

A Novel Z-Source DC-DC Converter

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Abstract: This paper proposes a novel Z-source dc-dc converter topology. Compared to the existing dc-dc converter circuits, they can reduce in-rush and harmonic current, provide larger range of output dc voltage and improve reliability. It can operate in voltage-fed and current-fed when the place of the source and load is exchanged each other, and it can be perform buck-boost function in these two conditions. The operating principle and control method of the proposed topology are presented. Analysis and simulation results are given using the voltage-fed Z-source dc-dc converter as an example.

Keywords: Dc-dc converter, buck/boost, Z-source, Bi-directional power flow, invertable.

I. INTRODUCTION

Z-source inverter is a novel topology [1]-[2]; it overcomes the conceptual and theoretical barriers and limitations of the traditional voltage-source inverter and current-source inverter. Its operating principle and application for fuel cell inverter and ASD system are illustrated in [1]-[4] respectively.

The concept of Z-source can be used in direct ac-ac power conversion [5]-[8]. Similarly, it also can be extended to dc-dc power conversion. This paper will propose the novel Z-source dc-dc converter topology, discusses its operating principle, the relationship between input and output, control method, etc.

II. PROPOSED Z-SOURCE DC-DC CONVERTER

TOPOLOGY

Figs.1 shows the proposed Z-source dc-dc converter. It includes two operating modes: voltage-fed and current-fed. When the power source is dc voltage-source, it operates in the voltage-fed condition, as shown in Fig.2 (a). When the power source is dc current-source, it operates in the current-fed condition, as shown in Fig.2 (b). Both

of the two modes utilize only two switches ($S1$ or $S2$). Each switch can be composed by a power transistor and an anti-parallel (or free-wheeling) diode, even a power MOSFET, to provide bi-directional current flow. Small inductors and capacitors are used for filtering purposes.

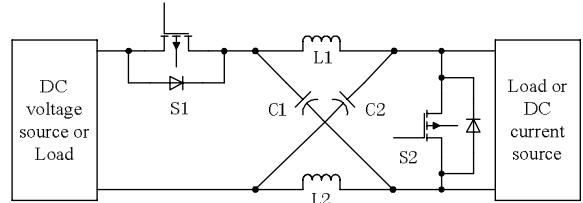
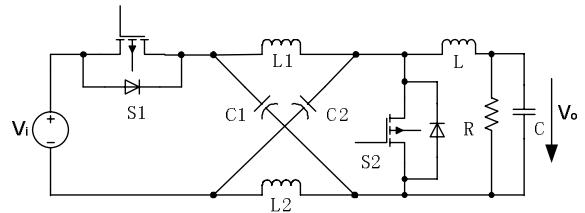
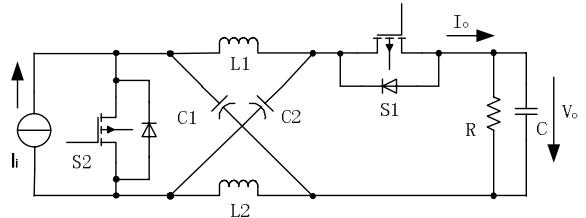


Fig.1. Z-source dc-dc converter topology



(a)



(b)

Fig.2. Two operating modes of the proposed converter:
(a) voltage-fed (b) current-fed

The proposed dc-dc converter can operate with PWM duty ratio control exact the same way as that for the conventional dc-dc converters. In the voltage-fed operating mode, the active part of the switch $S2$ and the diode of the switch $S1$ are turned on and off in complement, the other two devices are switched when the power flow is reversed. Similarly, in the current-fed operating mode, the

active part of the switch $S1$ and the diode of the switch $S2$ are turned on and off in complement, the other two devices are switched when the power flow is reversed. Table 1 shows the steady state input-output voltage gains of these converters as a function of the duty ratio D of the active device. By controlling the duty ratio, the output voltage can be regulated as desired.

TABLE 1

VOLTAGE TRANSFER RATIO OF Z-SOURCE DC-DC CONVERTER

Z-source ac-ac converter	Voltage Gain
Voltage-fed	$\frac{1-D}{1-2D}$
Current-fed	$\frac{2D-1}{D}$

III. ANALYSIS AND SIMULATION RESULTS OF VOLTAGE-FED DC-DC CONVERTER

As an example, the voltage-fed Z-source dc-dc converter shown in Fig.2 (a) is analyzed. A similar analysis can be extended to current-fed Z-source dc-dc converter.

To simplify the analysis, we only consider the power only flows from source to load, and don't consider the reverse case., then we can ignore the existence of the active part of the switch $S1$ and the diode of the switch $S2$, as shown in Fig.3. Two states exist in this circuit, Figs.4 (a) and (b) show their equivalent circuits.

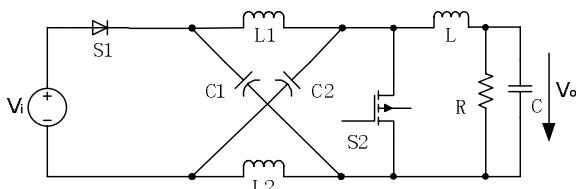


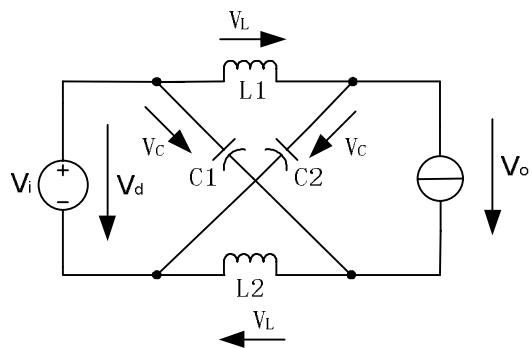
Fig.3. voltage-fed Z-source dc-dc converter

Same to other Z-source inverter/converter topologies, the Z-network of the Z-source dc-dc converter is also symmetrical, that is, the inductors $L1$ and $L2$ and capacitors $C1$ and $C2$ have the same inductance (L) and capacitance (C), respectively. From the symmetry and the equivalent circuits, we have

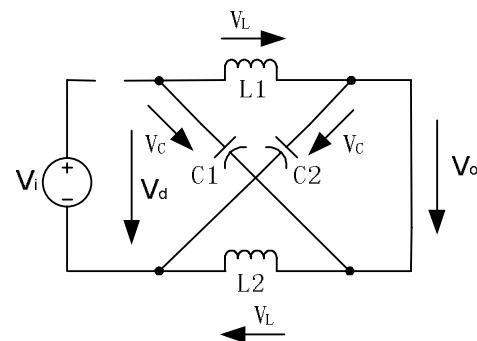
$$V_{C1} = V_{C2} = V_C \quad \text{and} \quad v_{L1} = v_{L2} = v_L.$$

In state 1, the switch $S1$ is turned on and $S2$ turned off. The dc source charges the z-network capacitors, while the inductors discharge and transfer energy to the load. The interval of the converter operating in this state is $(1-D)T$, where D is the duty ratio of switch $S2$, and T is the switching cycle, shown in Fig.4 (a), then one has,

$$V_C = V_i - v_L, \quad V_0 = V_i - 2v_L \quad (1)$$



(a)



(b)

Fig.4. (a) State 1: $S1$ is on and $S2$ is off. (b) State 2: $S1$ is off and $S2$ is on.

In state 2, the switch $S2$ is turned on and $S1$ turned off. The z-network capacitors discharge, while the inductors charge and store energy to release and transfer to the load. The interval of the converter operating in this state is DT , shown in Fig.4 (b), one has,

$$V_C = v_L, \quad V_0 = 0. \quad (2)$$

Where V_i is the value of the dc voltage source.

The average voltage of the inductors over one switching period (T) in steady state should be zero, from (1) and (2), thus we have

$$\frac{V_C}{V_i} = \frac{1-D}{1-2D} \quad (3)$$

Similarly, the peak output voltage of the converter in a switching cycle can be expressed as follow:

$$\hat{V}_0 = 2V_C - V_i = \frac{V_i}{1-2D} \quad (4)$$

The average output voltage of the converter can be expressed as follow:

$$\bar{V}_0 = V_C = \frac{1-D}{1-2D} V_i \quad (5)$$

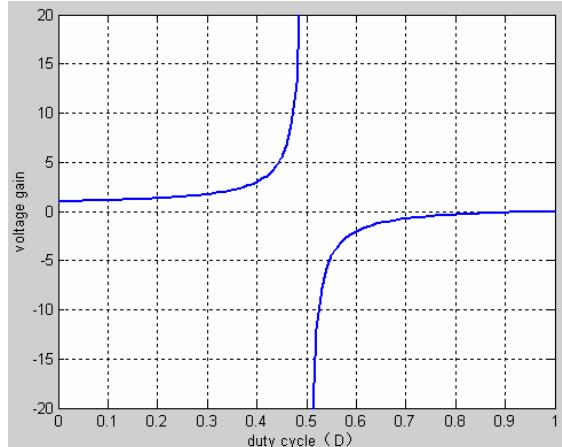
Evidently, by controlling the duty ratio D , the output voltage of the proposed dc-dc converter can be bucked or boosted. In addition, the output voltage can be in-phase or out-of-phase with the input voltage depending on operating regions of the duty cycle. This is a unique feature of the Z-source converter. Since the switching frequency is very high, the need inductance and capacitance of the Z-source network devices is low, then the size and weight of the whole system is low too.

Fig. 5(a) shows the voltage gain versus the duty cycle of the voltage-fed Z-source dc-dc converter. It clearly shows that there are two operating regions. When the duty cycle is greater than 0.5, the converter enters negative gain region, i.e., the polarity of the output voltage is reversed, and the converter operates in the buck/boost mode. When the duty cycle is less than 0.5, the output voltage is in-phase with the input voltage, and the converter operates in the boost mode. Similar analysis can be applied to the current-fed Z-source converter. Fig. 5(b) shows the voltage gain curve. Again, it is noticeable that the unique phase-reserving feature happens at the duty cycle of 0.5.

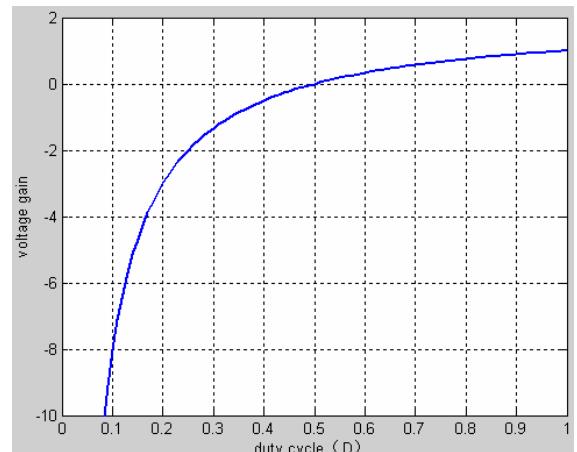
To suit to the bi-directional power flow application and both the voltage-source and the current-source power supply, the Z-network should be aborative designed

IV. SIMULATION RESULTS

Simulations of voltage-fed Z-source dc-dc converter were performed to confirm the analysis above, and simulation results are shown in Fig.6 (a), (b). the parameters of the Z-network is $L_1=L_2=L=500\mu H$, $C_1=C_2=C=1,000\mu F$. When the input dc voltage has nominal value 300V and has 50% voltage sag of 150V, by PWM duty ratio control, we can keep the output voltage constant at 220V. The converter operates in the buck mode when the input voltage is normal at its nominal voltage, the output and input voltage is inverted, and the converter operates in the boost mode during the voltage sag. In the simulation, the switching frequency is 10 kHz and the output power is 3kW.



(a)



(b)

Fig.5.voltage gain versus duty cycle: (a) voltage-fed (b) current-fed

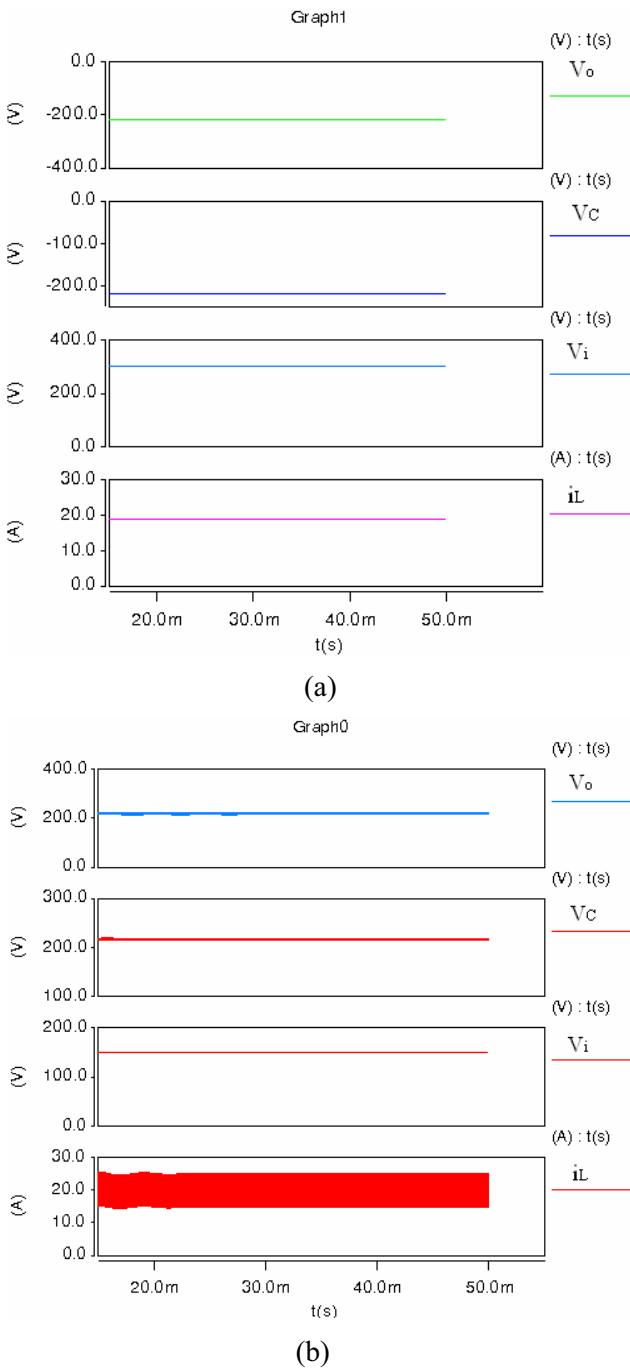


Fig.6. Simulation results

V. CONCLUSION

A novel Z-source dc-dc converter was proposed in this paper. By PWM duty ratio control, it can buck or boost the input voltage. It can reduce cost and improve reliability. Its source can be voltage-source or current-source. Steady state analysis and simulation results were illustrated using the voltage-fed converter as an example. The novel dc-dc converter could be used in the areas of

the traditional dc-dc converter.

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