ISSN 2348 – 8034
Impact Factor- 4.022

GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES

INTERFACE USING DC-DC HIGH STEP-UP NON-TRANSFORMER RESONANT CONVERTER FOR GRID CONNECTED NON-CONVENTIONAL ENERGY SOURCES

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ABSTRACT

In this work, interface using DC-DC high Step-up non-transformer resonant converter for grid connected Non-conventional energy sources is proposed. It is a promising option to make use of renewable energy sources to be connected to HVDC grid which require high voltage & high power renewable energy sources. A dc-dc step-up converter is used as major equipment which operates as a resonant converter with high voltage gain. The voltage stress on the semiconductor devices & switching losses is reduced by zero voltage switching (ZVS) turn-on and turn-off method and also with zero current switching (ZCS) turn-off of converter switches. The selection of required parameters for the dc-dc step-up resonant converter is presented in this paper. The proposed converter system operation, performance and simulation results have been successfully verified by using MATLAB/Simulink.

Keywords: *dc-dc step-up converter, parallel LC resonant tank, soft switching (zero voltage & zero current)*

I. INTRODUCTION

Now a day's, with the rapid increment of utilization of electrical energy, the generation of electrical energy by the conventional method is high cost with less efficiency. So it is essential to depend on the non-conventional energy sources such as solar, the wind and etc. The different energy storage devices and renewable energy sources are having low DC voltage, like photovoltaic (PV) cells, super-capacitor, battery and fuel cells are usually required to be stepped up to a high-level AC voltage for industrial applications. Moreover, in renewable energy sources such as solar and wind, the common issue is the large variations of output power, and the large scale connection of the renewable sources to the power grid is more challenging for the traditional electrical equipment, grid operation and structure. Recently, intensive research on DC-DC converters has been carrying out to implement for conversion and extensive voltage regulation.

At present, the generation of voltages over the dc stages in the equipment of the renewable energy sources is very low, such as several hundred volts. Since, HVDC grids are required high voltage high power electrical energy, step-up dc-dc converters are employed. The generated renewable energy passes through the step-up DC-DC converters and finally connected to HVDC grid by using special connectors. These connectors not only transmit electrical energy but also isolate or buff kinds of fault conditions. These are one of the key equipment in the DC grid.

For high power high voltage step-up DC-DC conversion, conventional boost converter and transformer-based switched-mode power supplies (SMPSs), such as Fly-back and Forward converters etc., are normally used because of their simple topology.

In general, with high duty cycle, as a boost converter is operated, the output voltage is high. But with high amplitude, a short pulse current is sustained by a rectifier diode, which increases the reverse recovery losses of a diode and electromagnetic interference (EMI) problem. And also requires the high rating of switches or power semiconductor devices, which also increases the conduction and switching losses. The power semiconductor switches during turn on and off process, the entire load current is carried by the switches. Then these switches are subjected to high switching stresses which results in high switching power losses. The step-up dc-dc converters are used in automotive applications with the help of bridge topology i.e., the full bridge or half bridge, with high

ISSN 2348 – 8034
DOI- 10.5281/zenodo.998004
Impact Factor- 4.022

frequency step-up ratio transformer. Due to this, the cost, weight, and volume of the converter are increased with less efficiency.

To overcome all these defects, a high step-up dc-dc transformer less resonant converter is used in this work. By adding an LC parallel resonant converter to the step-up dc-dc converter, the voltage and/or current undergo to a zero-level periodically. If the power semiconductor devices/switches of the converter are tuned on & off at zero voltage and/or zero current, then the voltages stress on devices/switches, switching losses and EMI generated etc., are drastically reduced. Hence the terms "zero voltage switching (ZVS) or zero current switching (ZCS)". It also improves the performance of the converter with soft switching technology and efficiency with less cost & weight. In this work, the input for DC-DC converter is generated from solar panel and the simulation results are provided to demonstrate the effectiveness of the proposed high step-up dc-dc resonant converter.

II. PROPOSED CONVERTER STRUCTURE

The proposed dc-dc high step-up resonant converter topology is shown in Fig.1. In this section, converter structure and brief operation of the converter is preserved. The proposed converter consisting of a full bridge network, which includes four IGBT's (S1, S2, S3 & S4) and an LC parallel resonant tank (Lr, Cr) and a voltage doubler converter/rectifier (D1, D2) & only one input blocking diode D_b. The steady-state operating waveforms of the proposed converter & the driving signals of all main switches & different modes of operation waveforms are shown in fig.2.

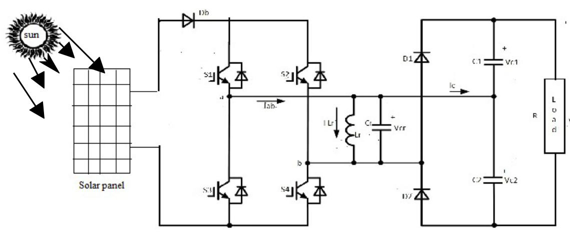

Figure 1. Circuit topology of the proposed converter

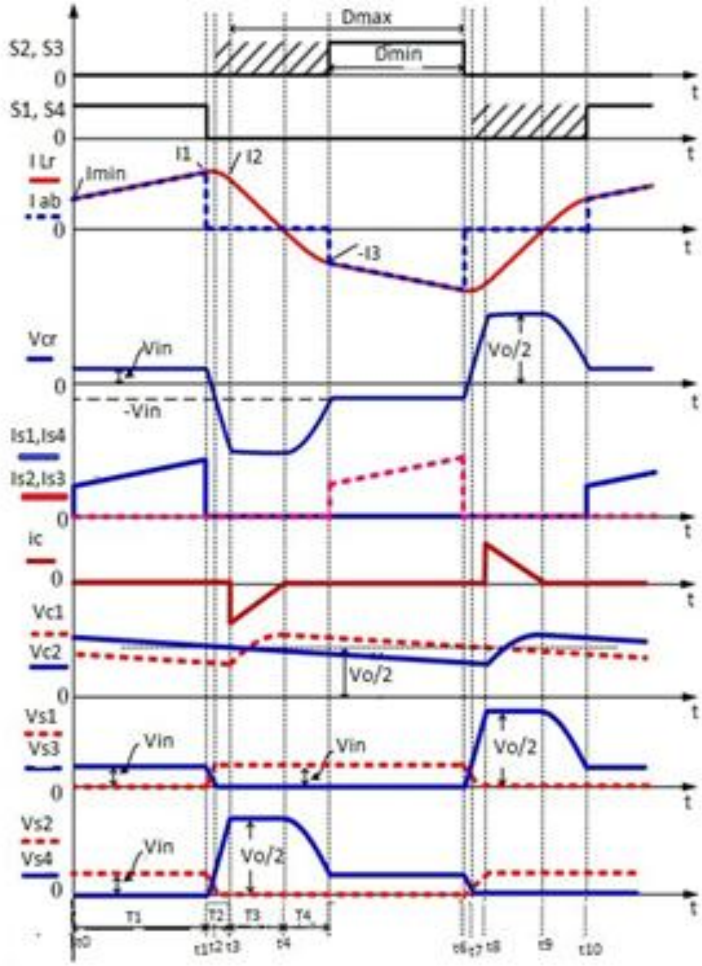

Figure 2. Operating waveforms of the proposed converter

III. PRINCIPLE OF OPERATION

The brief description and analysis of different modes of operation are shown in Fig.3. The required input DC voltage is generated from a solar panel and is fed to the DC-DC converter. In this topology, a total of eight different modes of operations are present for a switching period "T_S". For the proposed converter, S1 & S4 are turned on & off simultaneously; similarly, S2 & S3 are turned on & off simultaneously by giving driving signals. The Process of the converter is simplified by the assumptions as listed below;

1) All the power semiconductor devices/switches are IGBT's, Diodes, Capacitors and Inductors are ideal components.
2) The converter is under steady state operation.
3) The output capacitors C1& C2 are equal & with large values. So that in a switching period of 'Ts' the output voltage V_0 is considered as constant.

a) Mode 1 [t_0, t_1] [see through Fig. 3(a)]

In this mode of operation, S1& S4 are turned on and the input voltage V_{in} applied across the parallel LC resonant converter ie. $V_{Lr} = V_{Cr} = V_{in}$. During this mode, the operation of the converter is similar to a conventional boost converter & the current through the resonant inductor L_r is increases linearly from I_{min}, that inductor L_r is acts as boost inductor. At this condition, load is powered by C1 & C2. Finally at t_1, the I_{Lr} reaches to I_1.

$$I_1 = I_{\min} + \frac{V_{in}T_1}{L_r} \qquad (1)$$

Where T_1= time interval between t_0 to t_1.

The energy delivered to L_r is given by,

$$E_{Lr} = \frac{1}{2}L_r(I_1^2 - I_{\min}^2) \qquad (2)$$

b) Mode 2 [t_1, t_3] [see through Fig. 3(b)]

In this mode of operation, S1& S4 are turned off and then L_r resonates with C_r. At t_1, I_{Lr} starts to increase from I_1 to I_{max} and similarly, V_{Cr} starts to decrease from V_{in} to 0. At t_2, the V_{Cr} increases from ‘0” in negative direction $V_{Cr} = -V_{in}$ & the I_{Lr} starts to decrease from I_{max} ie. $I_{Lr} = I_{max}$. Also during this transition, the voltages across switches S1 & S4 reach V_{in} & the voltages across S2 & S3 falls to zero. Then these two switches are turned on at ZVS. After t_2, S2 & S3 are turned on but no current flows through these switches. The anti-parallel diodes of S2 & S3 are in conduction respectively. During this mode of switching period, the power doesn’t transfer from source to load. The total energy is said to be stored in LC parallel resonant tank, ie.,

$$\frac{1}{2}L_rI_1^2 + \frac{1}{2}C_rV_{in}^2 = \frac{1}{2}L_rI_2^2 + \frac{1}{2}C_r\left(\frac{V_0}{2}\right)^2 \qquad (3)$$

We have

$$\left.\begin{aligned} I_{Lr}(t) &= \frac{V_{in}}{Z_r}\sin[w_r(t-t_1)] + I_1\cos[w_r(t-t_1)] \\ V_{Cr}(t) &= V_{in}\cos[w_r(t-t_1)] - I_1Z_r\sin[w_r(t-t_1)] \end{aligned}\right\} \qquad (4)$$

$$T_2 = \frac{1}{w_r}\left[arc\sin\left(\frac{V_{in}}{\sqrt{V_{in}^2 + \frac{L_rI_1^2}{C_r}}}\right) + arc\sin\left(\frac{V_0}{2\sqrt{V_{in}^2 + \frac{L_rI_1^2}{C_r}}}\right)\right] \qquad (5)$$

Where T_2= time interval between t_1 to t_3.

$$w_r = 1/\sqrt{L_rC_r}\ , \quad Z_r = \sqrt{L_r/C_r}$$

ISSN 2348 – 8034
Impact Factor- 4.022

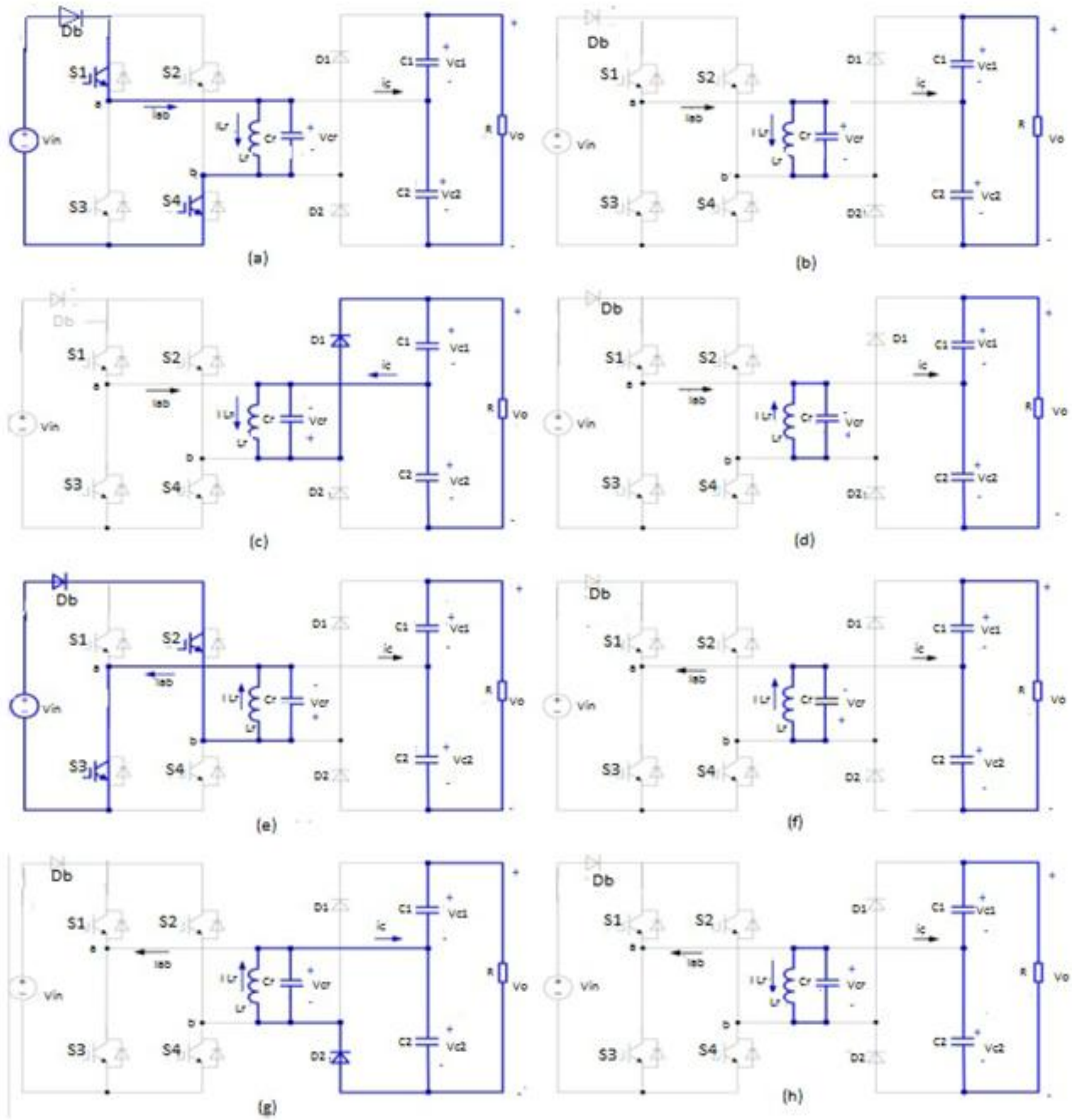

Figure 3. Equivalent circuits of each mode of operations stages. (a) [t_o, t_1]. (b) [t_1, t_3]. (c) [t_3, t_4]. (d) [t_4, t_5]. (e) [t_5, t_6]. (f) [t_6, t_8]. (g) [t_8, t_9]. (h) [t_9, t_{10}]

c) Mode 3 [t_3, t_4] [see through Fig. 3(c)]

In this mode of operation, at t_3, $V_{Cr} = -V_0/2$ and all switches are not in conduction mode. The diode D1 starts conducting naturally, the output capacitance C1 is charged because of I_{Lr} through diode D1 without any change in

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[Naik, 4(9): September 2017] ISSN 2348 – 8034
DOI- 10.5281/zenodo.998004 Impact Factor- 4.022

the V_{Cr} and I_{Lr} linearly decreases and finally reaches to zero at t_4. The delivered energy across load in this mode of operation is given by,

$$E_{out} = \frac{V_0 I_2 T_3}{4} \qquad (6)$$

Where T_3= time interval of t_3 to t_4

$$T_3 = \frac{2I_2 L_r}{V_0}$$

In half of the switching period, the total consumed energy is given by,

$$E_R = \frac{V_0 I_2 T_S}{2} \qquad (7)$$

Let as assuming the conversion efficiency of the converter is 100 % and we can write the equation for half of the switching period is,

$$\mathrm{E_{in}} = \mathrm{E_{out}} = \mathrm{E_R} \qquad (8)$$

Substituting the (6), (7) in (8), then we have

$$I_2 = V_0 \sqrt{\frac{I_{\min} T_S}{V_0 L_r}} \qquad (9)$$

$$T_3 = 2\sqrt{\frac{I_0 L_r T_S}{V_0}} \qquad (10)$$

d) Mode 4 [t_4, t_5] [see through Fig. 3(d)]

At t_4, I_{Lr} = 0 and current in the diode D1 also decreases to zero. At this condition, the D1 diode is turned off with ZCS; and hence there is no reverse recovery. After t_4, L_r resonates with Cr. Then Cr starts to discharge through Lr, V_{Cr} increases in positive direction & I_{Lr} increases in negative direction. And finally in this mode of operation at t_5, $V_{Cr} = -$Vin & $I_{Lr} = -I_3$.

In this mode of operation, the stored energy in the *LC* resonant tank is unchanged, i.e.,

$$\frac{1}{2} C_r \left(\frac{V_0}{2}\right)^2 = \frac{1}{2} L_r I_3^2 + \frac{1}{2} C_r V_{in}^2 \qquad (11)$$

We have

$$I_0 = I_3 = \frac{1}{2}\sqrt{\frac{C_r (V_0{}^2 - 4V_{in}{}^2)}{L_r}} \qquad (12)$$

$$I_{Lr}(t) = -\frac{V_0}{2 w_r L_r} \sin[w_r (t - t_5)] \qquad (13)$$

$$V_{Cr}(t) = -\frac{V_0}{2} \cos[w_r (t - t_5)] \qquad (14)$$

$$T_4 = \frac{1}{w_r} arc\cos\left(\frac{2V_{in}}{V_0}\right) \qquad (15)$$

Where T_4 = time interval of t_4 to t_5.

e) Mode 5 [t_5, t_6] [see Fig. 3(e)]

In this mode of operation, the switches S2 & S3 are turned on and L_r Starts charging by V_{in} through S2 & S3, I_{Lr} increases in negative direction.

The modes of operation from t_5 to t_{10} are similar to modes of operations of t_0 to t_5. All the equivalent circuits of these modes of operations were presented in Fig. 3. During mode 5 to mode 8, the switches S2 & S3 are turned on and switches S1 &S4 are turned off with ZVS and the diode D2 is turned off with ZCS condition.

IV. ANALYSIS OF THE CONVERTER

In the proposed converter, the input diode can act as a protection device for source/input side. It can block the output faults and prevent the fault pass through input side and vice versa.

From fig. 2, we have

$$T_1 + T_2 + T_3 + T_4 = \frac{T_s}{2} \quad (16)$$

By combining (1), (2) & (12)

$$V_0 I_0 T_S = \frac{V_{in}^2 T_1^2}{L_r} + V_{in} T_1 \sqrt{\frac{C_r (V_0^2 - 4V_{in}^2)}{L_r}} \quad (17)$$

Rewriting the above equation

$$T_1 = \frac{\sqrt{\frac{C_r (V_0^2 - 4V_{in}^2) + 4V_0 I_0 T_S}{L_r}} - \sqrt{\frac{C_r (V_0^2 - 4V_{in}^2)}{L_r}}}{2\frac{V_{in}}{V_0}} \quad (18)$$

From equation (15), the gain of the converter is given by,

$$\frac{V_0}{V_{in}} = \frac{2}{\cos(w_r T_4)} \quad (19)$$

Substitute the equation (18) in (1) yields,

$$I_1 = \sqrt{\frac{C_r (V_0^2 - 4V_{in}^2) + 4V_0 I_0 T_S}{4L_r}} \quad (20)$$

Substitute the equation (20) in (3) yields,

$$I_2 = \sqrt{\frac{V_0 I_0 T_S}{L_r}} \quad (21)$$

The resonant frequency of the converter is given by,

$$f_r = \frac{1}{2\pi\sqrt{L_r C_r}} \quad (22)$$

We can observe that the gain of the proposed converter is affected by the parameters of resonant converters (L_r & C_r) and the part of switching period of T_4. That implies, the gain of the converter is impacted by L_r, C_r and the switching frequency.

V. SIMULATION RESULTS

The proposed converter circuit has been simulated using MATLAB software. The results have verified to be acceptable with the theoretical results. The detailed simulated parameters are

ISSN 2348 – 8034
Impact Factor- 4.022

Input voltage, V_{in} = 40 V
Output voltage, V_0 = 800 V
Resonant inductance, Lr = 600µH
Resonant capacitance, Cr =1.68µF
Filter capacitance, C_1, C_2 = 22µF
Switching frequency, f_s = 4000HZ

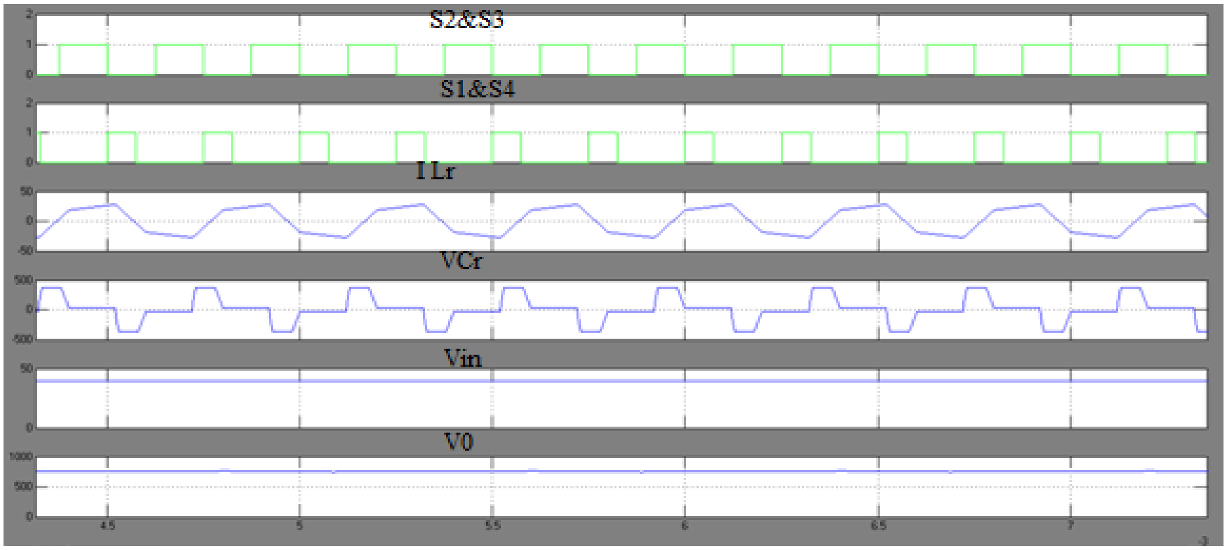

Figure 4. Experimental waveforms of switching signals and resonant inductor current & capacitance voltage with input voltage 40volts

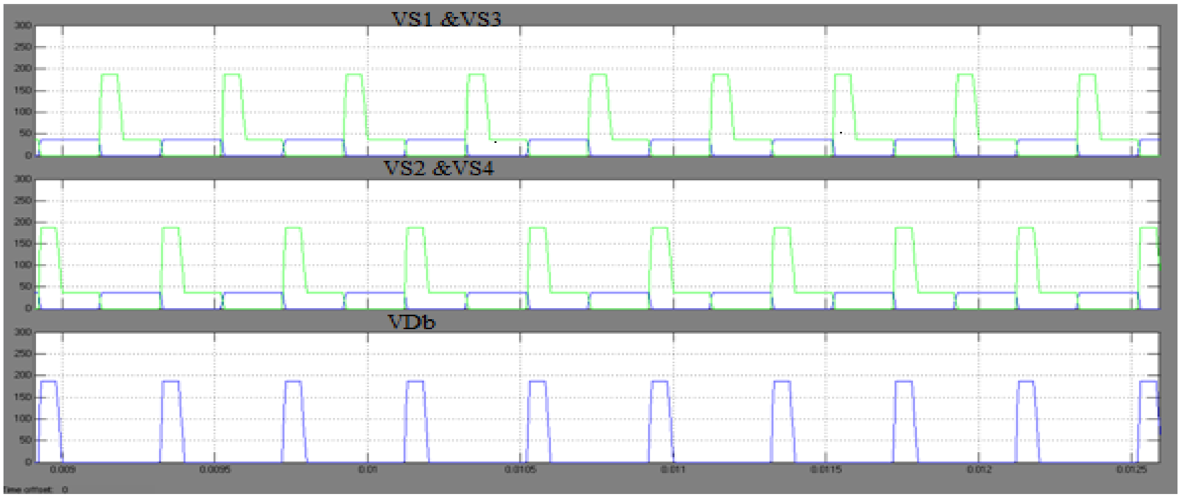

Figure 5. Voltages across switches and diodes

[Naik, 4(9): September 2017] ISSN 2348 – 8034
DOI- 10.5281/zenodo.998004 Impact Factor- 4.022

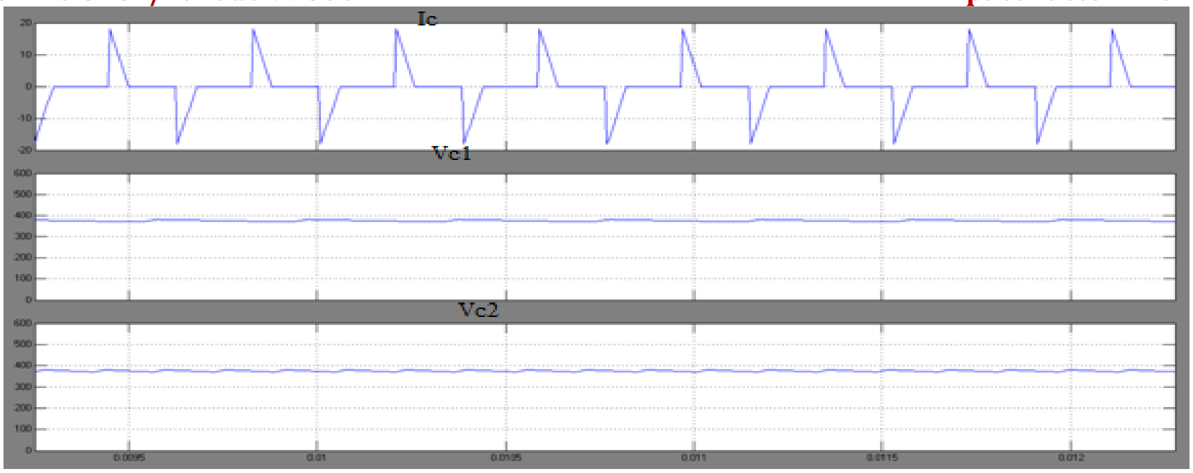

Figure 6. Output capacitance current and voltages

VI. CONCLUSION

In this work, interface using DC-DC high Step-up non-transformer resonant converter for grid connected Non-conventional energy sources is proposed, which can achieves very high step-up voltage gain and it is suitable for high-power high-voltage applications. The converter utilizes the resonant inductor to delivery power by charging from the input and discharging to the output. The resonant capacitor is employed to achieve zero-voltage turn-on and turn-off for the active switches and ZCS for the rectifier diodes. The analysis demonstrates that the converter can operate at any gain value (>2) with proper control, however, the parameters of the resonant tank determine the maximum switching frequency, the range of switching frequency and current ratings of active switches and diodes

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