A Comparative Study of Z-source Inverter and Enhanced Topologies

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(Invited)

[1]***Abstract*— This paper does some theoretical analysis and simulation studies on the most common topologies of Z-source inverter. As we all know, the traditional Z-source inverter has some problems, such as the voltage of the capacitor which belongs to this topology is higher and there is a startup shock, which caused researchers proposed a variety of improved Z-source topologies to solve these problems. Some of these topologies can increase boost capacity, and some can reduce the capacitor voltage. However, these topologies can improve only part of the problems of the traditional Z-source inverter, which leads to that the users are hard to choose which topologies. Faced with this situation, eleven Z-source topologies are analyzed in terms of boost capacity, inductance start-up current, capacitance stress and economy in this paper. Finally, two kinds of promising topologies were gotten.**

***Index Terms*—Boost capacity, inductance start-up current, capacitance stress, economy, simulation, Z-source inverter.**

I. INTRODUCTION

THE upper and lower switches of the bridge arm of the voltage-source inverter (VSI) cannot be switched on at the same time, otherwise, short circuit will be occurred and the inverter will be damaged [1-2]. Therefore, the dead time must be added between the switch signals of the upper and lower arms, but the dead time will make the output waveform distorted. On the other hand, it is necessary to add the boost circuit in the front stage of the inverter in the case of high voltage, which leads to the complexity of the whole system and the reduction of the efficiency [3-4]. The Z-source inverter can overcome the shortcomings of the traditional voltage-source inverter, which uses the upper-shoot-through state and lower-shoot-through state of the same bridge arm to realize the boost of the input DC voltage [5-6]. Because the shoot-through state that caused by electromagnetic interference becomes a kind of working mode of the inverter, which will not damage the inverter, and this can also avoid the distortion of the output waveform caused by the dead time

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However, the topology of the traditional Z-source inverter also has the following defects [7]: (1) The capacitor voltage of Z-source network is higher than the input DC voltage, which leads to higher capacitor volume and higher cost. (2) Limited boost capacity. (3) The input current of the Z-source inverter is discontinuous because the diode disconnects the Z-network from the source, which may be undesirable for some sources such as solar cells and fuel cells.

In order to solve the defects of traditional Z-source inverter, many scholars have done a lot of research and proposed a variety of improved Z-source topologies [8-9]. Among them, some of the improved Z-source topologies can improve the boost capacity of Z-source inverter, but other problems of the traditional Z-source inverter have not been improved or even deteriorated [10-11]. Meanwhile, some improved Z-source topologies can reduce the capacitor voltage and reduce the start-up shock, but this kind of topology can not completely improve the boost capacity of the inverter [12-13]. The aforementioned topologies have their own advantages and disadvantages in solving the different defects of the traditional Z-source inverter, which leads to the user being unable to select the topology quickly and accurately in practical.

In this paper, several improved topologies are analyzed and simulated. Finally, two kinds of topologies with good performance and application are selected for users' reference.

II. TRADITIONAL TOPOLAGY

The topology of the traditional Z-source inverter is shown in Fig.1. According to the topology and working principle, it can be introduced:

$$\begin{cases} U_{\mathrm{i}} = \dfrac{1}{1-2D_0} U_{\mathrm{dc}} = BU_{\mathrm{dc}} \\ U_C = \dfrac{1-D_0}{1-2D_0} U_{\mathrm{dc}} \end{cases} \quad (1)$$

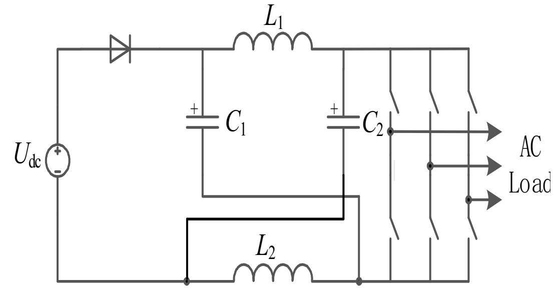
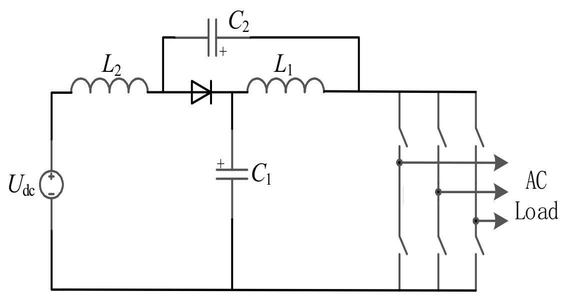


Fig.1. Topology of traditional Z-source inverter.

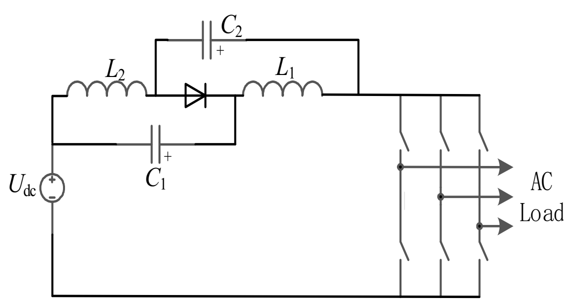
Where: U_{dc} is the power supply voltage of the DC side, U_i is the boost side voltage of the Z-source network, U_C is the capacitor voltage of the Z-source network, D_0 is the shoot-through duty ratio, and B is the boost factor.

III. Various Topologies Of Improved Z-Source Inverter

Fig.2(a) is the topology with continuous input current. It adopts asymmetric structure, the inductor is connected with the power supply in series, to make the input current of Z-source inverter continuous. Meanwhile, this topology can effectively simplify the filter circuit and reduce the system cost. Fig.2(b) adjusts the cathode position of the capacitor on the basis of Fig.2(a), which makes the capacitor voltage consistent with the power supply, thus reducing the capacitor voltage.



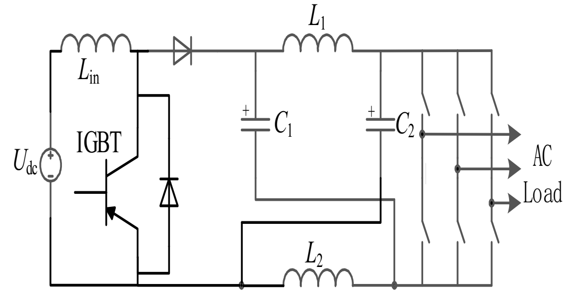
(a) Quasi-z-source inverter with continuous input current.



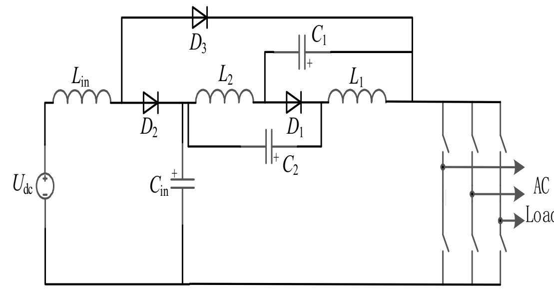
(b) Quasi-z-source inverter with lower capacitor voltage

Fig.2. Two kinds of quasi-Z-source inverters.

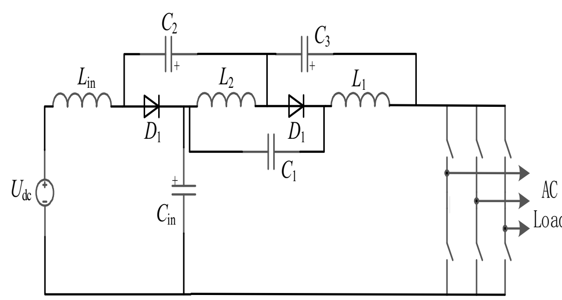
In order to improve the boost capacity of Z-source inverter, researchers have proposed four kinds of improved topologies shown in Fig.3. Fig.3(a) adds an active switch and inductor on the basis of the traditional Z-source inverter, which together with the diodes of the original circuit constitute a pre-stage boost circuit, thus improves the boosting capability. It can be seen from Fig.3 (b) that the topology adds a boost circuit composed of diodes, capacitors, and inductors on the basis of the topology of Fig.2(b). The boost circuit and the Z-source network are connected in series, which increases the boost capability. Fig.3(c) replaces the diode with capacitor on the basis of Fig.3(b), which can further increase the boosting capacity and has the advantage of continuous input current. The aforementioned three topologies have the advantage of continuous input current and, to some extent, increased boost capability. However, the booster effect is not particularly significant. The topology in Fig.3(d) replaces the inductor with the switch inductor. Unlike traditional topologies, the new topology adds three diodes and one inductor to each inductor circuit. Although the cost has increased, the boost capacity has been greatly improved.



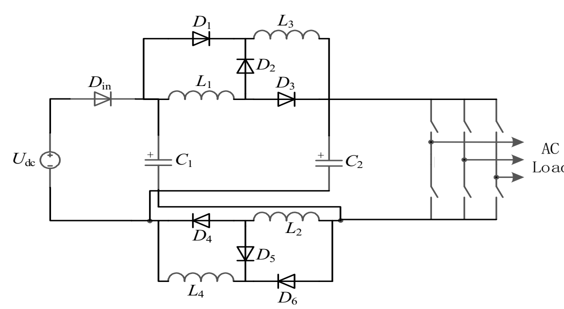
(a) Front-stage boost.



(b) Diode-assisted extension.



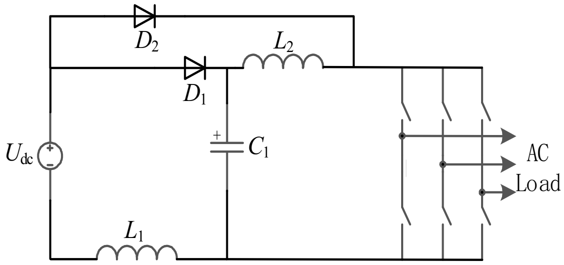
(c) Capacitor-assisted extension.



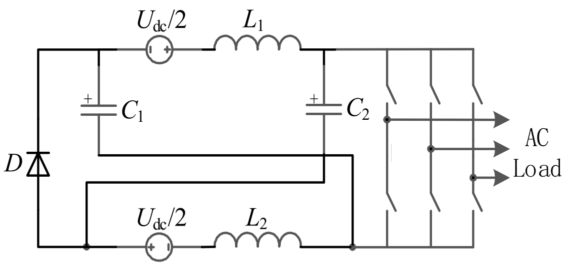
(d) Switching-inductor

Fig.3. Improved Z-Source inverter with boost capacity.

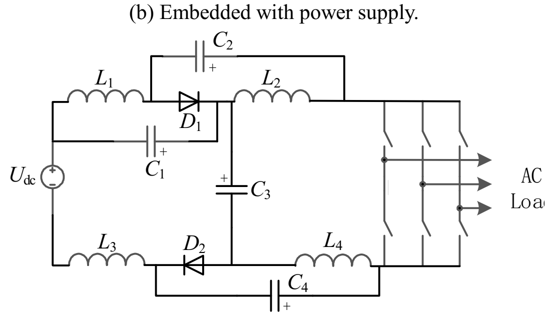
The improved topology shown in Fig.4(a) replaces the capacitor in the traditional Z-source network with a diode, which reduces the boost capacity of the topology slightly. However, the new topology reduces the cost and weight of the system and can effectively eliminate the impact of inrush current. The topology in Fig.4(b) has the advantage that the ripple of input current through the power supply is small, the capacitor voltage is halved, and the symmetry of the Z-source network is maintained. Both the improved topology of Fig.4(c) and Fig.4(d) reduce the voltage stress of components by increasing the number of quasi-Z source networks. However, neither topology will change the boost capability of the Z-source inverter.



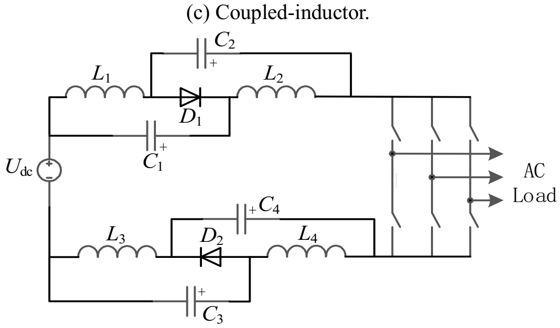
(a) Reduce boost factor.



(b) Embedded with power supply.



(c) Coupled-inductor.



(d) Inductor-series

Fig.4. The other improved Z-source inverters.

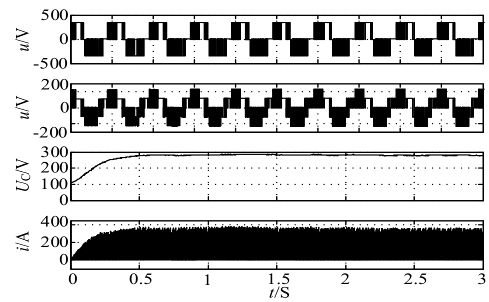
IV. SIMULATION

Based on the theoretical analysis of Z-source topology, eleven topologies are simulated by using the Simulink toolbox of Matlab software. The simulation parameters are as follows: the input DC voltage is 220V, the switching frequency of the inverter is 10 KHz, the modulation ratio of the inverter is 0.8, and the shoot-through duty cycle is 0.3.

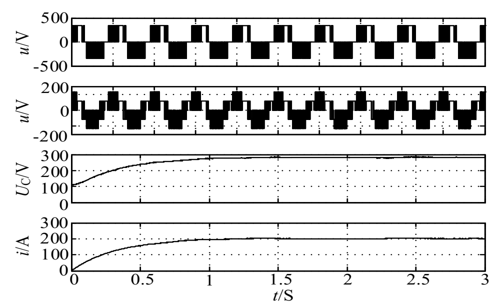
It can be seen from the TABLE I that four topologies of Fig.5(d), (e), (f) and (g) are significant in improving the boosting capacity of the Z-source inverter. Among them, the switching-inductor Z-source inverter has the strongest boost capacity, but the input current and the capacitor voltage are very large, which will increase the cost of the system. The front-stage boost Z-source inverter and the diode-assisted extension Z-source inverter have the same boost capacity and capacitor voltage. However, the diode-assisted extension Z-source inverter can make multistage extension and further improve the boost capacity. Although the capacitor-assisted extension Z-source inverter is similar to the diode-assisted extension Z-source inverter in terms of its boost capacity, its input current is large. In conclusion, diode-assisted extension Z-source inverter is the best choice to improve the boost capacity.

The four topologies in Fig.5(c), (f), (i) and (k) have obvious effect on reducing capacitor voltage, and the boost capacity of these four topologies is the same. From the view of input current, the embedded with power supply Z-source inverter have a lower input current and capacitor voltage while ensuring the boost capability. Therefore, this topology is the optimal scheme in the case of low capacitor voltage.

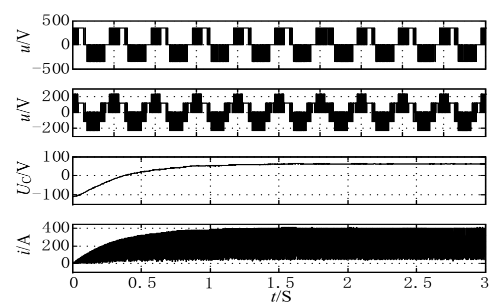
According the above simulation analysis, we know that the diode-assisted extension and the embedded with power supply Z-source inverters can solve several problems of traditional Z-source inverters with lower additional cost and higher operating efficiency.



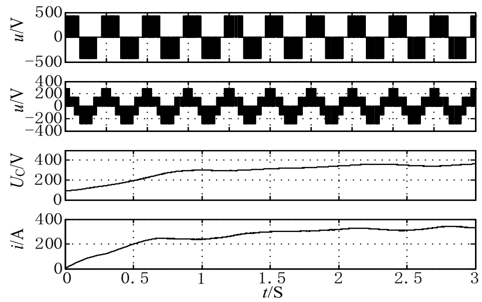
(a) Traditional Z-source inverter.



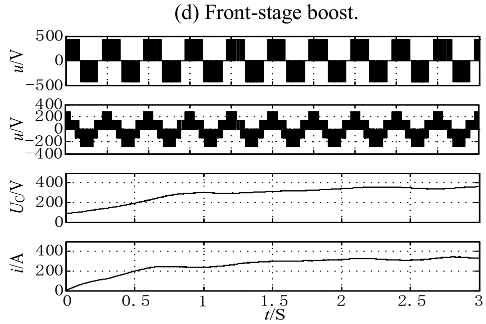
(b) Continuous input current.



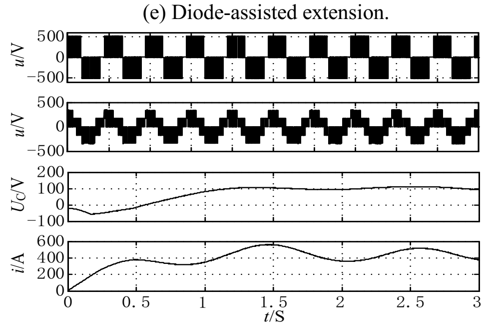
(c) Lower capacitor voltage.



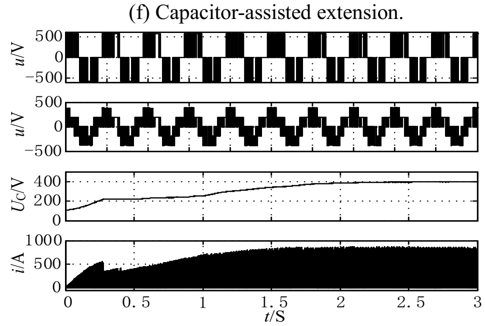
(d) Front-stage boost.



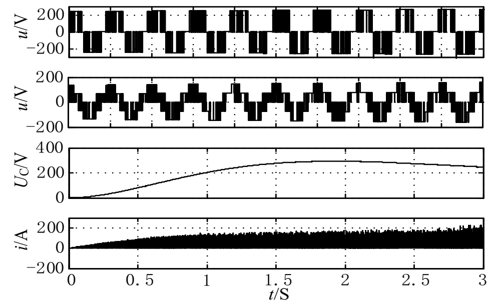
(e) Diode-assisted extension.



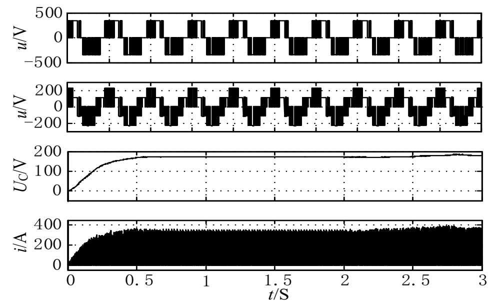
(f) Capacitor-assisted extension.



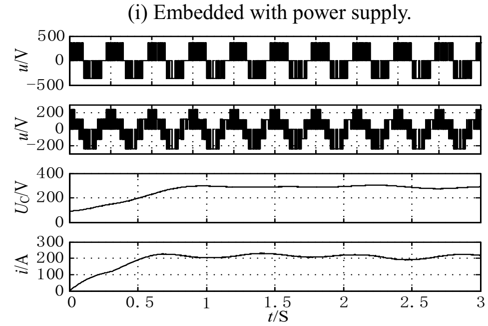
(g) .Switching-inductor.



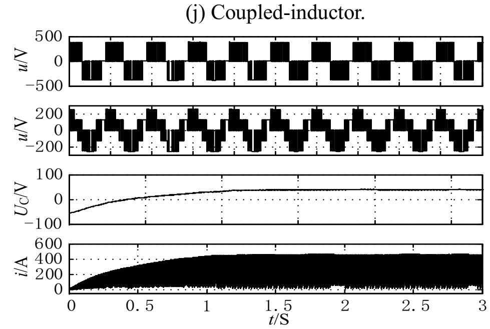
(h) Reduce boost factor.



(i) Embedded with power supply.



(j) Coupled-inductor.



(k) Inductor-series.

Fig.5. The simulation curves of eleven kinds of Z source topologies.

TABLE I
THE PERFORMANCE COMPARISION OF ELEVEN KINDS OF Z-SOURCE INVERTERS

Topology	Boost capccity	Line/Phase voltage (V)	Capacitor voltage（V）	Input current (A)	Cost	Efficiency
Fig.5(a)	1/(1-2D_0)	350/230	280	Intermittent 300	Low	Higher
Fig.5(b)	1/(1-2D_0)	350/230	280	continuous 200	Low	Higher
Fig.5(c)	1/(1-2D_0)	350/230	175	Intermittent 420	Low	Higher
Fig.5(d)	1/(1-D_0)(1-2D_0)	460/300	310	continuous 260	Lower	Low
Fig.5(e)	1/(1-D_0)(1-2D_0)	460/300	310	continuous 270	Higher	Higher
Fig.5(f)	1/(1-3D_0)	510/335	150	continuous 400	Lower	Higher
Fig.5(g)	(1+D_0)/(1-3D_0)	570/380	400	Intermittent 800	High	Lower
Fig.5(h)	1/(1-D_0)^2	275/185	240	Intermittent 170	Lower	Lower
Fig.5(i)	1/(1-2D_0)	350/230	180	Intermittent 330	Low	High
Fig.5(j)	1/(1-2D_0)	350/230	300	continuous 210	Higher	High
Fig.5(k)	1/(1-2D_0)	350/230	100	Intermittent 410	Higher	High

V. CONCLUSION

In this paper, some problems existing in traditional Z-source inverter are analyzed and summarized. Through theoretical analysis and simulation results, we can draw the following conclusions:

(1) Compared with the traditional Z-source inverter, the diode-assisted extension Z-source inverter can greatly improve the boost capacity without increasing the capacitor voltage and keeping a small continuous input current. Meanwhile, the circuit of this topology can be extended at multiple levels.

(2) The embedded with power supply Z-source inverter have a lower input current and capacitor voltage while ensuring the boost capability.

These two improved topologies will be widely used in fuel-cell generation, photovoltaic power generation, wind power generation and other new energy applications.

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