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DESIGN AND SIMULATION OF LLC RESONANT CONVERTER

Patel Bhumi[1], Jaydeepsingh Chauhan[2]

[1]*PG Student, S.V.B.I.T, Gandhinagar, 160750707007*
[2]*Assistant Professor-Electrical Department, S.V.B.I.T, Gandhinagar*

Abstract- *Recent advances in modern power semiconductor device technology have led to high utilization of PWM power converter in wide number of applications. In PWM converter the power switches are switched at higher frequency. Switching losses are more in PWM converter. An alternative for it is to replace the power switch by resonant switch. In resonant switch, switching at zero voltage/zero current at high frequency. At high frequency switching-loss and power loss are increase, but switched at ZVS/ZCS condition losses are decrease. This can be achieved by forcing current and voltage to pass through zero crossing by creating LLC resonant circuit. So, switching losses are decreased and efficiency is improved. Design steps of Full bridge LLC resonant converter and Simulation and its results are represent in this paper.*

Keywords: *LLC resonant converter, output voltage, ZVS/ZCS, design steps of LLC resonant converter.*

Introduction

At an early moment during the development of conventional Pulse Width Modulation (PWM) technique developed power by adjusting the duty cycle and Interfering the power flow. Most the switching devices are hard-switched with sudden changes of currents and voltages, which results in more than a few switching losses and noises. In order to resolve the limitations of the conventional converters, the resonant converter has been proposed. LLC resonant converter's merits is the capacity to achieve zero-voltage switching (ZVS) for primary side switches and zero-current switching (ZCS) for the secondary side rectifier. LLC converters do not suffer from reverse recovery issues and severe switching noise when compared against conventional converters, which generally have serious reverse recovery issues induced by hard switching. Soft-switching greatly reduces witching losses, allowing for LLC use in high-frequency applications.

Brief description of full bridge LLC resonant converter:
Figure 1 shows the half-bridge LLC topology. The circuit can be divided into the following function blocks: the square-wave generator, the series resonant tank, the transformer, the output rectifier circuit, and the output filter. Q1& Q4 and Q2 & Q3 implement the square wave generator, which commutates at a 50% duty cycle. The series resonant tank is composed of a series resonant inductor Lr, a series resonant capacitor Cr, and the Lm formed by the magnetizing inductance of transformer T1. The series resonant inductor can be an external component or the leakage inductance of T1. The rectifier circuit—which includes D1, D2, D3, D4 converts the resonant current into a unidirectional current. The output filter, Cf, modulates the high-frequency ripple current.

Specifically, the resonant DC-to-DC converter as shown now implemented with the LLC resonant network has two characteristic frequency points as the first characteristic resonant frequency f_{r1} determined by resonant component Lr and Cr and the Second characteristic resonant frequency f_{r2} determined by Lr, Cr and Lm.

$$f_{r1} = \frac{1}{2\pi\sqrt{LrCr}}$$
$$f_{r2} = \frac{1}{2\pi\sqrt{(Lr + Lm)Cr}}$$

Design of LLC resonant converter:
Figure-2 shows design flow chart for LLC resonant converter.

- Calculate maximum and minimum gain required at extreme values of input voltage range:

$$M_{max} = n \frac{V_{out}}{V_{dcmin}}$$

$$M_{min} = n \frac{V_{out}}{V_{dcmax}}$$

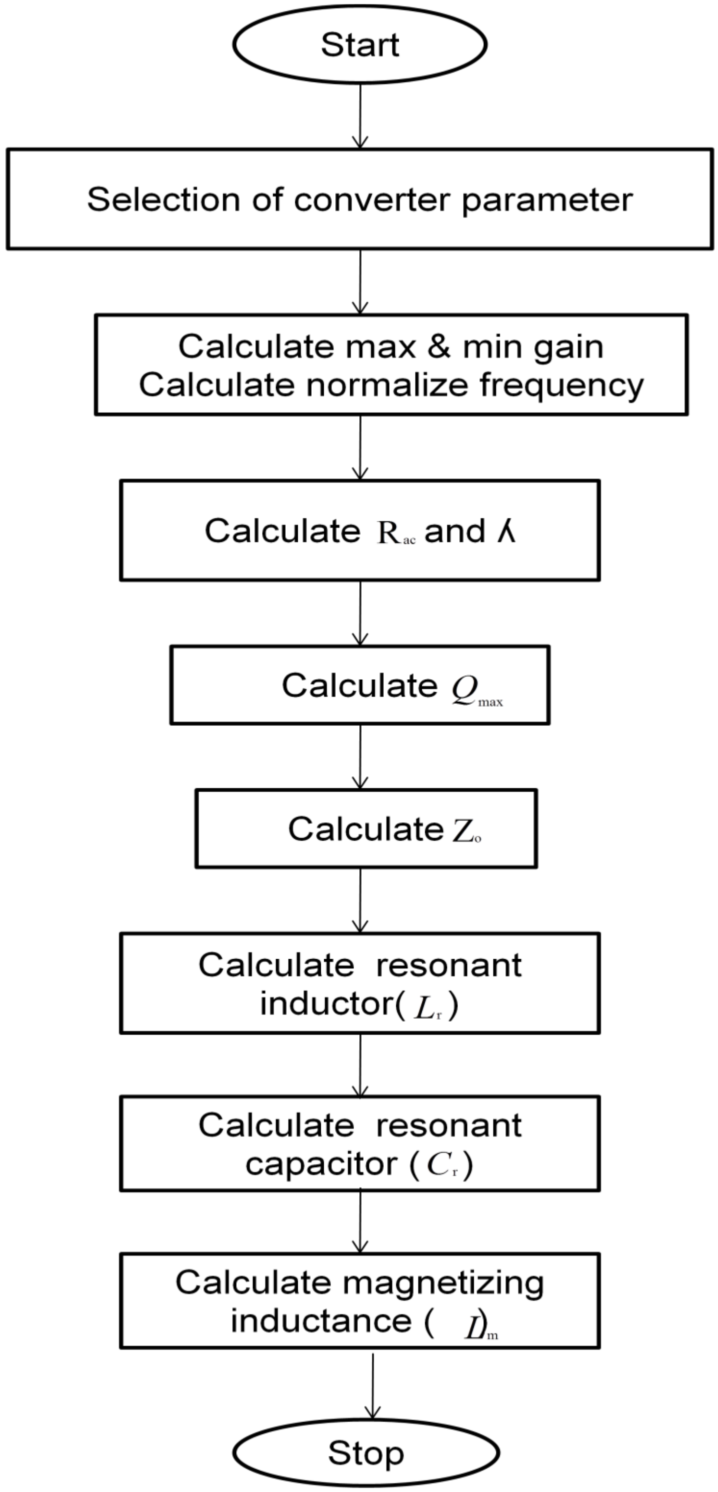

Figure-2 Design flow chart of LLC resonant converter

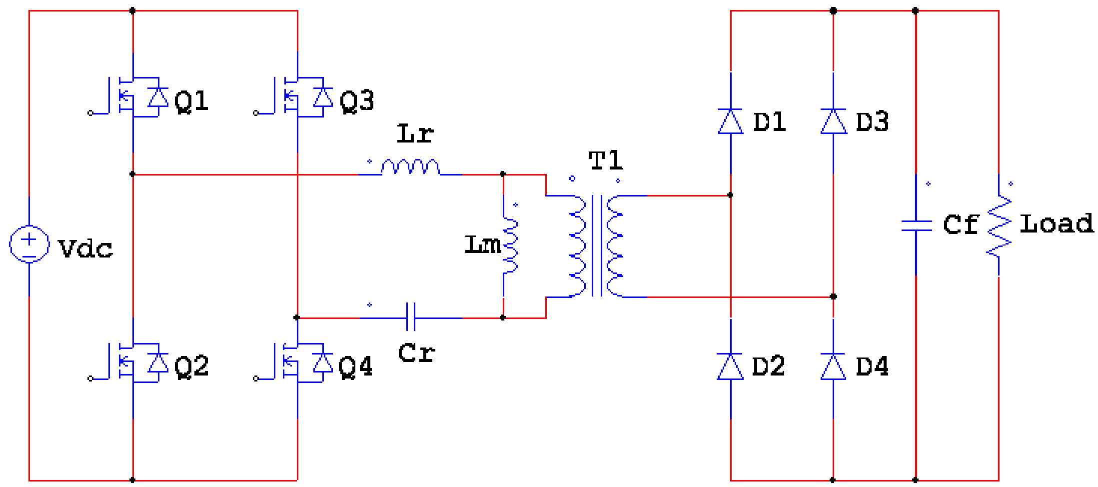

Figure 1 topology of Full bridge LLC resonant converter

- Calculate maximum normalize operating frequency:

$$f_{nmax} = \frac{f_{max}}{f_r}$$

- Effective load resistance reflected at primary side of transformer:

$$R_{ac} = \frac{8}{\pi^2} n^2 \frac{{V_{out}}^2}{P_{out}}$$

- Inductance ratio:

$$\lambda = \frac{1 - M_{min}}{M_{min}} \frac{{f_{nmax}}^2}{{f_{nmax}}^2 - 1}$$

- Calculate Q value to work in ZVS operating region at minimum input voltage and full load condition:

$$Q = \frac{\lambda}{M_{max}} \sqrt{\frac{1}{\lambda} + \frac{{M_{max}}^2}{{M_{max}}^2 - 1}}$$

- Calculate the characteristic impedance of resonant tank:

$$Z_o = Q.R_{ac}$$

- Calculate Resonant inductor:

$$L_r = \frac{Z_o}{2\pi f_r}$$

- Calculate Resonant capacitor:

$$C_r = \frac{1}{2\pi f_r Z_o}$$

- Calculate inductance of transformer:

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

Simulation and result

Figure-3 shows actual simulation circuit of Full bridge LLC resonant converter simulated in PSIM software.
As shown in figure MOSFETs are connected in full bridge configuration.

M1 and M4 operated with 0° delay and M2 and M4 opearted with 180° dealy at 50% duty cycle.
The gatepulse of MOSFETs are shown in figure-4 and voltage of MOSFETs are shown in figure-5.
Current passing through MOSFETs are shown in figure-6.
Transformer primary and secondary current shown in figure-7.
MOSFETs turn on at zero voltage switching(ZVS) and turn off at zero current switching(ZCS) is shown in figure-8.
Output voltage and output current are shoen on figure-9 and figure-10.

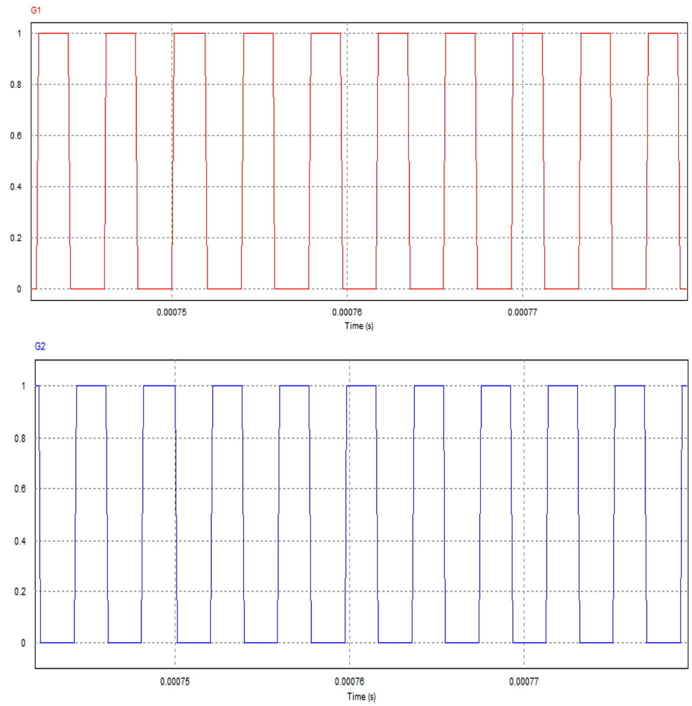

Figure-4 Gatepulse of MOSFETs M1 and M4 & M2 and M3

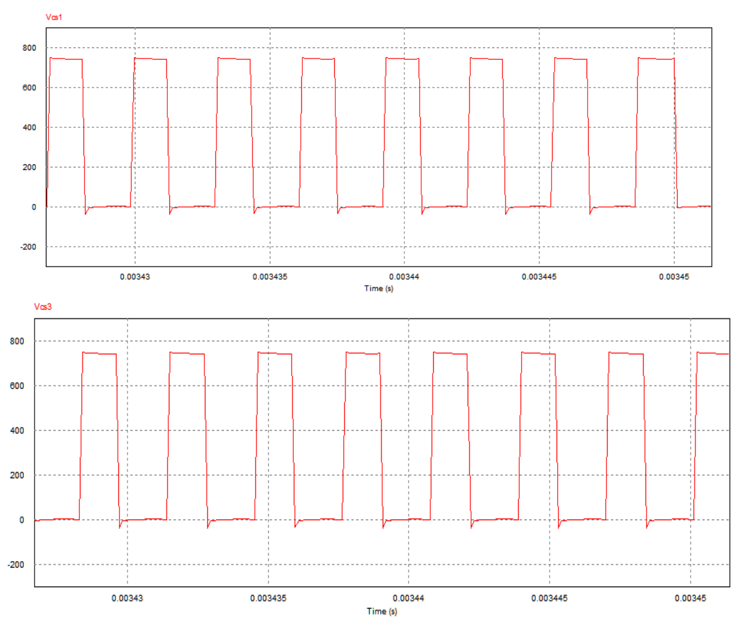

Figure-5 Voltage of MOSFETs

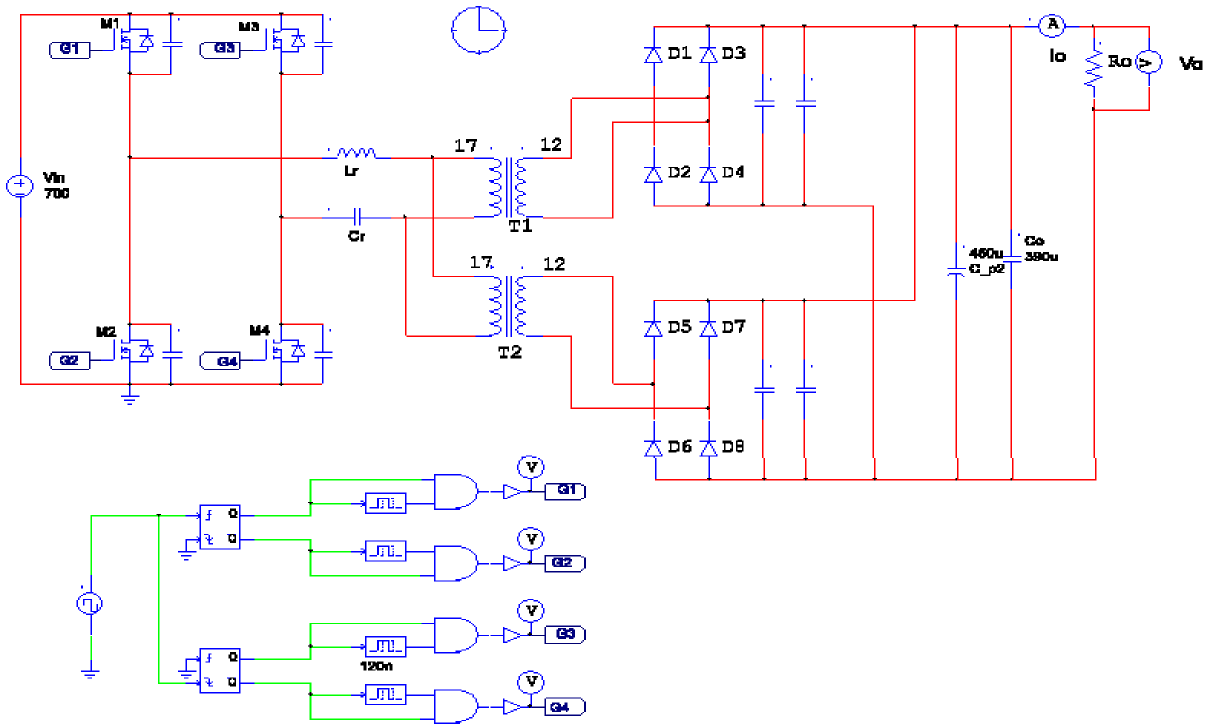

Figure-3 Simlink of Full bridge LLC resonant converter

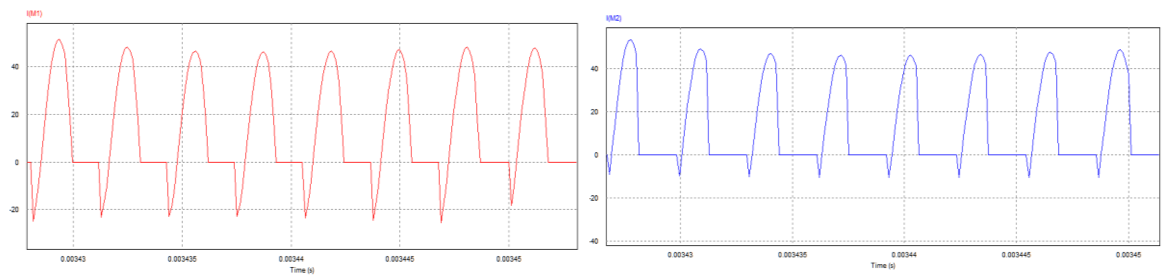

Figure-6 Current of MOSFETs

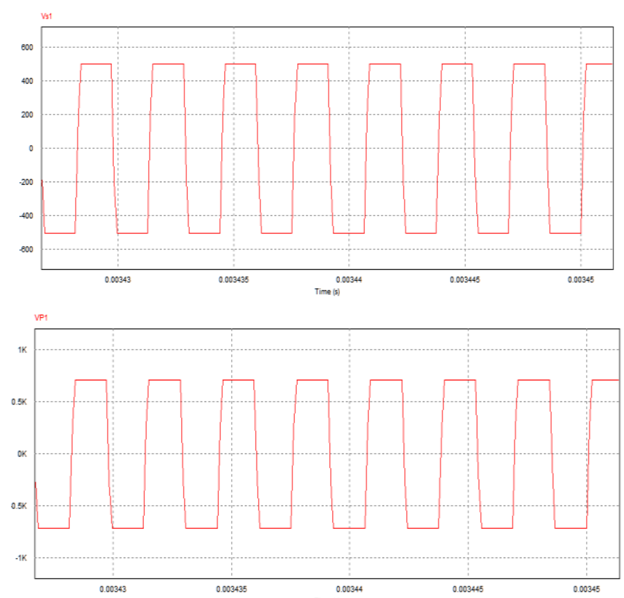

Figure-7 Transformer Primary and Secondary side voltage

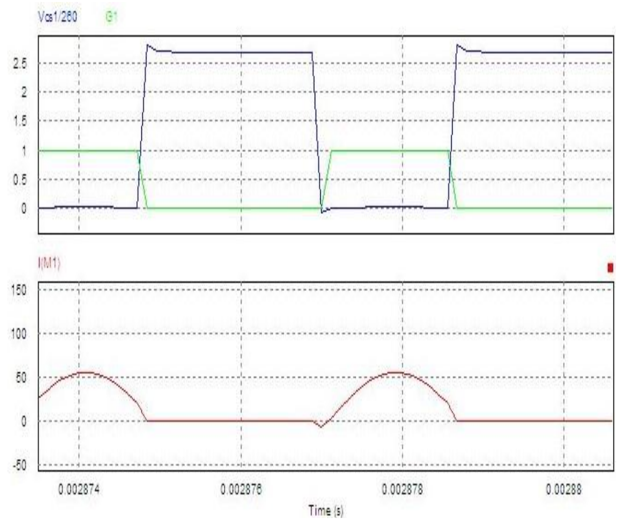

Figure-8 ZVS/ZCS turn ON and low current turn OFF of power switch

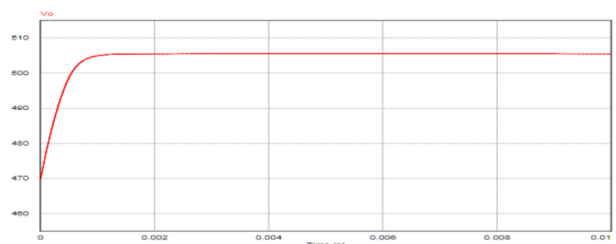

Figure-9 Output voltage

Figure-10 Output current

Conclusion

Theoretical study and design procedure of Full bridge LLC resonant converter is presented. Calculation of resonant component s defined. Simulation results are provided for Full LLC resonant converter which shows ZVS/ZCS at switch turn on and turn off.

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