2012 IEEE 7th International Power Electronics and Motion Control Conference - ECCE Asia
June 2-5, 2012, Harbin, China

Design on Topologies for High Efficiency Two-Stage AC-DC Converter

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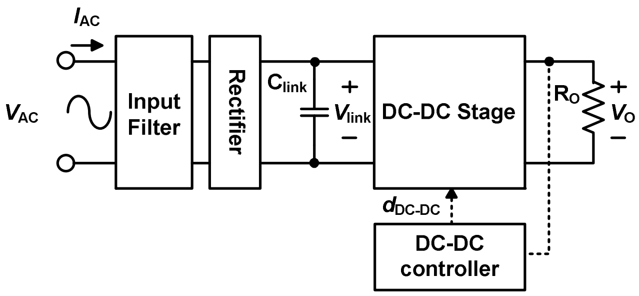
Abstract—**Design on topologies for high efficiency 60W level two-stage AC-DC adapter is proposed in this paper. Conventional 60W level single-stage AC-DC converter has wide input range. And flyback topology has low efficiency characteristic. Therefore, conventional 60W single-stage AC-DC adapter has low efficiency characteristic. In order to develop small and high efficiency AC-DC converter, propose two-stage AC-DC converter structure. Two-stage AC-DC converter is added PFC stage. But DC-DC stage easy to design Because input voltage fixed link capacitor voltage. Moreover, size of input-filter decrease due to PFC stage effect. Therefore, two-stage AC-DC converter has high efficiency. And it is possible to put in conventional single-stage AC-DC adapter case. Design procedures and experimental results for boost PFC, flyback, forward and LLC DC-DC converters are presented to select the suitable topologies of two-stage AC-DC converter.**

Keywords : AC-DC Adapter, Two-Stage AC-DC Converter

I. INTRODUCTION

The number of handheld device is increasing continuously in recent IT market. Therefore, the number of low power AC-DC adapter which can charge the handheld device is increasing too. As carbon dioxide (CO2) increases, the earth temperature increases. IT industry is one of the major factor generating CO2. To reduce generation of CO2, high efficiency is required for power supply such as server power supply, notebook adapter and desktop power supply. Furthermore, high power density is required for power supply as small size is preferred. So many IT companies want high efficiency power supply for energy saving and eco-friendly image. Efficiency of conventional single-stage AC-DC converter is 89.1% at 90Vac input voltage. And average efficiency is 90.21% at 90, 100, 115 and 230Vac input voltage. In other words, single-stage AC-DC converter has relatively low efficiency characteristic. And IT companies want higher efficiency product for power saving and eco-friendly image. And domestic annual supply data of electronic device shows 70-million adapters are provided, and this number accounts for the largest portion of total supply for electronic devices. This being so efficiency regulations of adapter will be strengthen. Conventional single-stage AC-DC converter structure in Fig.1 consists of input-filter, rectifier and DC-DC stage. DC-DC stage of conventional single-stage AC-DC converter is difficult to design, because single-stage AC-DC converter has wide input voltage range. And flyback has high switching loss and high snubber loss. And core loss accounts for the largest portion of total loss of conventional single-stage AC-DC converter. Because size of adapter case is limited, core size is limited too. So, conventional AC-DC converter has low efficiency characteristic. Therefore, the conventional single-stage AC-DC converter structure is hard to expect highly rising in efficiency.



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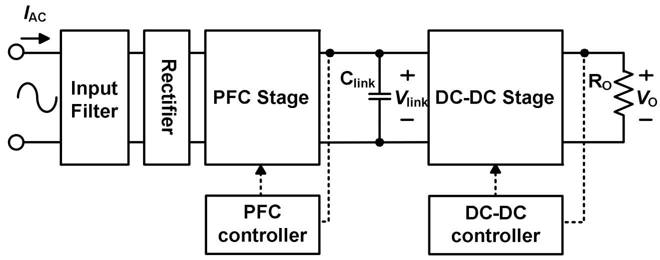


(b)

Fig. 1 (a) Conventional single-stage AC-DC converter structure
(b) Two-stage AC-DC converter structure

In order to develop small size and high efficiency AC-DC converter, review two-stage AC-DC converter structure.

Fig. 2 Conventional single-stage AC-DC adapter case

Two-stage AC-DC converter structure added PFC stage. Therefore, cost and size may be increased. But, DC-DC converter stage is easy to design, because input voltage is fixed link capacitor voltage. So size and efficiency of DC-DC stage are improved. Moreover, size of input-filter decrease due to PFC stage effect. Because of this, two-stage AC-DC converter structure is possible to put in conventional adapter case. Therefore, topologies research for small size and high efficiency two-stage AC-DC converter is essential.

II. TOPOLOGY CANDIDATES

Two-stage AC-DC converter structure consist of PFC stage, DC-DC stage. In case of PFC stage, boost PFC has high PF, low THD and high efficiency characteristic. Therefore boost converter in Fig.3 is selected. Boost PFC is widely used in IT industry. Control method of boost PFC divide three; CCM(Continuous-Conduction-Mode), BCM (Boundary-Condu ction-Mode), DCM(Discontinuous-Conduction-Mode). Becau se this research is focus on high efficiency AC-DC converter. BCM control method is selected considering minimize switching loss and conduction loss.

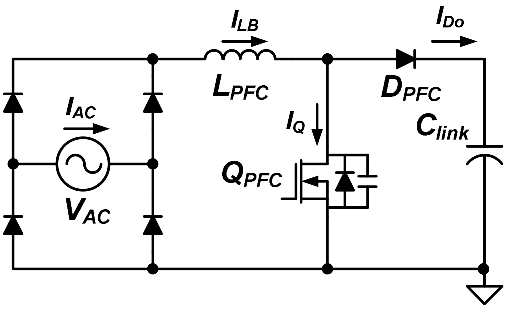


Fig. 3 Boost PFC converter

In case of DC-DC stage, topologies about one or two switches are considered, for small size AC-DC converter. First, flyback converter in Fig.4 is considered. The flyback converter has merits of simple structure and low price. But, flyback converter has hard switching loss and snubber loss. So, flyback converter has low efficiency characteristic.

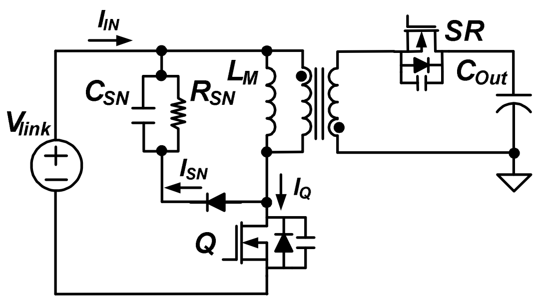


Fig. 4 Flyback converter

Second, active clamp forward converter in Fig.5 is considered. The active clamp forward has merits of soft switching and low RMS current in secondary side. But, active clamp forward converter has more complicated structure and higher cost than flyback converter.

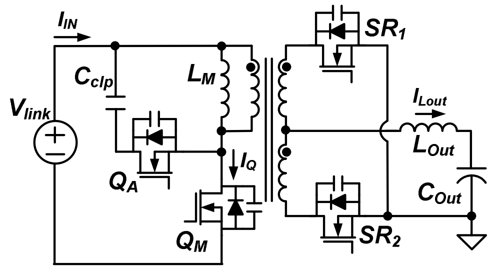


Fig. 5 Active clamp forward converter

Third, LLC resonant converter in Fig. 6 is considered. The LLC converter has merits of soft switching and high efficiency characteristic. But LLC converter has more complicated structure and higher cost than flyback converter too.

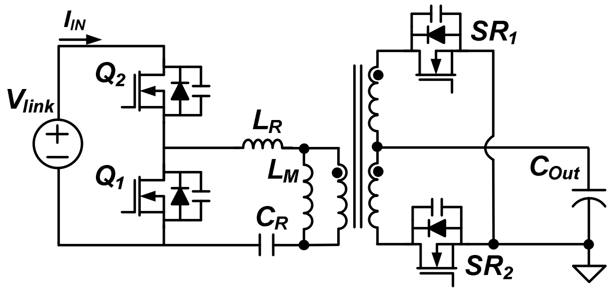


Fig. 6 LLC resonant converter

Flyback, active clamp forward and LLC converter are designed for adapter specification. And the loss of three converters is compared as shown in Fig.7. Eventually, the LLC converter has the lowest loss. So LLC converter is selected as first experiment candidate. And active clamp forward converter is selected as second experiment candidate for verification and comparison of loss analysis- tendency..

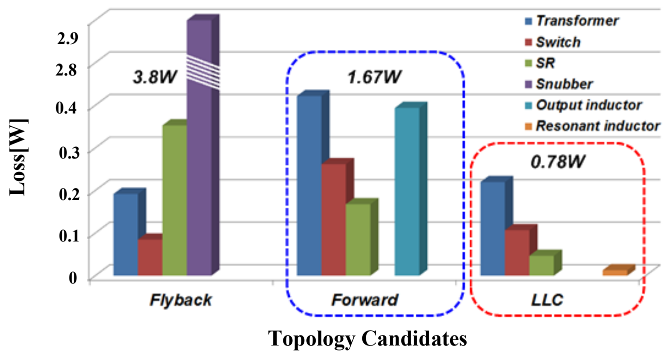


Fig. 7 Loss analysis of three DC-DC converters

III. DESIGN CONSIDERATION & EXPERIMENTAL RESULT

A. Boost PFC

First, RM8 core is selected for boost PFC inductor. RM8 core has maximum effective area which can possible to put in conventional single-stage AC-DC converter case. Inductance is calculated 350.78μH by these equations.

$$T_{on} = \frac{L \cdot i_{L\cdot pk}}{V_{in}} \quad (1)$$

$$T_{off} = \frac{L \cdot i_{L\cdot pk}}{V_{out} - V_{in}} \quad (2)$$

$$T_s = T_{on} + T_{off} = \frac{L \cdot i_{L\cdot pk} \cdot V_{out}}{V_{in}(V_{out} - V_{in})} \quad (3)$$

$$L \cong T_s \cdot \frac{V_{in}^2 (V_{out} - V_{in})}{4 \cdot P_{in} \cdot V_{out}} = 350.78uH \quad (4)$$

However, 341uH is selected. Switching loss and conduction loss are minimized at 341uH as shown in Fig.9. As a result, boost PFC has the highest efficiency characteristic at 341uH.

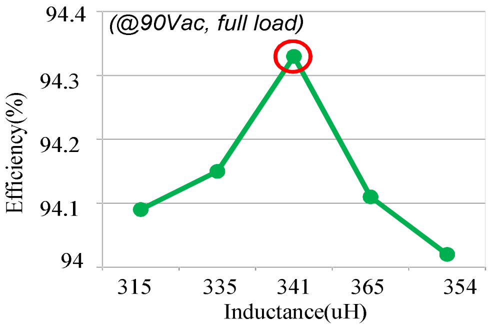
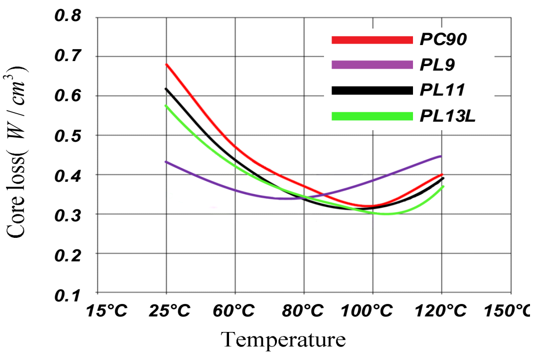


Fig. 8 Efficiency according to inductance value

Next, core material is checked. When boost PFC operates at full load condition, core temperature is about 70~80°C. and PL-9 causes minimum loss at 70~80°C as shown in Fig. 4-2. Actually, PL-9 is confirmed it has the highest efficiency characteristic through experiment result as shown in Fig. 10.



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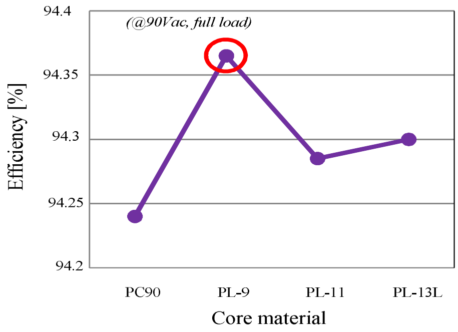

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Fig. 9 (a) Temperature characteristic according to core material
(b) Efficiency according to core material

Final selected device & value list is below in Tab.1. And efficiency is 94.39% at 90Vac input voltage. Fig. 10 is input voltage and current waveforms.

Tab.1 Selected device & value list

	Device & Value
Core	RM8(PL-9)
Wire	USTC 0.1 Φ-30strand-40turns
Inductance	341μH
Frequency	100 ~ 120kHz
Operating mode	BCM
Switch	IPP60R385CP
Diode	FFPF08H60S

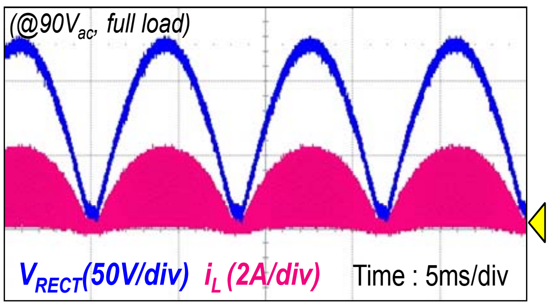

Fig. 10 Input voltage & current waveforms of boost PFC

B. Active clamp forward DC-DC converter

Switch voltage rating and duty cycle are selected by loss analysis according to different switch voltage rating as shown in Tab.2, Since switch voltage rating determines duty cycle in active clamp forward DC-DC converter.

Tab.2 Duty cycle and turn ratio according to different switch voltage rating

	650V	800V	1000V
Switch	IPD60R385	SPP11N80C	IRF2903ZS
$R_{DS(on)}$	0.385Ω	0.65Ω	3.5Ω
C_{oss}	38pF	46pF	100pF
Duty	0.23	0.375	0.5
Turn Ratio	10.86 (65:6)	17.65 (71:4)	23.53 (70:3)

650V switch has the lowest loss in 60W level two-stage AC-DC converter specification as shown in Fig. 11. The larger switch voltage stress, the more duty cycle and turn ratio increase. Therefore RMS current value is decreased. However, conduction resistance of switch is increase. So switch conduction loss increases remarkably.

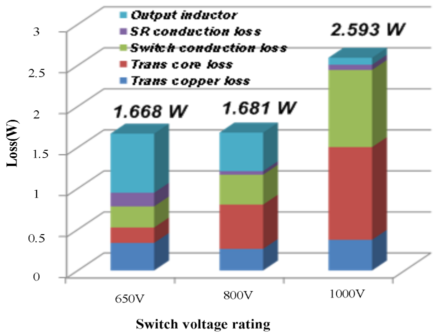

Fig. 11 Loss analysis according to different switch voltage rating

Next, magnetizing inductance and core material are selected. Magnetizing inductance value is selected 486 □H as shown in Fig.12. ZVS(Zero-Voltage-Switching) is ensured at 486uH and conduction loss is minimized at 486uH because RMS current is minimized at 486 uH. So, the highest efficiency is achieved at 486 uH. And core material is selected PL-9 like a boost PFC inductor core.

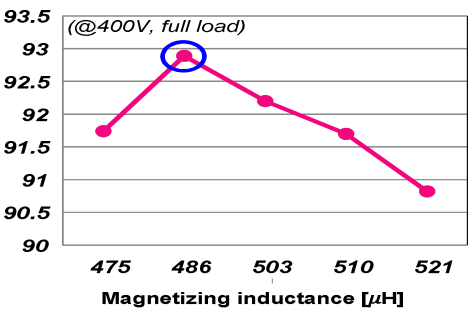

Fig. 12 Efficiency according to magnetizing inductance

Final selected device & value list is below in Tab.3. And efficiency is 92.89% at full load condition. Fig. 13 is primary transformer voltage and current waveforms.

Tab.3 Selected device & value list

	Device & Value
Core	RM8(PL-9)
Inductance	486μH
Switch	IPD60R385CP
Secondary SR	IRLB3813, IPB123N10N3
Output inductor core	CM127060

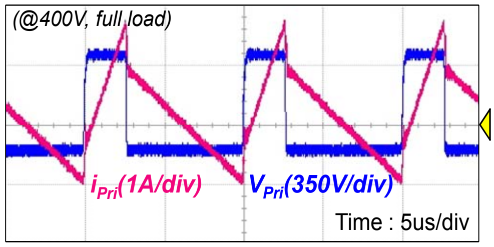

Fig. 13 Primary transformer voltage and current waveforms

C. LLC DC-DC converter

LLC resonant tank is designed by gain curve and below design equations. Magnetizing inductance value is designed to ensure ZVS. Resonant capacitance is designed considering voltage stress. Q value is divided two type; high Q and low Q. Low Q has low frequency variation according to output load variation and has small resonant inductor size. High Q has high frequency variation according to output load variation and has large resonant inductor size. Because Low Q is suitable for this study target, low Q is selected for resonant tank.

Resonant tank is designed by Q=0.05, k=30. Magnetizing inductance is selected 1.51 mH. Switching loss and conduction loss are minimized at 1.51 mH as shown in Fig.14. As a result, LLC DC-DC converter has the highest efficiency characteristic at 1.51 mH.

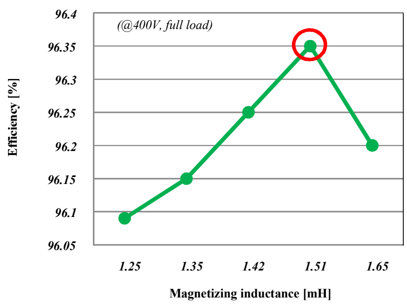

Fig. 14 Efficiency according to magnetizing inductance

Wire design of transformer is designed for '71:6' turn ratio as shown in Fig. 15. Copper loss and core loss is minimized at '71:6' turn ratio as shown in Fig. 18. Therefore, LLC DC-DC converter has the highest efficiency with '71:6' turn ratio. The more number of primary turns increases, the more leakage inductance increases. So size of external resonant inductor can decrease.

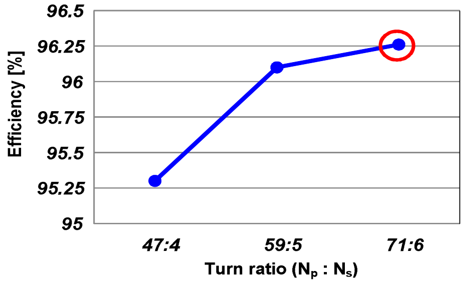

Fig. 15 Efficiency according to turn ratio

External resonant inductor core is selected CM102060. CM102060 is smaller than CM127060. CM102060 has little higher efficiency than CM127060. In case of primary switch, IPD60R385CP has little higher efficiency than IPD65R380E6. Conduction resistance of IPD65R380E6 is smaller than IPD60R385CP, but output capacitance of IPD60R385CP has smaller than IPD65R380E6. Therefore switching loss and total switch loss of IPD60R385CP is smaller than IPD65R380E6.

Tab.4 Selected device & value list

	Device & Value
Core	RM8(PL-9)
Inductance	1.51mH
Switch	IPD60R385CP
Secondary SR	IRFB7855
Output inductor core	CM102060

Final selected device & value list is below in Tab.4. RM8 core, PL-9 material is selected for LLC DC-DC converter transformer core. Inductance value is 1.51 mH. IPD60R385CP and IRFB7855 are selected for switch and secondary side SR(Synchronous Rectifier). And efficiency is 96.35% at full load condition. Fig. 16 is primary transformer voltage and current waveforms.

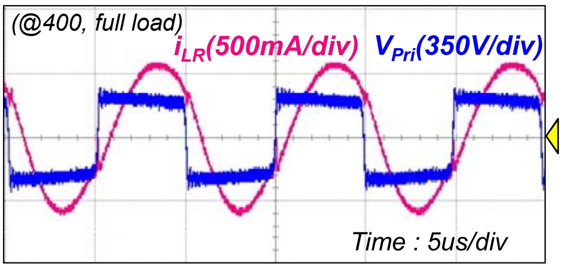

Fig. 16 Primary transformer voltage and resonant inductor current waveforms

Fig. 17 is efficiency graph of conventional single-stage AC-DC converter, boost PFC + LLC DC-DC two-stage AC-DC converter and boost PFC + active clamp forward DC-DC two-stage AC-DC converter. Efficiency of boost PFC + LLC DC-DC two-stage AC-DC converter is 90.94%. This graph shows that boost PFC + LLC DC-DC two-stage AC-DC converter is 1.92% higher efficiency than single-stage flyback AC-DC converter at 90Vac input voltage. Also, boost PFC + LLC DC-DC two-stage AC-DC converter is 1.5% higher average efficiency than single-stage flyback AC-DC converter.

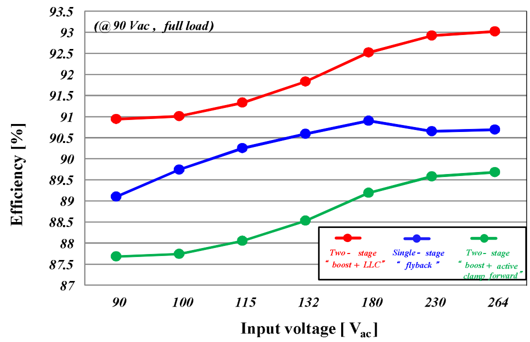

Fig. 17 Efficiency at 90 ~ 264 V_{ac} input voltage

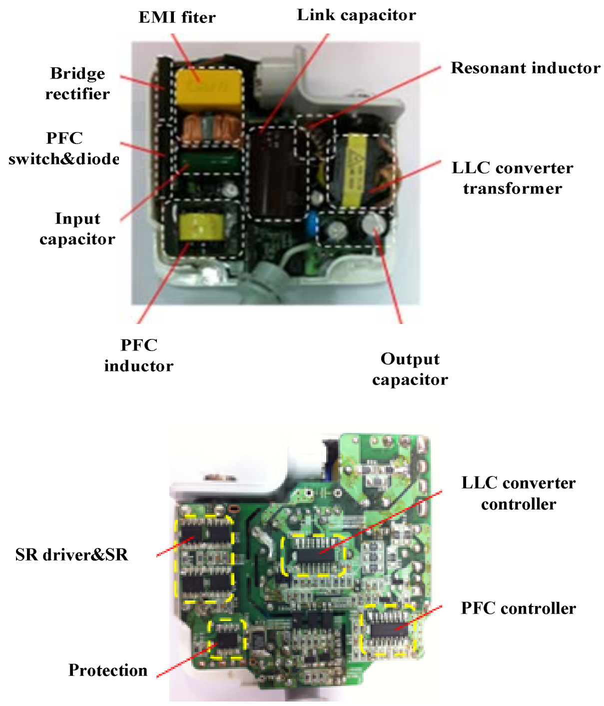

Fig. 18 Boost PFC + LLC DC-DC converter in conventional adapter case

Second target of this study is that two-stage AC-DC converter same size as conventional adapter. Fig. 18 shows that boost PFC + LLC DC-DC converter is possible to put in conventional adapter size.

IV. CONCLUSION

Two-stage AC-DC converter structure is studied for high efficiency AC-DC converter same size as conventional adapter. In case of PFC stage, BCM boost PFC is selected. Efficiency is 94.39% at 90Vac input voltage. In case of DC-DC stage, LLC resonant DC-DC converter is selected. Efficiency is 96.35% at full load condition. Finally, combination of boost PFC and LLC DC-DC converter is selected. Total two-stage efficiency is 90.94%. it is 1.92% higher than conventional single-stage AC-DC converter. Also, boost PFC + LLC DC-DC converter is possible to put in conventional adapter size.

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