Performance Evaluation of Fuel-Cell Connected Different Quasi-Z Source DC-DC Converters

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***Abstract*- Power generation through renewable sources is increasing day by day which needs voltage boosting methods that can enhance the output voltage level for various useful applications. This paper is dedicated to step-up the voltage level of 48 V Proton Exchange Membrane Fuel Cells (PEMFC) system by using the quasi-Z-source (QZS) dc-dc converter-based network as the boosting ability of conventional dc-dc converter is limited. This paper has discussed high voltage gain QZS dc-dc converter and hybrid two & three QZS converter with fuel-cell to enhance voltage level. The MATLAB Simulink software is used to check the feasibility of converters for voltage boosting. The experimental study with result analysis at different duty cycle is performed to validate the Simulink models. The obtained results are compared with one another for verdict the voltage boost up capacity of each converter topology.**

Keywords- Fuel-cell, DC-DC Converters, Quasi Z-Source Network, High Voltage Gain, MATLAB

1. INTRODUCTION

These days, conventional petroleum products-based electricity production sources are being replaced with inexhaustible production sources like solar photovoltaic (PV), wind, fuel cell on account of their problems [1]. The fundamental downside of conventional power sources is that on consuming the petroleum derivatives they transmit sulphur dioxide (SO_2), carbon dioxide (CO_2), nitrogen oxides (NOx) and other global warming discharges which are perilous to the living animals' health and climate likewise [2-4]. Though, voltage output of regular PEMFC fuel-cell framework is unregulated low dc voltage which can't be applied in modern applications while they need 200-600 V. Hence, high lift-up power electronic based dc-dc voltage converters are required for industrial applications which are majorly categorized into isolated and non-isolated types [3]. Non-isolated converters provide less voltage lift and have a smaller number of components and simple assembly than isolated converters. Converter with high number of components has low efficiency, high cost, and large volume. The limited range of voltage gain problem of non-isolated converters restricts their application in industry [5].

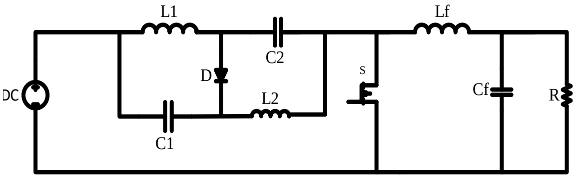

Fig.1 Basic QZS dc-dc converter

Researchers have employed various methods and arrangements for voltage boosting namely; non-isolated dc-dc converter, switched inductor, capacitor, cascade, voltage lift technique, multiplier cells topologies. The z-source dc-dc converters such as QZS as shown in figure 1, switched boost and quasi switched boost topologies are capable to provide higher gain and power density than conventional topologies but they have high cost, low efficiency and complex design [5-11]. In this paper, a family of quasi z-source converter-based topology with fuel-cell source is discussed and analysed for voltage boosting applications of non-isolated dc-dc converter [12-15, 19-20]. Here high voltage gain QZS dc-dc converter and hybrid two & three QZS boost converter is modelled in MATLAB for result analysis and compared to each other.

2. QZS NETWORK BASED TOPOLOGIES

There are various QZS network-based topologies discussed below in the paper and compared for the voltage boosting capability with fuel-cell power source. high voltage gain QZS dc-dc converter is realized using modified QZS network (where L_1 & L_2 inductors, C_1, C_2 & C_3 are capacitors, D_1, D_2 & D_3 diodes with switch S_1) and the switched capacitor network (contains capacitor C_4, Diode D_4 and switch S_2) with diode D_5 and C_0 output capacitor are also used in the network which is more suitable for fuel cells and solar PV. This terminology provides high voltage gain by using QZS and switched capacitor network and has low voltage stress on its elements [16].

Hybrid two-QZS boost dc-dc converter has traditional benefits of dc-dc converters with stronger boosting abilities which can be used in any type of power conversion i.e. ac-ac, dc-ac, and ac-dc. This topology has higher boosting capability (voltage gain $M = 1/(1-3Ds)$) than that of the quasi-Z-source network I (M = 1/(1-2Ds)) and inherits the merits of the QZS network, such as continuous input current and common ground between the input and output [17].

The hybrid three-QZS boost dc-dc converter consists L_1-C_1-D_1-C_2-L_2-D_2-C_3-C_4-L_3-C_5-D_3-C_6-L_4 with an active switch S output capacitor C7 and output diode D4. This topology has higher boosting capability (voltage gain M = 1/(1-4Ds)) than that of the hybrid two-QZS network I (M = 1/(1-3Ds)) [17].

2.1 High voltage gain QZS DC-DC converter

The modified high voltage-gain QZS dc-dc coverter works adopting a switched capacitor network. This converter can achieve high voltage gains in low duty cycles and low voltage stress on its elements. The calculation of the non-ideal voltage gain, power loss analysis is done in the paper. High voltage gain QZS dc-dc converter is realized using modified QZS network and the switched capacitor network with diode D_5 and C_0 output capacitor are also used [16].

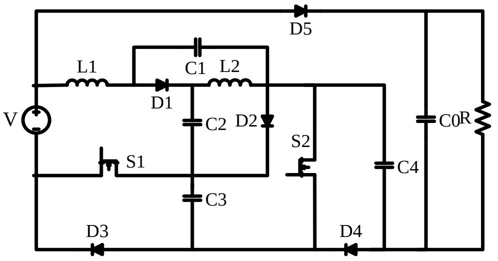

Fig. 2 Diagram of high voltage gain QZS DC-DC converter.

The proposed converter has two operating modes; first mode starts by turning off the switches S_1, S_2, and reverse biases diode D_5. This condition results in forward bias of diodes D_1, D_2, D_3 and D_4. In this mode, L_1, L_2 and C_2 are discharging, while C_1, C_3 and C_4 are charging. During second operating mode, S_1, S_2 and D_5 are conducting, while other switches are off and charging of L_1, L_2 and C_2 occurs, in addition to the discharging of C_1, C_3 and C_4. The gain M of the converter is given by formula written below in equation 1.

$$M = \frac{V_O}{V_{in}} = \frac{3(1-D)}{1-3D} \tag{1}$$

2.2 Hybrid two-QZS boost dc-dc converter

The hybrid two-QZS boost dc-dc converter consists L_1-D_1-C_1-C_2-L_2-C_3-D_2-C_4-L_3 with an active switch S output capacitor C_5 and output diode D_3. This converter has traditional benefits of dc-dc converter and provides higher boosting ability than conventional QZS network to fulfil the demand of loads [17]. The converter works in two modes of operation state-0 and state-1. During state-0 the switch S is on and diode D_1, D_2 & D_3 are off and during state-1 the switch S is off and diode D_1, D_2 & D_3 are on. The gain M of the converter is given by formula written below in equation 2.

$$M = \frac{V_O}{V_{in}} = \frac{1}{1-3D} \tag{2}$$

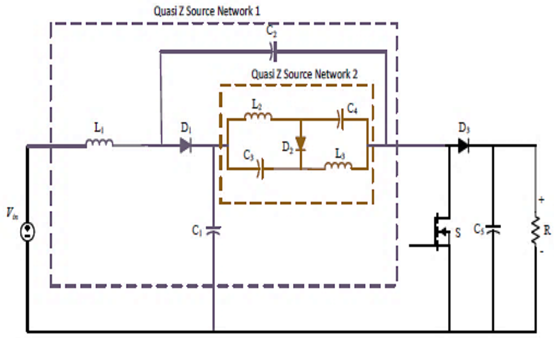

Fig.3 Basic diagram of hybrid two-QZS boost dc-dc converter

2.3 Hybrid three-QZS boost dc-dc converter

This converter topology has L_1-C_1-D_1-C_2-L_2-D_2-C_3-C_4-L_3-C_5-D_3-C_6-L_4 elements with an active switch S and output capacitor C_7 & output diode D_4. The converter is also working in two modes of operation state-0 and state-1. During state-0 the switch S is on and diode D_1, D_2, D_3 & D_4 are off and capacitors C_1, C_2, C_3, C_4, C_5 & C_6 discharges the energy into inductors L_1, L_2, L_3 & L_4. During state-1 the switch S is off and diode D_1, D_2, D_3 & D_4 are on and inductors L_1, L_2, L_3 & L_4 transfers the energy into capacitors C_1, C_2, C_3, C_4, C_5 & C_6 along with load R [17]. The gain M of the converter is given by formula written below in equation 3.

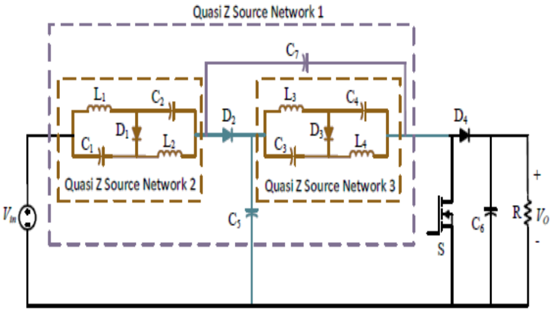

Fig. 4 Basic diagram of hybrid three-QZS boost dc-dc converter

$$M = \frac{V_O}{V_{in}} = \frac{1}{1-4D} \tag{3}$$

3. FUEL CELL

It is electromechanical conversion device, in which electrical energy is produced from chemical energy with water and heat as by-products using H_2 energy. In existing research, 2.4 kW and 48 V of PEMFC is used due to its low temperature operation suitability and quick response. The fuel-cell output voltage (VFC) is given by oxidized fuel and electricity is generated as given in equation 4 below. The power of fuel cell (PFC) is given by equation 5 as mentioned below:

$$V_{FC} = E - V_{act} - V_{\Omega} - V_{con} \quad (4)$$
$$P_{FC} = N * V_{FC} * I_{FC} \quad (5)$$

The electrical fuel cell efficiency is given by equation 6 written below.

$$\eta_{FC} = \frac{P_{FC}}{M_{H2}HHV_{H2}} \quad (6)$$

A fuel cell can yield around 0.6–0.75 V and the power and voltage level can swing from 2 kW to 50 MW with a couple of volts to 10 kV [16]. The fuel cell framework incorporates a QZS based boost converter to enhance the fuel cell voltage [18].

5. SIMULATION MODELS

The Simulink model of discussed three types of QZS DC-DC converters is in shown figures. The parameter values of inductor and capacitors employed for circuit implementation during simulation model designing are specified in table 1 for understanding.

Table 1: Constraints employed in MATLAB model structure.

Hybrid two & three-QZS boost dc-dc converter	Vi = 48V, fs =50 kHz, Z-source capacitors= 330 µF & Inductor= 470 µH, Co = 470 µF, Dmax = 0.25.
Modified QZS based New High Voltage Gain Converter	Vi =48V, fs =50 kHz, C1=C2=C3=C4=470 µF, L1=L2=500 mH, Co =470µF, and R=400 Ω, Dmax = 0.33.

4.1 High voltage gain QZS DC-DC converter:

Simulation model was realized by using MATLAB Simulation library toolboxes. PEMFC fuel-cell source of 48 V was used with high voltage gain QZS dc-dc converter topology and load to investigate the boosting capability of this converter, which is shown below in Figure 5.

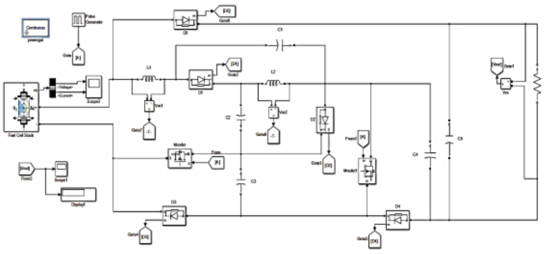

Fig.5 Simulation model of high voltage gain QZS dc-dc converter.

4.2 Hybrid two-QZS boost dc-dc converter

Simulation model was realized by using MATLAB Simulation library toolboxes. PEMFC fuel-cell source of 48 V was used with hybrid two-QZS dc-dc converter topology and load to investigate the boosting capability of this converter, which is shown below in figure 6.

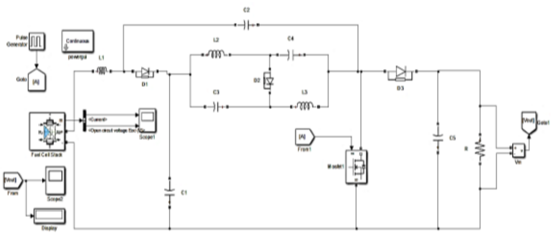

Fig 6 Simulation model of hybrid two-QZS dc-dc converter.

4.3 Hybrid three-QZS boost dc-dc converter

Simulation model was realized by using MATLAB Simulation library toolboxes. PEMFC fuel-cell source of 48 V was used with hybrid three-QZS dc-dc converter topology and load to investigate the boosting capability of this converter, which is shown below in figure 7.

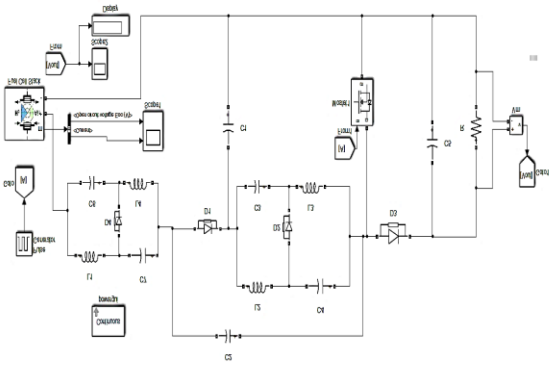

Fig. 7: Simulation model of hybrid three-QZS dc-dc converter.

These models are run for testing the voltage boosting capability at different duty cycle values according to their permissible limits and the outcomes are discussed in the next section.

5. COMPARATIVE RESULTS

The simulation models were run for 1 second of time and boosting output voltage are composed in scope block for result analysis. The output voltage of each converter at different duty cycle is shown in table 2 and figures (8-13). Figure 8 & 9 depicts output voltage of high voltage gain QZS converter at 0.27 & 0.32 duty cycle which is 560.6 & 774.3 V. The figure 10 & 11 portrays output voltage of hybrid two-QZS converter at 0.27 & 0.30 duty cycle that is 296.6 & 488.2 V. The figure 12 & 13 portrays output voltage of hybrid three-QZS converter at 0.20 & 0.22 duty cycle that is 276.4 & 409.7 V.

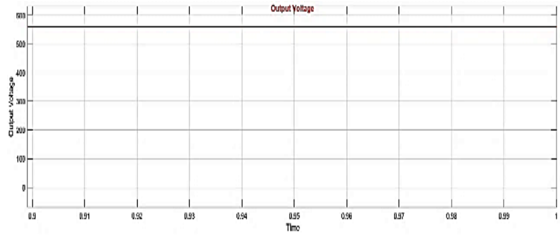

Fig. 8 High voltage gain QZS converter output voltage for duty cycle 0.27.

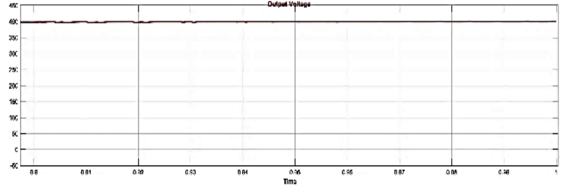

Fig. 9 High voltage gain QZS converter output voltage for duty cycle 0.32.

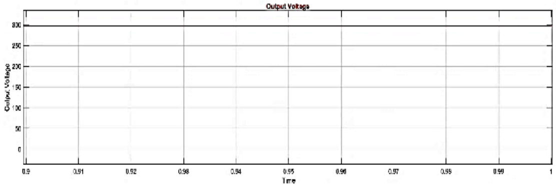

Fig. 10 Hybrid two-QZS converter output voltage for duty cycle 0.27.

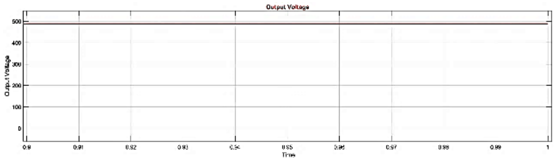

Fig. 11 Hybrid two-QZS converter output voltage for duty cycle 0.30.

The figure 12 & 13 represents output voltage of hybrid three-QZS converter at 0.20 & 0.22 duty cycle that is 276.4 & 409.7 V.

Table 2: Result analysis of used QZS converters for different duty cycles with 2.4 kW and 48 V fuel cell.

Reference/Duty Cycle	**Modified QZS**	**Hybrid two-QZS boost**	**Hybrid three-QZS boost**
15	267.3	113.3	-
20	349.2	151.5	276.4
22	376.2	187.9	409.7
27	560.6	296.6	-
30	774.3	488.2	-
32	400.3	700.3	-

6. CONCLUSION

Integration of renewable energy sources into grid needs voltage boosting ability which has been very important task. This paper has discussed two types of QZS dc-dc converters to investigate their boosting capabilities by simulating in MATLAB software. Results are taken with 48 V fuel cell source at different duty cycle values in the allowable range of respective converters. This paper has contribution of comparison of boosting capabilities of different QZS dc-dc converters with 48 V fuel cell source for high voltage boost.

For future research direction these converters can be used for boosting solar PV and other renewable energy sources output voltages up-to usable voltage limit and can be used for different real time application of medium and high voltage level.

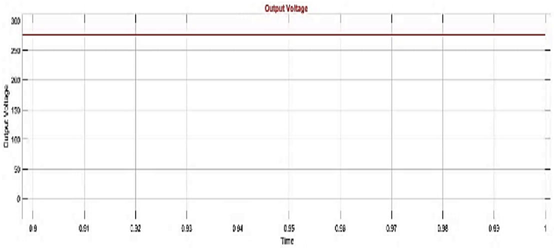

Fig. 12: Hybrid three-QZS converter output voltage for duty cycle 0.20.

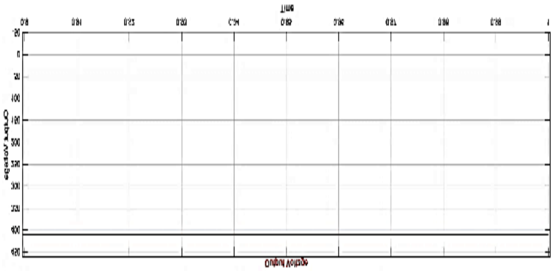

Fig. 13 Hybrid three-QZS converter output voltage for duty cycle 0.22.

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