International Journal of Scientific Research in Computer Science, Engineering and Information Technology
© 2018 IJSRCSEIT | Volume 3 | Issue 1 | ISSN : 2456-3307

Design and Analysis of Step-Up Resonant Converter for Renewable Energy Systems

Pasupulla Prasad[1], P. Balamaddilety[2]
[1]Research Scholar, SVR Engineering College, Nandyal, Andhra Pradesh, India
[2]Assistant Professor, Department of of EEE, SVR Engineering College, Nandyal, Andhra Pradesh, India

ABSTRACT

The rapid development in large scale renewable energy sources and HVDC grid, it is necessary to connect the renewable energy sources to HVDC grid with pure DC system. To achieve constant DC system with high power high voltage DC-DC converters are the key equipments. To transmit electric energy DC-DC converters are used. This paper presents resonant step-up converter which is well suitable for grid connection of renewable energy sources. This proposed converter can achieve high voltage gain using a parallel LC resonant tank. In this proposed converter zero voltage switching for turn-on and nearly zero current switching during turn-off can be achieved for main switches. The voltage doublers circuit that used in this converter also achieves zero voltage switching during turn-off period. In this proposed resonant step-up converter the voltage stress across the main switch and diodes are very less compared to the other resonant converters. The operating principle and selection of resonant converter parameters are discussed in this paper. The working principle of the resonant step-up converter has been successfully verified by simulation results and experimental results.
Keywords : Zero-Voltage, Zero-Current, Renewable Energy Source (RES), Voltage Stress And Step-Up Voltage.

I. INTRODUCTION

Nowadays we are facing power cuts because of lacking of proper energy sources. The generation of power is mainly by the fossil fuel like coal and crude oil etc. Today universe facing many problems caused by global warming and pollution effect become the important consideration for alternative energy. Renewable resources are considered as a technological option to get clean and safe energy. Among them, solar energy system has received a great attention as it appears to be one of the most upcoming renewable energy sources. Recently, due to its rapid development and reduction in cost, PV system becomes an effective solution for the global environmental problem.

Photo voltaic system cannot make as a constant Direct Current source because its output power is varied depending on the temperature, irradiation and load changes. The generation of power at the PV terminal is DC voltage and the generation is very low in terms of few volts to thousand volts. The generated power must be step up by using the conventional converter and then again it has to be converted to AC voltage. Here in conversion process there are many be power loss problem. These power losses should be minimized by using soft switching technology and zero voltage switching, zero current switching.

II. METHODS AND MATERIAL

1. Soft and Hard Switching

In SCR the conduction losses account for significant part of total losses. Now a day's fast converter operate at much higher switching frequency to reduce the size and weight of filter components. As the switching frequency is high the switching losses tend to predominate causing the junction temperature to rise. So to obtain loss less turn-on and turn-off we are adopting the soft-switching techniques. The converter consists of both controlled devices and uncontrolled devices (diode). Both devices are responsible for the conduction losses. The losses corresponding to each can cause the temperature rise of module.

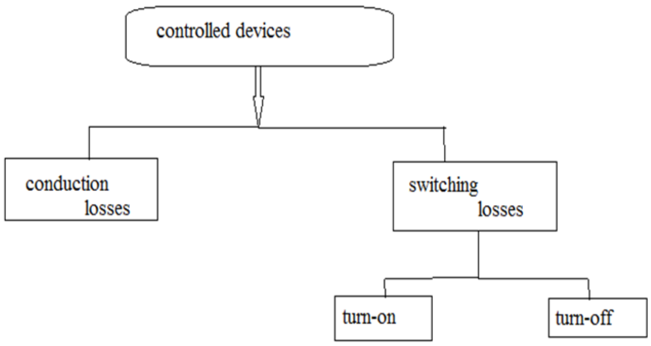

Figure 1. Losses in semiconductor devices

2. Conduction Losses

The conduction losses are caused by the forward voltage drop when semiconductor is ON. The fig 2 shows the conduction losses.

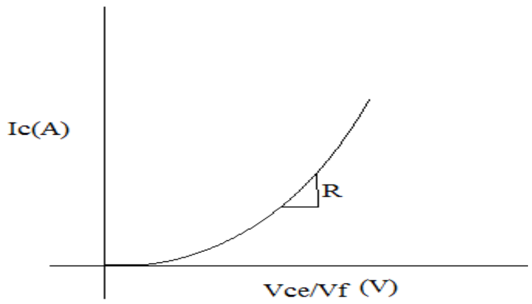

Figure 2. Typical characteristics of semiconductor

$$W_c = V_{ce(sat)} * I_c \qquad (1)$$

3. Switching Losses

The switches designed in switching converters are not for linear operation. It means switching time intervals are short. The switch can undergo turn-on and turn-off, losses occur during these switching intervals.

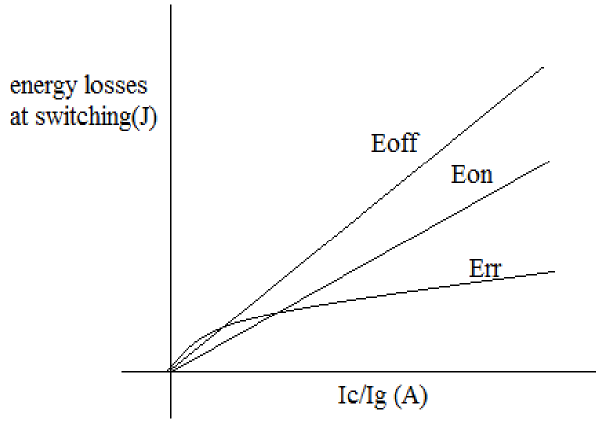

Figure 3. Switching losses in semiconductor devices

4. Soft Switching

The converters have vast applications in industry. The challenge faced by the designer is the size. So the size of the switched converter should be reduced without affecting the efficiency. This can be achieved by high switching frequency. Because Frequency and magnetic component is inversely proportional. In high switching frequency the switching losses are high. To reduce the losses at higher frequency we are going for switched resonance. From the above converter achieve lower size, weight and cost.

Therefore, the cost of the auxiliary switch and its gate drive circuit increases. Quasi-resonant converters are a category of soft-switching converters that do not use any auxiliary switch. In this method, soft-switching condition is provided by adding resonant elements to the main converter. These converters are controlled by changing the switching frequency.

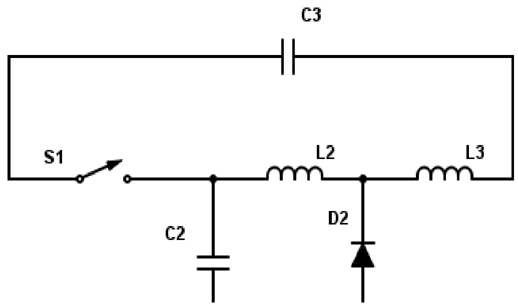

Figure 4. Zero voltage switching

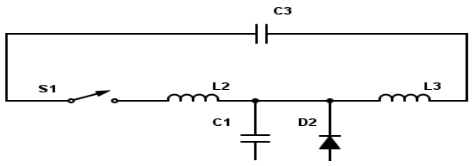

Figure 5. Zero current switching

In the converter part inductor of switching converter is the main to the size, weight and cost of converter. In Switched resonator converters, soft-switching converters that only use a small resonant inductor. The main drawback of these converters is employing more than one switch in their topologies. Where it can increase the overall converter cost.

The zero voltage switching can be obtained during the turn on process and nearly during the turn of process. In proposed converter the voltage stress across the switches is low compared to conventional full bridge converter and single active bridge. Here in proposed converter he voltage stress of upper leg switches are at the input voltage and bottom leg switches are at the value of half of output voltage.

5. Zero-voltage and Zero-current switching

To reduce the size of the transformer and filter components we are going for higher switching frequencies in the megahertz range, even tens of megahertz. The use of high switching frequency leads to cost reduction, size and weight of power electronics converter. If we design for such high switching frequencies then only the problem of switching stress, switching losses and EMI can be overcome. The switch stress can be reduced by connecting simple dissipative snubber circuit in series and parallel to the switches.

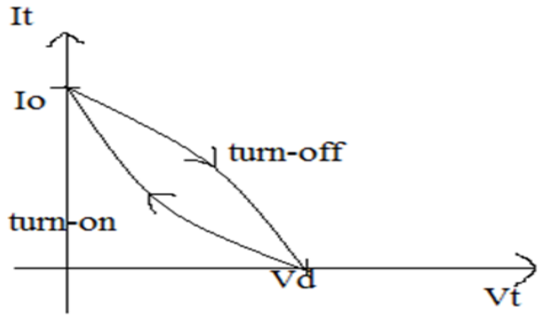

Figure 6. Switching losses of switching

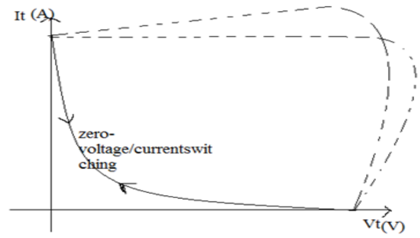

Figure 7. Comparison of soft & hard switching

6. Classification of resonant converter:

The resonant converters are classified based on the combination of converter topologies and switching strategies i.e. zero voltage switching or zero current switching.

Load resonant converter

Resonant switching converter

Resonant dc-link converter

High-frequency-link integral-half-cycle converter

7. Design specifications of resonant converter

The design specifications of proposed converter are discussed in below. In the design specification the gain of resonant converter depends on the parameters of the resonant tank i.e. L_r, C_r and the time period of switching frequency. If the switching frequency is not taken into consideration the voltage gain can be infinite. The voltage gain can be derived from the time delayt_4.

$$T_1 = \frac{(I_1 - I_0)L_r}{V_{in}}$$

$$T_3 = 2\sqrt{\frac{T_S I_0 L_r}{V_0}}$$

$T_4 = \frac{1}{W_r}\cos^{-1}(\frac{2V_{in}}{V_0})$

The voltage gain can be derived from the equation and it will depend on the resonant frequency and time period.

$$\frac{V_0}{V_{in}} = \frac{2}{\cos(W_r T_4)}$$

Where resonant frequency is given as

$$F_r = \frac{1}{2\pi\sqrt{L_r C_r}}$$

From the above equation the value of resonant inductor is given in below equation and resonant capacitor valve is obtained from resonant inductor or can be obtained from the voltage gain equation. The duty ratio for the switches can be obtained from resonant frequency and the minimum and maximum values of duty ratio are given in below equation.

$$L_r = \frac{1}{(2\pi f)^2 C_r}$$

$$C_r = \frac{P(V_0 - V_1)}{2V_1 V_0^2 f}$$

$$D_{min} = \frac{T_1}{T_s}$$

$$D_{max} = \frac{\frac{T_s}{2} - \Delta T}{T_s}$$

9. Operation of resonant step-up converter

The proposed resonant step-up converter consists of full-bridge converter in which four switches are used, LC parallel resonant tank and a voltage doubler circuit and two input blocking diodes. In proposed resonant step-up converter the high gain can be obtained by resonant tank impedance. When the resonant inductor and resonant capacitors are in resonance then the maximum gain can be obtained.

The operation of proposed converter also depends on the resonant frequencyF_r and switching frequencyF_s. In proposed converter the switches Q1 and Q4 can be turned-on and turned-off simultaneously. The fallowing assumptions are made in order to simplify the analysis:

The components that are used in the converter operation are ideal i.e. all switches, diodes, inductor and capacitors.

In proposed converter the output filter capacitors that are used in operation are large enough to meet the output voltage during the switching period.

The structure of proposed converter is shown in below fig: 8. The operational modes are explained in the fallowing stages.

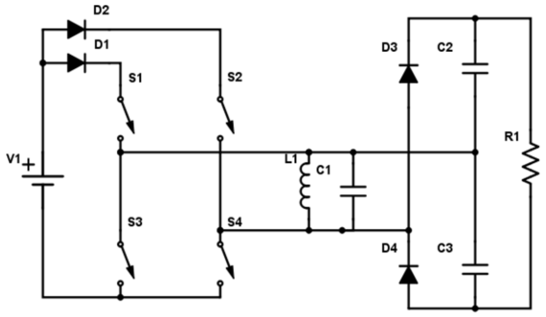

Figure 8. Topological structure of the proposed resonant step-up converter

Mode (1): During this mode of operation the switches S1 and S4 are trigged using gate pulse. And the current flows through the S1, resonant inductor and S4 to complete the operation. The positive input voltage is appeared across the LC parallel resonant tank. In this mode the converter operates similar to the boost converter and the resonant inductor acts boost inductor as like boost converter. The below fig:9 the mode 1 operation.

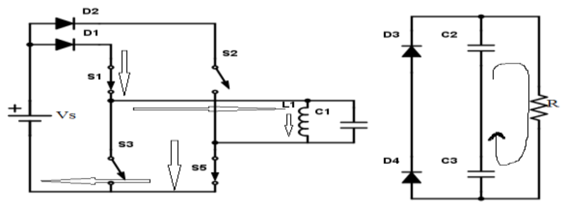

Figure 9. Mode-1 Operation

The current through the resonant inductor starts linearly from the steady state valueI_O. In this mode the load is powered by the output filter capacitors. After the completion of this mode the resonant converter is given as

$$I_1 = I_O + \frac{V_S T_1}{L_r}$$

In this mode the energy transferred is given as

$$E_{in} = \frac{1}{2} L_r (I_1^2 - I_0^2)$$

Mode (2): During this mode the switches S_1 and $S_4$are turned off at zero voltage and after that the resonant inductor L_r resonates with resonant capacitor C_r . The resonant capacitor voltage V_{cr} decrease from input voltage V_{in} and the resonant inductor currenti_{lr} increase from I_1 in resonant form. For better understanding of the converter during this mode consider parasitic output capacitors of S_1 throughS_4, the junction capacitor of blocking diode D_2 and the equivalent circuit after t_1 is shown in below fig: 10.

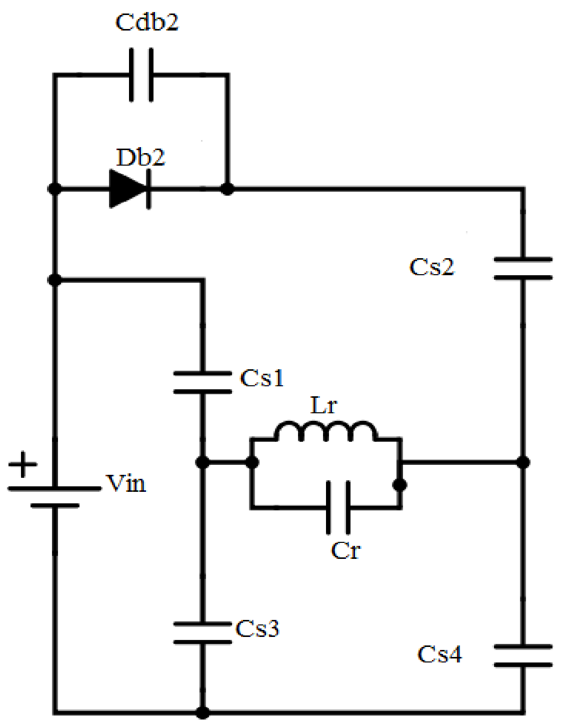

Figure 10. Equivalent Circuit of Mode 2

From the above fig:10 the capacitorsC_{Db2}, C_{s1} and C_{s4} are charged where as the rest of the capacitors are discharged. To realise zero voltage switching for S_2 and S_3 an additional capacitor is connected in parallel with respect to C_{s2} and the value of the capacitor is ten times the value of the capacitorC_{s2}. The value of resonant capacitor C_r is much larger than parasitic capacitances; hence the voltage across the switch S_1 and S_4 increase slowly. So the switches S1 and S4 are turned off at almost zero voltage in this mode.

When the voltage across the resonant capacitor decrease to zero then the resonant inductor current reaches to its maximum magnitude. After that resonant capacitor voltage increase in negative direction and i_{lr} declines in resonant form.

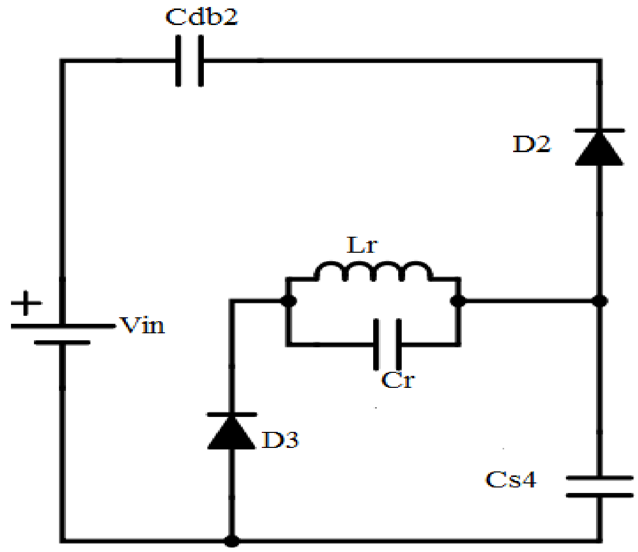

Figure 11. Equivalent Circuit of Mode 3

At time period t_2 $V_{cr} = -V_{in}$ and the voltage across switch S_1 and S_4 reaches to input voltage V_{in} as a result the voltage acrossS_2, S_3 fall to zero and it can be turned on under ZVS condition.As the switchesS_2, S_3 are turned on but there is current flowing through them because the gate pulse is not triggered. After t_2 the resonant inductorL_r is continues to resonate with resonant capacitorC_r and the voltage across V_{cr} keep on increase in negative direction. The voltage across the switch S_4 is continues to increase from V_{in} to half of the output voltage and the switch voltage across S_1 is kept at the input voltageV_{in}.

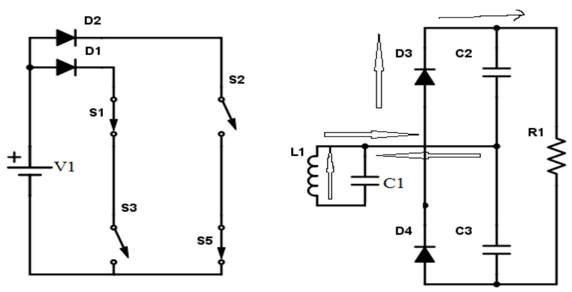

Figure 12. Mode-2 Operations

From the above fig: 12 the voltage stress across S_1 is at input voltage and the voltage stress across S_4 is the value of half of output voltage. During this mode no power transfer from input source to load and whole energy is stored in LC resonant tank. The fallowing equations represent the flow of power.

$$\frac{1}{2}L_rI_1^2 + \frac{1}{2}C_rV_{in}^2 = \frac{1}{2}L_rI_2^2 + \frac{1}{2}C_r\left(\frac{V_0}{2}\right)$$
$$i_{lr}(t) = \frac{V_{in}}{Z_r}\sin[(t-t_1)W_r] + I_1\cos[(t-t_1)W_r]$$

$$V_{cr}(t) = V_{in}\cos[(t-t_1)W_r] - I_1Z_r\sin[(t-t_1)W_r]$$

Where
$$W_r = \frac{1}{\sqrt{L_rC_r}}$$

Mode (3): In this mode the triggering pulse is given to the switches S_2 and S_3. The inductor current decrease in negative direction. The resonant capacitor voltage V_{cr} increase in positive direction. The switch voltages in this mode is given as across the switch S_2 is input voltage and voltage across the switch S_3 is the half of the output voltage. Therefore the voltage stresses across the switches are input voltage and half of output voltage.

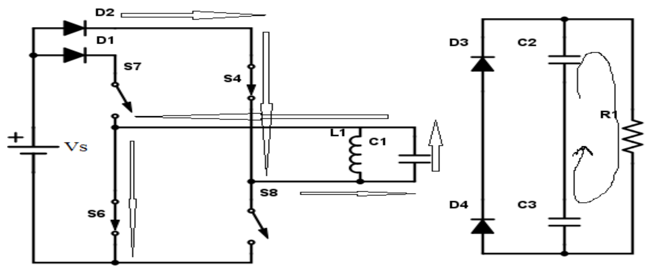

Figure 13. Mode-3 Operations

The fig: 13 show the mode of operation. The voltage across the output capacitors are the half of the output voltages. The voltage doubler circuit doubles the voltage of V_{cr} .

Mode (4): In this mode of operation the switch S_3 and S_2 are turned off by zero voltage switching condition. The inductor is resonant with the capacitor and the stored energy is delivered to the load. In this mode the current flows through the D_4 and to the load capacitors.

The voltage across the output capacitors are not equal i.e. $V_{c1} \neq V_{c2}$ because the average current flowing into C_1 will be higher than the average current flowing through the C_2 and vice versa. The capacitor C_1 and C_2 share the same power hence V_{c1} decrease and V_{c2} increases and finally they will share the same output voltage.

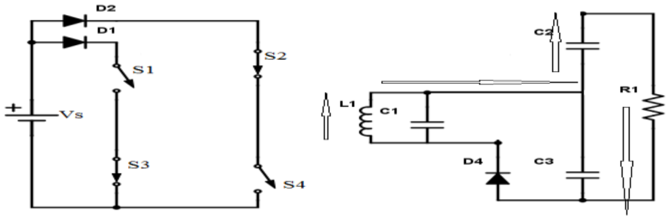

Figure 14. Mode-4 operation

From the above fig it is clear that the power flow to the load is fed by the stored energy in the LC resonant tank.

III. RESULTS AND DISCUSSION

Experimental Results

The hardware components specification and its rating given in the Table: and these specifications are the maximum ratings of the component and the storage components inductor and capacitor are the critical values of converter. These specifications and components are given based on the design of converter.

Gate Drive Circuit

Fig: 15 shows the circuit diagram of gate drive circuit for switches used in proposed converter. MOSFETs are voltage-controlled devices and very high input impedance. The gate draws a very small leakage current, in the order of nanoamperes. The turn on time of an MOSFET depends on the charging time of input or gate capacitance.

The gating circuit is an integral part of a power converter that consist of power semi-conductor devices. The output of a converter depends on how the gating circuit drives the switching devices is a direct function of switching. Therefore, the characteristics of the gating circuit are key elements in achieving the desired output and the control requirements of any power converter.

The design of a gating circuit requires knowledge of gate characteristics and needs of device such as thyristors, bipolar transistors, and MOSFETs. Because power electronics are increasingly used in applications that require gate drive circuits with advance control, high speed, high efficiency, and compactness, gate driver integrated circuits are becoming commercially available.

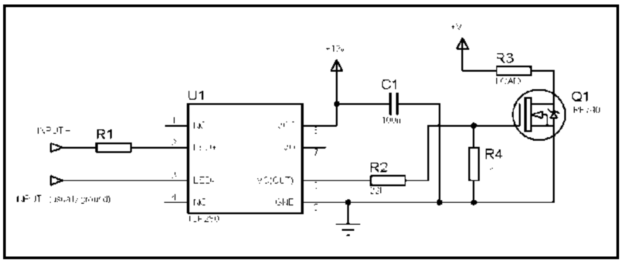

Figure 15. Gate driver circuit for switches

The hardware implementation of gate drive circuit shown in Fig:15 and circuit uses to boost the supply voltage for turning on the MOSEFET using PIC kit and connected directly to the gate terminal of the switch as shown in Fig: 4.6.

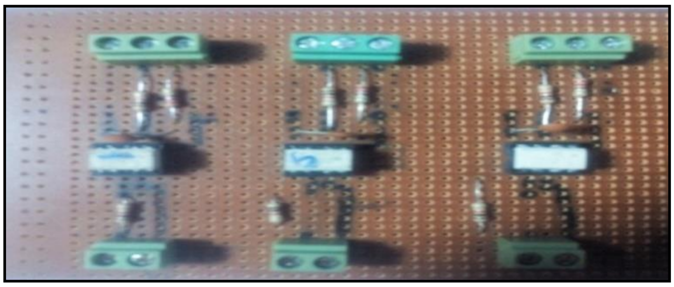

Figure 16. Hardware implementation of gate driver circuit

The below fig:16 show the experimental set up of a resonant step-up converter. In the diagram testing of a circuit by the PIC micro controller for the generation of pulse to trigger the main switches.

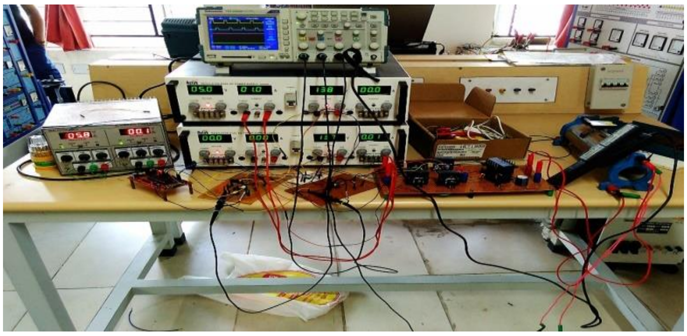

Figure 17. Hardware implementation of proposed converter

The fig:17 represent the input voltage and output voltage waveforms. In this waveform when the input voltage is given to converter and the gain obtained is eight times greater than the input voltage. The pulse is given to the switches with the 30% duty ratio so that the control of the circuit is easy.

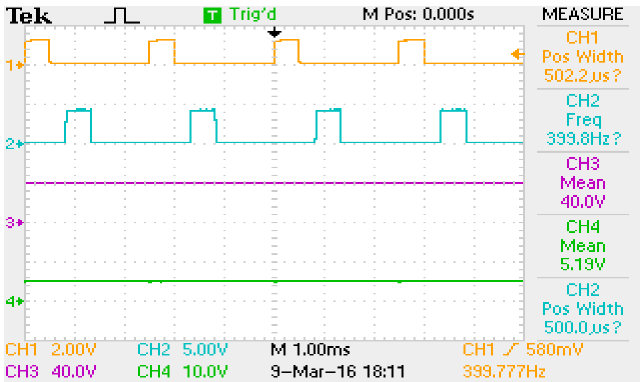

Figure 18. Input and Output voltage of converter

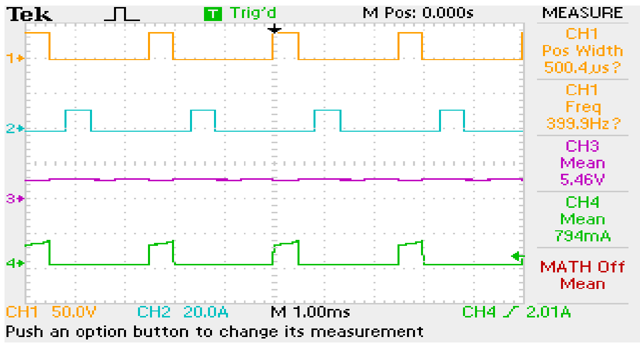

Figure 19. Input voltage and current of converter

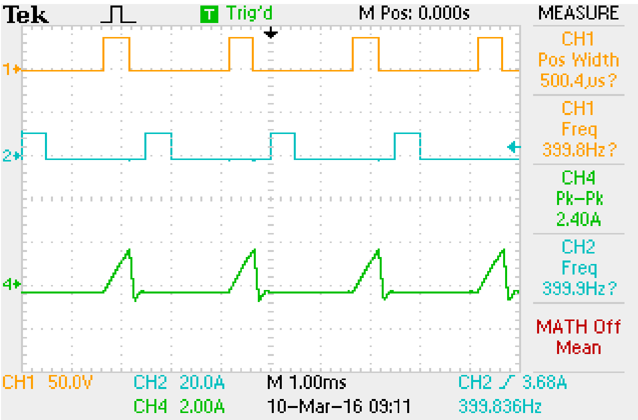

Figure 20. resonant inductor current of the converter

IV. CONCLUSION

A novel step-up resonant converter is suggested in this paper, which can achieve high voltage gain through the parallel LC resonant tank and it is well suitable for high-power high-voltage applications. The converter uses the resonant inductor to deliver power as that of boost converter. The resonant inductor charges from the input and discharges at the output. To achieve zero voltage switching during turn-on, turn-off for the active switches and zero current switching for rectifier diode the resonant capacitor is employed. From the analysis the converter can operate at any gain (>2) with proper control of active switch. The maximum switching frequency of the converter can be achieved from the parameters of resonant tank. And it also determines the range of switching frequency and current ratings of active switches and diodes. The proposed resonant converter is operated at constant switching frequency. The operation principle and selection of resonant parameters can be verified by simulation and experimental results.

V. REFERENCES

[1]. CIGER B4-52 working group, HVDC grid feasibility study. Melbourne, vic. Australia : int. council large electer.syst2011.

[2]. A.S.Abdel-khalik, A.M.massoud A.A elserougi, and s.ahmed, "optimum power transmission based droop control deasignfor multi – terminal HVDC of offshore wind farms ", IEEE trans. Power system.vol 28, no.3, pp. 3401-3409, aug 2013.

[3]. Jovic "Bidirectional, high power DC Transformer", IEEE Trans.Power Del.VOL.24, no.4, pp.2276-2283, oct 2009.

[4]. C.Zhan, A.Bullock, C.Smith and A.Crane, "Power collection and transmission systems" Eur Patent apple.EP2341594A1, 2011.

[5]. C Mayer "key components for future offshore DC grids", Ph.D.Dissertation, RWTH Aachen Uni..Asachen, Germany pp 9-12-2007.

[6]. K.Stephen " Moduler DC/DC converter for DC distribution and collection networks" Ph.D dissertation.EPFL Lausanne, Switzerland .pp.81-94-2012.