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Resonant Converter for the Application of DC-To-DC Energy Conversions

Ramesh Halakurki[1], Ramesh Gollapalli[2]

Professor, Dept. of EEE, Sreenivasa institute of technology and management studies, Chittoor, Andhra Pradesh, India[1]

PG Student, Dept. of EEE, Sreenivasa institute of technology and management studies, Chittoor, Andhra Pradesh, India[2]

ABSTRACT: Resonant power conversion has many advantages over conventionally adopted pulse-width modulation, which are, low electromagnetic interference, low switching losses, small volume, and light weight of components due to a high switching frequency, high efficiency, and low reverse recovery losses in diodes results to a low di/dt at switching instant. So, this resonant converter is used for direct current (dc)-to-dc energy conversion applications. The proposed resonant converter topology comprises a half-bridge inductor-capacitor-inductor (L-C-L) resonant inverter and a diode bridge rectifier. Then, the output stage of resonant converter is filtered by using low-pass filter. The measured energy conversion efficiency of the resonant converter reaches up to 88.3%. Capacitor-inductor-capacitor(C-L-C) resonant converter is more preferable than the L-C-L resonant converter; because of, it improves the energy conversion efficiency and also reduces the equipment cost. The efficiency of C-L-C resonant converter is up to 93%. Moreover, test results demonstrate a satisfactory performance of the resonant converter. Furthermore, the proposed converter is highly promising for applications of power electronic productions such as switching power supplies, battery chargers, uninterruptible power systems, renewable energy generation systems, and telecom power supplies.

KEYWORDS: Resonant inverter, diode bridge rectifier, L-C-L and C-L-C resonant tanks.

I.INTRODUCTION

DC-DC converter is a class of power converters. It converts a DC source of certain level of voltage to another dc voltage level. And also, DC-DC converter can regulate the output voltage. Dc to dc converter are generally operates in two conversion methods; one is linear mode conversion and another one is switched mode conversion. Linear regulators can only gives the output at lower voltages from the input. Linear regulators are very inefficient when the current is high corresponding voltage drop is more and as they dissipate heat, that is equal to the product of the output current and the voltage drop; due to this reasons normally they are not used for large-drop high-current applications. Switched-mode DC to DC converter converts one level of DC voltage to another level, by storing the input energy temporarily at one voltage and then releasing that energy to the output at a different voltage. The storage may be in either magnetic field storage components such as inductors, transformers or electro static field storage components which are capacitors. This conversion method is more efficient than linear mode voltage regulation, up to 75% to 98%. This efficiency is very useful to increasing the running time or operation time of the battery operated devices.

In power energy conversion applications, switching power converter plays a significant role. These, direct current (dc)-to-dc converters are morally adopted in industrial, commercial, and residential equipment. Most of the inverters available now days in the market utilize the PWM (Pulse Width Modulation) technology. PWM based inverter technologies are most superior in many factors compared to other inverters designed by using conventional technologies. In practical analysis, in which the voltage across or current through the semiconductor switch is abruptly interrupted is termed as a hard-switched PWM. Hard switched PWM schemes have been largely adopted in modern power energy conversion applications, because of its simplicity and ease in control.

Higher switching frequency implies that the smaller and lighter weight inductors, capacitors and filter components of these converters. With an increasing of switching frequency, electromagnetic interference (EMI) and switching losses are increases, ultimately the efficiency and performance of dc-to-dc power converters are decreases.

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To solve these above problems, some soft switching approaches must be operates under a high switching frequency. There are two commonly used soft switching methods, one is Zero voltage switching and other one is zero current switching schemes, in which either the voltage or current is zero during switching modes, which largely reduces the switching losses and Electro Magnetic Interference (EMI), these also increases power converters reliability.

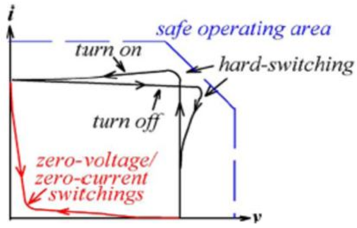

Figure 1 typical switching trajectory of power switches

A soft switching dc-to-dc converter is constructs in cascading fashion a resonant dc-to-alternating current (ac) inverter, resonant tank and a bridge rectifier. The given dc input power is first converted into ac power by the resonant inverter, this ac power is then converted back into dc power by the rectifier.

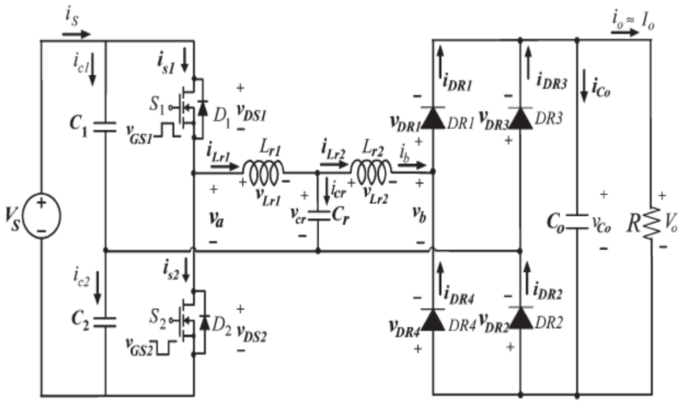

Figure 2 L-C-L resonant converter for a dc-to-dc energy conversion system.

The energy is extracted from a resonant tank; resonant converters can be classified into three categories first is series resonant converter second is parallel resonant converter and final one is series-parallel resonant converters. The resonant inductor L_r and resonant capacitor C_r are in series. The major problems occurs in this series converter has light load regulation, high circulating energy and turn off current at high input voltage condition. The parallel resonant converter is formed with the combination of the capacitor and an inductor and another capacitor is placed across the diode rectifier converter. The major problems in parallel resonant converter has high circulating energy, high turns off current at high input voltage condition. In series parallel resonant converter, the resonant tank of this converter is equivalent to that of the parallel resonant inverter, except for an additional capacitor in series with the resonant inductor. This converter cannot operate safely with a short circuit at a switching frequency close to the resonant frequency and also energy conversion stage of this converter has not been minimized and simplified which results size and cost are more in the applications of dc-to dc energy conversion. From the above three different resonant converter topologies reveals that the parallel resonant converter is the optimum topology for dc-to dc energy conversion applications because of its many advantages including low switching losses, low stresses, and low noise characteristics. So, parallel resonant converter is generally recommended for the dc-to-dc energy conversion applications due to its simple circuitry and typical input characteristics.

II. CIRCUIT DESCRIPTION AND OPERATING PRINCIPLES

Figure 2 shows the L-C-L tank resonant converter for a dc-to-dc energy conversion system, in these two capacitors C_1 and C_2 which are on the input side converter are large and split the dc input voltage into two halves. The elements L_{r1},

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L_{r2}, and C_r are form the T-shaped resonant tank. The given dc input power is first converted into ac power by the resonant inverter, this ac power is then converted back into dc power by using the rectifier circuit. And the load resistance *R* is connected across a bridge rectifier across this low-pass filter capacitor C_o connected to regulate the output.

A. Circuit operating principles

The following analysis assumes that the converter operates in the continuous conduction mode, in which the semiconductors have ideal characteristics. Figure 3 displays the idealized steady state voltage and current waveforms in the proposed L-C-L resonant converter for a switching frequency f_s that exceeds resonant frequency f_o. Operating above resonance is preferred because the power switches turn on at zero current and zero voltage; thus, the freewheeling diodes do not need to have very fast reverse-recovery characteristics.

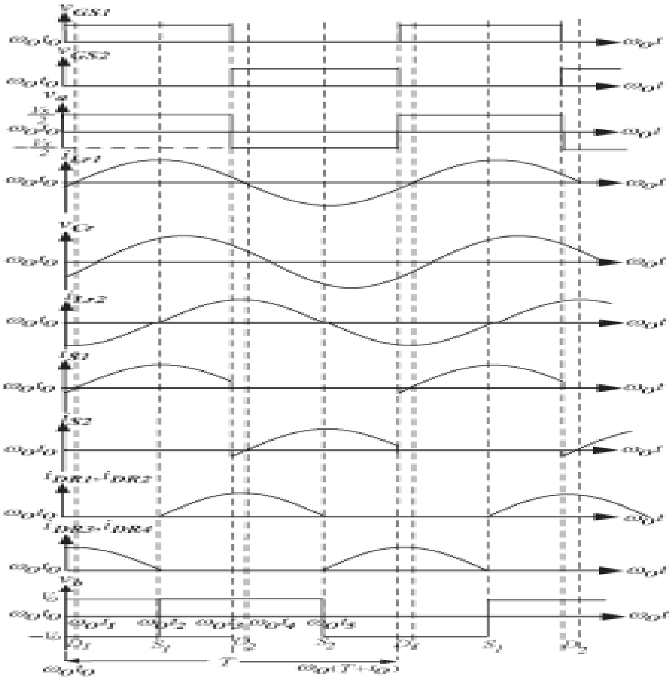

Figure 3 Idealized voltage and current waveforms.

Steady-state operations of the L-C-L resonant converter in a switching period can be divided into four modes.

Mode 1-(Between $\omega_0 t_0$ and $\omega_0 t_1$):

The voltage appears across the resonant energy tank is in between $+V_s/2$ and $-V_s/2$ generates a square-wave voltage across the input terminal. The input voltage to the full-bridge rectifier is V_b when i_{lr2} (*t*) is positive and is $-V_b$ when i_{lr2} (t) is negative. Before $\omega_0 t_0$, the active power switch S_2 is conducts, and the current equals to the resonant tank current $i_{lr1.}$ When the power switch S_1 is turned on at $\omega_0 t_0$, the resonant tank current i_{lr1} is negative and flows through freewheeling diode D_1. At that instant $\omega_0 t_1$, resonant tank current i_{lr2} reverses and naturally commutates from freewheeling diode D_1 to active power switch S_1. Figure 4 shows the mode1 equivalent circuit of the L-C-L resonant converter.

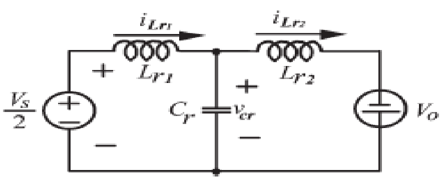

Figure 4 Equivalent circuit of mode I

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Mode 2-(Between $\omega_0 t_1$ and $\omega_0 t_2$):

This mode of operation is starts at $\omega_0 t_1$, when the current i_{lr1} resonant tank resonates from negative values to zero. At $\omega_0 t_2$, the switch S_1 is forced to turn off, the positive current i_{lr1} is flows through the bottom freewheeling diode D_2. Fig.5 shows the equivalent circuit of mode 2.

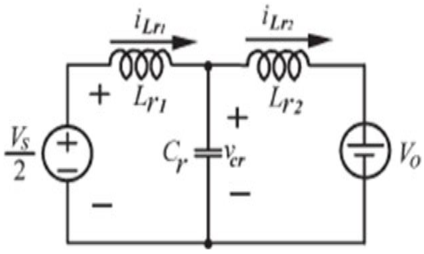

Figure 5 Equivalent circuit of mode 2

Mode 3-(Between $\omega_0 t_3$ and $\omega_0 t_4$):

This mode begins at $\omega_0 t_3$, when diode D_2 is turned on, subsequently producing a resonant stage between inductors L_{r1}, L_{r2} and capacitor C_r. Inductors L_{r1}, L_{r2}, and capacitor C_r resonate. Before $\omega_0 t_4$, gate pulse V_{GS2} excites active power switch S_2. Figure 6 shows the equivalent circuit of mode 3.

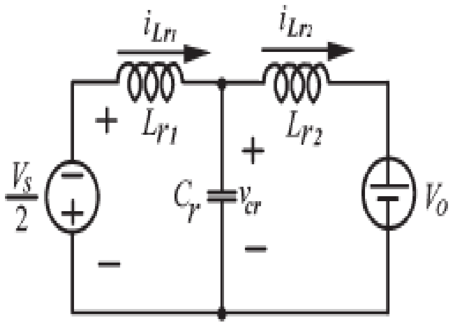

Figure 6 Equivalent circuit of mode 3

Mode 4-(Between $\omega_0 t_4$ and $\omega_0 t_5$):

Whenever the capacitor voltage i_{lr2} is positive, rectifier diodes DR1 and DR2 are turned on with zero-voltage condition at instant $\omega_0 t_4$. Figure 7 shows the equivalent circuit of mode 4. During the positive half-cycle of the inductor current i_{lr2}, the power is supplied to the load through bridge rectifier diodes DR1 and DR2. During the negative half-cycle of the inductor current, the power is supplied to the load through bridge rectifier diodes DR3 and DR4.

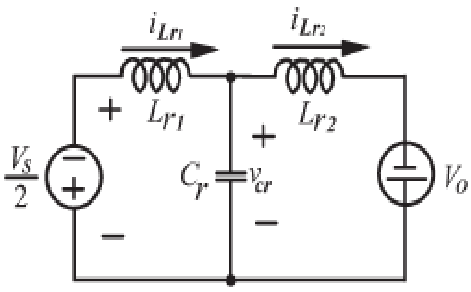

Figure 7 Equivalent circuit of mode 4

III. OPERATING PRINCIPLE OF C-L-C RESONANT CONVERTER

Circuit description of C-L-C resonant converter is same as compared to the L-C-L resonant converter, only the difference is resonant tank. In case of L_{r1}-C-L_{r2} resonant converter, the resonant tank is formed by connecting the

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components in T fashion, where as in C_{r1}-L-C_{r2} resonant converter, the resonant tank is formed by connecting the components in π fashion as shown in figure 8.

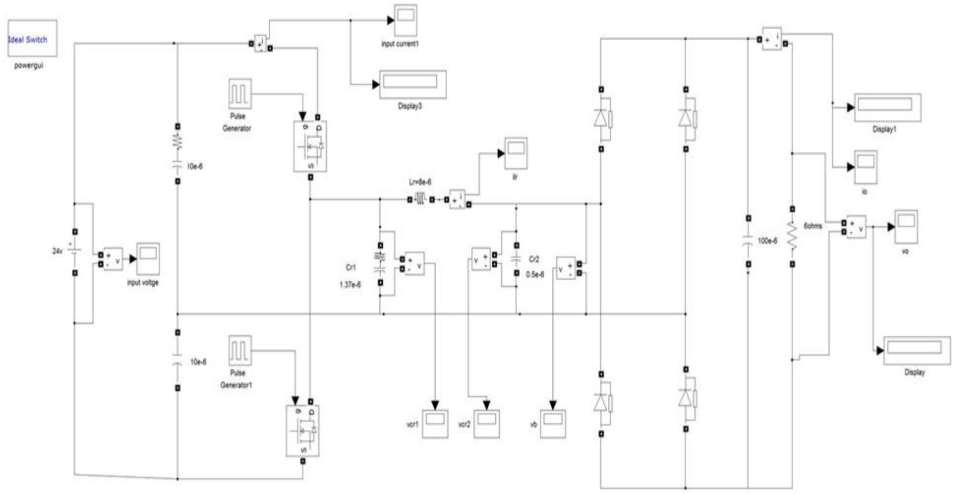

Figure 8 proposed C-L-C resonant converter

Like L-C-L resonant converter, the two capacitors divides the supply voltage into two halves and then the inverter circuit converts the given DC power into AC power, this can be given to the resonant tank. In resonant tank the storage devices stores the energy and then convert this AC power into DC power by using diode bridge rectifier and output can be regulate by using filter capacitor.

IV. OPERATING CHARACTERISTICS

The switching frequency of the active power switches is assumed to be greater than the resonant frequency so that the resonant current is continuous. Since the output voltage is assumed to be a constant V_o, then the input voltage of the bridge rectifier, V_b, is V_o when i_{Lr2} is positive and is $-V_o$ when i_{Lr2} is negative. The resonant converter with a bridge rectifier stage for dc-to-dc energy conversion system is analyzed by considering the fundamental frequency of the Fourier series for the voltages and currents. The error due to this approximation is rather small when the switching frequency is higher than the resonant frequency.

Next, the output voltage V_b of the bridge rectifier can be described by a Fourier series as

$$V_b(t) = \sum_{n=1,3,5...}^{\infty} \frac{4V_0}{n\pi} \sin(n\omega t) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

The fundamental component of voltage V_b is

$$V_{b1} = \frac{4V_0}{\pi} \sin(\omega t) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

The current at the output of the bridge rectifier is the full wave rectified form of inductor current i_{Lr2}. Therefore, the average of the rectified inductor current $|i_{Lr2}|$ equals output load current I_o. If inductor current i_{Lr2} is approximated as a sine wave of amplitude I_{LM1}, the average value of output current I_o is

$$I_0 = \frac{2I_{LM1}}{\pi} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

The fundamental component of input current is

$$I_{LM1} = \frac{\pi I_0}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

The value of output resistance in this equivalent circuit is based on the ratio of voltage to current at the
input terminal of bridge rectifier. The resistance can then be defined as

$$R_e = \frac{V_{b1}}{I_{LM1}} = \frac{8}{\pi^2}.\frac{V_0}{I_0} = \frac{8}{\pi^2}.R \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

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The required component values of L-C-L resonant converter is described in below table1

Input voltage V_s	24 V
Resonant Inductor L_{r1}	8µH
Resonant inductor L_{r2}	3.5µH
Resonant capacitor C_r	0.5µF
Resonant frequency f_0	80kHz
Switching frequency f_s	81kHz
Output voltage V_0	12 V
Filter capacitor C_0	100µF
Output resistance R_0	6 Ω

Table 1 Circuit parameters for L-C-L resonant converter

The circuit parameters of the C-L-C resonant converter are shown in the table 2. Here C-L-C resonant converter is also operates same frequency but only the differences is in resonant tank components.

Input voltage V_s	24 V
Resonant capacitor C_{r1}	1.37µF
Resonant inductor L_r	8µH
Resonant capacitor C_{r2}	0.5µF
Resonant frequency f_0	80kHz
Switching frequency f_s	81kHz
Output voltage V_0	12 V
Filter capacitor C_0	100µF
Output resistance R_0	6 Ω

Table 2 Circuit parameters for C-L-C resonant converter

Expression for resonant frequency f_0 is obtained from the C-L-C resonant tank is

$$f_0 = \frac{1}{2\pi\sqrt{LC_{r2}}} \quad \text{……………………………………………………………………} \quad (6)$$

C-L-C resonant converter has more advantages when compared to the L-C-L resonant converter, which are the cost of L-C-L resonant converter components is less, size of the converter is also less. In L-C-L resonant converter two inductors are used, due to this the size of converter is large but in case of C-L-C resonant tank converter only one inductor is used to obtain the required output. Faster response is obtained in the C-L-C resonant tank converter and also efficiency of this converter is increased up to 93%. So compared to these two converters C-L-C resonant converter is best preferred.

V. SIMULATION RESULTS FOR THE PROPOSED L-C-L RESONANT CONVERTER

A prototype was constructed and implemented in academic by taking many samples by varying inputs to demonstrate the effectiveness of the L-C-L resonant converter. The developed topology was connected to a 24-V dc source. Table I lists the circuit parameters for the proposed L-C-L resonant converter where the circuit simulations are also performed using MATLAB software in addition to this the resonant converter was implemented in practice and finally the simulation and practical results were compared with each other.

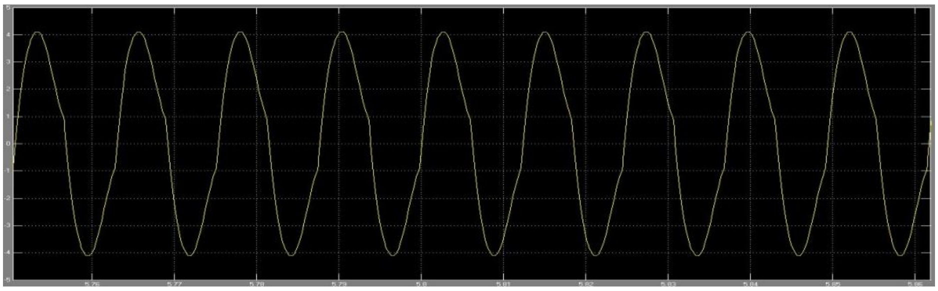

Figure 9 Current through the inductor-1 (I_{lr1})

The Figure shows the current through the inductor-1 (I_{lr1}) which is part of the component in L-C-L resonant tank the shape of this response is approximately sinusoidal.

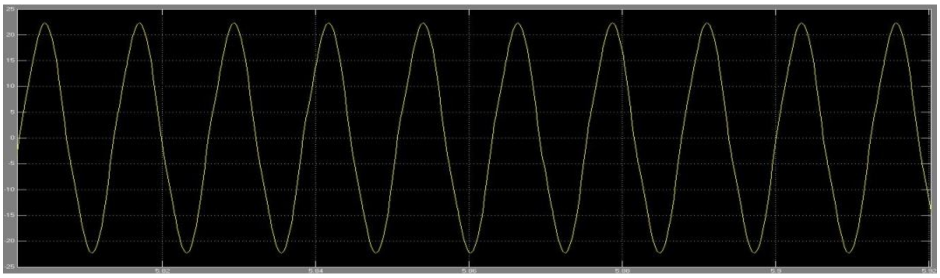

Figure 10 The voltage across the resonant capacitor (V_{cr})

The Figure 10 shows the voltage across the capacitor (V_{cr}) and the wave shape of this response is exactly sinusoidal

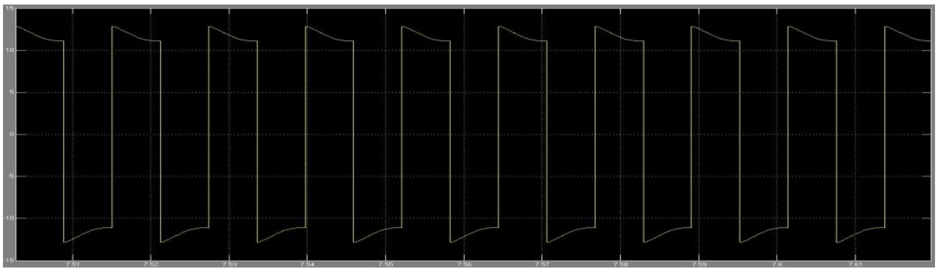

Figure 11 shows the voltage across the inverter circuit or voltage across the input terminals of L- C-L resonant tank.

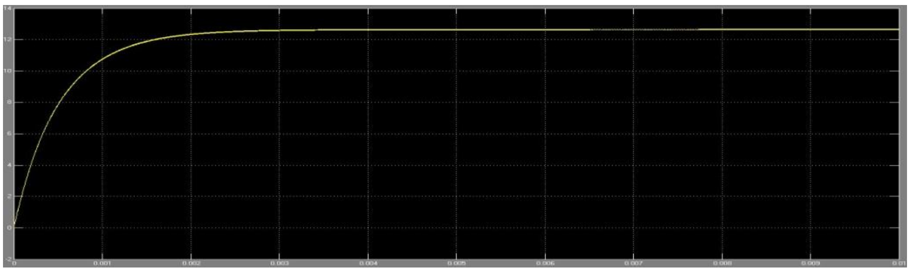

Figure 12 Output voltage obtained across the resistor R_0

The above figure 12 shows the output voltage (V_0) measured across the output resistor. The output of this converter is direct current so the wave shape is time invariant constant magnitude.

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VI. SIMULATION RESULTS FOR C-L-C RESONANT CONVERTER

In place of L-C-L resonant tank is replaced by C-L-C resonant tank, then by observes the simulation results with practical values and compares with the above results. The performance characteristics of the inductors, capacitors and output voltage waveforms are obtained from the simulation.

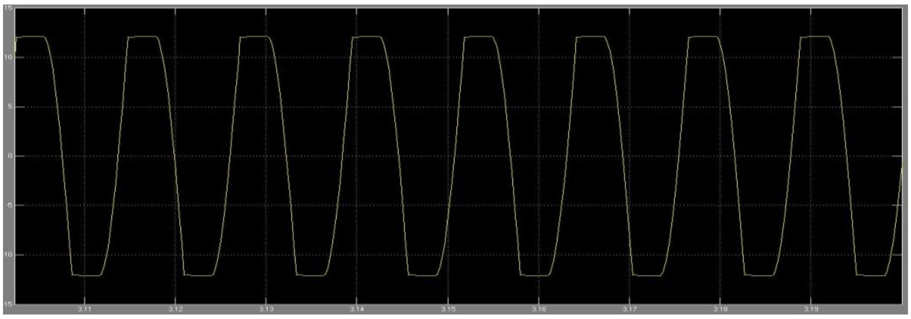

Figure 13 current through the inductor (I_{lr})

The figure 13 shows the current through the inductor which is connected in between two parallel resonant capacitors and the shape of this wave form is in rectangular in nature.

Figure 14 the voltage across the resonant capacitor (C_{r1})

The figure 14 shows the voltage across the capacitor which is connected at output of the resonant inverter that is input of the C-L-C resonant tank and the wave the shape is in sinusoidal in nature.

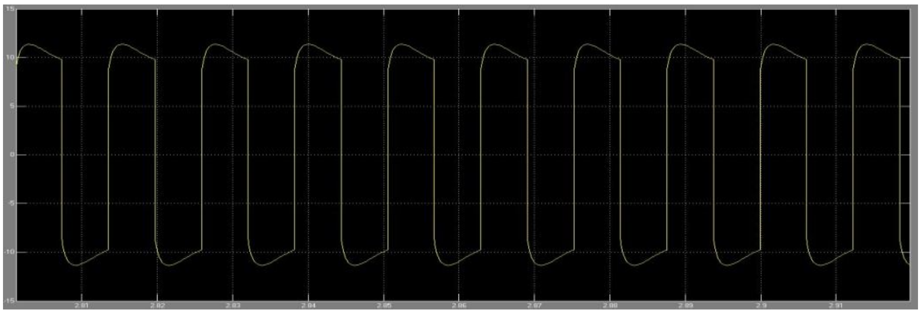

Figure 15 Voltage across the resonant capacitor (C_{r2})

The figure 15 shows the voltage across the resonant capacitor (C_{r2}) which is connected at output of the resonant tank that is input of the diode bridge rectifier.

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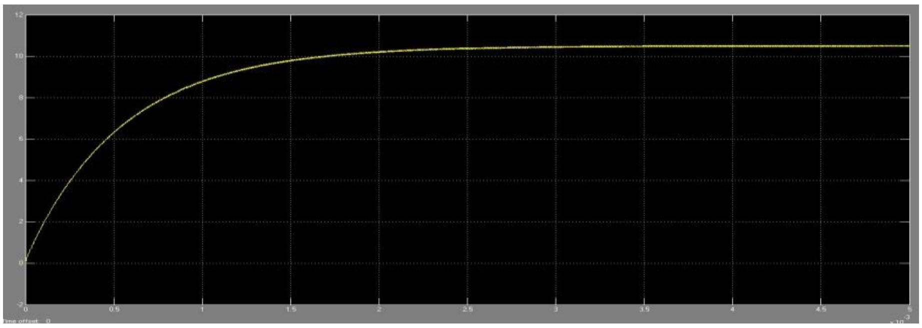

Figure 16 Output Voltage across the resistor

The figure 16 shows the output voltage measured across the resistor (R_0) which is connected at output terminals of the diode bridge rectifier and the shape of this wave form is unidirectional that means it has constant magnitude.

VII. CONCLUSION

This work develops L-C-L resonant converter and C-L-C resonant converter with a bridge rectifier for the application of dc-to-dc energy conversion. The L-C-L resonant converter structure is simpler and less expensive than conventional control mechanisms, which require many components. The L-C-L resonant converter topology is characterized by zero voltage switching, reduced switching losses, and increased energy conversion efficiency with the conventional converters. The output voltage/current can be determined from the characteristic impedance of the resonant tank by the adjustable switching frequency of the converter, where as the proposed resonant converter is applied to a load in order to yield the required output conditions. An experimental result gives the effectiveness of the proposed L-C-L resonant tank converter. The energy conversion efficiency in L-C-L resonant converter is 88.3%, which is quite satisfactory when the resonant circuit operating above resonance is applied to a dc-to-dc converter. In C-L-C resonant converter, reduces switching losses than L-C-L resonant converter and increase energy conversion efficiency up to 93%. An excellent performance is achieved at a lower cost and with fewer circuit components than with the C-L-C resonant tank converter with compared to the L-C-L resonant converter.

REFERENCES

[1] Y. C. Chuang, Y. L. Ke, H. S. Chuang, and H. K. Chen, “A novel loaded resonant converter for the application of DC to DC energy conversions” IEEE Trans. Ind. Appl., vol. 48, no. 2, March/April, 2012.

[2] W. Wongsaichua, W. J. Lee, S. Oraintara, C. Kwan, and F. Zhang, “Integrated high-speed intelligent utility tie unit for disbursed/renewable generation facilities,” IEEE Trans. Ind. Appl., vol. 41, no. 2, pp. 507–513, Mar./Apr. 2005.

[3] Y. C. Chuang, Y. L. Ke, H. S. Chuang, and H. K. Chen, “Implementation and analysis of an improved series-loaded resonant DC-DC converter operating above resonance for battery chargers,” IEEE Trans. Ind. Appl., vol. 46, no. 3, pp. 1052–1059, May/Jun. 2009

[4] C. Liu, A. Johnson, and J. S. Lai, “DC/DC converter for low-voltage fuel cell applications,” IEEE Trans. Ind. Appl., vol. 41, no. 6, pp. 1691–1697, Nov./Dec. 2005.

[5] R. M. Cuzner, D. J. Nowak, A. Bendre, G. Oriti, and A. L. Julian, “Mitigating circulating common-mode currents between parallel soft-switched drive systems,” IEEE Trans. Ind. Appl., vol. 43, no. 5, pp. 1284–1294, Sep./Oct. 2007.

[6] M. Ilic and D. Maksimovic, “Interleaved zero-current-transition buck converter,” IEEE Trans. Ind. Appl., vol. 43, no. 6, pp. 1619–1627, Nov./Dec. 2007.