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DESIGN CONSIDERATION OF LLC RESONANT CONVERTER

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Abstract— Resonant Converters have wide applications as they can produce a high voltage. Also these converters can reduce the switching losses by operating at Zero Current Switching and Zero voltage switching states. Series Resonant Converter can be used for low output current and Parallel Resonant converter can be used for high output current applications. Series Parallel Hybrid Resonant converters combines the advantages of both. This paper presents a Design of LLC Resonant Converter.

Keywords — Boost converter, Resonant tank, High frequency Transformer, Lamp

I. INTRODUCTION

At the earlier stages of research during 1960's, Linear Regulators were used. Linear Regulators are devices used to maintain a constant voltage in spite of varying load resistance. They were very simple but had a Poor efficiency. To overcome the drawbacks of Linear Regulators Switching Regulators were invented in 1970's. These Switching devices were used in all power converters. These regulators were giving a high efficiency at the rate of slow response with complex circuits.

The growth of Power Electronics has been immense after the invention of DC-DC Power Converters. A DCDC Converter is one which converts fixed DC input voltage into variable DC output voltage. These converters can step up or step down the voltage depending on the requirement. DC-DC Converters otherwise called as choppers are designed by semiconductor devices such as Bipolar Junction Transistor (BJT), Silicon Controlled Rectifiers (SCR),Metal Oxide Semiconductor Field Effect Transistor(MOSFET), Insulated Gate Bipolar Transistor(IGBT), Gate Turn Off Thyristors (GTO),etc.

To Process Power Electronics technology two methods are available.

1) Pulse Width Modulationtechnique.
2) Resonance.

During PWM Modulation Switches are operated in a switch mode where they are required to turn-on and turn-off the entire load current. In the switch mode operation, the switches are subjected to high switching stresses and high switching power loss that increases with the switching frequency of the PWM. Also the one more Problem is the Electromagnetic Interference (EMI) which is due to large di/dt and dv/dt. Resonance occurs in a circuit when Inductive Reactance is equal to capacitive Reactance. An inductor stores Magnetic Energy and a Capacitor stores Electrical Energy. At Resonance these both elements charge and discharge continuously. The converters using this as the principle are called as resonant converters.

Increasing switching frequency can dramatically reduce the passive component size, its effectiveness is limited by the converter efficiency and thermal management design. Meanwhile, to meet the holdup time requirement, bulky capacitors have to be used to provide the energy during holdup time, which is only affected by DC/DC stage operation input voltage range. The relationship between holdup time capacitor requirement and minimum DC/DC stage input voltage for different front-end converter power levels is shown in Figure 1. Apparently, wide operation range DC/DC stage can reduce the holdup time capacitor requirement and improve the system power density. However, when the minimum voltage is less than 200V, very limited effects can beobserved.

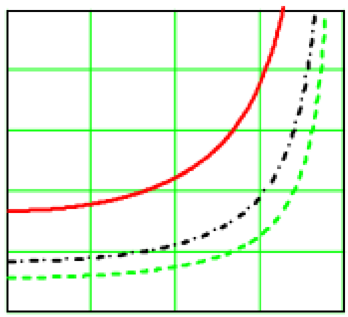

Figure1. Holdup time capacitor requirement for DC/DC stage with different minimum input voltage.

To reduce the holdup time capacitor requirement, different research efforts have been implemented, by using extra holdup time extension circuit or by developing better topologies. Among different solutions, LLC resonant converter becomes the most attractive topology due to its high efficiency and wide operationrange.

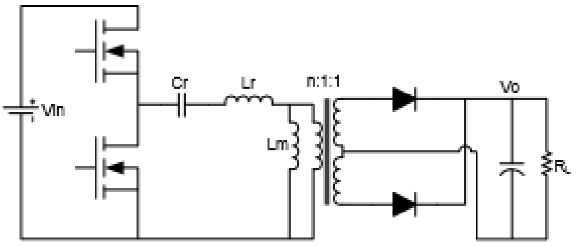

Figure 2 LLC Resonant Converter.

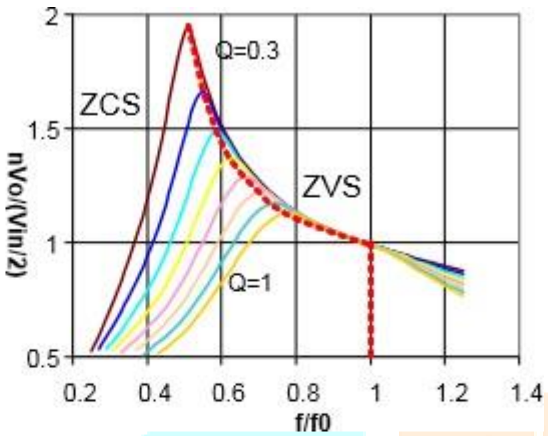

Figure 3 Gain Characteristic of LLC Converter.

II. RESONANT LLCCONVERTER

The LLC converter is similar to the traditional series resonant converter (SRC), and the disadvantages of traditional SRC, such as switching frequency being affected by the load and difficult control, are improved. 1) To overcome the limitation of series resonant converters, LLC resonant converter has been proposed. 2) LLC resonant converter is one of the most suitable circuit topologies that have been introduced for designing constant output voltage switched-mode power supplies.

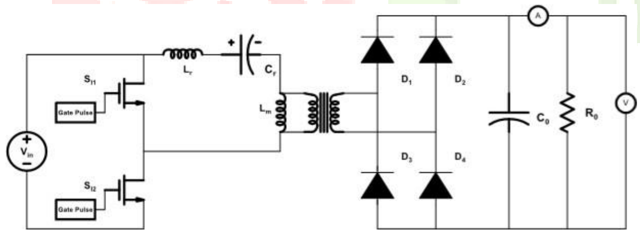

fig.4 Half bridge LLC Resonant converter.

LLC resonant converter is a modified LC series resonant converter implemented by placing a shunt inductor across the transformer primary winding. Operation at higher frequencies considerably reduces the size of passive components, such as transformers and filters. However, switching losses have been an obstacle to high-frequency operation. To reduce switching losses and allow high-frequency operation, resonant switching techniques have been developed. These techniques process power in a sinusoidal manner and the switching devices are softly commutated. Therefore, the switching losses and noise can be dramaticallyreduced.

The LLC resonant converter has two resonant frequencies (fr1 and fr2) and three kinds of operation regions. The main resonant frequency fr1, is related to resonant inductors and resonant capacitors. The second resonant frequency fr2, is related to resonant inductors, magnetic inductors, and resonantcapacitors.

$$f_r = \frac{1}{2\pi\sqrt{L_r C_r}}$$

$$fr2 = \frac{1}{2\pi\sqrt{(L_r + L_m)C_r}}$$

Two resonant frequencies, fr1 and fr2, have different characteristics. The resonant tank of the LLC converter resembles an inductive load ,resulting in zero-voltage switching (ZVS) being achieved on the power switches, and thus reducing switching losses. The voltage gain is lower than unity in region 1. When the LLC converter operates in region 2, its characteristics are like a parallel resonant converter (PRC) or a series resonant converter (SRC). When the switching frequency approaches the level described by equation (1), the circuit acts as an SRC. On the other hand, when the switching frequency approaches the level shown in equation (2), the circuit acts as a PRC. While the LLC converter operates in region 3, the switching frequency is lower than the resonant frequency. Unlike constant output voltage applications which need small converter inductance ratio and narrow switching frequency variation. The effort to obtain ever-increasing power density of switched-mode power supply has been limited by the size of passive components.

III. Operation of LLC Resonant Converter

1) Mode 1(t0-t1)

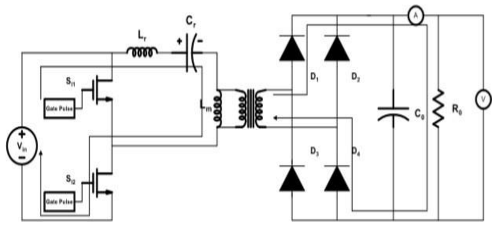

Fig.5 Half bridge LLC Resonant converter (Mode 1)

Fig. shows the operation mode in the powering section, which starts at the instant when the MOSFET Sl turns on. The resonant current flows through MOSFET Sl and the energy is transferred to the secondary side of transformer. The resonant capacitor Cr is charged and the resonant frequency fr is determined because the magnetizing inductance Lm does not involve in resonant.In the secondary side, diode D1 and D4 are on conduction and the current through the magnetizing inductance Lm is linearly increased.

2) Mode 2(t1-t2)

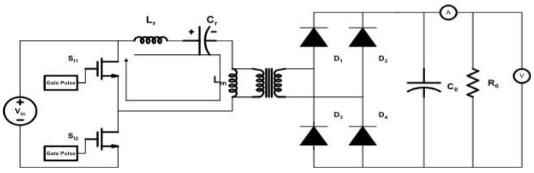

Fig. 6 Half bridge LLC Resonant converter (Mode 2)

Fig. shows the operation mode in the dead timesection, which starts at the instant when the switch Sl turns off. The current that was flown through the switch Sl flows through the diode inside the switch Sh. This allows the zero-voltage switching condition at switch Sh. At this section the magnetizing current does not increase any more, and the energy transfer to the secondary side of transformer is cut off.

3) Mode 3(t2-t3)

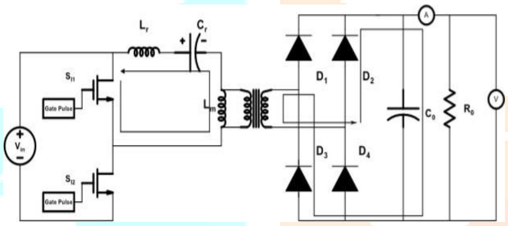

Fig. 7 Half bridge LLC Resonant converter (Mode 3)

Fig. shows the operation mode in the poweringsection, which starts at the instant when the switch Sh turns on. The energy that is charged in Cr transferred to the secondary side of transformer, in which the resonant frequency is determined. In the secondary side, diode D2 and D3 are on conduction, and the current through the magnetizing inductance Lm is linearly decreased.

4) Mode 4(t3-t4)

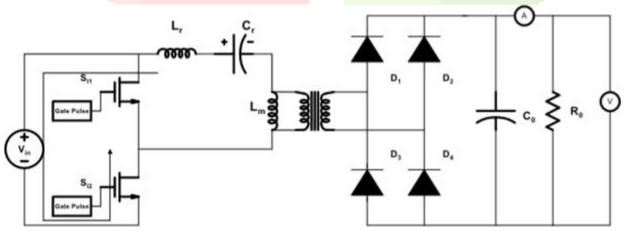

Fig. 8 Half bridge LLC Resonant converter (Mode 4)

Fig. shows the operation mode in the dead time section, which starts at the instant when the switch Sh turns off. The current that was flown through the switch Sh flows through the diode inside the switch Sl. This allows the zero-voltage switching condition at switch Sl. At this section the magnetizing current does not increase any more, and the energy transfer to the secondary side of transformer is cut off. These four operation modes are sequentially repeated according to the switching frequency of 300kHz. Although the switching frequency is rather high, the switching lossis quite small because of choosing the zero-voltage switching scheme.

IV. Design Consideration Of LLC Resonant Converter

- **The parameters need to be designedare**

  Transformer turns ratio: 1 : n

- **For Half Bridge LLC resonant converter, the transformer turn's ratio willbe:**

$$1:n = 1:\frac{V_o}{V_{in}}$$

$$= 1:\frac{440}{40} \quad = 1:11$$

- Due to the complexity of resonant tank, design of the LLC resonant converter needs to consider three key elements, resonant frequency, characteristic factor, and inductorratio,

$$f_0 = \frac{1}{2\pi\sqrt{L_r C_r}}$$

$$Q = \frac{\sqrt{L_r / C_r}}{n^2 R}$$

$$L_n = \frac{L_m}{L_r}$$

To ensure minimum switching loss, the magnetizing inductor needs to be smaller enough to achieve ZVS condition and large enough to have smaller turn off current. Therefore, considering both conduction loss and switching loss, the optimally designed Lm should make the primary side turn off current exactly the same as ZVS requirement Although the converter efficiency is mainly defined by the magnetizinginductance.

V. BoostConverter

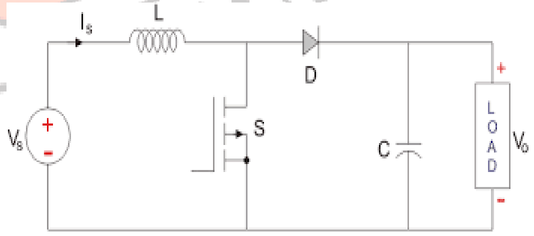

Fig. 9 Boost Converter

Shown in fig 9 Boost converter consist of voltage are input source, switch, inductor, diode, capacitor and resistor which is consider as a load. The switch can be open or closed depends on the output requirement. The output voltage across the load is always greater then input voltage. A boost converter is a step up the voltage. The output voltage of boost converter is deepened on duty cycle. The output voltage is givenby,

Vo=Vs/(1-D)

Vo= output voltage of boost converter

Vs= input voltage of boost converter

D= duty cycle

VI. High Frequency TransformerDesign

The fundamental requirements of magnetic material for power transformers are the highest relative permeability, the largest saturation flux density, the lowest core loss and the lowest remnant flux density. Magnetic materials using as the cores of power transformers keep changing as the operating frequency increased. At the line frequency of 50/60 Hz, iron, low-silicon iron and silicon steel are the major materials for the cores of the power transformers. They have high saturation flux density, thus they can handle high power transformation at low operating frequency. When the operating frequency of power transformer increased, the eddy current inside the magnetic cores becomes a critical problem for the transformer designers. Although the laminated core materials have been used, the power loss generated by the eddy currents still heat up the core and this hot spot generated inside magnetic core can destroy whole power transformer. As the operating frequency is increased more and more magnetic materials have been introduced for high frequency power transformer applications. Used in nowadays. Ferrite is ceramic materials, dark gray or black in appearance and veryhard.

The Characteristics of High Frequency Transformer Windings When the operating frequency increases, the total number of turns decreases significantly. Therefore the total length of the copper winding is also decreased dramatically. The power loss due to DC resistance almost becomes zero suddenly. It is very good for the power transformer design. However, with the disappearing of the DC resistance, the ac resistance increases enormously. The power loss due to this resistance is large than the one generated from DC component. At high frequencies, the major loss within windings is due to eddy currents produced by the skin and proximity effects. These effects can cause the windings losses to be significantly greater than the I2 R DC loss calculated using the DC resistance of thecopper winding.

VII. SIMULATION ANDRESULTS

A Power Circuit Of LLC Resonant Converter

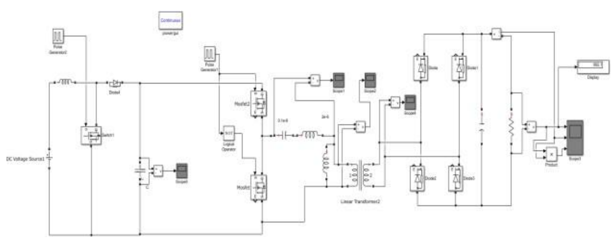

Fig. 10 Power Circuit Of LLC Resonant Converter.

B Output of boost converter

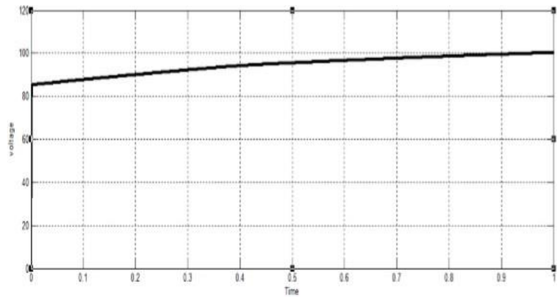

Fig. 11 Output waveform of Boost Converter.

C Resonant tank voltage

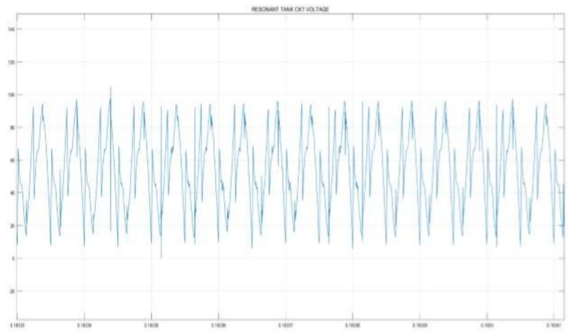

Fig. 12 waveform of Resonant tank Voltage.

D Primary voltage vp

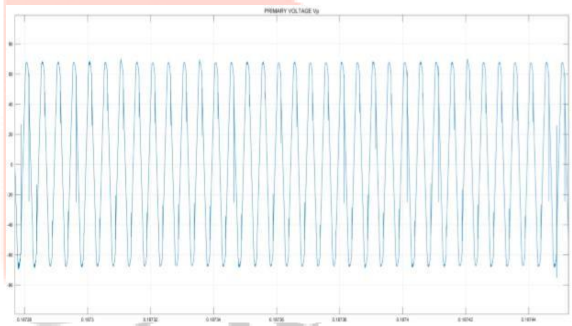

Fig. 13 primary voltage waveform.

E Secondary voltage vs

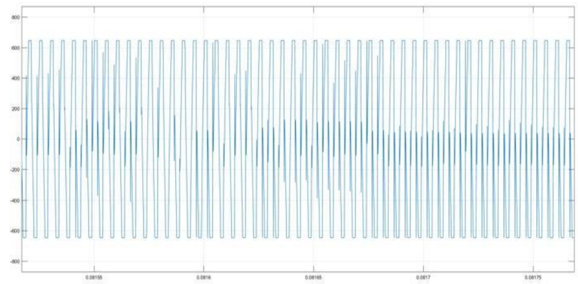

Fig. 14 Secondary voltage waveform.

F Load voltage, load current, load power

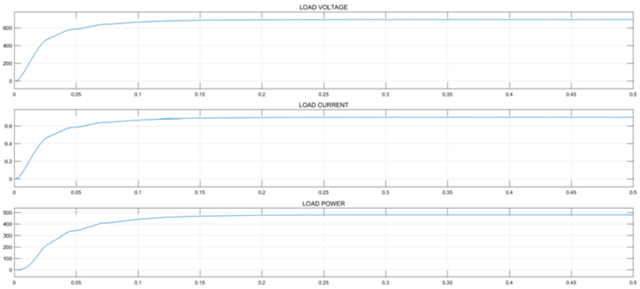

Fig. 15 Load voltage, load current, load power waveform

CONCLUSION

The disadvantages of Fundamental Harmoinc Approximation has been Overcome by Various other analysis. Also Boost and Buck operation can be obtained effectively when the Resonant Converter is operated with respect to frequency. By changing the topologies of the circuit also better voltage regulation can be obtained.A careful analysis on LLC Resonant converters has given a idea that it forms a good choice for high voltage applications. The most accurate modeling can beobtained by Mathematical calculations. Bidirectional LLC Resonant Converters can operate in forward and backward mode with a good output power.As Resonant converters have more applications such as X-ray Machine, Electrical vehicle Charger, High Voltage Pulsed load applications, a LLC Bidirectional Resonant converter with current sensing technique can be designed in future.

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