Performance Measure of LCC Resonant Converter for High Voltage Power Supply

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Abstract: This Work presents the Design and Analysis of LCC Resonant Converter for Power Supplies which are used for high Voltages. LCC Resonant Converter was designed and simulated in both Open loop and closed loop in Matlab Simulink. The Closed loop was found to have a lesser steady state error as compared with that of the open loop. The Stress across the Switches was measured for different input voltages and found that it is linearly proportional to the input voltage. Also the Output Voltage was plotted against different load conditions.

Keywords: LCC Resonant Converter, X-Ray, High Voltage Power Supply, Voltage Stress.

I. INTRODUCTION

X-Rays were initially discovered by Roentgen in 1901. X-Rays have many applications out of which their uses in the Medical field is endless. In Medicinal Field, X-Rays are being used for detection and Treatments. X-Rays are used to detect damages in tissue bones, Fractures and to view adverse effects.. Hard X-Rays have high energies as compared to Soft X-Rays. In Medicine, X-Rays are used for Fluoroscopy and Radioscopy. Fluoroscopy is used for medical imaging and Radioscopy is used for giving radiology treatments for patients affected with cancer. The Other uses of X-Rays include Material Testing, Food Inspection, Electrical Testing and also in Agriculture. In Material Testing X-Rays are used to find shrinkage or blow holes in Metal Castings. X-Rays are used to find the quality of the products in Sealed and packed foods in industries. Also in testing Printed Circuit Boards and to check the Quality of Seeds in Agriculture.

The essential requirement of X-Ray tube is a power supply and a transformer which are to be designed for a higher voltage. Different Topology of the Resonant Converter is discussed for different voltage and different Power applications. The simulation results explains that LCC Converter has less ripples than LLC and CLL Resonant Converter [1]. Electron Beam Melting Furnace uses LCC Resonant Converter in discontinuous Mode. A linear relationship exists for output voltage at low frequencies and this linearity changes over at higher frequencies for Electron Beam Melting [2]. LCC Resonant Converters has been employed for Electrostatic Precipitators in both Variable frequency control and Dual Control. The Resonant tank Parameters are selected such a way that electrostatic precipitators improves the overall efficiency [3].

II. OVERVIEW OF LCC RESONANT CONVERTER

Different topologies of Resonant Converter have been used in several applications because of their main advantage of Zero Voltage and Zero current Switching. The LCC Resonant Converters are often preferred for applications involving higher voltages such as Electrostatic Precipitators, Automotive applications, X-Ray, etc.. In many of these applications the Power supply is of high voltage and given at most importance. The Power supply needs to be designed as the circuit includes a transformer.

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Different topologies of Resonant tank has been studied for automotive applications. The Analysis has been done based on Energy stored in the resonant tank and Resonance elements stress. Based on the value of the parameters, the value of Q with minimum tank size is selected for automotive applications [4]. The optimum design curves were drawn after selecting the value of the Resonant Inductor. For the optimum size the hardware was developed. To measure the resonant tank size, the Resonant tank Energy and the power has been considered as the parameters [5]. Various Design Methodologies for LCC Resonant Converter has been done. The design can be based on Rectifier non-conduction angle, the Switch Power factor or also can be based on Series Inductor, Series Capacitor and Series Inductor [6]. The optimized resonant tank helps to reduce the turn-off losses of IGBT by increasing the lossless snubber capacitances. The Converter is operated with renewable energy system with over voltage and over current Protection [7]. The normalized behavior of LCC Resonant Converter has been analyzed and the tank gain at resonance has been studied. Also the Output Voltage has been analyzed for varying load conditions [8].The duty cycle is adjusted based on Phase Shifting. By adjusting the switching frequency, the LCC Resonant Converter can work with a higher load variation [9].This Work Comprises of Design and analysis of LCC Resonant Converter for Power Supply used for high voltages. The Design of Resonant Converter has been done for high Voltage and high power. The designed converter has been simulated in Matlab. The Voltage stress of the MOSFET Switches has been studied for different Variations of input voltages. This paper comprises of Introduction, Overview, Design of LCC Resonant Converter, Simulation, Results and Conclusion in section I, II, III, IV, V and VI Respectively.
The main Circuit arrangement is shown in Fig.1. Gain Curve of LCC Resonant Converter is shown in the Fig.2. X-Rays as high as 100KV and 50KW power. As they operate in higher value designing is always a challenge. In Resonant Converters, LLC and LCC Topology are very suitable for these types of applications. Among these both, LCC Voltage gain proves that these converters can operate in active region for wide load variations. Also LCC Converters have a good overload and Short-Circuit Protection. In X-Rays, two techniques can be used namely Fluoroscopy (low power consumption) and Radioscopy (high power consumption).

When the parameters of resonant tank and switching frequency are varied, the appropriate gain can be obtained. The switching frequency is selected by varying the curve for different load conditions. By varying the load conditions, the switching frequency can be well adjusted. The frequency can be varied below resonance, at resonance and above resonance to obtain the desired operation.

III. DESIGN OF CONVERTER

The assumptions made in designing the Converter are:

a) All the Switches and diodes are ideal and switches commutate linearly.

b) The passive components behave linearly.

The Converter design is done for the following specifications:

Input Voltage=500V, Output Voltage=45KV and the switching frequency is 100Khz. The resonant frequency is considered as one-half of the Frequency used for Switching. Has the switching frequency is higher the switching device selected was MOSFET.

\[ R_e = \frac{V_o}{I_o} \]  

Where \( I_o \) is given by the ratio of Output Power to Output Voltage.

Step 2: the Value of Parallel Capacitance and \( \gamma \) is calculated by

\[ C_p = \frac{\pi I_o}{2n\omega_p R_b} \]  

\[ \gamma = \pi + 2\omega R_p\pi^2 R_L \]  

\[ I_i = \frac{\pi I_o}{\pi(1+cos\Theta)} \]  

Where \( \Theta \) is the Angle for which the Rectifier doesn’t Conduct.

Step3: The Equivalent Resistance \( R_e \) and Capacitance \( C_e \) is then calculated by

\[ R_e = \frac{2\pi^2 R_b}{\gamma} \]  

\[ C_e = \frac{\pi^2 C_p}{\pi(1+cos\Theta)} \]  

Step 4: Then the total equivalent circuit capacitance is calculated.

\[ C_T = \frac{R_o - 1}{\omega \sqrt{\frac{4}{R_o^2} - R_o}} \]  

Where \( V_d \) is the Input Voltage of the Rectifier.

Step 5: Finally the value of Series Capacitance and Series Inductance

\[ C_s = C_T - C_T \]  

\[ L_s = \frac{1}{\omega^2 C_T} \]  

is obtained as 0.35µF and 42 µH respectively.

IV. SIMULATION

LCC Resonant Converter was simulated for high voltage power supply. A Matlab Simulation was conducted and results obtained.

A. Open Loop Response

An input voltage of 500V dc is given to the inverter circuit is fed initially. The inverter consists of four MOSFET Switches M1, M2, M3 and M4. The Pulses given for M1 and M3 are in phase with each other and 180 degrees out of phase with the pulses that are given to M2 and M4. Then the ac supply is fed to the LCC Resonant Converter and to the transformer. The transformer steps up the voltage to a higher voltage of 50kilo volts. This Voltage is fed to the Rectifier for converting it into dc voltage. Fig.3 represents the Voltage and Current of Load.
Fig 4. Represents the Transformer Primary and Secondary Voltages.

Fig 3. Output Voltage and Output Current for Open loop

Fig 4. Primary and Secondary Voltage of Transformer in Open loop

B. Closed Loop Response

LCC Resonant Converter was simulated with PID Controller and the closed loop output voltage and output current is shown in Fig 5. Also Fig 6. shows the transformer Primary and Secondary Voltage in Closed loop operation. The Output voltage clearly explains that the settling time is lesser in second case rather than the first case. So the steady state error is very less as compared to that of open loop.

Fig 5. Voltage and Current of Load for Closed loop

Fig 6. Primary and Secondary transformer Voltage for Closed loop

V. RESULTS & DISCUSSION

The Current and Voltage for both supply side and load side are obtained in Open loop and Closed and has been tabulated and compared.

Table 1: Parameters Measured

| Parameter      | Open Loop  | Closed Loop |
|----------------|------------|-------------|
| Input Voltage  | 540V       | 540V        |
| Input Current  | 73.35A     | 65.25A      |
| Input Power    | 39.61KW    | 35.23KW     |
| Output Voltage | 45.62 KV   | 60KV        |
| Output Current | 0.2395 A   | 0.3149      |
| Output Power   | 10.93KW    | 18.89KW     |

The Voltage stress across the MOSFET Switches were measured for both open loop and closed for different input voltages. It is observed that the stress on the switches are very higher in open loop. The stress is almost more than twice as that of the stress in closed loop. The fig 7. represents the voltage stress in open and closed loop.

Fig 7. Voltage Stress for different Input Voltage
The Output Voltage was measured in different load conditions in both open loop and closed loop. The load was varied in 25%, 50%, 75% and the results were plotted against the output voltage. As expected, the closed loop gained a better performance and higher output voltage than the open loop results. The output Voltage variations against different load conditions is shown in Fig 8.

VI. CONCLUSION

LCC Resonant Converter for has been designed and simulated for a high voltage power supply in both open loop and Closed loop. It has been proved that closed loop Simulation gives a better result than the Open loop. The Stress across the MOSFET Switches were measured for different input voltage in both open loop and closed loop. The Stress across the switch was found to be doubled in open loop as compared with closed loop. Also the load resistance was varied and found that the increase in output voltage is directly proportional to its load.

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