Impact Factor (SJIF): 3.632

International Journal of Advance Research in Engineering, Science & Technology

e-ISSN: 2393-9877, p-ISSN: 2394-2444

(Special Issue for ITECE 2016)

LLC Resonant converter Design and contolled with PWM technique

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Abstract *— There are different types of DC-DC converters available in a market for different applications. But in the conventional DC-DC converter there are some problems like, it creates high switching losses and poor voltage conversion ratio under certain conditions. So in this work proposed DC-DC converter is presents the analysis between conventional and proposed methods for DC-DC conversion techniques. In terms of achieving High efficiency the voltage conversion ratio must be improved. It is also include the study of Design and simulation of resonant converter. It provides the better idea for DC-DC conversion to gain the maximum efficiency without affected by supply variation.*

Keywords— DC to DC converter; Resonant DC-DC conversion; multi stage converter

I. INTRODUCTION

Nowadays, the world's energy structure is undergoing a fundamental readjustment: as the traditional fossil fuel based energy sources such as oil, gas and coals being the major cause of numerous environmental pollution problems, people are actively seeking renewable energy sources such as solar, wind and hydro power. These renewable energy sources, its having an advantage of clean, reliable, quiet and low maintenance cost are having an exponential growth in use [4].

Among them DC to DC Converters are important in portable electronics devices such as cellular phones or laptop Computers which are supplied the power from batteries primarily. DC to DC converters are developed to maximize the energy harvest from photovoltaic or wind generation system. "A DC to DC converter is an electronics circuit which is converts a source of DC from one voltage level to another voltage level. "The DC power supplies can be used industrial, commercial and domestic applications [4].

The DC-DC converter products are used extensively for diverse applications in the healthcare (bio life science, dental, imaging, laboratory, medical), communications, computing, storage, business systems, test and measurement, instrumentation, and industrial equipments. They are used in electric motor drives and in switch mode DC power supplies etc[1].

Power-system design for different applications has long been dominated by such issues as efficiency, thermal management, voltage regulation, reliability, power density, and cost. As one of the key building blocks, the DC/DC converter in the front-end converter is also under the pressure of increasing efficiency and power density. In a distributed power system, input AC voltage goes through the front-end converters, which includes PFC and DC/DC converters, then the generated bus voltage from front-end converters is transferred and converted into voltages by the downstream on-board voltage regulators for final loads [1].

The PWM approach is to control power flow by interrupting current or voltage by switching with control of the duty cycles. Conventionally, the voltage across or current through the semiconductor switch is abruptly altered; this approach is called hard-switching PWM. Because of its simplicity, relatively low current stress, and ease of control, hard-switching PWM approaches have been preferred in modern power electronics converters. Owing to the rapid developments of new power device technologies, the switching speed of power devices has increased greatly. Therefore, PWM power converters can now operate at a much higher switching frequency, reducing the size of passive components, reducing the overall cost of the system. However, the converter switching loss also increases in proportion to the frequency. The increment in dv/dt and di/dt caused by the increased in speed of conduction which increase stress on the device and system electromagnetic interference and noise[5].

There are several issues in conventional PWM Converters such as,

- Higher switching losses and lower conversion ratio.
- Cannot operate under high frequency operations.
- High dv/dt and di/dt cause electromagnetic interference and noise.
- Hard switching PWM

- Narrow input range

The voltage conversion ratio of the conventional PWM converters is not sufficient due to the high switching losses at high frequency operations. Hardly the ZVS can be achieved in the conventional approach. From the study of conventional converter it is clear that in conventional converters it is difficult to achieve high efficiency and wide input range at same time. In such case it creates compromise between them. Thus to create better voltage conversion ratio it is required to achieve ZVS in the converter. By means of ZVS soft switching the converter becomes Efficient and More Reliable. To overcome these issues here the conventional PWM converter is replaced with resonant converter. Through which those issues can minimized and developed a better design for high frequency operations and provide better voltage conversion[6].

II. Review of LLC Resonant Converter [3]

As showing in above fig.1 the controlled block diagram of LLC resonant converter with their feedback circuit. To achieve higher efficiency in DC/DC converter the voltage regulation of the system must be improved. Hence to achieve better regulation multistage stage conversion is necessary. The resonant converter provided that with better reliability and less complexity[3].

According to the block diagram input Vdc input is converted in Square wave by Half/Full bridge inverter with appropriate switching sequence. That signal will further Passes through LLC Resonant network and Allow only sinusoidal signal to flow through it. Further the transformer will readjust the output voltage of transformer by either stepped up/down. The secondary output signal of transformer will be rectified through Full bridge rectifier to load[3].

Any generated Error will be eliminated further by feedback circuit which consists the PI controller for proper regulation. The output signal is compares to the reference signal and the signal passes through PI controller and will become Proper input for switching network. By choosing appropriate control strategy either frequency modulation (FM) or constant frequency Pulse width modulation (PWM) technique[3]

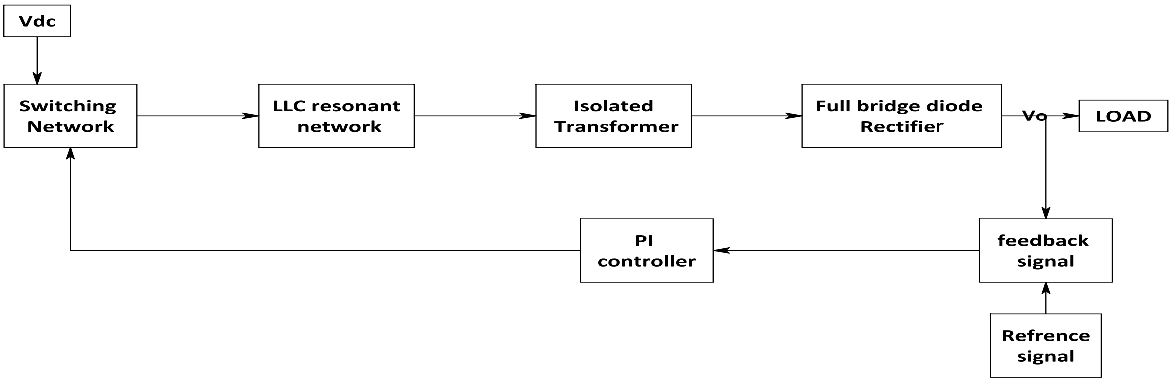


Fig.1: block diagram of controlled LLC

III. Study of LLC resonant converter

There are different types of topologies of resonant converters like series resonant converter (SRC), parallel resonant converter (PRC), LCC, are studied earlier. From their results, we came to know that all of them having big penalty for wide input range design[2].

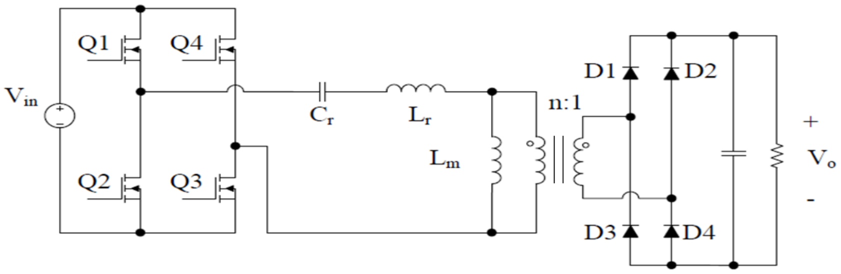


Fig. 2: Full bridge LLC Resonant converter

Also, High circulating energy and high switching loss will occur at high input voltage. They are not suitable for front end DC/DC application[2].

For LCC resonant converter, although it has two resonant frequencies unfortunately, the lower resonant frequency is in ZCS region. For this application, we are not able to design the converter working at this resonant frequency. Although the lower frequency resonant frequency is not usable, the idea is how to get a resonant frequency at ZVS region. By change the LCC resonant tank to its dual resonant network, this is achievable. As shown in Figure 2 by change L to C and C to L, A LLC resonant converter could be built. Which means it was designed to operate in switching frequency higher than resonant frequency of the series resonant tank of Lr and Cr. When operating in this region, LLC resonant converter acts very similar to SRC. The benefit of LLC resonant converter is Narrow switching frequency range with light load and ZVS capability with even no load[2].

IV. Operation Analysis of LLC Resonant Converter

Since the LLC network, the converter can operate in three modes depending on input voltage and load current conditions, as listed below.

1. At resonant frequency operation, (fs=fr.)
2. Above resonant frequency operation (fs>fr.)
3. Below Resonant frequency operation, (fs<fr.)

(A).Power delivery operation[12]

Power delivery operation, which occurs twice in a switching cycle; first when the resonant tank is excited with a positive voltage, so the current resonates in the positive direction in the first half of the Switching cycle, the equivalent circuit of this mode is shown in Figure 3(a).

The second occurs when the resonant tank is excited with negative voltage, so the current resonates in the negative Direction in the second half of the switching cycle; the equivalent circuit of this mode is shown in Figure 3(b). During the power delivery operations, the magnetizing inductor voltage is the positive/negative reflected output voltage and the magnetizing current is charging/discharging respectively.

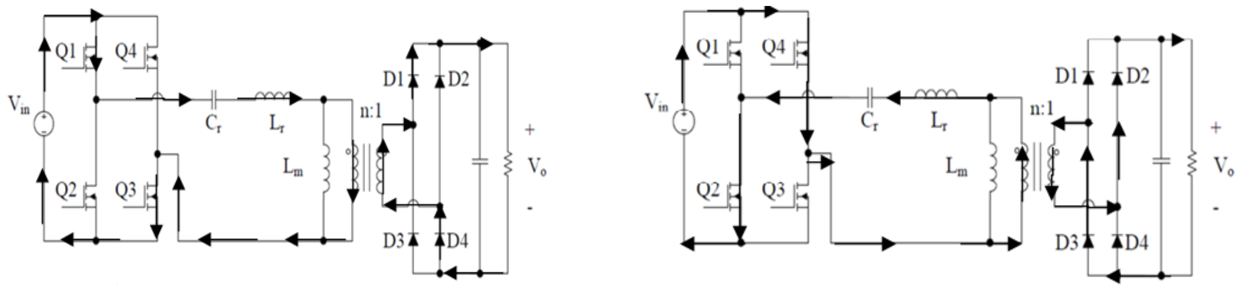


Fig.3 Power delivery operations

The difference between the resonant current and the magnetizing current passes through the transformer and rectifier to the secondary side, and power is delivered to the load.

(B).Freewheeling mode[12]

Freewheeling operation, which can occurs following the power delivery operation only if the resonant Current reaches the transformer magnetizing current, this only happens when fs<fr, causing the transformer secondary current to reach zero and the secondary side rectifier to disconnect.

Consequently the magnetizing inductor will be free to enter the resonance with the resonant inductor And capacitor, the frequency of this second resonance is smaller than the original resonant frequency fr, especially at high value so fm where Lm>>Lr, thus the primary current during the freewheeling operation will only changes lightly and can be approximated to be unchanged for simplicity. The equivalent circuits of the freewheeling operation in both halves are shown in Figure 4.

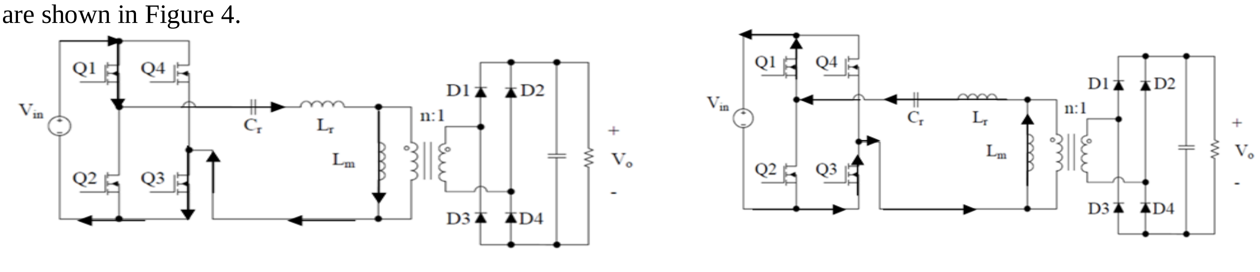


Fig. 4: Freewheeling modes

V. DESIGN PARAMETERS FOR LLC RESONANT CONVERTER [7]

Table 1: Design parameters of LLC resonant converter Design for the given specification,

Parameters	Values
Input voltage (Vin)	380 Vdc
Output voltage (Vo)	24 Vdc
Output current (Io)	5 A
Output power (Po)	120 watts
Resonant frequency (fo)	85 kHz

1] Define the system specification

1) Efficiency:

Assuming efficiency = 95%
Pin = Po/eff. = 120/0.95 =126 watts

2) Input voltage Range:

Typically it is assumed that input voltage is provided from power factor correction converter (PFC). So, when input voltage is supplied from PFC the minimum input voltage.

$$\text{Vin (min.)} = \sqrt{\text{Vout(PFC)} - 2\text{Pin} * \text{Thu/Cdl}} \qquad (1)$$

Where, Vo (PFC) = Output voltage of PFC
Thu = Hold up time =17 ms
Cdl = 100μF
Thu = Hold up time =17 ms, Cdl = 100μF are data taken from the PFC.
Thus, Vin (min.) = 319 V & Vout (max.) = Vo (PFC) = 380Vdc.

2] Determine the max./min. Voltage gain

$$\text{M (min.)} = \frac{\text{Lr}+\text{Lm}}{\text{Lm}} \qquad (2)$$

Assumed that $\frac{\text{Lm}}{\text{Lr}} = \frac{\text{K}}{1}$

$$\text{M (min.)} = \frac{\text{K}+1}{\text{K}}$$

Here, $\text{M (max.)} = \frac{\text{Vin(max)}}{\text{Vin(min.)}} * \text{M (min.)} \qquad (3)$

Typically, the value of K should be chosen to obtain Minimum gain but if the K is chosen too small it will Result in A poor Coupling.

By selecting the value of K between 5 to 10 we can achieve gain between 1.1≈1.2
Ideally to achieve this gain, K=7

$\therefore$ M (min.) = $\frac{\text{K}+1}{\text{K}}$ = 1.14

$\therefore$ M (max.) = 1.36

3] Determine the transformer turn Ratio

$$\acute{\eta} = \frac{\text{Np}}{\text{Ns}} = \frac{\text{Vin (max)}}{2(\text{Vo}+2\text{Vf})} * \text{M (min)} \qquad (4)$$

Where, Vf = Secondary side rectifier diode Forward voltage (PFC Converter Data)

$$\acute{\eta} = \frac{\text{Np}}{\text{Ns}} = \frac{380}{2(24+2(0.6))} * 1.14 = 8.6$$

4] Calculating equivalent load resistance

$$Rac. = \frac{8}{\pi^2} * (ή)^2 * Vo^2/Po \qquad (5)$$

$$Rac = 288\ \Omega$$

5] Design the Resonant network

$$Cr = \frac{1}{2\pi Q} * \frac{1}{f_0} * \frac{1}{Rac}$$

$$Cr = 15\ nF$$

$$Lr = \frac{1}{(2\pi f_0)^2 * Cr}$$

$$Lr = 234\ \mu H$$

$$Lm = \frac{(K+1)^2}{(2K+1)} * Lr$$

$$Lm = 998\ \mu H$$

VI. Simulation and Results of close loop system of LLC Resonant converter

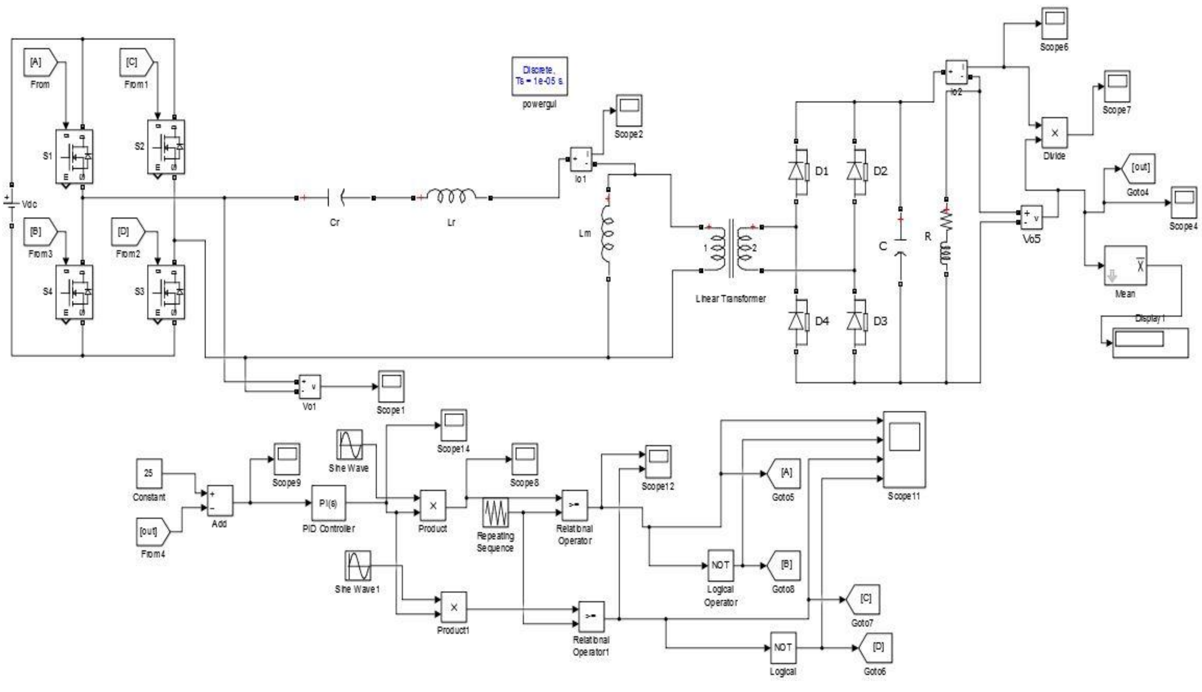


Fig.5: SPWM based close loop simulation

Simulation model of close loop system for LLC resonant converter topology is shown below in Fig.5 as per the prototype rating as shown in table 1.

In figure 5 represents the SPWM based close loop control strategy in which the output voltage is compares to the Reference and further PI controller's proper tuning will eliminating the error. Further by using the sinusoidal pulse width modulation the gate pulses will be generated and that signal will control the converter for the required output [9] [11] [10]

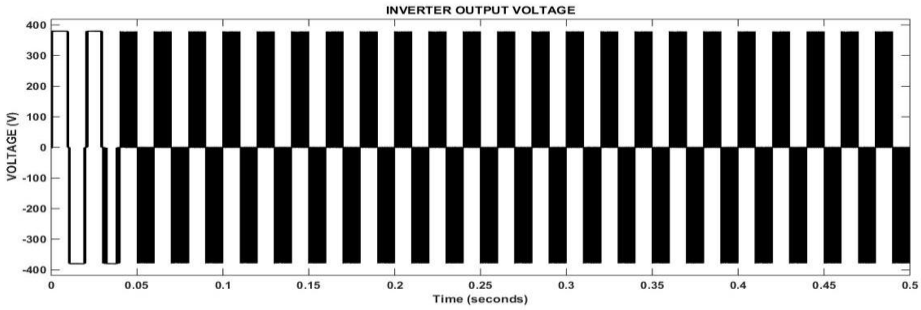


Fig.6: closed loop inverter output

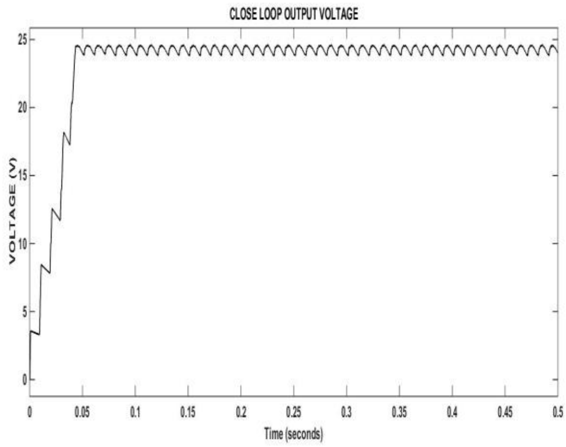


Fig.7: closed loop output voltage

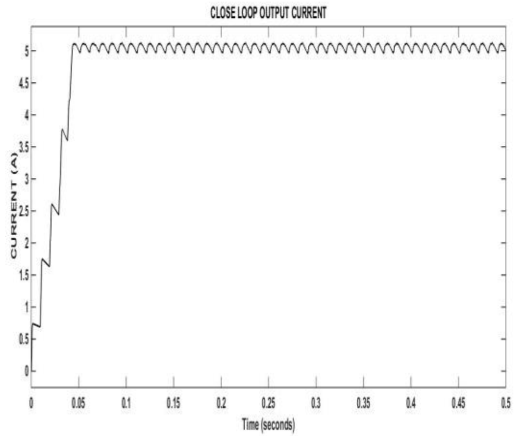


Fig.8: closed loop output current

In figure 6 the Inverter output is showing for a close loop system and figure 7 and 8 are showing the amount of output voltage and current. As compare to the output results of open loop system in close loop it becomes lesser pulsating and almost constant at a required value.

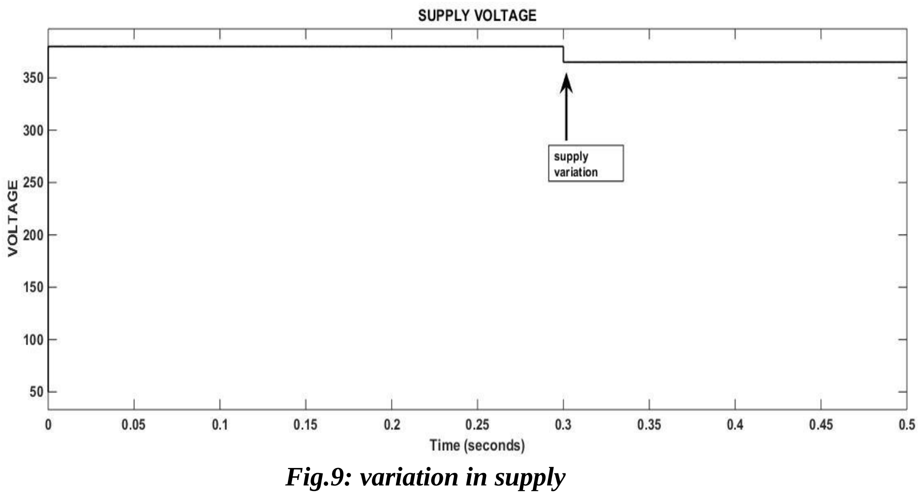
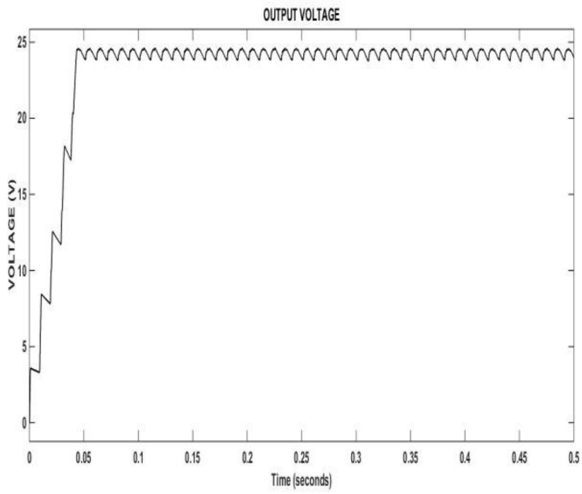


Fig.9: variation in supply

Figure 9 showing the step input supply variation in the system, according to this there will be a change in supply at time 0.3 sec. There is Rated supply of 380V for 0 to 0.3 sec and after that it will be varied around 5% and becomes 360 for 0.3 sec to 0.9 sec. The effect of this supply variation on output will be shown below**.**



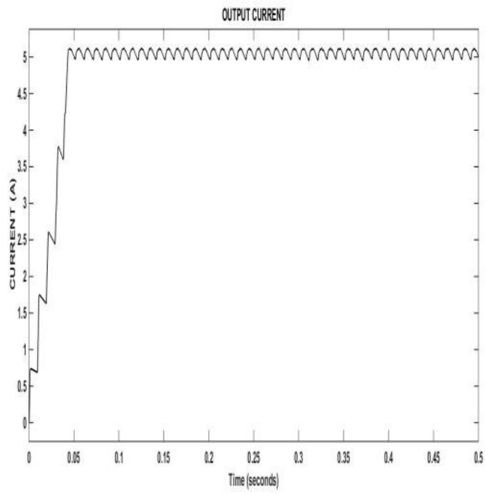


Fig 10: output voltage and current at variable supply

Figure 10 showing that there is no change in output during the variation in supply. Which suggest that the system becomes more stable and a small amount of variation in supply can maintain the output constant.

VII. CONCLUSION

To achieve better efficiency and voltage regulation for DC-DC conversion by creating LLC topology with PWM control technique. The proposed control strategy for LLC resonant converters provide better voltage regulation without adding extra components. This strategy improves the stability of the system and reduces the switching /Conduction losses remarkably. It's also provide the constant output voltage irrespective of load and supply variation.

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