Boost-Half Bridge Single Power Stage Configured PWM DC-DC Converter for Residential PEFC Stack Interface.

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Abstract—This paper presents the design and implementation of 1 kW prototype DC-DC power converter with bridge voltage-doubler suitable for small scale PEM fuel cell system and its associated control scheme. The operation principle of this converter is described using some operating waveforms and the switching mode equivalent circuits based on simulation results and a detailed circuit operation analysis and soft-switching conditions.

Keywords: Zero voltage soft switching, fuel cell power conditioner, High frequency link, PWM DC-DC converter.

I- Introduction

A typical PEM fuel cell produces low voltage, high current DC. A schematic of the power conditioning system satisfying this application is shown in Fig. 1. The system consists of a fuel cell stack, electrically isolated fuel cell converter to interface stack output power to the DC bus, a super-capacitor bank that maintain voltage within set limits during load transients when the fuel cell temporarily cannot supply the load, this super-capacitor bank requires recharging when the fuel cell can generate surplus power and Unidirectional DC-AC converter to produce sinusoidal 110Vrms to supply the load. A 300V DC bus for interconnecting the system blocks to allow efficient power transfer between them. This prototype uses proton exchange membrane (PEM) fuel cell module that converts hydrogen and oxygen (from air) into 1200 watts of unregulated DC electrical power.

To transform this relatively low-voltage dc output into a reliable and efficient source of power that is comparable in performance and cost with the conventional ac grid, you need a carefully designed electrical subsystem that accounts for the unavoidable characteristics of a fuel cell. The dc output of the cells varies with their load and age and with a polarization curve that is a function of the electrochemistry. In addition, a fuel cell is relatively slow to respond to load changes, due to the mass of its reactants, thermal lags, and reaction time of its hydrocarbon reformer. They are best suited for relatively steady loads. A variety of topologies have been used for high frequency isolated DC-DC converter, in this paper to avoid transformer saturation problem we use half bridge converter topology to generate a symmetrical ac waveforms at the primary side of the transformer , in which the core flux is excited bidirectionally which have advantage of better utilization of the core. And then the full bridge topology has the same advantage but the full bridge is more suitable for high input voltage applications since the power switching devices are required to block only Vin . This paper presents boost half-bridge ZVS DC-DC converter for small scale fuel cell application. Fuel cell model is introduced, simulation results are discussed and operating performance analysis using switching waveforms and equivalent circuit for each mode are presented.

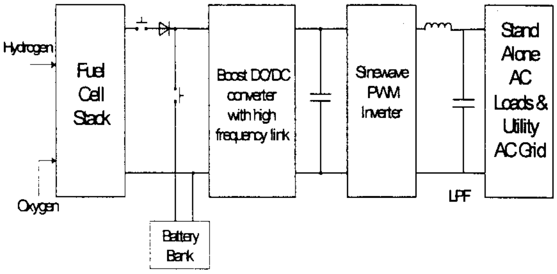

Fig. 1 A schematic block diagram of fuel cell system

2- Boost-Half Bridge Dc-Dc Converter For Fuel Cell Stack

A- Circuit Description

Figure 2 represents the novel circuit configuration of the proposed one stage soft switching PWM dc-dc power converter incorporating two switch only for boost chopper and half-bridge zero voltage soft switching (ZVS) high frequency PWM dc-dc converter. The boost-half bridge one stage high frequency converter circuit topology includes two active power switch blocks Q_1 (SW_1/D_1), Q_2 (SW_2/D_2), divided series capacitors C_1 and C_2 , high frequency transformer, bridge voltage-doubler rectifying circuit, which can achieve double of output voltage . In addition, the voltage boosted (charge-up) block composed of the boost inductor L_b and active power switch Q_1 (SW_1/D_1). Due to the negative current, the diode at the output of the fuel-cell stack is necessary to prevent the negative current going into the stack.

As we can see from the circuit configuration of proposed topology, the switching block Q_1 (SW_1/D_1) performs the operation of both single-phase boost chopper converter and high frequency ZVS high frequency PWM inverter.

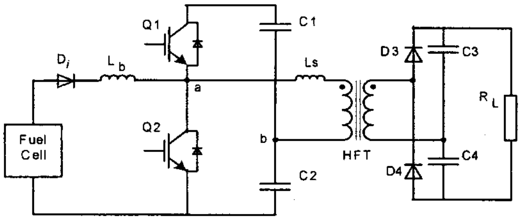

Fig. 2 A voltage-fed half-bridge ZVS PWM high frequency DC-DC converter with a transformer and voltage doublers.

B- Fuel Cell Modeling

The fuel cell can be modeled as a voltage source in series with source resistance but this model is accurate in the middle region of fuel cell V-I curve (resistance polarization region), but not accurate in activation polarization region and concentration polarization region.

A more accurate model we have used in this paper, To model the fuel cell we have used dynamic link library (DLL) which is linked to PSIM program. The variables to be passed from PSIM by value to DLL are the time, time step and feedback current. The DLL uses these values to determine the fuel cell output voltage then sent it back from DLL to PSIM. Fig. 3 shows the schematic diagram of the fuel cell stack nonlinear model.

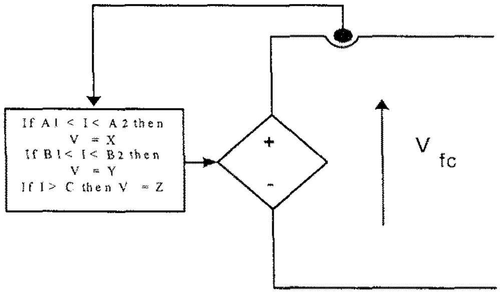

Fig 3 Fuel cell stack modeling with DLL algorithm

C- Principle of Operation and Equivalent Circuit Switching Modes

Fig. 4 shows the operating voltage and current waveforms and the operation modes of the proposed one stage high frequency power converter during one switching cycle. The operation modes include eight operating modes during one switching period, which will be simply explained in the following:

Mode 1 (D_1: on, SW_2: off and D_3: off, D_4: on)

This switching mode equivalent circuit is shown in Figure 4(a). In this mode, two current loops in the equivalent circuit are composed. L_s-D_1-C_1-L_s in which the primary current is negative value and decreasing toward zero, the second loop is FC- L_b-D_1-C_1-C_2-FC,

Mode 2 (SW_1: off, D_1: on, and D_4: off) the diode D_3 start to conduct, the primary current direction is changed to be positive value .at the same time the current through the primary of HFT changed to be positive direction , D_4 commutates naturally , the current through C_3 decreases toward zero to change its direction in the next mode, Vc1 increases to reach its maximum value

Mode 3: The current through capacitor C_1 reverse its direction to negative direction, SW_1 is turned on at ZVS, D_1 is turned off. In this mode the voltage across C1 now decreases until reaches its minimum value because the current through C1 is reversed. At the same time in the secondary circuit current through C3 changed to the positive direction and increases gradually and consequently current through D3 and current in the secondary side of the high frequency transformer (HFT) increases.

Mode 4: The gate signal is removed from SW_1 at the same time ic1 =0 , the diode D_2 starts to conduct, the current in the primary circuit of HFT and through C_2 decreases and no current flow through C_1, at the end of this mode D_2 naturally commutates

Mode 5: D_2 stops to conduct and voltage appear across SW_2, the current through capacitor C_1 is constant value and current flow through loop PEM-FC - L_b - L_s-C_2-FC.

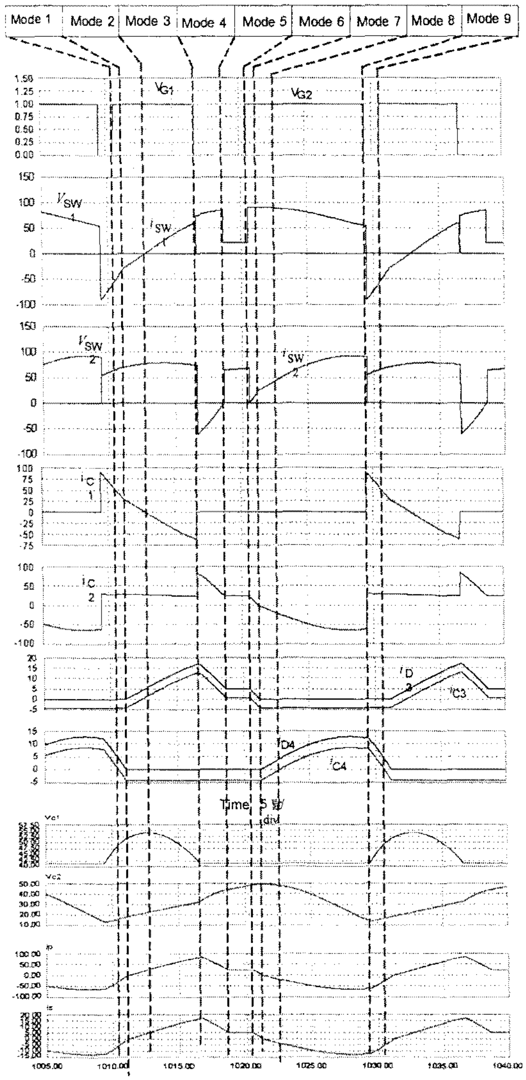

Fig. 4 Voltage and current operating waveforms

Mode 6 : The switch SW_2 starts to conduct , current in C_2 decreases toward zero and current reverses its direction through C_3, i_{D3} decreases, Voltage across C_2 increase to reach its maximum value at the end of this mode. The primary and secondary current of the transformer decreases toward zero at the end of this operating mode.

Mode 7 : The current through C_2 reverse its direction so the capacitor C_2 discharging, Vc_2 decreases. The magnetic energy is stored into the boosting inductor L_b through the loop of L_b-Q_1-C_2, while the energy is delivered to the load through D_1-C_1-L_s-C_2. In this mode the current through the primary and secondary side of HFT is reversed to negative direction, Diode D_3 stops to conduct and D_4 now conducting.

Mode 8; The current through C_4 changes direction to be a positive value.

Mode 9 : The gate signal is removed from SW_1, D_1 starts to conduct. The current through C_4 decreases to reverse direction at the end of this operating mode.

3- Operating Performances and Discussions

In this topology the switching frequency is 50 kHz. The high frequency makes the harmonics much easier to filter, producing high power quality without large filter capacitors. Similar planar transformers with ferrite cores are used in the two units. These operate efficiently at high frequencies with low conduction and eddy current losses and low magnetic losses. The leakage inductance of the transformers is adjusted to match its inductance required by the resonant circuit. The transformer provides voltage isolation between the fuel cell and the ac output voltage improving overall safety of the system. A voltage doubler on the high voltage side decreases the turns ratio of the transformer, which reduces leakage inductance and makes the system more efficient and easier to control. And at the same time, the voltage and current stresses on the low voltage side are also minimized.

The ripple current seen by the fuel-cell stack due to the switching of the boost converter has to be reduced. It is inversely proportional to boost inductor values. The output wave forms is shown in Fig. 5. The fuel cell voltage drops from 47 V to 32 V according to load current, Fig. 6 shows the input voltage and current dynamic operating waveforms.

4- CONCLUSIONS

This paper presents a soft-switched DC-DC converter for PEM-FC residential applications. This half-bridge topology has the advantage that fewer switching devices, compared with the full-bridge topologies, this converter has half the number of switching devices. This reduction also leads to significant savings on the gate drivers and heat sink. No auxiliary circuit or complex control dedicated for soft switching. Extensive simulation based on a detailed circuit analysis and fuel cell model verified the circuit operation and soft-switching conditions. A prototype rated at 1 kW was designed. This topology, therefore, provides a solution for low-cost, lightweight, compact, higher efficiency and reliable DC-DC converter designs for automotive applications and the other application areas are in uninterrupted DC power supplies and battery charging and discharging systems.

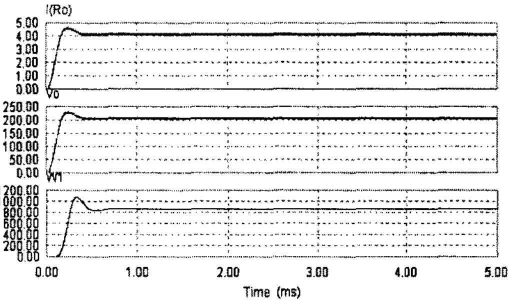

Fig 5 Output waveforms of the proposed DC-DC converter

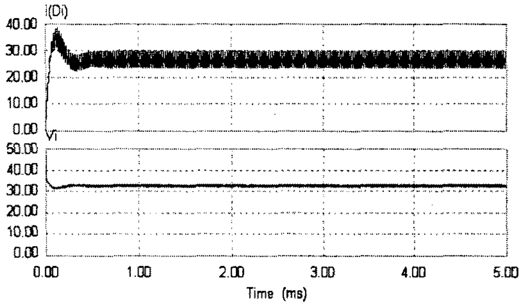

Fig. 6 Input voltage and current dynamic operating waveforms

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References

[1] Nergaard, T.A.; Ferrell, J.F.; Leslie, L.G.; Jih-Sheng Lai; "Design considerations for a 48 V fuel cell to split single phase inverter system with ultracapacitor energy storage"Power Electronics Specialists Conference, 2002. pesc 02. 2002 IEEE 33rd Annual, Volume 4, 23-27 June 2002 Page(s):2007 - 2012

[2] Hong Mao; Abu-Qahouq, J.; Shiguo Luo; Batarseh, I.; "Zero-voltage-switching half-bridge DC-DC converter with modified PWM control method", Power Electronics, IEEE Transactions on, Volume 19, Issue 4, July 2004 Page(s):947 - 958

[3] Peng, F.Z.; Hui Li; Gui-Jia Su; Lawler, J.S.; "A new ZVS bidirectional DC-DC converter for fuel cell and battery application", Power Electronics, IEEE Transactions on, Volume 19, Issue 1, Jan. 2004 Page(s):54 – 65

[4] Jin Wang; Peng, F.Z.; Anderson, J.; Joseph, A.; Buffenbarger, R.;" Low cost fuel cell converter system for residential power generation", Power Electronics, IEEE Transactions on, Volume 19, Issue 5, Sept. 2004 Page(s):1315 – 1322.