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Simulation of Coupled Inductor Based Boost Inverter Connected To 3-φ Grid

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ABSTRACT

A coupled inductor based boost inverter connected to a 3-φ grid. Zero Voltage switching inverter with coupled inductor based DC-DC boost converter is proposed for a fuel cell, battery based module systems. The proposed system uses a coupled inductor based boost converter connected to a zero voltage source inverter. As a fact it generates ac output voltage larger than the dc input. Main advantage of coupled inductor converter is that the converter can be operated at a duty cycle nearer to 0.5 with PWM modulation as a result higher voltage conversion gains can be achieved. As the power conversion removes usage of transformer from its configuration this makes the system economical and efficient. The proposed model is simulated with matlab/simulink and simpowersystemsblockset.

KEYWORDS: soft switching, space vector modulation (SVM), Coupled inductor, DC-DC converter, PWM scheme, Boost converter, zero voltage switching (ZVS).

I. INTRODUCTION

Fuel cells generate electricity via chemical reactions between hydrogen and oxygen. The Proton Exchange Membrane Fuel Cell (PEMFC) is most commonly used for low and medium power generation applications. The proton exchange membrane fuel cell transfers oxygen and hydrogen energy into electrical energy and produces water.
The reactions at anode is given by

$$H_2 \text{----}> 2H^+ + 2e^-$$

Cathode reaction is given by

$$\frac{1}{2}O_2 + 2H^+ + 2e^- \text{----}> H_2O$$

Global reaction is given by

$$H_2 + \frac{1}{2}O_2 \text{----}> H_2O + \text{Heat} + \text{Electricity}$$

Generally the output voltage of the fuel stacks is varied from 24V to 40V depending upon output power. But a utility ac source requires rms voltage of 220V at 50Hz/60Hz. This requires a high conversion ratio. The low output voltage from a fuel cell is converted into high dc bus voltage (380V-400V) and then high dc voltage is converted into ac voltage.
General fuel cell power generation system is shown in figure 1.

The drawback with FC among others is that its time constants dominated by fuel delivery systems. As a result fast load demand will cause a high voltage drop in a short time. FC's are low voltage generators, it is necessary to use a power electronic converter to increase the FC output voltage. To achieve a high conversion ratio isolated dc-dc converter is used. Instead of using a cascaded dc-dc converter an attempt is made to replace the cascaded structure with a single boost converter.

DC-DC converters with steep voltage ratio are required for industrial applications. Grid connected systems with front-end stage for clean-energy sources such as photo voltaic cells, dc back-up power supplies, and telecommunications industry require dc-dc converters with steep voltage ratio. The conventional boost converters cannot provide such a high dc voltage gain at extreme duty ratios. This results a serious reverse-recovery problem and increases ratings of the semiconductor devices. This results in degraded conversion efficiency and also causes serious electromagnetic interference (EMI) problem.

To increase the conversion efficiency and voltage gain, boost voltage with coupled inductor is chosen. Conventional boost converters use flyback topologies, flyback converters with active clamp techniques are preferred for high conversion ratio. Transformer that used in these topologies chosen such that the required conversion gain is achieved. But the problem of reverse-recovery not eliminated. Many more modifications are suggested for improved recovery of the switches during reverse biased conditions and using active clamp devices and snubber circuits' reverse-recovery characteristics are improved. But voltage stress and current stress of the devices are not improved.

This makes no considerable reduction in switching losses. Another drawback of active clamp techniques is increased number of semiconductors switches. The only way to overcome the problem is to design of soft switching scheme to overcome the mentioned issues. This makes the devices are to be operated at high frequency as a result the power delivered to the load is limited. To have a better voltage gain coupled inductors are preferred. Many circuit configurations with reduced power losses and improved voltage stress and current stress are available. By using proper snubber and capacitor the switching losses and voltage stress are reduced.

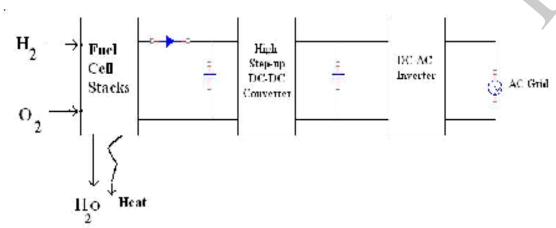

Figure 1: Block diagram of Coupled Inductor Based DC-DC Converter connected to ZVS based 3-φ inverter

In high-power grid-connected inverter application, three-phase inverter with six switches is preferred. This topology offers lower current stress over the switches and higher efficiency. When these inverters are to be operated with grid supply, these are required to supply quality line current and supply frequency. If these are designed to operate at higher switching frequency, switching losses will be higher which in turn reduces efficiency. To make the inverter circuit more efficient soft switching technique is preferred. This results in lower switching losses and reduced EMI noise.

In the recent past many schemes are available for soft switching of inverter configurations. They may be realized as dc-side and ac-side soft switching. In the proposed scheme boost converter with coupled inductor is considered for high voltage gain and reduced voltage and current stress over the switches. Zero voltage switching of 3-Ø inverter offers reduced switching losses. As a result the circuit can converts very low dc voltages into grid level ac voltages.

II. PROPOSED CONVERTER

As shown in figure 1, the proposed converter uses a coupled inductor based boost converter for obtaining desired voltage level for micro inverter from low voltage FC stack and a 3-Ø space vector pulse width modulation based inverter is used in dc-ac conversion. Boost converter used in proposed configuration uses a coupled inductor instead of a transformer. Operation of boost converter is explained in III. A 3-phase SVPWM inverter is connected to the 3-Ø grid. PWM based closed loop controlled is used to regulate duty ratio of boost converter. The IGBT switches are in both the converters.

III. MATHEMATICAL MODEL OF DEVICES USED

A. PEMFC

The proposed FC has the advantage of providing continuously large magnitudes of current, including no current with anode and cathode. Pressure equal to 1atm and with cell temperature equal to 60^0c, the cell voltage is given by

$$V_e = \frac{Vo}{1+\frac{if}{ih}}\delta$$

Where V_0 is the open circuit voltage and i_f the fuel cells stack is current. δ and i_h are the FC parameters. Two such stacks with each stack containing 16 cells are connected in parallel to obtain a power rating of 1000W.

B. BOOST CONVERTER

Boost converter with a coupled inductor and three switches is shown in figure 2. The switches S_1 and S_2 are realized with IGBT's and are controlled with one control signal. S_3 is realized with a diode. The use of diode will restrict reversal of power flow. The operating principle under steady state with continuous conduction mode is explained in detail as follows.

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Mode I:

During mode I of operation the switches S_1 and S_2 are turned on. During this period inductors L_1 and L_2 are connected in parallel to the dc source and the energy stored in the output capacitor C_0 is released to the load. The voltage across L_1 and L_2 are given by

$$V_{L1} = V_{L2} = V_{in}$$

Mode II:

In this mode S1 and S2 are turned off. The inductors L1 and L2 are connected in series with the dc source, and transfer energies to C_0 and the load. The voltage across inductors are given by

$$V_{L1} = V_{L2} = \frac{Vin-Vo}{2}$$

Using volt-second balance principle on L_1 and L_2, then

$$\int_0^{DTs} Vin\,dt + \int_{DTs}^{Ts} \frac{Vin-Vo}{2}\,dt = 0$$

$$V_{in}\,DTs + \frac{Vin}{2}[Ts\text{-}DTs] - \frac{Vo}{2}[Ts\text{-}DTs] = 0$$

$$V_{in}\frac{DTs}{2} + V_{in}Ts - \frac{Vo}{2}Ts + V_o\frac{DTs}{2} = 0$$

$$V_{in}[D+2] = V_o[1-D]$$

$$\frac{Vin}{Vo} = \frac{2+D}{1-D}$$

Voltage gain is $M = \frac{2+D}{1-D}$

Voltage stress in S_1, S_2 and D_0 is given by

$$V_{S1} = V_{S2} = \frac{Vin+Vo}{2}$$

$$V_{D0} = V_o + V_{in}$$

By choosing proper duty ratio D, output voltage can be regulated to a suitable value.

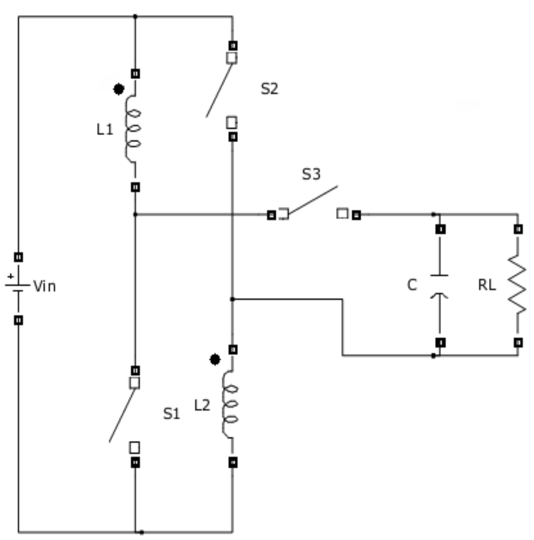

Figure 2: Boost converter model used in proposed circuit [1].

C. ZVS Inverter

The topology in Fig. 3 is composed of a standard PWM inverter and a clamping branch. The clamping branch consists of active switch S3, resonant inductor Lr, and clamping capacitor Cc. During most time of operation, the active switch S3 is in conduction, and energy circulates in the clamping branch. When the auxiliary switch S3 is turned OFF, the current in the resonant inductor Lr will discharge the parallel capacitors of the main switch and then the main switch can be turned ON under the zero-voltage condition. When the main switch is turned ON, Lr suppresses the reverse recovery current of an anti parallel diode of the other main switch on the same bridge.

Since there are three legs in the main bridge, normally the auxiliary switch must be activated three times per PWM cycle if the switch in the three legs is modulated asynchronously. To make the auxiliary switch having the same switching frequency as the main switch, a special SVM scheme is proposed to control the inverter.

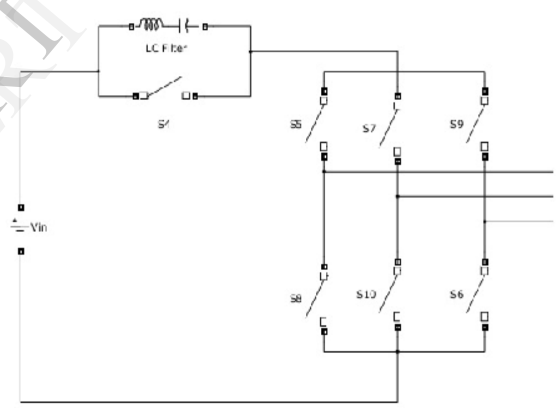

Figure 3: ZVS inverter model used in proposed circuit [2].

IV. SIMULATION RESULTS

Circuit configuration is shown in figure 1. is simulated for the models derived in III .each converter is considered as a separate sub system in MATLAB/SIMULINK realization .the switches S_1, S2 are MOSFETs, S_3 is diode, S_4-S_{10} are realized with MOSFETS operating frequency of DC-DC converters is taken as 45KH_z and the inverter is controller with SVPWM to give the output voltage frequency equal to 50H_z the other parameters of the circuit are L_1=L_2 =10^{-4} H C_0 =1000μF, V $_{dc}$ =200V and V_{rms}=230V on AC side. MATLAB/SIMULINK model of the configuration is shown in figure.4 load voltage and currents are shown in figure 5 and 6 respectively

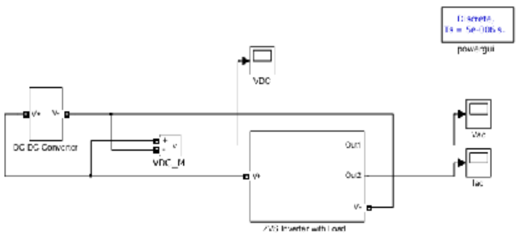

Figure 4: Simulation diagram of proposed converter.

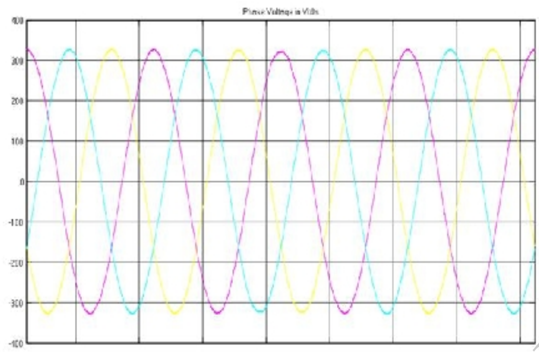

Figure 5: Shape of Load Voltage for load 1KVA at Unity Power factor.

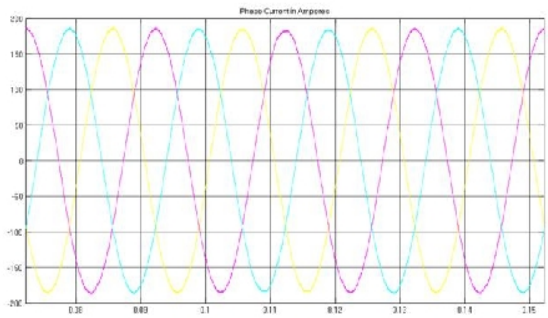

Figure 6: Shape of Line current for load 1KVA at Unity Power factor.

V. CONCLUSION

The simulation analysis of coupled inductor based zero voltage switching 3-φ inverter connected to grid is made and the results are presented. DC-DC controller used in the converter makes use of coupled inductor for achieving high conversion ratio. Inverter is controlled with SVPWM And an additional zero voltage switch branch is introduced in series with the inverter verify that the SVM-controlled three-phase soft-switching branch is connected in series with inverter branch. As a result ZVS condition can be achieved in the grid-connected ZVS inverters under the load with unity power factor or less. As the inverter system works with reduced switching loss increases its efficiency, DC-DC converter achieves high conversion gains, therefore the circuit suitable for practical applications.

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