Implementation of Different Controller for Fourth Order LCLC Resonant Power Converter

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Abstract- A closed loop control of the fourth order (LCLC configuration) resonant converter has been simulated and presented in this paper. The PI controller has been used for closed loop operation and the performance of proposed converter has been estimated with the closed loop and the open loop condition. The steady state-transient responses of nominal load, sudden line and load disturbances have been obtained to validate the controller performance. The proposed approach is expected to provide better voltage regulation for dynamic load conditions.
Keywords –Resonant Power Converter, LCLC configuration, PI Controller, State Space analysis.

I. INTRODUCTION

The increasing efforts on pushing to high power density and high efficiency DC/DC converter have lead us to develop converters capable of operating at higher switching frequency with high efficiency. For this reason, resonant converters have made lots of attentions due to high efficiency, high switching frequency and high power density. The invention and evolution of various DC–DC resonant converters (RC) have been focused for telecommunication and aerospace applications in the recent past. It has been set up that these converters experience high switching loss, reduced reliability, increased electro-magnetic interference (EMI) and high acoustic noise at high frequencies [1-12]. The LCLC resonant inverter is a forth order resonant topology which has been successfully used in different industrial applications such as space power distribution systems, resonant inverters, Ion generator power supplies, multi lamp operation ballasts, renewable energy power conditioning systems, constant-current power supplies and dual-output resonant converters [13]. This topology employs more parasitic elements and has many desirable features. Thus, it appears to be a serious prospect for high voltage conversion. The converter of this topology uses an inductive output filter similar to a Parallel Resonant Converter (PRC) [1, 2]. In [12] LCLC resonant converters with an LC output filter are analyzed using the First Harmonic Approximation technique (FHA). In high voltage applications, a resonant converter with a capacitive output filter is used, because the inductor in an output filter is bulky and very difficult to fabricate.

II. RESONANT CONVERTERS

Resonant converters contain resonant L-C networks whose voltage and current waveforms vary sinusoidally during one or more subintervals of each switching period. The resonant network has the effect of filtering higher harmonic voltages such that a nearly sinusoidal current appears at the input of the resonant network [4]. There are three main types of resonant networks, which are shown in Figure. 1.

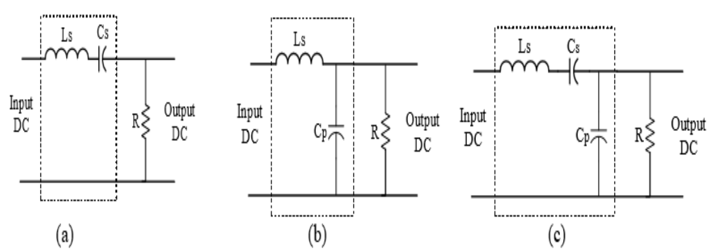

Figure.1 Resonant Networks: a) Series Resonant b) Parallel Resonant c) Series-Parallel Resonant

Series resonant, parallel resonant and series-parallel resonant. Depending on how the resonant networks are combined with other circuit configurations, one can obtain several types of resonant converters. The more common configurations are DC-to-high-frequency-AC inverters, resonant DC-DC converters and resonant link converters. In this work, the focus will be on the resonant DC-DC converters.A main advantage of resonant converters is the reduced switching losses. Resonant converters can run in either the zero-current-switching (ZCS) or zero-voltage-switching (ZVS) mode. That means that turn-on or turn-off transitions of semiconductor devices can occur at zero crossings of tank voltage or current waveforms, thus reducing or eliminating some of the switching loss mechanisms. Since the losses are proportional to switching frequency, converters can operate at higher switching frequencies than comparable PWM converters.

III. SERIES PARALLEL RESONANT CONVERTERS (SPRC)

The closed loop control of series-parallel resonant DC-DC converter (LCLC) with capacitive output filter is shown in Figure. 2.

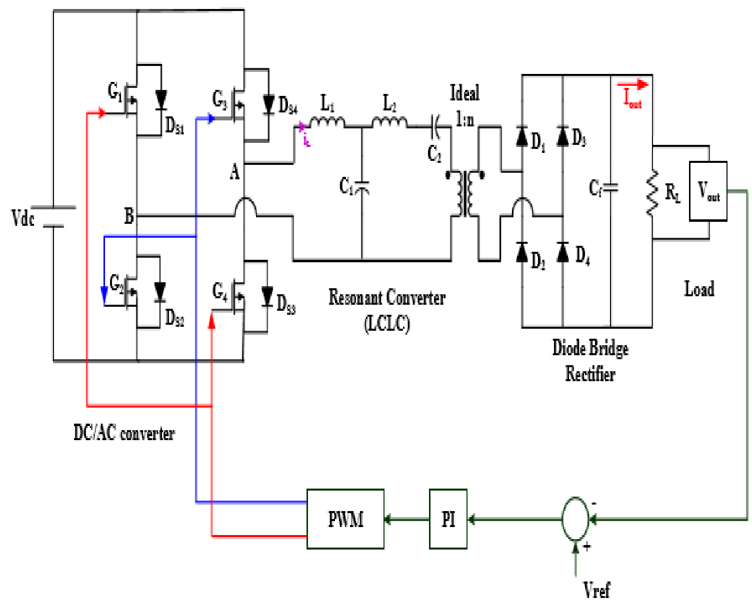

Figure. 2 Closed loop control of resonant converter with LCLC configuration

This converter has also been often used with inductive output filter [4]. However, in the current work the focus will be on the converter with capacitive output filter because this configuration is better suited for high-voltage applications.

Equation. (1) gives the voltage conversion ratio of the series-parallel resonant converter.

$$\frac{V_o}{nV_{in}} = \frac{4}{\pi} \cdot \frac{k_{21}}{k_v} \qquad (1)$$

$$k_{21} = \frac{1}{\sqrt{\left[1-\alpha\cdot\left(f_{s,N}^2-1\right)\cdot\left(1+\frac{\tan(|\beta|)}{\omega C_p R_e}\right)\right]^2+\left[\alpha\cdot\left(f_{s,N}^2-1\right)\cdot\frac{1}{\omega C_p R_e}\right]^2}}$$

$$Kv = 1+0.27.\sin\left[\frac{\theta}{2}\right]$$

Where

α = Cp / Cs - Ratio of the parallel to the series capacitors

θ - Output rectifier conduction angle

β-Phase displacement of the fundamentals of the voltageacross the parallel capacitor and theinputcurrent of theoutput rectifier

□CpRe - Dimensionless parameter

n -Transformer turns ratio

fs, N = fs.fo - Normalized switching frequency

fs - Switching frequency

fo = $\left(2\pi\sqrt{LsCs}\right)$-1-Series resonant frequency

This converter operates for low power close to the parallel resonant frequency (2π/ LpCs)-1) and for full load, close to the series resonant frequency (2π/ LsCs)-1). The real resonant frequency of the circuit changes with the load as shown in Fig.3. This happens because the load defines the influence of Cp on the resonant frequency. For high load the resonant current flows for only a small part of the switching period through Cp. Thus, the converter behaves as a series resonant converter and the resonant frequency is almost equal the series resonant frequency fo. On the other hand, for low load the resonant current flows almost the whole switching period through Cp. Therefore, the converter behaves as a parallel resonant converter. When operating above resonance, the converter behaves as a series resonant converter at lower frequencies (high load operation) and as a parallel resonant converter at higher frequencies (low load operation). At higher switching frequencies, the series capacitance becomes so small that it behaves just as a DC blocking capacitance.

The resonant inductor then resonates with the parallel capacitor and the converter operates in the parallel resonant mode. By proper selection of the resonant elements, the series-parallel resonant converter has better control characteristics than the resonant converters with only two resonant elements being less sensitive to component tolerances. This configuration aims to take advantage of the desirable characteristics of the series and the parallel converter while reducing or eliminating their drawbacks. Unlike the series resonant converter, the series-parallel resonant converter is capable of both step-up and step-down operation. This capability can be observed in the voltage conversion ratio curves of the series-parallel resonant converter as shown in Figure. 3.

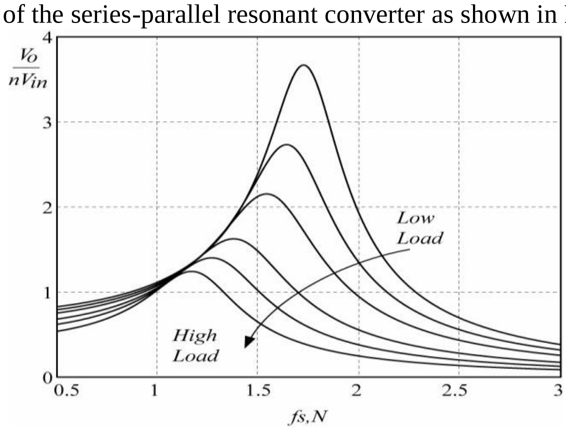

Figure. 3Voltage conversion ratio of a series-parallel resonant converter independency on the load and on the normalized switching frequency

The voltage conversion ratio curves also show that the output voltage can be regulated at no load. Thus, the main disadvantage of the series resonant converter is successfully eliminated with this configuration. It is important to note that the lower the value of the parallel resonant capacitor Cp the more the circuit will have the characteristic of a series resonant converter. Therefore, the value of the parallel resonant capacitor Cp may not be too low in order to permit that the converter takes the characteristic of the parallel resonant converter at light load. When the resonant current flows for a long interval of the switching period through Cp (and this is the case at light load operation), it is increased above the level expected in the series resonant converter, producing a higher output voltage. Therefore, the presence of Cp in combination with Ls results in boosting of the converter output voltage at light load.

IV. SIMULATION RESULTS

4.1 Open Loop System

The performance analysis of the proposed Open loop LCLC resonant power converter has been tested with MATLAB/Simulink software platform. Simulation circuit diagram of LCLC Resonant DC-DC Converter is shown in Figure.4.1. The driving pulses for the MOSFETs were shown in Figure.4.2. The transformer primary voltage is shown in Figure.4.3. The DC input voltage is 20V was shown in Figure.4.4. The output voltage and current of this converter were shown in Figure.4.5 and Figure.4.6. It is observed that the output voltage and current for this converter are 32 Volts and 4.6 Amperes.

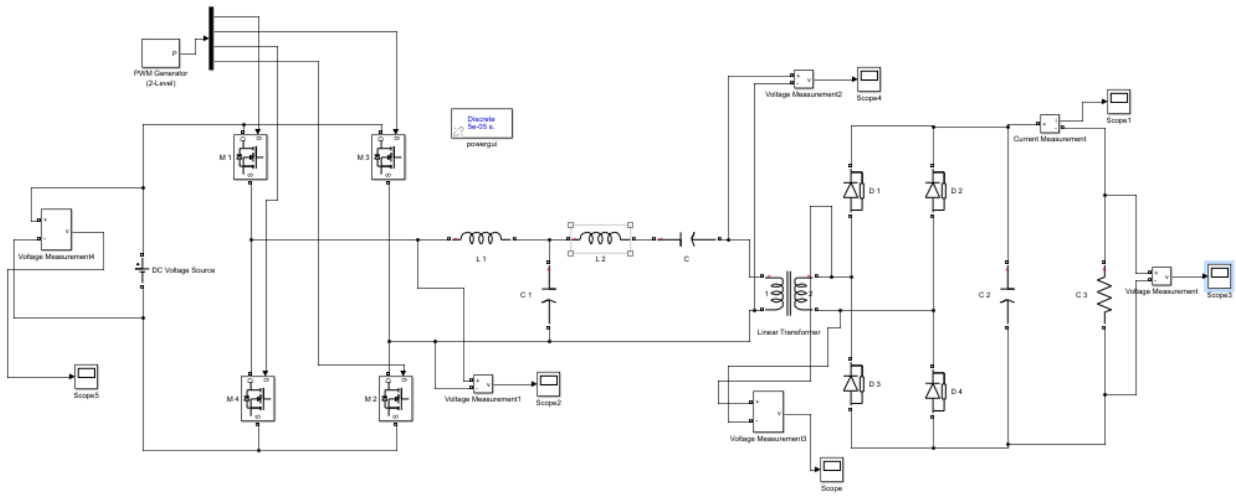

Figure.4.1 Simulation Circuit Diagram for open loop LCLC Resonant Converter

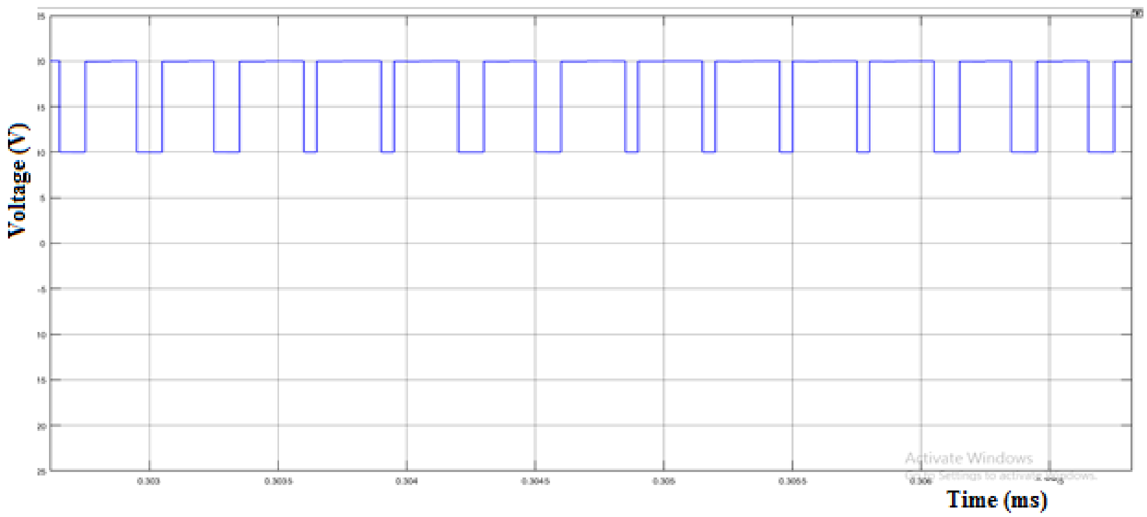

Figure.4.2 Driving Pulses for the MOSFETs

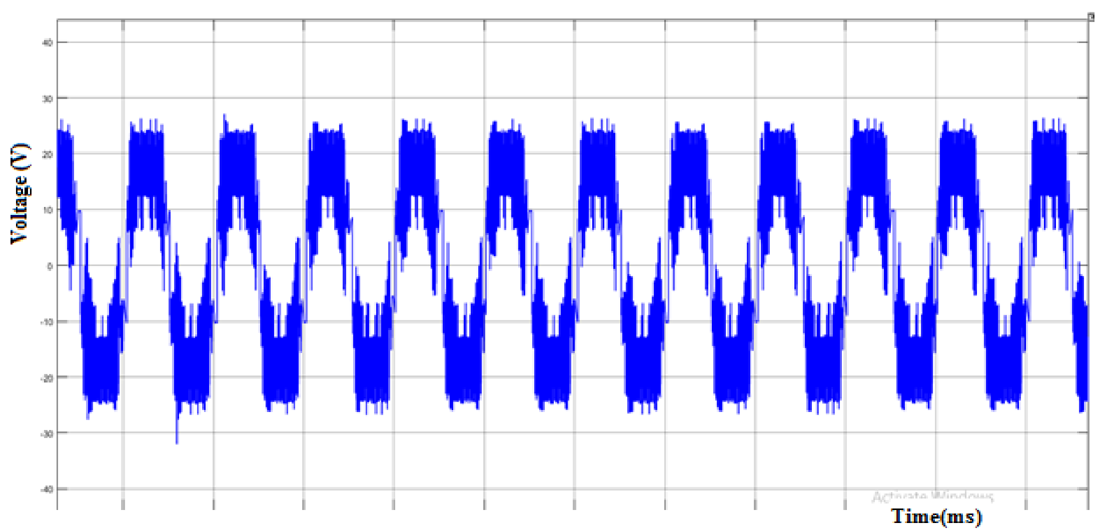

Figure. 4.3 Primary Voltage of the Transformer

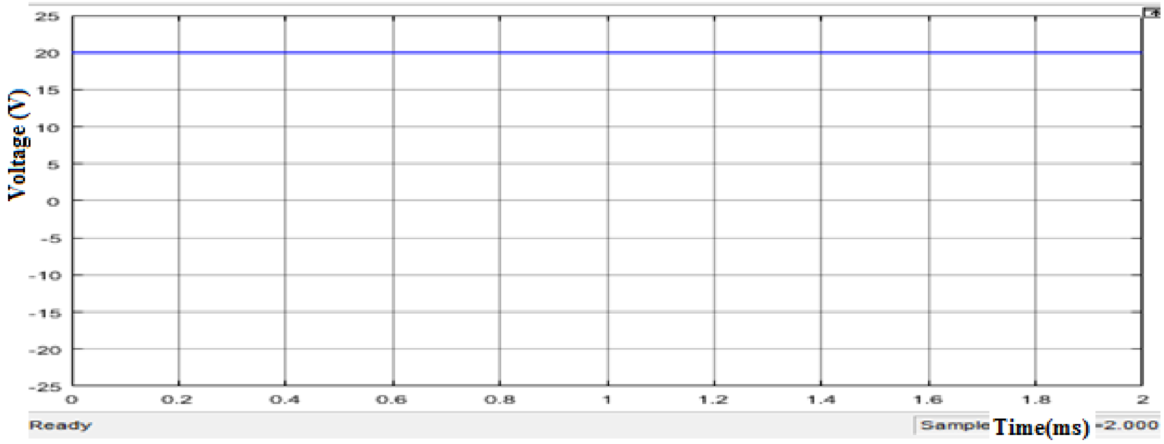

Figure. 4.4 Input Voltage

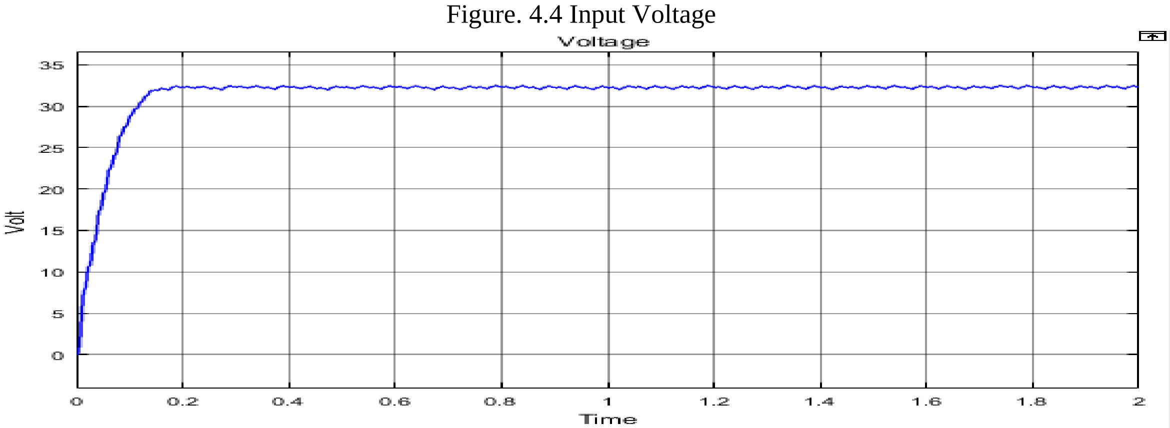

Figure.4.5 Output Voltage Waveform of Open Loop System

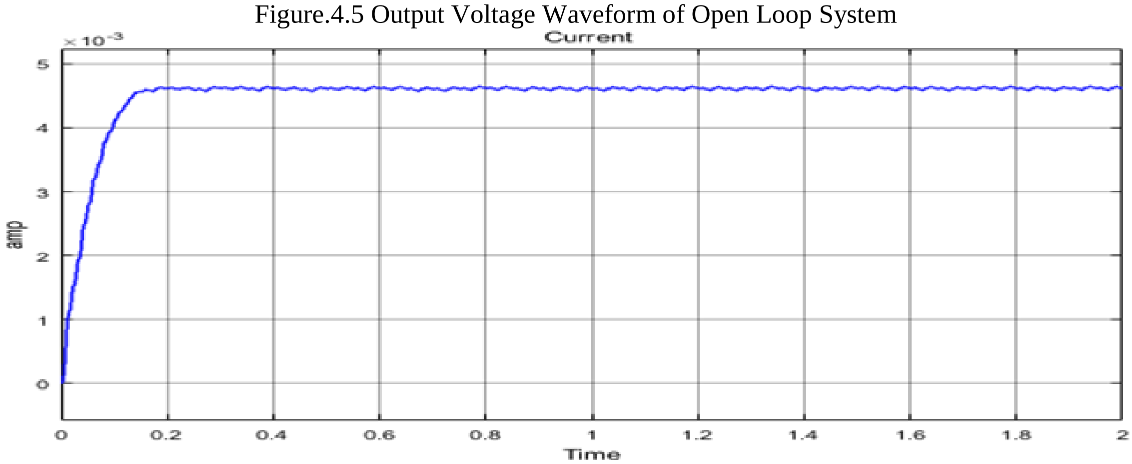

Figure.4.5 Output Current Waveform of Open Loop System

4.2 Closed Loop System For Different Controllers

LCLC Closed loop system has been designed for PI controller for reducing the steady state error. Here it has been compared with the different types of controllers like P and PID with respect to the steady state error. The Figure. 4.6 show the closed loop system of P controller circuit diagram. The output voltage and current waveforms were shown in theFigure.4.7 and 4.8. It reaches the steady state condition quickly. Figure.4.9 shows the circuit diagram of closed loop system with PI controller. The output voltage and current waveforms were shown in the Figure.4.10 and 4.11. It is observed that the steady state error is reduced. The closed loop system with PID controller is shown in Figure.4.12. The output voltage and current waveforms were shown in the Figure.4.13 and 4.14. It observed that the steady state error and the settling time are reduced.

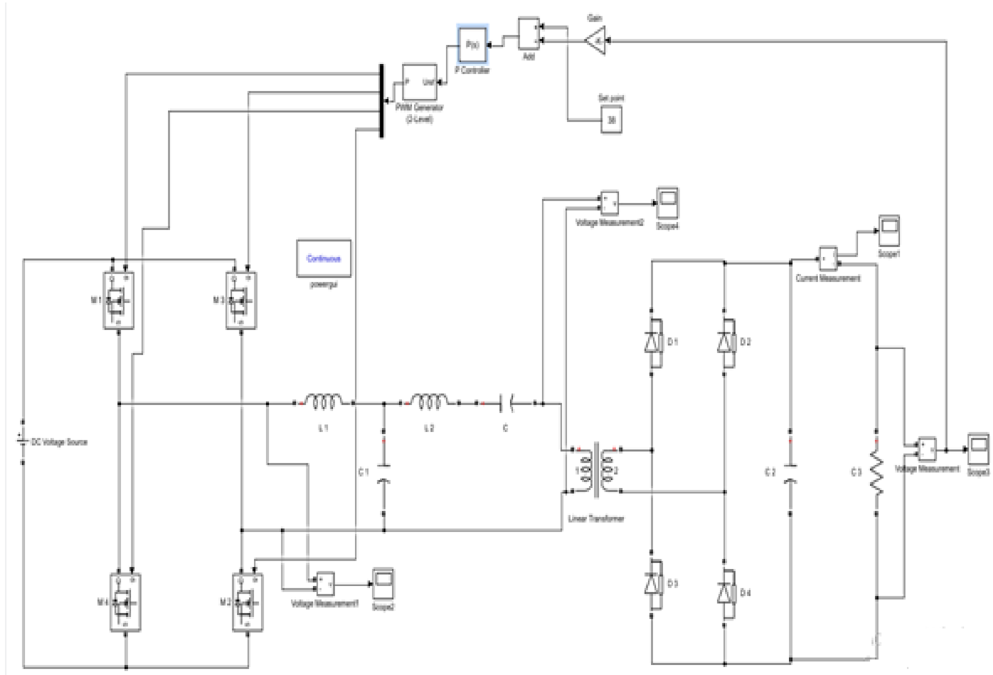

Figure.4.6 Closed Loop System with the P Controller

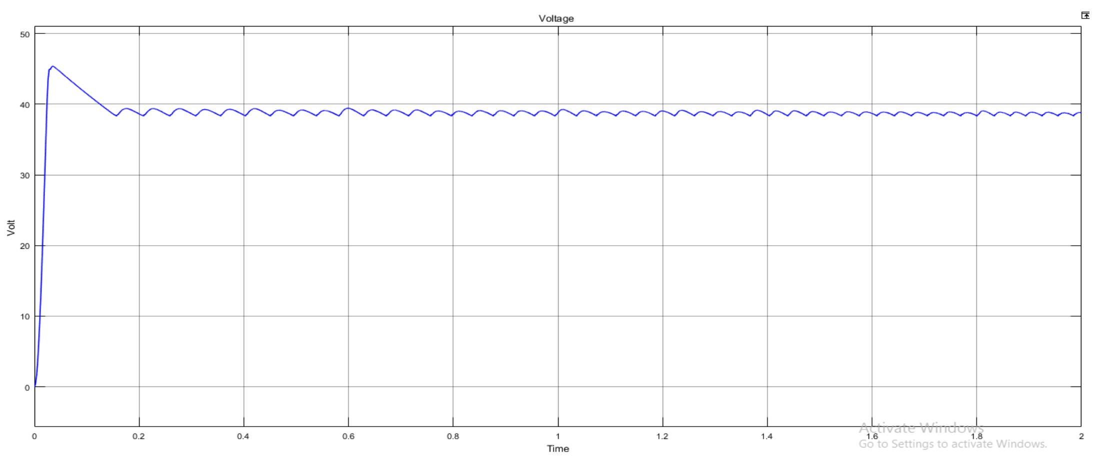

Figure.4.7 Output Voltage Waveform with the P Controller

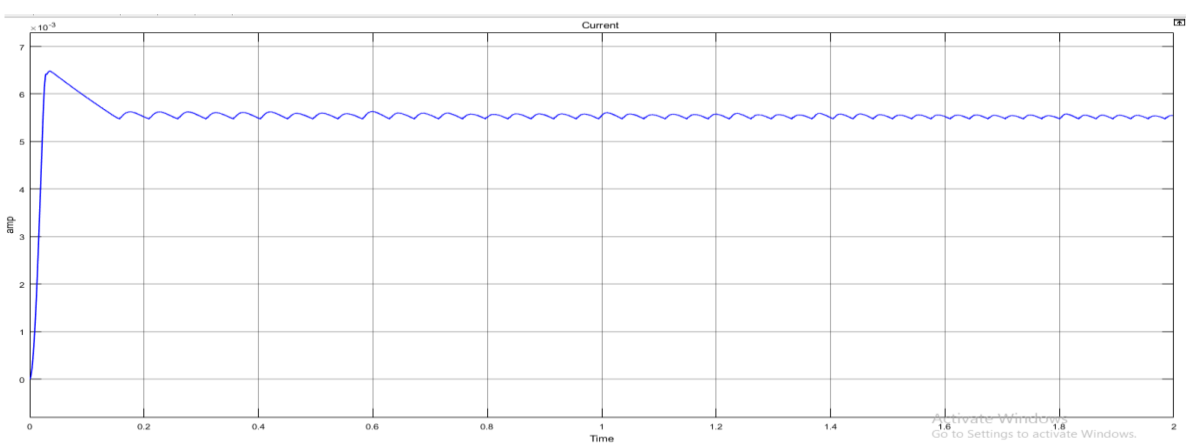

Figure.4.8 Output Current Waveform with the P Controller

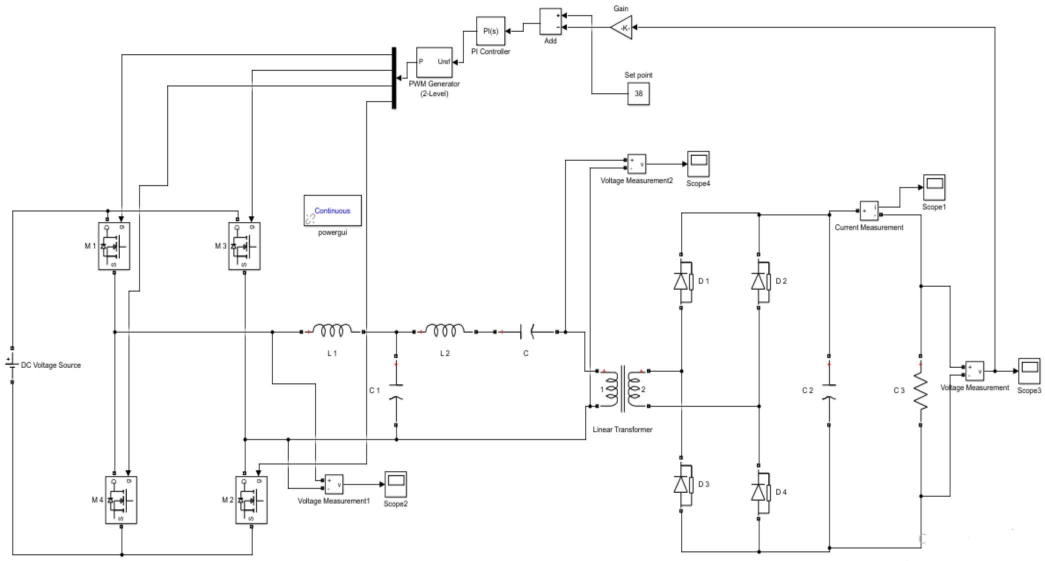

Figure.4.9 Closed Loop System with the PI Controller

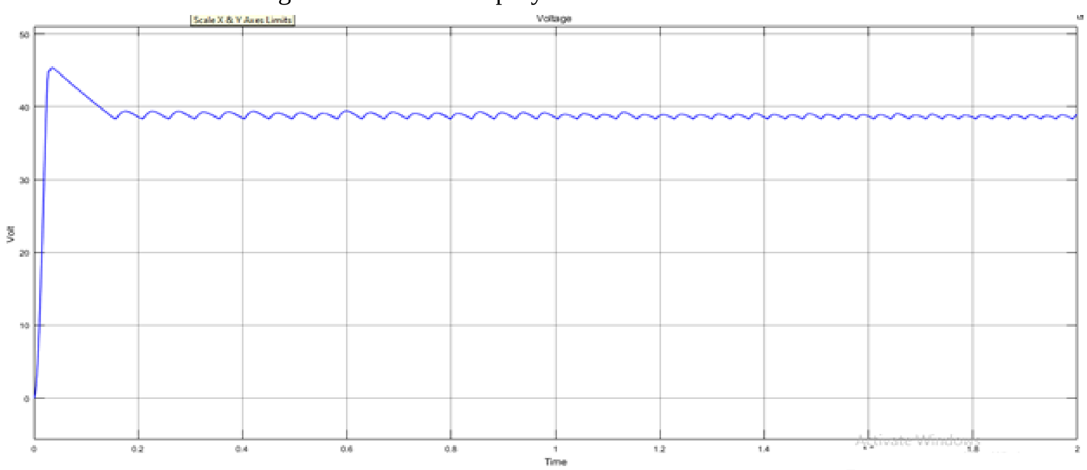

Figure.4.10 Output Voltage Waveform with the PI Controller

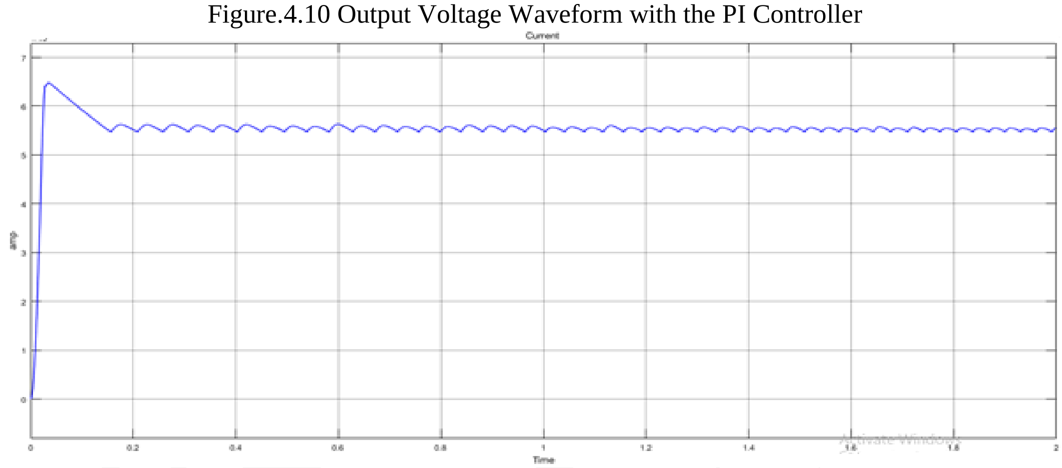

Figure.4.11 Output Current Waveform with the PI Controller

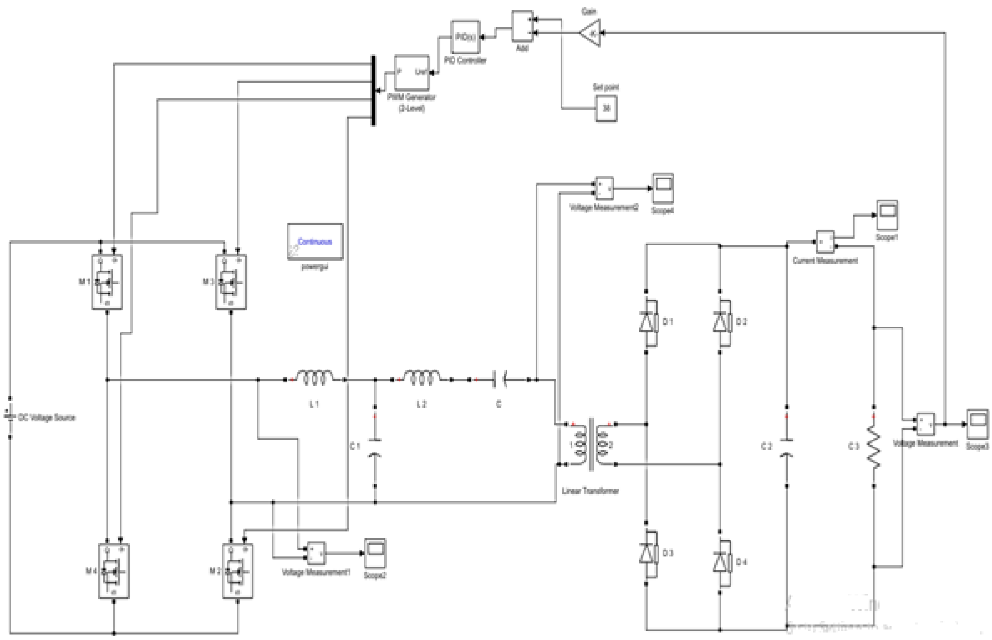

Figure.4.12 Closed Loop System with the PID Controller

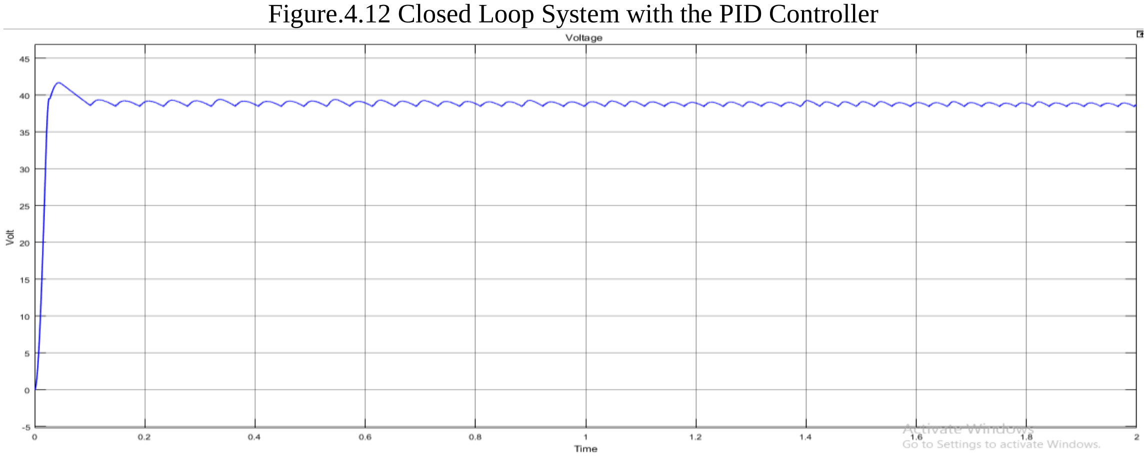

Figure.4.13 Output Voltage Waveform with the PID Controller

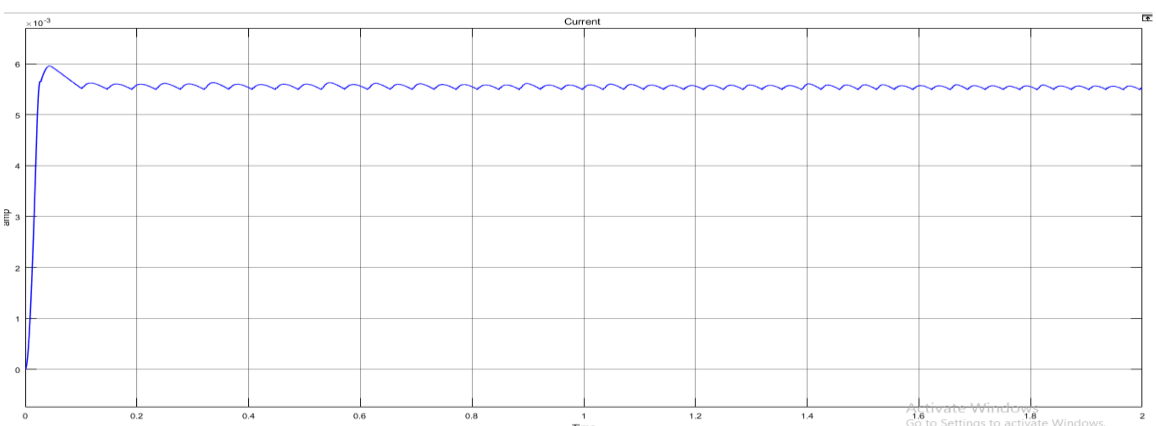

Figure. 4.14 Output Current Waveform with the PID Controller

V. COMPARISON OF CLOSED LOOP RESPONSE FOR DIFFERENT CONTROLLERS

The comparison of closed loop response of LCLC converter system with P, PI and PID controllers is given in Table 4.1. The settling time with PID controller is 7% less than that of PI controller and 17% less than P controller system. The steady state error with PID controller is 5% less than that of PI controller and 10% less than P controller system. Therefore, PID controller is preferred for closed loop system instead of P and PI controllers.

Table 4.1 Comparison of Closed Loop Response for Different Controllers

Controllers	Delay Time (Td)	Rise Time (Tr)	Settling Time (Ts)	Peak Time (Tp)	Max Over shoot Voltage (Mp)	Steady state Error (Ess)
P	0.017	0.252	0.25	0.042	0.114	0.020
PI	0.015	0.024	0.15	0.040	0.090	0.015
PID	0.014	0.023	0.08	0.034	0.052	0.010

VI. CONCLUSION

Open loop and closed loop controlled LCLC type Resonant DC-DC converter fordifferent controllers is designed, modeled and simulated by MATLAB Simulink. Thisconverter is popular due to reduced EMI, reduced stresses and high power density. The closed loop system is found to regulate the output voltage for step change in input at different instants. The output voltage and current are obtained using zero voltage and zero current switching time using different controllers. From the simulation results, it is apparent that the proposed LCLC resonant power converter has reached its steady state response without any oscillations with implementation of PID controller. From the results the PID controller is preferred for closed loop systems.The output voltage control using DC-DC converter system can also do by neuralnetwork and genetic algorithm, to obtain better response.

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