC conversion stage. Since the boost converter has many advantages such as direct control of line current and low input current ripple, it is the most popular converter for front-end stage. For the DC/DC conversion stage, several converters based on the HB topology can be considered. Among them, LLC resonant HB converter is the attractive candidate for the back-end stage [1]. It is a modified LC series resonant converter implemented by placing a shunt inductor across the transformer primary winding, as shown in Fig. 2. It can be very effective in improving efficiency for high-input voltage application where the switching loss is much more dominant than the conduction loss. By the magnetizing inductor current, it can achieve zero voltage switching (ZVS) over the entire operating range and allow high-frequency operation. Also, it can regulate the output over wide line and load variations with a relatively small variation of switching frequency. But, in the notebook computer adaptor applications, LLC resonant converter should be changed its operating frequency according to the load condition to meet the specification of the output voltage variation. This increases the switching loss or conduction loss depending on the operating frequency range where the LLC resonant converter can operate at frequency below or above the resonance frequency. This results in decreasing conversion efficiency of the converter.

To solve these problems, link voltage adjustment converter employing load power estimator for notebook computer adaptor is proposed. The proposed circuit guarantees the operation of LLC resonant converter at resonant frequency by adjusting the link voltage, namely output of front-end boost converter, according to the load condition. To adjust the link voltage effectively, load power estimator in the transformer primary side is used. These features achieve high efficiency over the entire load range, despite of the output voltage variation.

The design consideration of conventional converter will be given and then design consideration of the proposed circuit will be

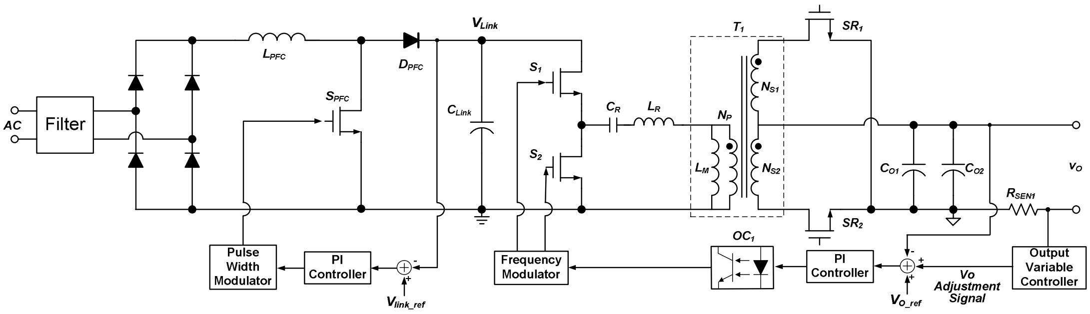
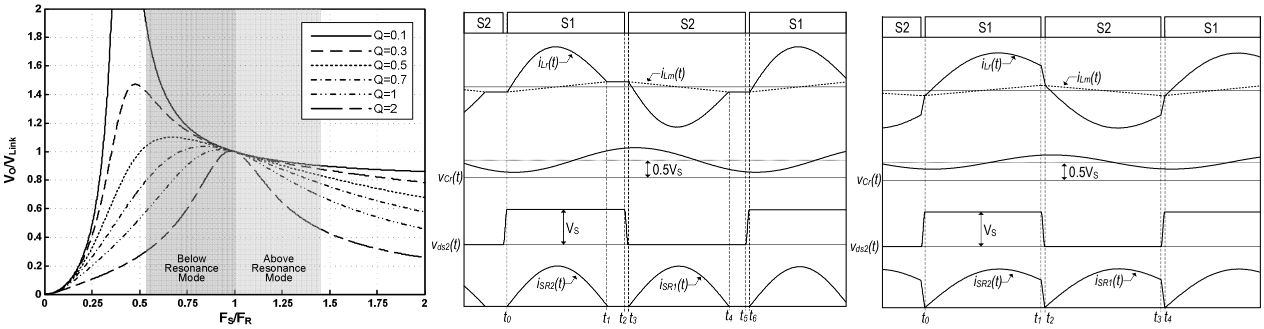


Fig. 2 Block diagram of conventional adaptor consisted of boost converter and LLC resonant converter with output voltage variation controller



(a) DC characteristic (b) Waveforms of below resonance mode (c) Waveforms of above resonance mode

Fig. 3 Operation mode of LLC resonant converter

described. To verify the validity of proposed circuit, the prototype has been built with 85W adaptor and its experimental results are given.

2. Design Consideration of Conventional Converter for Adaptor Application

In a conventional adaptor shown in Fig. 2, the link voltage, in other words, the input voltage of LLC resonant converter is fixed at about 400V. Therefore, to meet the output voltage variation specification shown in Fig. 1, the gain of LLC resonant converter should be changed according to the load condition. Generally, the LLC resonant converter can operate at frequency below or above the resonance frequency as shown in Fig. 3a. Fig. 3b and 3c show the key operational waveforms for each operation mode.

In operation mode below the resonant frequency, the gain of converter is changed from 1 to 1.12 to satisfy the output voltage variation. This operation mode allows the soft commutation of the secondary rectifiers. Also, since the frequency is limited below the resonance frequency even at no load condition, this mode has a narrow frequency range with respect to the load variation. But, while the operation frequency moves downward from the resonant frequency, the circulating current increases more in the transformer primary side and the output voltage ripple is significantly increased by enlarging the non-powering period.

On the other hand, in operation mode above resonant frequency, the gain of converter is changed from 0.88 to 1 to meet the output voltage specification. This above resonance operation has less conduction loss than the below resonance operation since this mode allows the circulating current to be minimized. However, since the secondary rectifiers in this operation are not softly commutated, reverse recovery problems are significant. Also, above resonance operation causes too much frequency increase under the quarter of full load condition. Thus, this mode usually requires frequency skipping mode to prevent too much increase of the switching frequency, which decreases average efficiency of the converter due to repeated hard switching in start-up period of pulse group.

As can be seen so far, there is a limitation to improve average efficiency under the specification of the output voltage variation in the both of below resonance and above resonance mode of LLC resonant converter. Therefore, to solve these problems, link voltage adjustment converter employing load power estimator is suggested.

3. Proposed Link Voltage Adjustment Converter Employing Load Power Estimator

Fig. 4 and Fig. 5 show the proposed converter and its key waveforms under the load variation, respectively. As shown in these figures, link voltage can be adjusted by the variation controller when the load current is in the range from I_{O1} to I_{O2}. This allows the operation frequency of LLC converter to be maintained at resonant frequency, satisfying the output voltage variation specification. Thus it guarantees high average efficiency over the entire load range. In the proposed circuit, the variation controller is located in the transformer primary side while the conventional variable controller is in the transformer secondary side. This is because the load power estimator informs the variable circuit the information of load variation. Proposed circuit can estimate load power by measuring current and voltage of resonant components in the primary side since the current and voltage of resonant components are directly proportional to the load current. There are three types of load power estimator as shown in Fig. 6. Fig. 6a shows a voltage detection type that measures the voltage ripple of resonant capacitor and Fig. 6b is a current detection type that measures the partial current through the resonant capacitor to estimate the load current. Finally, Fig 6c shows using auxiliary winding of resonant inductor as load power estimator. Since proposed circuit uses voltage and current information of the resonant components to obtain load condition information, instead of using current sensing resistor and current transformer, proposed converter shows less power loss and smaller size than those of the conventional one. Operational principle of proposed circuit is the same as those of conventional one, except for load transient response. As shown in Fig. 5, at t_0 where the load current is increased from I_{O1} to I_{O2}, output voltage of adaptor is linearly increased by control loop of DC/DC conversion stage. But, since the response of the front-end AC/DC converter is very slow compared with DC/DC converter and the link voltage is maintained to be V_{link_min}, there is a limitation to increase the output voltage and operating frequency moves to minimum switching frequency. And then, after the link voltage increases linearly, operating frequency moves upward to resonant frequency.

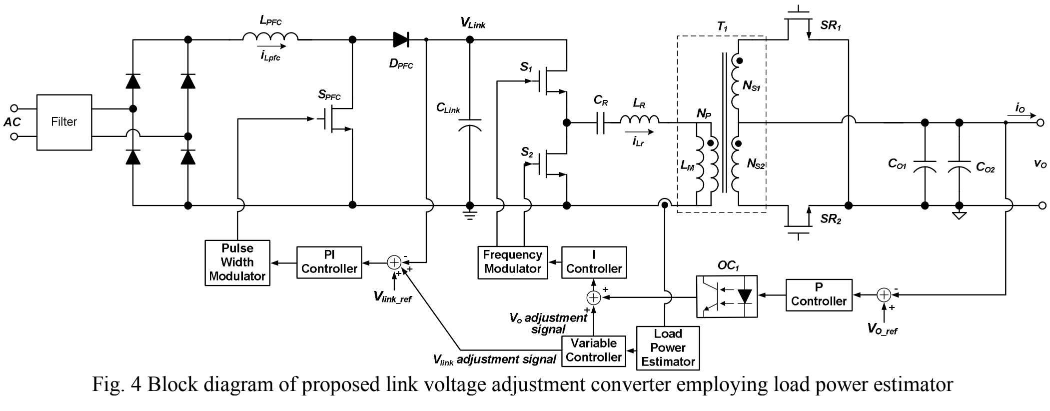


Fig. 4 Block diagram of proposed link voltage adjustment converter employing load power estimator

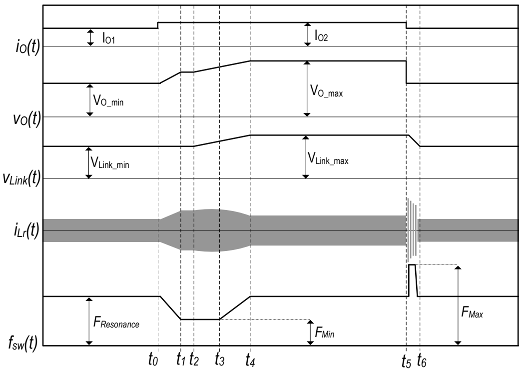
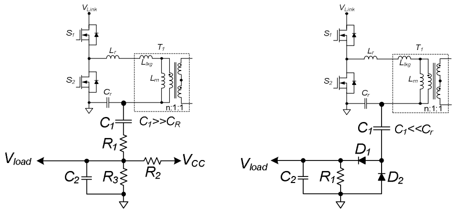
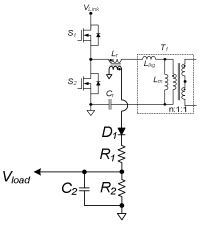


Fig. 5 Key waveforms of proposed converter



(a) Voltage ripple detecting method (b) Current dividing method



(c) Auxiliary winding method

Fig. 6 Schematic diagram of proposed load power estimators

When link voltage reaches V_{Link_max}, operating frequency is near the resonant frequency. On the other hand, when the load current is decreased form I_{O2} to I_{O1}, output voltage of adaptor quickly follows target output voltage because frequency skipping mode is achieved regardless of slow link voltage variation. After the link voltage is set to the V_{Link_min}, operating frequency is near the resonant frequency again.

4. Experimental Results

The prototype has been built with an 85W adaptor satisfying the output voltage variation specification. IPD60R385 (650V/5.7A) is used for main switches and SR switches are implemented with IRF7855 (60V/9.4mΩ), which has a very small SO-8 package. Among proposed load power estimators, voltage ripple detection type is chosen for prototype. The secondary proportional controller is built with shunt regulator, TL431, and the primary integral controller is implemented with general OP-amp, TS321. The resonant frequency is designed as 120 kHz and link voltage is in the range from 365V to 405V. With the selected parameters, the transformer and inductor of LLC resonant converter can be implemented with RM8 and toroidal cores. Fig. 7 shows the measured waveforms under load variation. The measured efficiency is shown in Fig. 8 and it shows 95.6% at maximum load condition.

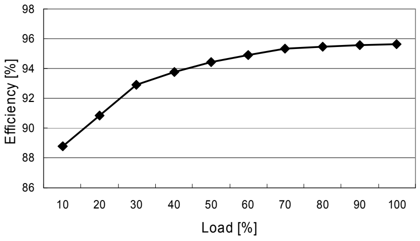


Fig. 8 Measured efficiency under load variation

5. Conclusion

The proposed converter offers a high-efficient and high-power-density approach based on LLC resonant converter. Since the operating frequency of LLC resonant converter is nearby resonant frequency over all the load condition and load power estimator helps to vary output voltage according to the load variation, proposed circuit can improve the average efficiency and power density for notebook computer adaptor

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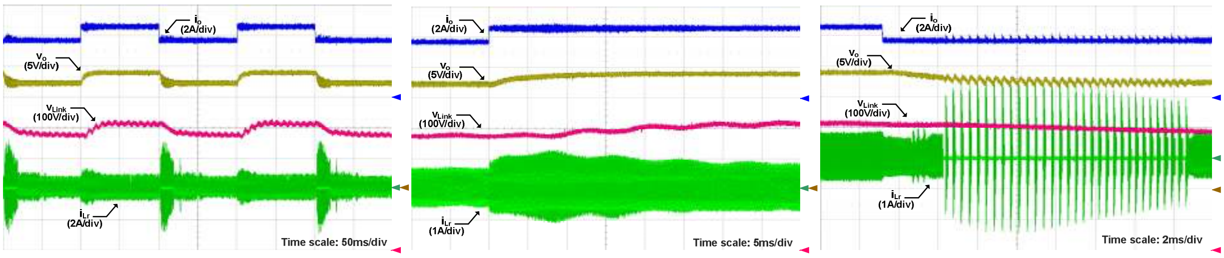
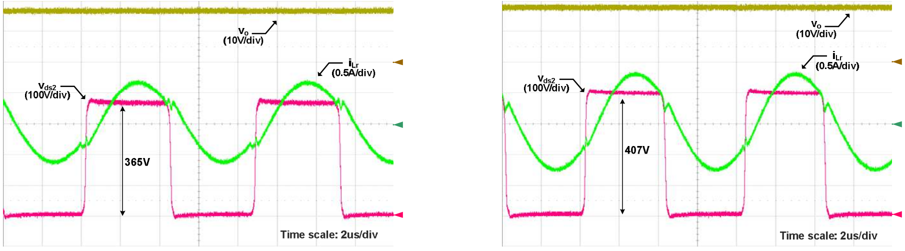
Reference

[1] Bo Yang, Fred C. Lee, Alpha J. Zhang, and Guisong Huang, "LLC resonant Converter for Front End DC/DC Conversion", IEEE APEC Conf. Rec., pp. 1108-1112, 2002, Feb.



(a) According to the load variation (b) load changed from 3.6A to 4.6A (c) load changed from 4.6A to 3.6A



(d) Enlarged waveforms at 60W load condition (e) Enlarged waveforms at 80W load condition

Fig. 7 Experimental waveforms of proposed converter