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Novel Loaded-Resonant Converter & Application of DC-to-DC Energy Conversions systems

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Abstract:- *As there are many advantages of resonant power conversion due to which it is being adopted traditionally as pulse-width modulation that includes a low electromagnetic interference with low switching losses with its small volume and light weight of components that enables high switching frequency that produces high efficiency and low reverse recovery losses in diodes owing at a low di/dt at switching instant.*

This paper presents a novel loaded-resonant converter for direct current (dc)-to-dc energy conversion applications that uses the topology that comprises of a half-bridge Inductor Capacitor Inductor (LCL) resonant inverter and a bridge rectifier which yields the output stage of the proposed loaded-resonant converter is filtered by a low-pass filter that is prototyped with dc-to-dc energy converter circuit that is a novel loaded-resonant converter which is designed for a load is designed then developed and tested to verify its logical predictions. The measured energy conversion efficiency of the proposed novel loaded-resonant topology reaches up to 86.3% and all the test results demonstrate a satisfactory performance of the proposed topology and hence the proposed topology is highly promising for applications of power electronic productions such as switching power supplies or for battery chargers or for uninterruptible power systems or for renewable energy generation systems and for telecom power supplies.

Keywords: *Resonant converter, Loaded-resonant converter, Soft-Switching converter.*

I. INTRODUCTION

As the immense use of the semiconductor power switches in power electronic technology has led to rapid development of this technology in very recent years. As the switching power converter plays a major role in the power energy conversion applications mainly with respect to direct current dc-to-dc converters are extensively used in industrial, commercial, and residential equipment [1].

These converters are power electronics circuits that translate a dc voltage into a diverse level often providing a regulated output. Power semiconductor switches are the key component of power energy conversion systems by using the Pulse-width modulation (PWM) which is the simplest way to control power semiconductor switches and the PWM approach controls power flow by interrupting current or voltage through means of switch action with control of duty cycles. Practically speaking a situation in which the voltage across or current through the semiconductor switch is suddenly interrupted is referred to as a hard-switched PWM due to its simplicity and ease in control as we know that the hard switched PWM schemes have been largely adopted in modern power energy conversion applications. Hence a large switch voltage and a large switch current stirring simultaneously requires the switch withstands elevated switching stresses with a safe operating area as shown by the dashed lines in **Fig. 1**.

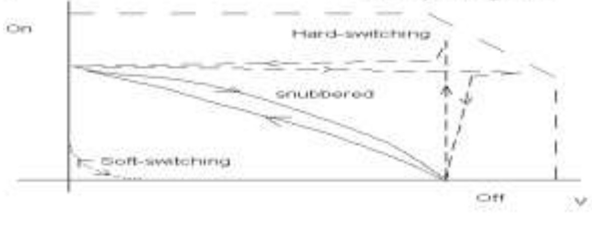


Figure 1 switching trajectories of power switches.

By connecting simple dissipative snubber circuits in series and parallel through switches in hard-switched PWM the converters can decrease switch stresses though these dissipative snubber circuits moves the switching power loss from the switch to the snubber circuit by making it impossible to reduce the overall switching power loss. The modern dc-to-dc power converters must be in small size and light weight as well as have high energy conversion efficiency within the range.

Higher switching frequency results to smaller and lighter inductors or capacitors as well as filter components of these converters where as electromagnetic interference (EMI) and switching losses increase with an increasing switching frequency by ultimately decreasing the efficiency and performance of dc-to-dc power converters. To solve this kind of problem some soft switching approaches must operate under a high switching frequency such as Zero voltage switched and zero current switched schemes that are two commonly used soft switching methods in which either the voltage or current is zero during switching transitions which largely reduce the switching losses and EMI which intern increase the reliability of the power converters.

While attempting to devise dc-to-dc converters that are capable of operating at low switching losses as the power electronics engineers started developing converter topologies that helps us to shape either a sinusoidal current or a sinusoidal voltage waveform by significantly reducing switching losses and these converters are called soft switching dc-to-dc converters. A soft switching dc-to-dc converter is developed by cascading a resonant dc-to-dc alternating current (ac) inverter and a rectifier dc input power is first converted into ac power by the resonant inverter and then the ac power is then converted back into dc power by the rectifier. Along with the existing soft switching converters the loaded-resonant converters are the most popular type owing to its simplicity of circuit configuration as well as easy realization of control scheme, low switching losses and high flexibility for energy conversion applications which depend on how energy is extracted from a resonant tank then loaded-resonant converters can be classified into series resonant or into parallel resonant and series-parallel resonant converters.

The series resonant charger is in general formed by an inductor, capacitor, and a bridge rectifier and the ac through the resonant tank is rectified at the output terminals making it possible to obtain the output dc and in contrast to the series resonant converter a parallel loaded- resonant converter can manage the output voltage at no load by running at a frequency above resonance and the parallel loaded- resonant converter contains an inductive output filter explaining why the output current through the capacitor is low and reducing the conduction losses and the ripple voltage of the converter.

Additionally the parallel-loaded-resonant converter is inherently short circuit protected since the parallel loaded resonant converter is highly impacting for dc-to-dc energy conversion applications as specifically the output voltage at resonance is a function of load and can rise to very high values at no load if the operating frequency is not raised by the regulator. Though the series-parallel converter merges the finest characteristics of series resonant and parallel resonant converters the resonant tank of this converter is equivalent to that of the parallel loaded- resonant inverter except for an extra capacitor in series with the resonant inductor. As the series-parallel converters output can execute over a wider range of input voltage and load ranges from no load to full load as per the series-parallel converter with a capacitive output filter analyzes the converter operations and designing circuit parameters that are complex tasks because the capacitive output stage is decoupled from the resonant stage for a significant period during the switching cycle and the series-parallel converter cannot operate safely with a short circuit at a switching frequency close to the resonant frequency.

Consequently the energy conversion stage of the series-parallel converter has not been minimized and simplify the results in a bulky size and high cost in the applications of dc-to-dc energy conversion and by comparing the above three different loaded resonant converter topologies specifies that the parallel loaded resonant converter is the most advantageous topology for dc-to-dc energy conversion applications since its many merits including low switching losses or low stresses and low noise characteristics.

Furthermore for dc-to-dc power conversion applications the parallel loaded resonant converter is generally suggested as the energy conversion stage due to its simple circuitry and typical input characteristics where as a large filter inductor to the output side of the bridge rectifier in a traditional parallel loaded resonant converter might add significant weight and volume and also cost which is based on the parallel loaded resonant converter and this paper presents a novel loaded resonant converter. The proposed solution for the problem space is superior to the conventional parallel resonant converter in terms of miniaturize in terms of size or light weight or its simple topology and easy control.

A broader classification of resonant type dc-to-dc converter used is:

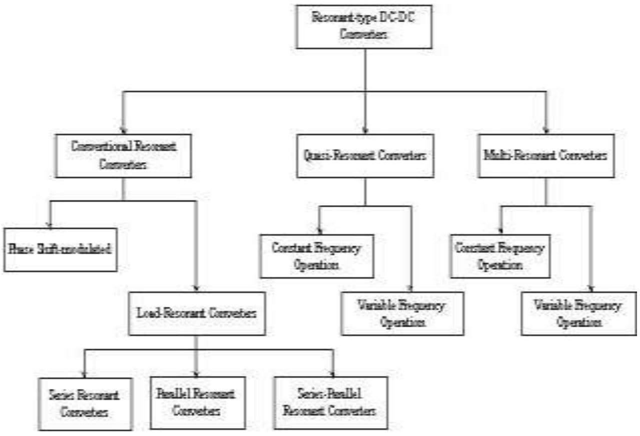


Figure 2 Classification of Resonant type dc-to-dc converter.

The papers implementation is tested in academic environment in our college with different inputs and by gathering distinct output results that are filed in this paper and the rest of this paper is organized as follows: Section II describes the proposed novel loaded-resonant converter and specifies the operation of the proposed converter. Section III describes in detail about the operating characteristics of the proposed converter and the Section IV summarize the simulation and experimental results to demonstrate the effectiveness of the proposed converter and finally conclusions are drawn in Section V along with recommendations for future scope.

II. CIRCUIT DESCRIPTION AND OPERATING PRINCIPLES

2.1 A. Circuit Description

Drastic increase in oil price and immense energy shortages have created the demand for a high energy conversion efficiency and performance as the growing electronic product market that increases the demand for high energy conversion efficiency and high power density of dc-to-dc energy power converters and the soft switching scheme is the most attractive dc-to-dc energy conversion topology in recent years. The soft-switching method is capable of reducing the switching losses and EMI of the switch-mode converter and the Figure 3 illustrate the proposed loaded-resonant converter for application of the dc-to-dc energy conversion system that uses two capacitors say C_1 and C_2, on the input that are at large and split the voltage of the input dc source.

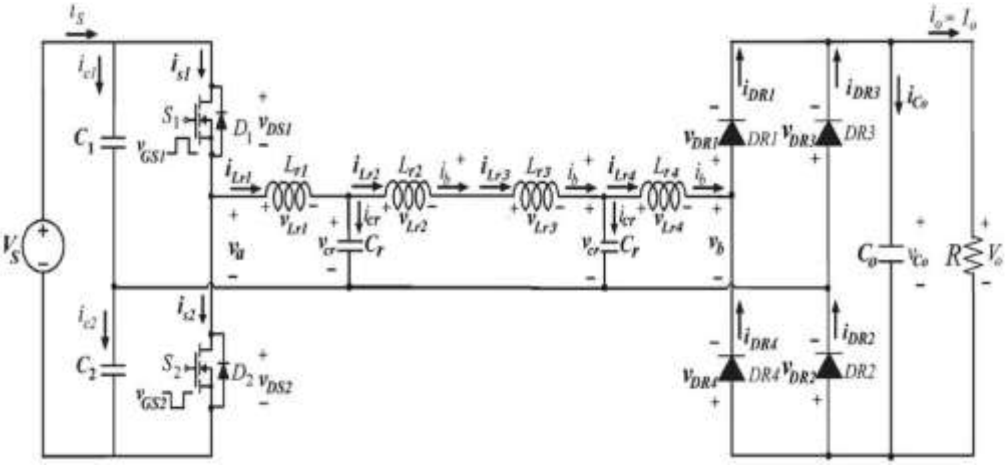


Figure 3 Proposed loaded-resonant converter for a dc-to-dc energy conversion system.

The elements L_{r1}, L_{r2}, L_{r3}, L_{r4}, and C_r form the resonant tank the load resistance R is connected across a bridge rectifier via a low-pass filter capacitor C_o. For analyzing the power switching devices are assumed here to be represented by a pair of bidirectional switches working at a 50% duty ratio over a switching period T for the half-bridge topology each bidirectional power switch has an active power switch and an anti-parallel diode where the active power switches are driven by non-overlapping rectangular-wave trigger signals v_{GS1} and v_{GS2} with dead time. Hence we may denote the outcome of the power switches by considering an equivalent square wave voltage source with amplitude equal to $\pm V_s/2$. Resonant inductor current i_{Lr2} is rectified to obtain a dc bus whose voltage can be varied and closely regulated by controlling the switching frequency due to which the ac-to-dc power conversion in this case is achieved by rectifying the current through resonant inductors L_{r2}, L_{r3}, L_{r4} a large filtering capacitance C_o is needed not only to minimize the loading effect of the output circuit but also to ensure that the voltage across it is mostly constant. Consequently, the voltage across the bridge rectifier has constant amplitudes $+V_o$ and $-V_o$, depending on whether the current $i_{Lr2}(t)$, $i_{Lr3}(t)$, $i_{Lr4}(t)$ are positive or negative, respectively.

The frequency of this voltage waveform is the same as that of the switching frequency that is based on the above observations where the novel loaded-resonant converter can be modeled as a series $L_{r1} - C_r - L_{r2} - C_r - L_{r3} - C_r - L_{r4}$ circuit and a square-wave voltage source $\pm V_o$ in series with the resonant inductor L_{r4}. Figure 4 shows the simplified equivalent circuit for the proposed loaded-resonant converter.

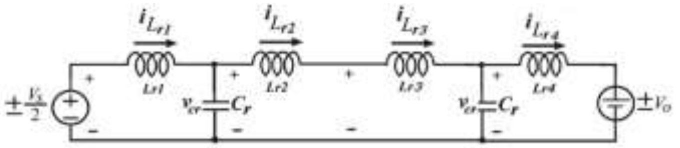


Figure 4 A Simplified equivalent circuit of the proposed loaded-resonant converter.

2.2 Circuit Operating Principles

The below analysis assumes that the converter operates in the uninterrupted or iterative conduction mode in which the semiconductors have ultimate characteristics.

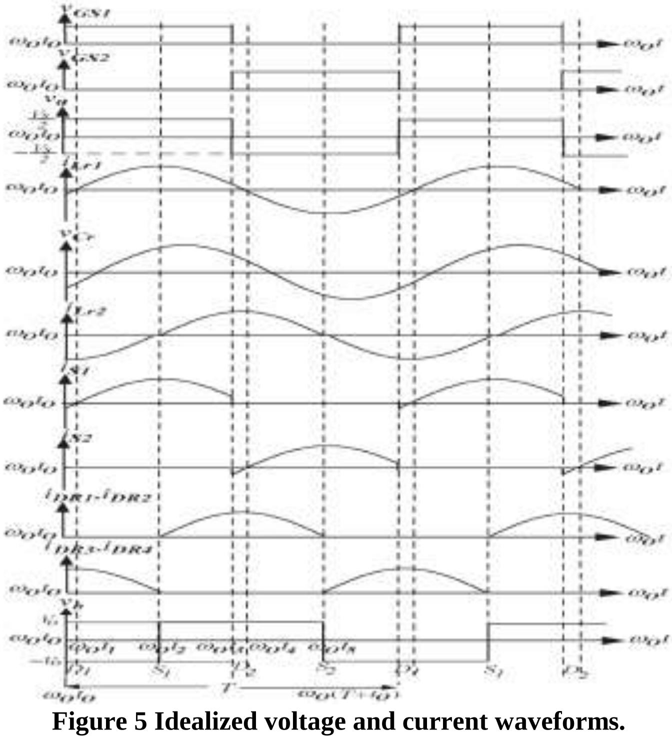


Figure 5 Idealized voltage and current waveforms.

Figure 5 displays the idealized steady state voltage and current waveforms in the proposed novel loaded-resonant converter for switching frequency fs that exceeds resonant frequency f_o which is operated above the 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 during the positive half-cycle of the current through the resonant inductor L_{r4}, the power is supplied to the load resistor R through diodes D_{R1} and D_{R2} and during the negative half-cycle of the current through the resonant inductor L_{r2} the power is passed to the load resistor R through diodes D_{R3} and D_{R4}.

The novel loaded-resonant converter for the implementation of the application of dc-to-dc energy conversion is being analyzed based on the following assumptions.

1) Switching the elements of the converter that are ideal such that the energy diminish in forward voltage in the on-state resistance of the power switch is negligible.

2) Equivalent series resistance of the stray capacitance and capacitances is almost considered to be negligible.
3) The characteristics of inactive components are assumed to be linear or time invariant and frequency independent.
4) Filter capacitor C_o at the output terminal of the full bridge rectifier is almost always very large and the output voltage across capacitor C_o can further be treated as an ideal dc voltage in each switching cycle and
5) Active power switches S_1 and S_2 are switched on and off alternately by applying a square-wave voltage across the novel loaded-resonant circuit where there lies a situation in which the load quality factor of the novel loaded-resonant converter is sufficiently high which suggests that resonant currents, i_{Lr1} and i_{Lr2}, are sinusoidal.

The operations of steady-state of the novel loaded-resonant converter in a switching period can be divided into four modes:

Mode I—(Between $\omega_o t_0$ and $\omega_o t_1$): Periodic switching of the resonant energy tank voltage lies between $\pm V_s/2$ that is used to generate a square-wave voltage across the input terminal since the output voltage is assumed to be a constant voltage V_o and the input voltage to the full-bridge rectifier is V_o when $i_{Lr4}(t)$ is positive and is $-V_o$ when $i_{Lr4}(t)$ is negative hence Figure. 6 displays the suitable circuit of the proposed novel loaded resonant converter for the application of dc-to-dc energy conversion in Fig. 3 whose time interval ends when $i_{Lr4}(t)$ reaches zero at $\omega_o t_1$.

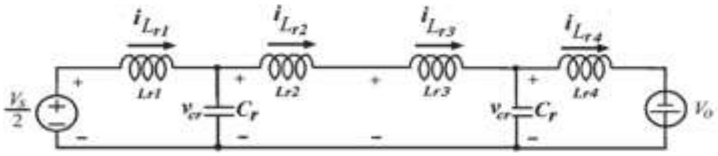


Figure 6 Suitable circuit of Model I

Before $\omega_o t_0$ active power switch S_2 is excited and conducts a current that equals resonant tank current i_{Lr1} where the active power switch S_1 is turned on at $\omega_o t_0$ however resonant tank current i_{Lr1} is negative and flows through freewheeling diode D_1 at the instant $\omega_o t_1$ resonant tank current $iLr1$ reverses and naturally commutates from freewheeling diode D_1 to power switch S_1 and in this mode the power switches are turned on naturally at zero voltage and at zero current then the current flows through the active power switch is negative after turning on and positive before turning off.

Even though the current in the switches is turned on at zero voltage and zero current to eliminate turn-on losses the switches are forced to turn off a finite current thus allowing turn-off losses exit since the small capacitors can be placed across the switches to function as snubbers in order to eliminate turnoff losses.

Mode II—(Between $\omega_0 t_1$ and $\omega_o t_2$): The cycle starts at $\omega_o t_1$ when the current i_{Lr1} resonant tank resonates from negative values to zero and at $\omega_o t_2$ before the half-cycle of resonant current i_{Lr1} oscillation ends switch S_1 is forced to turn off forcing the positive current to flow through bottom freewheeling diode D_2. Fig. 7 shows the suitable circuit where the positive dc input voltage applied across the resonant tank causes the resonant current that flows through the power switch to go quickly to zero.

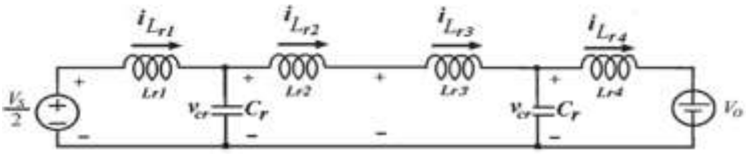


Figure 7 Suitable circuit of Model II

Mode III—(Between $\omega_o t_3$ and $\omega_o t_4$): A turn-off trigger signal is applied to the gate of the active power switch $S_1$where the inductor current then naturally commutates from active power switch S_1 to freewheeling diode D_2 Mode III begins at $\omega_o t_3$ when diode D_2 is turned on, subsequently producing a resonant stage between inductors L_{r1}, L_{r2}, L_{r3}, L_{r4} and capacitor C_r here the inductors L_{r1}, L_{r2}, L_{r3}, L_{r4} and the capacitor C_r resonate before which $\omega_o t_4$ trigger signal v_{gs2} excites active power switch S_2 and at this time interval ends when $i_{Lr1}(t)$ reaches zero at $\omega_o t_4$ Figure. 8 show the suitable circuit.

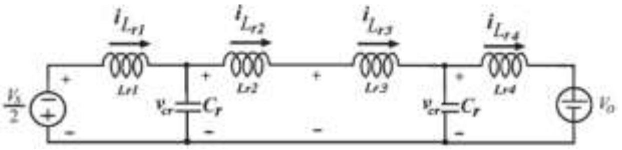


Figure 8 Suitable circuit of Model III

Mode IV—(Between $\omega_o t_4$ and $\omega_o t_5$): When capacitor voltage i_{Lr4} is positive rectifier diodes D_{R1} and D_{R2} are turned on with zero-voltage condition at instant $\omega_o t_4$ Figure. 9 shows the suitable circuit when inductor current i_{Lr4} that changes direction with the rectifier diodes D_{R1} and D_{R2} are turned off at instant $\omega_o t_5$ and Mode IV ends and when driving signal V_{gs1} again excites active power switch S_1 this mode ends and the operation returns to mode I in the subsequent cycle and in the positive half-cycle of the inductor current i_{Lr2} the power is supplied to the load through bridge rectifier diodes for D_{R1} and D_{R2} during the negative half-cycle of the inductor current the power is supplied to the load through bridge rectifier diodes D_{R3} and D_{R4}.

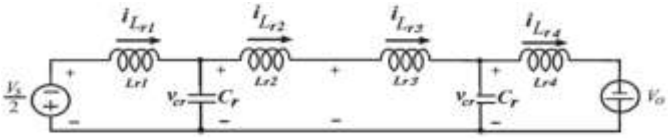


Figure 9 Suitable circuit of Model IV

III. OPERATING CHARACTERISTICS

The novel loaded-resonant converter for the application of dc-to-dc energy conversion application system is shown in Figure. 3 where the switching frequency of the active power switches is predicted to be greater than the resonant frequency so that the resonant current is uninterrupted with a large capacitive filter at the output terminal of the bridge rectifier where the output voltage may be predicted to be constant for providing the analysis of the operation of the novel loaded resonant converter where the circuit in Fig. 3 can be simplified to a schematic circuit as shown in Fig. 4 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_{Lr4} is negative then the input part of the novel loaded-resonant converter for the application of dc-to-dc energy conversion comprises of a dc input voltage source V_s and a collection of power switches where the active power switches are controlled for producing a square-wave voltage v_a since a resonant circuit forces a sinusoidal capability of transferring the power of the fundamental component from the input source to the resonant circuit because it is sufficient to consider only the fundamental component of this converter where the novel loaded-resonant converter with a bridge rectifier stage for dc-to-dc energy conversion system is analyzed by taking into consideration of the fundamental frequency of the Fourier series transformation for the voltages and currents where the error rate due to this approximation is very small and if the switching frequency is higher than the resonant frequency and the fundamental mode equivalent circuit is shown in **Figure. 10**.

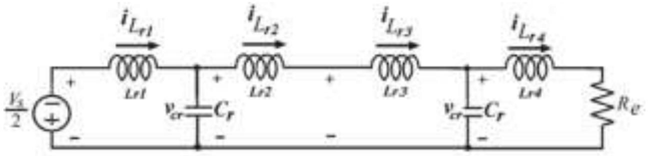


Figure 10 Equivalent AC circuit

The expected output voltage *vb* of the bridge rectifier can be described by a Fourier series transformation as:

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

The fundamental component of expected voltage v_b is:

$V_{b1}=\frac{4V_0}{\pi}\ \sin(\omega t) = 1.2730\ V_0 \sin(\omega t)$

$V_{b3}= 0.4243\ V_0 \sin(\omega t)$ (2)

The specified current at the output of the bridge rectifier is the full-wave rectified form of inductor current i_{Lr4} and the average of the rectified inductor current $|i_{Lr4}|$ balances the output current load I_o if the inductor current i_{Lr4} is
approximated to a sine wave of amplitude I_{LM1} then the average value of output current is considered to be I_o is:

$I_0=\frac{2ILM1}{3.142}$ (3)

And the fundamental component of input current is:

$$I_{LM1} = \frac{3.142\ I0}{2} \qquad (4)$$

The value of output resistance in this provided solution space that is the equivalent circuit is based on the ratio of voltage to current at the input terminal of bridge rectifier where the resistance can then be defined as:

$$R_e = \frac{V_{b1}}{I_{LM1}} = \frac{\frac{4}{3.142}V_0}{\frac{3.142}{2}I_0} = \frac{8}{(3.142)^2} \,.\, I_{LM1} = \frac{V_0}{I_0} \qquad (5)$$

The bonding between the input and output is approximated from ac circuit analysis and by using which the fundamental frequencies of the voltage and the current equations specified above are used for developing equivalent resonant capacitor *C_{eq}* and equivalent resistor *R_{eq}* can be evaluated respectively as:

$$C_{eq} = \frac{(\omega R_e C_r)^2}{\omega^4 L_{r4}^2 C_r} + \frac{(\omega L_{r4} C_r - 1)^2}{(\omega^2 R^2 C_r - \omega^2 L_{r4})} \qquad (6)$$

$$R_{eq} = \frac{R_e}{\omega^2 R_e^2 C_r^2} + \frac{1}{(\omega L_{r4} C_{r-1})^2} \qquad (7)$$

And the loaded quality factor of the novel loaded-resonant circuit can be defined as:

$$Q_L = \frac{\sqrt{L_{r1}}}{\sqrt{C_{eq}}} \cdot \frac{1}{R_{eq}} \qquad (8)$$

Hence forth the proposed novel loaded-resonant converter is characterized by the aspect that the reactance of the resonant tank depends on the switching frequency and the output voltage can be regulated by adjusting the switching frequency of the proposed novel loaded-resonant converter based on which the characteristic are proposed that the loaded-resonant converter is the preferred configuration for the applications of dc-to-dc energy conversion.

IV. EXPERIMENTAL RESULTS

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

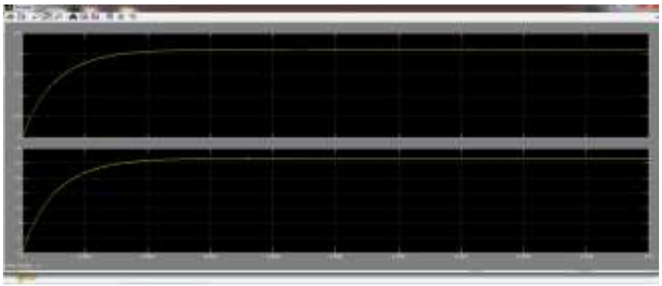


Figure 11 Load current & voltage

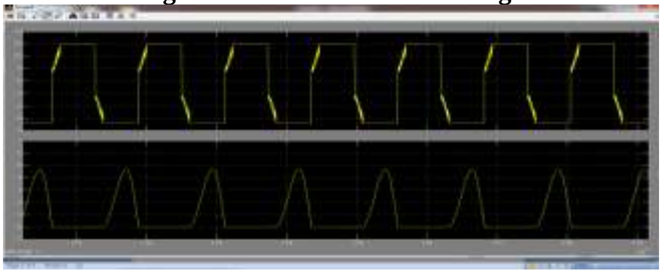
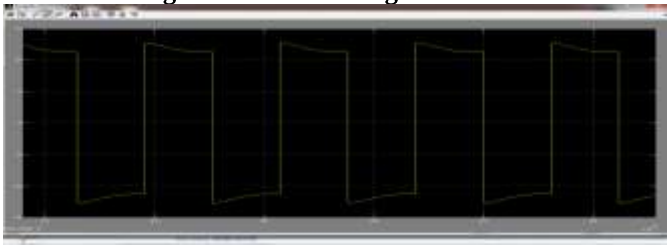


Figure 12 Diode voltage & current



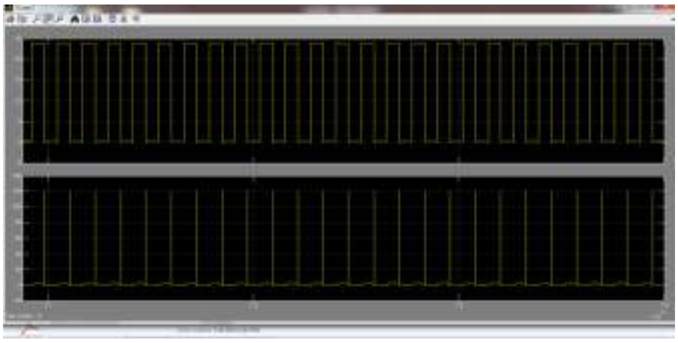


Figure 13Switches voltage and current

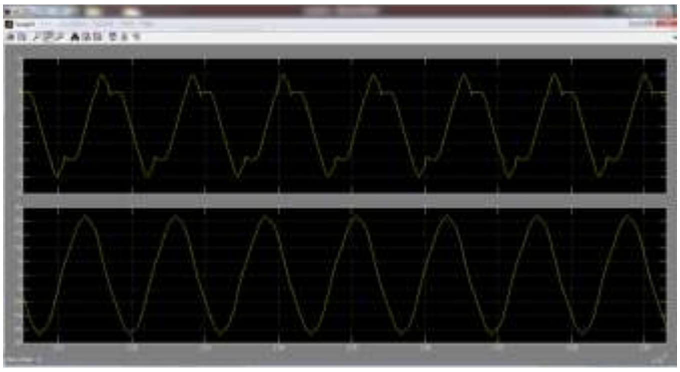


Figure 14 Capacitor current & voltage outputs

V. CONCLUSION

In the proposed system which we proposed the circuit structure is very simpler and less expensive than other control mechanism that requires many components and the developed topology is characterized by zero voltage switching or reduced switching losses and increased energy conversion efficiency where the output voltage/current can be determined from the characteristic impedance of the resonant tank by adjusting the switching frequency of the converter whereas the proposed loaded-resonant converter is applied to a load in order to yield the required output conditions. All the experimental results demonstrate the effectiveness of the proposed converter where the energy conversion efficiency is 88.5% which is quite satisfactory when the proposed loaded-resonant circuit operating above resonance is applied to a dc-to-dc converter where as in contrast with the conventional parallel-loaded-resonant converter the energy conversion efficiency can be improved using the proposed topology and excellent performance can be achieved at a lower cost and with fewer circuit components than with the conventional converter.

REFERENCES

[1]. 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.

[2]. Z. Liang, R. Guo, J. Li, and A. Q. Huang, “A high-efficiency PV module integrated DC/DC converter for PV energy harvest in FREEDM systems,” IEEE Trans. Power Electron., vol. 26, no. 3, pp. 897–909, Mar. 2011.

[3]. A. M. Rahimi and A. Emadi, “Discontinuous-conduction mode DC/DC converters feeding constant-power loads,” IEEE Trans. Ind. Electron., vol. 57, no. 4, pp. 1318–1329, Apr. 2010.

[4]. R. Morrison and M. G. Egan, “A new power-factor-corrected singletransformer UPS design,” IEEE Trans. Ind. Appl., vol. 36, no. 1, pp. 171– 179, Jan./Feb. 2000.

[5]. Y. M. Lai, S.-C. Tan, and Y. M. Tsang, “Wireless control of load current sharing information for parallel-connected DC/DC power converters,” IET Power Electron., vol. 2, no. 1, pp. 14–21, Jan. 2009.

[6]. S. M. Lukic, J. Cao, R. C. Bansal, F. Rodriguez, and A. Emadi, “Energy storage systems for automotive applications,” IEEE Trans. Ind. Electron., vol. 55, no. 6, pp. 2258–2267, Jun. 2008.