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A novel high step-up DC-DC converter combining KY and CUK converters for fuel-cell system applications

Sowmya K P* and Rajkumar G**

A novel high step-up DC-DC converter which combinig KY and CUK converters for fuel cell system applicationshas been proposed in this paper. The voltage conversion ratio is greater, which combines one KY converter, one CUK converter and one coupled inductor with the turns ratio. The proposed converter consists of two-phase version configuration. A CUK type converter is integrated to the first phase to achieve a much higher voltage conversion ratio and avoid operating at extreme duty ratio. In addition, additional capacitors are added as voltage dividers for the two phases,which provide a boost operation for the second phase this proposed converter. So, the second phase of the proposed converter is a boost circuit. This converter possesses high gain ,non-pulsating output current, and also reducing the output voltage ripple. A detailed description of the proposed converter is presented along with a simple mathematical deduction and some experimental results. Finally, prototype system is also constructed to verify the effectiveness of the proposed converter.

Keywords: *Charge pump, coupled inductor, KY converter, CUK converter*

1.0 INTRODUCTION

The DC–DC converter with high step-up voltage gain is widely used for many applications, such as fuel-cell energy-conversion systems, solar-cell energy conversion systems, and high intensity discharge lamp ballasts for automobile headlamps. A typical fuel-cell system consists of fuel-cell stacks, back-up batteries, a high step-up converter, and a DC/AC converter as shown in Figure 1. The battery is mainly used as an auxiliary device for compensating the dynamic characteristic of the slow fuel-cell dynamics. The output voltage of the fuel-cell stack is normally rather low. Hence, a high step-up converter is required as an interface to convert the low DC voltage of fuel-cell stacks (22-48 V) into a sufficiently high DC link voltage (200 V) for supplying standalone AC loads or for delivering energy to the connected grid.

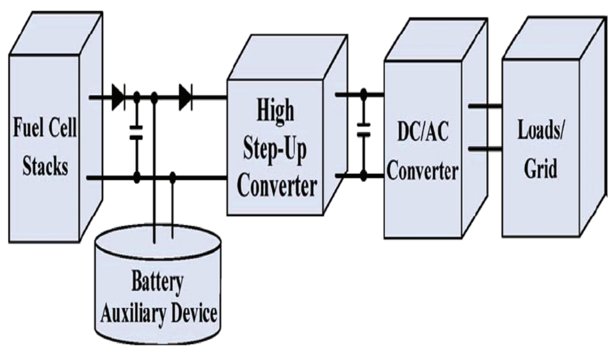

FIG. 1 TYPICAL FUEL-CELL SYSTEM

The conventional boost and buck-boost converters may be the simplest topologies. However, they are limited in practical applications by the latch-up condition and the degradation in the overall efficiency as the duty ratio *D* approaches unity. Up to now, many kinds of voltage-boosting techniques have been presented, including several inductors that are magnetized and then pump the stored

*P. G. Student, Department of EEE, NCERC, Pampady, India. E-mail: soumyakp018@gmail.com
**Assistant Professor, Department of EEE, NCERC, Pampady, India. E-mail: raj06@gmail.com

energy into the output with all inductors connected in series [13], coupled inductors with turns ratios [1], [5-10], auxiliary transformers with turns ratios [2], etc. But these techniques have some drawbacks,such as the output terminal is floating, thereby increasing application complexity. These converters contain too many components, thereby making the converters relatively complicated. The output currents are pulsating [2-12], therefore causing the output voltage ripples to tend to be large [13-14]. Although the output currents are nonpulsating, but their voltage gains are not high enough.

Based on the aforementioned, a novel step-up converter is presented. This converter combines one KY converter, one CUK converter, and one coupled inductor with the turn's ratio as can be seen in Figure 2. One can see that the turns ratio is greater than one. This converter illustrates two-phase version configuration. For the first phase of this proposed converter combining one KY converter and one CUK type converter. A CUK type converter is integrated to the first phase to achieve a much higher voltage conversion ratio and avoid operating at extreme duty ratio. In addition, capacitors are added as voltage dividers for the two phases for reducing the voltage stress of active switches and diodes. By adding these additional capacitors also provide a boost operation for the second phase this proposed converter. So, the second phase of the proposed converter is a boost circuit. This converter possesses non-pulsating output current, and also reducing the output voltage ripple.

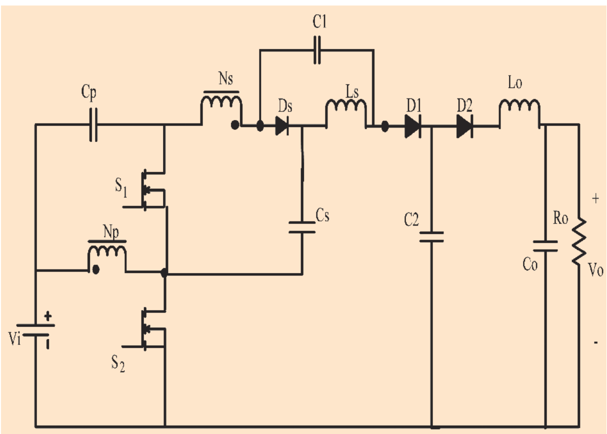

FIG. 2 PROPOSED STEP-UP CONVERTER

2.0 PROPOSED CONVERTER CONFIGURATION

A novel voltage- boosting converter with one charge pump capacitor and one coupled inductor as shown in Figure 2. It contains two MOSFET switches S_1 and S_2, one coupled inductor compose of the primary winding with N_P turns and the secondary winding with N_S turns, one energy-transferring capacitor C_1. As can be seen in Figure 2, the proposed converter consists of two phase circuits with interleaved operation. The first phase includes KY converter and boost integrated Cuk-type converter, which contains a shared inductor L_m and switch S_1 for the boost and the isolated CUK type converter with turn ratio N. The second phase of the proposed converter is a boost circuit which contains switch S_2, blocking capacitor C_2, and diode D_2 followed by the common output capacitor C_0. In addition, the input voltage is denoted by Vi, the output voltage is signified by V_0, and the output resistor is represented by R_0.

3.0 BASIC OPERATING PRINCIPLES

The proposed converter operates in the Continuous Conduction Mode (CCM). There are four operating modes according to the on/off status of the active switches.

3.1 Mode 1

During this operation mode, switch S_1 remains conducting and S_2 is turned off. In addition,diodes D_1 and D_S remain off and D_2 is on. The corresponding equivalent circuit is shown in Figure 3. Therefore, the $-V_{CP}$ voltage is imposed on N_P, thereby causing the magnetizing inductor Lm to be demagnetized and the voltage across N_S to be induced, equal to $-V_{CP} \times N_S/N_P$. However, the operation in first phase circuit, including the Cuk-type converter, remains the same as above. In addition, D_2 becomes forward biased, thus voltage across C_2 (V_{C2}), provides the energy to L_0 and the load.

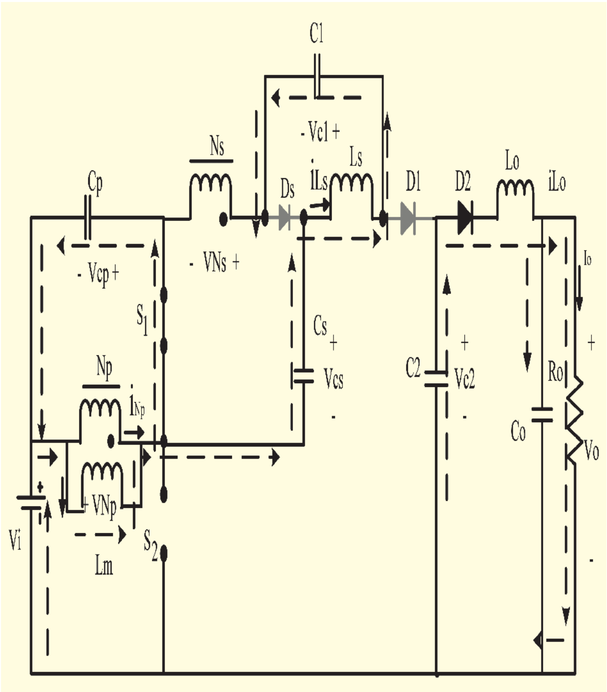

FIG. 3 POWER FLOW DIAGRAM IN MODE 1

3.2 Mode 2

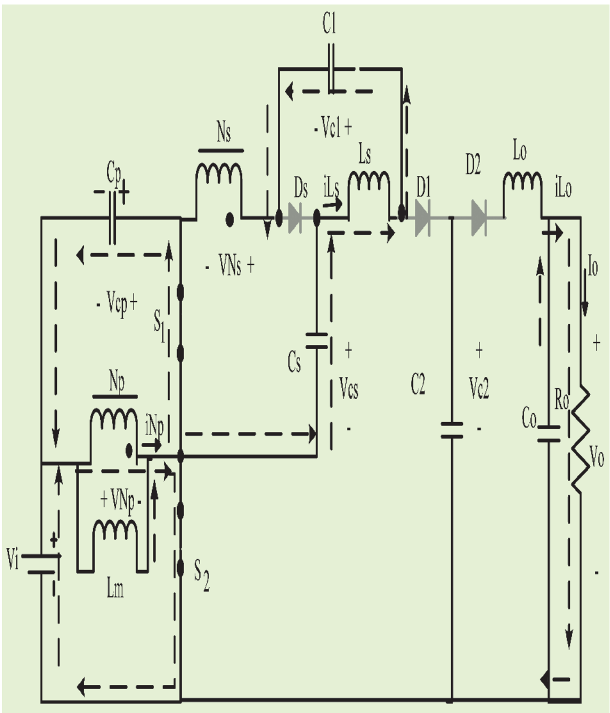

FIG. 4 POWER FLOW DIAGRAM IN MODE 2 AND 4

During this interval, as shown in Figure 4, both Switches S_1 and S_2 are turned on and diodes D_1, D_2, and D_S are all off. Therefore the $-V_{CP}$ voltage is imposed on N_P, thereby causing the magnetizing inductor L_m to be demagnetized and the voltage across N_S to be induced, equal to $-V_{CP} \times N_S/N_P$. Meanwhile, the capacitor voltage of C_P is discharged through the ideal transformer, C_S, and L_S to charge capacitor C_1. In addition, the output power is supplied from capacitor C_0.

3.3 Mode 3

During this interval, as shown in Figure 5, switch S_1 is turned off and S_2 is turned on. In addition, diode D_2 is off and diode D_1, D_S is on. Therefore, input voltage V_i is imposed on Np, thus causing L_m to be magnetized and the voltage across Ns to be induced, equal to $V_i \times N_S/N_P$. In addition, D_1 becomes forward-biased. Input voltage V_i charged through the ideal transformer, C_S, C_2 and L_S to charge capacitor C_1. In addition, the output power is supplied from L_0 through capacitor C_0.

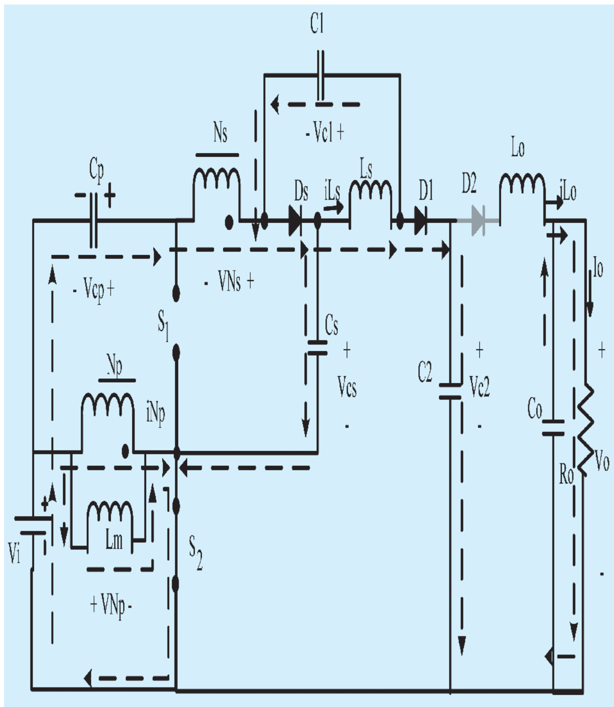

FIG. 5 POWER FLOW DIAGRAM IN MODE 3

3.4 Mode 4

During this interval, both Switches S_1 and S_2 are turned on and diodes D_1, D_2, and D_S are all off. The corresponding equivalent circuit as shown in Figure 4. The circuit operation as same as above in mode 2.

4.0 SIMULATION RESULTS

MATLAB/SIMULINK™ is applied to simulate the mathematic model and control strategy of the proposed converter. The proposed converter was simulated through MATLAB. The converter was tested with input voltage V_{in}=12 V, and to get the output voltage V_0 = 280 V. The simulation diagram of proposed converter with two MOSFET switches is shown in Figure 6.

Simulation parameters and its value are listed in Table 1. The simulation results are presented in Figures 7-9 ,which shows the voltage across capacitors C_1, C_2 and output voltage V_0. Figure 7 shows the output voltage waveform of proposed converter, which is equal to 280 V. Voltage across capacitor C_S is 132.9 V as can be seen in Figure 8. In Figure 9 shows the voltage waveform across capacitor C_1.

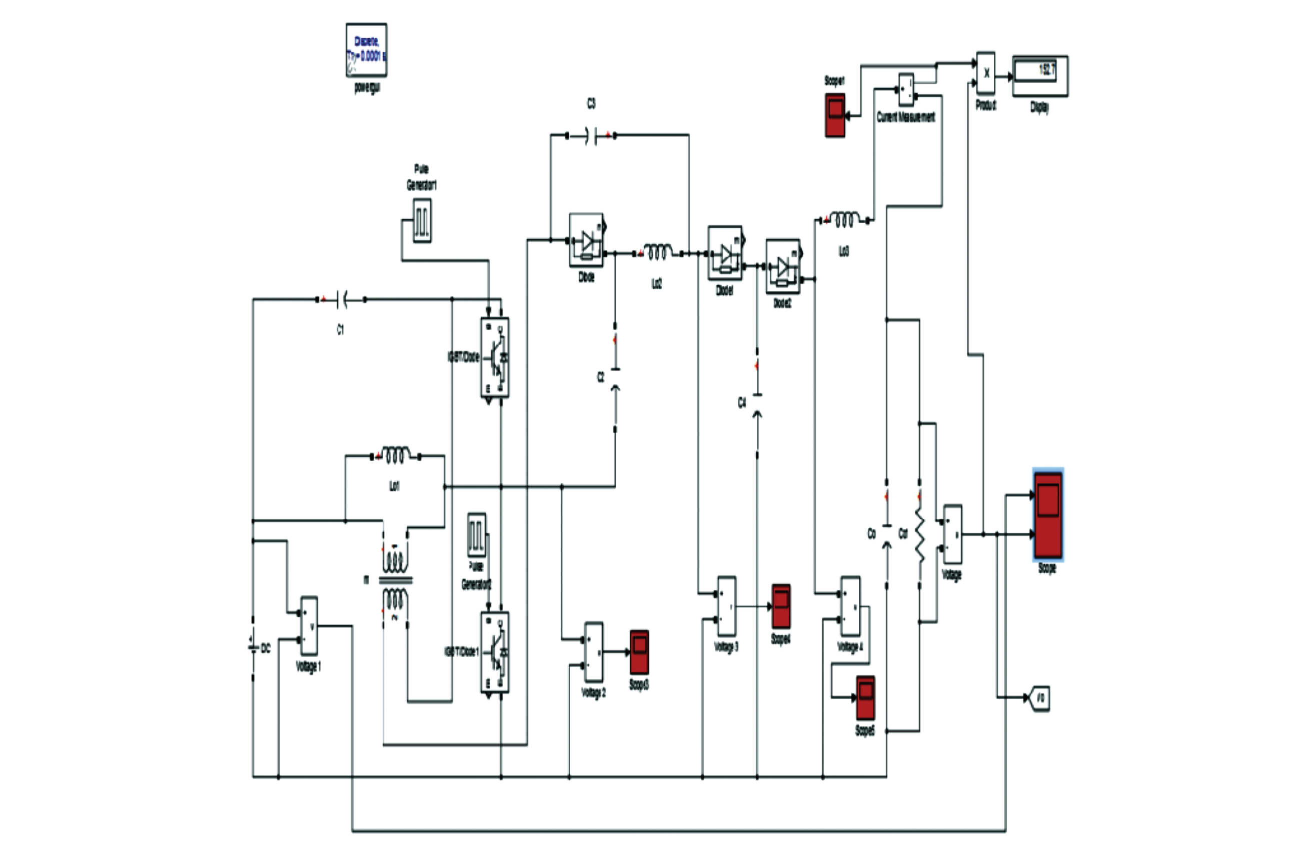

FIG. 6 SIMULATION DIAGRAM OF PROPOSED STEP UP CONVERTER

TABLE 1	
SIMULATION PARAMETERS	
Parameters	**Values**
Rated Power	240 W
Input voltage	12 V
Output voltage	280 V
Switching frequency	100 kHz
Transformer turns ratio	1:3
Rated output current	0.8908 A

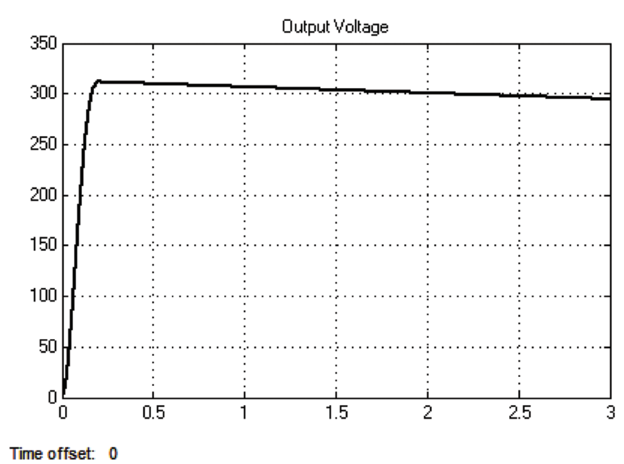

FIG. 7 OUTPUT VOLTAGE WAVEFORM. V_0= 280 V

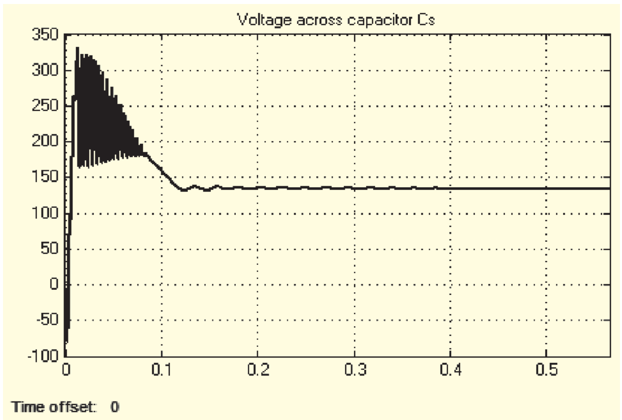

FIG. 8 VOLTAGE WAVEFORM ACROSS CAPACITOR C_S (V_{CS}= 132.9 V)

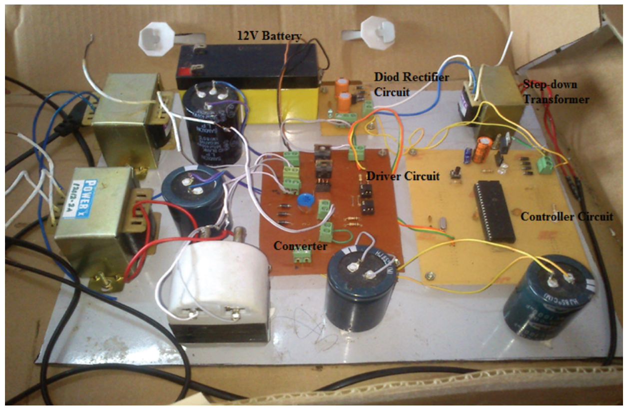

FIG. 10 PROTOTYPE SYSTEM OF PROPOSED CONVERTER

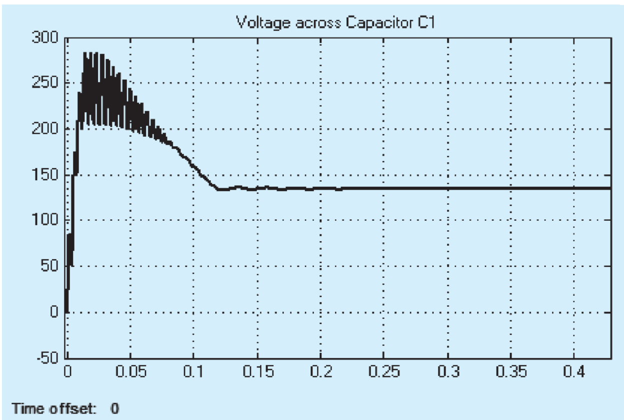

FIG. 9 VOLTAGE ACROSS CAPACITOR C_1 (V_{C1}= 134.068 V)

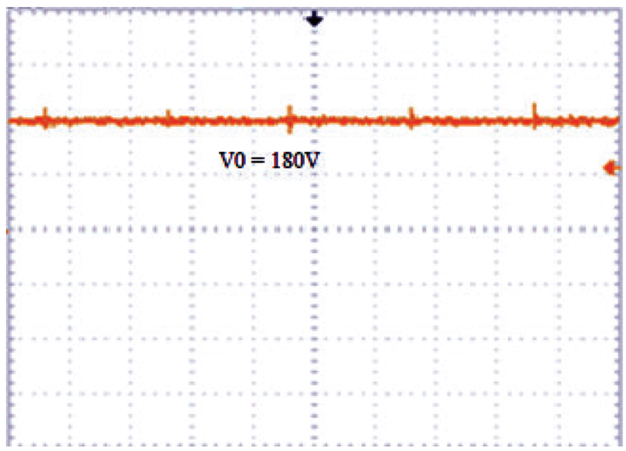

FIG. 11 EXPERIMENTAL WAVEFORM. V_0 = 180 V

Comparing with the existing voltage boosting converter [12], the proposed voltage boosting converter combining KY and CUK converters provide high gain and more efficient. Further more, this converter has no floating output, possesses non-pulsating output current, and also reducing the output voltage ripple.

5.0 EXPERIMENTAL RESULTS

To verify the effectiveness of proposed converter, a Prototype system is constructed as shown in Figure 10 and components used in the prototype is shown in Table 2. Experimental waveform is given in DSO as shown in Figure 11. From this experimental setup we obtained the output voltage is 180 V with 12 V input voltage. Because, unavailability of some capacitors in proper value within the simulation. From this experimental result, I can conclude,with proper design and used switch components with lower voltage ratings to achieve higher efficiency.

TABLE 2

COMPONENTS USED IN THE PROTOTYPE

Components	Specification
MOSFET switches S_1, S_2	N channel MOSFET TO-220AB, V_{DS}=60 V, I_D = 50 A, $R_{DS(on)}$=0.028 Ω
Charge pump capacitor C_P	56 µF/450 V (electrolytic capacitor)
Coupled inductor	N_P: N_S =1:3, L_m=100 µH
Energy transferring capacitor C_S	1000 µF/315 V (Electrolytic capacitor)
Cuk capacitor C_1	1000 µF/315 V (Electrolytic capacitor)
Blocking capacitor C_2	1000 µF/315 V (Electrolytic capacitor)
Inductors L_S, L_O	168 µH
Output capacitor C_O	100 µF
Output resistor R_O	500 Ω

6.0 CONCLUSION

Anovel high step-up DC-DC converter which combining KY and CUK converters for fuel cell system applications has been proposed in this paper. The voltage conversion ratio is greater, which combines one KY converter, one CUK converter and one coupled inductor with the turns ratio. This converter illustrates two-phase version configuration. A CUK type converter is integrated to the first phase to achieve a much higher voltage conversion ratio and avoid operating at extreme duty ratio. The second phase of the proposed converter is a boost circuit. This converter possesses non-pulsating output current, and also reducing the output voltage ripple. Moreover, the structure of the proposed converter is quite simple and very suitable for industrial applications.

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