A NOVEL ZERO VOLTAGE TRANSITION DC-DC BOOST CONVERTER FOR PHOTOVOLTAIC (PV) ENERGY SYSTEM

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ABSTRACT

In this work, a boost converter operating all the switching devices under Zero Voltage Transition is designed and a model converter which can supply a load of 250W is designed to be used in a PV energy system. In this converter topology, a part of the circuit resonates for a small portion of the switching cycle of the converter, known as the auxiliary circuit that enhances the soft transition from ON state to OFF state and vice versa, there by improving the converter efficiency by reducing the dominating portion of in losses i.e. the losses that occur due to hard transition of the switches. Due to reduced losses during switching transitions heating effect of MOSFETs is reduced and they have a longer life. The comparative study between the new topology and conventional hard switching converter is analyzed in terms of reduction of switching losses and improvement of efficiency.

Keywords: Boost Converter, PV Energy System, Resonant Circuit, Soft Switching, ZVT.

I. INTRODUCTION

Usually, the converters operating under Zero Voltage Transition (ZVT) help solving the problem of prohibitive Electromagnetic Interference (EMI) either by using a diode whose recovery characteristics are not fast, to increase the turn OFF time of switch present in the boost circuit, which increases the switching losses [3], or by using passive snubber circuits which increase the conduction losses [4] [5], thus reducing the converter efficiency and limiting the switching frequency. So the problem of EMI is solved only at the cost of reduced efficiency. So there is a need for highly efficient converters with reduced EMI.

The most important thing in the converter design is the positioning of the auxiliary switch. If the source terminal of the switching MOSFET is not connected to the common point of grounding in the circuit, we will need a floating gate drive, which demands an effective gate voltage greater than the input voltage. A reduced stress of voltage and current peaks on the switching devices is always recommended for safety of devices.

The principle of ZVT is that the auxiliary circuit carries a current higher than the input current flowing through the boost inductor just for a fractional part of switching time, in order to attain soft turn ON and OFF transitions of the main and auxiliary switches. So, these converters have higher losses than the simple or conventional converters that do not operate under soft transition of switching. But the efficiency of soft switching converters is high as the losses due to hard switching in the soft switching converters are very low as compared to the conventional hard switching converters. Also, as the auxiliary circuit it-self is soft switching and due to the creative placing of the snubber capacitor which controls the ON to OFF transition of the switch in the boost circuit, this converter reduces the EMI and increases the efficiency.

II. HIGH SWITCHING FREQUENCY OPERATION

A power electronic converter has energy storage elements such as inductors, capacitors and transformers that account for much of its overall size. These components are used to store and transfer energy as part of the power conversion process. As a converter's switching frequency is increased, the component values of its energy storage elements Decrease, as do their physical size and weight, due to the shorter time they are required to store voltage or current. As a result, the higher the switching frequency a converter operates with, the smaller its energy storage elements (and thus its overall size) will be.

There are, however, drawbacks to operating a switch-mode power electronic converter with high switching frequency, the key one being that doing so increases the converter's switching losses. Unlike an ideal switch that would be able to turn on and off Instantaneously without any overlap between the voltage across it and the current flowing through it, a real switch does have these overlaps in voltage and current whenever a switching transition from on to off or vice versa is made.

Since power is dependent on the product of voltage and current, the fact that there is voltage/current overlap during switching transitions means that there are power losses during these times. These losses are referred to as switching losses in the power Electronics literature and the higher the switching frequency that a power converter operates with, the more switching losses it will have.

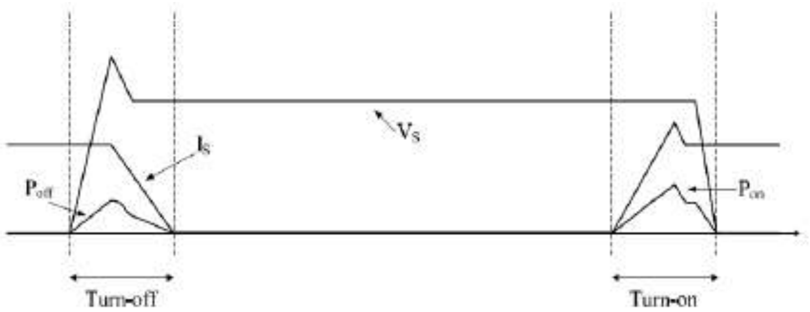


Fig 1: Typical switch voltage and current waveforms

III. POWER LOSSES IN HARD SWITCHING CONVERTER

In the switching converters, when the switching device is in ON state, as the voltage blocked by the switch is zero, the power losses are zero. When the switch remains in the off state, as the current allowed by the switch is zero, the power losses are zero. But during the transition of the switch from both ON state to OFF state and OFF state to ON state, if there is no mechanism to make either voltage or current zero, power losses occur. This is in the case of hard-switching converters.

In the hard switching converters, power losses will occur when there will be a simultaneous non-zero voltage applied across and non-zero current flowing through the switch. When the switching device turns ON or OFF, the device voltage and current are high in simultaneous cases resulting in high losses. This is shown as waveforms in figure 2, (i) showing control pulse given to the switching device, (ii) the device voltage and current and (iii) power losses per switching cycle.

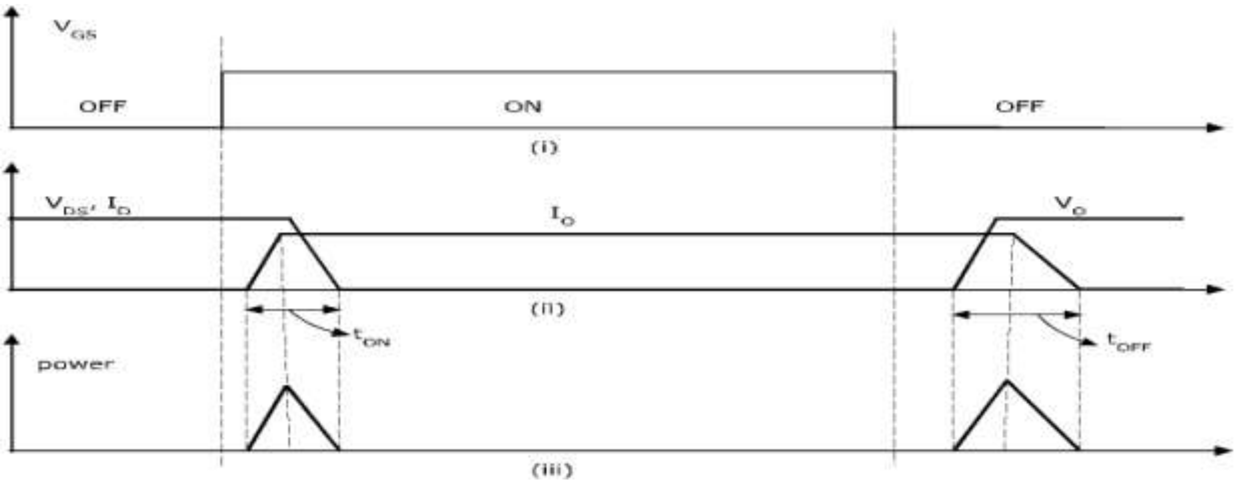


Fig 2: Switching losses in hard switching converters

The power losses corresponding to a single switching transition are the product of the voltage that appears across the terminals of the switch and the current flowing through the switch. The entire switching losses are the product of energy or power lost per switching transition and the switching frequency. The power losses that occur due to these switching transitions are referred to as switching losses.

The switching losses in one switching cycle can be denoted in equation (1)

$$P_{sw} = V_s I_s f_s \left(\frac{T_{on} + T_{off}}{2} \right) \quad (1)$$

From the above equation, the switching losses in any semiconductor device vary linearly with switching frequency and delay times. Therefore such hard switching converters cannot be used for high frequency switching applications. Though use of passive snubbers across the switch reduces voltage stresses, the efficiency cannot be improved due to high switching losses. From the equation of switching losses, it can be observed that the switching losses can be reduced in two ways

i. By reducing the delay times during turn ON and turn OFF, by using faster and more efficient switches in converter.
ii. By making the voltage across or current through the switch zero before turning it ON/OFF, the concept of soft switching converters.

IV. SOFT SWITCHING

A power converter can be operated with high switching frequencies only if the problems of switching losses can be overcome; this can be done using "soft-switching" techniques. This term "softswitching" refers to various techniques that make the switching transitions more gradual than just simply turning a switch on or off (which is referred to as "hard-switching" in the power electronics literature) and that force either the voltage or current to be zero while the switching transition is being made. Switching losses are reduced as there is no overlap of switch voltage and switch current during a switching transition as one of the two is zero during this time.

V SOFT SWITCHING TECHNIQUES

There are two basic methods to attain soft switching, zero current switching (ZCS) and zero voltage switching (ZVS), based on the parameter that is made zero, either the voltage or current through the device.

5.1 Zero Current Switching

A switch operating with ZCS has an inductor and a blocking diode in series with it. The switch turns ON under ZCS as the rate of rise of current after the voltage becomes zero is controlled by the inductor. As the inductor does not allow sudden change in current, it rises linearly from zero.

When a negative voltage is made to appear across the combination of inductor and switch using a resonant circuit, the current flowing through the switch is naturally reduced to zero which results in the turn OFF of the switch under zero current switching.

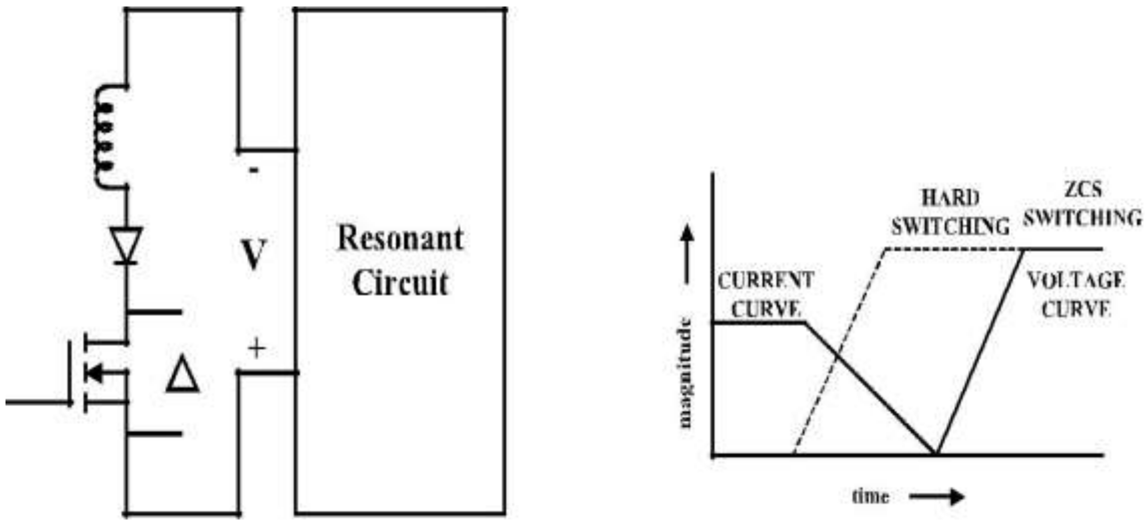
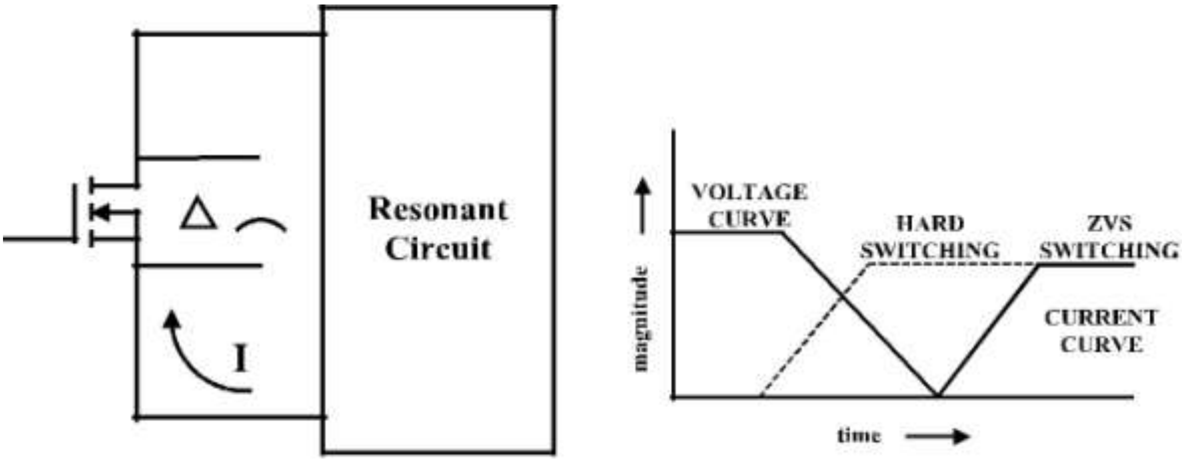


Fig 3: (a) ZCS turn OFF using negative voltage (b) Switching waveforms of hard switching and ZCS during turn OFF

5.2 Zero Voltage Switchiing

A switch operating with ZVS has an anti-parallel diode and a capacitor across it. During turn OFF as the current reduces to zero, the rate of voltage rise that takes place across the switch is controlled by the capacitor. As the capacitor does not allow sudden change in voltage, it rises linearly from zero.

The turn OFF characteristics of the switch are controlled by a capacitor connected across it. This capacitor reduces the voltage rise rate as current flow reduces to zero.



(a) (b)

Fig 4: (a) ZVS turn ON using negative current (b) Switching waveforms of hard switching and soft switching

VI. ZERO VOLTAGE TRANSITION CONVERTERS

The ZVT converters accomplish zero voltage switching during both turn-ON and turn-OFF transitions of the primary or boost switch. The zero voltage transition in zero voltage switching converters is accomplished by turning OFF the switch which has capacitor and a diode connected in parallel with it. As the flow of current through the switch falls to zero, the capacitor maintains zero voltage across the switch. Where as in zero voltage transition, as the switch turns OFF, the current in the switch is transferred to the capacitor connected in parallel to it. The turn ON transition in zero voltage switching is accomplished by discharging the capacitor connected in parallel by making use of the energy stored in a magnetic circuit element like a transformer winding or an inductor coil. The switch is turned ON after the parallel diode enters into the state of conduction. This ensures a zero voltage across the switch during transition.There are various zero voltage switching techniques. Each one differs from other in the techniques used to control and modulate to attain regulation and also in the mechanism of storing energy to attain zero voltage turn ON.

VII. PROPOSED ZVT BOOST CONVERTER

The circuit schematic of the zero voltage transition DC-DC boost converter is shown in Figure 5. It is just a simple boost converter with a diode D_1, input boost inductor L_{in}, main switch S_1 and an output capacitor C_0 across a load $R_{load.}$ In addition to the boost circuit, it also constitutes of an additional circuit that resonates, consisting of an inductor L_r, a capacitor C_r, diodes D_2-D_5 and a capacitor C_b to feed the resonant energy to the load. The capacitance C_s shown across the main switch S_1 is its parasitic capacitance and not an external capacitance.

The basic principle of Zero Voltage Transitions is that the auxiliary circuit carries a current higher than that of the input supply current, for a small portion of the entire switching cycle in order to attain soft switching of the switching elements present in the converter. Therefore Zero Voltage Transition converters have higher ohmic losses than that of those converters that operate under hard-switching. But the efficiency of the converters that operate under soft switching is inflated unlike the hard switching converters on account of diminished switching losses.

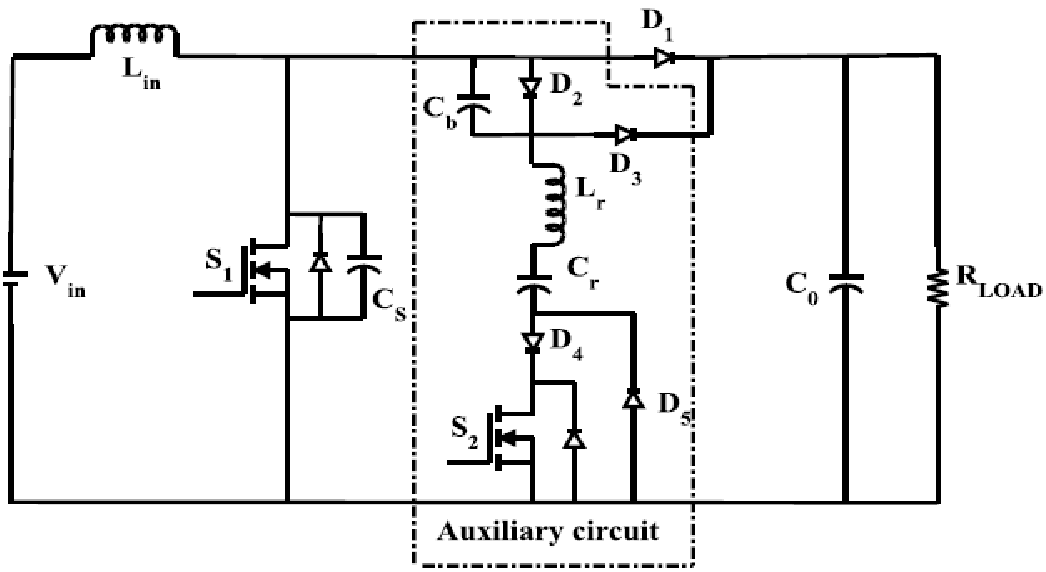


Fig 5: Schematic Diagram of ZVT DC-DC Boost Converter

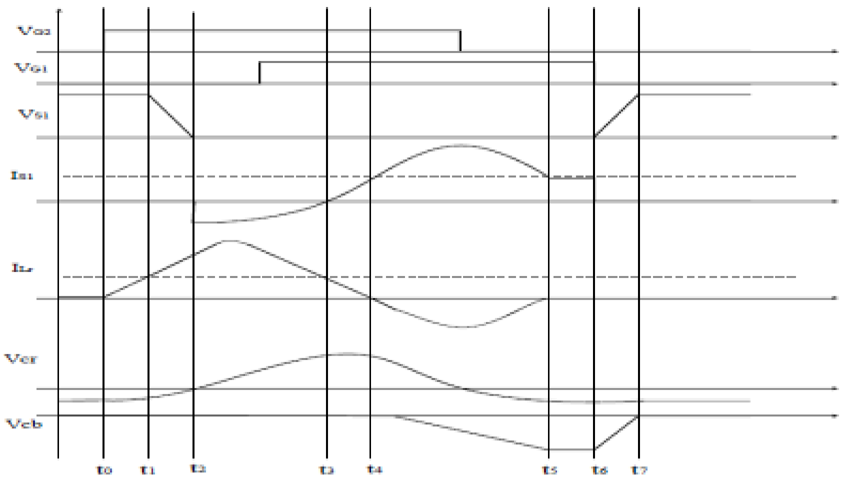


Fig 6 : Hypothetical waveforms of the converter

VIII. BOOST CONVERTER FOR PV ENERGY SYSTEM

The efficiency of a photovoltaic system is very low since the output of the PV array depends on various environmental conditions most likely to be temperature and solar irradiation. Therefore, there is a need for a system to condition the power output of the PV array before supplying it to the domestic loads. Figure 7 represents a block diagram showing the use of a converter for PV energy system. The PV array's output is supplied to the load after being conditioned by the ZVT DC-DC boost converter. The switching of the MOSFETs constituting the circuit is controlled by a maximum power point tracking (MPPT) algorithm which tracks that operating point of the PV array that meets the DC load line (including the effect of converter).

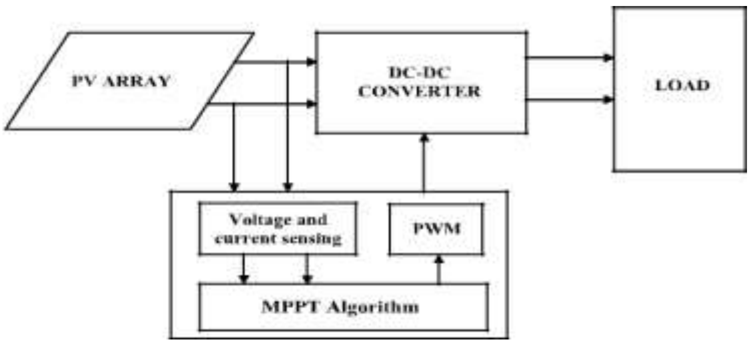


Fig 7: Block diagram of DC-DC converter with PV energy system

IX. SIMULATION AND RESULTS

The operation of the converter is verified and the waveforms of the auxiliary circuit elements for a resonant cycle and the main switch current and voltage waveforms for one switching cycle are shown below.

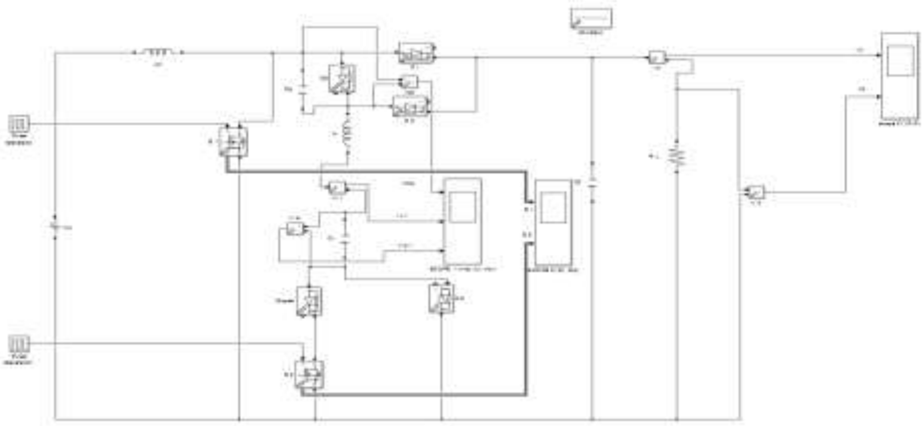


Fig 8: Simulink Model of Proposed ZVT Boost Converter

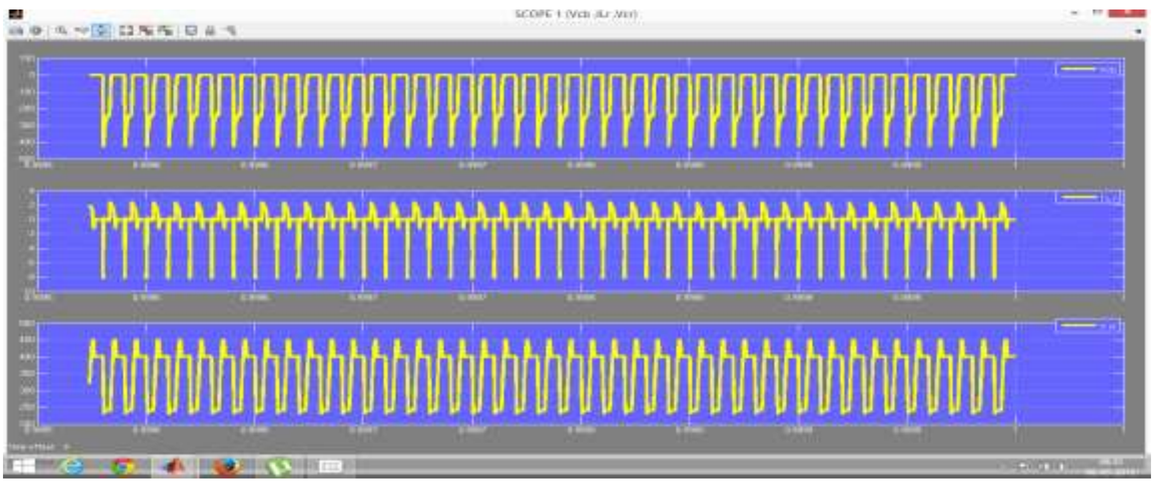


Fig 9: Feed-Forward capacitor Voltage , Auxiliary inductor current and Auxiliary capacitor voltage

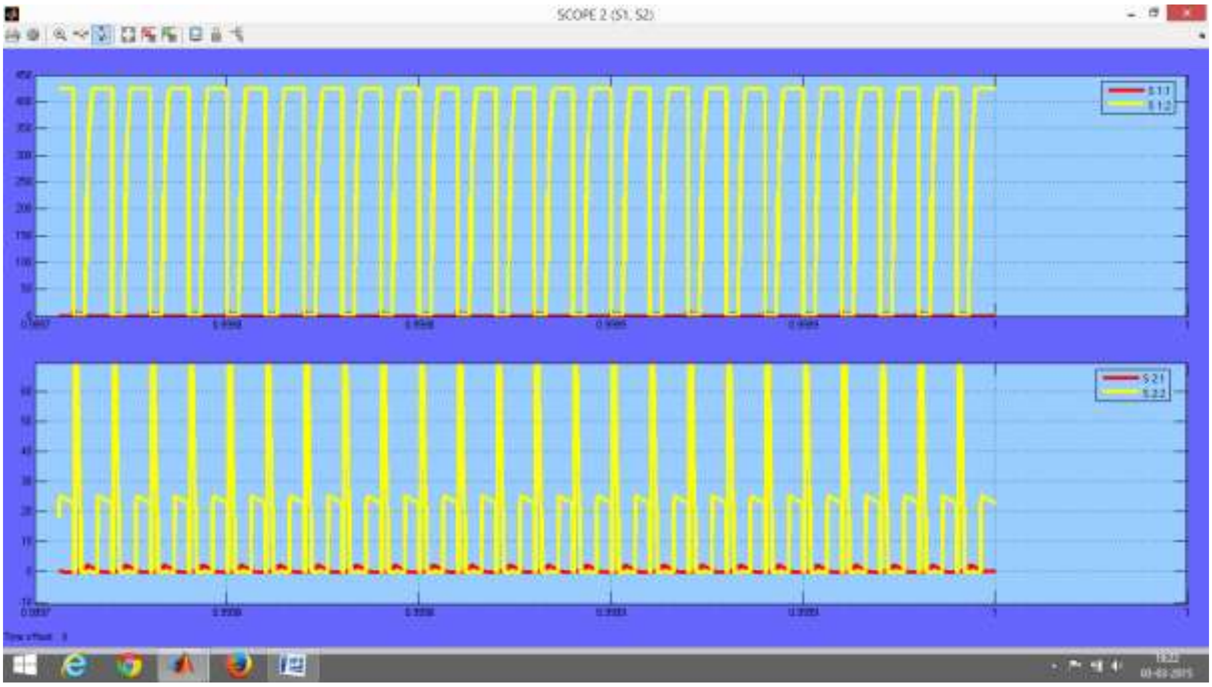


Fig 10: Mainswitch current & voltage and Auxiliary switch current & voltage

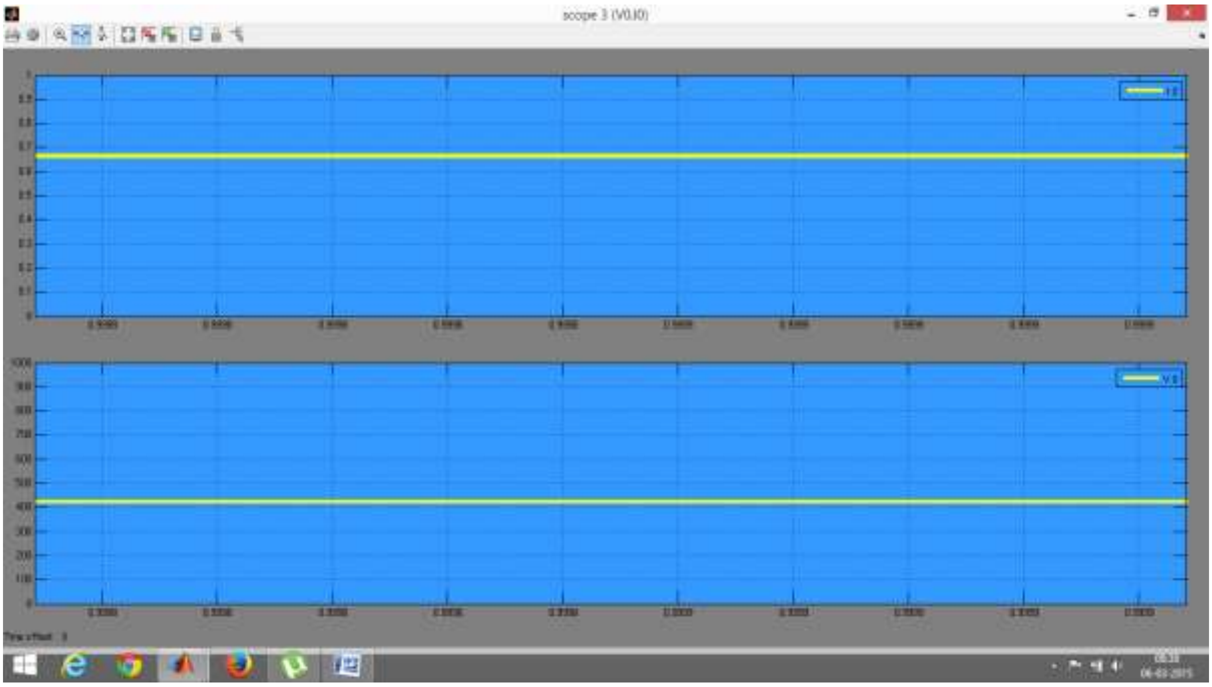


Fig 11: Current and voltage across load

The circuit is run under different input conditions with input voltage ranging from 90-265V and the circuit is found to give an output voltage of 400V for different values of duty cycles ranging from 35-80%.

X. CONCLUSION

A conventional hard switching converter is designed for the same specifications and simulated and the losses of both the converters are compared. In this paper soft switching boost converters with auxiliary resonant circuit for photovoltaic applications have been reviewed. Through this auxiliary resonant circuit, all of the switching devices perform soft-switching under zero-voltage and zero-current conditions. These boost converters have high efficiency, low cost, and ease of control. The efficiency of these boost converters is more than 98% and are useful for photovoltaic application.

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