Performance Evaluation of Different High Step-Up Voltage Gain Quasi-Z Source DC-DC Converters

Mayank Singh, Seema Agrawal, Dheeraj Kumar Dhaked
Department of Electrical Engineering, Rajasthan Technical University Kota-324010 (India)
Email: singhmayank1194@gmail.com, sagrawal@rtu.ac.in, ddhakar9@gmail.com
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***Abstract*- The solar PV source is getting more attention due to abundant availability and cost effectiveness but the generated power has low DC voltage. Hence, Voltage step up is becoming the most important task for researchers and engineers due to more adaptability of renewable power generation sources into daily life. This paper is dedicated to step-up the voltage level by using a dc-dc converter domain with the quasi-Z-source (QZS) network. This paper has discussed QZS dc-dc converter with a switched capacitor, active switched-capacitor/switched-inductor QZS converter, a dc-dc converter with modified QZS network and modelled in MATLAB Simulink for experimental study and result in analysis is done at different duty cycles. The obtained results are compared along with one another for finding the voltage boost up the capacity of each converter topology.**

Keywords- Power Electronics Converter, DC-DC Converters, Quasi Z-Source Network, High Voltage Gain, Switched capacitor.

1. INTRODUCTION

Nowadays, conventional fossil fuels-based power generation sources are being replaced by renewable generation sources like wind, solar photovoltaic (PV), fuel cell because of their disadvantages [1]. The main drawback of conventional power sources is that on burning the fossil fuels they emit carbon dioxide (CO_2), sulphur dioxide (SO_2), nitrogen oxides (NO_x) and other global warming emissions which are hazardous to the public health and environment also [2-4]. Although, the voltage output of typical solar PV system is unregulated low dc voltage which cannot be applied in industrial applications whereas they desire 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 apparatuses have low efficiency, high cost, large volume for isolated converters. The limited range of voltage gain problem of non-isolated converters restricts their application in industry [5].

Researchers have employed various methods and arrangements for voltage gain with non-isolated dc-dc converter. Switched inductor, capacitor, cascade, voltage lift technique, multiplier cells are the mostly used topologies for voltage enhancement. 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 more gain and power density than conventional voltage and current gain topologies but they have low efficiency, complex design and high cost [5-8].

Z-source inverter (ZSI) topology is capable of doing buck-boost in a single unit whereas voltage source inverters (VSI) and current source inverter (CSI) can perform either boost or buck conversion [5]. ZSI can utilise shoot through state which was forbidden in conventional inverters along with it gives flexibility, reliability, voltage sag mitigation and reduced harmonics. ZSI has some shortcomings as limited boost capability, isolated source, high voltage stress, discontinuous input current so quasi ZSI (QZSI) was introduced with change in ZSI topology [9-11].

In this paper, a family of quasi z-source converter (QZSC) based topology is discussed and analysed for voltage boosting applications of non-isolated dc-dc converter [12-15]. Here quasi z-source (QZS) dc-dc converter with switched capacitor, active switched-capacitor/switched-inductor quasi z-source (ASC/SL-QZS) converter and modified QZS dc-dc network is modelled in MATLAB for result analysis and compared to each other.

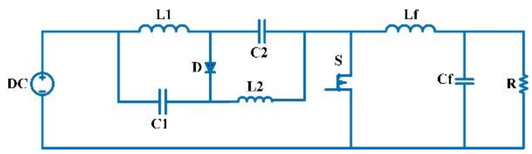

Fig. 1 Basic QZS dc-dc converter

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 DC voltage source. Switched capacitor contains two capacitor and diodes in QZS dc-dc converter with switched capacitor which enhances boosting capability of QZS which is more suitable for fuel cells and solar PV. This converter also provides low voltage stress on Z-network capacitors, high voltage gain and continuous input and output current [16].

ASC/SL-QZS converter have low number of components, low voltage stress on Z network capacitors and cascading can additionally boost its boosting capability [17]. High voltage gain modified QZS dc-dc network consists switched capacitor with modified QZS which reduces voltage stress on capacitor and semiconductor components and provides high voltage gain in lower duty cycles [18].

2.1 QZS Converter with Switched Capacitor

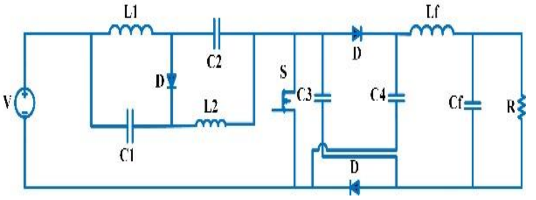

Fig. 2 Diagram of QZS converter with Switched Capacitor.

This circuit topology contains two capacitor and diode in QZS dc-dc converter with switched capacitor which enhances boosting capability of QZS which is more suitable for fuel cells and solar PV. This converter also provides low voltage stress on Z network capacitors, high voltage gain and continuous input and output current. ASC/SL-QZS converter have low number of components, low voltage stress on Z-network capacitors and cascading can additionally boost its boosting capability. High voltage gain modified QZS dc-dc network consists switched capacitor with modified QZS which reduces voltage stress on capacitor and semiconductor components and provides high voltage gain in lower duty cycles [16].

It works in two modes according to switching conditions, switch is on that's mode-1 and when it's off than mode-2. Voltage gain for this circuit is given in equation 1.

$$G = \frac{1+D}{1-2D} \tag{1}$$

2.2 ASC/SL-QZS Converter

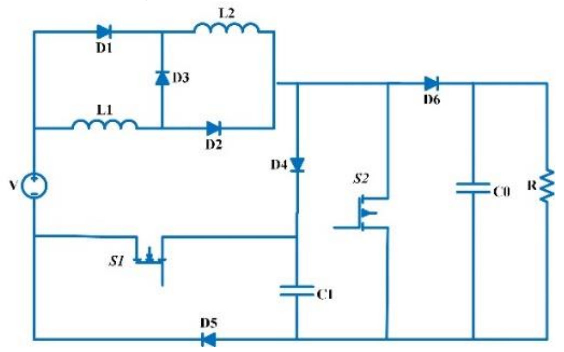

Fig. 3 Basic diagram of ASC/SL-QZS converter

One cell containing three diodes & one inductor is added to the ASC-QZS converter to increase the boosting ability of converter, which is shown in figure 3. This configuration is named as ASC/SL-QZS converter. Related to other QZS based topologies under similar working condition, this ASC/SL-QZS converter gives higher boost ability, needs less passive elements such as capacitor & inductor, and accomplishes lower voltage stress across the switching device of the main converter. Additional advantage of this topology is its expandability. By cascading an extra cell at the Z-network by adding three diodes & one inductor higher boosting ability can be realized easily [17].

The boosting capability formula is given by gain (G) in equation 2 and next equations 3 & 4 give the formula to find out inductor and capacitor values.

$$G = \frac{V_C}{V_{dc}} = \frac{1+D}{1-3D} \tag{2}$$

$$L_{1,2} = C_i \frac{2D_{sh}(1-D)}{(1-3D)} \tag{3}$$

$$C = C_V \frac{2D_{sh}(1-3D)}{(1+D^2)} \tag{4}$$

2.3 Modified QZS based New High Voltage Gain Converter

This converter comprises of two primary parts: the altered QZS organization and the exchanged capacitor organization. The adjusted QZS network is included inductors L_1 & L_2, capacitors C_1, C_2 & C_3, diodes D_1, D_2 & D_3, and a switch S_1. Furthermore, a switch S_2, a diode D_4 and a capacitor C_4 structure the exchanged capacitor organization. The diode D_5 associates the positive terminal of the info voltage to the positive terminal of the yield voltage and Co is the yield capacitor [18].

This converter has two operating modes. The first mode begins with turning off switches S_1, S_2, and reverse bias the diode D_5. This results in forward bias of diodes D_1, D_2, D_3 & D_4. In this mode, L_1, L_2 and C_2 are discharging, while C_1, C_3 and C_4 are charging. In the second operating mode, S_1, S_2 and D_5 are conducting, while other semiconductors are off. Which leads to the charging of L_1, L_2 and C_2, in addition to the discharging of C_1, C_3 and C_4. The gain of the converter is given by formula written below in equation 5. The working and build-up of this converter can be understood in [18].

$$G = \frac{V_o}{V_{in}} = \frac{3(1-D)}{1-3D} \tag{5}$$

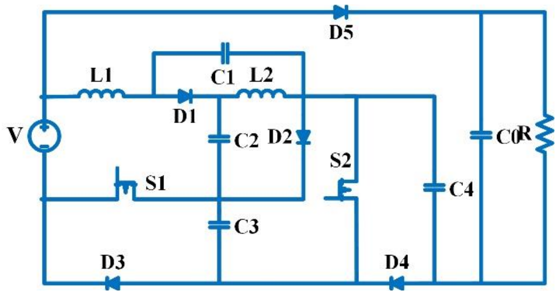

Fig 4 Basic diagram of Modified QZS based New High Voltage Gain Converter

3. SIMULATION MODELS

The simulation model of all three type of QZS dc-dc converters is shown figures (5-7). The parameter values of inductor and capacitors used for circuit making during simulation model designing are given in table 1 for understanding [16-18].

Table 1: Parameters used in MATLAB model building

ASC/SL-QZS Converter:	QZS Converter with Switched Capacitor:	Modified QZS based New High Voltage Gain Converter:
V_i = 40 V, f_s = 100 kHz, $C_1 = C_2 = C_3 = C_4$ = 100 µF, $L_1 = L_2$ = 300 µH, C_f = 100 µF, L_f = 300 µH and R = 50 Ω, D_{max} = 0.33.	V_i = 40 V, f_s = 5 kHz, C_1 = 500 µF, $L_1 = L_2$ = 1 mH, C_o = 100 µF, and R = 60 Ω, D_{max} = 0.5.	V_i = 40 V, f_s = 50 kHz, $C_1 = C_2 = C_3 = C_4$ = 470 µF, $L_1 = L_2$ = 500 mH, C_o = 470 µF, and R = 400 Ω, D_{max} = 0.33.

3.1 QZS Converter with Switched Capacitor

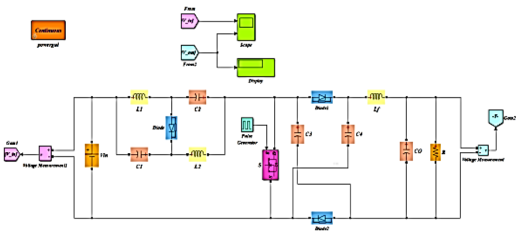

Fig. 5 Simulation model of QZS converter with Switched Capacitor

Simulation model was realized by using MATLAB Simulation library toolboxes. DC voltage source of 40 V was used with QZS converter with switched capacitor topology and load to investigate the boosting capability of this converter, which is shown in above figure 5.

3.2 Modified QZS based New High Voltage Gain Converter

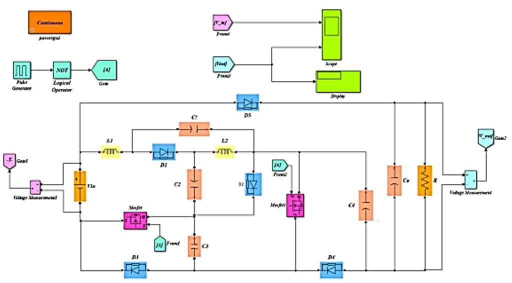

Fig. 6 Simulation model of Modified QZS based New High Voltage Gain Converter

Simulation model was realized by using MATLAB Simulation library toolboxes. DC voltage source of 40 V was used with Modified QZS based New High Voltage Gain Converter topology and load to investigate the boosting capability of this converter, which is shown above in figure 6.

3.3 ASC/SL-QZS Converter

Simulation model was realized by using MATLAB Simulation library toolboxes. DC voltage source of 40 V was used with Modified QZS based New High Voltage Gain Converter topology and load to investigate the boosting capability of this converter, which is shown below in figure 7.

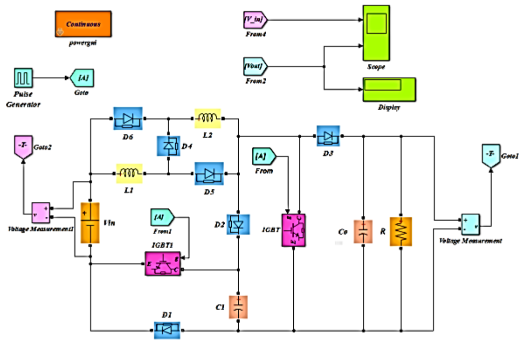

Fig 7 Simulation model of ASC/SL-QZS QZS converter

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

4. COMPARATIVE RESULTS

The simulation models are run for one seconds of time and boosting output voltage are collected in scope block for result analysis. The output voltage of each converter at different duty ratio is shown in table 2 and figures (8-13).

Figure 8 shows output voltage of QZS with SC converter at 0.22 duty ratio which is 82.67 V. Figure 9 shows output voltage of QZS with SC converter at 0.40 duty ratio which is 229.3 V.

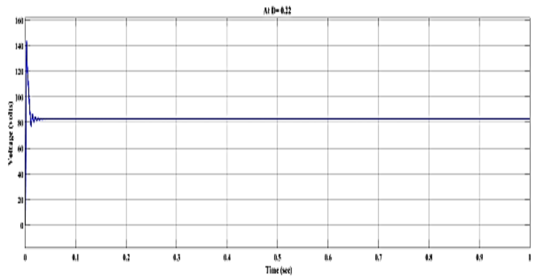

Fig. 8 QZS with SC Converter output voltage for duty cycle 0.22.

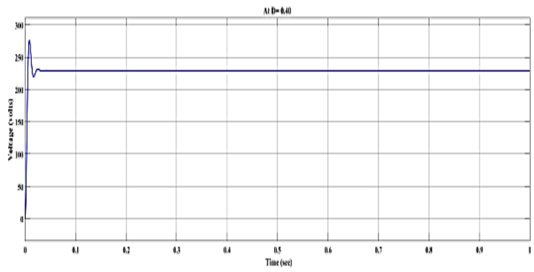

Fig. 9 QZS Converter with SC output voltage for duty cycle 0.40.

Figure 10 shows output voltage of ASC/SL-QZS Converter at 0.22 duty ratio which is 134.4 V. Figure 11 shows output voltage of Modified QZS based New

High Voltage Gain Converter at 0.29 duty ratio which is 369.7 V.

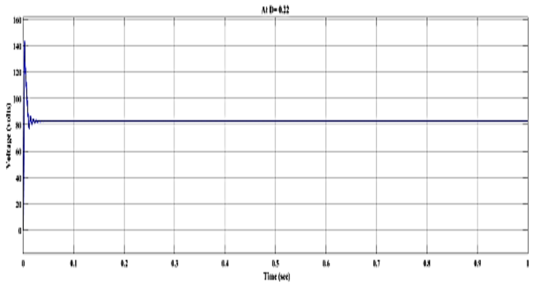

Fig.10 ASC/SL-QZS Converter output voltage for duty cycle 0.22.

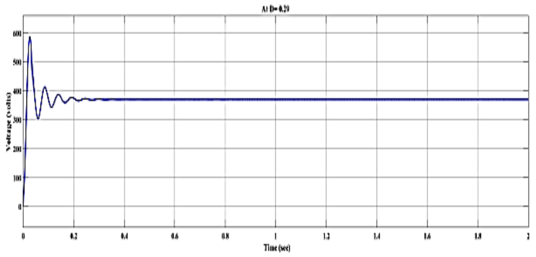

Fig. 11 ASC/SL-QZS Converter output voltage for duty cycle 0.29.

Figure 12 shows output voltage of modified QZS Converter at 0.21 duty ratio which is 239.8 V. Figure 13 shows output voltage of modified QZS Converter at 0.27 duty ratio which is 412 V.

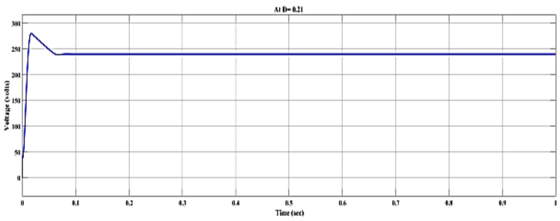

Fig. 12 Modified QZS Converter output voltage for duty cycle 0.21.

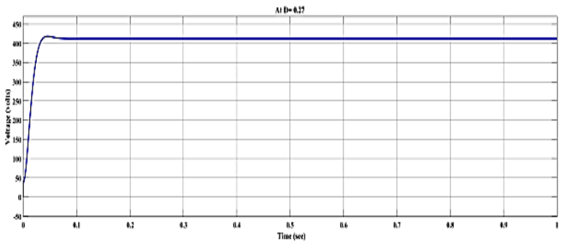

Fig. 13 Modified QZS Converter output voltage for duty cycle 0.27.

Table 2: Result analysi of used dc-dc converters for different duty cycles with 40 volt DC source.

Reference/ Duty Cycle	QZS Converter with Switched Capacitor	Modified QZS	ASC/SL-QZS converter
05	44.08	46.4	126.1
10	52.14	58.97	145.4
18	70.07	96.14	201.3
22	82.67	134.4	256.8
26	99.14	218.4	365.5
30	121.4	482.5	647.7
35	162.7	-	-
38	199.8	-	-
42	264.3	-	-

It it can be observed from the table 2 that all three converter provides the high voltage gain. These converter can be used for step up the output voltage of low voltage source according to the requirement of the load by operating it at different duty ratio. It is observed that QZS with SC converter can give gain upto 7.5, ASC/SL-QZS converter can give gain upto 12 and Modifieed QZS converter can give gain utpo 16 times.

5. CONCLUSION

Integration of renewable energy sources with grid needs voltage boosting which has been very important task. The power gtenerated from solar PV and fuel cell has low voltage that needs to step-up upto grid voltage level. This paper has discussed three types of quasi z-source dc-dc converters and according to their boosting capabilities by simulating in MATLAB software. Results are taken for DC source voltage at different duty ratio in the allowable range of respective converters. This paper has contribution of comparison of boosting capabilities of different QZS DC-DC converters for high voltage boost. The manuscript has concluded that the modified QZS converter has the highest boosting capability among used converters. These converters can be used for boosting PV, fuel cell and other renewable sources output voltages up-to usable voltage limit and can be used for different real time application of medium and high voltage level for the future research direction work.

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