# A Modified Loaded Resonant Converter for Renewable Energy Conversions

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*Abstract*: **This Project describes how soft-switching technique using zero voltage switching (ZVS) Resonant converter provides power lossless switching transitions in Dc-to-Dc energy conversion systems. Also it ensures reduced EMI at transitions, avoids high peak currents, better efficiency with high voltage at any frequency. Therefore, it largely reduces the power losses of the converter. Zero voltage switching can best be defined as conventional square wave power conversion during the switch's on-time with resonant switching transitions. A closed loop series parallel resonant converter with LCL-T configuration has been simulated. The PID controller has been used for closed loop operation and the performance of proposed converter has been estimated from the open loop to the closed loop resonant converter system. The Mathematical model using MATLAB. The performance of the converter has been found to be better when the PID controller has been considered. The harmonic spectrum and steady state error for various load condition have been obtained to validate the role of controllers. The proposed analysis of simulation results are carried out in MATLAB/SIMULINK model.**

*Keywords*: **Zero Voltage Switching, Resonant converter, Closed Loop with PID Controller, Electromagnetic Interference (EMI).**

## I.   INTRODUCTION

Recent development in semiconductor devices and control strategies has enabled the use of variable Renewable sources, industries and Residential applications. The Resonant switching topology is to date one of the most efficient solutions for switch mode power supply design. There has been increasing interest in the soft switching power conversion technologies in order to overcome the limitation of the hard switching technologies. The soft switching (SS) converter had many advantages. for example ,soft switching converters has lower switching losses, reduce voltage/current stress, reduced Electromagnetic interference and allow a greater high switching frequency in high power applications. Despite the advantages of soft switching converters its applications have been so far limited due to complexity in the design of soft switching circuits and difficult in control realization. Hence, there has been growing demand for a sample design that
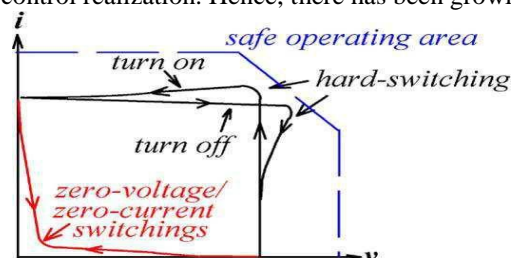


**Fig.1. Normal switching actions of power switches**

provides reliable control in a wide range of operational condition. So far this paper tackle this problem by the resonant converters which operated as electrical inverter based on the current oscillation. Basically, there are two circuit schemes for processing of power electronic technology. They are pulse width modulation (PWM) and Resonance. During each switching in all pulse width modulated dc-dc and dc-ac converter topologies, the controllable switches are operated in a switch mode where they are required to turn-on and turn-off the entire load current. In the switch mode operation, the

switches are subjected to high switching stresses and high switching power-loss that increases linearly with this operation is the electromagnetic interference (EMI)

Which is due to large di/dt and dv/dt? Using high frequency in all the four types of converters will be desirable because it will provide tremendous savings in component sizes (reduce converter size) and weights and hence achieves high power density High frequency Resonant converters have become increasingly popular among power supply designs, especially at frequencies above 100kHz because they offer small size, good reliability and reduced EMI/RFI. Resonant converter describes as a class of converters in which the topology consists of at least one resonant tank circuit as a sub circuit. The resonant tank is consisting of at least one inductor and one capacitor. The above mentioned disadvantage of PWM control can be eliminated or minimized if the switching devices are turned on and turned off when the voltage across a device and its current become zero. The voltage and current forced to pass through zero crossing by creating an L-C circuit.

The resonant technique process power in sinusoidal form. The power switches are often turned - off under zero current and turned –on with large increase of device current. The resonant converter can be operated either below resonant frequency or above resonant frequency. If it is operated at frequencies above the resonant frequency, the switches are turned-on at zero voltage across them but turned-off abruptly. In these converters, the switching losses and device stresses are lower compared to PWM converters but the conduction losses are higher because the peak and rms device currents are much higher in resonant converter. The control of PWM technique is simpler and is largely used in power conversion at present  however, it is limited to low and medium power applications. The resonant converter can be used in lo w, medium and high power applications using high power switches but the control circuit is rather complex.

Two methods are employed in resonant converters. First, the switch generates a square wave of voltage that is applied to a series LC circuit. This c configuration is known as series-resonant converters. Second, the switch generates a square-wave of current that is applied to a parallel-resonant converter. The output of these converters is supplied to the load or processed further for the desired output. The following fig.2.shows that the equivalent circuit of resonant converter.

## II.    CIRCUIT DESCRIPTION AND OPE RATING PRINCIPLES

**A. Circuit Description:**

Energy shortages and increasing oil prices have created the demand for a high energy conversion efficiency and performance. The growing electronic product market has increased the demand for high energy conversion efficiency and high power density of dc-to-dc energy power converters. The soft-switching scheme is the most attractive dc-to-dc energy con-version topology in recent years. The soft-switching method can reduce switching losses and EMI of the switch-mode converter application of the dc-to-dc energy conversion system. The two capacitors, C1 and C2, on the input are large and split the voltage of the input dc source. The elements Lr1, Lr2, and Cr form the resonant tank. The load resistance R is connected across a bridge rectifier via a low-pass filter capacitor Co. For analysis, the power switching devices are assumed here to be represented by a pair of bidirectional switches operating at a 50% duty ratio over a switching period T. For the half-bridge topology, each bi-directional power switch has an active power switch and an anti-parallel diode. The active power switches are driven by non-overlapping   rectangular- wave trigger  signals  vGS1and vGS2 with dead time. Thus, we may represent the effect of the power switches by means of an equivalent square-wave voltage source with an amplitude equal to $\pm V_s/2$. Resonant inductor current iLr2 is rectified to obtain a dc bus. The dc bus voltage can be varied and closely regulated by controlling the switching frequency.
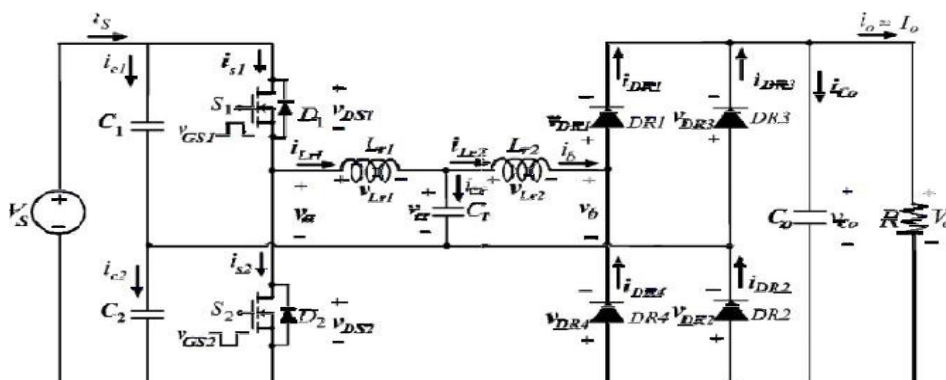


**Fig:  2. Proposed resonant converter for a dc-to-dc energy conversion**

Because of that, the ac-to-dc power conversion, in this case, is achieved by rectifying the current through    resonant inductor  $L_{r2}$,  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 $i_{Lr2}$ $(t)$ is positive or negative, respectively. The frequency of this voltage waveform is the same as that of the switching frequency. Based on the above observations, t he novel loaded-resonant converter can be modeled as a series $L_{r1}- C_r- L_{r2}$circuit and a square-wave voltage source $\pm V_o$ in series with the resonant inductor $L_{r2}$. Fig. 3 shows the simplified equivalent circuit for the proposed loaded-resonant converter.

### B. Circuit Operating Principles:

The  following  analysis  assumes  that  the  converter  operates  in  the  continuous  conduction  mode,  in  which  the semiconductors have ideal characteristics. Fig. 4 displays the idealized steady-state voltage and current waveforms in the proposed  novel  loaded-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. During the positive half-cycle of the current through the resonant inductor $L_{r2}$, the power is supplied to the load resistor $R$ through diodes $D_{R1}$ and $D_{R2}$. During the negative half-cycle of the current through the resonant inductor $L_{r2}$, the power is fed to the load resistor $R$ through diodes $D_{R3}$ and $D_{R4}$.overshoot and at some point it may begin to oscillate becoming unstable if it has insufficient damping. The integral control technique that accumulates the error signal over time multiplies the sum by a user specified gain factor $K_I$ and uses the result as a corrective signal to the motion system. Since this technique also acts upon past errors, the correction factor does not go to zero as error approaches zero allowing steady state errors to be eliminated.

### C. Proposed Resonant converter closed loop with PID Controller:

Closed loop refer to a control technique that measures the output of the system compared to the desired input and takes corrective action to achieve the desired result. Electronic feedback mechanisms in closed-loop systems enhance the ability to correctly pl ace and move loads. Depending upon how the feedback signals are processed by the controller, different levels of performance can be achieved. The simplest type of feedback is called proportional control. Other types are called derivative control. Combining all three techniques into what is called PID control provides the best results.
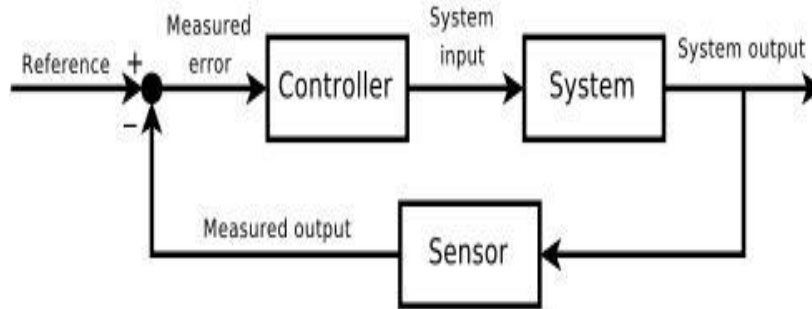


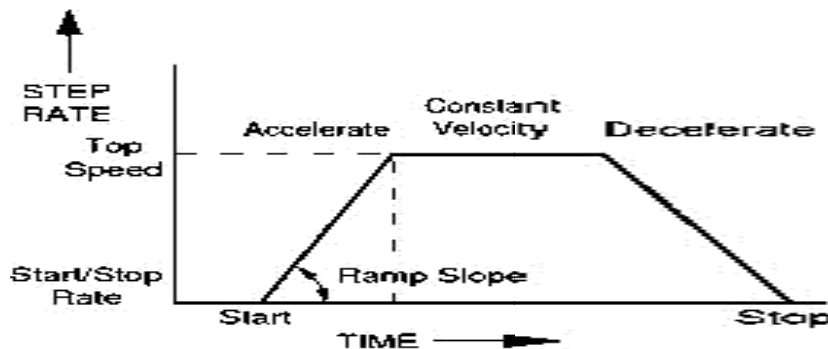**Fig.3.PID control with closed loop**



**Fig.4.Closed loop control**

The combination of proportional ,integral and derivative control. For motion systems, the PID loop has become a very popular control algorithm . The feedback elements are interactive and knowing how they interact is essential for tuning a motion system. Optimum system performance requires that the coefficients $K_P$, $K_i$ and $K_d$ be tuned for a given combination of motion mechanics and pay load inertias.
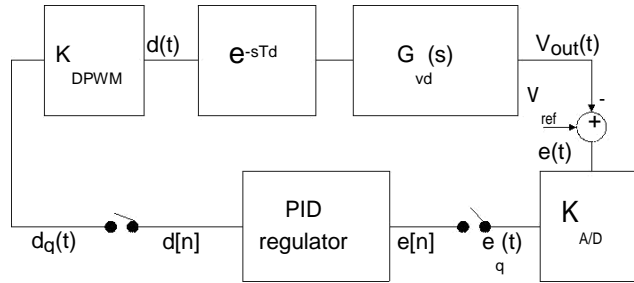


**Fig.5. PID controller error detecting circuit design**

A control technique that multiplies the error signal (the difference between actual and desire d position) by a user specified gain factor $K_P$ uses it as a corrective signal to the motion system. The effective results to exaggerate the error and react immediately to correct it. Changes in position generally occur during com mended acceleration, deceleration and in moves where velocity changes occur in the system dynamics during motion. As $K_P$ is increased, the error is more quickly corrected. However, if $K_P$ becomes too large, the electrical system will begin to The equation of controllers with this combined action is given by

$$MV(t) = K_p e(t) + K_i \int_0^t e(\tau)\,d\tau + K_d \frac{d}{dt} e(t)$$

the gain parameters are related to the parameters of the standard form through $K_i = k_p /T_d$ and $K_d = K_P T_d$ .This parallel form, where the parameters are treated as simple gains, is the most general and flexible form. However, it is also the form where the parameters have the least physical interpretation and is generally reserved for theoretical treatment of the PID controlled . The standard form, despite being slightly more complex mathematically, is more common in industry.

## III. CIRCUIT ANALYSIS

The input part of the novel loaded-resonant converter for the application of dc-to-dc energy conversion is composed of a dc input voltage source Vs and a set of power switches. The active power s witches are controlled to produce a square-wave voltage $v_a$. Since a resonant circuit forces a sinusoidal current, only the power of the fundamental component is transferred from the input source to the resonant circuit. Hence , it is sufficient to consider only the fundamental compo-nent of this converter with the bridge rectifier stage for dc- 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. The fundamental mode equivalent circuit is shown in Fig.6.
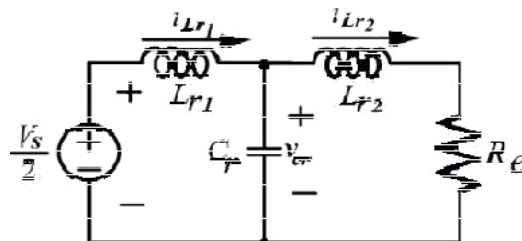


**Fig.6.equivalent ac circuit of resonant converter**

*B. Closed Loop Response & PID Controller:*

The response for a reference voltage of 10V the output voltage is 12V.In the closed loop response by using PID Controller, the overshoot and settling time is less compared to open loop, and the response is oscillatory. The plots of

resonant voltage resonant current, output voltage across load and measured values are shown in fig.8. Where the electromagnetic interference (EMI). High speed switching power supplies improves efficiency but leads to EMI Different kind of conducted interference and regulation introduced in this paper. Modeling and simulation is the first step of EMI evaluation, regulation of the output voltage is accomplished by adjusting the effective duty cycle.
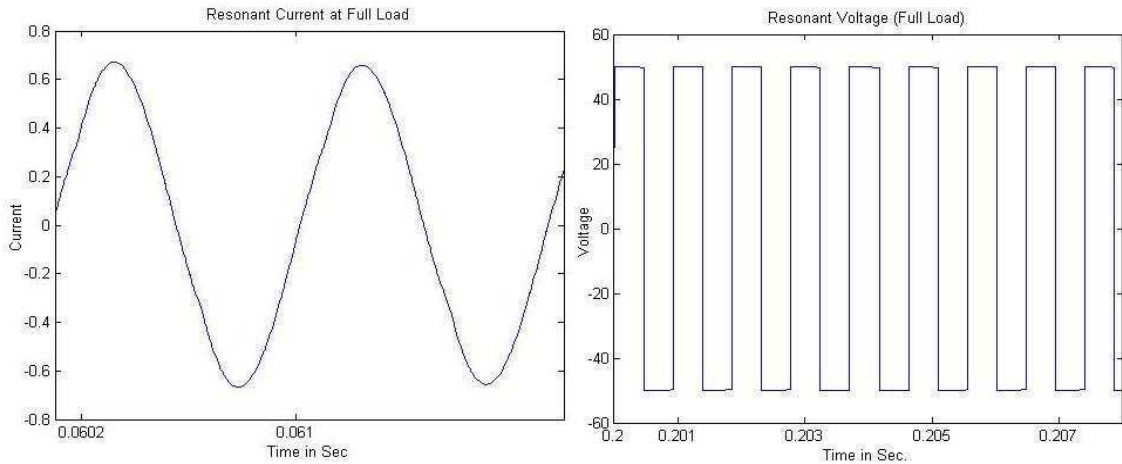


**Fig.7. Resonant current and resonant voltage at 100% of load**

The voltage across $V_{AB}$ and primary current of the transformer are in shown in fig.17-18 .The slight droop in the Resonant characteristics is due to the increase in conduction losses in the bridge inverter and resonant network. The output voltage of the LCL-T SPRC with PID controller are shown i n Fig.8, here the settling time 0.058 for 50% of load and 0.1 for 100% of load ,the steady state error for 50 % of load is 0.06 and 100% of load is 0.079.
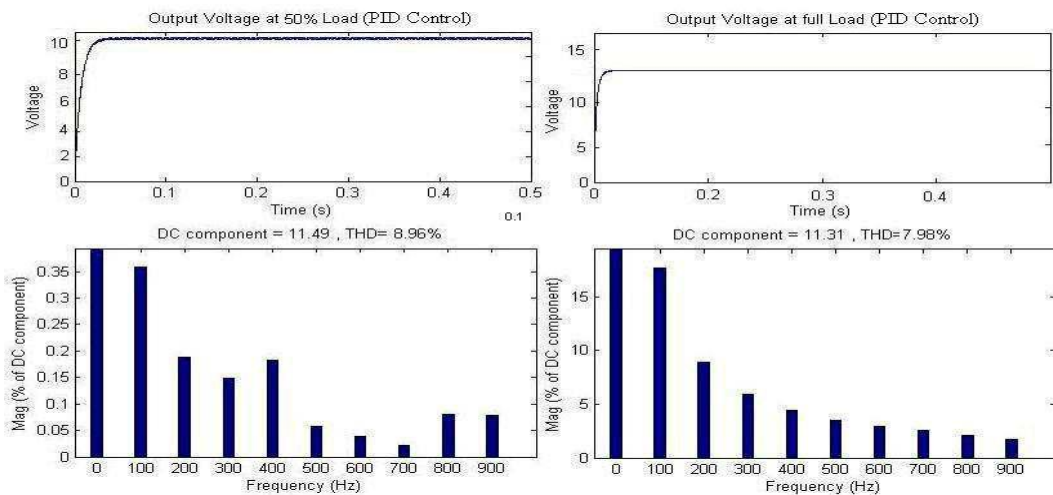


**Fig.8. Output voltage and Harmonic Spectrum at 50% and 100% of load (PID)**

Clearly, the proposed modified resonant converter is idealized by the feature o f the reactance that the resonant tank depends on the switching frequency. Therefore, the output volt age can be regulated by adjusting the switching frequency of the modified resonant converter. Owing to this characteristic, the proposed loaded-resonant converter is the preferred configuration for the applications of dc-to-dc energy conversion.

## V.    SIMULATION RESULTS

A prototype was constructed to demonstrate the effectiveness of the proposed modified resonant converter. The developed topology was connected to a24v dc source. Circuit simulations are also performed using MATLAB/SIMULINK software. In addition, the modified resonant converter was implemented in practice.

Fig.9. shows the trigger signals on the power switches, where $v_{GS1}$ denotes the trigger signals on $S_1$ and $v_{GS2}$ represents the trigger signal on switch $S_2$ resonant tank. Fig.10. and shows the waveforms of resonant capacitor voltage $v_{cr}$ and resonant capacitor current $i_{cr}$. Fig.11. and shows the waveforms of input voltage $v_b$ and current $i_b$ of the bridge rectifier.
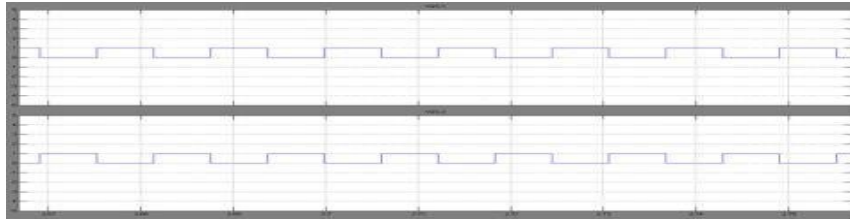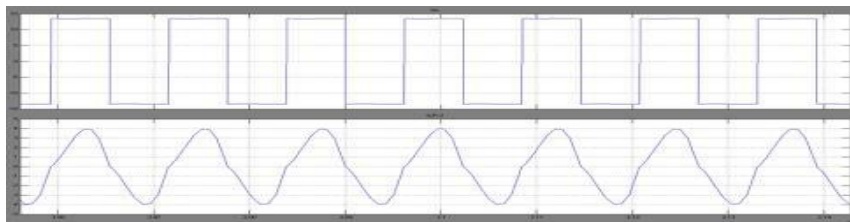


**Fig.9.Trigger signals on the power switches $V_{GS1}$&$V_{GS2}$**



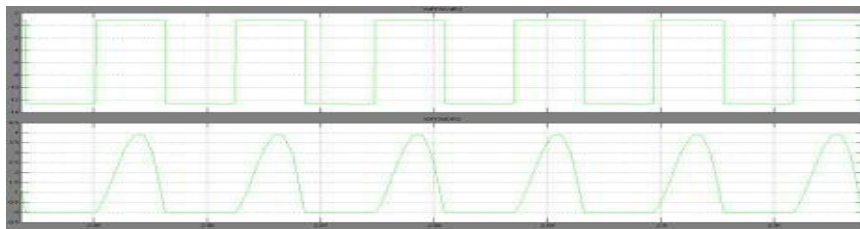**Fig.10.Input voltage & current waveform of Resonant tank $V_a$& $I_a$**



**Fig.11.Voltage and current waveforms of rectifier diodes$V_{DR1}$ '$V_{DR2}$ &$I_{DR1}$, $I_{DR2}$**

Fig. 12 and plots the waveforms of switch signal $v_{DS1}$ and switch current $i_{S1}$. Notably, power switch voltage $v_{DS1}$ equals zero when the switch is turned on. Therefore, power switch can be turned on without retaining voltage, thus achieving ZVS condition with low switching losses. Fig. 13. plots the input voltage and output voltage waveforms of the resonant tank. Fig. 14 reveals the voltage and current waveforms of rectifier diodes $D_{R1}$ and $D_{R2}$. the load voltage and current waveforms. According to the above figures, wave-forms of the simulations are consistent with the results of the experimental circuit results. The energy conversion efficiency of the proposed novel loaded-resonant converter reaches 89.5%.
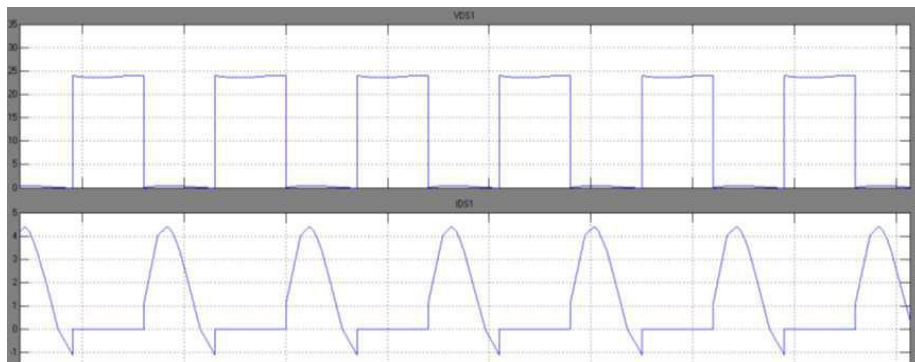


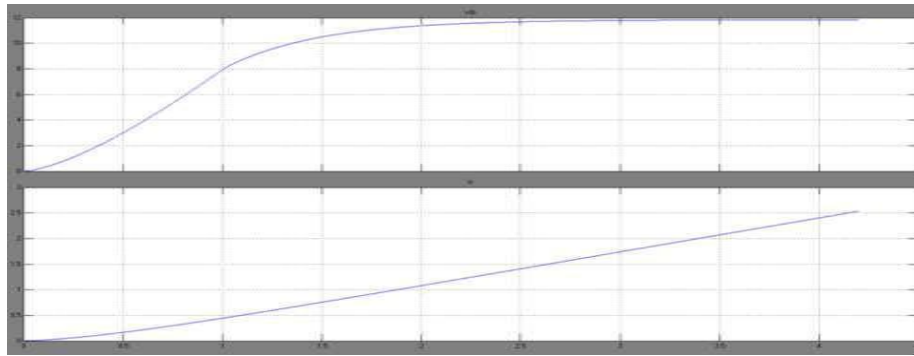**Fig.12.Waveforms of switch signal $V_{DS1}$& $I_{S1}$**

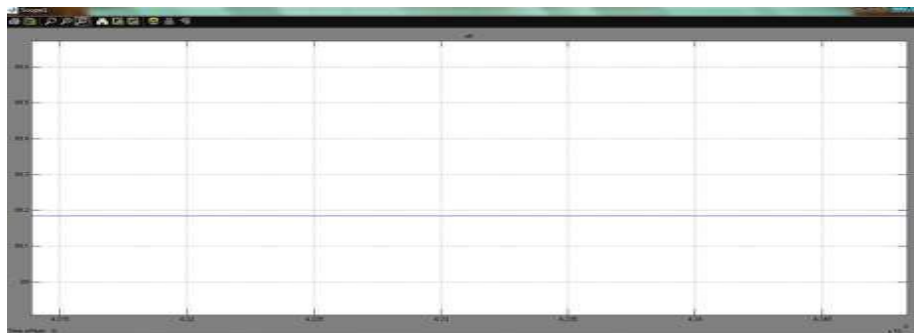**Fig.13.Load voltage and current waveforms $V_{L \&} I_L$**



**Fig.14.Energy conversion efficiency waveform**

## VI.    CONCLUSION

In this paper modified series-parallel resonant converter with control loop PID control for dc-dc energy conversion systems. Here the proposed and analyzed the complex circuit structure to simple and less expensive than other control mechanisms which require many components. The developed topology is characterized by zero voltage switching, reduced switching losses and energy conversion efficiency is increased. The energy conversion efficiency is 89.5% which is quite satisfactory when the proposed modified resonant circuit operating above resonance is applied to a dc to dc converter. In contrast with the conventional full bridge rectifier top parallel loaded resonant converter's energy efficiency can be improved using the ZVS modified series-parallel loaded resonant converter with closed loop PID control topology. An excellent performance is achieved at a lower cost with fewer circuit components than with the conventional converter.

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