Z-Source Converter with Maximum Boost Voltage Gain

Nguyen Minh-Khai*, Young-Gook Jung+, and Young-Cheol Lim*

*Dept. of Electrical Engineering, Chonnam National University, Kwang-ju, KOREA
+Dept. of Electrical Engineering, Daebul University, Yongam-gun, Chonnam, KOREA
email: jyg@mail.daebul.ac.kr

Abstract

This paper proposes a new two-stage Z-source converter (TSZC). The purpose of the proposed system is to obtain the ac voltage with a maximum boost voltage for fuel cell applications as a renewable energy source. In order to provide a continuous current path, a switching strategy for the dc-ac ZSI and ac-ac ZSC of the proposed system was used. The operation principle, analysis and simulation results of 1.2 kW fuel cell stack were also presented.

1. Introduction

Distributed generation (DG) has been widely used in recent years due to the environment and energy shortage problem. DG units including fuel cell, photovoltaic and wind energy produce power through small-scale local generation or secondary energy sources. In general, conventional DG power converters generate the desired power using a dc-dc boost converter and a conventional voltage source inverter (VSI). Conventional DG power converters have the low efficiency and the ac voltage with a boost limitation. Recently, to overcome these problems, Z-source inverter (ZSI) has been proposed and it has some advantages when applying to the fuel cell system because of its unique features [1-4]. Also, as the ac-ac conversion application of Z-source converter (ZSC), the family of single-phase Z-source ac-ac converters proposed in [5, 6] has merits such as providing a larger range of output voltage with buck-boost mode, reducing in-rush and harmonic current.

In this paper, we proposes a two-stage Z-source converter (TSZC) which is combined a dc-ac Z-source inverter (ZSI) and an ac-ac Z-source converter (ZSC). A switching strategy for dc-ac ZSI and ac-ac ZSC of the proposed topology is proposed. The operating principles, analysis, and simulation results of the proposed system are described.

2. The principles

Fig. 1 shows the basic configuration of the proposed system. It consists of two Z-source networks, diode, switches, LC filter and load. The bi-directional switches Q1, Q2 are common emitter back to back switch cells. They can be implemented by connection of two diodes and two IGBTs in anti-parallel as shown in Fig. 1(b). Fig. 2 illustrates the PWM switching strategy for the proposed system which is combined the dc-ac ZSI and the ac-ac ZSC. As shown in Fig. 2, D is an equivalent duty-ratio; T is a switching period. Four IGBT switches S1-S4 are synthesized for PWM uni-polar output voltage. Two bi-directional switches Q1j, Q2j (j = a, b) (where 'a' and 'b' are representing drivers one and two, respectively) are controlled to eliminate voltage and current spikes on switched as presented in [6].

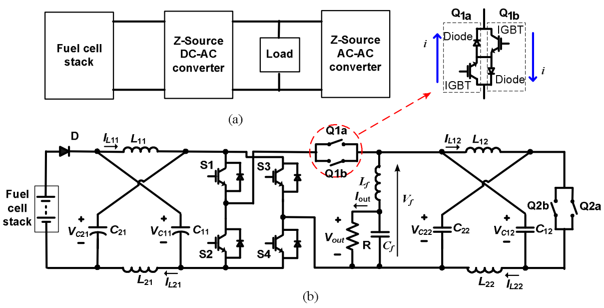

Fig. 1 Proposed TSZC topology. (a) General block diagram. (b) Basic configuration.

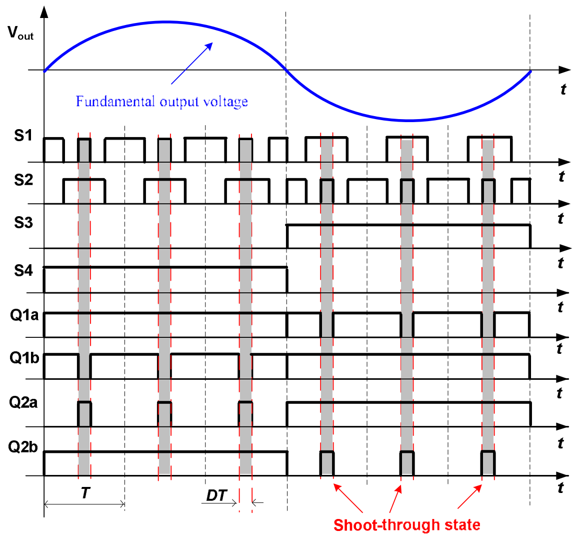

Fig. 2 PWM switching strategy of the proposed system.

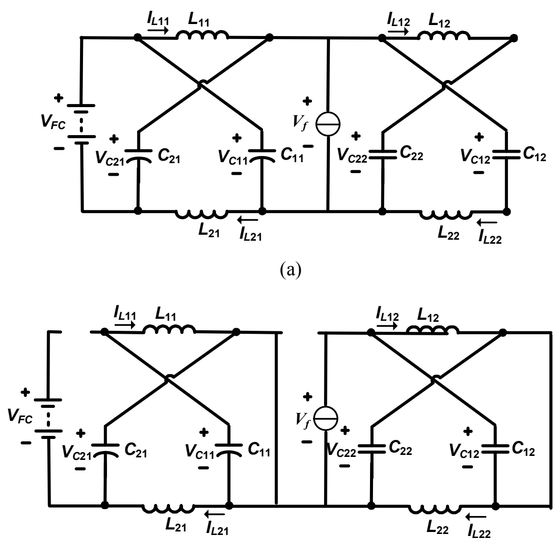

Fig. 3 Equivalent circuit of the proposed system.

Because the inductors L11, L21 and capacitors C11, C21 of the dc-ac ZSI, the inductors L12, L22 and capacitors C12, C22 of the ac-ac ZSC have the same inductance (L1), capacitance (C1), inductance (L2) and capacitance (C2), respectively, the Z-source network becomes symmetrical. Ignoring the effects of dead time, the proposed system has two operating states in one switching period: state 1 (active state) and state 2 (shoot-through state) as shown in Fig. 3. Then we have

$$V_{C11} = V_{C21} = V_{C1};\ V_{C12} = V_{C22} = V_{C2}. \quad (1)$$

In state 1 as shown in Fig. 3(a), the time interval is (1-D)T, where D is the equivalent duty-ratio; T is the switching period. We can get

$$\begin{cases} V_{FC} = L_1 \dfrac{di_{L1}}{dt} + V_{C1}; \\ V_f = -L_1 \dfrac{di_{L1}}{dt} + V_{C1} = L_2 \dfrac{di_{L2}}{dt} + V_{C2} = -V_{FC} + 2V_{C1} \end{cases} \quad (2)$$

In state 2 as shown in Fig. 3(b), the time interval is DT. We can get

$$L_1 \frac{di_{L1}}{dt} = V_{C1};\quad L_2 \frac{di_{L2}}{dt} = V_{C2};\quad V_f = 2V_{C2} \quad (3)$$

In steady-state, the average voltage of the inductors over one switching period should be zero. From (2) and (3), thus, we get

$$\begin{cases} L_1 \dfrac{di_{L1}}{dt} = (1-D)(V_{FC} - V_{c1}) + D \cdot V_{c1} = 0 \\ L_2 \dfrac{di_{L2}}{dt} = (1-D)(-V_{FC} + 2V_{c1} - V_{c2}) + D \cdot V_{c2} = 0 \end{cases} \quad (4)$$

Thus, we have

$$\begin{cases} V_{c1} = \dfrac{(1-D)}{(1-2D)} V_{FC} \\ V_{c2} = \dfrac{(1-D)}{(1-2D)^2} V_{FC} \end{cases} \quad (5)$$

Assuming that the inductor in Z-network is very small and there is no line frequency drop across the inductor, the voltage across the load should equal the voltage across the capacitor of the as-ac ZSC, that is

$$V_{out} \approx V_{c2} = \frac{(1-D)}{(1-2D)^2} V_{FC} \quad (6)$$

The voltage gain (K) can be defined as

$$K = \frac{V_{out}}{V_{FC}} = \frac{1-D}{(1-2D)^2}, \quad (7)$$

where V_{out} is a peak value of ac output voltage

Fig. 4 shows the voltage gain versus the duty cycle. As shown in Fig. 4, the ac output voltage V_{out} can be boosted when the duty cycle (D) increases from 0 to 0.5. In comparison with conventional dc-ac ZSI or ac-ac ZSC, the proposed system (TSZC) can provide a higher ac output voltage.

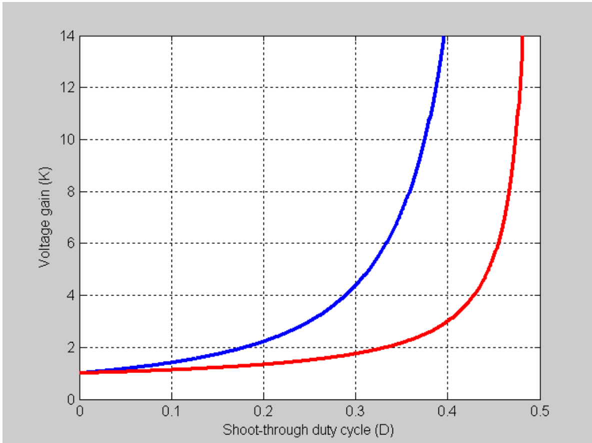

Fig. 4 Relationship between output voltage gain (K) and duty cycle (D).

3. Simulation Results and Discussions

Fig. 5 shows the simulation results of the proposed system as shown in Fig. 1(b) at 1.2 kW fuel cell stack voltage V_{FC} = 42 x 2 = 84 V. The simulation parameters are $L_{11} = L_{21}$ = 1.5 mH, $C_{11} = C_{21}$ = 1500 μF, $L_{12} = L_{22}$ =0.8 mH, $C_{12} = C_{22}$ = 3.3 μF, L_f = 3 mH, C_f = 3.3 μF. The switching frequency is 20 kHz, the dead time for commutation is 0.5 μs.

From simulation results as shown in Fig. 5 (a), we observe that the capacitor V_{C11} of the dc-ac ZSI was boosted to 186 V, the capacitor V_{C12} of the ac-ac ZSC was boosted to 612 Vpeak or 433 Vrms and the ac output voltage V_{out} was also boosted to 603 Vpeak or 426 Vrms from the fuel cell voltage V_{FC} = 84 V. Fig. 5 (b) shows the maximum output voltage at D = 0.39, modulation index (M = 1 - D = 0.61). The ac output voltage V_{out} was boosted to 1430Vpeak or 1010Vrms from the fuel cell voltage V_{FC} = 84 V.

It is clear that the proposed system is to obtain the ac voltage with a maximum boost voltage which is useful for fuel cell applications as a renewable energy source.

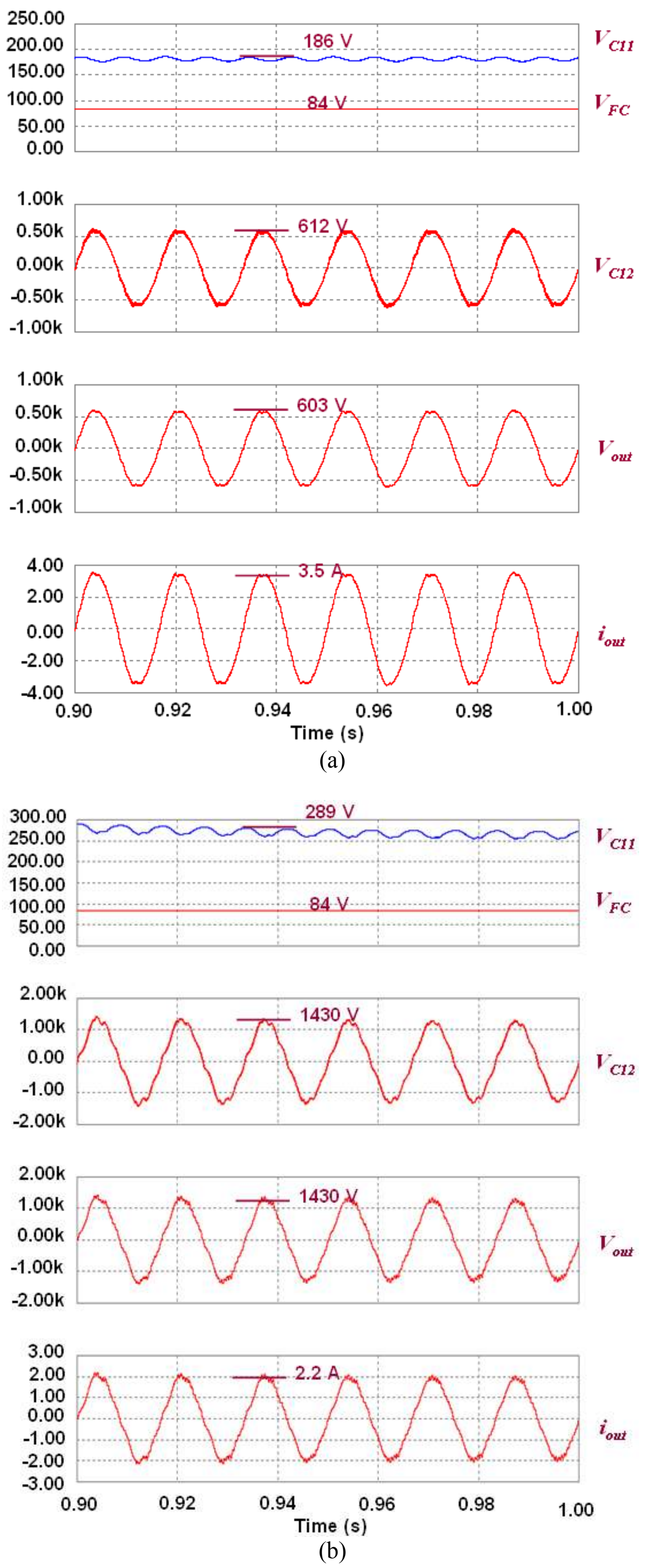

Fig. 5 Simulation result at (a) $D = 0.35$, modulation index ($M = 1 - D = 0.65$); (b) $D = 0.39$, modulation index ($M = 1 - D = 0.61$).

4. Conclusions

In this paper, we have proposed a new two-stage Z-source converter (TSZC). The proposed system can generate the ac output voltage with maximum boost which is adapted for fuel cell applications. The simultaneous switching strategy for the dc-ac ZSI and ac-ac ZSC of the proposed system was proposed, and it also provides a continuous current path by using the commutation strategy. Steady-state analysis, operation principle and simulation results of 1.2 kW fuel cell stack were also presented.

This research project received supporting funds from the third-stage Brain Korea 21.

REFERENCES

[1] F. Z. Peng, “Z-source inverter,” *IEEE Trans. Ind. Applic.*, vol. 39, no.2, pp. 504-510, March/April, 2003.

[2] K. Holland, M. Shen, and F. Z. Peng, “Z-source inverter control for traction drive of fuel cell – battery hybrid vehicles,” *in Proc. IEEE IAS’05*. 2005, pp. 1651-1656.

[3] Y. H. Kim, H. W. Moon, S. H. Kim, E. J. Cheong, and C.Y. Woo: “A fuel cell system with Z-source inverters and ultra-capacitors,” *in proc. Power Electronics and Motion Control Conference,* IPEMC’04, 2004, pp. 1587-1591.

[4] M. Shen, A. Joseph, J. Wang, F. Z. Peng, and D. J. Adams, “Comparison of traditional inverter and Z-source inverter for fuel cell vehicles,” *in proc. IEEE WPET04,* 2004, pp. 125–132.

[5] X. P. Fang, Z. M. Qian, and F. Z. Peng, "Single-phase z-source PWM ac-ac converters," *IEEE Power Electronics Letters*, vol. 3, no. 4, pp. 121-124, 2005.

[6] Y. Tang, C. Zhang, and S. Xie, “Single-phase four switches Z-source ac-ac converters,” *in Proc. IEEE APEC’07*, 2007, pp. 621-625.