Bi-directional Soft Switched Quasi Z-Source DC-DC Converter with Buck and Boost Capabilities

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ABSTRACT

The Voltage Source Converter and the Current Source Converters have the limitations that either they buck or boost the voltage but cannot buck-boost. Quasi Z-source DC-DC converter has an impedance network which performs buck-boost operations. In Quasi Z-Source dc-dc converter the input current is continuous and also the voltage stress across the switches is less. The Quasi Z-Source can boost the input voltage using reduced passive component with improved reliability and reduce cost. Compared to the existing dc-dc converter circuits, they reduce in-rush and harmonic current. Therefore this paper aims at a soft switched Quasi Z-source Converter (qZSC). The simulation results for the proposed configuration are also presented in this paper.

KEY WORDS: dc-dc converter, Quasi Z-source (qZS) network, buck/boost.

1. INTRODUCTION

The voltage source converter acts as a step-down converter for dc-ac power conversion and current source converters acts as a step-up converter for ac-dc power conversion. For applications where the available dc voltage is finite, an additional dc-dc boost converter is needed to obtain the desired ac output from voltage source converters. To overcome the problems in the traditional voltage source converters and current source converters, Peng (2003) was proposed Z-source converter. A Z-source converter is a unique x-shaped network called Z-source network that couples the converter main circuit to the power source. The converter has all conversion types - if it is of ac-to-dc type, the Z-source converter (ZSC) is called Z-source inverter (ZSI). Since 2003 when this conversion concept appeared, it solved lot of conversion problems. The voltage-fed quasi Z-source inverter (VFqZSI) with continuous input current was first proposed by Anderson (2008), with features of single stage power conversion technology that provides a great alternative with low cost, high reliability, and high efficiency.

A quasi-Z-source inverter (qZSI) which is derived from the traditional ZSI inherits all the advantages of the ZSI and features its unique merits. It can realize buck/boost power conversion in a single stage with a wide range of gain that is suited well for application in PV power generation systems. Furthermore, the qZSI has advantages of continuous input current, reduced source stress, and lower component ratings when compared to the basic Z-source inverter.

The Z-source networks can be used in dc-dc power conversion also. Z-source dc-dc converter was first proposed in Z-source dc-dc converter to achieve four quadrant operations has been investigated in which can be used for dc drives. A voltage mode control method for the quasi-Z-source isolated dc-dc converter was proposed in Conventional control methods for Z-source or quasi-Z-source converters were based on the DC-link voltage regulation, which indirectly also influences the output. The control method proposed in measures the output voltage directly and therefore and gives better dynamic response during load change. A qZSI based DC-DC converters with a high-frequency step-up transformer and a voltage doubler rectifier as an alternative for the front-end dc-dc converter for residential power systems was proposed. A Cascaded qZS network was proposed in for optimization of the voltage-fed quasi Z-source inverter. To compose the cascaded qZS-network, one diode, one inductor, and two capacitors were added to the traditional voltage-fed qZSI. This configuration inherits all the advantages of basicl configuration. Moreover, the voltage-fed qZSI with the cascaded qZS-network reduces the shoot-through duty cycle by over 30% at the same voltage boost factor and component stresses as the conventional qZSI. The cascaded qZSI can be applied to almost all dc-ac, ac-dc, ac-ac, and dc-dc power conversion schemes.

This paper presents a single switch quasi Z-source converter with boost and buck capabilities. Section II describes the Z-source DC-DC converter. The quasi Z-source DC-DC converter configuration is described in section III. The modes of operation, relevant equations and design considerations are presented in section IV. The simulation results are given in section V and ends with conclusion in section VI.

Z-Source DC-DC Converters: Z-source converters can be voltage fed or current fed. A voltage fed Z-source converter is considered in this paper. The input voltage V_{in} given to impedance network through diode D_0. Impedance network consists of two inductors L_1, L_2 and two capacitors C_1, C_2. $L_1 = L_2$ and $C_1 = C_2$. Switch S is used to control the output. The output voltage is smoothened using L_f - C_f filter. ZSC has two operating states; state 0 and state 1. State 0: switch S is on during this state. The Z-network inductors L_1, L_2 will store the energy and the capacitors C_1 and C_2 discharge.

State 1: The switch S is off. The inductors L_1, L_2 and input voltage source V_{in} provide the energy to the load and also charge the capacitors C_1 and C_2. Therefore the voltage is boosted. Z-Source dc-dc converters are used in applications

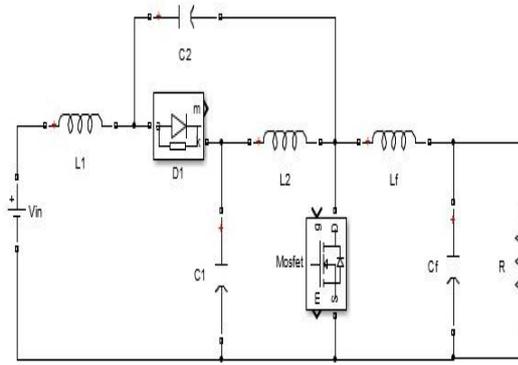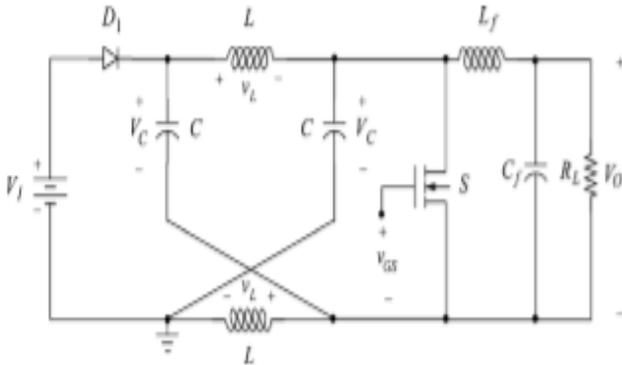like solar and fuel cell with high voltage gain and low ripple input current.

Figure1.Voltage-fed Z-source DC-DC converter   Figure.2.Voltage-fed Quasi Z-source DC-DC converter

Quasi Z-Source Converter: In Z-source converters, the input current is discontinuous and the voltage stress across the switch is more and also there is no common ground.

To overcome these limitations quasi Z-source converter is used. The qZSC is shown in Figure 2. The converter configuration shown in Figure 2 acts as a Boost converter. When the source and the load are interchanged it acts as a Buck converter.

Models of operation: qZSC has two operation modes: state 0 and state 1.

State 0($t_o \leq t \leq t_{on}$) : During this state , the switch S is on and the diode D_1 is off as shown in Figure 3. The inductor L_1 gets charged during this mode by the input voltage source V_{in} and the capacitor C_2. The capacitor C_1 discharges through the inductor L_2. The voltage equations during state 0 are given in equation (1) and (2).

$$V_{in} + V_{L1} + V_{C2} = 0 \qquad (1)$$

$$V_{C2} + V_{L2} = 0 \qquad (2)$$

$$V_{Cf} = V_0 \qquad (3)$$

Where V_{in} is the supply voltage, V_{C1} is the capacitor C_1 voltage, V_{C2} is the capacitor C_2 voltage, V_{Cf} is the filter capacitor C_f voltage, V_{L1} is the voltage across the inductor L_1, V_{L2} is the voltage across the inductor L_2 with reference to Figure 2.
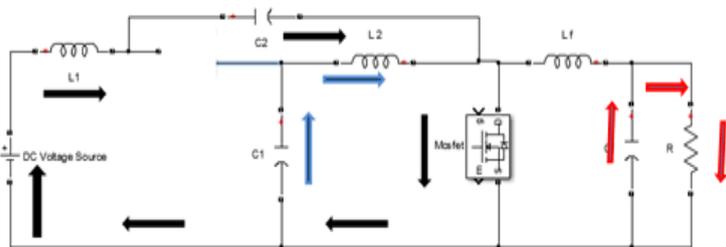

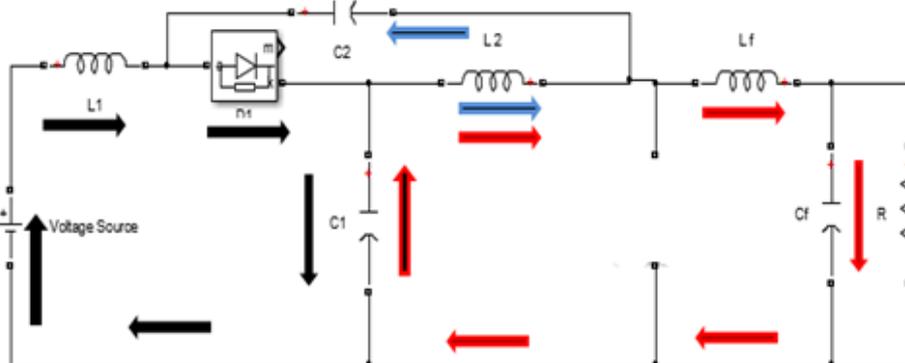**Figure.3. State 0($t_o \leq t \leq t_{on}$): Equivalent circuit**

Figure.4. State 1($t_{on} \leq t \leq t_{off}$): Equivalent circuit

State 1 ($t_{on} \leq t \leq t_{off}$): The switch S is turned off during this state and the diode D_1 is turned on because of the reversal of inductor voltage polarity as shown in Figure 4. The input voltage V_{in} and the inductors L_1, L_2 supply the energy to the load resistance R_0. Moreover, the capacitor C_1 is charged gets charged during this mode by the supply voltage V_{in} and the inductor L_1. The energy stored in the inductor L_2 is released in this state. This charges the capacitor C_2.

From Figure 4, the following equations are arrived during State1.

$$V_{in} + V_{L1} - V_{C1} = 0 \qquad (4)$$
$$V_{L2} = V_{C2} \qquad (5)$$
$$V_{c1} + V_{L2} + V_{Lf} = V_0 \qquad (6)$$
$$T_{ON} = DT_S \qquad (7)$$
$$T_{off} = (1 - D)T_S \qquad (8)$$

Where D- Duty Ratio, T_s- Total Time Period, T_{on}- Switch ON Period, T_{off}- Switch OFF Period.

In steady-state, the average voltages of the inductors L_1 and L_2 are zero for a switching cycle T_S. Therefore, the following equations are obtained.

$$1/T_s \left[\int_{t0}^{ton} V_{L_1} \, dt + \int_{ton}^{toff} V_{L_1} \, dt\right] = 0 \qquad (9)$$
$$\frac{1}{T_s} \left[\int_{t0}^{ton} V_{L_2} + \int_{ton}^{toff} V_{L_2} \, dt\right] = 0 \qquad (10)$$

Substitute (1) and (5) in (10)

$$1/T_s \left[\int_{t0}^{ton}(-V_{in} - V_{c_1}) \, dt + \int_{ton}^{toff}(V_{c_1} - V_{in})dt\right] = 0 \quad (11)$$

Substitute (4) and (5) in (10)

$$1/T_s \left[\int_{t0}^{ton}(-V_{c_1}) \, dt + \int_{ton}^{toff}(V_{c_2}) \, dt\right] = 0 \qquad (12)$$

Since the capacitor C_1 and C_2 charging and discharging voltages are linear during both the states, the capacitor voltage equations are given in equations (13) and (14). The average capacitor voltages V_{C1}, V_{C2} are:

$$V_{C1} = 1/T_0 \int_{t0}^{ton}(V_{c_1}) dt = 1/T \int_{ton}^{toff}(V_{c_1}) dt \qquad (13)$$
$$V_{C2} = 1/T_0 \int_{t0}^{ton}(V_{c_2}) \, dt = 1/T \int_{ton}^{toff}(V_{c_2}) \, dt \qquad (14)$$

On simplification

$$V_{C2} = [V_{C1}(1 - D) - V_{in}]/D \qquad (15)$$

Substituting (9), (8),(13) and (14) in (12) gives

$$V_{C2} = V_{C1}D/(1 - D) \qquad (16)$$

Equating equations (15) and (16) we will get

$$V_{c1} = V_{in}(1 - D)/(1 - 2D) \qquad (17)$$

In steady-state, the averaged voltage of the inductor L_f is zero. Therefore, the following equations are satisfied.

$$\frac{1}{T_s} \left[\int_{t0}^{ton} V_{Lf} + \int_{ton}^{toff} V_{Lf} \, dt\right] = 0 \qquad (18)$$

Substituting equations (3), (6) in (18) we will get

$$V_0 = V_{in}(1 - D)/(1 - 2D) \qquad (19)$$

In steady-state, the output power is equal to the input power

$$P_{in} = P_0 \qquad (20)$$
$$I_{L1} = I_0(1 - D)/(1 - 2D) \qquad (21)$$

The ripple Current allowed to the inductance

$$\Delta_{I_L} = I_L * \delta\% \qquad (22)$$
$$\delta - \text{allowed ripple} = 5\%$$

2. SIMULATION RESULTS

The simulation is carried out using PSIM software. The circuit design parameters are listed in Table 1. The waveforms for the boost operation are shown from Figure 5-11. The proposed converter is designed to boost the voltage from 20 V to 280 V with the switching frequency $f_s = 20kHz$ and load Resistance $R_0 = 200\Omega$.

Table.1.Circuit parameters

	Component	Values
Quasi Z-source Network	Inductor L_1	6.8717mH
	Inductor L_2	6.8717mH
	Capacitor C_1	33.763μF
	Capacitor C_2	33.763μF
Low pass filter	Inductor L_f	6.87mH
	Capacitor C_f	0.4815μF
	Switching Frequency	20 kHz
	Load Resistance	200Ω
	Duty Cycle	0.47
	Output Power	392 W

The switching pulses, voltage across the switch and switch currents are shown in Figure 5. Inductor L_1 and L_2 currents are shown in Figure 6 and 7 respectively. The capacitor C_1 and C_2 voltages are shown in Figure 8 and 9 respectively. The output voltage and currents are shown in Figure 10 and 11 respectively.
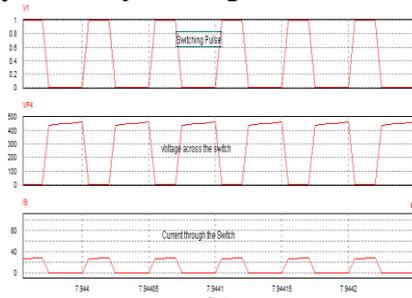

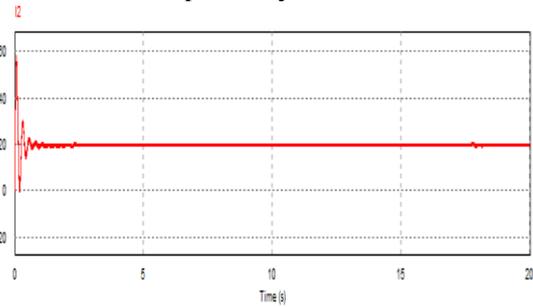**Figure.5.Gating Pulses, Voltage across the switch and current through the switch S**
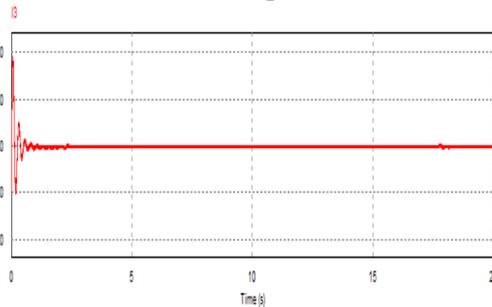

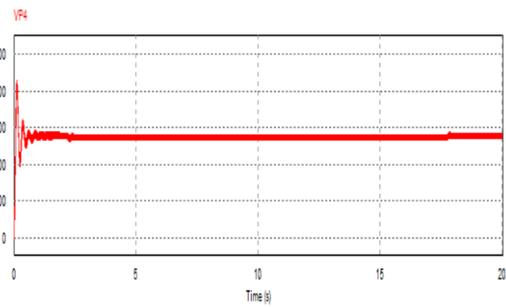
Figure.6.Inductor L_1 current

Figure.7.Inductor L_2 current

Figure.8.Capacitor C_1 Voltage
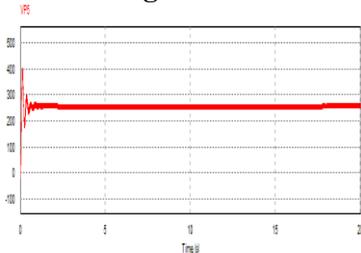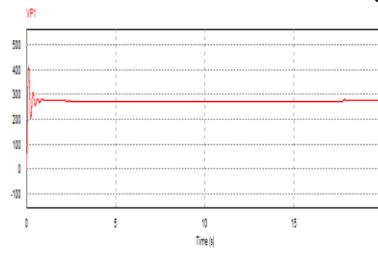

Figure.9.Capacitor C_2 Voltage
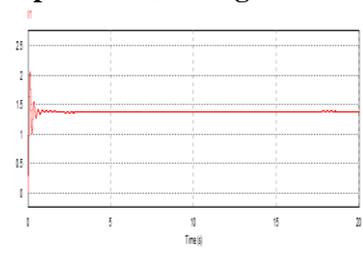

Figure.10.Output Voltage

Figure.11.Load Current

`As observed from Figure 5, when the switch is turned on, the current though the switch is zero, therefore turn on losses are reduced. The switch is turned off, when the voltage across the switch is zero. Therefore turn off losses are reduced.

For buck operation, the load and sources are interchanged. The simulation circuit during buck mode is shown in Figure 12. Output Voltage, Load Currents are shown in Figure 13. The input voltage is 20 V. The output voltage is 5.5 V and the load current is 0.02 A. Figure 14 shows the Gating Pulses, Voltage across the switch and the current through the switch. As observed from Figure 14, zero current turn on and zero voltage turn off of the switch S is achieved during buck operation also. Hence the switching losses are reduced. Since the converter has step-up and step-down the voltage, it can be used as a bi-directional converter for battery charging and discharging application.
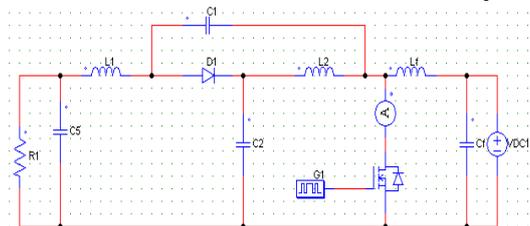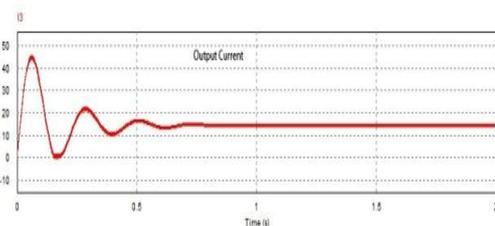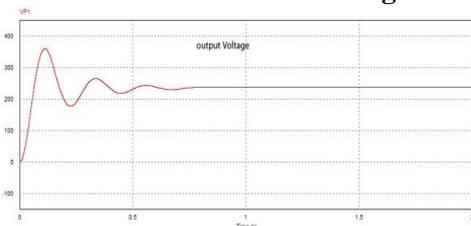

Figure.12.qZSC during buck mode

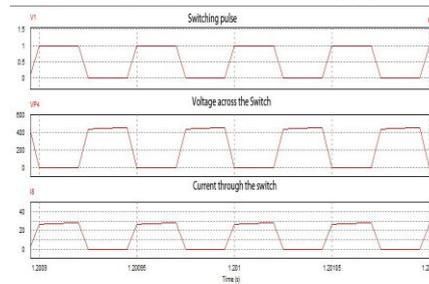**Figure.13.Output Voltage and Load Current**

Figure.14.Gating Pulses, Voltage across the switch and the current through the switch

3. CONCLUSION

A quasi z-source bidirectional converter with buck and boost capabilities was presented in this paper. It is observed from the simulation results that the converter is soft switched and hence the switching losses are reduced. Further the work can be extended to obtain the multi-outputs.

REFERENCES

Anderson J, and Peng F.Z, A Class of Quasi-Z-Source Inverters, Industry Applications Society Annual Meeting, 2008. IAS '08, IEEE, 2008, 1-7.

Anderson J, and Peng F.Z, Four quasi-Z-source inverters, in Proc.IEEE Power Electron, Specialists Conf., 2008, 2743-2749.

Cao D, and Peng F.Z, A family of Z-source and quasi-Z-source dc-dc converters, in Proc. IEEE Appl. Power Electron, Conf., 2009, 1093-1101.

Dmitri Vinnikov, and Indrek Roasto, Quasi-Z-Source-Based Isolated DC/DC Converters for Distributed Power Generation, IEEE Transactions on Industrial Electronics, 58 (1), 2011, 192-201.

Dmitri Vinnikov, Indrek Roasto, Ryszard Strzelecki, and Marek Adamowicz, Step-Up DC/DC Converters With Cascaded Quasi-Z-Source Network, IEEE Transactions on Industrial Electronics, 59 (10), 2012, 3727-3736.

Fang X, A novel Z-source dc-dc converter, in Proc. IEEE Int. Conf. on Ind. Tech., (ICIT'08), 2008, 1-4.

Florescu A, Stocklosa O, Teodorescu M, Radoi C, Stoichescu D.A, and Rosu S, The advantages, limitations and disadvantages of Z-source inverter, IEEE International Semiconductor Conference (CAS), 2, 2010, 483-486.

Peng F.Z, Z-source inverter, IEEE Trans. Ind. Appl., 39 (2), 2003, 504-510.

Roasto I, and Vinnikov D, New voltage mode control method for the quasi-Z-source-based isolated DC/DC converters, 2012 IEEE International Conference on Industrial Technology (ICIT), 2012, 644-649.

Yuan Li, Joel Anderson, Fang Z Peng, and Dichen Liu, Quasi-Z-Source Inverter for Photovoltaic Power Generation Systems, IEEE Applied Power Electronics Conference and Exposition, APEC, 2009, 918-924.