Design and Analysis of Half Bridge Resonant Converter

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ABSTRACT: Inductor inductor Capacitor (LLC) resonant converter has gained attention of researchers and engineers these days because of its advantages such as low switching losses due to ZVS turn on, possibility of high frequency operation, high power density over other existing resonant converters. Here in this paper the LLC resonant converter of constant output voltage is designed using first harmonic approximation and controlled through PI controller to get the constant output with better transient.

I. INTRODUCTION

The DC-DC converter is heart of power electronics. For highly efficient, reliable operation, the DC-DC converter in any power electronics application must be highly efficient and reliable. Nowadays, resonant converters are widely used in power electronics. In flat-screen TVs, laptop adapters, lighting, computers, battery chargers, renewable energy, and transportation, LLC resonant converter has become more popular.

The LLC resonant converter is one of the most useful topologies for designing constant output voltage power supplies. These converters have been designed for using in battery chargers. It requires low inductance ratio and low switching frequency variation range, for wide output voltage applications, these parameters simultaneously raised and should be optimized. In many cases extracting the proper values and characteristics of the components in the closed form is not possible, due to the complexity of the equations and high order of the circuit.

Using a computer and numerical techniques for optimizing the power electronics converters has become a common approach. One well known technique is based on the FHA (first harmonic approximation) approach that the ac equivalent circuit is considered for analyzing the converter. In fact, this linear circuit replacement is the result of the power processing in the main switching frequency component and ignoring the effects of the other components. Other approaches like state-plane or time-domain analysis are based on the exact model of the converter to provide precise description of the circuit behavior. But these approaches are usually are difficult to be used. Due to lack of the convenient analysis tools, previous design methods often rely on circuit simulation or graphical design tools. Also, the existing optimal design approaches for choosing the components values, usually provide ranges or boundaries of the components variations values and they are not exactly determine the parameters. It should be noted that in some applications it may not be necessary to have maximum efficiency exactly at-or near the -full load condition.

In series resonant converter the resonant tank circuit is connected in series with load, hence the gain of the converter is always less than unity. At light-load or no-load condition to regulate output voltage we need to increase the switching frequency to very high value, ideally to infinity. But in parallel resonant converters since the load is connected in parallel with the resonant capacitor, it is quite easy to regulate the output voltage. But PRC suffers from high circulating energy losses.

II. LLC RESONANT CONVERTER FEATURES: (Black – 9)

The circuit schematic of an LLC resonant converter in its half-bridge implementation is shown in Figure 1. The half-bridge driver switches two MOSFETs Q1 and Q2 on and off 180º out-of-phase at the frequency fs. The on time of each MOSFET is exactly the same and is slightly shorter than 50% of the switching period Ts = 1/fs. In fact, a small dead-time inserted between the turn-off of either MOSFET and the turn-on of the other one. This is must required for the operation of the converter. It ensures that Q1 and Q2 do not cross-conduct and allows soft-switching for both of them, that is the zero-voltage switching at turn-on (ZVS). The resonant tank includes three reactive elements (Cr, Lr and Lm) and thus features two resonance frequencies.

One is related to secondary winding conduction: only Lr is active, while Lm disappears because there is a constant voltage across it reflected back from the secondary side; its value is:

$$F_{r1} = \frac{1}{2\pi\sqrt{Lr\ Cr}} \text{ ……….. (1)}$$

The other resonant frequency corresponds to the condition of the secondary winding(s) is being open. The tank circuit turns from LLC to LC because Lr and Lm are effectively in series:

$$F_{r2} = \frac{1}{2\pi\sqrt{(Lr+Lm)\;Cr}} \text{ …………….. } (2)$$

The following, of course, is true: fR1 > fR2. The separation between fR1 and fR2 depends on the Lm to Lr ratio. Power flow is controlled by the operating switching frequency fs. Normally, a reduced power demand from the load produces a rise in frequency, while an increased power demand causes a decrease in frequency. When working at a resonant frequency, fs is equal to fR1, the converter is said to operate at resonance condition. When, operation at frequencies fs > fR1 is termed as above-resonance and in the frequency region fs < fR1 is called below-resonance.

The region below resonance is practically limited to a relatively narrow range fR2< fs < fR1, to prevent the converter from losing soft-switching of the half-bridge leg. In fact, this is what would happen if fs got too close to fR2. Losing ZVS would cause such adverse effects that the converter's safety would be seriously compromised.

III. OPERATION ANALYSIS: [4]

As observed in Fig 2, the LLC resonant converter shows nearly load independent characteristics when the switching frequency is around the resonant frequency. This is a distinctive advantage of LLC-type resonant converter over conventional series-resonant converter. Therefore, it is natural to operate the converter around the resonant frequency to minimize the switching frequency variation at light load condition.

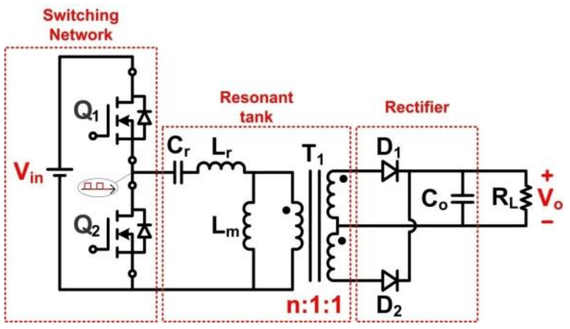
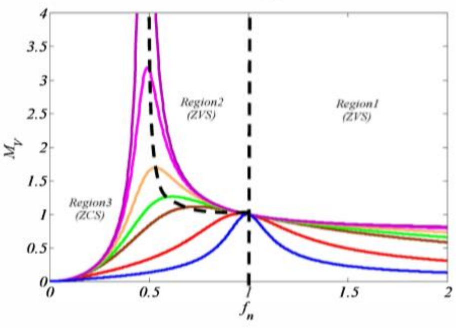


Figure 1



Voltage gain characteristics of the *LLC* resonant converter

Figure 2

The operation range of LLC resonant converter is determined by the available peak voltage gain. As shown in Fig. 2, higher peak gain is obtained as Q decreases (as load decreases). Another important factor that determines the peak gain is the ratio between Lm and Llk. Even though the peak gain at a given condition can be obtained by using the gain,

$$M_{@w=wo} = \frac{L_m}{L_p - L_r} \text{ …………….}(3)$$

$$\omega_o = \frac{1}{\sqrt{L_r C_r}}, \omega_p = \frac{1}{\sqrt{L_p C_r}} \text{ …………….}(4)$$

$$Re = \frac{Voe}{Ioe} = \frac{8\times n^2}{\pi^2} \times \frac{Vo}{Io} \text{ …….. } (5)$$

$$Q = \frac{\sqrt{L_r C_r}}{R_e} \text{ ……………. } (6)$$

It is difficult to express the peak gain in explicit form. Moreover, the gain obtained from (3) has some error at frequencies below the resonant frequency due to the fundamental approximation. In order to simplify the analysis and design, the peak gains are obtained using simulation tool.

The value of Mv is not less than zero. This is obvious since Mv is from the modulus operator, which depicts a complex expression containing both real and imaginary numbers. These numbers represent both magnitude and phase angle, but only the magnitude is useful in this case. Within a given Ln and Qe, Mg presents a convex curve shape in the vicinity of the circuit's resonant frequency. This is a typical curve that shows the shape of the gain from a resonant converter. The normalized frequency corresponding to the resonant peak is moving with respect to a change in load and thus to a change in Qe for a given Ln.

IV. DESIGN CONSIDERATION

As discussed earlier, fn is the control variable in frequency modulation. Therefore the output voltage can be regulated by Mv through controlling fn, as indicated by Fig. 2,Mv can be written as,

$$Vo = Mg\ (Fn, Ln, Qe) \times \frac{1}{n} \times \frac{Vin}{2} \ldots\ldots\ldots (7)$$

Although this discussion has so far determined that the design should operate in the vicinity of the series resonance, or near fn = 1,

Basic Design Requirements,

For a typical design of a power-supply converter, as is well-known, three basic requirements are almost always considered first—line regulation, load regulation, and efficiency.

Line regulation is defined as the maximum output-voltage variation caused by an input voltage variation over a specified range, at a given output load current.

Load regulation is defined as the maximum output-voltage variation caused by a change in load over a stated range, usually from no load to maximum. These two types of regulation are actually achieved through the voltage-gain adjustment—and in an LLC converter, the gain adjustment is made through frequency modulation. The recommended area of operation described in Fig. 7 shows a relatively steep slope for the gain, which can narrow the range of the frequency modulation. As such, a design has to make the gain adequately adjustable in a range that meets the required regulating specifications.

Efficiency is one big benefit of using an LLC converter. The converter's switching losses can be reduced significantly by ensuring that primary side ZVS is maintained over the whole operating range. As will be explained, ZVS cannot be achieved everywhere in the gain-plot area, but keeping the design within the recommended region will ensure ZVS.

Zero-Voltage Switching (ZVS)

A major benefit of the LLC converter topology is its potential for significantly reduced switching losses, primarily achieved through primary-side ZVS; however, as stated earlier, it is ZVS considerations that drive the recommended design area to be only on the right side of the resonant gain curves in Fig. 2.

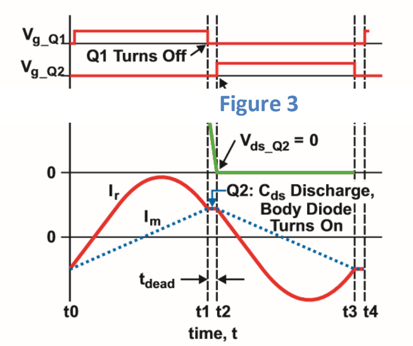
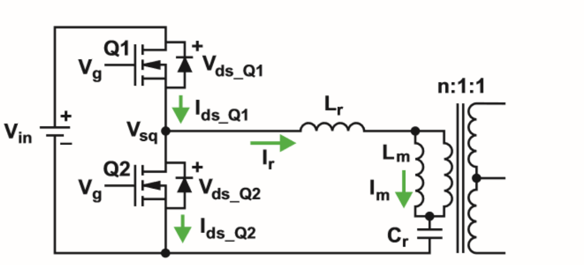


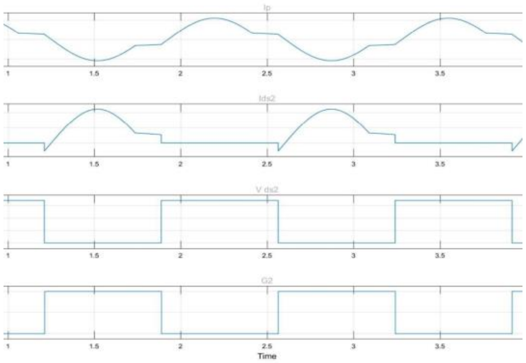
Figure 3

b. ZVS timing waveform.

This section discusses how ZVS is achieved and why it affects the design area. Achieving ZVS To achieve ZVS, a MOSFET is turned on only after its source voltage, Vds, has been reduced to zero by external means. One way of ensuring this is to force a reversal of the current flowing through the MOSFET's body diode while a gate-drive turn-on signal is applied (see Fig. 3b). As shown in Fig. 3, when Q1 turns off at t1, the Q2 gate's turn-on drive signal is not applied until t2, such that there exists a dead time, tDead, from t1 to t2. During tdead, the current in the resonant circuit (Ir) is diverted from Q1 to Q2, first discharging Q2's drain-to-source capacitance, Cds, to make its voltage zero, and then forward biasing Q2's body diode. At t2, conduction through the Q2 body diode maintains zero Vds_Q2 (ignoring the Q2 body diode's forward-voltage drop) until the Q2 gate's turn-on drive signal is applied. So the critical condition is when Q1 turns off. A nonzero current (Ir) should still continue in its same direction as when Q1 was on, normally accomplished by external circuit inductance. And, of course, the same conditions are necessary for a Q1 ZVS turn-on.

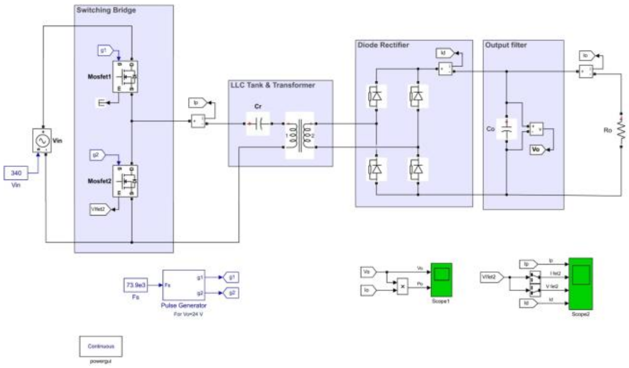


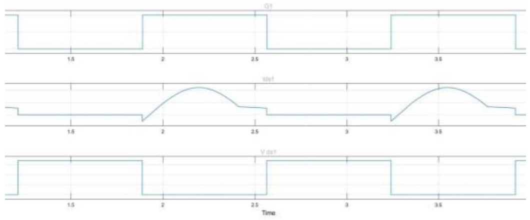
a. LLC resonant circuit.



RESULTS:

MATLAB MODEL:





Input: 340V-400V Output: 24V, 192W
if, Output power is 192W , Io is 8A. Switching frequency is 73.9 Khz at Vin = 340V, 91.3 KHz at Vin= 390V.

If, Output is very low 1.9W Output Power and Io is below .1A, Switching Frequency is 77.8 kHz at Vin = 340V and 96.5 Khz at 390V

Related waveforms are shown below. Fig 4A shows the output voltage Vo and Output power Po respectively. Fig 4B and 4C shows Gate Pulses G1 and G2 , Voltage across drain and source of Q1 and Q2, Vds1 and Vds2 respectively , primary current (Ip) and Diode current (Id).

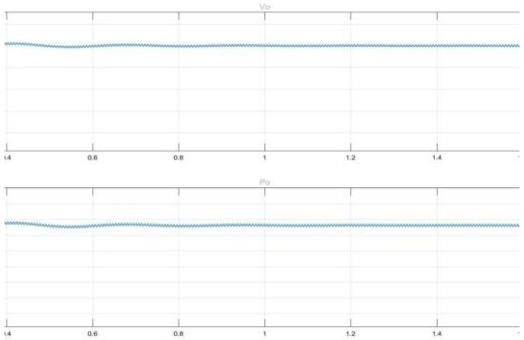


Figure 4A

VI. CONCLUSION

This paper has presented design consideration for LLC resonant converter with integrated transformer, which utilizes the leakage inductances and magnetizing inductance of transformer as resonant components. In this paper half bridge LLC resonant converter is discussed. MATLAB model of LLC resonant converter is designed.

VII. REFERENCES

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