Analysis and Design considerations of LLC Resonant Converter Including Parasitic Components

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Abstract

Since conventional analysis of LLC resonant converter has a limit to explain a practical operation of LLC Resonant Converter, LLC resonant converter designed by conventional analysis can not regulate output voltage in several conditions. To solve this problem, analysis and design of LLC resonant converter including parasitic components is proposed. Experimental results are shown to confirm the feasibility of the proposed method.

1. Introduction

Since LLC resonant converter as shown in Fig.1 has a lot of advantages over other series- or parallel-resonant converters like as simple structure, Zero-Voltage-Switching (ZVS), relatively small variation of switching frequency, it has been used for various applications such as Plasma-Display-Panel(PDP) power, server power supply and high power density adapter [1].

Input-output voltage conversion ratio based on Fundamental Harmonic Analysis with ideal components can be obtained as shown in Fig. 2 [2]. However, practical input-output voltage conversion of LLC resonant converter is different from the conventional one as shown in Fig. 3. Due to this difference, LLC resonant converter is designed by conventional analysis can not regulate the output voltage when the converter operated in Region 1. It's the reason why the operating region of conventional LLC resonant converter is limited in Region 2 or Region 3. However, to get high efficiency, to meet the stand-by requirements, and to reduce the current stress during soft-start, the operating region of LLC resonant converter has to be extended in Region 1.

To extend the operation region of LLC resonant converter to Region 1, in this paper, analysis and design considerations of LLC resonant converter including parasitic components is proposed. Moreover, experimental results are shown to demonstrate the feasibility of the proposed method.

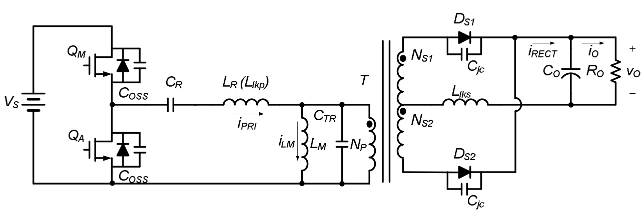


Fig. 1 Circuit Diagram of the LLC resonant converter including parasitic components

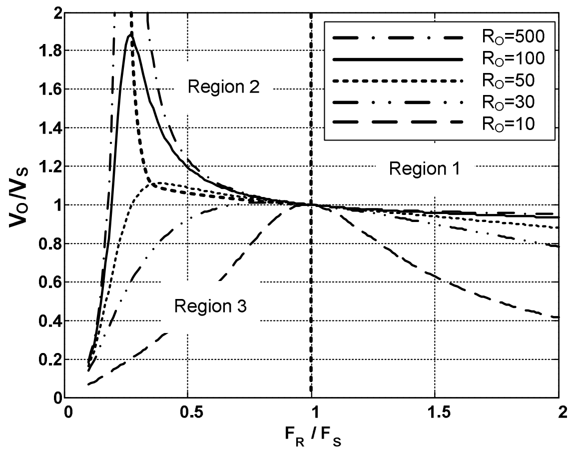


Fig. 2 Voltage Conversion Ratio of conventional analysis for LLC Resonant Converter

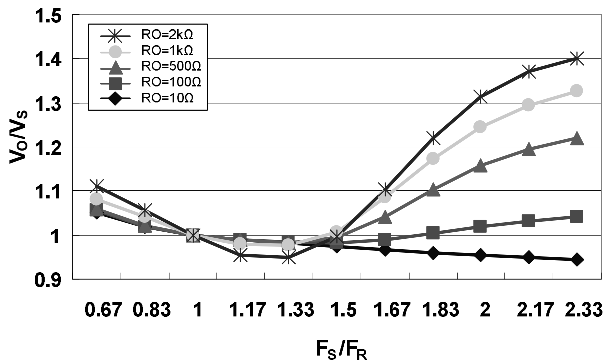


Fig. 3 Experimental voltage conversion ratio of LLC Resonant Converter

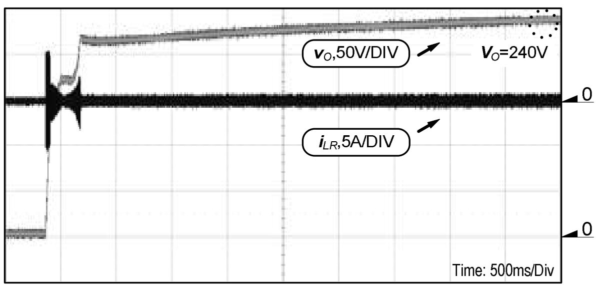


Fig. 4 Unregulated output voltage during start-up period

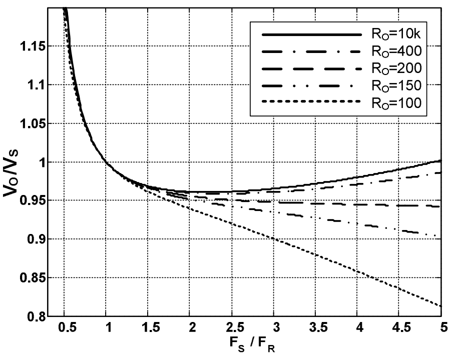
2. Proposed Analysis and Design Considerations of LLC Resonant Converter Including Parasitic Components

Input-output voltage conversion ratio of LLC resonant converter including parasitic components based on Fundamental Harmonic Analysis can be expressed as follows.

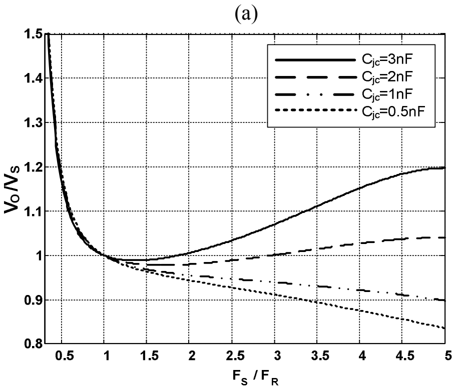
$$\frac{V_O}{V_S}=\frac{1}{2n}\left|\frac{n^2R_{ac}}{n^2R_{ac}\left[(1-\frac{\omega^2}{\omega_{JC}^2})\left\{1-\frac{\omega_M^2}{\omega^2}\times\left(1-\frac{\omega^2}{\omega_R^2}\right)\right\}+\frac{\omega_M^2}{\omega_{JCM}^2}\times\left(1-\frac{\omega^2}{\omega_R^2}\right)\right]+j\omega\left[n^2L_{lks}\left\{1-\frac{\omega_M^2}{\omega^2}\times\left(1-\frac{\omega^2}{\omega_R^2}\right)\right\}-L_M\times\frac{\omega_M^2}{\omega^2}\times\left(1-\frac{\omega^2}{\omega_R^2}\right)\right]}\right| \quad (1)$$

,where $\omega_R=\frac{1}{\sqrt{C_RL_R}},\omega_M=\frac{1}{\sqrt{C_RL_M}},\omega_{JCM}=\frac{1}{\sqrt{C_{JC\_eq}L_M}},\omega_{JC}=\frac{1}{\sqrt{C_{JC\_eq}n^2L_{lks}}}$.

The normalized voltage gain of equation (1) is plotted in Fig. 5 with different load condition and junction capacitance of rectifier diode. As shown in Fig. 5, the result of the proposed analysis is similar with practical phenomena of LLC resonant Converter. Notable difference between without and with parasitic components is the increase of voltage gain as switching frequency increases. Cause of this voltage gain increase is a resonance between junction capacitance of rectifier diode and resonant inductor. Degree of voltage gain increase with lighter load condition, larger junction capacitance of rectifier diode. To overcome this problem, there are four applicable solutions as follows.



(a)



(b)

Fig. 5 Voltage conversion ratio of the LLC resonant converter with all parasitic components (a)C_{jc}=50pF, (b) R_O=100Ω

2.1 Adding Dummy Load

Adding dummy load can reduce the effect of junction capacitance, because the effect of junction capacitance increases as load decreases. By adding the dummy load, it can be possible to reduce the effect of junction capacitance. However, since adding dummy load makes continuous losses by equation (2), the efficiency of the converter is degraded.

$$P_{Loss\_Dummy}=\frac{V_O^2}{R_{Dummy}} \quad (2)$$

2.2 Limiting the Maximum Switching Frequency

Limiting the maximum switching frequency is an approach to prohibit the converter operating in the operation region of converter where they are affected by junction capacitance of rectifier diode. In case that the maximum switching frequency is limited, the converter can be avoided to operate in region that is affected by junction capacitance, C_{jc}. However, by limiting maximum switching frequency, it increases current stress during soft-start, because the current stress is determined by equation (3).

$$i_{LR\_peak}=\frac{V_S}{2L_RF_{S\_MAX}} \quad (3)$$

2.3 Low Q Design

By selecting low Q design, it can reduce the effect of junction capacitance. However, by choosing low Q factor, it can increases variation of switching frequency over input and load change and current stress during soft-start by equation (3).

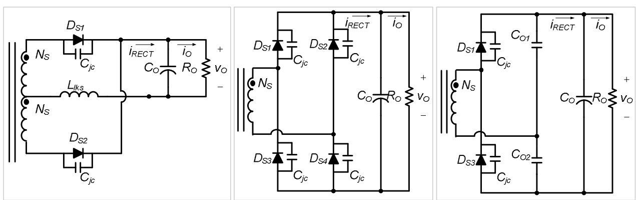
2.4 Selection of Rectifier Types

There are three possible rectifier types such as Center-Tapped, Full-Bridge or Voltage-Douber as shown in Fig. 6. The equivalent junction capacitance with different rectifier type can be obtained as described in equations (4), (5) and (6), Center-Tapped, Full-Bridge and Voltage-Doubler in that order.

$$C_{jc\_eq\_Center-Tapped}=2C_{jc}(N_S/N_P)^2 \quad (4)$$

$$C_{jc\_eq\_Full-Bridge}=C_{jc}(N_S/N_P)^2 \quad (5)$$

$$C_{jc\_eq\_Voltage-Doubler}=2C_{jc}(N_S/N_P)^2 \quad (6)$$



(a) (b) (c)

Fig. 6 Possible rectifier types (a) Center-Tapped (b) Full-Bridge (c) Voltage-Doubler

Considering the transformer turn ratio for same output voltage and same rectifier diode, the equivalent junction capacitance is obtained as described in Table 1. The Center-Tapped rectifier has the largest equivalent junction capacitance, but the Voltage-Doubler rectifier has the smallest equivalent junction capacitance. Therefore, selecting different rectifier can reduce the effect of junction capacitance. However, selecting the rectifier type can be limited according to applications. Because Voltage-Doubler type needs two additional capacitors, it can increase the cost and size.

Table 1. Equivalent junction capacitance with different rectifier

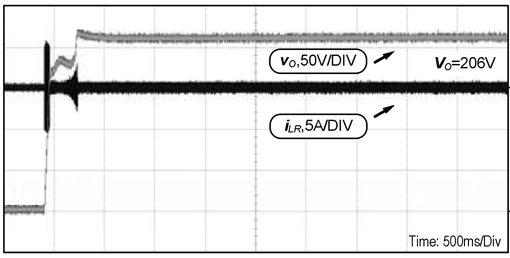
	Center-Tapped	Full-Bridge	Voltage-Doubler
Equivalent C_{jc}	**2*C_{jc}**	**C_{jc}**	**C_{jc} /2**

3. Experimental Results

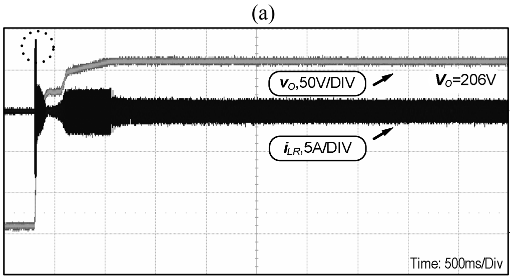
To confirm the feasibility of the proposed method, the prototype is implemented with specification described in Table 2. LLC resonant converter based on conventional analysis can not regulate the output voltage when the converter operates in Region 1 as shown in Fig. 4. However, in case that the converter based on the proposed analysis and design guideline such as adding dummy load, limiting the maximum switching frequency, F_{S_MAX}, and the low Q factor design, the output voltage of the converter can be regulated as shown in Fig. 7(a), Fig. 7(b), and Fig. 7(c), respectively. Moreover, the effect of junction capacitance of rectifier diode is different according to rectifier types as shown in Fig. 8. Therefore, the output voltage of center-tapped and full-bridge rectifier can not be regulated as shown in Fig. 9(a) and Fig. 9(b), respectively. However, in case of voltage-doubler rectifier, the output voltage is regulated as shown in Fig. 9(c).

Table 2. Used experimental parameter lists

Parameters \ Applications		PDP
V_S		**385V**
V_O		**206V**
L_R		**20uH**
C_R		**94nF**
Transformer	L_M	**310uH**
	L_{lks}	**1.3uH**
	N_P:N_S	**23:21**
Rectifier-Type		**Center-Tapped**



(a)



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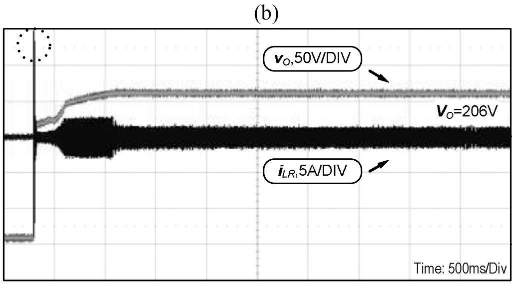


(c)

Fig. 7 Regulated output voltage load during start-up period (a) adding dummy (b) low Q design (c) limiting F_{S_MAX}

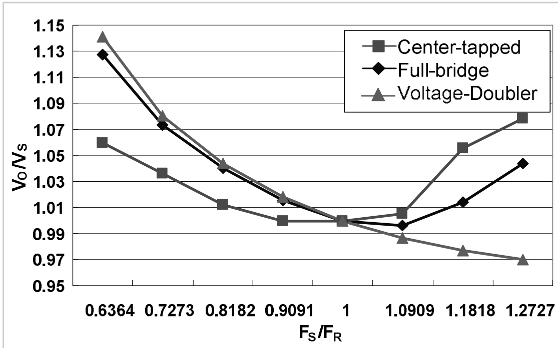
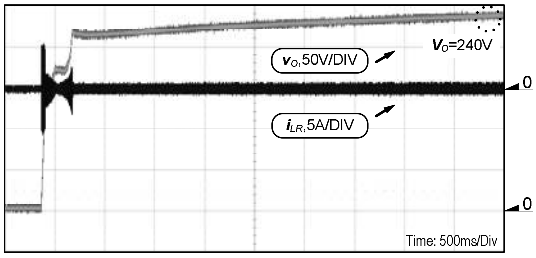
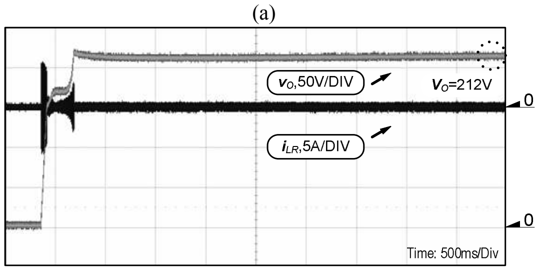


Fig. 8 Experimental results with different rectifiers



(a)



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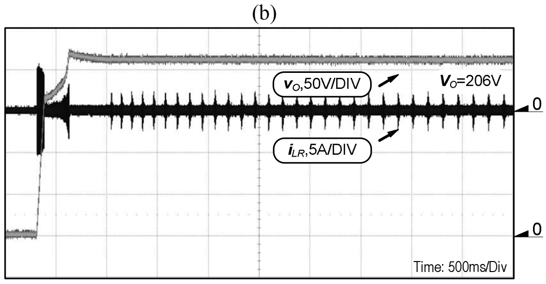

(c)

Fig. 9 Experimental results (a) Center-Tapped (b) Full-Bridge rectifier (c) Voltage-Doubler

4. Conclusion

In this paper, analysis and design of LLC Resonant Converter including parasitic components are proposed. The proposed method can explain the practical operation of LLC Resonant Converter. Moreover, by applying the proposed method, the problem of LLC Resonant Converter based on conventional analysis can be solved. Therefore, the proposed design guideline is greatly suited for practical design of LLC resonant converter.

Reference

[1] R. Steigerwald, "A Comparison of Half-Bridge Resonant Converter Topologies," in *IEEE Trans. on Power Electronics,* Vol. 3, No. 2, pp. 174~182, April. 1988.

[2] B. Yang, F.C. Lee, A.J. Zhang and G. Huang, "LLC resonant converter for front end DC/DC conversion", in *IEEE Proc. APEC*, 2002, pp. 1108~1112.