OPTIMALIZATION AND DESIGN TRANSMISSION RESPONSE LLC RESONANT CONVERTER

Jozef Kandráč, Martin Priečinský, Michal Frívaldský

University of Zilina, Faculty of Electrical Engineering, Department of Mechatronics and Electronics

Abstract

The paper describes design and optimalization the main circuit of LLC resonant convertert with respect to transfer function with output 1kW/48V, switching frequency 500 kHz and a way to optimize given on the size the transformer, conductivity losses, size of resonant capacitor current and scope of regulatory to ensure stable operation with using ZVS (zero voltage switching). In this design, it is necessary to consider various assumptions, limitations and compromises for the specific properties of LLC converter given by requirements.

1 Introduction to issue the LLC resonant converter

Higher energy density in the switching power supply is conditional on the size of passive components. Operation at higher frequencies significantly reduces the size of passive components, but at the expense of increased switching losses. To reduce switching losses, while the operation with high switching frequency have been developed resonant switching technique. LLC resonant converters are widely used for high performance applications, since at higher input voltage making it more effective. They are capable of switching ZVS for the main switching elements, which can operate with higher switching frequency and thereby increase the power density. Another advantage of LLC resonant ZCS converters is switching over diode, which is improved efficiency. Wiring LLC resonant circuit in half bridge involved:

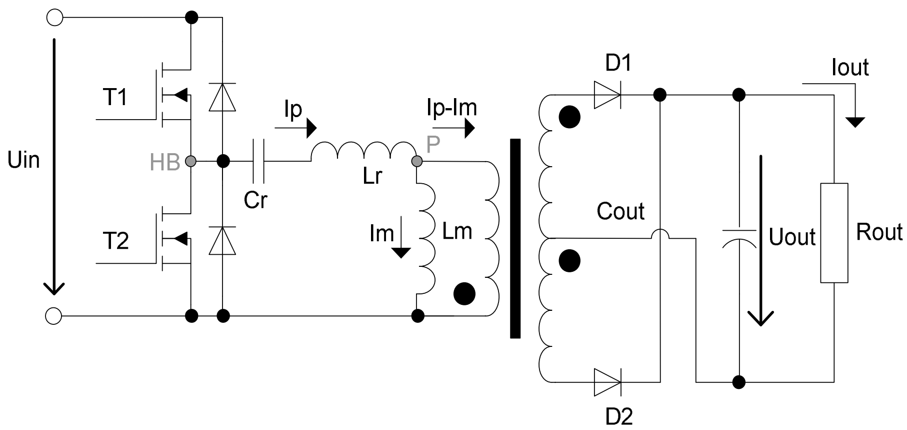

Fig. 1. Schematic involvement LLC resonance converter

2 Important parameters

Motion parameters consist of a thorough analysis of the DC characteristics of the converter. Operating principle of LLC resonance converter voltage gain characteristics and require a lot of knowledge. Analysis of the characteristics of voltage gain is based on the well-known method of FES (Fundamental Element Simplification) [4]. In the design of resonance LLC converter is necessary to consider three essential elements:

- ratio of magnetization and the resonance inductance

$$m = \frac{L_m}{L_r} \tag{1}$$

- quality factor

$$Q = \sqrt{\frac{L_r}{L_m}} \cdot \frac{\pi^2}{8.n^2.R_L} \tag{2}$$

- resonant frequency

$$f_0 = \frac{1}{2.\pi.\sqrt{L_r.C_r}}, \qquad f_p = \frac{1}{2.\pi.\sqrt{(L_r + L_m).C_r}} \tag{3}$$

These parameters have ultimate influence on the operation of LLC resonant converter. By selecting proper value of each parameter, we can find compromise between amount of switching and conduction losses, or it is possible to determine volume of transformer and volume of passive non – linear components (capacitors, inductances). For projection of the frequency dependency on the ratio of the output to input voltage utilization of the equation of voltage gain of LLC converter is very useful. The basic formula is defined as follows:

$$M = \frac{V_0}{V_i} = \frac{1}{2n\sqrt{\left[1+\frac{1}{m}\left(1-\frac{f_0^2}{f^2}\right)\right]^2 + \left[\left(\frac{f_0}{f}-\frac{f}{f_0}\right)Q\right]^2}} \tag{4}$$

where V_o and V_i are output and input voltages and f is switching frequency of converter.

But for the required DC gain characteristics, the equation (4) is not suitable; therefore it has to be rewritten. Design of mentioned characteristics is able to be done by utilization of equation (5).

$$M = \left| \frac{\left(\frac{\omega}{\omega_0}\right)^2 .\sqrt{m.(m-1)}}{\left(\frac{\omega^2}{\omega_p^2} - 1\right) + j.\left(\frac{\omega}{\omega_0}\right).\left(\frac{\omega^2}{\omega_0^2} - 1\right).(m-1).Q} \right| \tag{5}$$

3 Determine the parameters

The efficiency of LLC resonant converter is chosen for low voltage applications ranging from 0.88 to 0.92 and for high voltage applications ranging from 0.92 to 0.98. The frequency is seen to be achieved by changing the frequency of different values of voltage gain, which is a big advantage in managing the converter. Input voltage range depends on the parameters of the source from which the inverter power. The value of the minimum input voltage V_{inmin} is 325V and the maximum V_{inmax} input voltage is 425V.

4 Minimum and Maximum voltage gain (M_{min}, M_{max})

At nominal input voltage with a switching frequency employed in the vicinity of the value of the resonance frequency f0. In case our 500 kHz. The size of the voltage gain at the resonance frequency f0 is determined in proportion to the value m, which is defined as the ratio of magnetization inductance Lm and resonance inductance L_r ($m = L_m / L_r$). The higher peak gain can be achieved by a lower value of m, but will lead to a reduction in force if the deterioration of the converter transformer connection. Because the higher the value of m, conductivity losses, the regulatory scope and content of the transformer core will be higher contrast value of the current resonant capacitor and the lower resonant frequency is reduced, as shown below. It is therefore necessary to seek mutual compromise in choosing the value of m. In the figure 1 is frequency characteristic LLC resonant converter for value m = 4 and full load.

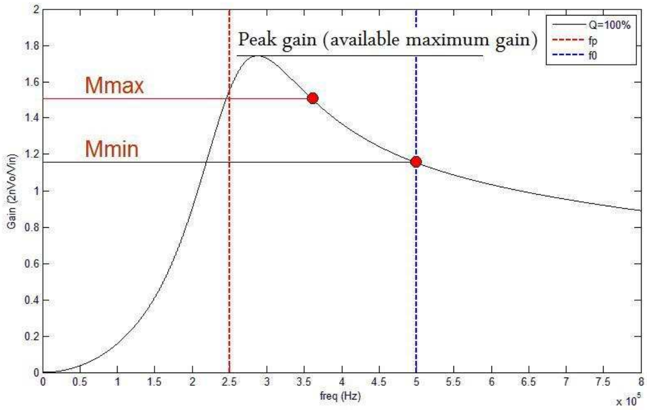

Figure 1: Frequency response for full load resonant LLC converter with input voltage 425V, output voltage 48V, output current 21A and resonant frequency 500 kHz

Figure 2: Illustrates the maximum and minimum gains depending on the value of m.

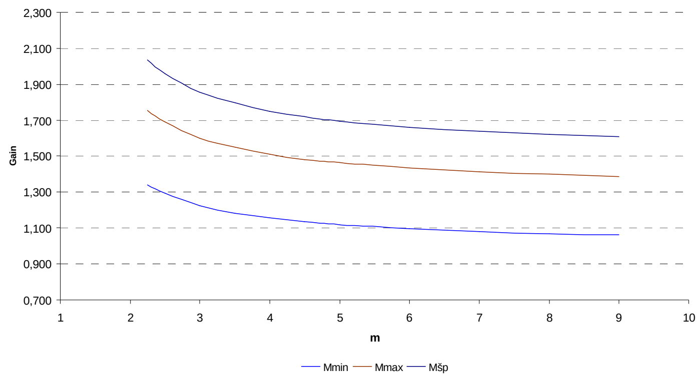

Figure 2: Dependence of voltage gain on the value of m-factor

Figure 3 shows frequency characteristics which are plotted for different values of m (2,25 – 9) at 25% load (Q = 25%) and full load (Q = 100%). In most cases the value of m is being chosen in the range 3 – 7. This results in value of voltage gain between 1,1 – 1,2. From fig. 3 it can be seen that by increasing the value of m the lower value of peak gain while lower value of parallel resonant frequency come into being. Also it is visible that at the series resonant frequency (fo) the voltage gain is independent and is unity for any value of m.

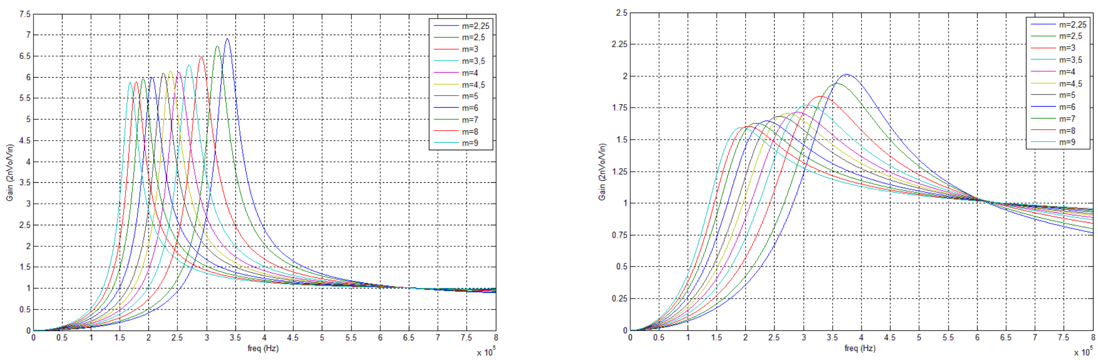

Figure 3: Frequency characteristics at 25% load (left) and at full load (right)

For the selected value of m we have prepared individual dependency between voltage gain and frequency at various loads, what is shown on figure 4. From figure, it is clear to say that during variations in output load the frequency modulation is necessary to keep output voltage on constant value. For selected value of m = 4, the regulation range is equal to 250 kHz, whereby parallel resonant frequency fp is equal to 250 kHz, and series resonant frequency is equal to 500kHz. These parameters are influencing the construction of transformer, at which lower value of frequency has to be starting point of transformer design, because during various operating conditions transformer has to withstand also operation at low switching frequency.

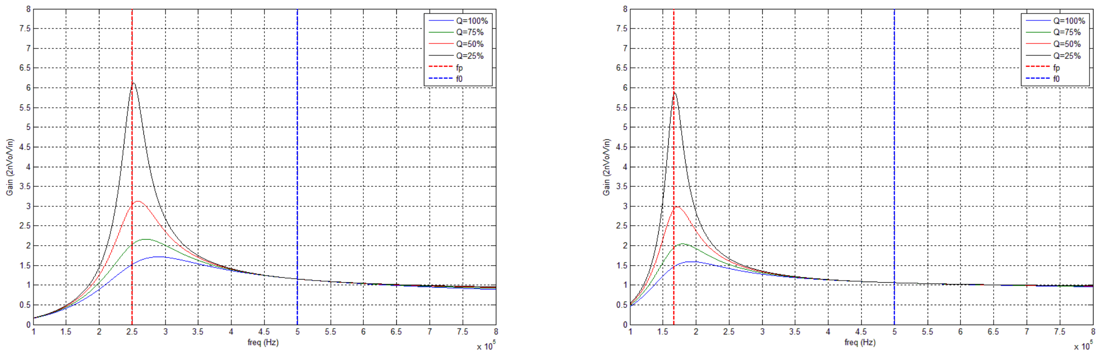

Figure 4: DC – gain characteristics of considered LLC resonant converter for m = 4 (left) and m = 9 (right) for various loads

The figure 5 considering various assumptions, limitations and compromises so that the proposed LLC converter has unique specific properties used in the field. When considering the need to find a compromise between the size of the transformer and the regulatory scope.

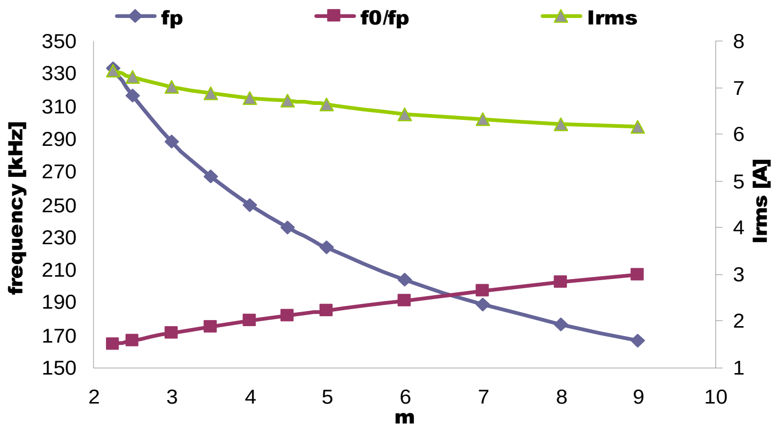

Figure 5: Dependency of parallel resonant frequency (f_p), ratio f_0/f_p and I_{RMS} on m value

5 Results

This paper has demonstrate the way of optimal design of LLC resonant converter and its frequency response suited for high frequency operation with high output power. As previously mentioned the strategic parameter “m” has to be optimally set to meet both low conduction and switching losses of semiconductor devices. Only in this way, the efficiency target could be met. The result of proper design LLC resonant converter and the frequency characteristics will of the converter with unique properties for a given application field.

Acknowledgment

The authors wish to thank to project VEGA "Research of Topology and Control of Power Electronic Supply System with Single-Phase HF Input and Two-Phase Orthogonal Output for Two-Phase SM/IM Electrical Motors". Next to grant agency APVV project no. 20-051705 and no. APVV-0535-07. Also we would like to thanks to VMSP-P-0085-09 and LPP-0366-09

References

[1] FAIRCHILD SEMICONDUCTOR CORPORATION.: *Application note AN4151*, 2007

[2] ELZBIETA SZYCHTA.: *Multirezonansowe przeksztaltniki ZVS napiecia stalego na napiece stale*, Oficyna Wydawnicza Uniwersytetu Zielonogorskégo 2006, ISBN 83 – 7481 – 040 -8

[3] BENDA, V.: *Power Semiconductors and Integrated Structures.* ČVUT Editor, Prague (CZ), 1994

[4] PERANTZAKIS G.S., XEPAPAS F.H., MANIAS S.N.: *A Novel four-level voltage source inverter-influence of switching strategies on the distribution of power losses,* IEEE Transactions Vol.22, No.1, January 2007

[5] DUDRÍK J., DZURKO P.: *Series-Parallel Resonant DC-to-DC Converter for Arc Welding, Proceedings of the Conference PEMC´98*, Prague, September 1998, Volume 7, pp. 16-20

[6] LU B., QIU Y., WANG CH., KANG Y., SUN J., DONG W., CANALES F., BARBOSA P., XU M., LEE F. C., GEAN R., TIPTON G., URCIUOLI D.: A High Power Density High Voltage Distributed Power System for Pulse Power Applications, ISSN 0-7803-89751/05/$20 2005 I EEE.

[7] GUAN CH. H., CHENG Z. T., SHIH H. H.: Design considerations for LLC series-resonant converter in two-resonant regions, 1-4244-0655-2/07, IEEE

[8] LEE F. C., WANG CH., XU M., LU B., WANG S., PENGJU K.: Optimized Design of Distributed Power Systems for High Efficiency, High Power Density and Low EMI Noise, ISBN 978-1-4244-1668-4/08/ 2008 IEEE

[9] Fang Y., Xu D., Zhang Y., Gao F. A., Zhu L.: Design of High Power Density LLC Resonant Converter with Extra Wide Input Range, ISBN: 1-4244-0713-3, Feb. 25 2007

Ing. Jozef Kandráč
University of Zilina, Faculty of Electrical Engineering, Department of mechatronics and electronics, Univerzitna 1, SK-010 26 Zilina, Slovakia, jozef.kandrac@fel.uniza.sk, tel.: +421 41 513 1630

Ing. Martin Priečinský
University of Zilina, Faculty of Electrical Engineering, Department of mechatronics and electronics, Univerzitna 1, SK-010 26 Zilina, Slovakia, martin.priecinsky@fel.uniza.sk, tel.: +421 41 513 1632

Ing. Michal Frívaldský, PhD.
University of Zilina, Faculty of Electrical Engineering, Department of mechatronics and electronics, Univerzitna 1, SK-010 26 Zilina, Slovakia, michal.frivaldsky@fel.uniza.sk, tel.: +421 41 513 1619