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An Interleaved DC-DC Converter with High Efficiency for High Voltage DC Bus

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***Abstract*—This paper presents a two stage interleaved dc-dc converter with reduction in input ripple current for high voltage applications of PEM fuel cells. Fuel cells offer the potential for clean and efficient energy fueled by one of the earth's most common elements: hydrogen. Since the output of fuel cell is low voltage, fuel cell stacks need to be used for high voltage applications. When fuel cells are used in stack for increasing voltage level, ripple current at input side is great concern which leads to energy losses inside fuel cell stacks due to hysteresis. Hence it is vital to reduce input current ripple of converters used along with PEM fuel cells. Interleaving is considered as a method for reducing ripple. In this paper, interleaving is used both at input stage and output stage to reduce the input current ripple and output voltage ripple.**

***Index Terms*— Fuel cell, interleaved dc-dc converter, ripple cancellation.**

I. INTRODUCTION

Proton exchange membrane fuel cell is a device that converts chemical energy into electrical energy, with many advantages such as clean electricity generation, high-current output ability and high efficiency. The PEM fuel cell presents a low voltage output with a wide range of variations. A step-up dc–dc converter is always necessary for providing a regulated high-voltage output for high power applications. For the PEM fuel-cell system applications, the dc–dc converter must be concerned with the following design criteria: large step-up ratio, low input-current ripple and isolation. Typically, an input choke with high inductance is needed at the low-voltage side because high ripple current may cause undesired hysteresis energy losses inside the fuel-cell stacks. Increased power loss and component size on the input choke are significant to result in poor conversion efficiency and low power density for the step-up dc–dc converters in high-power PEM fuel-cell systems. Interleaving along with a phase shift design used in this paper reduces the ripple current, thus eliminating the need of high valued inductor.

Because the fuel-cell stack lacks storage ability for electric energy, an energy-storage device such as the Li-ion battery is usually used on the high-voltage output dc bus of the power converter in practical high-power applications. Combined with the interleaved operation, output sides of the current-fed dc–dc converters are connected in parallel to present a low-output-voltage ripple that is preferred for the battery charging considerations. Moreover, there is no voltage-imbalance problem that exists among the output capacitors of dc–dc converters connected in series. Also interleaving at the output side reduces the output voltage ripple which is desirable for battery charging conditions. A voltage doubler used at the output side reduces voltage stress on the rectifier components.

II. FUEL CELL

A fuel cell is a device that converts the chemical energy from a fuel into electricity through a chemical reaction with oxygen or another oxidizing agent. Hydrogen is the most common fuel, but hydrocarbons such as natural gas and alcohols like methanol are sometimes used. Fuel cells are different from batteries in that they require a constant source of fuel and oxygen/air to sustain the chemical reaction; however, fuel cells can produce electricity continually for as long as these inputs are supplied.

A typical fuel cell produces a voltage from 0.6 V to 0.7 V at full rated load. Voltage decreases as current increases, due to several factors. To deliver the desired amount of energy, the fuel cells can be combined in series and parallel circuits to yield higher voltages and parallel-channel of configurations allow a higher current to be supplied. Such a design is called a fuel cell stack.

There are different types of fuel cells like PEM fuel cell (PEMFC), alkaline fuel cell (AFC), Phosphoric Acid fuel cell (PAFC), Molten Carbonate fuel cell (MCFC) etc.

1) PEM Fuel Cell

PEM fuel cells are a type of fuel cell developed for both stationary and transportation applications.

Proton Exchange membrane fuel cell uses hydrogen fuel and oxygen from the air to produce electricity. PEM is a thin solid organic compound, typically the consistency of plastic wrap and about as thick as 2 to 7 sheets of paper. This membrane functions as an electrolyte, a substance that conducts charged ions (in this case protons), but does not conduct electrons. This allows solution to conduct electricity. This membrane must be kept moist to allow conduction partially through it.

Hydrogen fuel is channeled to the anode, where the catalyst separates the hydrogen's negatively charged electrons from the positively charged protons. The membrane allows the positively charged electrons protons to pass through the cathode. The negatively charged electrons must flow around the membrane through an external circuit forming electric current. At cathode, negatively charged electrons and positively charged hydrogen ions(protons) combine with oxygen to form water and heat.

The advantage of PEM fuel cell compared to other types of fuel cells is that it uses solid electrolyte which reduces corrosion related problems. Also it provides operation at low temperature (typically 80degree centigrade.).The basic structure of a PEM fuel cell is shown in figure below.

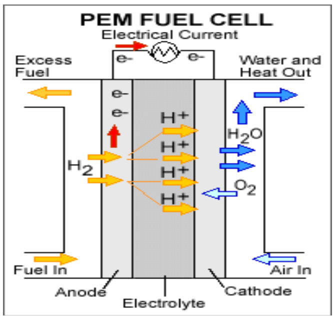

Fig.1 PEM fuel cell

III. EXISTING SYSTEM

There are different types of converters used for fuel cell applications. But for a high voltage dc application dc to ac conversion and then back to dc conversion is necessary along with a high step up transformer. A normal circuit with a rectifier, transformer and an inverter is shown in figure below.

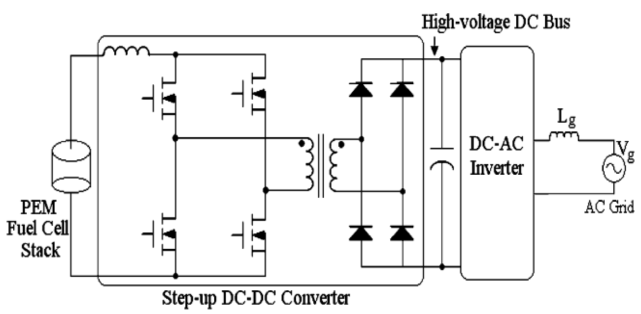

Fig. 2 DC-DC converter for HVDC

While using this type of conversion, one may have to use high value inductance at the input side to reduce the ripple and reduce losses inside fuel cell stacks. Increased power loss and component size of this inductor will lead to reduced conversion efficiency and lower power density of the converter.

There are various methods used for reduction of this input ripple and inter leaving is a common method used. In this paper a two stage interleaved converter with low value inductance and additional capacitor at input side is presented which gives reduced ripple and better efficiency.

IV. CONVERTER INTERLEAVING

Converter interleaving is a method paralleling converters for getting improved performance. In this paper two converters are paralleled both at input side and output side. The parallel connection at input side reduces input current ripple thus improving fuel cell performance. The parallel connection at output side provides a low output voltage ripple for the battery charging considerations.

Advantages compared with single converter:

- Lower input and output ripple,
- Reduced capacitor current translates into smaller and less expensive capacitors,
- Doubling of ripple frequency,
- Smaller filter components,
- More compact in size due to smaller filter components and heat-sink,
- Higher efficiency due to lower conduction losses for a given input or load current,
- Improved transient response as a result of smaller filter components,
- Reduction in peak currents translates into lower EMI noise generation

Disadvantages compared with single converter:

- More complex control,
- Higher number of components,
- Higher number of switches and gate drive circuits

V. PROPOSED SYSTEM

The proposed system uses a two phase interleaved converter with interleaving at both ends. Also the capacitors at the output side of the converter acts as voltage doubler thus reducing the stress on converter components. The circuit diagram of the proposed interleaved converter is shown in figure 3 below.

The number of interleaving stages (phases), phase shift, switching device used, pulsing method used, duty ratio and the component values are given below.

3.1 Number of phases

A two phase interleaving connection is used in this paper. As the number of phase increases, the ripple content reduces. This is achieved by ripple cancellation by providing phase shift between different stages. But there will not be much reduction in ripple with increase in number of phases. Also cost increases as the number of phase increases. Hence, as a choice between cost and benefit, the number of phases is taken as two.

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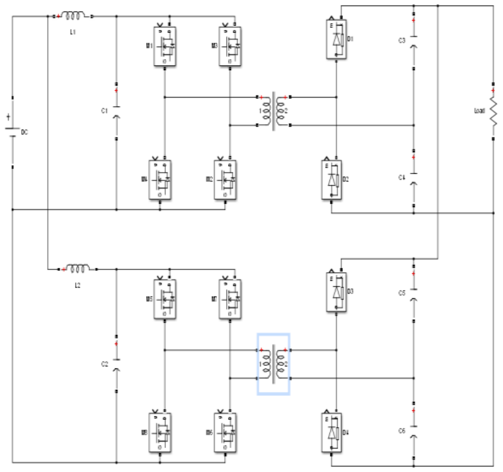

Fig. 3 Interleaved Converter

3.2 Phase Shift

A phase shift of 90 degree is provided between the two phases of the converter.

3.3 Duty ratio

The duty ratio is to be greater than or equal to 50% for getting ripple cancellation. Here the duty ratio is taken as 50%.

3.4 Switching device

The switching device used is MOSFET as it is suitable for high frequency applications with less switching losses. The switching frequency chosen is 30KHz. At the secondary side power diodes as used for the converter.

The values of LC filter at the input side is L1=L2=65mH and C1=C2=10µF. at the output side the capacitance values for the voltage doubler circuit is taken as C3=C4=C5=C6=1000µF.

VI. SIMULINK MODEL

Simulation of the circuit was done using MATLAB/ SIMULINK and the Simulink model of the circuit is given below.

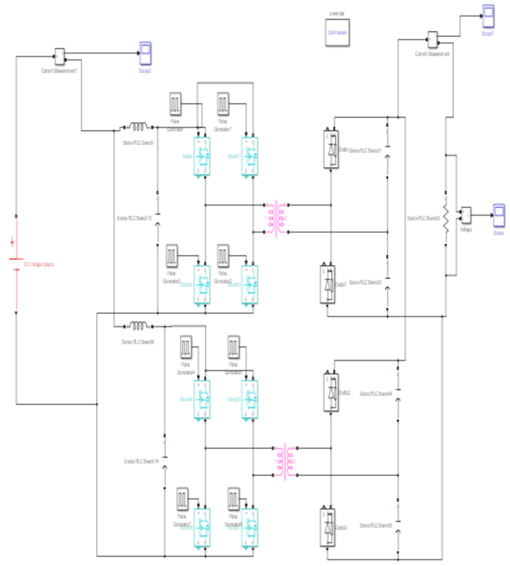

Fig. 4 SimuIink Model

In the simulation, output voltage, output current, input current waveforms were observed. The waveforms show that the ripple is much reduced thus reducing the power loss inside fuel cell stack. Also the output voltage ripple is much less which helps charging conditions for the battery.

The circuit parameters and the output voltage obtained is shown in table 1 below.

Parameter	Value
L1,L2	65mH
C1,C2	10µF
C3-C6	1000µF
Vin	100V
Switching Ferequency	30KHz
Output Voltage	430V

Table 1. Circuit Paremeters

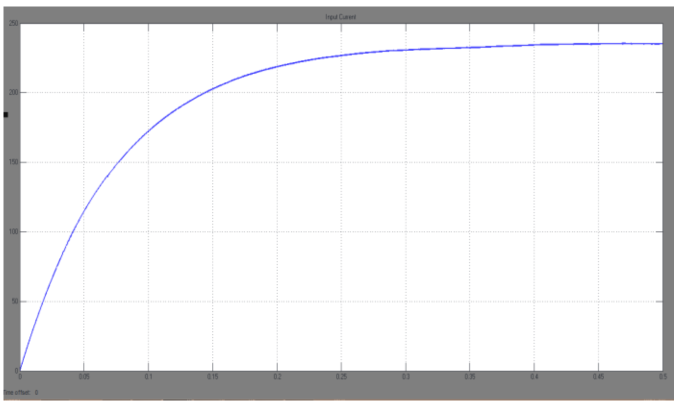

Fig.5. Input Current waveform

The waveform for input current reveals that the ripple content is very less. For a total input current of 230A, the ripple is less than 1A, thus the requirement of high value inductance is reduced.

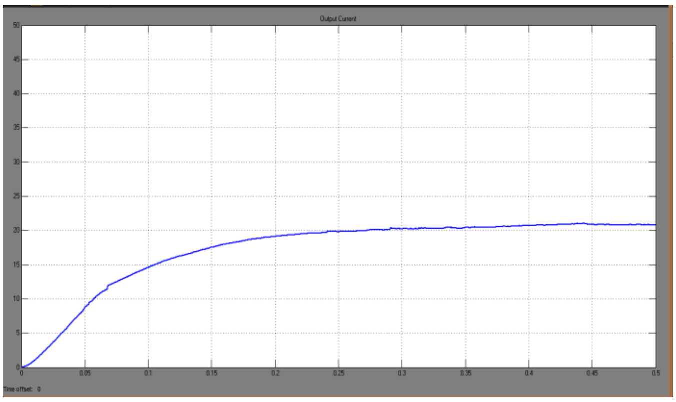

Fig.6. Output current waveform

Output voltage has very less ripple. This is a desirable condition for battery charging conditions as the system requires a capacitor to be connected for high voltage bus.

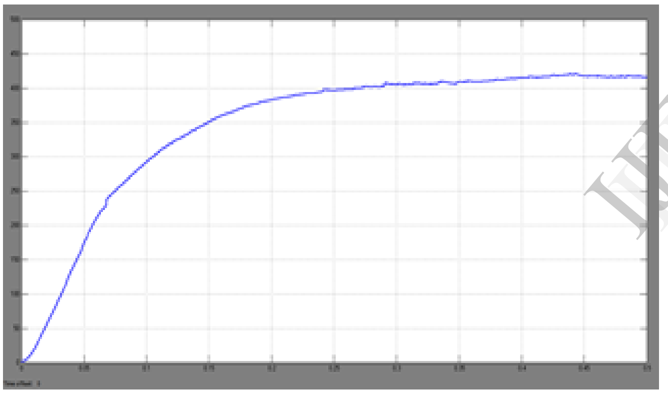

Fig 7. Output Voltage waveform

VII. CONCLUSION

A two phase interleaved converter with LC filter at the input is proposed for fuel cell applications. A phase shift of 90degree between the two phases was given for proper ripple cancellation. The prosed circuit was simulated in MATLAB 2013a and the observations are summarized as below.

With an input voltage of 100V an output voltage of amplitude 430V was obtained. The ripple at the input current is observed as reduced compared to a single stage circuit or an interleaved circuit with inductive filter. With the ripple reduction the value, size and cost of inductor can be reduced. Also the output also found to have very less ripple. The voltage doubler topology used at the output side reduces the voltage stress on the converter components.

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