International Journal of Electronics Communication and Computer Engineering
Volume 3, Issue 4, ISSN (Online): 2249–071X, ISSN (Print): 2278–4209

Comparative Analysis Between LLC and LCC DC-DC Resonant Converter for High Voltage Applications

Ritu Sharma
PG Scholar
Power Electronics, Department of Electrical Engineering,
LNCT Bhopal, E-mail ID : rkurchaniya@yahoo.com

Amol Barve
Asst. Professor
Department of Electrical Engineering, LNCT Bhopal,
E-mail ID : amol.barve22@gmail.com

***Abstract* — The aim of this paper is do comparative study between LLC and LCC DC-DC resonant converter for high voltage applications, the two most promising topologies of this converter class are presented and compared in this paper. LCC and LLC resonant converters can achieve both high efficiency and wide input voltage range capability because of its voltage gain characteristics and small switching loss. It is shown that the Different combination of series-parallel resonant converter, which takes the desirable characteristics of the pure series and the pure parallel converter, removes the main disadvantages of those two converters. The proposed circuit of the bridge LLC and LCC resonant converter with 48V output voltage at 12A output current is built to verify the design criteria for the resonant tank.**

***Keywords* – DC-DC Resonant converter, LLC resonant converter, LCC resonant converter zero-voltage switching, soft-switching.**

INTRODUCTION

Resonant converter topologies are being widely used in power processing systems because of their soft-switching characteristics at high frequencies. The advantages of this topology is high-frequency operation include smaller size and lighter weight for the passive components.[2][3] There are two methods were proposed and compare in this paper LLC and LCC resonant converter to improve the efficiency and reduced switching losses through Zero voltage switching. Operation can be achieved even at narrow frequency variation over wide load range. The generalize circuit diagram of resonant converter is shown in figure 1[17]. Which can be converted into different topology of resonant converter. Figure 2 shown LCC type topology of resonant converter in which additional capacitor is placed in series with the resonant inductor. Figure 3 shown LLC type topology of resonant converter in which an additional inductor in connected in parallel with the resonant capacitor in the series resonant converter[1]. This type of converter is also known as multiple energy storage element resonant power converters. The high frequency causes low efficiency because of high switching losses. Since the resonant converter has ZVS or ZCS function for reducing switching losses, the resonant converter has been widely used in Power industry.

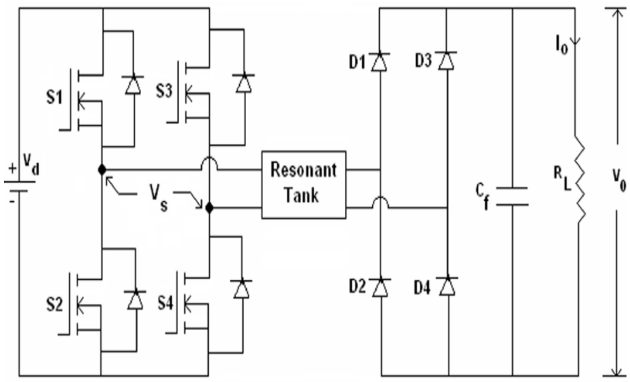

Fig.1. Generalized Resonant Converter

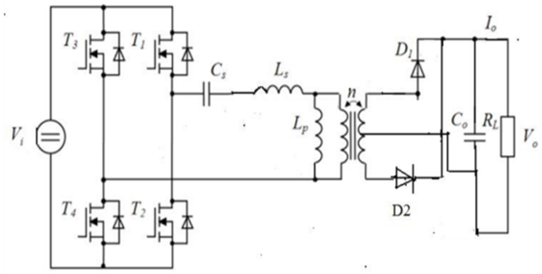

Fig.2. High voltage LCC converter

LCC and LLC Resonant Converter Analysis

LCC is series parallel converter combines the advantageous properties of both the series and parallel resonant converter. Its topologies are obtained by cascading a half bridge or a full bridge series parallel inverter. In this converter the load is connected in parallel with one of the resonant capacitor. Main objectives of this section is that to obtain analytical equation for LCC in the continuous conduction mode, to determine operating conditions for achieving high efficiency at part load.[11] The input-output voltage transfer function M(v), is given by equation no.1 for LCC resonant converter, the relationship between the resonant frequency fr and the undamped natural frequency fo of the tank is given by equation no 2 , where $A=C_p/C_s$ is the ratio of parallel and series capacitances, and $Q_L$is the loaded quality factor at the corner frequency. Efficiency of the system is given by equation no 3.Mathematical expression for different quantities of resonant circuit are shown below which is essential for calculation of transfer function ,normalized frequency, efficiency of LCC resonant converter[13]

Equivalent capacitor of Cp and Cs connected in series:

$$C = \frac{Cp\,Cs}{Cp+Cs}$$

International Journal of Electronics Communication and Computer Engineering
Volume 3, Issue 4, ISSN (Online): 2249–071X, ISSN (Print): 2278–4209

The corner frequency : $\omega o = \frac{1}{\sqrt{LC}} = \sqrt{\frac{Cp+Cs}{L\,Cp\,Cs}}$ (6)

The loaded quality factor at the corner frequency fo

$$QL = \omega 0\, C\, Ri = \frac{Ri}{\omega o\, L} = \frac{Ri}{Z0}$$

Capacitance of equivalent circuit of LCC resonant converter :

$$Ceq = \frac{Cp\,Cs}{Cp+Cs}$$

$$M(v) = V_o / V_i = \frac{4}{n\pi^2 \sqrt{(1+A)^2\left[1-\left(\frac{\omega}{\omega o}\right)^2\right]^2 + \left[\frac{1}{QL}\left(\frac{\omega}{\omega 0} - \frac{\omega 0}{\omega}\frac{A}{A+1}\right)\right]^2}} \quad \ldots (1)$$

fr / fo =

$$\sqrt{\frac{QL^2(1+A)^2\ 1+\sqrt{[QL^2(1+A)^2-1]^2 + 4QL^2 A(1+A)}}{2QL^2(1+A)^2}} \quad \ldots (2)$$

The resonant frequency f_r depends on Q_L and A.As $Q_L \rightarrow 0$,

$$fr / fo \rightarrow \frac{1}{\sqrt{1+\frac{1}{A}}}$$

$\eta = \eta_I\, \eta_R$ =

$$\frac{\eta tr}{\left\{1+\frac{r}{Ri}\left\{1+\left[\frac{Ri}{Zo}\left(\frac{\omega}{\omega o}\right)(1+A)\right]^2\right\}\right\}\left(1+\frac{VF}{VO}+\frac{RF+rLF}{RL}+ a h w^2 \frac{rac\, RL}{f^2 Lf^2}\right)} \quad \ldots (3)$$

LLC resonant circuit formed with one resonant capacitor, and two resonant inductor. Equation no 4,5,6 gives ,input output voltage transfer function, normalized frequency and efficiency of LLC resonant converter. Again we required some mathematical expression for find above mention equations. Ratio of the inductances is $A = \frac{Lp}{Ls}$

Equivalent inductance of Lp and Ls connected in series:

$L = Lp+Ls = Lp(1+A)= Ls(1+\frac{1}{A})$

The corner frequency : $\omega o = \frac{1}{\sqrt{LC}} = \sqrt{\frac{1}{(Lp+Ls)C}}$

The loaded quality factor at the corner frequency fo

$$QL = \omega 0\, C\, Ri = \frac{Ri}{\omega o\, L} = \frac{Ri}{Z0}$$

Inductance of equivalent circuit of LLC resonant converter :

Leq = Lp+ Ls

$M(v) = V_o / V_i$ =

$$\frac{4}{n\pi^2 \sqrt{(1+A)^2\left[1-\left(\frac{\omega 0}{\omega}\right)^2\right]^2 + \left[\frac{1}{QL}\left(\frac{\omega}{\omega 0}\frac{A}{A+1} - \frac{\omega 0}{\omega}\right)\right]^2}} \quad (4)$$

fr/fo =

$$\sqrt{\frac{\left\{1-QL^2(1+A)^2+\sqrt{[QL^2(1+A)^2-1]^2 + 4QL^2 A(1+A)}\right\}(1+A)}{2A}} \quad (5)$$

$\eta = \eta_I\, \eta_R$ =

$$\frac{\eta tr}{\left\{1+\frac{r}{Ri}\left\{1+\left[\frac{Ri}{Zo}\left(\frac{\omega}{\omega o}\right)(1+A)\right]^2\right\}\right\}\left(1+\frac{VF}{VO}+\frac{RF+rLF}{RL}+ a h w^2 \frac{rac\, RL}{f^2 Lf^2}\right)}$$

DESIGN

MATLAB software is used for simulate the LCC and LLC full bridge converter. In this simulation circuit inverter is composed of full bridge with IGBT switches. The output voltage of the inverter is rectified by rectifier. Because this voltage is sensitive to the switching frequency f the DC output voltage Vo can be controlled by varying the switching frequency. Transformer is used to achieve an isolation and/ or a desired voltage transfer function.

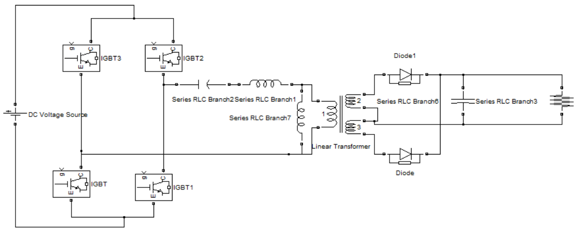

Fig.3. Simulation of LLC resonant converter

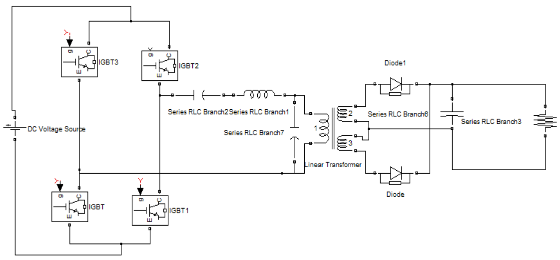

Fig.4. Simulation of LCC resonant converter

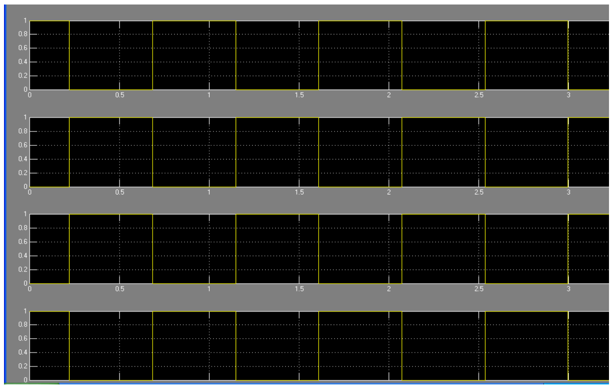

Fig.5. Gate Signal for IGBT 1, 3 & 2, 4

LLC resonant converter design and analysis:- α = 0.5 so that the theoretical value of VR is 400 V, assuming no voltage drop across the diode and the IGBT. Run the simulation and observe the inductor current (I_L), the IGBT collector current (I_C), the diode current (I_D), the IGBT device collector-emitter voltage (V_{CE}), and the load voltage (V_R). The load voltage (397 V) is slightly lower than the theoretical value (400 V) mainly because of the forward voltage (Vf) of the diode (0.8 V) and of the IGBT (V_f = 1 V)..

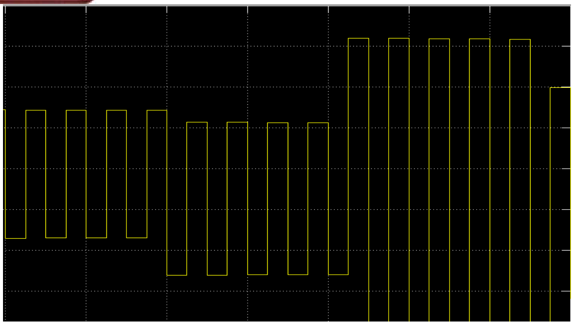

Fig.6. Output response of resonant tank

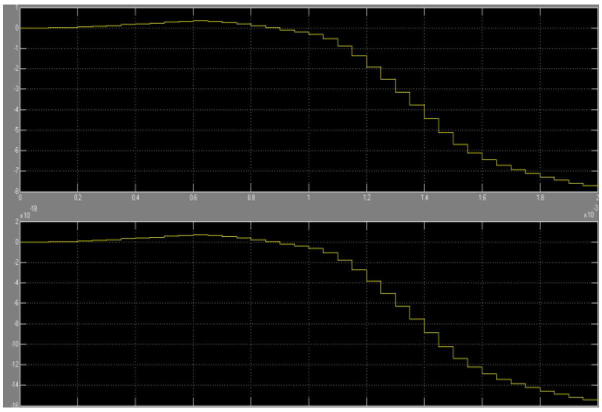

Fig.7. output response of LLC resonant circuit

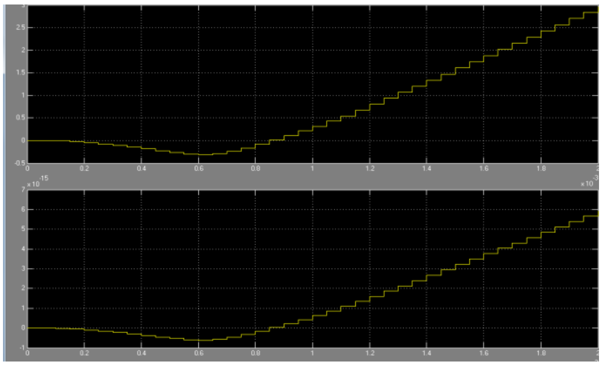

Fig.8. output response of LCC resonant circuit

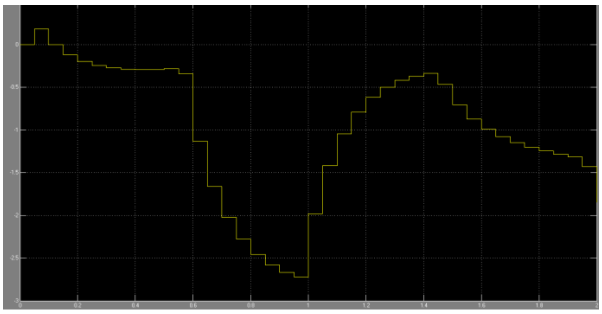

Fig.9. Resonant tank response of LCC circuit

Table 1 PARAMETERS OF LLC & LCC RESONANT TANK.

Specifications and Parameters	**Values**
DC (VDC)	400V
Output Voltage(Vo)	40V
Lr-Cr Resonant Frequency (fr)	100kHz
Turns Ratio of Transformer (np:ns)	9:1
Parallel Inductor (Lm)	318μH
Equivalent Load Resistor(Req)	100Ω
Series Capacitor Cs	629nF
Parallel Capacitor Cp	629nF

Table 2 : Circuit parameter and their normalized values for LCC and LCC resonant circuit

Circuit parameters	Symbol	Normalized Variables
Output Voltage	Vo	Voltage gain= Vo/ Vin
Output Current	Io	Jo = oZo/ Vin
Characteristic Impedance	$Zo = \sqrt{\frac{Lr}{Cr}}$	
Resonant Frequency	$\omega o = \sqrt{\frac{1}{LrCr}}$	
Switching Frequency	fs = 1 / Ts	F = fs/fr
Capacitance Ratio	A = Cp/ Cs	
Inductance Ratio	A = Lp/ Ls	

CONCLUSIONS

This paper presents the comparative analysis and study of LLC And LCC resonant DC-DC converter. The parallel resonant inductor is determined for load matching to ensure optimal efficiency. Additionally, the inductance ratio of the series and parallel resonant inductors is specified in terms of the voltage gain and input power factor for the LLC resonant tank.. The DC-bus voltages of 400V. Considering the turns ratio, quality factor and frequency limitation, the proposed converter covers wide input and load variation. In a first step, both converters are analyzed and revealing the first differences and similarities. Based on the obtained results, the LLC converter is a suitable topology for high efficient power adapters, providing a high and nearly constant efficiency throughout the complete load and input voltage range. Since the parallel inductance and the series inductance can be integrated within one single transformer, only an additional series capacitor for the resonant tank is necessary, reducing the component count. Nevertheless, the integration of two magnetic within the transformer complicates its design dramatically, due to the difficult prediction of the magnetizing and leakage inductance. Moreover, even small variations of the inductance ratio result in a rather large drop of the efficiency of this converter. By contrast, the design of the resonant tank of the LCC converter is much easier, since only the series inductance has to be integrated as the leakage inductance. While at the LLC converter a certain inductor ratio must be set, a certain capacitor ratio is necessary at the LCC converter simplifying the design process. Since the efficiency increases with falling input voltage, fields of applications are single mains with a limited range of input voltage. Hence, the resonant LCC tank is the preferred solution for electronic ballast for compact fluorescent lamps, where in addition the parallel capacitor provides a current path for filament heating and a sufficient starting voltage for ignition. Additional fields of applications for the LCC converter are high voltage applications. Since there is a transformer with a high turn's ratio necessary, the parasitic capacitances on the secondary side are sufficient for acting as the parallel capacitor in the resonant tank.

REFERENCES

[1] D. Fu, F. C. Lee, Y. Liu, and M. Xu, "Novel Multi-Element Resonant Converters for Front-end DC/DC Converters," in *Proc. IEEE Power Electron. Spec. Conf.*, Jun. 2008, pp. 250-256.

[2] R. Steigerwald, "A comparison of half-bridge resonant converter topologies," *IEEE Trans. Power Electron.*, vol. 3,no. 2, pp. 174-182, Apr. 1988.

[3] H. J. Jiang, G. Maggetto, and P. Lataire "Steady-State Analysis of the Series Resonant DC–DC Converter in Conjunction with Loosely Coupled Transformer—Above Resonance Operation," *IEEE Trans. Power Electron.*, vol. 14, no. 3, pp. 469-480, May 1999.

[4] Y. Ye, C. Yan, J. Zeng and J. Ying "A Novel Light Load Solution for LLC Series Resonant Converter," in *Proc. IEEE Telecommunications Energy Conf.*, Oct. 2007, pp. 61-64.

[5] B. Yang, F. C. Lee, A. J. Zhang, and G. Huang, "LLC resonant converter for front end DC/DC conversion," in *Proc. IEEE Appl. Power Elec. Conf. and Expo.*, Mar. 2002, vol. 2, pp. 1108 -1112.

[6] J. F. Lazar, and R. Martinelli, "Steady-State Analysis of the LLC series Resonant Converter," in *Proc. IEEE Appl. Power Elec. Conf. and Expo.*, Mar. 2001, vol. 1, pp. 728-735.

[7] B. Yang, "Topology Investigation for Front End DC/DC Power Conversion for Distributed Power System," Ph.D. Thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA, USA, May 2003.

[8] B. Lu, W. Lu, Y. Liang, F. C. Lee, and J. D. Van Wyk, "Optimal Design Methodology for LLC Resonant Converter," in *Proc. IEEE Appl. Power Elec. Conf. and Expo.*, Mar. 2006, pp. 533-538.

[9] S. D. Johnson, A. F. Witulski, and R. W. Erickson, "Comparison of Resonant Topologies in High-Voltage DC Applications," *IEEE Trans. of Aerospace an Electronic systems*, Vol. 24, No. 3, pp. 263-274, May 1988.

[10] H. S. Choi, "Design Consideration of Half-Bridge LLC Resonant Converter," *J. of Power Electronics*, Vol. 7, No. 1, pp. 13-19, January 2007.

[11] Marian K. Kazimierczuk, Dariusz Czarkowski, *Resonant Power Converters*, John Wiley sons, inc 1995, ISBN 0-471-04706-6 , Chapter 8 & 17

[12] K. Ashoka, S. Bhat, and S. B. Dewan, "Analysis and Design of a High-Frequency Resonant Converter Usign LCC-Type Commutation," *IEEE Trans. on Power Electronics*, Vol. PE-2, No. 4, pp. 291-301, October 1987.

[13] A. J. Gilbert, D. A. Stone', C. M. Binghan "Rapid Design of LCC Current-output Resonant Converters with Reduced Electrical Stresses" Power Electronics and Applications, 2005 European conference on 11-14 Sept 2005.

[14] M. K. Kazimierczuk, N. Thirunarayan, and S. Wang, "Analysis of Series-Parallel Resonant Converter, " *IEEE Trans. of Aerospace an Electronic systems*, Vol. 29, No. 1, pp. 88-99, January 1993.

[15] J. Liu, L. Sheng, J. Shi, Z. Zhang, and X. He, "LCC Resonant Converter Operating under Discontinuous Resonant Current Mode in High Voltage, High Power and High Frequency Applications," in *Proc. APEC09* pp.1482-1486, February 2009.

[16] A. J. Gilbert, D. A. Stone, C. M. Bingham*, M. P. Foster "Design of an LCC current-output resonant converter for use as a constant current source"

[17] M. Prabhakar, V. Kamaraja "Analysis and implementation of LCC dc dc resonant converter for automotive application. IETE Journal of research Vol 56 issue 4 July-Aug 2010

[18] Alexander Pawellek, Christian Oeder "Resonant LLC vs. LCC Converter Comparing Two Optimized Prototypes"

[19] Fang Lin Luo "Advanced dc/dc converter" chapter no:11 multiple quadrant soft switched converter

AUTHOR'S PROFILE

Ritu Sharma
received her B.E. from Rajiv Gandhi Technical University, Bhopal. She is currently pursuing M.E. in from Rajiv Gandhi Technical University, Bhopal. Her area of interest is Power Electronics.
Email ID : rkurchaniya@yahoo.com