Performance Analysis of Modified LLC Resonant Converter

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Abstract— In this paper a modified form of the most efficient resonant LLC series parallel converter configuration is proposed. The proposed system comprises of an additional LC circuit synchronized with the existing resonant tank of LLC configuration (LLC-LC configuration). With the development of power electronics devices, resonant converters have been proved to be more efficient than conventional converters as they employ soft switching technique. Among the three basic configurations of resonant converter, Series Resonant Converter (SRC), Parallel Resonant Converter (PRC) and Series Parallel Resonant Converter (SPRC), the LLC configuration under SPRC is proved to be most efficient providing narrow switching frequency range for wide range of load variation, improved efficiency and providing ZVS capability even under no load condition. The modified LLC configuration i.e., LLC-LC configuration offers better efficiency as well as better output voltage and gain. The efficiency tends to increase with increase in input voltage and hence these are suitable for high input voltage operation. The simulation and analysis has been done for full bridge configuration of the switching circuit and the results are presented

Index Terms— LLC converter, LLC-LC converter, Full-bridge converter, Soft switching converter, Series-Parallel resonant converter.

I. INTRODUCTION

Resonant converter is a switching converter that includes a tank circuit which actively participates in determining the output power flow. In resonant converter, the switch network drives the resonant tank symmetrically in both voltage and time and thus acts as a voltage source. Resonant converters are preferred over PWM converters due to advantages like high frequency operation, high efficiency, smaller size, light weight, low component stress and reduced EM interference.

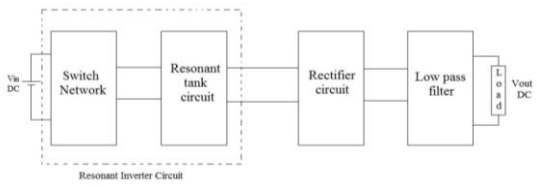

Fig.1 Block Diagram of Resonant Converter

Fig.1 gives the block diagram for resonant converter which illustrates that the input DC voltage is first transformed to AC and then rectified back to DC. The difference from other conventions lies in the resonant tank circuit that is introduced before the rectification stage. With inductor (L) & capacitor (C) comprising the resonant tank, eight configurations are possible among which four are practically applicable with voltage source input. These are categorized into three as SRC, PRC & SPRC. SPRC is further sub divided into LLC configuration and LCC configuration. Though both LLC and LCC configuration are efficient than regular converters, LLC is considered to be the best due to features like narrow frequency variation over wide range of load or input variation. Also ZVS takes place at higher resonant frequency as well as at no load condition in LLC configuration. To improvise the output voltage for the same, extra elements are introduced on the resonant tank circuit and the modified circuit namely LLC-LC is proposed which has a LC filter circuit in series with the resonant tank of LLC. Comparative analysis of the operation of LLC and LLC-LC resonant converters is carried out by using soft switching techniques like ZVS and ZCS for converters [1].

The half and full bridge configuration of LLC is proposed in [2],[3].The circuit design for half and full bridge configuration of LLC is illustrated in [4], [5], [6].The control strategies like closed loop control of LLC and implemention of LLC for dual output at the same time are proposed in [7] and [8] respectively. A solar array simulator is explained in [9].Optimization using mode solver technique is shown in [10].Introduction of an extra LC circuit in the resonant tank is proposed in [11] .

II. LLC SERIES PARALLEL RESONANT CONVERTER

The ideal LLC resonant converter comprises of a resonant tank with a series inductance (Lr) and capacitance (Cr) which are in series with one more inductance (Lm) across which the load is connected in parallel. Actually Lm is connected to primary of a transformer and the secondary side of the transformer has the rectifier circuit and then the load. Fig.2 shows the half bridge configuration of LLC converter.

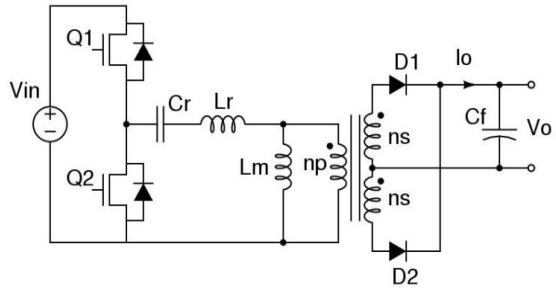

Fig. 2 Half bridge LLC converter

The operation of LLC depends on parameters like transformer turns ratio (n), series resonant inductor (Lr), series resonant capacitor (Cr) and resonant inductor ratio (A=Lm/Lr). The full bridge configuration for LLC is given as in Fig.3.

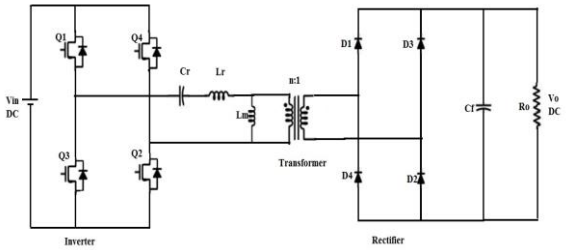

Fig. 3 Full Bridge LLC converter

The resonant tank gives rise to two resonant frequencies one (ω_h) due to the series Lr and Cr, and the other (ω_L) due to (Lm+Lr) and Cr. The equivalent circuit for the LLC converter is given as in Fig.4 where Vab represents the output of the inverter circuit which is then given to the resonant tank and the load on the secondary side is represented as Ri referred to the primary side. The transfer function has been derived and found to be

$$\left|\frac{V_o}{V_i}\right| = \frac{1}{2n\sqrt{(1+A)^2\cdot\left(1-\left(\frac{\omega L}{\omega}\right)^2\right)^2+\left(\frac{1}{QL}\right)^2\cdot\left(\left(\frac{\omega}{\omega L}\right)\left(\frac{A}{1+A}\right)-\left(\frac{\omega L}{\omega}\right)\right)}} \quad (1)$$

Where, Vo is the output DC voltage, Vi is the input DC voltage, ω is the switching frequency, QL is the quality factor given by

$$Q_L = R_i\sqrt{\frac{C_r}{L_r+L_m}} \quad \ldots\ldots (2)$$

III. LLC-LC SERIES PARALLEL RESONANT CONVERTER

In order to improve the output voltage and the efficiency of LLC converter, modified form namely LLC-LC is proposed. The modified converter has all the advantages of LLC converter and also has better efficiency than it. The circuit diagram LLC-LC converter is given as in Fig.5.

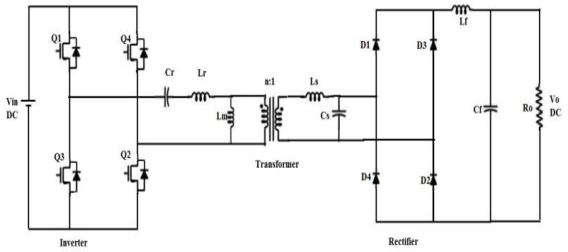

Fig. 5 Half bridge LLC-LC converter

As compared with the conventional LLC, it can be observed that an LC circuit (Ls & Cs) is inserted on the secondary side of the transformer before the rectifier circuit. Moreover the filter circuit has an additional inductance Lf in order to compensate the effects of the extra capacitor attached.

IV. SIMULATION CIRCUIT & OUTPUT

The full bridge configurations for both LLC & LLC-LC converter are considered for simulation. The simulation is carried out at input DC voltages of 100V, 200V & 300V for resonant frequency of 100 kHz , resistive load of 100 ohms and transformer's turn ratio of unity. With these parameters , the operation of converter is simulated for nine different cases, seeking switching frequency relation with resonant frequency (whether greater, less or equal) and the resonant inductance ratio (>, <, =) with respect to unity.

The simulation circuit for LLC converter is given as in Fig.6.

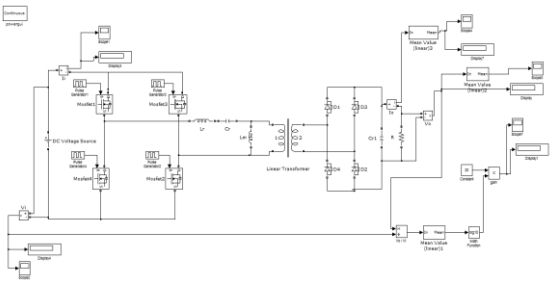

Fig. 6. Full bridge LLC simulation circuit

Of the nine simulations carried out, maximum efficiency is obtained when the converter's switching frequency is equal to resonant frequency for the inductance ratio equal to unity. The output voltage and gain plot are shown in Fig.7 and Fig.8 respectively.

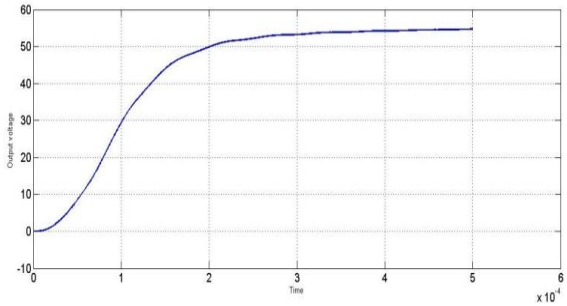

Fig. 7. Output Voltage for LLC converter

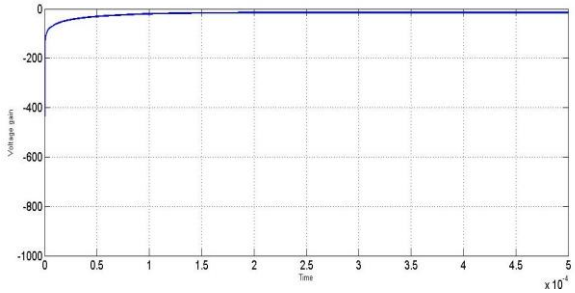

Fig. 8 Voltage gain for LLC Converter

The simulation circuit for full bridge LLC-LC converter is shown in Fig. 9.

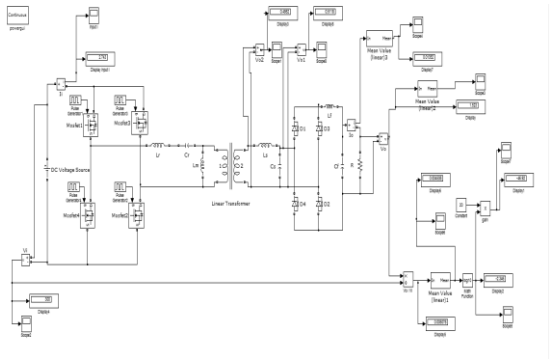

Fig. 9. Full bridge LLC-LC simulation circuit

Similar to LLC, maximum efficiency is obtained at a switching frequency equal to resonant frequency for the resonant inductance ratio equal to unity. The output voltage and voltage gain for LLC-LC converter are as given in Fig.10 and Fig.11.

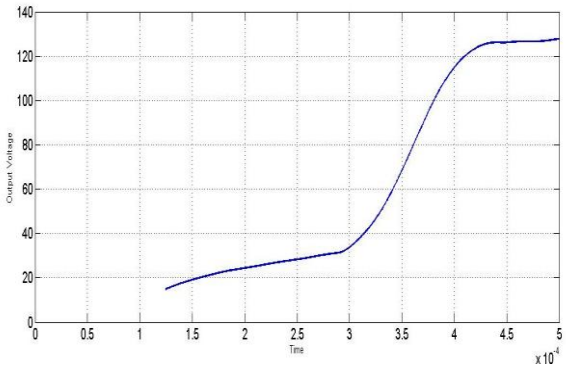

Fig. 10. Output Voltage for LLC-LC converter

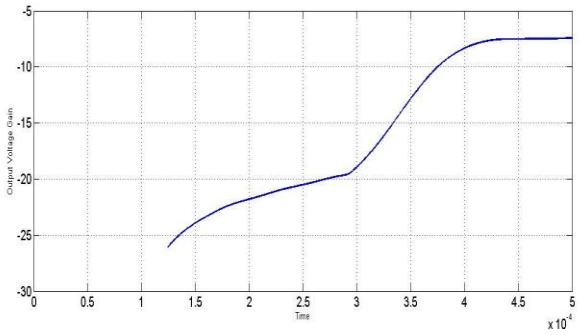

Fig. 11. Voltage gain for LLC-LC converter

From the above plots, it can be deduced that the output voltage of LLC-LC is approximately equal to twice that of LLC. Also the voltage gain increases from -14.78 for LLC to -7.411 for LLC-LC converter. Even though the output is more for LLC-LC converter is more, it can be noted that it takes more time to stabilize than LLC.

For three different input voltages, gain and efficiency for both LLC & LLC-LC circuit is calculated and is tabulated as follows in Table I and Table II respectively.

TABLE I
LLC PERFORMANCE PARAMETERS

S. No	Vin {V}	Vout {V}	Gain	Efficiency (η){%}
1.	100	18.18	-14.89	48.09
2.	200	36.69	-14.81	50.42
3.	300	55.24	-14.78	51.39

TABLE II
LLC-LC PERFORMANCE PARAMETERS

S. No	Vin {V}	Vout {V}	Gain	Efficiency (η){%}
1.	100	41.5	-9.032	49.52
2.	200	56	-10.96	54.01
3.	300	132	-7.411	55.52

As seen from the above tables, efficiency as well as voltage gain of the converter increases with increasing input voltage. The efficiency, output voltage and gain of LLC-LC shows significant difference from LLC for the same set of parameters.

V. CONCLUSION

The performance of the LLC-LC which is a modified form of LLC is compared with LLC, the conventional form. It is concluded that the performance of LLC-LC resonant converter is better in comparison to LLC resonant converter giving better output voltage and efficiency. Even though LLC-LC takes more time to stabilize, yet it

yields approximately twice the output voltage as LLC with increased gain.

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