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Buck/Boost DC–DC Converter Topology with Soft Switching for PV Converter Stations

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Abstract: ***This paper deals with a buck/boost dc–dc converter topologywith Soft Switching for PV converter stations. In power electronic switches,soft switching is a possible way of reducing losses.Soft switching refers to the operation of power electronic switches are zero-voltage switches (ZVS) or zero-current switches (ZCS).All the power electronic switching devices are below zero-current switching during turn-on and zero-voltage switching during turn-off. In the converter, the switches is active undergo zero-capacitive turn-on lossesunlike switches in other soft-switched topologies. The switches do not practice any over voltage/over current stress proportional to load as in resonant converters. A detailed analysis of the DC-DC converter is discussed and simulation results obtained are presented.***

Keywords: Zero current switching (ZCS), Zero voltage switching (ZVS), PV panel, buck-boost converter, DC-DC converter

1. Introduction

Due to advancement in power electronics techniques, the various types of renewable energy sources are solar energy and wind energy have become very popular and difficult. Photovoltaic (PV) sources are used in many applications. Grid-connected photovoltaic (PV) system is reducing investment outlay because it does not need battery to store energy. Additionally, the use of power electronic devices is increasing and nonlinear loads to cause serious problems in electric power systems. Hence, the technology that combines PV grid connected generation and active filtering is proposed. Both the 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.

In buck-boost converter, the output voltage magnitude is either greater than or less than the input voltage magnitude. The buck–boost converter is called DC-to-DC converter. There are two different topologies in buck–boost converter. One is inverting topology and another one is non-inverting topology. Both of them can produce a range of output voltages. The output voltage is opposite polarity than the input. This is called a switched-mode power supply (SMPS) with a same circuit topologies to the boost converter and the buck converter.Based on the duty cycle of the switching transistor,the output voltage is adjustable. The main problem of this converter is that theswitch does not have a terminal at ground and this complicates the driving circuitry. If the power supply is isolated from the load circuit because the supply and diode polarity can be reversed. The switch can be on either the ground side or the supply side. The next topology is a step-downconverter (buck) followed by a step-up converter (boost). The output voltage is of the same polarity of the input, and can be lower or higher than the input. A non-inverting buck-boost converter may use a single inductor which is used for both the buck and the boost inductors.

During the time of transition,Soft-switching forces either the voltage or the current to be zero; therefore there is no overlap between voltage, current andno switching loss. There are two types of soft-switching one is zero-voltage switching (ZVS) and another one is zero-current switching (ZCS).The transistor turn-on transition occurs at zero voltage is called asZero-voltage switching. Diodes may also operate with.Zero-voltage switching removes the switching loss induced by diode stored charge and devices output capacitances. The transistor turn-off transition occurs at zero current is known as the Zero-current switching. Zero-current switching eliminates the switching loss caused by IGBT current tailing and by stray inductances. The developed converter is applied to boost the output of a PV panel. In order to develop voltage less than or more than the input voltage,the buck-boost version is selected.

2. Proposed Converter Operation

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

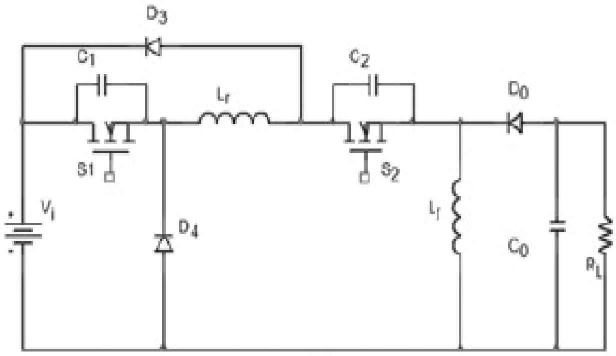

Figure 1: Proposed buck-boost converter

The sub-circuit formed by the auxiliary devices comprising of S1, C1, D4, Lr and D3. Lr and C1 form the resonant tank to supply ZVS switching. From providing ZVS condition, the path created by D3 and Lr is to remove the charge across S2. During turn-off, C2 is added in parallel with the main switch S2 to supply ZVS. The proposed buck-boost converter operation is discussed below. There are seven topological stages undergoes in one switching cycle.

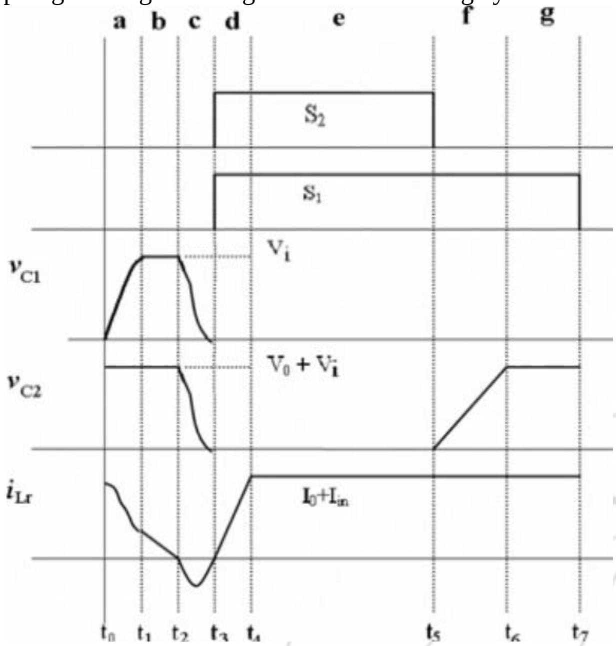

Figure 2: Waveforms of the converter

3. Topological Stages of the Buck-Boost Converter in a Switching Cycle

Stage 1:
Prior to this stage, D0, D3 and S1 are in conduction while S2 is off and C2 is charged to V_0 =V_i. The current in L_r is flowing through D3 and S1. S1 is turned off with ZVS to initiate this stage in order to allow C1 to charge from L_r.In final stage, D4 conducts and clamps Vc1,at the input voltage V_i.

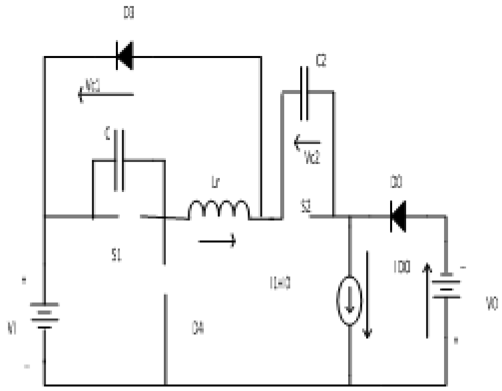

Figure 3: Capacitor C1 charging mode (t0-t1)

Stage 2:
Overthe diodes D3 and D4, the energy stored in the inductor Lr is completely discharged into the input voltage.At ZVS and ZCS, D3 and D4 switch off. Actually, the PV cells cannot accept any current from external circuit.A capacitor connected across the PV cell absorbs the current and provides a path for the inductor to discharge its stored energy.

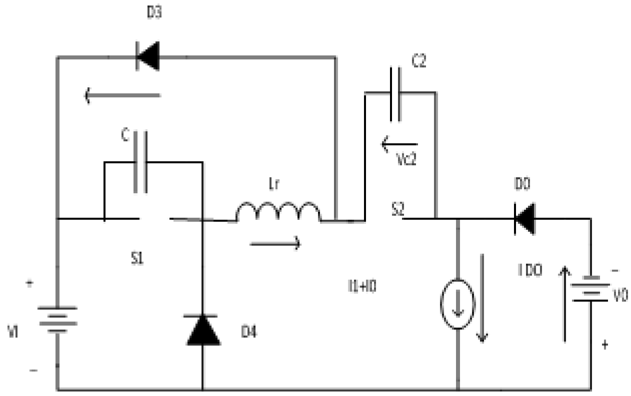

Figure 4: Inductor discharging mode (t1- t2)

Stage 3:
In stage 3,Lr, C1 and C2 resonate producingVC1 , VC2, and ILr to go to zero. The zero-voltage and zero current is turn-on of S1 and S2 switches. Since, the switches are turned on when the current and voltage are zero, the switches do not practice any capacitive turn-on loss in other converters.

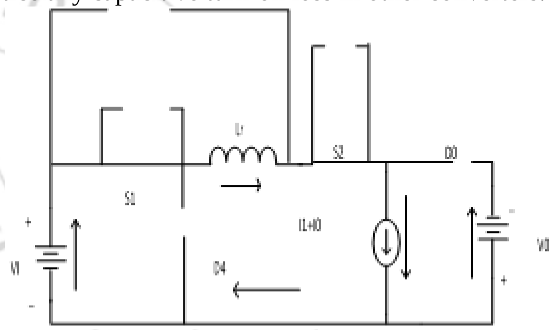

Figure 5: Resonant stage: (t2-t3)

Stage 4:
To start on this mode, at ZCS and ZVS, Switches S1 and S2 are turned on to charge Lr with constant current until the current in the charge Lr is equal to the current in the output filter. At the end of this stage, D0 is turned off with ZCS.

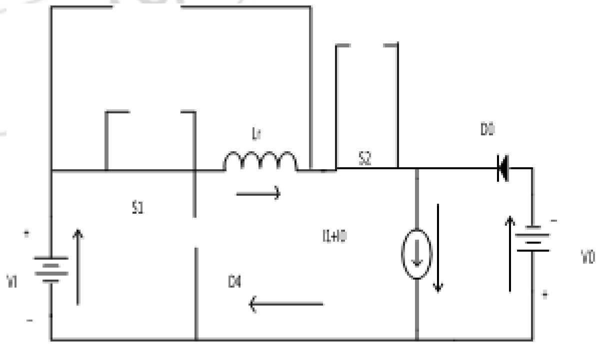

Figure 6: Inductor charging stage (t3 - t4)

Stage 5:
During this period, the input and the output are isolated such that the constant current flows from the input to the filter inductor.This stage is controlled by the feedback loop to regulate the output voltage.

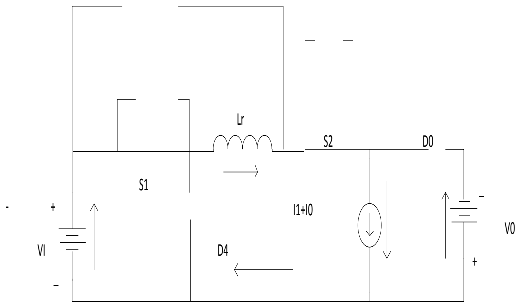

Figure 7: Constant current stage: (t4 - t5)

Stage 6:
At this Stage, the operation is to charge C2 with constant current and S2 is opened at ZVS. When VC2= Vo +Vi at which diodes D3 and D0 conduct to end the current stage.

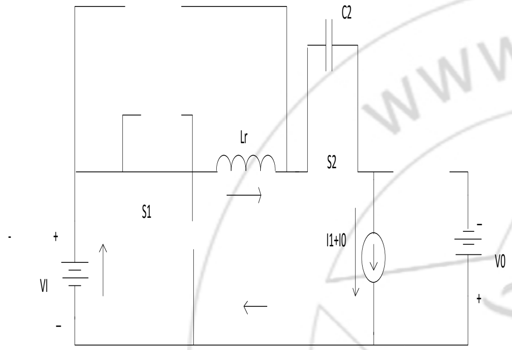

Figure 8: Capacitor C2 charging mode (t5- t6)

Stage 7:
In this stage the output capacitor and load obtain energy from the filter inductor. While the current in Lr freewheels through D3 and S1.

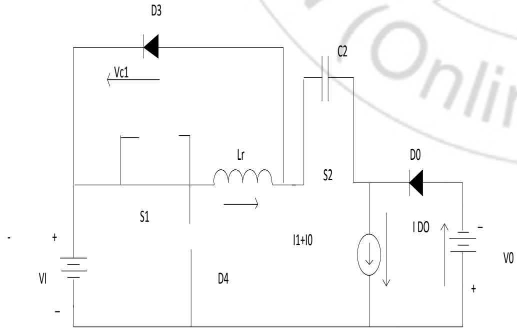

Figure 9: Freewheeling stage (t6- t7)

4. Pv Cell Model

The equivalent circuit of a PV cell is shown in fig 10. Photovoltaic module is a voltage controlled current source. It converts solar energy into DC. The output voltage depends on the change in irradiance and temperature. It includes a current source, a diode, a series resistance, a shunt resistance.

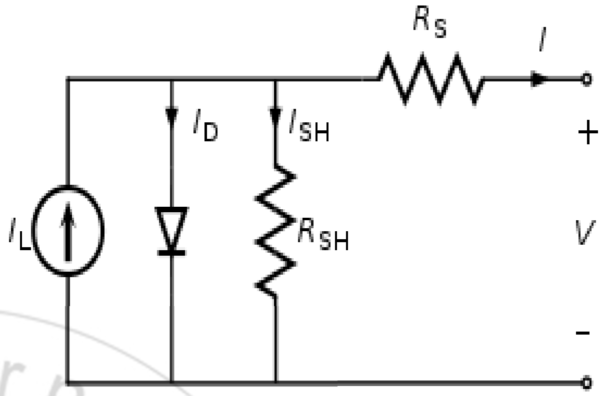

Figure 10: Equivalent circuit of Photovoltaic Cell

The current to the load can be given as

$$I = I_{ph} - I_s\left(\exp\frac{q(V+R_sI)}{NKT} - 1\right) - \frac{(V+R_SI)}{R_{sh}} \qquad (1)$$

In the above equation,
I_{ph} is the Photocurrent
I_S 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
R_S and R_{sh} is the Series and Shunt resistors of the cells

5. Simulation Results

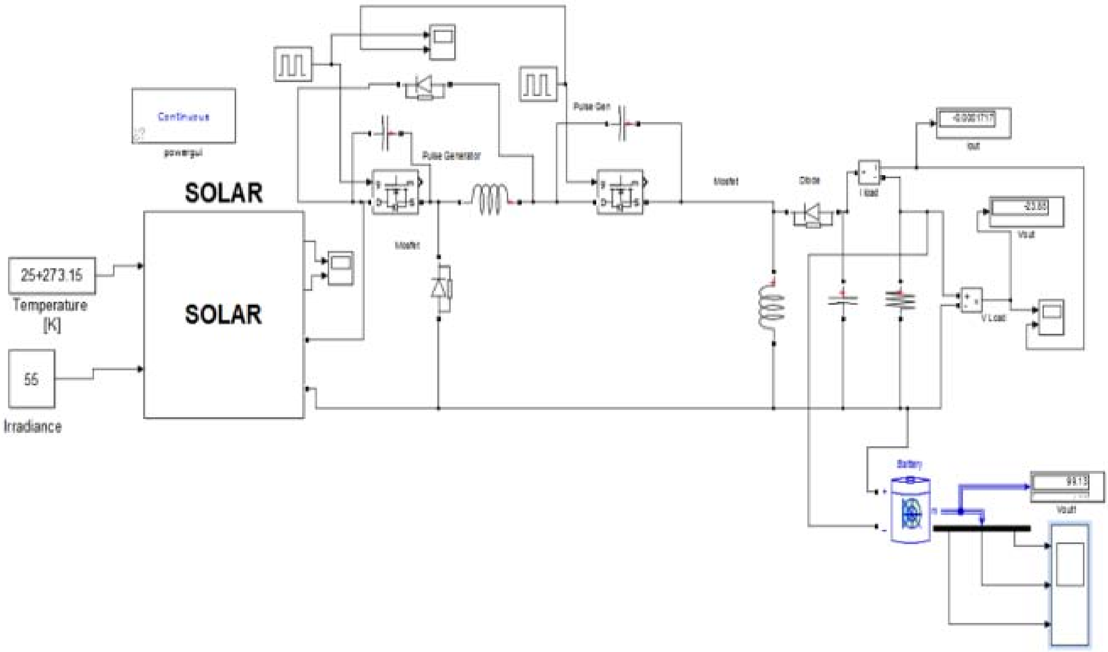

Figure 11: Simulation diagram of the system

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

Table 1: System Parameters

Parameters	Specification
PV Panel	Output Voltage=24V Output Current =1A
Resonant Inductor ,L_r	3.2 MH
Filter Inductor , L_f	1.25 MH
Capacitors C1&C2	5 MF
Load Capacitance, C_0	2µF
Load Resistance ,R_0	5 Ohm

Table 2: Maximum Power and Voltage at Different Temperature and G=1Kw/m^2.

Temperature	P_{max}	V_{max}	I_{max}
0^0C	89.62W	39.48V	2.222A
25^0C	81.00W	36.4V	2.227A
50^0C	73.37W	31.9V	2.217A
75^0C	62.73W	28.21V	2.199A

Table 3: Radiation and Maximum Power Available at Different Places.

Places	G	P_{max}	V_{max}	I_{max}
Cochin	1.088kW/m^2	84W	39.48V	2.611A
Delhi	1.027kW/m^2	81.36W	35.7V	2.465A
Wellington	0.8819kW/m^2	68.81W	35.11V	1.96A
Paris	0.7617kW/m^2	58.59W	34.8V	1.68A

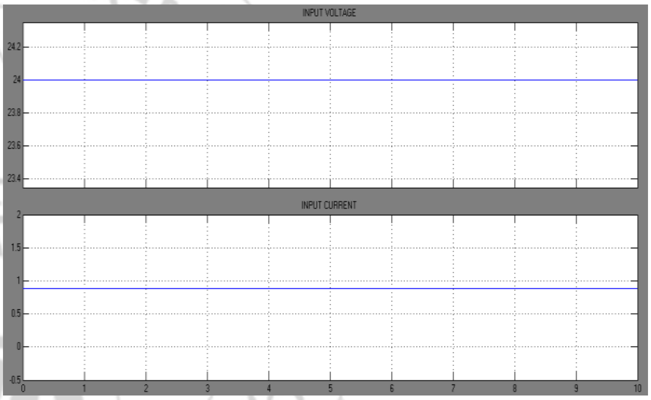

Figure 12: Input voltage and Input Current

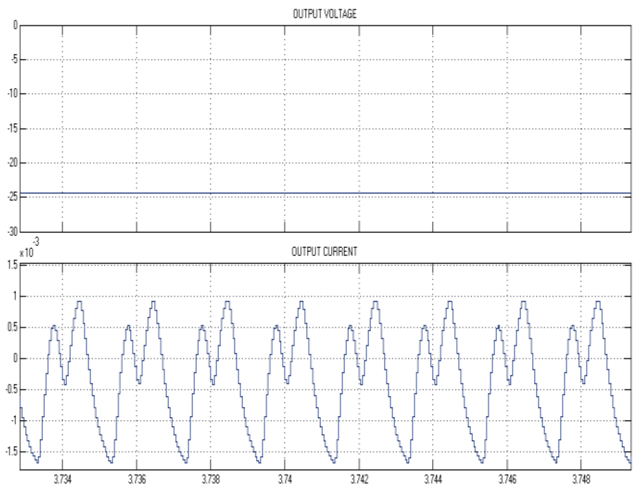

Figure 13: Output Voltage and Output Current

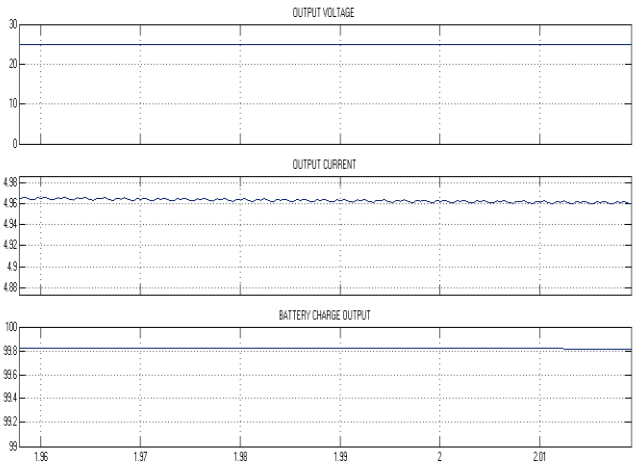

Figure 14: Battery Charge Output

6. Conclusion

A constant switching frequency with zero-capacitive turn-on loss of zero-switching buck-boost converter is developed and analyzed. The converter do not have any other voltage or high-current stress when compared with the other converters. At high voltage,the capacitive turn-on loss is proportional to the square of the input voltage. The near zero switching losses and zero capacitive losses during turn-off and turn-on make the converter better to use at high voltage and low current. Finally, the simulation result of the battery charger output is 99.9V and then the output voltage is 25V and output current 4.98A obtained.

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