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Performance analysis of Multiple Energy Storage Element Resonant Power Converters

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ABSTRACT:A steady-state design of Multiple Energy Storage Element Resonant Power Converters is presented. The method uses a set of Prederived equations for a two-inductor two-capacitor series parallel resonant converter (LLCC-SPRC). Although four-tank elements are present in an LLCC-SPRC, only two ratios of the tank elements are needed during the design. The values of the four-tank elements can be found from the aim outcomes.An open loop Multiple Energy-Storage Element Resonant converter with LCLC configuration has been simulated and presented in this report.The operation of proposed converter has been estimated with the open loop condition. The proposed approach is expected to provide better voltage regulation for dynamic load conditions.

KEYWORDS: Resonant Converter, Multi energy storage element, LCLC configuration.

I.INTRODUCTION

In recent years the design and development of various DC-DCResonant Converters (RC) have been focused on telecommunication andaerospace applications. It has been found that these converters experiencehigh switching losses, reduced reliability, electromagnetic interference (EMI)and acoustic noise at high frequencies. The series and parallel ResonantConverter (SRC and PRC respectively) circuits are the basic resonantconverter topologies with two reactive elements. The RC is found to besuitable, due to various inherent advantages. The merits of SRC include betterpower conversion efficiency due to the series capacitor in the resonantnetwork and the inherent dc blocking capability of the isolation transformer.However, the load regulation is poor and output-voltage regulation at no-loadis not possible by switching frequency variations. On the other hand, PRCoffers better no-load regulation but suffers from poor power conversionefficiency due to the lack of a dc blocking element before the isolationtransformer. Hence a RC with three reactive components is suggested forbetter regulation.

II.LITERATURE SURVEY

The developments related to the study, research and applications ofresonant converters are increasing now-a-days because of their outstandingperformance. The researches in this field have been shown more interest bymany researchers focused for telecommunication and aerospace applications.

Forward DC-DC converter topologies have demonstrated in [1-3]. The majordisadvantages of two-switch forward converters are hard switching and thelarge filter inductor. Hard switching leads to high switching loss for highfrequency operation. In addition, the voltage-second on the output inductor ismuch higher in two-switch- forward converters than in half-bridge and full bridgeconverters. Because of these penalties, two-switch forward convertersare not very desirable for meeting higher efficiency.

In [4-13] has demonstrated soft-switching techniques for PWM full bridgeconverters. The major problems of this converter are the high circulatingcurrent during normal operation and a large amount of conduction loss. In [14] a range winding approach is proposed to dealwith the settling time operation problem. The concept of a range windingsolution is to change the transformer turns ratio according to different inputvoltages, so that the transformer can be optimized for high input voltage.

In [15], a holdup time extension circuit is proposed todeal with the holdup time operation problem. The concept of the holdup timeextension circuit is to employ an additional DC-DC boost type converter forthe higher voltage gain required for holdup time.To solve the holdup time issue in buck-type PWM converters,boost-type PWM converters are proposed in [16]. The dual activeboost converter (DAB) can achieve ZVS and be designed optimally atnominal conditions. During holdup time, due to the boost gain function, DABcan achieve enough gain. Thus, the isolated boost converter can achievehigher efficiency than conventional buck-type PWM converters.However, the drawbacks of the isolated boost converter are theZVS is lost at light load, the primary side switch turn-off current is relativelyhigh, and hence leads to relatively high turn-off switching loss.

The LCL tank circuit based DC-DC resonant converter has beenexperimentally demonstrated with open loop by [17-20]. A three element LCL resonant converter capableof driving voltage type load with load independent operation is analyzedusing state space approach. The operation of the converter with variablefrequency control was reported. In [21] has experimentally demonstrated an LCL load resonant inverter for inductive power transfer applications is investigated.

In [22] have experimentallydemonstrated the open loop series parallel resonant converter withindependent load operated at resonant frequency. The converter was operatedin Discontinuous Current Mode of (DCM) operation and the performancecharacteristics are presented. The converter was analyzed using the statespace approach and optimized for peak component stresses. Thecharacteristics curves were obtained using the PROMATLAB and SPICEsimulation. The performance of the designed converter for variations insupply voltage as well as load were studied and presented.

In [23] has experimentally demonstrated modifiedasymmetrical pulse width modulated resonant DC–DC converter topology.Borage et al [24] have demonstrated the open loop LCL-Tresonant converter with constant current output fed with resistive load. TheA.C. analysis is used to drive the voltage and current rating of thecomponents, converter gain and component stresses. It was found that theconverter exhibits load-independent voltage and current gain at resonantfrequency. Various methods for the control of output current over wide loadrange and against variation in input dc voltage are presented.

Borage et al [25-26] has developed the LCL-Thalf bridge resonant converter operated in constant current power supply. TheLCL-T half bridge resonant converter with clamp diodes was described andsimulated results demonstrating inherent constant current-constant voltagecharacteristics of the converter were presented. The output current / voltageare sensed for every change in load due to the output voltage or current whichincrease linearly. In this case, the feedback control circuit has not beenconsidered.

Mangesh Borage et al [27] has demonstrated design of LCL-Tresonant converter including the effect of transformer winding capacitanceand Borage et al [28] has demonstrated the characteristics of asymmetricalduty cycle controlled LCL-T resonant converter using state space model. Fourdistinct operating modes were identified and operated in different conditions.The zero voltage switching operation has been used to operate the switches inthe asymmetrical duty cycle control and clamped mode control. Thesecontrollers are derived and compared with the performance.

The series parallel resonant converter operated in both thecontinuous capacitor voltage mode and the discontinuous capacitor voltagemode has been demonstrated and presented using state space approach in [29-33]. The closed-form expressions arederived for steady-state operation, converter gain, peak component stressesand their ratings. An optimization procedure with a design example has beenpresented. It was observed that the optimum point lies in the discontinuouscapacitor voltage mode.

Sivakumaran and Natarajan [34] have demonstrated a CLC seriesparallel resonant converter using FLC which regulates the output voltage ofSeries parallel resonant converter (SPRC) for the load regulation and lineregulation. The performance of controller has been evaluated and found thatthe load independent operation may not be possible.

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 [35]. This topology employs more parasitic elements and has many desirable features.Thus, it appears to be a serious prospect for high voltage conversion [36]. The converter of this topology uses an inductive output filter similar to a Parallel Resonant Converter (PRC) [37-38]. In [39] 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 [36].

It is obvious from the above literature that the output voltage regulation of the converter, against load and source side disturbances, has important role in designing high-density power supplies.The Resonant Converter is expected to have fast response, better voltage regulation and improved load independent operation.Motivated by these facts, the Resonant Converter has been modelled and analysed for estimating various responses.The closed loop models have been simulated using MATLAB/Simulink.

III.RESONANT CONVERTER

Resonant converters are switching converters that include a tank circuit actively participating in determining input-to-output power flow. The working rule is founded along the characteristic gain curve of the resonant tank", which allows to convert the gain by a moderate variation of the alternating frequency, therefore resulting in an effective regulation of output voltage or current in relation to load and input voltage changes. Resonant power converters contain resonant L-C networks whose voltage and current waveforms vary sinusoidally during one or more subintervals of each switching period.

Multiple energy-storage element resonant power converters (x-element RPC) are the sixth generation converters. As the transfer power becomes higher and higher, traditional methods are unable to deliver large amounts of power from the source to the final actuators with high efficiency. In order to reduce the power losses during the conversion process the sixth generation converters multiple energy-storage elements resonant power converters (x-element RPC), were created. They can be classified into two main groups.

- DC/DC resonant converters
- DC/AC resonant inverters

Both groups consist of multiple energy-storage elements: two, three, or four elements. These energy-storage elements are passive parts: inductors and capacitors. They can be connected in series or parallel in various methods. If no restriction such as 2 L -2C for four-element RPC, the number of the topologies of four-element RPC can be very large. Although these topologies have comparable complex circuit structures, they can still transfer the power from source to end-users with higher power efficiency and lower power losses. Usually, the four-element RPC has a wide response frequency band, which is defined as the frequency width between the two half-power points. If the circuit is a low-pass filter, the frequency bands can cover the frequency range from 0 to the high half-power point, which is definitely higher than the natural resonant radian frequency.

$$\omega_o = 1/\sqrt{LC} \qquad (1)$$

The working point can be selected in a wide area across (lower and higher than) the natural resonant radian frequency. Fig. 1 shows a Multiple Energy-Storage Element Resonant converter with LCLC configuration.

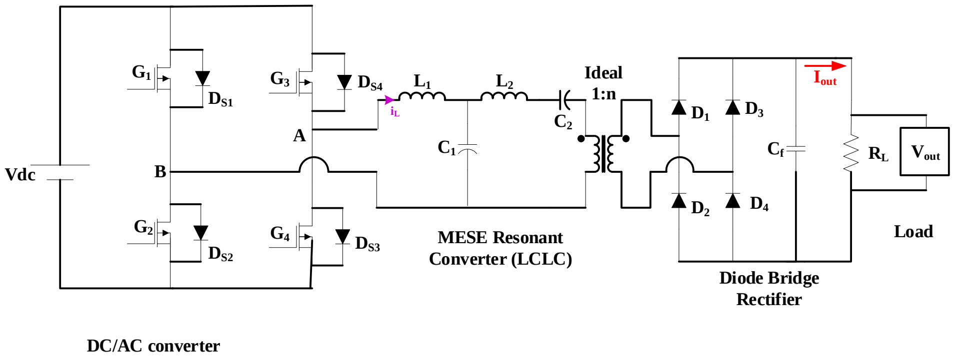

Fig. 1 Multiple Energy-Storage Element Resonant converter with LCLC configuration

IV. MODELLING OF PROPOSED LCLC RESONANT CONVERTER

The equivalent circuit of LCLC resonant converter is shown on in Fig. 1. The mathematical model using obtained assuming all the components to be ideal.

The state space equation for the proposed converter is given by

$$\dot{X} = AX + BU \tag{2}$$

Where,

$$\dot{X} = \frac{d}{dt}\begin{bmatrix} iL_1 \\ vC_1 \\ iL_2 \\ vC_2 \end{bmatrix}, \quad X = \begin{bmatrix} iL_1 \\ vC_1 \\ iL_2 \\ vC_2 \end{bmatrix}, \quad U = \begin{bmatrix} V_i \\ V_o \end{bmatrix}$$

The state space equation for LCLC resonant converter is get from Fig.1.

$$\frac{diL_1}{dt} = m\frac{V_i}{L_1} - \frac{vC_1}{L_1} \tag{3}$$

$$\frac{dvC_1}{dt} = \frac{1}{C_1}\left(iL_1 - iL_2\right)$$

$$\frac{diL_2}{dt} = \frac{1}{L_2}\left(vC_1 - vC_2\right)$$

$$\frac{dvC_2}{dt} = n\frac{V_o}{C_2} - \frac{iL_2}{C_2}$$

From equations (2) and (3), we can get,

$$\frac{d}{dt}\begin{bmatrix} iL_1 \\ vC_1 \\ iL_2 \\ vC_2 \end{bmatrix} = \begin{bmatrix} 0 & -\frac{1}{L_1} & 0 & 0 \\ \frac{1}{C_1} & 0 & -\frac{1}{C_1} & 0 \\ 0 & \frac{1}{L_1} & 0 & -\frac{1}{L_2} \\ 0 & 0 & -\frac{1}{C_2} & 0 \end{bmatrix} \begin{bmatrix} iL_1 \\ vC_1 \\ iL_2 \\ vC_2 \end{bmatrix} + \begin{bmatrix} -\frac{1}{L_1} & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & -\frac{1}{L_2} \end{bmatrix} \begin{bmatrix} V_i \\ V_o \end{bmatrix} \tag{4}$$

From equation (4), we get,

$$A = \begin{bmatrix} 0 & -\frac{1}{L_1} & 0 & 0 \\ \frac{1}{C_1} & 0 & -\frac{1}{C_1} & 0 \\ 0 & \frac{1}{L_1} & 0 & -\frac{1}{L_2} \\ 0 & 0 & -\frac{1}{C_2} & 0 \end{bmatrix}, B = \begin{bmatrix} -\frac{1}{L_1} & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & -\frac{1}{L_2} \end{bmatrix}$$

V.SIMULATION AND DISCUSSION OF LCLC RESONANT CONVERTER

The performance analysis of the proposed LCLC resonant power converter has been tested with MATLAB/Simulink software platform. Zero voltage and Zero current switching time are obtained through simulation for the proposed converter. The Simulink diagram of the LCLC resonant power converter is shown in Fig.2. The simulated results are shown in Figs. 3-8.

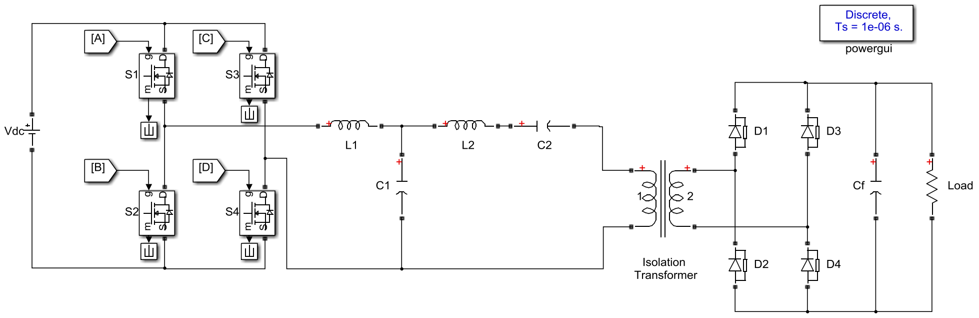

Fig. 2 Matlab Simulink model of the proposed LCLC Resonant converter

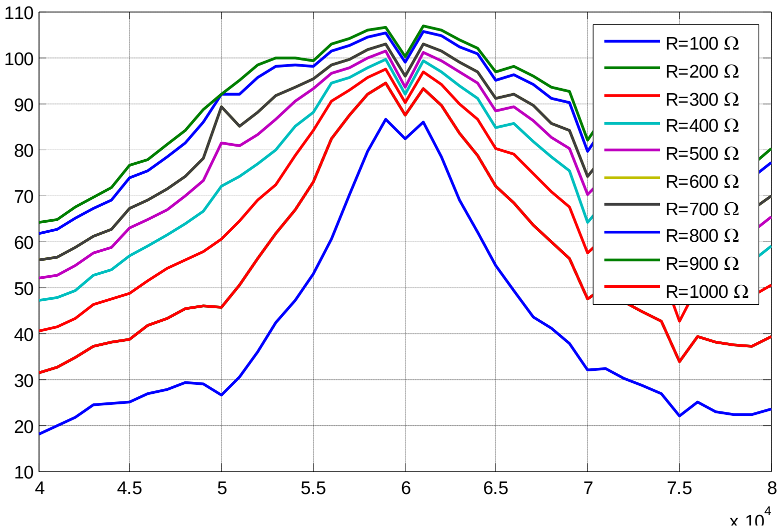

Fig. 3: Frequency Vs gain response of LCLC Resonant Converter for different Load Conditions

When the switching frequency is higher than resonant frequency, the voltage gain of LCLC converter is always less than one, and it operates as a resonant converter and zero voltage switching (ZVS) can be achieved. When the switching frequency is lower than resonant frequency, for different load conditions, both ZVS and zero current switching (ZCS) could be achieved. At the boundary of ZVS and ZCS regions, as shown in the dashed line in Figure 3, converter voltage gain reaches it's maximum value. The responses show optimum frequency and gain value are 59 kHz and 86.44 respectively.

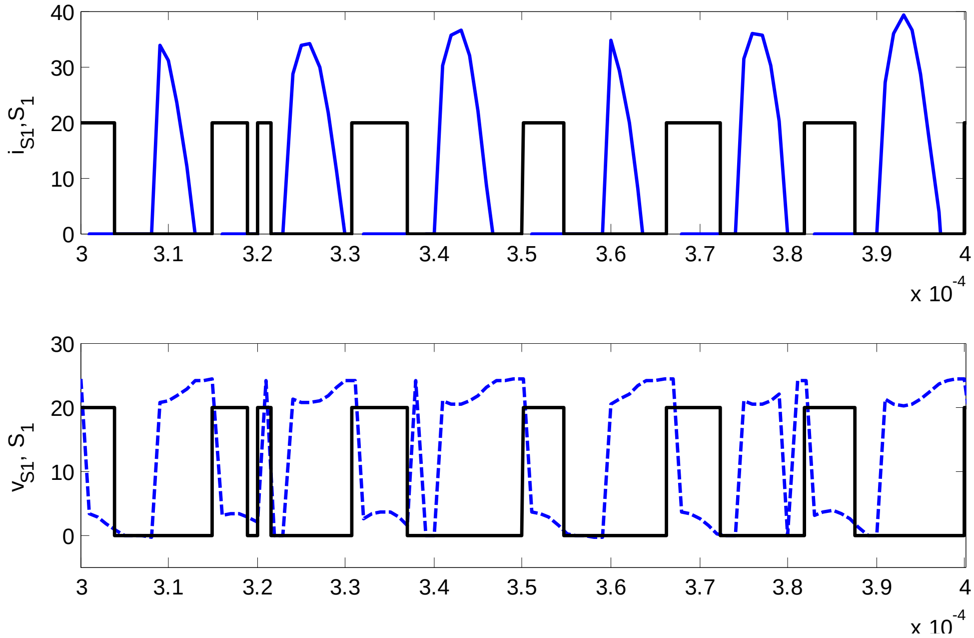

Fig. 4: Zero current Switching and Zero Voltage switching response of switch S1 of the resonant converter

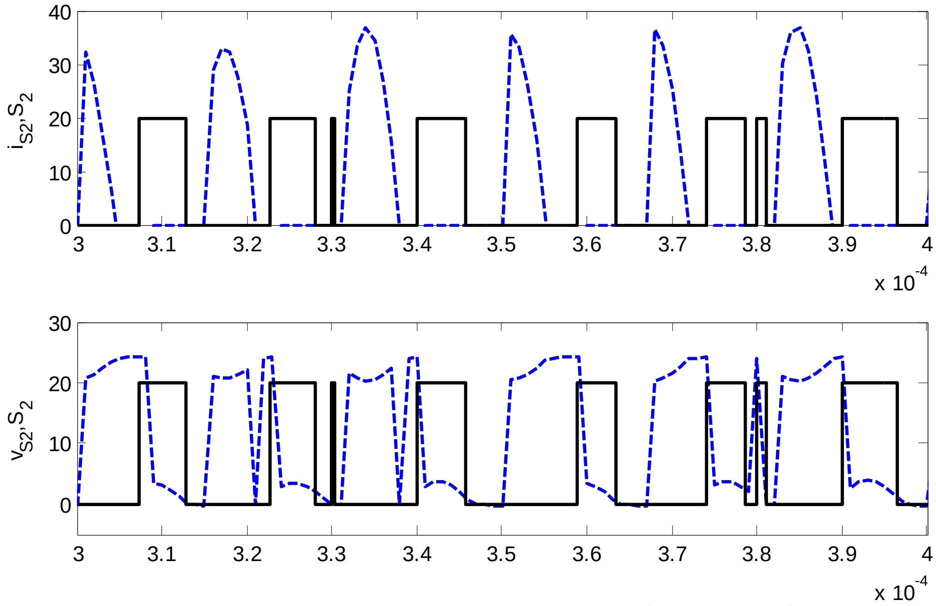

Fig. 5: Zero current Switching and Zero Voltage switching response of switch S2 of the resonant converter

Fig.4 shows the zero voltage and zero current switching responses of switch S1 of the LCLC resonant power converter. Similarly the zero voltage and zero current switching responses of switch S2 is shown in Fig.5.

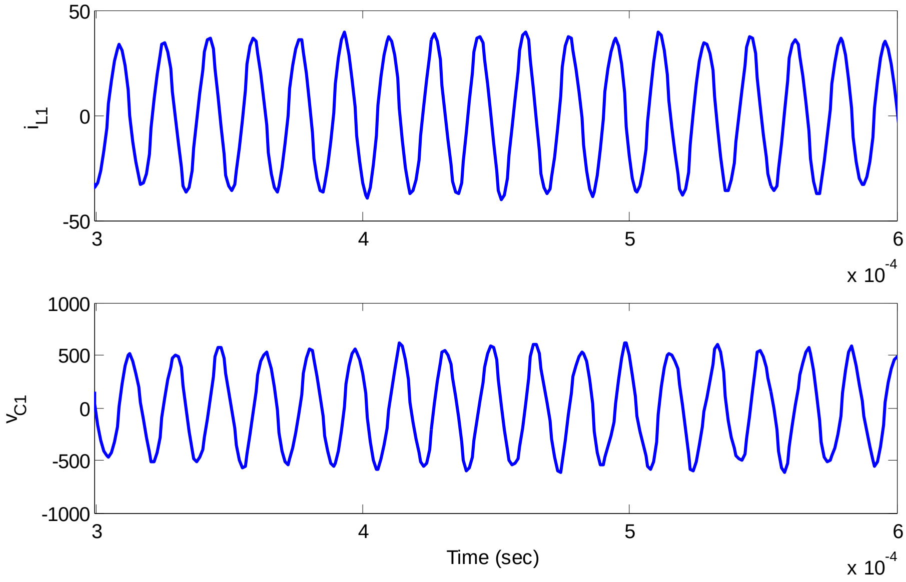

Fig. 6: Current and Voltage response of resonant Inductor L1 and Capacitor C1

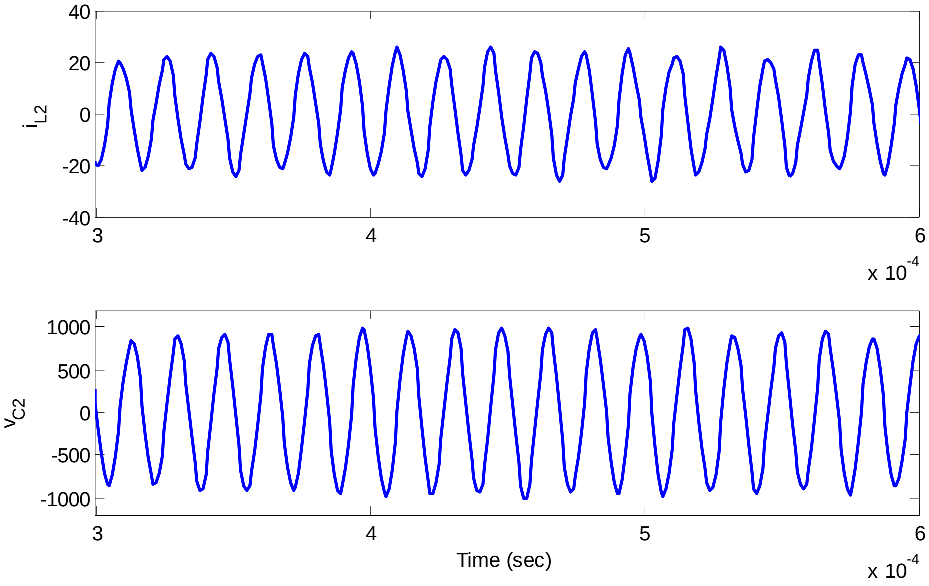

Fig. 7: Current and Voltage response of resonant Inductor L2 and Capacitor C2

Figs. 6 and 7 shows the voltage and current flow through the resonant inductors L1, L2 and capacitors C1, C2. From the figure, it is observed that the maximum current flow through the resonant inductors L1 is 30A and L2 is 20A, and the voltage across the resonant capacitors C1 is 500V and C2 is 800V approximately.

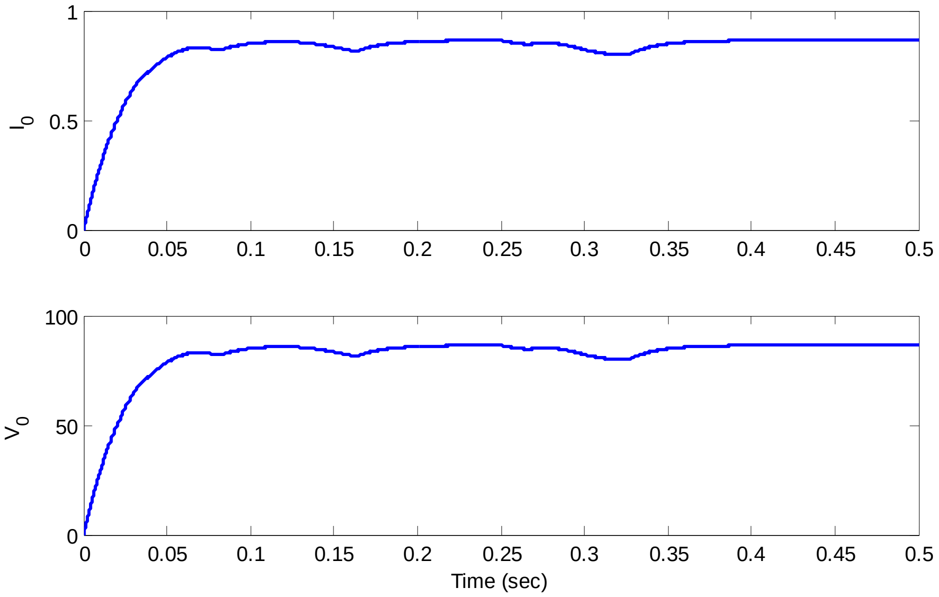

Fig. 7: Output Voltage and current response of proposed LCLC resonant Converter

Fig.8 shows the output voltage and current waveforms of the proposed LCLC resonant converter. From the figure 8, it is observed that the voltage and current of the converter reached its steady state at 0.4 Sec with output voltage at 80V.

VI.CONCLUSION

In this paper, a new LCLC configuration is proposed by using state space analysis. The output voltage and current are obtained using zero voltage and zero current switching time. The steady state analysis is examined through a simulation and proven its accuracy.

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