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Dual transformer LLC Resonant Converter

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Abstract - **This paper presents the Inductor- Inductor Capacitor (LLC) resonant converter with series transformers that are connected in series suitable for high input and high output voltage applications. The converter has two transformers connected in series. The leakage inductances are used as LLC circuit, resulting in resonant series inductance circuit while the other one is used as magnetizing element for each transformer. External capacitance (C) is included in the circuit to complete the LLC structure. These transformers induce voltages into the LLC network and enhance the voltage gain, while the other works as a regular LLC converter transformer. Proposed topology has multiple advantages: a) high voltage gain is achieved with reduced switching losses, b) higher efficiency at higher voltage. The simulation results of the converter prove that efficiency is higher, obtained for broad range of voltages.**

***Key Words*: LLC converter, dual-transformer, resonant circuit.**

1. INTRODUCTION

Resonant converter is electric power converters that consists of resonant tank mainly inductors and capacitors are tuned at a particular frequency [1]. There are different types of resonant converter namely series resonant converter, parallel resonant converter and series parallel resonant converter. LLC resonant converter is a type of DC/DC converter that allows soft-switching operation. Soft-switching operation is that the pulses are turned on or turned off at Zero Voltage Switching (ZVS) [2-4]. So the LLC resonant converter circuit reduces the switching losses through ZVS. The LLC resonant converter keeps the output voltage regulated even under light load condition [5].

LLC converter mainly includes three set of components namely the switch network, the resonant tank and also rectifier network. The block diagram of the LLC resonant converter is as shown in the Fig.1 [1]. Some of the important characteristics of LLC DC/DC converters are soft-switching capabilities, lesser electromagnetic interference (EMI) and simple in structure [6-7]. Series parallel or LLC resonant converter is commonly used in applications that demand high input output voltage ratio, high power density, renewable energy power generation applications and electric vehicle on-board chargers [9].

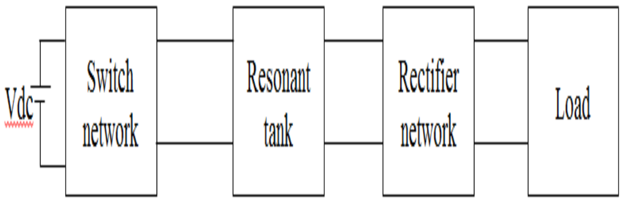

Fig.1. Block Diagram of LLC Converter

2. PROPOSED CONFIGURATION

The proposed topology is as shown in Fig.2. The ideal transformer includes the leakage inductances and the magnetizing inductance consisting of a primary switch network, LLC resonant circuit, a diode rectifier and a full bridge. Primary switch network consists of inner full bridge converters and outer full bridge converter is built with switches S_1, S_2 ,S_3 ,S_4. The inner full bridge converter is made up of S_5, S_6 ,S_7 ,S_8. The LLC resonant circuit consists of two numbers of high frequency transformers T_{r1} and T_{r2} having transformation ratios equal to n_1 (n_{s1}/ n_{p1}) and n_2 (n_{s2}/ n_{p2}) for T_{r1} and T_{r2} respectively. There are two transformers and both of them are connected in series, and they have magnetizing inductances L_{m1} and L_{m2} for T_{r1} and T_{r2} respectively. Leakage inductances L_{l1} and L_{l2} for T_{r1} and T_{r2} respectively are used as series resonant inductance $L_{l1}+L_{l2}$, while L_{m2} is the magnetizing inductance element. External capacitance C_r is included to complete the LLC resonant circuit structure. The full bridge diode rectifier consists of diodes D_1, D_2, D_3, D_4. The output voltage ripple is reduced by adding capacitor C_o to the output of the diode rectifier. The load resistance is R_L.

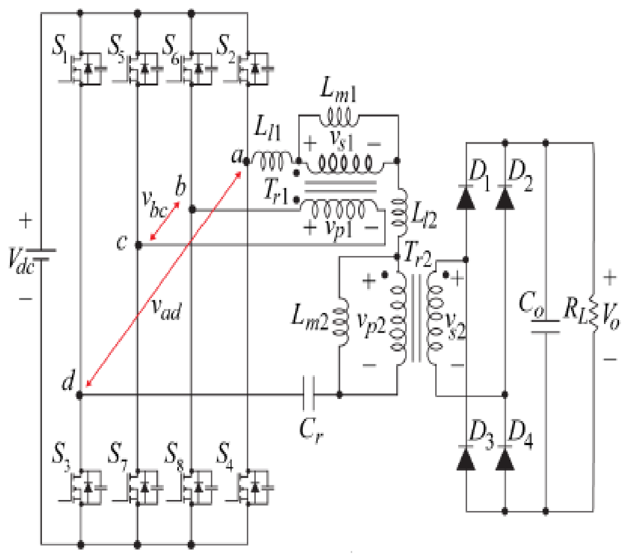

Fig.2 Proposed Converter Including Transformers Modelled by Magnetizing and Leakage Inductances

3. MODELLING

The voltage gain G_o is obtained by analysing fundamental or first harmonic analysis (FHA) [2].Voltage gain is used to obtain resonant frequency and load quality factor. The magnetics ratio of the proposed converter is in equations respectively. The equivalent circuit of the converter is obtained using the

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fundamental components V_{bc}, V_{ad} as depicted in Fig.3 and the simplified equivalent circuit of the converter is shown in Fig. 4.

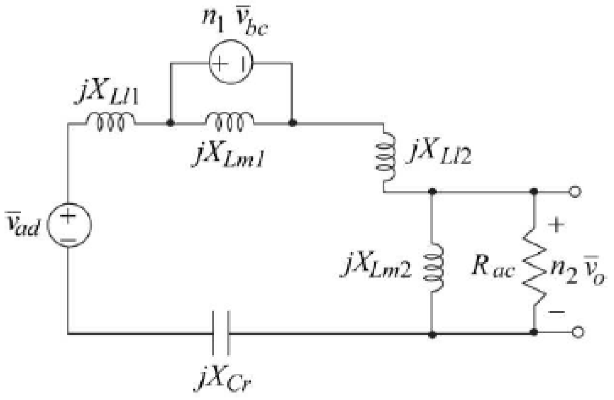

Fig.3 Equivalent Circuit of Resonant Tank using FHA.

The design of the proposed dual transformer LLC resonant converter system and the design parameters are shown in Table 1.

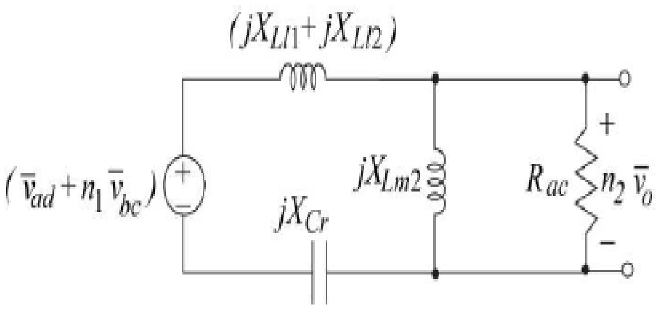

Fig.4. Simplified Equivalent Circuit (of Fig. 3.)

Table 3.1: Parameters considered for simulation of proposed converter

Design parameters	**Specifications**
Supply voltage V_{dc}	50V
Output capacitor C_o	60uF
Capacitance C_r	0.73uF
Load resistor R_L	250Ω
Output voltage V_o	250V
Magnetizing inductance L_{m1} = L_{m2}	12.2uH
Leakage inductance L_{l1} = L_{l2}	1.1uH
Primary transformer ratio $n_{p1}: n_{s1}$	1
Secondary transformer ratio $n_{p2}: n_{s2}$	2:5

Transformer turns ratio,

$$n = \frac{V_{dc}}{V_{out}}$$

Here, n is transformer turns ratio

V_{dc} is the supply voltage

V_{out} is the output voltage

Voltage gain is provided by the equation

$$G_o = \frac{1}{\sqrt{\left(1+\frac{1}{k}\left(1-\frac{1}{fn^2}\right)\right)^2 + Q^2 * \left(\left(fn^2 - \frac{1}{fn^2}\right)\right)^2}}$$

Here, k is magnetics ratio

L_{l1}, L_{l2} is leakage inductance

C_r is external capacitance

f_r is resonance frequency

f_n is normalized switching frequency

$$f_r = \frac{1}{2\pi\sqrt{(L_{l1}+L_{l2}) * C_r}}$$

Load quality factor Q is

$$Q = \frac{\sqrt{\frac{(L_{l1}+L_{l2})}{C_r}}}{R_{ac}}$$

$$f_n = \frac{f_s}{f_r}$$

$$k = \frac{L_{m2}}{L_{l1}+L_{l2}}$$

L_{m1} and L_{m2} are magnetizing inductances
R_L is load resistance

4. SIMULATION RESULTS

The dual transformer LLC resonant converter is simulated with the designed values. The simulations are performed in the PSIM software. This section includes the simulation of the circuit and gives the results obtained from the simulations. The parameters values used for the simulations are as in the Table.1. The circuit diagram of proposed converter is as shown in Fig.5. The input and the output voltages are as shown in Fig.6. Fig.7 represents the current across the load resistor varying with time.

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Voltages V_{12}, V_{23} ,V_{34} ,V_{14} varying with time is as shown in Fig 8.

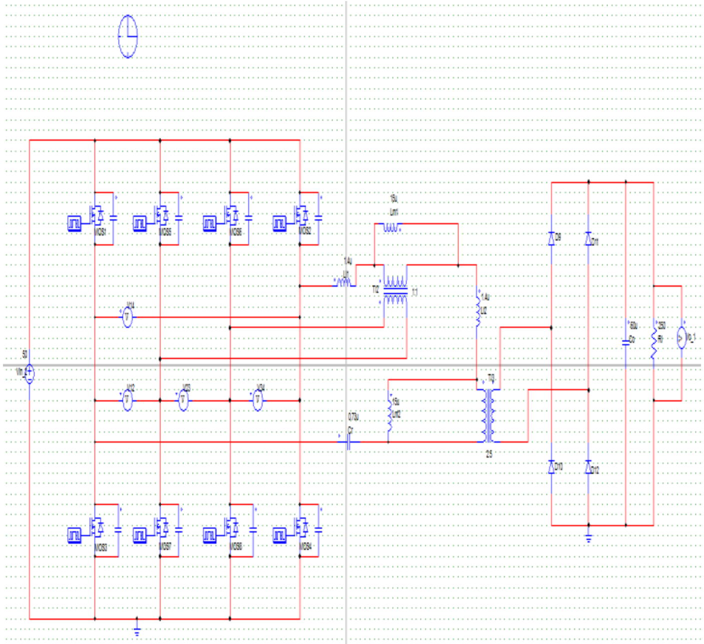

Fig.5 Dual transformer LLC resonant converter

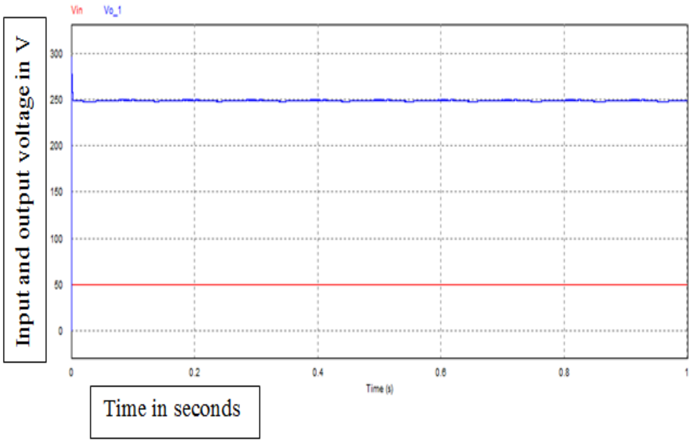

Fig.6. A plot of input voltage and output voltage varying with time

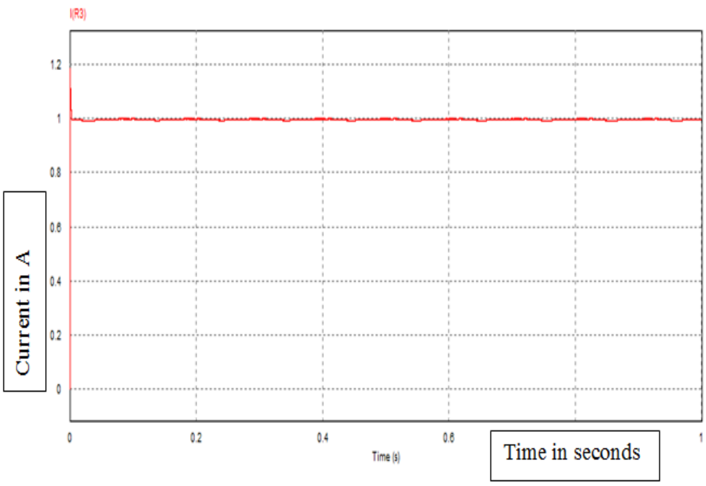

Fig.7. Current across load resistor varying with time

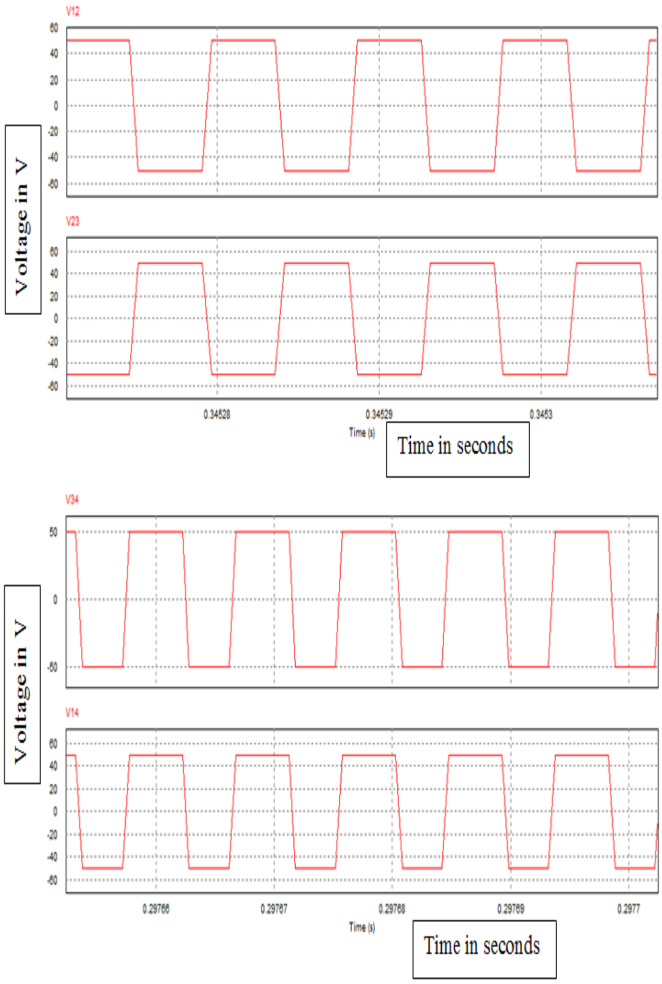

Fig.8. Voltages V_{12}, V_{23} ,V_{34} ,V_{14} varying with time

The proposed LLC resonant converter is simulated using PSIM software with the following parameters as shown in Table I. The supply voltage (Vdc) of the proposed converter is 50V and the resonant frequency (f_r) is 111 kHz. The two transformers T_{r1} and T_{r2} has the same magnetizing inductances L_{m1} = Lm_2, primary transformer with the turns ratio = 1:1 and secondary transformer with turns ratio = 5/2 respectively. The filter capacitor C_o connected across the output is large enough to obtain a constant output voltage V_o. The converter operates at a switching frequency that is equal to the resonance frequency. The maximum possible efficiency and the duty cycle is set to 50%. The output voltage V_o and output current I_o waveform is obtained. The output voltage V_o is approximately five times more than the input voltage. The supply voltages V_{12}, V_{23}, V_{34}, V_{14} are depicted in the Fig.8. The voltages are fluctuating between -50V to +50V is injected into the LLC resonant circuit to maximize the voltage gain without changing the switching frequency. Fig. 9 represents the closed loop output voltage varying with time using PI controller.

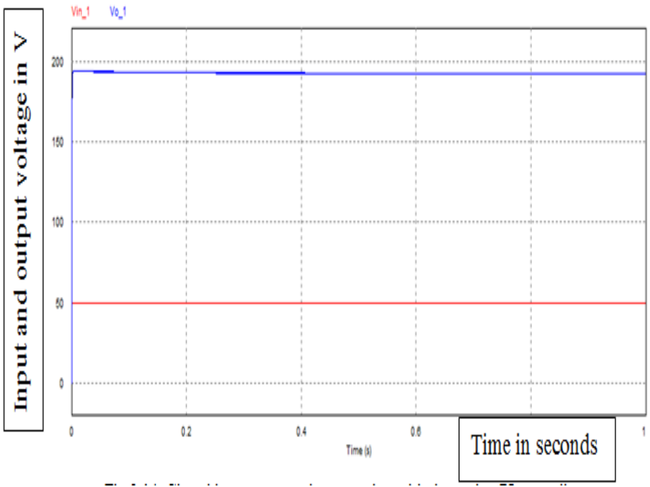

Fig.9 Closed loop output voltage varying with time using PI controller

5. CONCLUSION

The dual-transformer Inductor Inductor Capacitor (LLC) resonant converter is applicable in applications that demands high output voltage range. The leakage inductance (L_{l1}, L_{l2}) of the transformer uses as series resonant element, reduces high conversion efficiency, external inductance, during the comparison of the conventional LLC converter with one transformer. The additional switches and transformer is justified by using the high conversion efficiency at high voltage gains.

The proposed converter is simulated using PSIM software. The dual transformer LLC resonant converter is designed for supply voltage of 50V. The simulation results provide an output voltage of 250 V, the output voltage is almost five times more than the supply voltage.

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