Z-SOURCE INVERTERS: DESIGN AND APPLICATIONS

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1. INTRODUCTION

Since the invention of power conversion systems, power inverters including both simple two-level and comparatively complex multi-level topologies have so far been broadly applied for dc-dc power inversions such as ac-motor drive, renewable energy interfacing and uninterruptable power supply. For the control of electric power or power conditioning, the conversion of electric power from one form to another is necessary and the switching characteristics of the power devices permit these conversions. A static power converter, which is usually considered as a switching matrix, perform as a major power converter. Traditionally, a front-end dc-dc boost converter is inserted between renewable source and inverter circuitry to stabilize the output voltage forming a two-stage power conversion (19). Particularly a two-stage or multi-level solution is definitely not optimally integrated and it just adds to the system complexity and cost. Comparatively, a Z-source inverter, which is basically a single stage solution and has a unique passive structure with inherited advantages of buck-boost operations, is attracting the attention of new generation of researchers (2-6,8-9,11-16).

Based on the source of current, traditionally converters are of two types: Voltage-source or the Voltage fed and the Current source or the Current fed inverters and for convenience these are abbreviated as VSI and CSI respectively. In the traditional single phase voltage fed inverters, the main converter circuit is fed by dc voltage source, which could be a battery, diode rectifier, fuel-cell stack, with a large capacitor. The main circuit has four switches, where each switch is composed of a power transistor and a free-wheeling diode that facilitates the bidirectional current flow and holds unidirectional voltage blocking capability. On the other hand, in a traditional single phase current-source converter, also called as I-source converter, a dc-current
source, which is comparatively large, viz., a battery, fuel-stack, thyristor, rectifier or a diode converter. In the main circuit, it has four switches, each having a semiconductor switching device with reverse block capability such as SCR and a Gate-turn-off thyristor (GTO) or a power transistor with a series diode that facilitates unidirectional current flow with bidirectional voltage blocking (33).

2. DESIGN ANALYSIS

There are mainly three reasons for which Z-source inverters are being adopted and appreciated, these are:

- The traditional inverters with Pulse width modulation (PWM) has only one control freedom, that controls the output AC voltage, whereas in a Z-source inverter, there are two control freedoms that are independent to utilize shoot-through duty cycle and modulation index to produce the desired output in the form of AC voltage(7).
- The Z-source inverter provides the same features of a DC-DC boosted inverter, however these are less complex and more cost effective.
- Z-source inverters are more reliable because of the momentary shoot-through as in traditional inverters, does not hamper the Z-source inverter and its output.

So far, the Z-source inverters have been well designed in voltage-type and current-type topologies with the development of their system modeling, optimal modulation schemes and controller design (3,5,14,15). Chopping operation of dc source when switching states alternate, is the common feature in all types of Z-source inverters. The jumping current flow increases the current rating and the complexity of controlling the maximum power of clean energy sources.

2.1. Traditional Z-source inverter

The very first Z-source inverter proposed by (2) as in Fig.1, used a symmetrical LC impedance network to replace the dc-link capacitor in traditional VSI. Furthermore, with the help of series diode D embedded in the source side, the input dc source can be effectively disconnected from the Z-source network by naturally reverse-biasing the diode D during the unique shoot-through interval, which can be initiated by turning ON all the switches of one phase-leg simultaneously. As far as the operational states of Z-source inverter is studied, it can be classified as shoot-through and nonshoot-through states with six active and two null states. In its active state, the inverter circuit and load can be treated as a constant current source, where the diode D is naturally conducting as the capacitor discharging process and the need for powering load from input source resulting in the following voltage relationships among dc source, inductors, capacitors and dc-link by assuming C1=C2 and L1=L2. For optimally controlling the Z-source inverter, shoot-through stage should be inserted in the traditional switching sequence without affecting the normalized voltage and introducing any additional switching.
2.2. Single stage Z-source inverter

These types of inverters are capable of boosting voltage and delivering power in a single stage structure and thus is suitable for photovoltaic applications. The design consists of three important parts: a PV array, a DC link circuit, which is a typical Z-source network and an inverter bridge (Fig. 2). In the design, the PV array is a group of a number of PV cells connected in a series of parallel arrangement to provide desired value of output voltage and current. The impedance source inverter employs a unique impedance network coupled with the main inverter circuit to the power source. The impedance network receives the DC voltage from the PV source and according to the boosting factor required the impedance network will buck or boost the input voltage. In the design the impedance network is a two-port network with split-inductor L1 & L2, two capacitors C1 & C2, which are connected to each other in such a way that it forms the shape of alphabet ‘X’. Switches used in the converter can be a combination of switching devices and diodes connected in anti-parallel form, as in Fig.3 proposed by (32) used MOSFET as switches with the assumption that L1=L2=L3 and C1=C2=C3, thus making the single stage Z-source inverter a symmetrical device.

The basic idea of control is to turn zero states into shoot through states and keep the active switching states unchanged so that the sinusoidal output can be maintained along with the boost in voltage which is achieved from the DC link. Therefore a Z-source inverter can produce an output voltage which is greater than the AC input voltage just by controlling the boost factor. The modified system is a very promising energy system especially for households. The proposed system uses only a single stage inverter for direct DC-AC conversion, with less switches.
2.3. Embedded Z-source inverters

(10) studied the buck-boost impedance network and suggested a new type of inverter with embedded features and thus were referred to as embedded Z-source inverter. Also (16) proposed voltage type Z-source inverter with a partially shunt-embedded battery implemented in a fuel cell powered hybrid electric vehicle. Fig.4 gives the topology with dc sources inserted into X-shaped network, where the two isolated dc sources are embedded with each other connecting to the inductor L1 or L2. Operational principle of the inverter can easily be analyzed by studying its behavior in different switching cycles. Besides performing at the same output as of a buck-boost operation without distorting the waveform, the parallel embedded Z-source inverters are not considered the ideal alternatives for the traditional Z-source inverters, as it is unable to optimize the components and also it is difficult to avoid the circulation of current in the system. However the fully parallel embedded Z-source inverters can easily be used in PV applications. The voltage rating of shunt capacitors is significantly reduced when the designed maximum boost voltage deviates from infinite. Even for applications where only single dc-source is available, the embedded Z-source inverters are advantageous in respect of smooth source current and reduced capacitor rating.

2.4. Switched-inductor Quasi-Z-source Inverter

A number of workers (17,23,26) proposed a class of quasi-Z source inverters to overcome the shortcomings of the classical Z-source which had various advantages such as, reducing passive component ratings and improving input profiles. The
inverters proposed by (25,28) added inductors, capacitors and diodes to the Z-impedance network to produce high dc-link voltage for the main power circuit from a very low input dc-voltage, whereas (27) replaced two inductors of the impedance Z-network with transformer to obtain high voltage gain. Therefore applying switched-capacitor, switched-inductor, hybrid switched-capacitors/switched-inductor structures, voltage-lift techniques and voltage multiplier cells (18,20,22) to dc-dc conversion provides a high boost in cascade and transformerless structures with high efficiency and high power density. They named this combo as switched-inductor-ZSI or SL-ZSI (28). Further (29) proposed an modified inverter with improved input current, reduced passive component count and more reliability and called it as switched-inductor-quasi-Z-source inverter (SL-qZSI). The proposed inverter as given in Fig. 5 has three inductors, L1, L2 and L3; two capacitors, C1 and C2; and four diodes Din, D1, D2, D3. The combination of inductors L2-L3 with diodes D1-d2-D3 are used as switches. The proposed topology provides inrush current suppression, unlike the SL-ZSI, because there is no flow of current towards the main circuit during the start-up. It has an extra shoot through states in addition to the six active and two zero states in the traditional inverters. In comparison to the traditional Z-source inverters and the SL-ZSI’s the proposed inverter gives high boost voltage inversion ability, continuous input current and it shares the dc source ground point. Also it can suppress the start-up inrush current which otherwise is a threat for all kinds of devices.

![Figure 5 SL-qZSI with continuous input current](image)

### 2.5. Trans-Z-source inverter

The voltage fed Z-source/ quasi-Z source inverters cannot have bidirectional operations unless replacing the diode with a bidirectional conducting, unidirectional blocking switch (21). Additionally, the current-fed-Z-source/quasi-Z-source inverters (17,24,15) can have voltage buck-boost and bidirectional power flow only with a diode in the impedance network. Keeping all these in mind (30) proposed two current fed trans-Z source inverters that are capable of reaching wider voltage boost range and bidirectional power flow with a single diode. These topologies helped in obtaining wider output voltage especially for running HEV/EV motor devices. A rearrangement of voltage-fed-quasi-Z-source inverter gives the topology of voltage-fed-trans-Z-source inverter and similarly rearrangement of current-fed-quasi-Z source inverter gives the topology of current-fed-trans-Z-source inverter. The trans-quasi-Z-source inverter has an extra shoot-through zero state besides the six active states and two traditional zero states. Fig. 6 shows the design of a voltage-fed trans-quasi-Z-source inverter. In the voltage-fed-trans-Z-source inverter one of the capacitors, as originally found in voltage-fed-quasi-Z-source inverter, is removed thus making the voltage across the L2 proportional to the voltage across L1 making the turns ratio n2/n1. As the voltage constraint across the removed capacitors is released, the two
windings act as a flyback transformer (1). Similarly, in the current-fed-trans-Z-source inverter, the inductors L1 and L2 are coupled and the dc current is provided through a dc inductor Ldc (Fig.7). when the turns ratio of the two windings is over 1, the voltage-fed-trans-Z-source inverter can obtain a higher boost gain with the same shoot-through duty ratio and modulation index (30). In the current-fed-trans-Z-source inverter, the motoring operation range can be extended as compared to that obtained in the traditional inverters. The voltage-fed-trans-Z-source inverter has a promising potential in the applications with very low input voltage, such as the micro-inverter for the photovoltaic systems.

![Voltage-fed trans-quasi-Z-source inverter](image1.png)

**Figure 6** Voltage-fed trans-quasi-Z-source inverter

![Current-fed trans-quasi-Z-source inverter](image2.png)

**Figure 7** Current-fed trans-quasi-Z-source inverter

### 3. CONCLUSION

The basic Z-source inverter performs buck-boost functions, as compared to the traditional voltage-source inverter. In addition, the two switches in the same phase leg can be gated on simultaneously. Thus there is no dead time required hence the output distortion is greatly reduced and improves reliability (31). Besides that, the Z-source inverters have many drawbacks, viz:

- To perform the voltage boost function for the Z-source stage, the Z-capacitor voltage is larger than the input voltage. As a result, high voltage Z-capacitors should be used, which increases the cost as well as the volume of the system.
- The Z-source inverter cannot suppress the rush current and resonance between the Z-capacitors and inductor start-up, which causes voltage and current surges and may destroy the device.
- Various researchers are working towards the modification of these inverters to increase its performance and applicability.
REFERENCES


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