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Study of Developed Cuk Converter for Renewable Energy Sources

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Abstract— Fuel cells are one of today's fastest growing renewable energy technologies that have a great promise for distributed generation and electric vehicle application because of their high efficiency, low environmental impact and scalability. This paper compares developed topologies of Dc–Dc cuk converters for renewable energy sources, like fuel cell. The studied topologies have the advantages of clear conversion processes, high efficiency and high output voltage with a small ripple. Also these topologies have simple structure, and fewer switches compare to a simple cuk converter and other classic Dc-Dc converters used in renewable energy applications. To be precise and real, we use Fuel cell stack and simulate this with Matlab simulink.

Index Terms— DC-DC converter, Renewable energy sources, Fuel cell stack, Cuk Converter.

1. INTRODUCTION

Due to economic problems and depletion of world fossil fuel supplies, renewable energy development for power generation received many attentions. Fuel cells are one of the alternative energy resources that have recently attracted a great deal of attention. Fuel cell is a device that converts the chemical energy of a fuel directly to electrical energy. Fuel cell has higher energy storage capability and is a clean energy source [1-5].

Fuel cells can serve as an emergency energy source during long-term power outages; also they can be used as a portable power system. The fuel cells are used in every aspect because of their advantages: clean and efficient way of supplying electric power [6-8]. For example they are used in the standalone purposes at homes, hospitals, industries and now are use in numerous vehicles.

However, fuel cells have a slow response due to their slow internal electromechanical and thermodynamic response [1,2]. To optimize the fuel cell system performance, a fuel cell DC-DC converter with an appropriate controller which can regulate the power flow and automatically adjust the converter output voltage is needed.

The Dc-Dc converter should have high efficiency and minimum ripple.

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Cuk converter is a combined type of converter which is using both circuits of boost and buck converter and will change the voltage to a lower or to higher level of voltage based on the characteristics that are designed for it. It can also reverse the voltage waveform and act as a step-down and step-up voltage source. Reversing the voltage is only in capability of this type of converter and this makes it special.

Voltage-lift (VL) technique is an effective method that could be applied in electronic circuit design.

In this paper we use a developed high efficient Dc-Dc cuk converter based on voltage lift type converters and analysis the simulation results in matlab simulink. Using this method avoids using transformers and cascade connection and lead to a simple structure.

In designing the converter for fuel cell, we consider the fuel cell innate characteristics instead of considering it only as an ideal DC voltage source. We use a 10 volt fuel cell in our simulation.

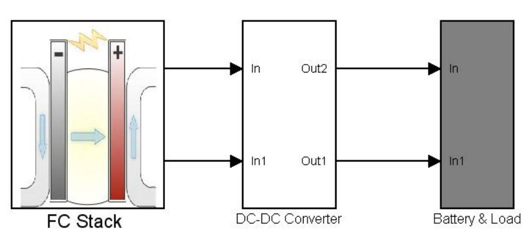

Figure 1. Block diagram of a fuel cell system used for portable applications.

2 ANALYSIS OF DEVELOPED DC-DC CUK CONVERTER

2.1 DC-DC INTERFACE

Currently, no standard output voltage rating for fuel cells has been established. Most of the present fuel cell stack modules produce an output voltage in the range 24–150 VDC. Hence, due to nonideal characteristics of fuell cell the development and designing of power conditioning units play an important role to interface the fuel cell system with standalone / grid connected systems. This interface should:

- Control the fuel cell voltage
- Convert the fu el cell output to the appropriate type and magnitude
- Deliver a hig h power factor (grid applications)
- Provide little to no har monics
- Operate efficiently under all conditions and
- Add little to the cost of the overall system.

The power electronics interface for fuel cells often utilise DC–DC converters and inverters to modify the fuel cell voltage and convert the DC voltage to AC. In this section we use a new topology for the DC-DC interface.

2.2 The Developed Converter

The Selection of power conditioning unit is based on some significant factors like lower cost, higher efficiency, and electrical isolation, ripple free and reliable operation. The efficiency of the power conditioner unit depends upon the conduction and switching losses. The conduction losses can be effectively reduced by reducing the usage of components and their operating ranges. The switching losses can be reduced by soft switching technics

In order to reduce the cost and to increase their reliability the selection of topology must have reduced component count.

The voltage-lift (VL) technique is an effective method that could be applied in electronic circuit design. A negative output dc–dc converter (Voltage-lift-type Cuk converters) applying series Cuk implementing VL techniques is studied as the interface of a fuell cell system.

The developed Cuk Dc-Dc converter is based on voltage lift type Cuk converters is a suitable choise for fuel cell interface [9]. We show that compared with the Cuk converter prototype, this converters can perform positive to negative dc – dc voltage increasing conversion with higher voltage transfer gains.

The circuit diagram is shown in figure 2 and the equivalent circuits during switching-on and switching-off are shown in figure 3.

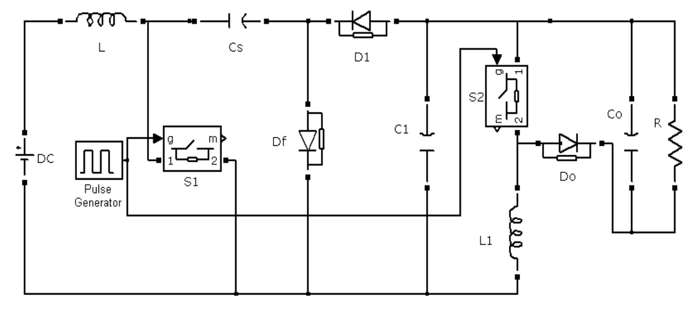

Figure 2. Developed Cuk converter

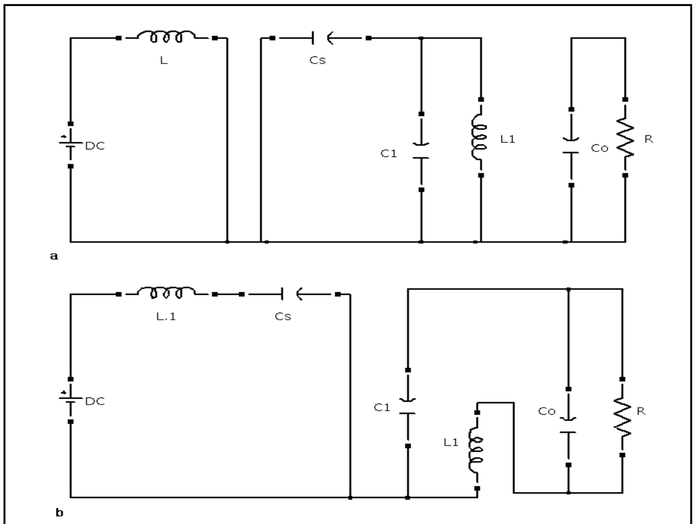

Figure3. Developed Cuk converter equivalent, a) during Switch on, b) during switch off.

The switches S and S1 are switched simultaneously. When S and S1 turn on, D_1 is on, Df and Do are off. When S and S1 turn off, D_1 is off, Df and D_o are on. Capacitor C_1 performs its characteristics to lift the output capacitor voltage V_{Co} by the capacitor voltage V_{Cs}.

As shown in figure 3, when the switches are on, the capacitores C1 and Cs are parallel. Since C_s and C_1 are sufficiently large, we have:

$$V_{C1} = V_{C2} = \frac{1}{1-D} V_{in} \quad (1)$$

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The inductor current i_{L1} increases when the switch is on and decreases when the switch is off. The corresponding voltages across L are V_{Cs} and $-(V_{Co} - V_{C1})$.

Therefore with the sec-voltage balance principle, we can obtain the relationship between the input and output voltages

$$V_O = \frac{1}{(1-D)^2} V_{in} \qquad (2)$$

In this converter the peak-to-peak voltage variation of v_o, Δv_o is equal to ($I_o DT / C_o$). Therefore the variation ratio of v_o can be calculated from equation 3. It indicates that the output voltage variation ratios are determined by the interactions caus ed by D, R, f and C_o. So increasing the capacitance of output capacitor can effectively improve the output ripper.

$$\varepsilon_s = \frac{\Delta v_0 / 2}{V_0} = \frac{D}{2RC_o f}$$

3. Simulation Results

The simulink model of a fuel cell system with the proposed DC-DC converter was shown in figure 6.

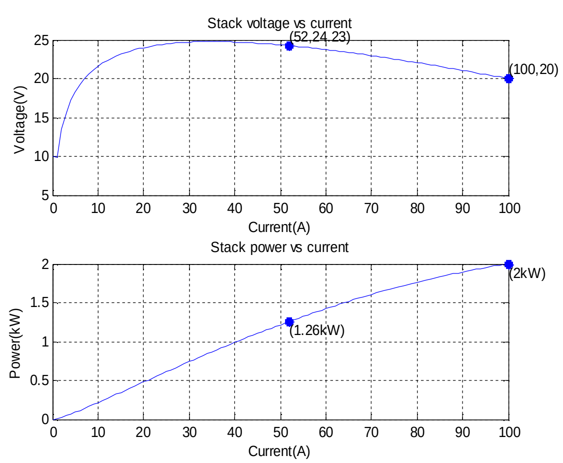


Fig. 4. Fuel cell Stack characteristics.

The circuit are under the simulation condition that V_{in}=10V, R =100 Ω ,L =1mH, L_1 =500µH, C_s =110µF, C_1=22µF, C_o=4µF and f 100 kHz.

The output characteristics of the fuel cell stack was shown in figure 4 and figure5. The fuel cell provides a 10 volt Dc voltage with a small ripple. This simulation is performed in CCM mode.

In this simulation with the input voltage V_{in}=10v that we obtain from the fuel cell, the duty cycle is 50% and V_o=40 volt.

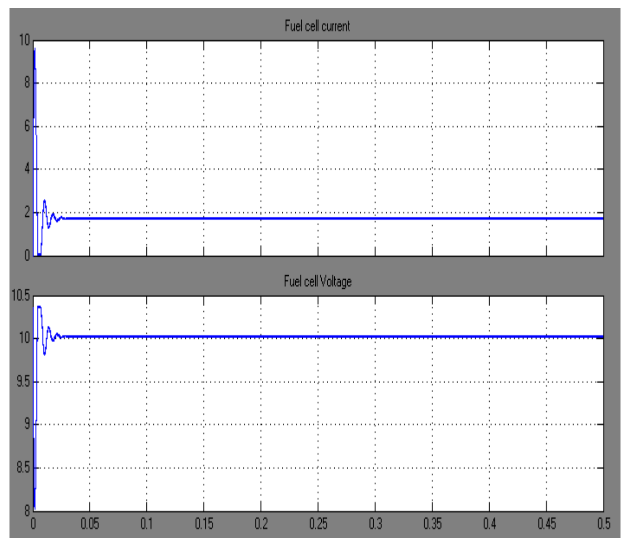
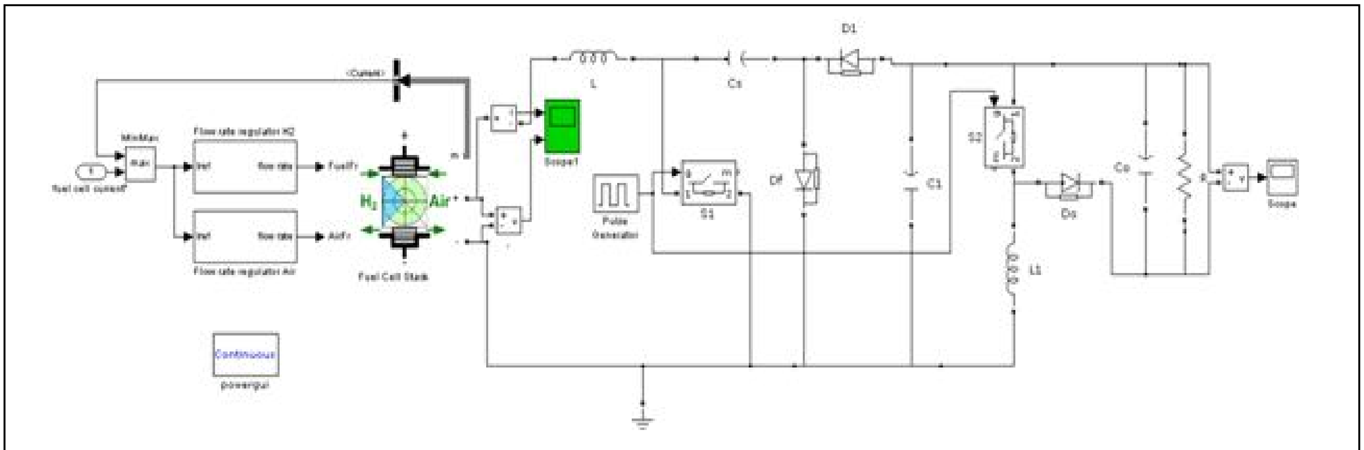


Fig. 5. Output voltage and current waveforms of Fuel cell Stack.

The simulation results show that using this developed converter can increase the efficiency and decrease the output ripple. We obtain that the output voltage variation ratios ε_s is equal to 5.3e-4. Therefore the near-zero ripple is achieved with this topology.



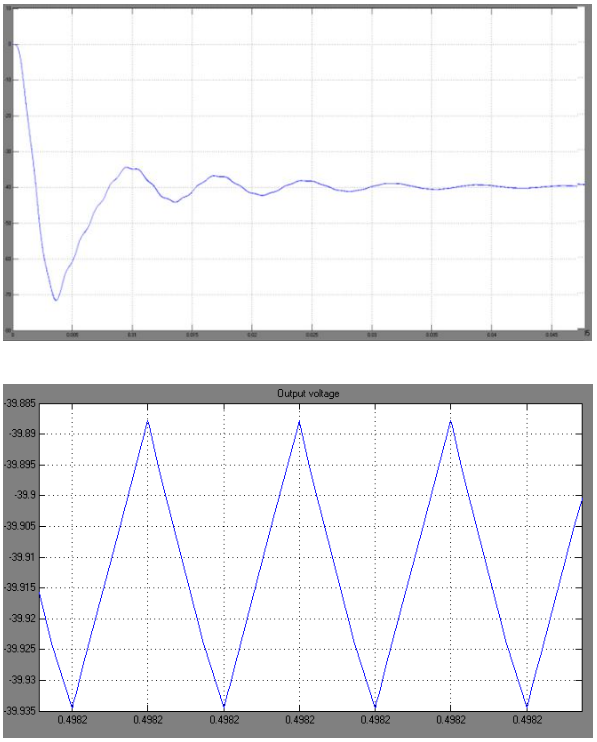


Figure7. Output voltage of the DC-DC developed Converter

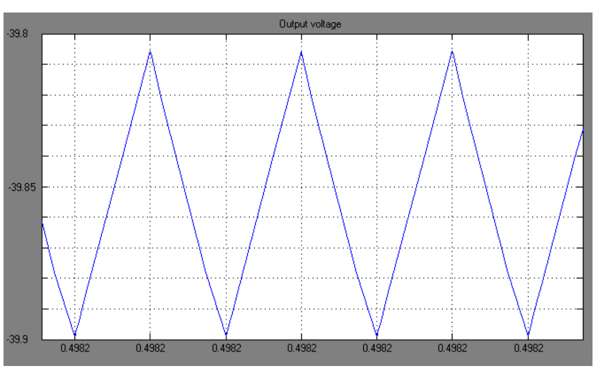


Figure8. Output voltage of the classic DC-DC cuk Converter.

Also we should attain that in a classic cuk converter, to obtain a 40 volt Dc output, the duty cycle must be 80%, and this is not a good condition. Because there are a limiton increasing duty cycle due to the parasitic elements. This problem solved in the new structure. In addition to these advantages, the circuit structure is simple and can be used in practical implementations.

CONCLUSIONS

A simulation analysis of using a developed DC-DC cuk converter for fuel cell systems is studied. Simulation results show that this topology has high efficiency with high output voltage and a small ripple compare to classic cuk converters and can be a suitable choice to use as the DC-DC converter in fuel cell renewable systems. Since the studied converters avoid using transformers and cascade connection, the relative simple structures are beneficial to potential practical applications in future.

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