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Dual Output DC-DC Converter with Wide Voltage Gain for Fuel Cell Vehicles

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ABSTRACT
The demand for energy efficient, cleaner and sustainable solutions for transportation is increased due to the frightening situation of environmental concerns and petrochemical goods. Because of these difficulties, transportation electrification become more popular. DC-DC converters play an important role in electric vehicles to meet the required demand. The inherent requirements for DC-DC converters are high voltage gain to meet out the higher DC link voltage demand, presence of common grounding to avoid electromagnetic interference issue and lower voltage stress with reduced components and continuous input current to improve the life span of the fuel cell. A high voltage gain DC-DC converter by combining the switched capacitor and quasi switched boost network modules. The converter providing the voltage gain 10.8 for input voltage 28 V. The performance study of the converter is carried out with MATLAB/SIMULINK R2017a. From simulation result it is observed that the converter has an efficiency of 92%.

***Keywords* -** Common grounding, Continuous input current, Fuel Cell, Voltage stress

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I. INTRODUCTION

The demand for energy efficient, cleaner and sustainable solutions for transportation is increased due to the frightening situation of environmental concerns and petrochemical goods. Because of the foregoing difficulties, now is the time petrochemical cars are replaced by electric cars. Various plug-in hybrid electric vehicles and electric cars have been designed to get a more environmentally friendly and cost effective mode of transportation. Vehicles with a variety of energy sources. Photovoltaic energy or fuel cell energy are the primary sources of energy for cars. Nonetheless, because solar energy is intermittent and highly reliant on weather conditions, it will have an impact on the system's efficiency. Fuel cell energy, rather than photovoltaic energy, could be used to solve this problem. The fuel cell energy is constant and unaffected by the weather.

In fuel cell vehicles, the DC-DC converter plays a critical role in meeting demand. The converter's primary goal is to get a large voltage conversion ratio. Additionally, the converters being used fuel cell cars must have a constant input current to maximize the fuel cell's performance. Other goal is to establish a common grounding between the input and output ports to avoid electromagnetic interference and leakage current. Various topologies for DC-DC converters have been established over time [1]. There are two types of converters: isolated and non-isolated converters. Isolated converters improve voltage gain by raising the number of transformer turns. However, increasing the number of turns results in increased leakage inductance, significant voltage spikes, and electromagnetic interference [2].

Non-isolated converters, on the other hand, are transformer-less converters that produce a high voltage in a single stage at a cheap cost and with improved efficiency. Various non-isolated DC-DC converters are now being created and developed. The traditional boost converter is able to generate higher voltage. It is evident that the boost converter may enhance voltage gain by expanding the duty cycle, however this results in increased conduction loss and voltage stress.

Cascaded boost converters are used to increase the voltage gain of a standard converter. The disadvantages include low efficiency and accuracy, massive cost, and huge size [3]. It can be overcome by using a boost converter with a switched inductor cell [4]. It yields a large gain. Raising the number of switched inductor cells linked and increasing the voltage gain. The disadvantage of this topology is that it has a larger number of inductors, which results in more stress and decreased efficiency. The use of switched capacitor topologies can reduce voltage stress, as shown in [5].

[5][6] Describe a variety of Z-source based DC-DC converter topologies. These Z-source converters, on the other hand, have some drawbacks, such as excessive current ripple, high starting current, and the lack of common grounding. These issues can be overcome by employing a large number of quasi Z-source converters [7]. The coupling of a switched capacitor module and a quasi switched boost module is utilized in a variety of configurations for high voltage gain [8]. These topologies, however, have issues with complexity, size, and efficiency.

In order to overcome the problems pointed in above papers a dual output high gain DC-DC converter is introduced which has higher efficiency and higher gain. The converter is a combination of quasi- switched boost network and switched capacitor module which has lower voltage stress across semiconductor devices.

II. WORKING PRINCIPLE

The proposed converter is motivated by the desire to optimize voltage gain while using fewer components and reducing voltage stress across semiconductor devices. Four switches (S_1, S_2, S_3, S_4), one inductor (L), five capacitors (C_1, C_2, C_3, C_4, C_5) and four diodes (D_1, D_2, D_3, D_4) and two output resistors (R_{01} and R_{02}) make up the converter. The input and output voltages are denoted by V_{in}, V_{01} and V_{02} are the numbers assigned to them. The converter is made up of a switched capacitor module (C_3, C_4, C_5, D_2, D_3, and D_4) and a quasi-switched boost module (L, S_1, and D_1).

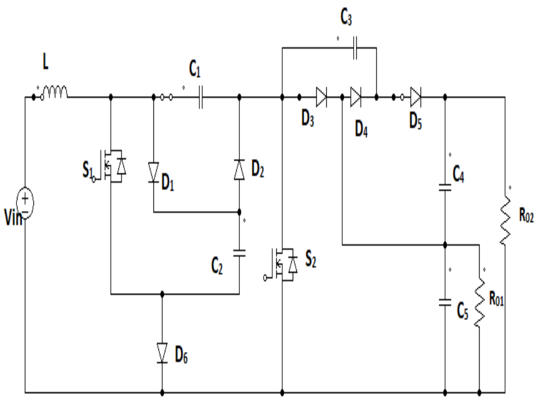

Fig. 1 Proposed converter

2.1 Modes of Operations

Fig. 4 shows the converter's working waveform. There are two operational modes for the time period Ts. Below are the corresponding circuits for various functioning modes.

Mode 1: In mode1, the switches S_1, S_2 and S_4 are turned ON and S_3 turned OFF. The diode D_3 is forward biased and diodes D_1, D_2 and D_4 are reverse biased. The capacitors C_1 and C_2 are parallel. As a result, the capacitor voltage V_{C2} becomes equal to voltage V_{C1}.

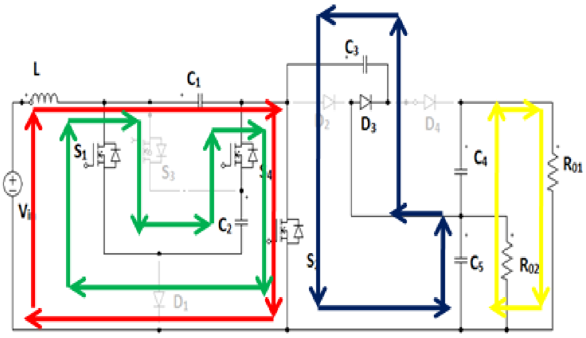

Fig. 2 Mode 1

The inductor L is charged to sum of voltage $V_{in}+V_{C1}$ through switch S_2. The capacitor C_5 discharged in order to charge the capacitor C_3 and the two capacitors are paralleled. Therefore, the voltage V_{C3} becomes equal to voltage V_{C5}. The capacitor C_4 and C_5 supplies the power to load R_{01} and R_{02} respectively.

Mode 2: In mode 2, the switches S_1, S_2 and S_4 are turned OFF and S_3 turned ON. The diodes D_3 reverse biased and diodes D_1, D_2 and D_4 are forward biased. The capacitor C_3 and C_4 are parallel. So, voltage V_{C3} is equal to voltage V_{C4}. The capacitor C_1 and C_2 are charged through the sum of voltage $V_{in}+V_L$. The capacitor C_3 discharges to charges the capacitor C_4. The capacitor C_5 is also charging.

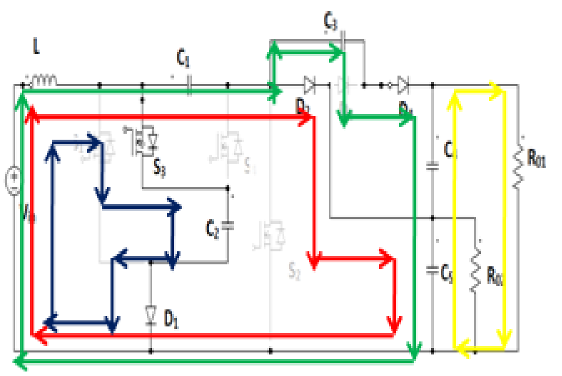

Fig. 3 Mode 2

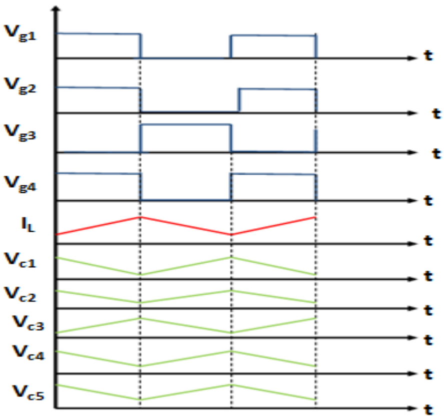

Fig. 4 Theoretical waveform

2.2 Design Consideration of Main Components
The input voltage is taken as 28 V. The pulses are switched at the rate of 40 kHz with a duty ratio of 0.25.

A. DUTY RATIO
For any practical applications, the dc-dc converter must be operated at lower duty ratios to get maximum efficiency.

$$V_0 = \frac{4}{(1-2D)} \times V_{in} \qquad (1)$$

B. LOAD RESISTOR
Taking P_0 as200 W and output power as 200 V, load resistance is calculated as,

$$R = \frac{V_0{}^2}{P_0} = \frac{200^2}{200} = 200\,\Omega \qquad (2)$$

C. INDUCTOR
Let %x be the ripple in inductor. In order to find ripple current, need inductor current.

$$I_L = \frac{4}{1-2D} \times I_0 = 8A \qquad (3)$$

Let assumes as %x is 2% of I_L.

$$L = \frac{V_{in} \times (1-D) \times D}{\%x \times 2 \times I_0 \times f_s} \qquad (4)$$

The inductor L is designed as 0.4 mH.

D. CAPACITORS
ΔV_{C1}, ΔV_{C2}, ΔV_{C3}, ΔV_{C4} and ΔV_{C5} are the maximum tolerant voltage ripple on the capacitors C_1, C_2, C_3, C_4 and C_3 respectively.

$$C_1 = \frac{2D \times I_0}{(1-D) \times \Delta V_{c1} \times f_s} \qquad (5)$$

$$C_2 = \frac{(1+D) \times I_0}{(1-D) \times \Delta V_{c2} \times f_s} \qquad (6)$$

$$C_3 = \frac{I_0}{\Delta V_{c3} \times f_s} \qquad (7)$$

$$C_4 = \frac{(1+D) \times I_0}{\Delta V_{c4} \times f_s} \qquad (8)$$

$$C_5 = \frac{D \times I_0}{\Delta V_{c5} \times f_s} \qquad (9)$$

The capacitor C_1, C_2 is designed as 40μF and capacitor C_3, C_4 and C_5 are 100μF.

III. CONTROL STRATEGY

The duty cycle of switches S_1, S_2 and S_4 are 0.25 and same pulse with 180 degree phase shift is given to switch S_3.

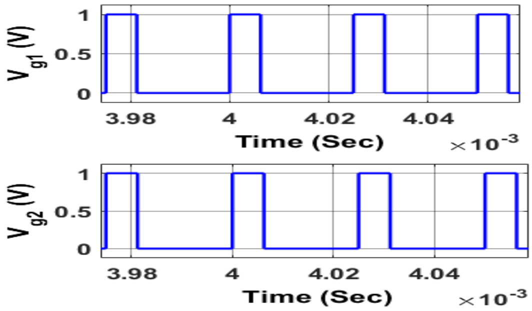

Fig. 5 Switching pulses to S_1, S_2,

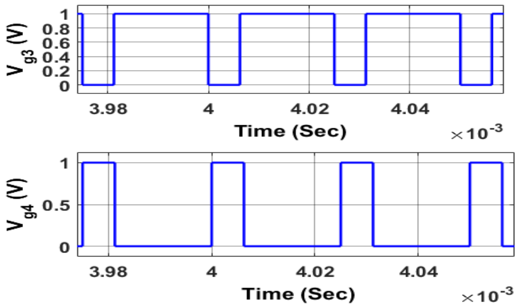

Fig. 6 Switching pulses to S_3 and S_4

IV. SIMULATION RESULTS

The proposed converter is simulated in MATLAB/SIMULINK by choosing the parameters listed in Table1 and the Simulink model is shown in Fig.5. An input voltage Vin of 28 V gives an output voltage V_0 of 300 V (V_{01}=200 V, V_{02}=100 V) for an output power P_0 of 200 W. The switches are MOSFET/Diode with constant switching frequency of 40 kHz.

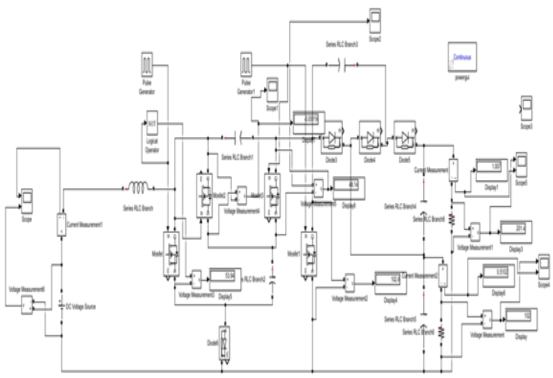

Fig. 7 Simulink model of converter

TABLE I
SIMULATION PARAMETERS

Parameters	**Specifications**
Input Voltage (V_{in})	28V
Output Voltage	V_{01}=200V V_{02}=100V
Switching Frequency(f_s)	40kHz
Inductor L	400μH
Capacitors C_1, C_2	40μF
Capacitors C_3, C_4, C_5	100μF
Load Resistance (R_{01}=R_{02})	200Ω

Fig. 8 shows the input voltage (Vin) and input current (Iin) and its zoom version. Input voltage (Vin) is 28 V and input current (Iin) is about 9.8 A.

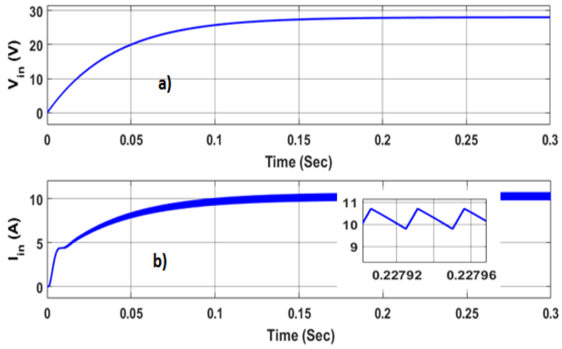

Fig. 8 a) input voltage b) input current

Fig. 9 shows the output voltage (V_{01}) and output current (I_{01}) and its zoom version. Output voltage (V_{01}) is about 201 V and has a ripple of 0.3 V. Output current (I_{01}) is about 1 A and output current ripple is in the range of 0.002 A.

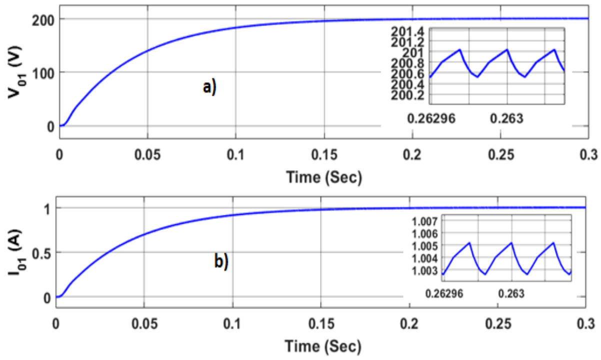

Fig. 9 (a) output voltage (V_{01}) (b) output current (I_{01})

Fig. 10 shows the output voltage (V_{02}) and output current (I_{02}) and its zoom version. Output voltage (V_{02}) is about 102 V and has a ripple of 0.2 V. Output current (I_{02}) is about 0.5 A and output current ripple is in the range of 0.002 A.

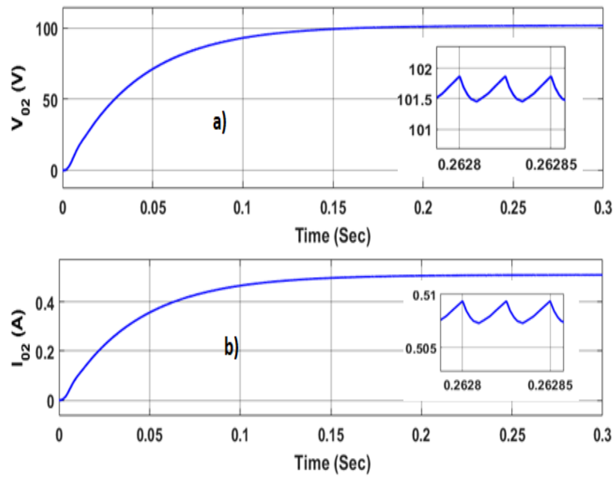

Fig. 10 (a) Output voltage (V_{02}) (b) Output current (I_{02})

The current flows through the inductor L and its zoom version is shown in the Fig. 11. Inductor current is same as input current. Inductor current is about 9.8 A and ripple current is about 0.8 A.

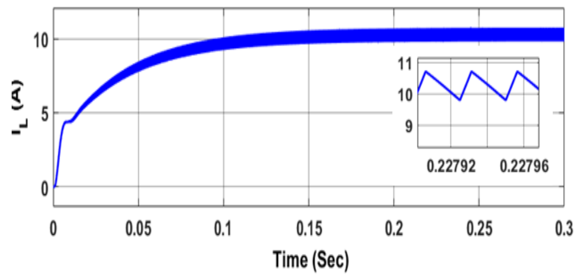

Fig. 11 Inductor current I_L

The voltage across capacitors C_1 and C_2 are shown in Fig. 12 with magnitude of V_{C1}=52 V and ΔV_{C1}=2V, V_{C2}=52 V and ΔV_{C2}=2 V.

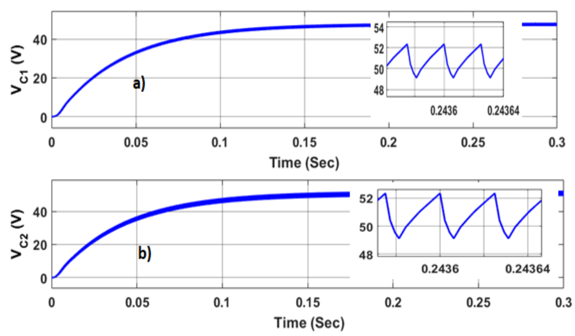

Fig. 12 Voltage across capacitors (a) C_1 (b) C_2

The voltage across capacitors C_3, C_4 and C_5 are shown in Fig. 13 with magnitude of V_{C3}=96 V and

ΔV_{C3}=0.1 V, V_{C4}=99 V and ΔV_{C4}=0.25 V, V_{C5}=99 V and ΔV_{C5}=0.25 V.

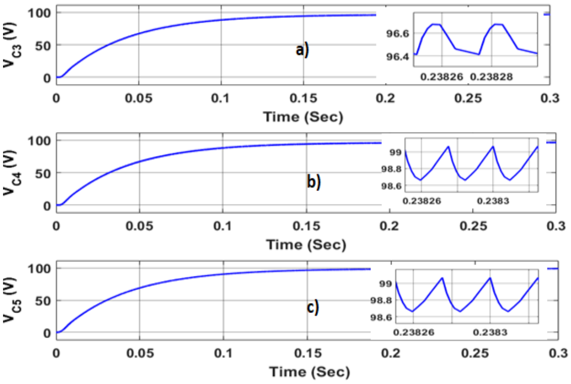

Fig. 13 Voltage across capacitors (a) C_3 (b) C_4 and (c) C_5

V. ANALYSIS

The analysis dual output DC-DC converter is carried out by considering parameters like voltage gain, efficiency, and duty cycle.

A. Efficiency Vs Output power

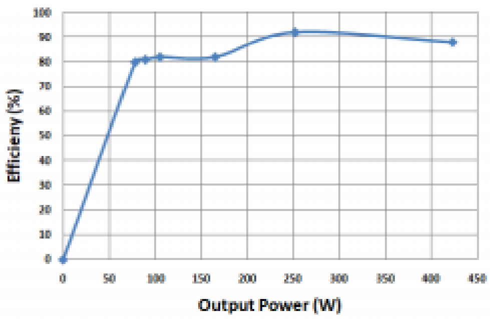

Fig. 14 Efficiency Vs Output power

Efficiency of a power device is defined at any load as the fraction of the power output to the power input. Fig. 14 and 15 are shows typical curve for the variation of efficiency as a function of output power for R load and RL load respectively. The converter achieves maximum efficiency of about 92% for the converter.

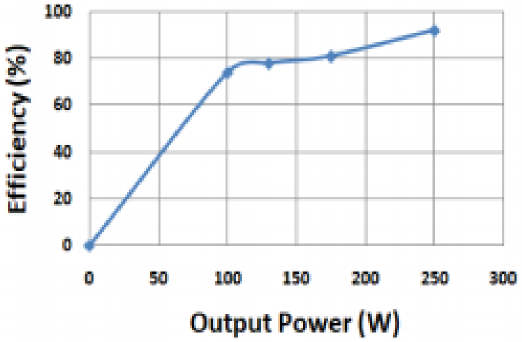

Fig. 15 Efficiency Vs Output power

B. Voltage gain Vs Duty ratio

The analysis of voltage gain as a function of duty ratio is shown in Fig.16. The voltage gain is initially increases with increasing duty ratio and reaches a maximum point. Further increasing of duty cycle, gain starts to decreases.

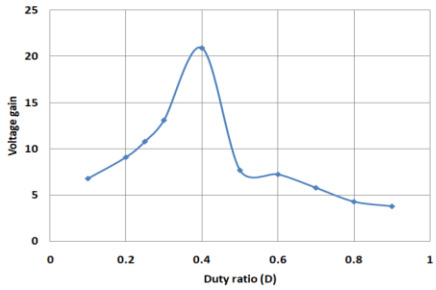

Fig. 16 Voltage gain Vs Duty cycle

According to this figure, the voltage gain of boost converter is highest when the duty cycle is equal to 40%.

C. Output voltage ripple Vs Switching frequency

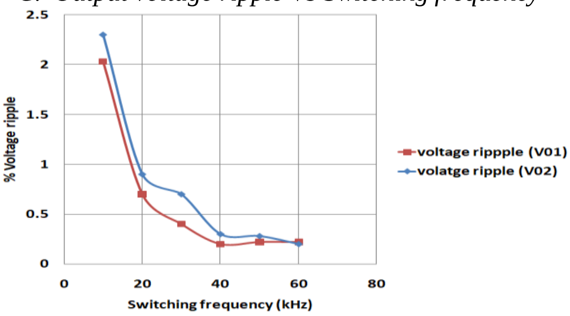

Fig. 17 Output voltage ripple Vs Switching frequency

The plot of output voltage ripple as a function of switching frequency is shown in Fig. 17. According to this figure, for R_{01} load the converter has ripple about 0.3 V and for R_{02} load the converter has ripple about 0.2 V for switching frequency of 40 kHz.

VI. CONCLUSION

A high-gain DC-DC converter that effectively meets the demands of fuel cell vehicles, such as constant input current, high voltage gain, common grounding and a light weight. The operation of CCM is described, as well as design guidelines. The proposed converter has a larger voltage gain than a standard converter. When compared to a traditional boost converter, the converter produces less voltage stress across semiconductor components. The problem of electromagnetic interferences and leakage current is eliminated by providing a common grounding between the input and output ports. As a result, the converter has a lot of potential in terms of fuel cell vehicles. According to analysis, the converter has a maximum efficiency around 92% and a voltage gain of 10.8.

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