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Active Clamped Current Fed Buck – Boost Converter For Traction Applications

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Abstract:
In recent years, the increase of energy demand and the problems of fossil-fuel sources due to their environmental pollution and future shortages, have led to the development of technologies need to use non-polluting alternative energy sources such as solar and wind sources. Growing demand, advancements in semiconductor technology and magnetic materials such as high frequency inductor cores, has a significant impact on PV topologies and their efficiencies. This paper presents analysis and design of active clamped current fed buck-boost converter for traction applications. The source voltage is taken from the PV Array. PV Array is developed using basic circuit equations of the photovoltaic (PV) solar cells including the effects of solar irradiation and temperature changes. The Buck boost converter is used in this paper to boost up the PV Array voltage. The proposed system consists of a PV Array, buck-boost converter and HF DC/DC converter. The designed converter maintains ZVS of all switches from full-load down to very light load condition over wide input voltage variation. The additional auxiliary active clamping circuit absorbs the turn-off voltage spike limiting the peak voltage across the devices allowing the selection and use of low voltage devices with low on-state resistance. And this converter is given to the dc series motor. The proposed system can improve the voltage at the load. The performance of the proposed system was analysed using MATLAB/SIMULINK

Key words: *PVA, buck-boost converter, High-frequency DC/DC Converter, Zero voltage switching (ZVS), dc series motor, renewable energy systems.*

1.Introduction

Clean and green energy for distributed generation and modern/future transportation system has been of increasing interest to the academic and industrial researchers or community for sustainable and smart living. Power converter is an essential interface for the conversion of non-conventional energy sources into useful and regulated electrical ac or dc form. Power converter is a weak link and its efficiency determines the utilization of the source and controls the power output. Its cost, volume, and weight are the deciding factors for the overall cost and volume of the installation system. Therefore, the design and development of low cost, high-efficient and small size power conversion systems is still an attention of researchers. The use of new efficient photovoltaic solar cells (PVSCs) has emerged as an alternative measure of renewable green power, energy conservation and demand-side management. They have been used extensively for water pumping and air conditioning in remote and isolated areas where utility power is not available or is too expensive to transport. Although PVSC prices have decreased considerably during the last years due to new developments in the film technology and manufacturing process. Distributed generation for standalone and grid-tied applications for residential and remote power systems are important applications.

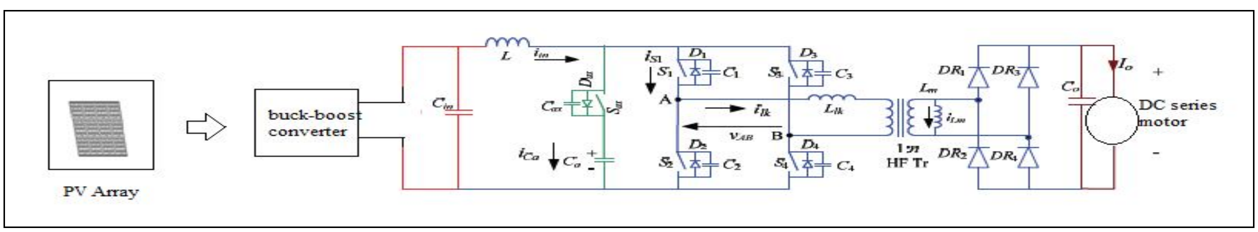

Figure 1: Block Diagram Of Proposed System

Two-stage inverter, i.e. high-frequency (HF) transformer isolated dc/dc converter followed by an inverter has been adopted by industries and has been proposed with different configurations and modulations. HF transformer isolated dc/dc converter translates the low PVA voltage to higher than the peak of the utility line or inverter output voltage specification with necessary isolation. Soft-switching is necessary to operate the converter at HF and to realize small size, light weight and low cost converter. It reduces the thermal stress on the components, switching losses, and improves the efficiency, particularly at light load where the switching and conduction losses are comparable or switching losses dominate the conduction losses.

2.Operation And Analysis Of The Converter

Operation and analysis of the proposed design including the effect of magnetizing inductance/current is presented in this Section. The following assumptions are made to study and understand the operation and analysis of the converter: 1) Input inductor L is large so that the current through it is considered constant. 2) Clamp capacitor Ca is large to maintain constant voltage across it. 3) All components including devices and diodes are ideal. Switches S1 and S4 are operated by identical gating signals, and S2 and S3 are operated by the common gating signals. Gating signals of switch pair S2, S3 are shifted in phase by 180o with gating signals of switch pair S1, S4 with an overlap. The duty cycle of the main switches is always kept greater than 50% to prevent increased circulating current through the auxiliary active-clamp circuit. The switching frequency of auxiliary switch Sax is double of that of main switches. It is controlled by gating signal complementary to the main switches' gating signals. So, the duty cycle of the auxiliary switch is always less than 50%.%. The operation of the converter during different intervals (t0 to t 9) in a HF half cycle is explained using the equivalent circuits.

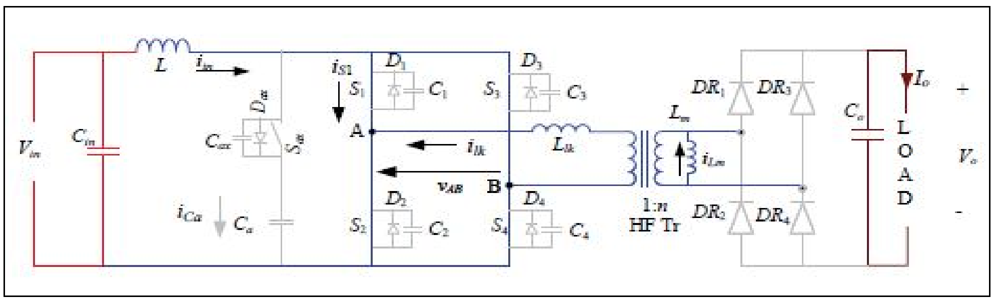

Figure 2: Active-Clamped ZVS Current-Fed Full-Bridge DC-DC Converter

All four main switches S1 ~ S4 are on. Auxiliary switch Sax is off. Input inductor L is storing energy. Power is transferred to the load by the energy stored in the output filter capacitor Co. Transformer magnetizing current circulates through its leakage inductance in interval 1. At t = t1, main switches S2 and S3 are turned off. Current in the input boost inductor (Iin) is diverted into the auxiliary circuit path causing zero current through all main switches. The magnetizing current flows through leakage inductance Llk, anti-parallel diodes D1, D4 of main switches S1 and S4. Therefore, switch currents through S1 and S4 quickly dips to negative, which is equivalent to peak value of the reflected magnetizing current. Device capacitances C2 and C3 of main switches S2 and S3 start charging and auxiliary switch snubber capacitor Cax starts discharging linearly. On secondary side, rectifier diodes are reverse biased and power is still transferred to the load by the output filter capacitor. The constant current (I′Lm,peak) continues to flow through magnetizing inductance.

Interval3. In this interval is very short. Snubber capacitors which are partially charged in interval 2, are still going through charging and discharging. The anti-parallel body diode Dax of the auxiliary switch Sax starts conducting and Sax can be gated for ZVS turn on. Leakage inductance current ilk is increasing with the slope. In interval 5, switch current (through S1 and S4) changes direction to positive magnitude. Current through the magnetizing inductance is increasing with the same slope in interval 4. Interval 6 the auxiliary switch Sax is turned on with ZVS. Current ilk rises above Iin with the same slope as interval 4 and current iCa falls linearly below zero. Magnetizing current iLm is increasing with the same slope as interval 4.The auxiliary switch Sax is turned off at t = t5. Current ilk charges Cax and discharges C2 and C3. The leakage inductance Llk resonates with snubber capacitors Cax and C2+C3. This time interval is very short and the leakage inductance current ilk drops by a small value.

In interval 8, anti-parallel body diodes D2 and D3 of main switches S2 and S3 respectively start conducting and now S2 and S3 can be gated for ZVS turn on. Current ilk decreases with a negative slope. switches S2 and S3 are turned on with ZVS. Currents iS2 and iS3 start increasing and the current ilk is decreasing with the same slope. Current ilk is transferred to the switches S2 and S3 in interval 9. For the next half cycle, the intervals are repeated in the same sequence with other symmetrical devices conducting to complete the full HF cycle.

3.Simulation Results And Discussion

3.1.PVA Model

PV Arrays are built up with combined series/parallel combinations of PV solar cells, which are usually represented by a simplified equivalent circuit model as shown in Figure 3. A photovoltaic array (PV system) is a interconnection of modules .The power produced by a single module is seldom enough for commercial use, so modules are connected to form array to supply the load. The connection of the modules in an array is same as that of cells in a module. Modules can also be connected in series to get an increased voltage or in parallel to get an increased current.

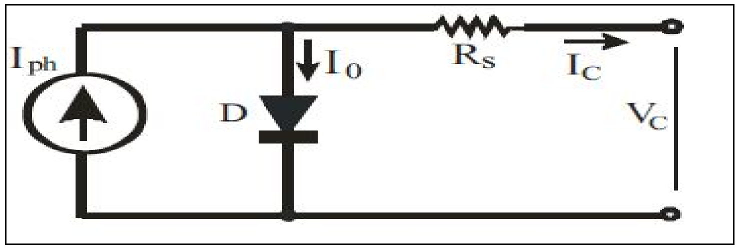

Figure 3: Simplified Equivalent Circuit Of Photovoltaic Cell

A photovoltaic system simulation model is developed using basic circuit equations (Lorenzo mathematical model) of the photovoltaic solar cells including the effects of insulation and temperature changes as shown in Figure 5. The block called PVA model for GUI is the last stage of the model. This block contains the sub models that are connected to build the final model. A diode (D1) is connected in series with the load circuit to prevent the reverse current flow. The PVA consists of 8 PV cells all connected in series to have a desired voltage output. Depending on the load power required, the number of parallel branches can be increased to 2 or more. The effects of the temperature and solar irradiation levels are represented by two variables gains. They can be changed by dragging the slider gain adjustments of these blocks named as variable temperature and variable solar irradiation. Since the main objective is the development of the PVA functional model for the Simulink environment, the other parts of the operational block diagram given in Figure are not going to be explained in full detail. However, just to describe the main diagram, as it can readily be seen, the system is modelled to supply power to dc loads.

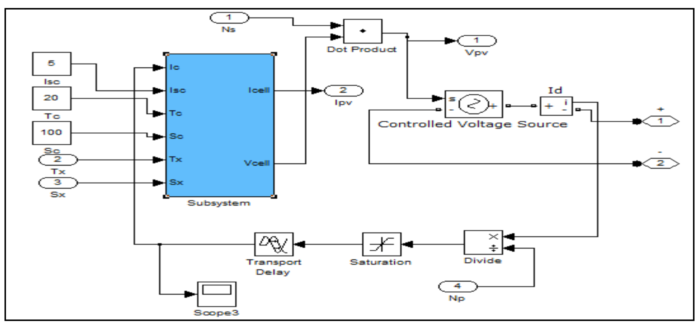

Figure 4: MATLAB-Simulink Model Of PV Array

3.2.Buck-Boost Converter Model

The buck-boost converter model is built and simulated as below

Output voltage of PV Array is taken as input of buck-boost converter to boost up the voltage. In this converter IGBT switch is used. Inductor L limits the di/dt of the fault current when the device is under the fault condition. Switch is in on condition capacitor supplies the load current. Output voltage compare with vref by using pi controller and relational operator and given to the IGBT. In this, converter boosts up the voltage upto 120 volts.

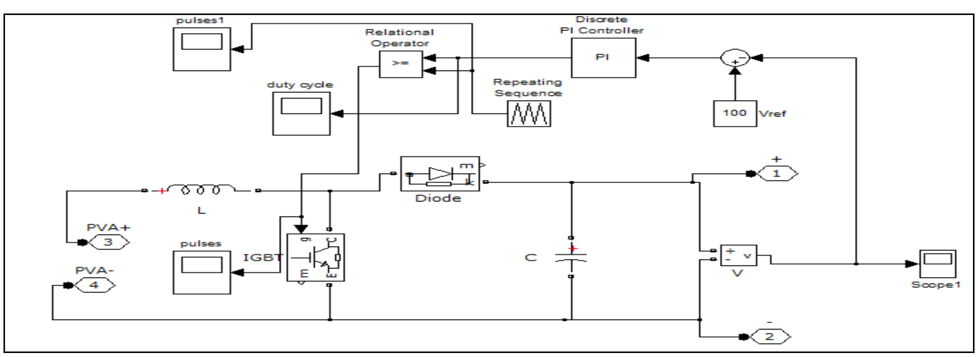

Figure 5: Buck-Boost Converter Model

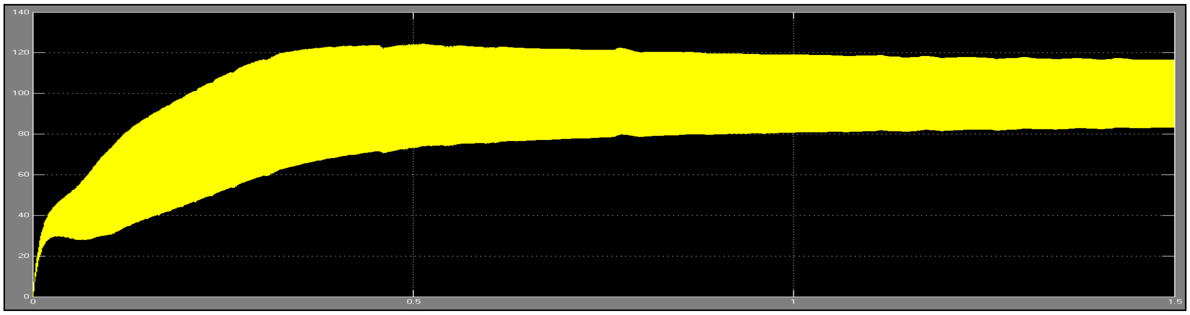

Figure 6: Buck-Boost Converter Output Voltage

PV Array is taken as source. PVA voltage is taken as 33 volts and this voltage is given to the buck-boost converter. Buck-boost converter boost the PVA voltage up to 120 volts.

3.3.High Frequency Dc/Dc Converter Model

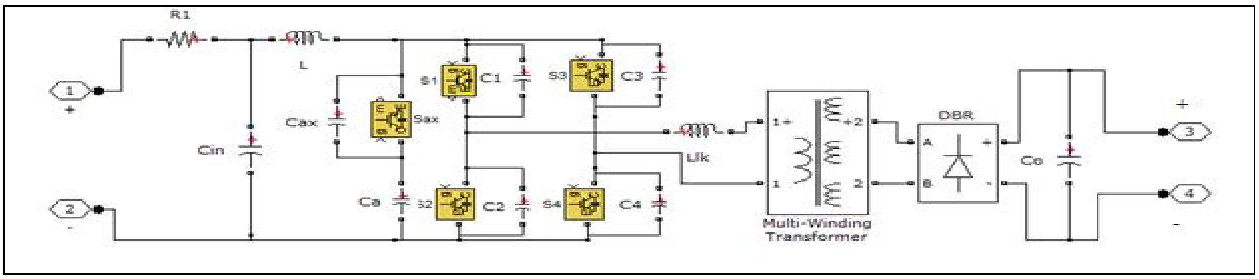

Figure 7: Dc/Dc Converter Model

Description	Value
Converter inductance	132[µH]
Leakage inductance	0.4[µH]
Semiconductor type	IGBT
Switching frequency	100[kH$_Z$]
Output capacitor capacitance	4.9[µF]
Auxiliary capacitor capacitance	4[µF]

Table 1: Dc/Dc Converter Parameters

3.4.Traction Application

Dc series motor is taken as traction application.

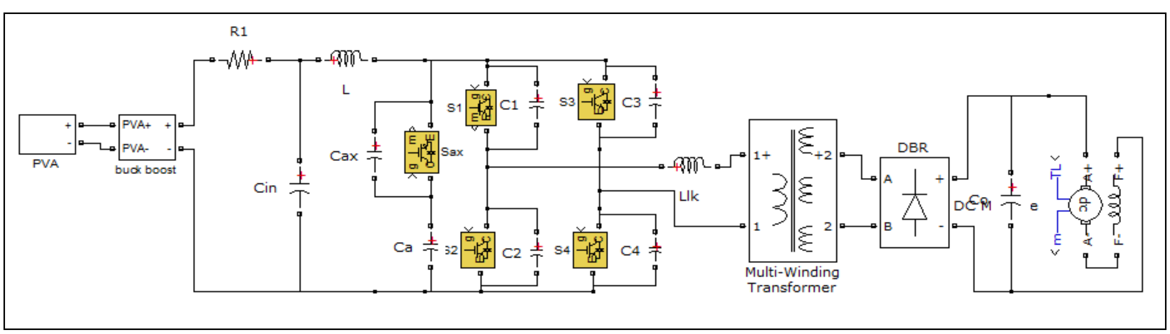

Figure 8: Model Of Active Clamped Current Fed Buck-Boost Converter For Dc Series Motor

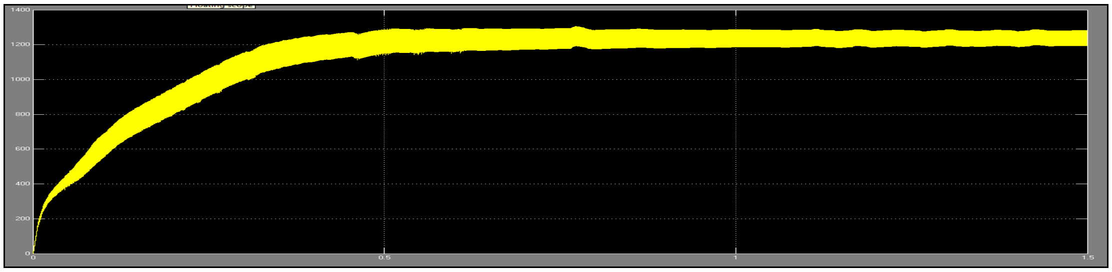

Figure 9: Load Voltage With Buck-Boost Converter

The input of the PV Array is 33 volts. PV Array voltage is boosted by using buck-boost converter up to 120 volts and this voltage is given to high frequency dc/dc converter. The output voltage at the converter is 1280 volts. And this is given to the dc series motor.

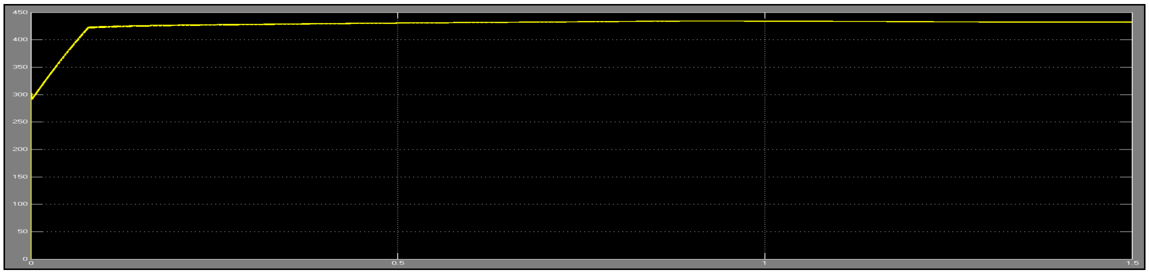

Figure 10: Load Voltage Without Buck-Boost Converter

Load voltage with buck-boost converter by using dc/dc converter is 1280 volts. Without buck boost converter by using PV Array and dc/dc converter is 420 volts.

4.Conclusion

Active clamped current fed buck boost converter for traction applications is proposed in this paper. To achieve ZVS for wide source voltage variation and varying output power/load while maintaining high efficiency has been a challenge, especially for low voltage higher current input applications. The magnetizing inductance increases the leakage inductance current value at light load and therefore, the energy stored in leakage inductance to maintain ZVS of main switches as well as auxiliary switch. Detailed operation and analysis of active clamped current fed buck-boost converter, modeling of PV Array and traction application have been presented. PV Array is developed using basic circuit equations of the photovoltaic (PV) solar cells including the effects of solar irradiation and temperature changes. Dc series motor is used as traction application because speed control of dc motor is easier and power operation of dc motor is simple. The converter has limitation that duty cycle of the main switch should be greater than 50%. The input of the PV Array is 33 volts. PV Array voltage is boosted by using buck-boost converter and high frequency dc/dc converter. The output voltage at the load is 1280 volts. The voltage at load with the converter and without converter has been presented.

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