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An Approach to Use Genetic Algorithm for Designing LLC Resonant Converter

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ABSTRACT: Nowadays the trend of power supply market is more inclined to high switching frequency, high efficiency and high power density. Resonant power supply has gained much popularity and has been a major area of research. Among various topologies of resonant converters, LLC topology has been proved to be very advantageous. The aim of this paper is to introduce generalized design and optimization methodology for LLC resonant converters. Fundamental Harmonic Approximation (FHA) has been used to obtain the mathematical models used for optimization purpose. Genetic Algorithm (GA) is used as an optimization tool for obtaining the best possible combination of resonant tank elements. Gain function and input impedance obtained by FHA model are used as fitness function and constrain functions. Zero voltage switching operation is obtained by providing the constrain function in the operation of GA.

KEYWORDS: LLC Converter, Fundamental Harmonic Approximation (FHA), Genetic Algorithm (GA), Zero Voltage Switching (ZVS).

I.INTRODUCTION

In modern times, the pursuance of high conversion efficiency, high power density, and high reliability are few of the major driving forces in the field of power electronics. Resonant converter gained a position as a major area of research due to these reasons, among which resonant DC-DC converter is the most popular. Resonant converters are switching converters that include resonant tank circuit actively participating in determining input power to output power flow. Several topologies of resonant converter have been introduced in which LLC topology is considered to be the best. In electrical and electronics field this tendency comes out in the form of less power intake generating efficient and sufficient output power. Energy efficiency is a hot topic that has drawn the attention of researchers and engineers for decades. Resonant converter is emerging to meet the high-efficiency requirements of power converters and it is becoming increasingly popular in industrial applications. The resonant DC-DC converters are preferred over other conventional topologies due to its features like high frequency operation, high efficiency, smaller size, light weight, low component stress and reduced EM interference. The resonant DC-DC converter basically comprise of three main building blocks:

- Switch Network consist Resonant Inverter which Converts DC input to AC
- Resonant tank circuit
- Rectifier: Converts AC back to DC
- Low pass filter: Rectified DC output

In the figure 1 we can see that resonant inverter comprised of two major blocks as mentioned above. The switch network can be half bridge or full bridge designed with various power electronics switches. Here we have

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considered MOSFET due to its feature corresponding to ZVS (Zero Voltage Switching) technique. The second sub block of resonant inverter is resonant tank circuit. This is the block which is responsible for various topologies. The resonant tank comprises of inductance and capacitor arranged together. Among all the arrangements only four gave supposed results and those ended up in becoming the main three topologies of resonant converters namely;

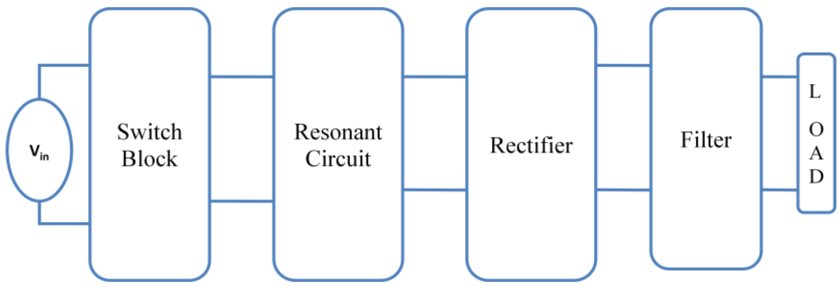

Fig. 1 Block Diagram of Resonant DC/DC Converter

1). Series Resonant Converter. 2) Parallel Resonant Converter. 3). Series Parallel Resonant Converter.

Series resonant converter (SRC)

The circuit diagram of a half bridge Series Resonant Converter is shown in Fig 1. The resonant inductor Lr and resonant capacitor Cr are in series circuit. They form a series resonant tank. The resonant tank will then in series with the load.

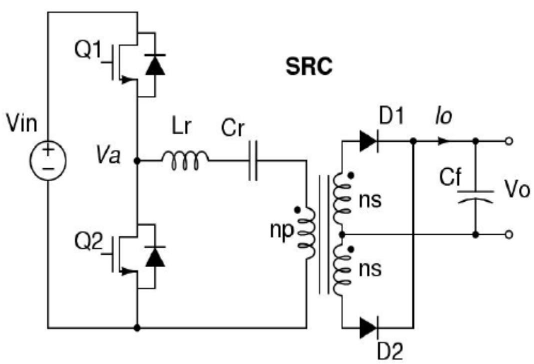

Fig. 2 Half Bridge Series Resonant Converter

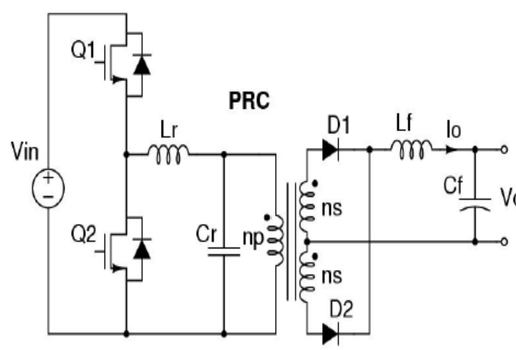

Fig. 3 Half Bridge Parallel Resonant Converter

Parallel resonant converter (PRC)

The schematic of parallel resonant converter is shown in Figure3. For parallel resonant converter, the resonant tank is still in series. It is called parallel resonant converter circuit because in this case the load is in parallel converter with the resonant capacitor. More accurately, this converter should be called series converter with parallel load. Then transformer primary side is a capacitor, an inductor is added on the secondary side to match the impedance.

Series-parallel resonant converter (SPRC)

Third is SPRC (fig. 4), this is combination of SRC and PRC, an inductive or capacitive element is connected in series with a series resonant combination of resonant inductor and capacitor. The load is connected in parallel to this third element. Based on the third element, two configurations are possible as; LCC & LLC.

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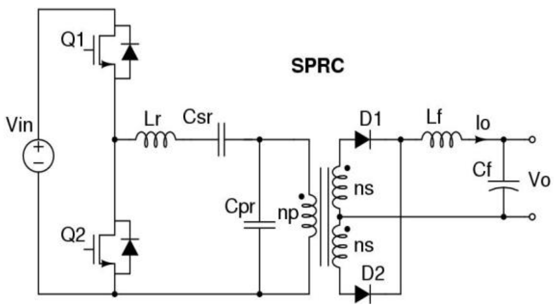

Fig. 4 Half Bridge LCC Series Parallel Resonant Converter

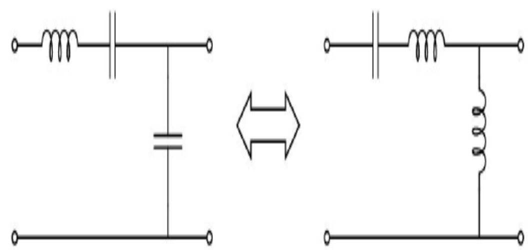

Fig. 5 Duality of LCC into LLC

The performance of above three topologies is not satisfactory for a front end DC/DC converter. High circulating energy and high switching loss will occur at high input voltage. So by taking duality of the circuit we can obtain LLC topology as shown in fig. 5.

The LLC converter is a second topology among SPRC's as shown in fig. 6. This topology of resonant converter is considered to be the best among all the above topologies due to its advantages like ZVS capability even at no load condition & the narrow switching frequency range with light load.

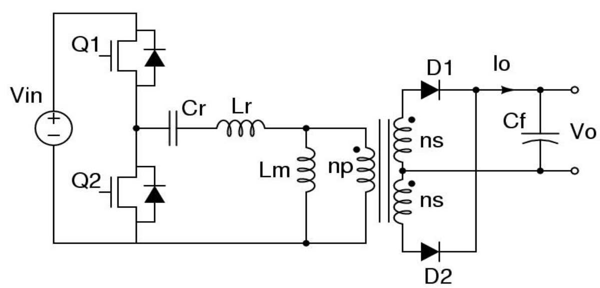

Fig. 6 Half Bridge LLC Series Parallel Resonant Converter

II. FUNDAMENTAL HARMONIC APPROXIMATION (FHA)

The LLC converter is operated in the vicinity of series resonance converter. This means that the main composite of circulating current in the resonant network is at or close to the series resonant frequency.

$$f_o = \frac{1}{2\pi\sqrt{L_r C_r}} \qquad (1)$$

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

The FHA method can be used to develop the gain, or the input-to-output voltage-transfer function. The first steps in this process are as follows:

- Represent the primary-input unipolar square wave voltage and current with their fundamental components, ignoring all higher-order harmonics.
- Ignore the effect from the output capacitor and the transformer's secondary-side leakage inductance.
- Refer the obtained secondary-side variables to the primary side.
- The represent the referred secondary voltage, which is the bipolar square-wave voltage (Vso), and the referred secondary current power with only their fundamental components, again ignoring all higher-order harmonics.

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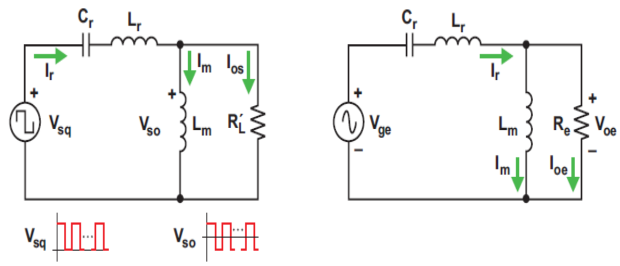
With these steps a circuit model of LLC resonant half bridge converter as shown in figure 7. Using figure 7 we can obtain Voltage–Gain function given by equation 3. A circuit model of the LLC resonant half-bridge converter shown in Figure. 7(a) can be obtained by simplifying figure 6 and a combined load consisting of transformer and rectifier losses is taken. In Figure. 7(b), Vge is the fundamental component of inverter output, and Voe is the fundamental component of rectifier output referred to primary side.



a. Nonlinear nonsinusoidal circuit. b. Linear sinusoidal circuit.

Fig: 7 Model of LLC resonant half-bridge converter.

Fundamental voltage (Vsq) is given by

$$V_{ge}(t) = \frac{2}{\pi} \times V_{DC} \times \sin(2\pi f_{sw} t), \quad (3)$$

RMS value is

$$V_{ge} = \frac{\sqrt{2}}{\pi} \times V_{DC} \quad (4)$$

Output voltage (V_{so})

$$V_{oe}(t) = \frac{4}{\pi} \times n \times V_o \times \sin(2\pi f_{sw} t - \varphi v) \quad (5)$$

Where φv is the phase angle between V_{oe} and V_{ge}.

Its RMS output voltage is

$$V_{oe} = \frac{2\sqrt{2}}{\pi} \times n \times V_o \quad (6)$$

Hence the voltage-gain function can then be obtained in the normalized form which is expressed as.

$$M_g = \frac{V_{oe}}{V_{ge}} = \left| \frac{L_n \times f_n^2}{[(L_n+1) \times f_n^2 - 1] + j\,(f_n^2 - 1) \times f_n \times Q_e \times L_n]} \right| (7)$$

Where,

$$f_n = \frac{f_{ws}}{f_o} \quad (8)$$

$$L_n = \frac{L_m}{L_r} \quad (9)$$

The quality factor.

$$Q_e = \frac{\sqrt{L_r}}{L_c} / R_e \quad (10)$$

Here the series resonant frequency (f0) is selected as the base for normalization function. Notice that fn, Ln, and Qe are no-unit variables.

To achieve acceptable efficiency profile the design will be done such that for switching frequencies higher than f_p(in inductive region), slope of gain function is maximized which is given by:

$$\frac{-d}{d f_n} M_g(Q_e, f_n, L_n) \quad (11)$$

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III. GENETIC ALGORITHM (GA)

Genetic algorithm (GA) is a search technique used in computing to find exact or approximate solutions to optimization and search problems. In this algorithm we use for finding the optimum value in our project. Genetic algorithm (GA) is a method for solving both constrained and unconstrained optimization problems that is based on natural selection, the process that drives biological evolution. A genetic algorithm repeatedly modifies a population of individual solutions. The genetic algorithm selects individuals at random from the current population to be parents and uses them produce the children for the next generation. It is over successive generations, the Population "evolves" toward an optimal solution. You can apply the genetic algorithm (GA) to solve a variety of optimization problems that are not well suited for standard optimization method, including problems in which the objective function is discontinuous, no differentiable, stochastic, and highly nonlinear. Genetic algorithm uses three main types of rules at each step to create the next generation from the current population. The important steps for genetic algorithm:

1). Initial Population. 2). Evolution of Fitness function. 3). Selection. 4). Crossover, 5). Mutation..

The most common type of genetic algorithm works like this: the population is created with a group of randomly. The evaluation function is provided by the programmer and gives the individuals a score based on how well they perform at the given task. Two individuals are then selected based on their fitness, and the higher the fitness, the higher and the chance of being selected. These individuals then "reproduce" to create one or more offspring, in after which the offspring are mutated randomly. This continues until a suitable solution has been found or a certain number of generations have passed, depending on the needs of the programmer.

IV. APPLICATION OF GENETIC ALGORITHM

The genetic algorithms are a very effective way of quickly finding a reasonable solution to a complex problem. They aren't instantaneous, or even close, but they do an excellent job of searching through a large and complex search space. Genetic algorithms are most effective in a search space for which little is known. They can also produce solutions that only work within the test environment and flounder once you try to use them in the real world.=

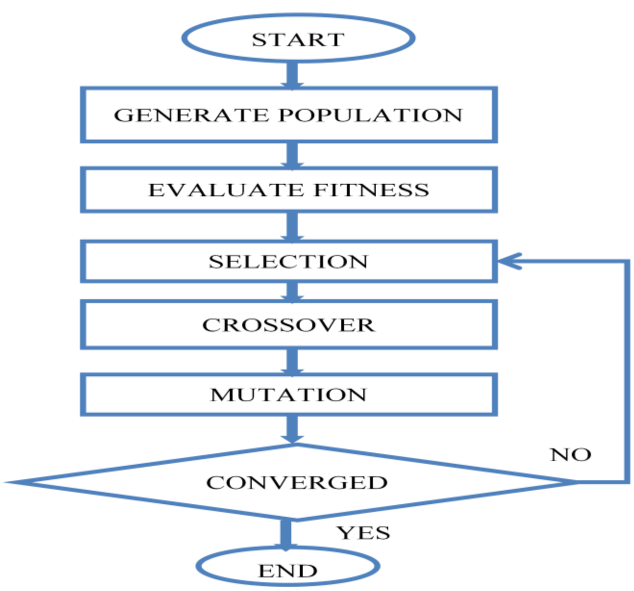

Fig. 8 Flow chart of GA

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V. RESULTS AND DISCUSSION

Table 2 shows the optimized values of design parameters obtained by genetic algorithm. As the slope of gain is maximum for design 3, it is the best among all the three designs.

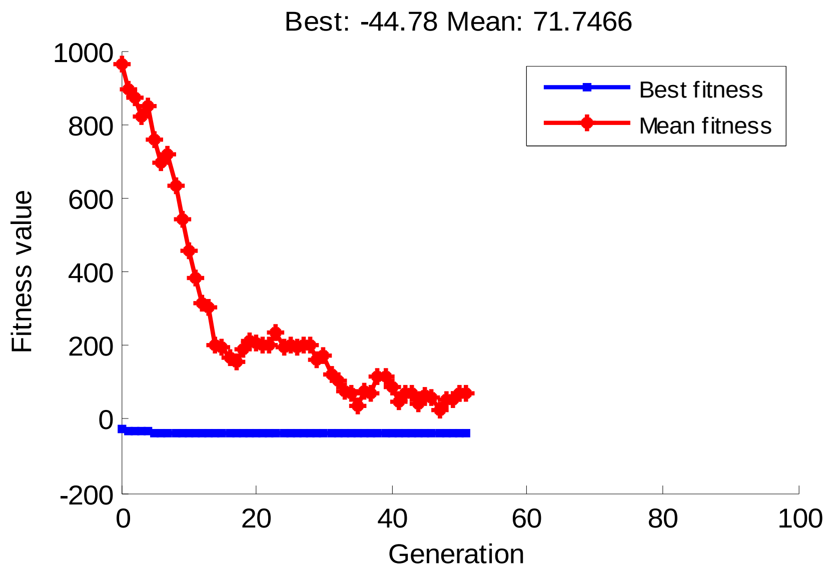

Fig: 9 Performance of generation Vs firness value

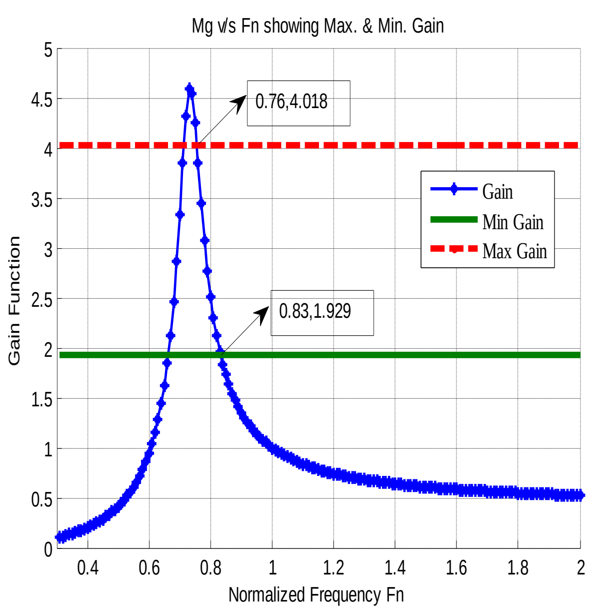

Fig. 10 Gain function Vs normalized frequency (Fn) for design 2

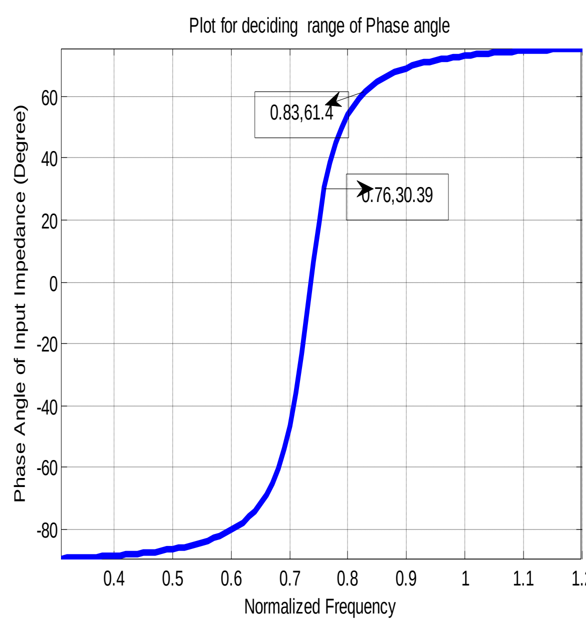

Fig. 11 Phase angle of input impedance (φz) Vs Normalized frequency (Fn) for design

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Figure 10 shows the minimum and maximum gain corresponding to which we can get the switching frequency range for the operation of LLC converter. Figure 11 shows the range of phase angle of the input impedance corresponding to the switching frequency limits and figure 13 shows the attainable peak gain for different values of Qe.

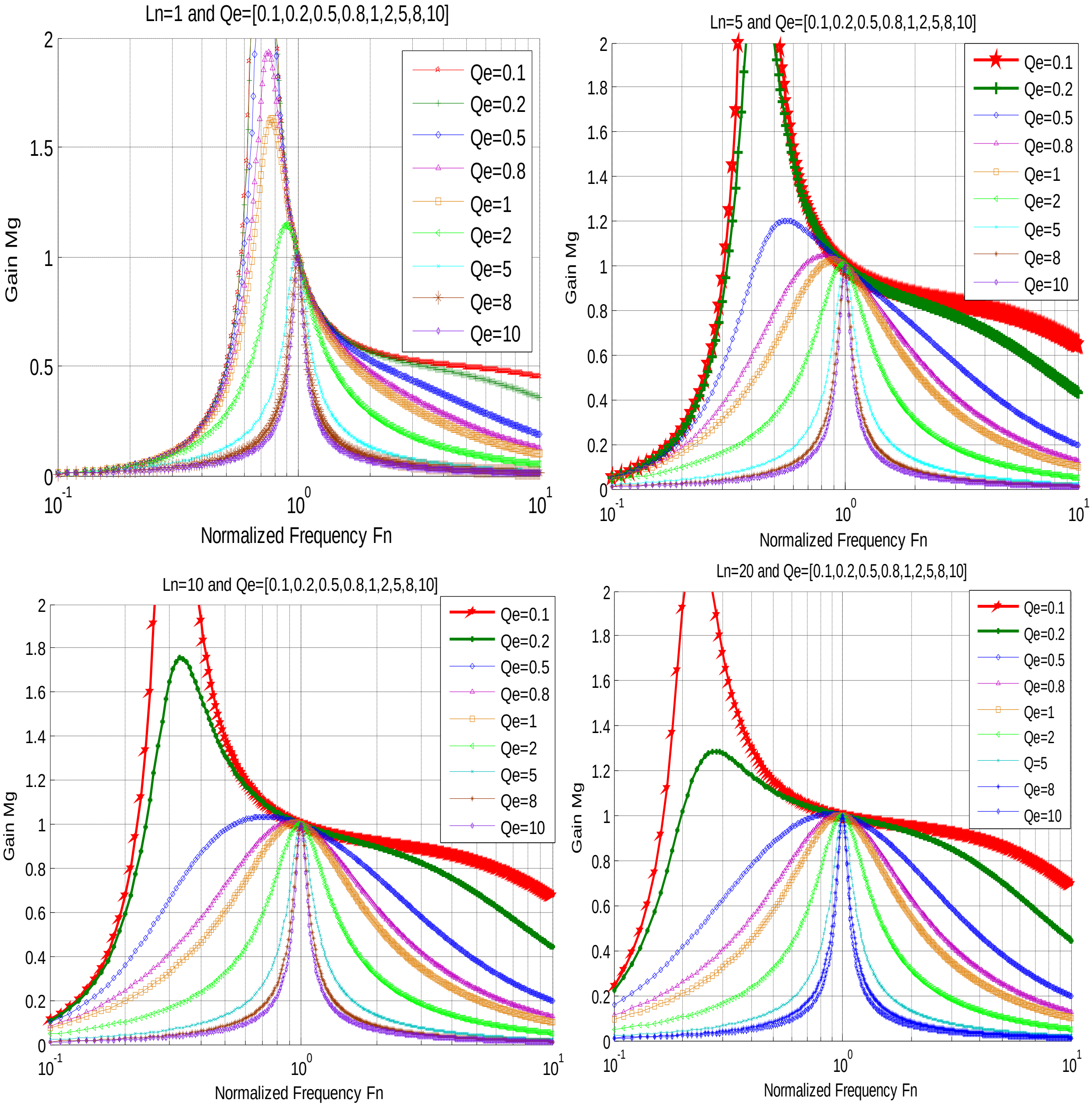

Fig. 12 Plots of voltage gain function (Mg) Vs normalized frequency (Fn) for different values of Ln

In figure 12 each plot is defined by a fixed value for Ln (Ln = 1, 5, 10, 20) shown in the title of the figure and shows a family of curves with nine values of Qe (Qe=0.1-10). From these plots, we can predict the operating region of LLC converter for getting maximum efficiency as we can ensure negative slope of gain function.

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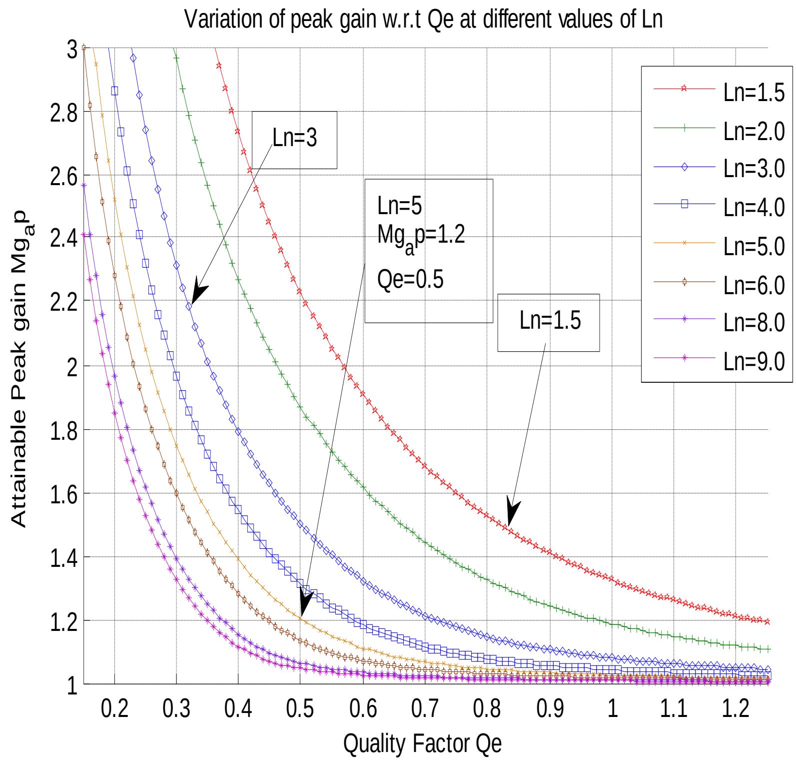

Fig. 13 Peak gain Vs quality factor (Qe) for different values of Ln

Figure 13 shows the variation of Attainable peak gain with change in Quality Factor Qe. It is very clear that the value of peak gain decreases with increase in Qe.

Table: 1 Results of genetic algorithm

S.No.	Ln, Qe and n	Cr(n)	Lr(µ)	Lm(µ)	fn	Φz range	Peak Im (A)	Peak Ir (A)	Slope of gain
1	0.47 0.63 7.5	3.22	464	218	0.85-0.91	27-62	3.33	3.47	-34.79
2	0.81 0.36 8.6	4.49	333	269	0.76-0.83	30.4-61.4	3.31	3.42	-33.57
3	1.08 0.22 11.8	4.18	357	387	0.71-0.76	21.3-59.4	3.83	3.89	-44.78

VI. CONCLUSION

This paper proposes an approach for designing a half bridge LLC resonant converter using Genetic Algorithm. The performance has been analyzed based on the fundamental harmonic approximation (FHA). Gain function and input impedance function obtained by FHA model are used as fitness function and constrain function respectively. Zero voltage switching (ZVS) operation is obtained by providing the constrain function to Genetic Algorithm.

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