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# Zero-Voltage and Zero-Current Switching Buck-Boost Converter for PV Applications

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***Abstract***

*A ZVS and ZCS buck boost converter is presented for PV panel applications. The salient points are that all the switching devices are under zero-current switching during turn-on and zero-voltage switching during turn-off. The active switches in the converter undergo zero-capacitive turn-on losses unlike switches in other soft-switched topologies. The switches do not experience any over voltage/over current stress proportional to load as in resonant converters. This soft-switching technique can also be applied to other classical switched mode power converters. A detailed analysis of the converter under steady state is discussed and simulation results obtained are presented.*

*Keywords: Zero current switching, Zero voltage switching, PV panel, Buck-boost converter*

## 1. Introduction

The increasing demand for renewable energy has increased significantly over the years because of shortage of fossil fuels and greenhouse effect. Among various types of renewable energy sources, solar energy and wind energy have become very popular and demanding due to advancement in power electronics techniques. Photovoltaic (PV) sources are used today in many applications as they have the advantages of being maintenance and pollution free. And grid-connected photovoltaic (PV) system can reduce investment outlay because it does not need battery to store energy; it became a hot subject by now. Moreover, the increasing use of power electronic devices and nonlinear loads is known to cause serious problems in electric power systems. Therefore, the technology that combines PV grid-connected generation and active filtering is proposed and develops rapidly. Both of PV grid-connected generation and active filtering need to keep DC bus stable and the key of unified control is generating the uniform current reference accurately.

The buck–boost converter is a type of DC-to-DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude. Two different topologies are called buck–boost converter. Both of them can produce a range of output voltages, from an output voltage much larger (in absolute magnitude) than the input voltage, down to almost zero. The first one is the inverting topology. The output voltage is of the opposite polarity than the input. This is a switched-mode power supply with a similar circuit topology to the boost converter and the buck converter. The output voltage is adjustable based on the duty cycle of the switching transistor. One possible drawback of this converter is that the switch does not have a terminal at ground; this complicates the driving circuitry. Neither drawback is of any consequence if the power supply is isolated from the load circuit (if, for example, the supply is a battery) because the supply and diode polarity can simply be reversed. The switch can be on either the ground side or the supply side. The next topology is a buck (step-down) converter followed by a boost (step-up) converter. The output voltage is of the same polarity of the input, and can be lower or higher than the input. Such a non-inverting buck-boost converter may use a single inductor which is used for both the buck inductor and the boost inductor.

One of the major trends in power electronics is increasing the switching frequencies. The advances in semiconductor fabrication technology have made it possible to significantly improve not only voltage and current capabilities but also the switching speed. The faster semiconductors working at high frequencies   result in the passive components of the

converters-capacitors, inductors and transformers-becoming smaller thereby reducing the total size and weight of the equipment and hence to increase the power density. The dynamic performance is also improved. This frequency elevation is responsible for the growing importance of pulse-width modulation on the one hand and for the use of resonance on the other hand. Another important trend resides in reduction of voltage and current stresses on the semiconductors and limitation of the conducted and radiated noise generated by the converters due large di/dt and du/dt. Both these requirements, size and noise, are minimised if each switch in a converter utilises soft switching technique to change its status.

This paper presents the work of the new buck-boost converter that provides zero-voltage turn-on and zero current turn-off. This is more useful than purely ZCS or ZVS operation. The developed converter is applied to boost the output of a PV panel. Similar report on high efficiency power conversion can be seen in many researches. The buck-boost version is selected because of its ability to develop voltage less than or more than the input voltage. The new buck-boost converter is analysed in Section 2, PV panel design guidelines are presented in Section 3, PSIM simulations are given in Section 4 followed by concluding remarks.

## 2. Proposed Converter Operation

The proposed converter aims to provide the ZVS (ZCS–ZVS) to the main switch. This is done by adding auxiliary devices to the classical converter. The auxiliary device is also needed to switch under ZCS– ZVS by itself, so that no additional switching loss will be occurred in the creation of the ZVS circuit. Figure 1 shows the converter circuit developed for this purpose.
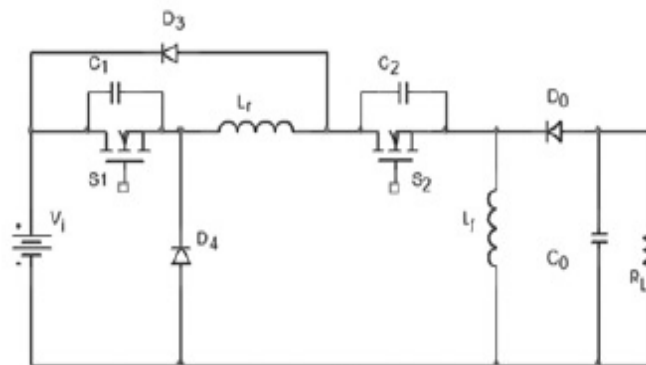


Figure 1. Proposed buck-boost converter

The auxiliary devices comprising of S1, C1, D4, Lr and D3 form the sub-circuit to provide favourable switching condition for the main device S2. Lr and C1 form the resonant tank to provide ZVS switching. The path created by D3 and Lr is to remove the charge across S2 for providing ZVS condition. C2 is added in parallel, with the main switch S2 to provide ZVS during turn-off. The operation of the proposed buck-boost converter is discussed here. The converter undergoes seven topological stages in one switching cycle, and the key waveforms and the equivalent stages are shown in Figures 2 and 3 respectively.

Stage a: Capacitor C1 charging mode (t0-t1): Prior to this stage, D0, D3 and S1 are in conduction whereas S2 is off and C2 is charged to Vo =Vi. The current in Lr is circulating through D3 and S1. S1 is turned off with ZVS to initiate this stage in order to allow C1 to charge from Lr. At the end of the stage, D4 conducts and clamps Vc1 at the input voltage Vi.

Stage b: Inductor discharging mode (t1- t2): In this mode, the energy stored in the inductor Lr is completely discharged into the input voltage through D3 and D4. At the end of this mode, D3 and D4 switch off at ZVS and ZCS. In practice, the PV cells cannot accept any current from external circuit and as a result, a capacitor connected across the PV cell absorbs this current and provides a path for the inductor to discharge its stored energy.
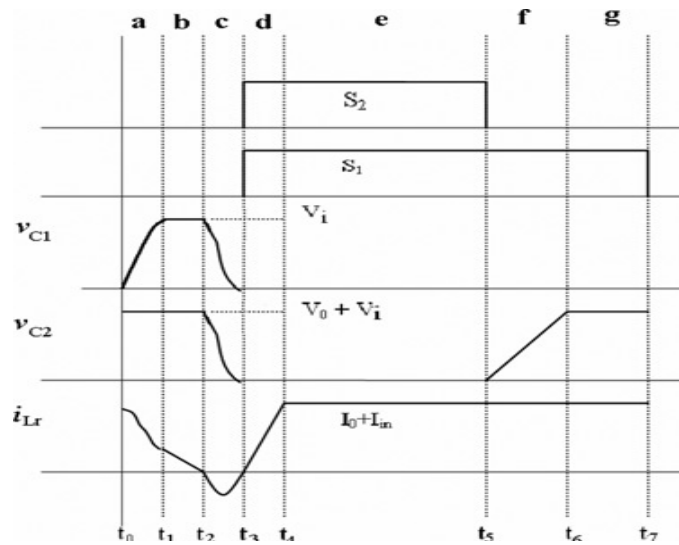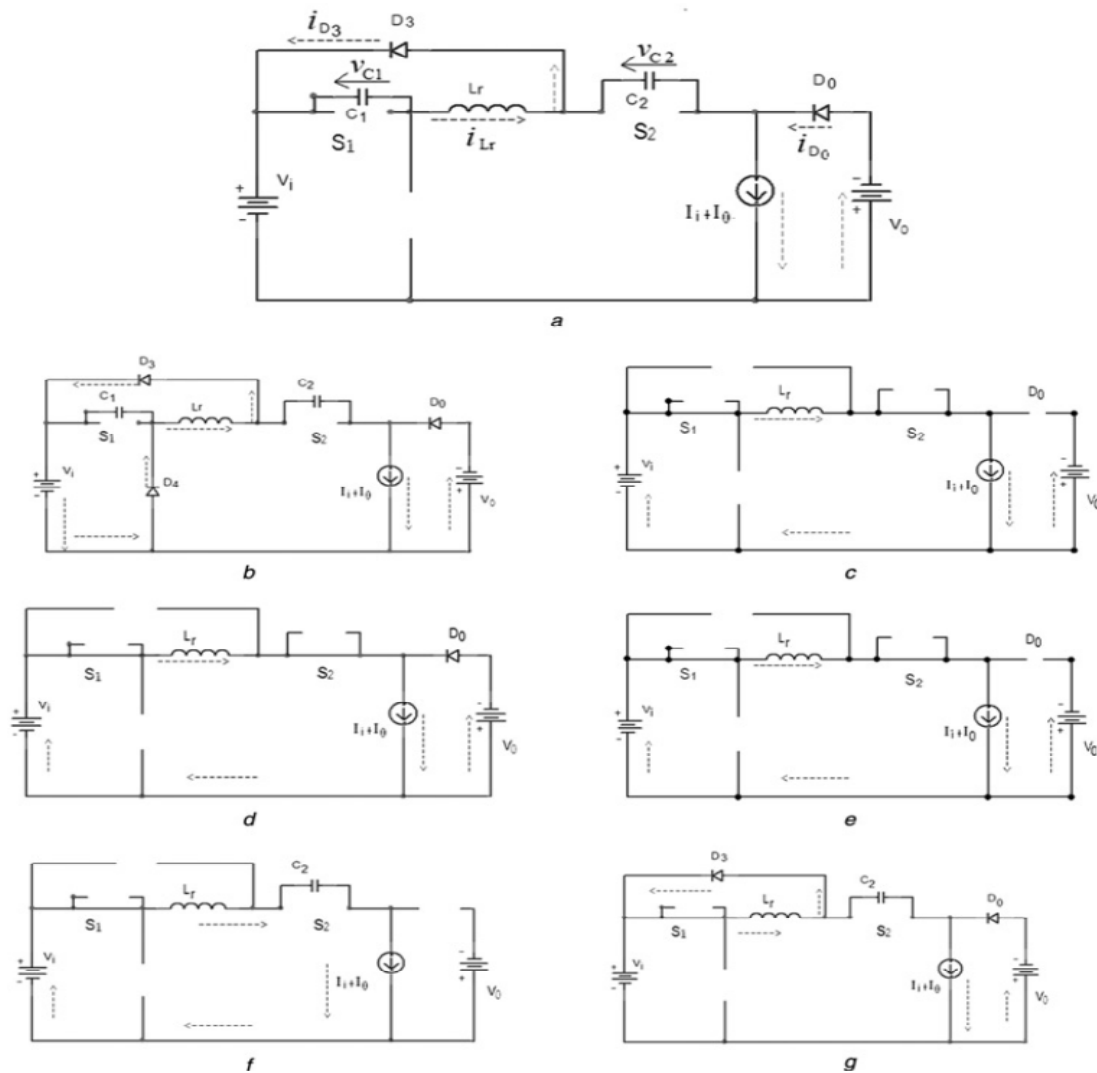
Figure 2. Waveforms of the converter



Figure 3. Topological stages of the buck-boost converter in a switching cycle

Stage c: Resonant stage: (t2-t3): In this stage Lr, C1 and C2 resonate causing VC1, VC2, and ILr to go to zero at the same time. This condition creates the zero-voltage and zero current turn-on of S1 and S2. Since the switches are turned on when the current and voltage are zero, the switches do not experience any capacitive turn-on loss as in other converters.

Stage d: Inductor charging stage (t3 - t4): To begin this mode, S1 and S2 are turned on at ZCS and ZVS to charge Lr with constant current until the current in Lr is equal to the current in the output filter. At the end of this stage, D0 is turned off with ZCS.

Stage e: Constant current stage: (t4 - t5): During this period, the output is isolated from the input and constant current flows from the input to the filter inductor. The duration of this stage is controlled by the feedback loop to regulate the output voltage.

Stage f: Capacitor C2 charging mode (t5- t6): S2 is opened at ZVS to begin Stage 6 operation to charge C2 with constant current. The stage ends when VC2= Vo +Vi at which diodes D3 and D0 conduct to end the current stage.

Stage g: Freewheeling stage (t6- t7): In this stage, the energy in the filter inductor is released into the output capacitor and load while the current in Lr freewheels through D3 and S1.

## 3. PV Cell Model

The equivalent circuit of a PV cell is shown in Figure 4. It includes a current source, a diode, a series resistance and a shunt resistance. In view of that, the current to the load can be given as:

$$I = I_{ph} - I_s \left( exp \frac{q(V + R_S I)}{NKT} - 1 \right) - \frac{(V + R_S I)}{R_{sh}} \tag{3.1}$$

In this equation, *Iph* is the photocurrent, *Is* is the reverse saturation current of the diode, *q* is the electron charge, *V* is the voltage across the diode, *K* is the Boltzmann's constant, *T* is the junction temperature, *N* is the ideality factor of the diode, and *Rs* and *Rsh* are the series and shunt resistors of the cell, respectively.

$$I_{ph} = [I_{sc} + K_i(T - 298)] \frac{\beta}{1000} \tag{3.2}$$

Where *Ki*=0.0017 A/∘C is the cell's short circuit current temperature coefficient and *β* is the solar radiation (W/m2).

As a result, the complete physical behaviour of the PV cell is in relation with *Iph, Is*, *Rs* and *Rsh* from one hand and with two environmental parameters as the temperature and the solar radiation from the other hand. For a given radiation, temperature, *Rs* and *Rsh*, the *I-V* and *P-V* curves are generated as shown in Figure 5.
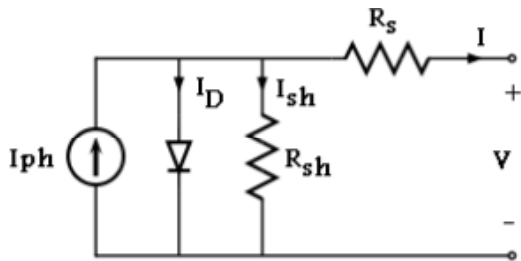

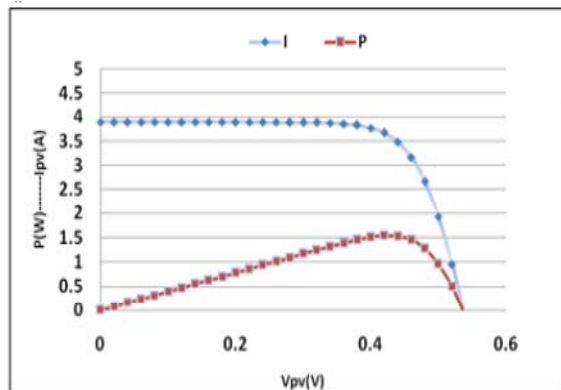
Figure 4. Equivalent circuit of a PV cell



Figure 5. I-V and P-V curves of the PV panel for a given solar radiation

## 4. Simulation Results

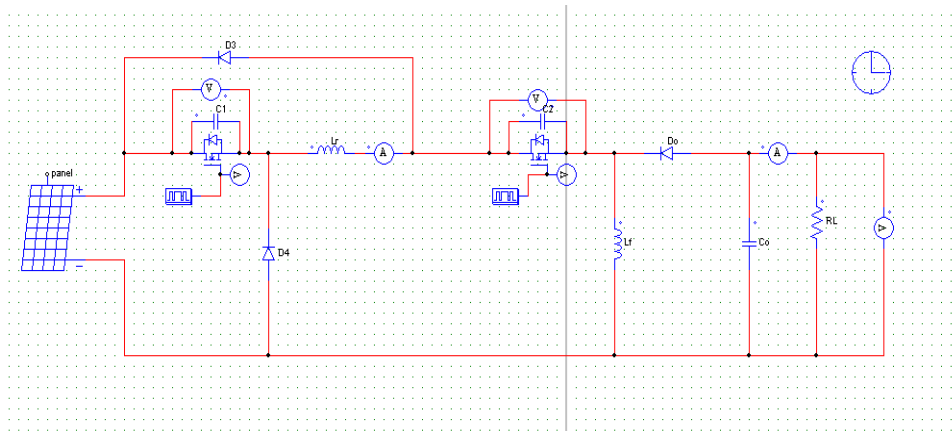The above-mentioned circuit is simulated in PSIM as shown in Figure 6.



Figure 6. Simulation diagram of the system

The specifications of the components used in simulation are given in the table below.

Table 1: Parameter Specifications

| Parameters | Specifications |
|---|---|
| PV panel | Output Voltage= 24 V |
| Resonant inductor, Lr | 5 mH |
| Filter inductor , Lf | 100 uH |
| Capacitors, C1 & C2 | 800 pF |
| Load capacitance, Co | 220 uF |
| Load resistance, Ro | 20 ohm |

The results are shown in Figure 7 and 8. The zero-voltage and ZCS of S1 and S2 is clearly visible from the PSIM simulation, wherein vC1 , vC2 and ILr come to zero before S1 and S2 are turned on.
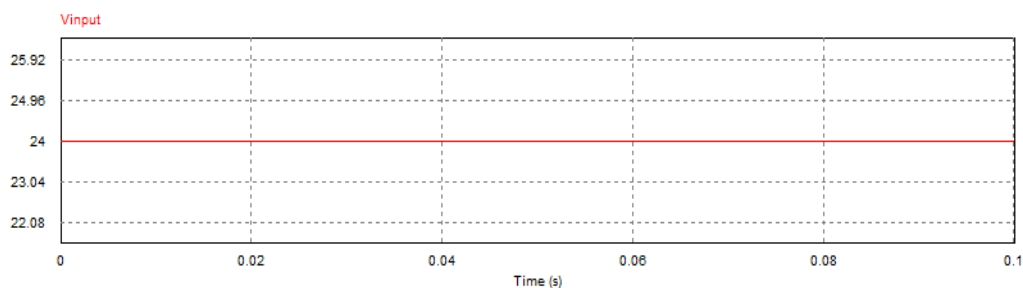


Figure 7. Input DC voltage

## 5. Conclusion

A zero-switching buck-boost converter operating at a constant switching frequency having zero-capacitive turn-on loss is developed and analysed. The converter does not experience any over voltage or high-current stress when compared with the other converters in its class. This is particularly beneficial at high voltage as the capacitive turn-on loss is proportional to square of the input voltage. The near zero-switching losses during turn-off and zero-capacitive turn-on losses make the converter a good candidate for use at high voltage and low current.
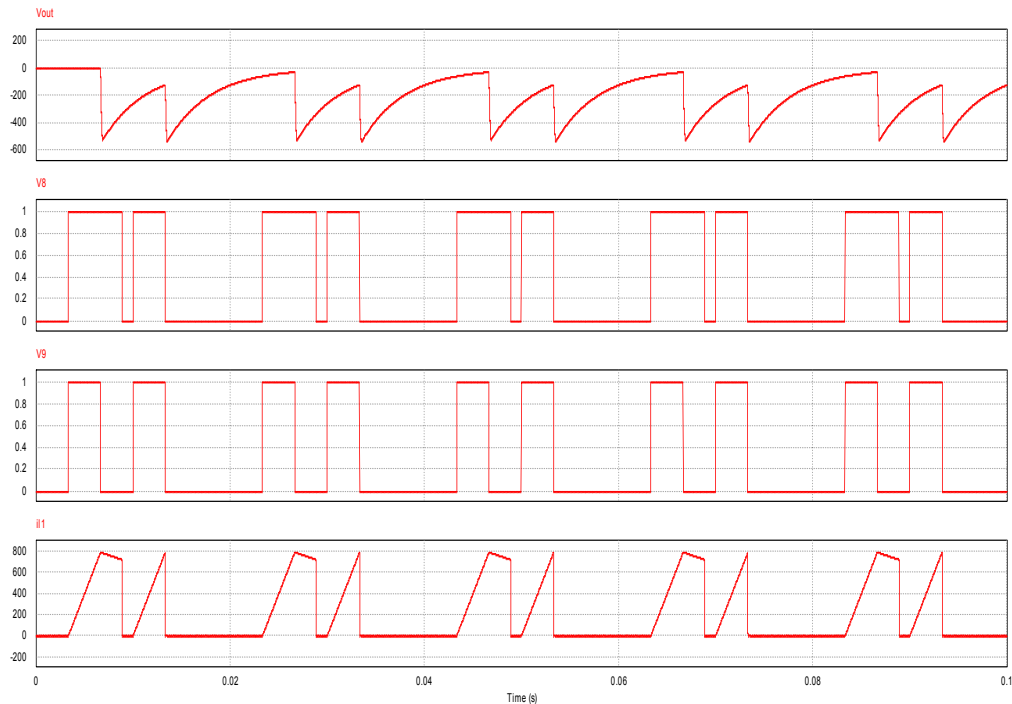
Figure 8. Simulation waveforms

## References
[1]   BP Divakar, KWE Cheng, D Sutanto. "Zero-voltage and zero-current switching buck-boost converter with low voltage and current stresses". *IET Power Electron*. 2008; 1(3): 297–304/297.
[2]   Barbi J, Bolacell CO, Martins DC, Libano FB. 'Buck quasi resonant converter operating at constant frequency: Analysis, design and experimentation'. *IEEE Trans. Power Electron*. 1990; 5: 27–283.
[3]   Hua G, Leu CS, Jiang Y, Lee FCY. 'Novel zero-voltage transition PWM converter'. *IEEE Trans. Power Electron*. 1994; 9: 213–219.
[4]   Tarak Salmi, Mounir Bouzguenda, Adel Gastli, Ahmed Masmoudi. "MATLAB/Simulink based modeling of photovoltaic cell". *International Journal Of Renewable Energy Research Tarak Salmi Et Al*. 2012; 2(2).
[5]   Moisseev S, Soshin K, Nakaoka M. 'Tapped-inductor filter assisted soft-switching PWM DC–DC power converter'. *IEEE Trans. Aerospace Electron. Syst*. 2005; 41(1): 174–180.
[6]   Wei H, Ioinovici A. '*Dc–Dc Zero-Voltage-Transition Converter with Pwm Control and Low Stresses On Switches*'. Proc. IEEE Applied Power Electronics Conf. Exposition. 1995: 523–529.
[7]   Jin K, Ruan X. 'Hybrid Full-Bridge Three-Level Llc Resonant Converter-A Novel Dc–Dc Converter Suitable For Fuel-Cell Power System'. *IEEE Trans. Indus. Electron*. 2006; 53(5): 1492–1503.
[8]   Cheng KWE, Evans PD. '*Parallel-mode extended-period quasi resonant converter*'. Proc. Inst. Elect. Eng. 1991; 138: 243–251.
[9]   Zhu L. 'A novel soft-commutating isolated boost full bridge ZVS–PWM DC–DC Converter for bidirectional high-power applications'. *IEEE Trans. Power Electron*. 2006; 21(2): 422–429.
[10]  Junming Zhang, Xiaogao Xie, Xinke Wu, Guoliang Wu, and Zhaoming Qian, Senior Member, IEEE "A Novel Zero-Current-Transition Full Bridge DC/DC Converter". *IEEE Transactions On Power Electronics*. 2006; 21(2).
[11]  R Farrington, MM Jovanovic, and FC Lee. "*Analysis of reactive power in resonant converters*". in Proc. PESC'92 Conf. 1992: 197–205.
[12]  G Hua. "Soft-switching techniques for pulse-width-modulated con- verters". Ph.D dissertation, Virginia Polytech. Inst. State Univ., Blacksburg, 1994.