# A Review on LLC Half Bridge Resonant Converter

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***Abstract-*** Resonant Converters is most efficient converter and have wide applications. LLC resonant converter reduces the switching losses by operating at ZVS (Zero voltage switching) and ZCS (Zero Current Switching). This paper presents the review study on Resonant Converters and modelling of LLC converter using First Harmonic Approximation Method.

## I. INTRODUCTION

During Research In 1960's, Linear Regulators were used which maintain the constant output voltage in spite of Varying Load Resistance. These are very simple and had very low efficiency. To overcome the drawbacks of Linear Regulators, Switching Regulators were invented in 1970's. These regulators were giving a high efficiency at the rate of slow response. The growth of Power Electronics has been extensive after the invention of DC-DC Power Converters which converts fixed DC input voltage into variable DC output voltage. To Process Power Electronics technology two methods are available. They are Pulse Width Modulation technique and Resonance [1]. The Conventional PWM technique controls power by changing the duty cycle /Pulse width [11]. All the switching Devices are hard-switched with sudden change of voltages and currents, which results high switching losses and EMI noise [5]. When Inductive Reactance becomes equal to capacitive Reactance, Resonance occurs in a circuit. Magnetic Energy stored in an inductor and Electrical Energy stored in Capacitor.

Among different type of resonant converters, half-bridge LLC resonant converter is the most popular topology because this topology has many advantages over other topologies; it can regulate the output for wide input range and load variations, In resonant converters, pulse widths of the gate control signals are equal [13], It can achieve zero voltage switching (ZVS) over the entire operating range, the magnetic components can be integrated into a transformer and all essential parasitic elements, including junction capacitances of all semi-conductor devices, are utilized to achieve ZVS.

In half-bridge topology, any asymmetry in gate control signals causes dc current which can saturate the transformer core. But resonant capacitor prevents this unpleasant event by deleting the aforesaid component. Forming a resonant circuit, this has an important role in the resonant converter [4].

## II. OVERVIEW ON RESONANT CONVERTERS

In series Resonant converter (Shown in Fig 1), resonant Inductor Lr and Capacitor Cr are connected in series and forms a series resonant tank [25].The DC gain of SRC is always lower than 1. At resonant frequency, the impedance of series resonant tank is very small. When resonant frequency is more than switching frequency, the SRC worked under zero current switching (ZCS) condition but Zero voltage switching is preferred for semiconductor device. At light load condition, the switching frequency need to increase to keep output voltage regulated. As switching frequency increases, the impedance of the resonant tank is increased. This means more energy is circulating in the resonant tank instead of transferred to output. The circulating energy is explained as the energy send back to input source. The more energy sends back to the source, higher the energy needs to be processed by the semiconductors, Low conduction loss.

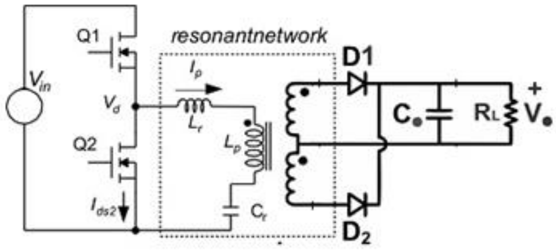


FIG - 1

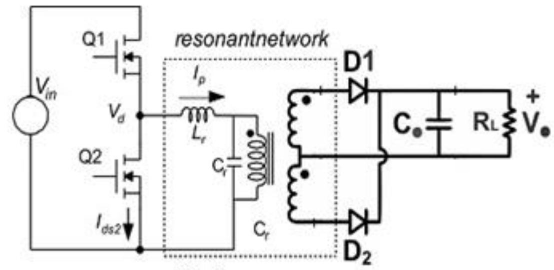


FIG - 2

In parallel Resonant converter (Shown in Fig 2), the resonant Inductor and Capacitor are connected in parallel. These converters can produce continuously controlled current so it gives short circuit protection. A Parallel Resonant Converter can regulate the output voltage from full load to no-load by running at a frequency above resonance But the Conduction losses in the Semiconductor devices are fixed from no load to full load. At no load condition, impedance of the resonant tank very low. This will induce much high circulating energy.

Series Parallel Hybrid resonant converter, combines the features of both series and Parallel Resonant Converters.

These converters are Suitable from no load to high load. At Low load Condition, Converter operates below resonance at high frequency and during high Load operates above resonance at low frequencies. With wide input range, the conduction loss and switching loss will increase at high input voltage. The switching loss is similar to that of PWM converter at high input voltage .

A LLC Resonant Converter has several features such as high efficiency, Low Electromagnetic Interference and high Power density. These converters can operate at resonance with a nominal input voltage. As they operate with ZVS and ZCS, the switching losses are also reduced. ZVS can also be done at no load condition.

## III. OPERATION OF LLC HALF BRIDGE RESONANT CONVERTER:

Fig. 3 shows the Circuit of half-bridge LLC resonant converter. The magnetic components can be integrated into a transformer, Lm is the magnetizing inductance, Lr is resonant inductor and Cr is resonant capacitor. There is very small amount of magnetizing current presents in Magnetizing inductor. In general, the LLC resonant topology consists of three stages. A square wave voltage is produced by driving switches, Q1 and Q2 with 50% fixed duty cycle. The resonant network has an effect of filtering the higher harmonic currents. Thus, essentially only sinusoidal current is allowed to flow through the resonant network even though square wave voltage is applied, which allows the MOSFETs to be turned on with zero voltage. The current is lagging the voltage applied to the resonant network. When current is flowing through the parallel diode, MOSFET will turns ON and the voltage across the drain to source is zero. The output rectifier network can be full-wave Bridge or centre-tapped with capacitor output filter.

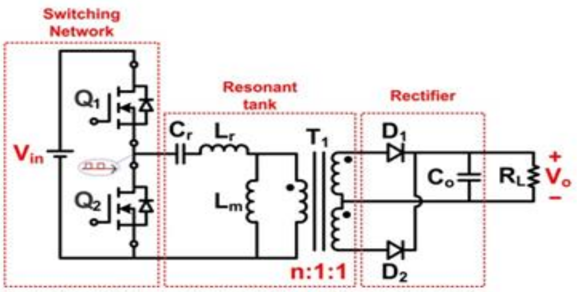


Fig.3:

The DC characteristic of LLC resonant converter is divided into two operating regions, ZVS region and ZCS region. This contains two different resonant frequencies. One is obtained by the resonant inductor (Lr) and Capacitor (Cr). The other one is determined by Magnetizing current Lm, capacitor Cr and load condition. As load getting more, the resonant frequency will shift to higher frequency. The two resonant frequencies are:

$$Fo = \frac{1}{2\pi\sqrt{Lr\ Cr}}$$

$$Fp = \frac{1}{2\pi\sqrt{(Lr+Lm)\ Cr}}$$

Operation of Resonant converter below, at and above resonant frequency, The LLC resonant converter can be explained in terms of the switching frequency and resonant frequency. Fig. 5 shows the typical waveforms of an LLC resonant converter in all three conditions. Gate signal of Q1 (Vg1), the Q2 gate signal (Vg2), the switch-node square voltage (Vsq), the resonant circuit current and magnetizing current (Ir & Im). Output side diode current (Is). Primary current is equal to the sum of magnetizing current and the secondary current referred to the primary side of converter. If only magnetizing current flows in the primary side, No power will transfer to the secondary side.

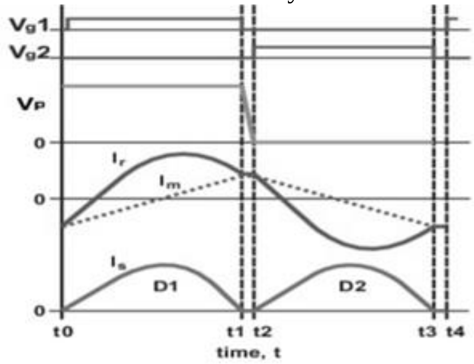


FIG-(5a) $At\ f_O$.

At Resonance (Fig. 5a), the switching frequency is equal to the series resonant frequency. When switch Q1 turns off, the resonant current follow the magnetizing current, and there is no power transfer to the secondary side. By adding dead time between gate pulses, the circuit achieves.

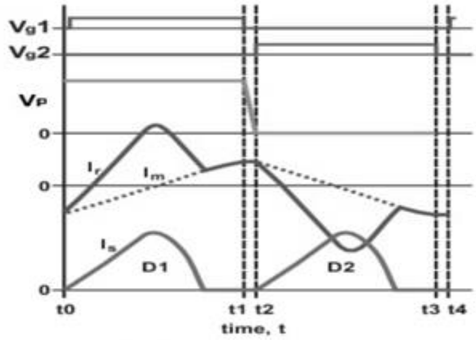


FIG-5(B) $Below\ f_O$.

Operation below Resonance (Fig. 5b), Resonant current has fallen to the value of the magnetizing current before the end of the driving pulse width, Operation below the series resonant frequency can still achieve primary ZVS and obtain the soft commutation of the rectifier diodes on the secondary side. The primary ZVS may be lost if the switching frequency becomes too low. This will result in high switching losses and several associated issues.

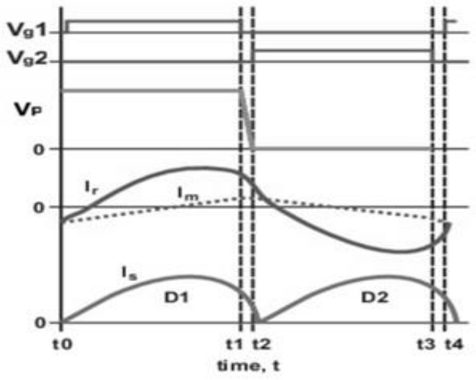


FIG - 5(C) *Above $f_O$.*

Operation above Resonance (Fig. 5c), the primary side have small circulating current in the resonant circuit. Conduction losses get reduced because resonant circuit operates in continuous-current mode and conduction losses will get reduced. This results less RMS current for the same amount of load. The rectifier diodes are not softly turned on/off and reverse recovery losses takes place. Also, ZVS can be achieved above the resonant frequency.

## IV. ANALYSIS OF LLC RESONANT CONVERTERS

Resonant converter. A higher efficiency can be obtained for light loads with reduced EMI Losses. A current Driven Synchronous Rectifier can also be used with Parallel Resonant Inductor for high output current applications with increased efficiency at Full load operation.

## V. MODELLING OF LLC RESONANT CONVERTER

A transfer function is the mathematical relationship between the input and output voltages which requires to design a converter for variable energy transfer and output regulation. More other frequency components got include in the circuit if square wave will be differ from the series resonance. By ignoring all higher order harmonics, approximation by single fundamental harmonic of the square wave can be done. This method is called first harmonic approximation (FHA) method, now widely used for resonant-converter design. This method provides the acceptable design results as long as the converter operates at or close to the series resonance. In FHA, ignoring all higher-order harmonics and effect from the output capacitor.

Relationship of Electrical Variables,

$V_{ge}$ is Sinusoidal Fundamental of $V_{sq}$ (Square Wave voltage at primary side,

$$Vge = \frac{2}{\pi} \times Vdc \times \sin(2\pi ft) \text{ ........... (1)}$$

Rms Value of $V_{ge}$ is,

$$Vge = \frac{\sqrt{2}}{\pi} \times Vdc \text{ ................................ (2)}$$

LLC Resonant Converter can be analyzed in Steady State by Fundamental Harmonics approximation (FHA) Method. During steady state analysis with wide load ranges, high efficiency is obtained but Disadvantage of FHA, output overvoltage protection is dropped at no load. To overcome the disadvantages of the Fundamental Harmonic Analysis of LLC Converter, Harmonic Analysis Model is designed in such a way that it controls Power Factor Correction in overvoltage condition within the specified Voltage level. To overcome the inaccuracy of Fundamental Approximation Method for wide load and frequency variations, an approximation method is designed to calculate the Peak gain. The approximation method is improvised by a Mathematical Analysis to calculate the operating point and to optimize the tank circuit of the converter.

In Terms of efficiency, An LLC Half bridge resonant converter gives a high efficiency as compared to Pulse Width Modulated DC-DC Converter in steady state as well as in Transient Operation. If input voltage is less, Half Bridge Resonant Converters are more efficient and if input voltages are high, Full Bridge Converters are more efficient. The conduction loss of frequency modulated resonant converter can be reduced by replacing one leg of full bridge diode rectifier by a synchronous rectifier switch.

To increase the input impedance and output voltage, a large inductance will be added to the

$V_{oe}$ is Sinusoidal Fundamental of $V_{o,}$

$$Voe = \frac{4}{\pi} \times n \times Vo \times \sin(2\pi ft - \theta) \text{.... (3)}$$

Rms Value is,

$$Voe = \frac{2\sqrt{2}}{\pi} \times n \times Vo \text{ ........................ (4)}$$

Output RMS current is,

$$Ioe = \frac{\pi}{2\sqrt{2}} \times \frac{1}{n} \times Io \text{ .......................... (5)}$$

AC equivalent resistance,

$$Re = \frac{Voe}{Ioe} = \frac{8 \times n^2}{\pi^2} \times \frac{Vo}{Io}$$

$$\text{Where } \frac{Vo}{Io} = R_L$$

$$Re = \frac{Voe}{Ioe} = \frac{8 \times n^2}{\pi^2} \times R_L \text{ ................ (6)}$$

The RMS magnetizing current,

$$Im = \frac{Voe}{\omega Lm} = \frac{2\sqrt{2}}{\pi} \times \frac{n \times Vo}{\omega Lm} \text{ ............. (7)}$$

Circulating current in the series resonant circuit,

$$Ir = \sqrt{Im^2 + Ioe^2}$$

Voltage Gain,

$Mg = \frac{Vso}{Vsq} = \frac{n \times Vo}{Vdc/2}$ ..................... (8)

Output Voltage,

$Vo = Mg \times \frac{1}{n} \times \frac{Vin}{2}$ .............. (9)

The series resonant frequency (f0) can be selected as the base for normalization. Then the normalized frequency ratio is expressed as,

$Fn = \frac{Fsw}{Fo}$ ............. (10)

Inductance ratio can be defined as,

$Ln = \frac{Lm}{Lr}$ .............. (11)

The quality factor of the series resonant circuit is defined as,

$Qe = \frac{\sqrt{Lr/Cr}}{Re}$ ............ (12)

## VI. CONCLUSION

A detailed analysis on LLC Resonant converters gives idea that it is a good choice for high voltage and varying load applications. The most accurate and efficient modelling can be obtained by Mathematical calculations.LLC converter can achieve ZVS from no load to full load. By doing small variation in switching frequency, compensation of the load variations and adjustment of the regulated output voltage in a wide range has been achieved. Soft switching is achieved for all power devices under all operating conditions.

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