International Journal of Power Electronics and Drive System (IJPEDS)
Vol. 9, No. 1, March 2018, pp. 174~179
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v9.i1.pp174-179

Analysis of High Voltage High Power Resonant Converters

Bhuvaneswari.C[1], R.Samuel Rajesh Babu[2],
[1]Department of Electrical and ElectronicsEngineering, Sathyabama University, India
[2]Department of Electronics and Instrumentation Engineering, Sathyabama University, India

Article Info

Article history:

Received Nov 17, 2017
Revised Dec 6, 2017
Accepted Dec 21, 2017

Keyword:

DC-DC Converter
High Frequency Transformer
High Power Converters
Resonant Converter

ABSTRACT

Various Resonant Converters for high voltage and high power applications have been designed. Different Topologies of LLC, LCC, and CLL Resonant Converters have been simulated and compared for the same input voltage. The simulation was done at a very high frequency. The Output Power and the Efficiency of all the three Resonant Converters were calculated.With the results, it has been proved that LCC Resonant Converters were very much suited to give an output voltage of around 62 Kilovolts with a output power of 20 kilowatts.

Corresponding Author:

Bhuvaneswari.C,
Department of Electrical and Electronics Engineering,
Sathyabama University,
Chennai, India.
Email: bhuns_sekar@yahoo.co.in

1. INTRODUCTION

DC-DC Converters are very widely used in almost all the sectors. The conventional switched mode regulators are replaced by resonant converters due to various advantages like low Electromagnetic Interferences, High Power Density, Low switching losses and low switching stresses (even at high frequencies) as switching is done at Zero Voltage or Zero Current.

Resonant Converters are broadly classified into Series Resonant Converter and Parallel Resonant Converter. These both converters remain outstanding in their own advantages. Series Resonant Converters have a good efficiency in spite of broad load variations. But the output voltage regulation is not good at light loads. Parallel resonant converters have high voltage regulation even at light loads. But due to the conduction losses, the overall efficiency is a drawback. Hybrid Resonant Converters combines advantages of both Series Resonant Converter and Parallel Resonant Converters [1]. To enhance the output voltage, the resonant converter with a high frequency transformer, is switched at a frequency higher than the Resonant Frequency [2].But here the current and voltage stress are higher.

Whenever high voltages are aimed at the output side, transformer is essentially used in the circuit. High voltage Transformers are to be designed for the Particular voltage and power requirement [3]. When high frequency high voltage transformers are selected, Insulation becomes an important criteria. Polytetrafluoroethylene has been used in many cases. But this material requires a rapid cooling requirement which is an additional burden for the design [4]. Also transformer to be used is of higher rating, which makes the circuit complex. So a secondary winding made of stacked double sided PCB is used which makes the circuit simple and cheap. But here the Leakage Inductance parameter to be determined is very essential and finite element tools have to be used [5]. If Step down operation is performed, frequency variation required is very wide and also the turns ratio to be used for the transformer is restricted [6].If high power is preferred, a LCC Resonant Converter of 60KW power has been designed for an electrostatic precipitator, but the

reference control signal has to be supplied separately [7] .If high voltage is preferred, a Single tube fed by a High Voltage power supply has been developed instead of the conventional techniques using two tubes (used for computer Tomography). But it gives a high Pulse Repetition rate which has to be looked into [8]. Analysis for steady state condition using Fundamental Approximation Method has been done [9].A Mathematical Model has been Presented for the Multilevel Resonant converter for radiography and fluoroscopy at steady state conditions [10].

Similarly focusing on high voltage applications, the simulation of LLC, CLL and LCC resonant converters were done. This paper presents the comparative analysis of resonant converters for a higher output voltage. In addition to the output voltage, the output power and the efficiency is also calculated. Out of all the three resonant converters, the waveform of the LCC Resonant Converter is free of ripples and so it has been found out to be best suited for high voltage applications.The paper comprises of Section I describing the Introduction, Section II explaining the System Configuration, Section III, IV and V about the Software Implementation, Results and Discussion and the Application respectively. The Last section VI gives the conclusion of the work.

2. SYSTEM CONFIGURATION

Resonant Converters are LC Networks capable of generating high voltages at zero voltage switching or zero current switching. They can be used for high voltage applications such as Electronic Precipitators, Electric Vehicle system, X-ray, etc., One such system configuration has been described below.

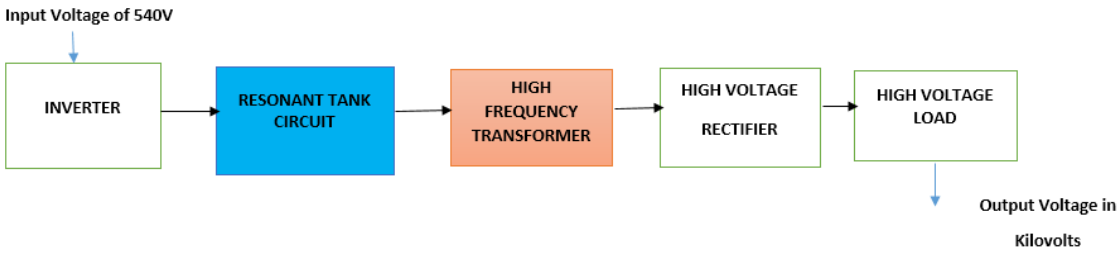

Figure 1. Configuration of the converter

Figure 1gives the configuration of the converter.The dc Voltage of 540 volts is given as an input is converted to ac voltage by the inverter. The converted ac voltage is fed to the transformer through the resonant tank circuit. Different tank circuit configurations such as LLC, LCC and CLL have been analyzed in this paper. The transformer steps up the voltage to meet the required load specifications. The output dc voltage is in the range of few kilovolts depending on the topology of the resonant tank circuit.

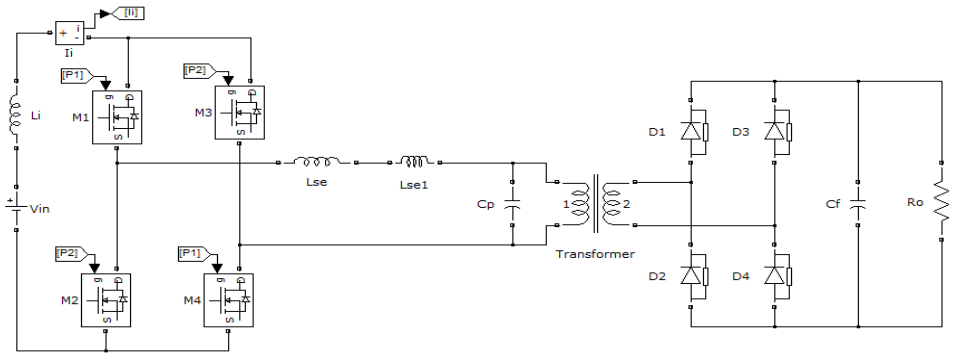

Figure 2. LLC Resonant Converter

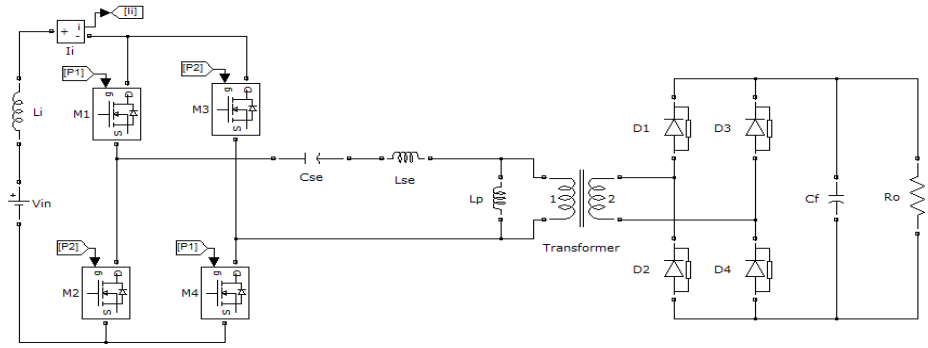

Figure 3. CLL Resonant Converter

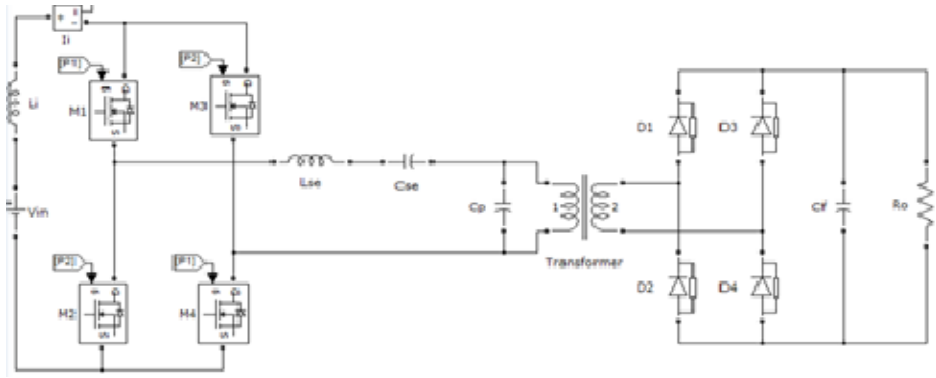

Figure 4. LCC Resonant Converter

Figure 2, Figure 3 and Figure 4 represents the LLC, CLL and LCC Resonant Converter respectively. The tank circuit constitutes of capacitor and inductor arranged in different combinations. LLC Resonant Converter consists of two series Inductors Lse and Lse1 and a parallel capacitor Cp. LLC are considered to be best as they can operate in Zero Voltage switching at no load and at narrow switching frequency range. At heavy load, Series Features are dominant and at light load, Parallel Features are dominant. The switching losses are also very less. LLC Resonant converters are also capable of producing high efficiency and high power for a wide operating range.

CLL Resonant Converter consists of Series Capacitor C_{se}, Series Inductor L_{se} and a parallel inductor C_p. In CLL Resonant Converters, the load voltage can be varied by varying the switching frequency. LCC Resonant Converter consists of Series Inductor L_{se}, Series Capacitor C_{se} and a parallel capacitor C_p. The different topologies of Resonant Converters also have variations in their DC Characteristics.

3. SOFTWARE IMPLEMENTATION

LCC, CLL, LLC Resonant Converter have been simulated in MATLAB and various Parameters have been calculated. The values of the components have been tabulated

Table 1.Components Specifications

Components	Values
Input Voltage	540V
Series Inductor	42µhenry
Series Capacitor	0.35 µfarad
Parallel Capacitor	120nfarad
TransformerTurns Ratio	1:300
Capacitor Filter	5.5µfarad
Load Resistor	190kiloohms

The same input voltage of 540 volts has been given to the above setup and the output waveforms for the three topologies have been shown.

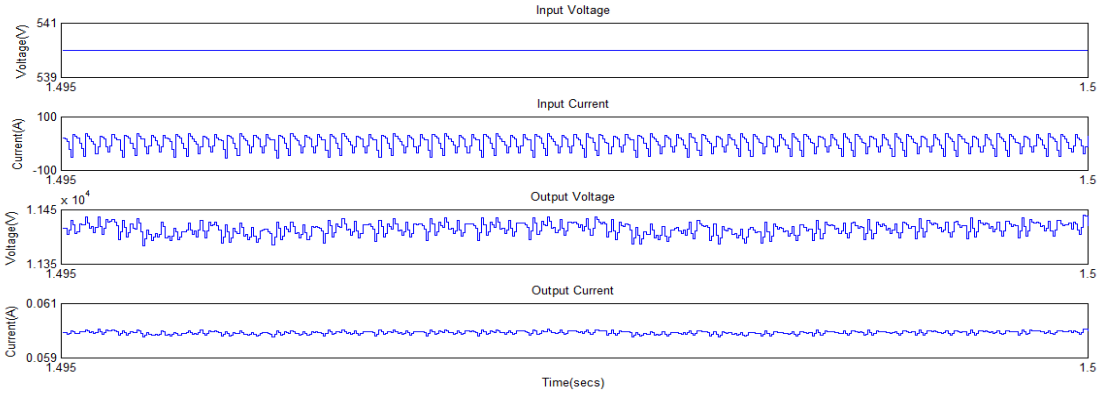

Figure 5. Waveforms of LLC Resonant Converter

Figure 5 represents the Input Voltage, Current and Output Voltage, Current of LLC Resonant Converter. An output Voltage of 11.41KV has been obtained with an output Current of 59milli amps. The output voltage is a dc voltage with high ripples. The ripples can be reduced by including a filter in the output circuit. An efficiency of 87.66 % is produced with LLC Resonant Converter.

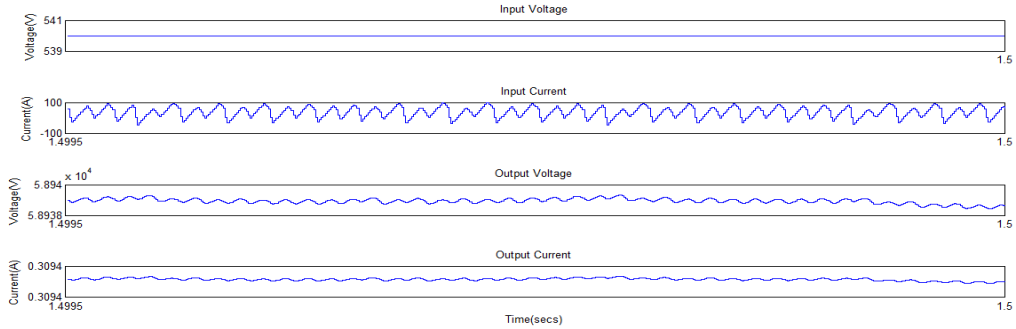

Figure 6. Waveforms of CLL Resonant Converter

Figure 6 represents the Input Voltage, Current and Output Voltage, Current of CLL Resonant Converter. An output Voltage of 58.93KV has been obtained with an output Current of 309milli amps. The output voltage is a dc voltage with ripples. Also an efficiency of 91.94% is also produced.

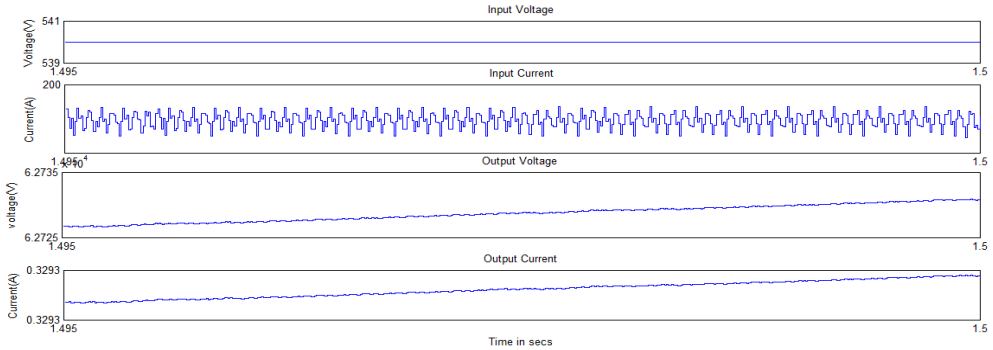

Figure 7. Waveforms of LCC Resonant Converter

Figure 7 represents the Input Voltage, Current and Output Voltage, Current of LCC Resonant Converter. An output Voltage of 62.73KV has been obtained with an output Current of 329milli amps. The output voltage is a dc voltage with very less ripples. Also an efficiency of 90.44% is also produced.

4. RESULTS AND DISCUSSION

The Output Voltage, Output Current, Input and Output Power has been calculated and tabulated in table2 for the three resonant Converters. The table shows that LCC Resonant Converter is proved to give a high output voltage and power as compared with others.

Table 2. Calculated values of the three Converters

Converter	Output Voltage (KV)	Output Current (A)	Input Power (KW)	Output Power (KW)
LLC Resonant Converter	11.41	0.0599	0.783	0.684
CLL Resonant Converter	58.93	0.3093	19.83	18.23
LCC Resonant Converter	62.70	0.3293	22.80	20.66

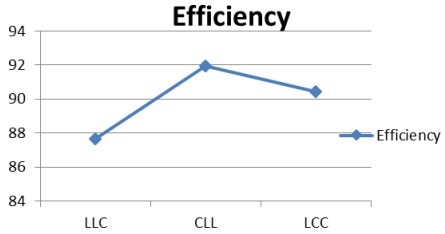

Figure 8. Comparison of Efficiency

Figure 8 gives the comparison of efficiency with all the three converter in which CLL Resonant Converter yields a high efficiency of 91.94%.

So both the comparison proves that LCC Resonant converter can give a high output voltage of 62.73kv but an efficiency of 90.44%. Also CLL Resonant Converter can give an output voltage of 58.93kv with an efficiency of 91.94%. So if a high output voltage is required then LCC Converter is preferred and if a high efficiency is required then CLL Resonant Converter is preferred.

If the output voltage of the three converters are examined closely, LLC Resonant converter is free of ripples as compared with the other two converters.As the converter is to be used for high voltage applications, Converter with less ripples is preferred.

5. APPLICATIONS

High Voltages have wide applications in many fields. Electronic Precipitators, Electric Vehicles, X-ray are some of these. X-Rays was originally discovered by Rontgen in 1895. X-Rays have been used for various purposes namely Medical Applications ,Material Testing, Food Inspection, Electrical and Electronic Testing, Tire Inspection, Seed Inspection ,etc., In Medicinal Field, X-rays have been used for Computer Tomography, Fluoroscopy, Radiotherapy, etc.,

6. CONCLUSION

Simulation of LCC, CLL LLC Resonant Converters using MATLAB Simulink has been done. A uniform input voltage of 540v has been given with a view to obtain a high voltage in the range of Kilovolts. This paper has discussed on two views

1. If high output voltage is the target, then LCC Resonant Converter is Ideal.
2. If high efficiency is the target rather than the voltage, then CLL Resonant Converter is Ideal.

So the selection of the converter depends purely on the parameter specifications of the application.The work can be extended with artificial Intelligence.

REFERENCES

[1] Bhuvaneswari.C, Dr. R.Samuel Rajesh Babu. *A Review on LLC Resonant Converter*. International Conference on Computation of Power, Energy Information and Communication (ICCPEIC). 2016

[2] Mohamed Salem, Awang Jusoh, N. Rumzi N. Idris, Tole Sutikno, Iftikhar Abid. ZVS Full Bridge Series Resonant Boost Converter with SeriesConnected Transformer. *International Journal of Power Electronics* and Drive System (IJPEDS). 2017; 8(2): 812-825.

[3] Jun Liu, Licheng Sheng, Jianjiang Shi, Zhongchao Zhang, Xiangning He. *Design of High Voltage, High Power and High Frequency Transformer in LCC Resonant Converter*. Applied Power Electronics Conference and Exposition, IEEE Xplore, 2009, 1034-1038.

[4] Zhiqiang Wang , Guofeng Li , Yawei Wang, "Design of a high voltage DC power supply with PFC function*", Industry Applications Society Annual Meeting*, IEEE 2013

[5] Juan A. Martin-Ramos, Alberto M. Pernía, Juan Díaz, Fernando Nuño, and Juan A. Martínez. Power Supply for a High-Voltage Application. *IEEE Transactions on Power Electronics.*2008; 23(4):1608-1619.

[6] Nor Azura, S. Iqbal and SoibTaib. *LLC Resonant DC-DC Converter for High VoltageApplications.C*onference on Energy Conversion(CENCON) .2014

[7] Thiago B. Soeiro, Jonas Mühlethaler, JörgenLinnér, Per Ranstad, Johann W. Kolar. Automated Design of a High-Power High-Frequency LCC Resonant Converter for Electrostatic Precipitators. *IEEE Transactions On Industrial Electronics*.2013; 60(11): 4805-4819.

[8] Alex Pokryvailo, Costel Carp and Cliff Scapellati. A 100 kW High Voltage Power Supply For Dual Energy Computer Tomography Applications. *IEEE Transactions on Dielectrics and Electrical Insulation.2015;* 22(4) :115-118.

[9] Arnold Fredderics, K.Vinoth Kumar, A.Shankar, Jeya Selvan Renius, Raja Guru Sree Lakshmi Nair, K.Viswanathan. The FHA Analysis of Dual-Bridge LLC Type Resonant Converter. *International Journal of Power Electronics and Drive System (IJPEDS).2014;*4(4): 538~546.

[10] Juan A. Martín-Ramos, Óscar Pardo Vaquero, Juan Díaz González, Miguel A. José Prieto, Juan A. Martínez Esteban, Alberto Martín Pernía. *Modeling a multilevel converter for radiography and fluoroscopy*, 18th European Conference on Power Electronics and Applications *(*ECCE Europe).2016.

BIOGRAPHIES OF AUTHORS

C. Bhuvaneswari has obtained her B.E.Degreein Electrical and Electronics from Madras Univerity. She has obtained her M.E. Degree in Power Electronics and Industrial Drives from Sathyabama University. Presently She is doing her research work with Sathyabama University in the area of DC-DC Converters. Her areas of interest include Power Electronics and its applications.

R. Samuel Rajesh Babu has obtained his B.E degree from Madras University in 2003. He has obtained his M.E degree from Anna University and Doctorate from Sathyabama University. Presently he is doing his research at Sathyabama University. His area of interests is DC - DC converters