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Buck-Boost Operation Using a Z-Source Inverter

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Abstract: An impedance-source (or impedance-fed) power converter (abbreviated as Z-source) and its control method for implementing dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion are presented in this paper. This impedance converter employs a unique impedance network (or circuit) to couple the converter main circuit to the power source, hence provides a unique feature that cannot be obtained in the traditional converters where a capacitor and inductor are used, respectively. The Z-source converter overcomes the conceptual and theoretical barriers and limitations of the usual source converter (known as a V-source converter and I-source converter) and provides a novel power conversion concept. The Z-source concept can be applied to all ac-to-ac, dc-to-ac, dc-to-dc, and ac-to-dc power conversion. To describe the control and operating principle, this paper explains an example: a Z-source inverter for dc-ac power conversion needed in fuel cell applications. Experimental results and simulation are presented to demonstrate the new features.

Index Terms: Converter, Current-Source Inverter, Inverter, Voltage-Source Inverter, Z-Source Inverter.

1. INTRODUCTION

Since the invention of power conversion systems, power inverters including both simple multi-level and comparatively complex two-level topologies have so far been broadly applied for dc-dc power inversions such as ac-motor drive, renewable energy uninterruptable and interfacing power supply. For electric power control and conditioning of power, the conversion of electric power from one form to another is necessary permit these conversions are implemented by the switching characteristics of the power devices. A static power converter acts as a major power converter. Traditionally, a front-end dc-dc boost converter is employed between the renewable source and inverter circuitry stabilizing the output voltage forming a two-stage power conversion. Normally a multi-level solution is not optimally integrated and it just increases system complexity and cost. Relatively, a Z-source inverter, which is generally a single stage solution and has a unique passive structure with genetic advantages of buck-boost operations, is grabbing new generation researcher's attention (2-6,89,11-16).

On the basis of sources, traditional converters are of two types: Voltage source or the Voltage fed converters and the Current source or the Current fed converters and for convenience, these are abbreviated as VSI and CSI respectively. In the traditional single phase voltage inverters, the main converter circuit is connected to the dc voltage source, which can be a battery, diode rectifier, fuel-cell an SMPS, with a large capacitor. The main circuit consists of four switches, where each switch is made up of a power transistor and a free-wheeling diode that supports the bi-directional flow of current. Whereas in a traditional single phase current source converter, also called as I-source converter, a dc-current source, which is comparatively large, viz., an SMPS, a battery, fuel-stack, thyristor, rectifier or a diode converter. In the main circuit, it comprises of four switches, where each switch has a semiconductor switching device with reverse block capabilities such as SCR and a Gate turn-off thyristor (GTO) or a power transistor connected with a series diode that allows unidirectional current flow with bi-directional voltage blocking (33).

2. Z-SOURCE CONVERTER

For compensation of the above problems occurring in the traditional I-source and V-source converters, an impedance-source (or impedance-fed) power converter (also known as Z-source converter) and its control method for implementing ac-to-dc, dc-to-dc, ac-to-ac, and dc-to-ac power conversion are presented here in the paper. Fig. 1 depicts the proposed general Z-source converter structure. It makes use of a unique impedance network (or circuit) to connect the converter main circuit to the power source, load, or another converter, which provides unique features that cannot be obtained in the traditional V- and I-source converters where a capacitor and inductor are used, respectively. The Z-source converter removes the above-mentioned conceptual.

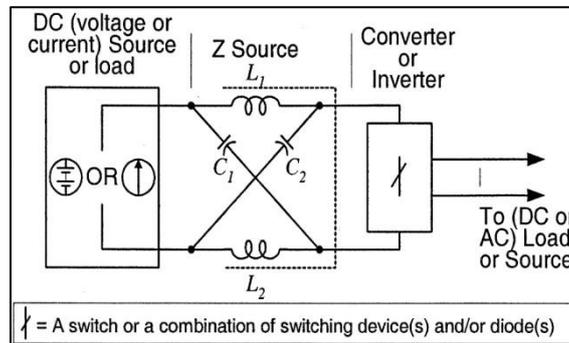


Fig. 1. The general structure of the Z-source converter.

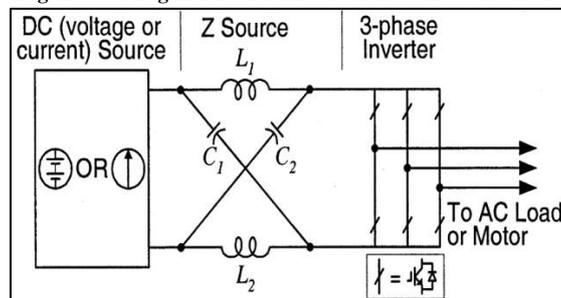


Fig. 2. Z-source converter structure using the antiparallel combination of switching device and diode.

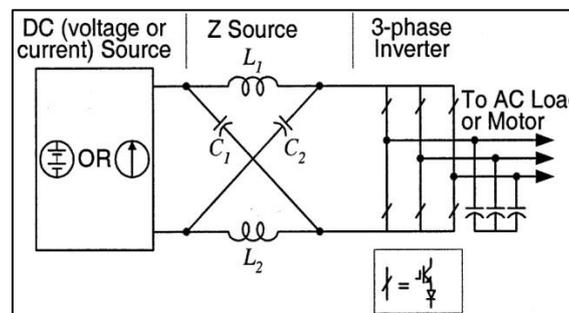


Fig. 3. Z-source converter structure using the series combination of switching device and diode.

and theoretical obstruction and limitations of the traditional VSC and ISC and provides a novel power conversion concept. In Fig. 3, a two-port network that comprises of a split inductor and a pair of capacitors and connected in X shape is employed to provide an impedance source (Z-source) coupling the converter (or inverter) to the dc source, load, or another converter. The dc source/ load can be either a voltage or a current source/ load. Therefore, the dc source can be a battery, diode rectifier, thyristor converter, battery, cell, an inductor, a capacitor, or a combination of them. Switches used in the converter can be a combination of switching devices and diodes such as the antiparallel combination as shown in Fig. 1, the series combination as shown in Fig. 2, etc. As examples, Figs. 4 and 5 show two three-phase Z-source inverter configurations. The inductance and can be provided with the help of a split inductor or two separate inductors.

The Z-source idea can be applied to all dc-to-dc, ac-to-dc, ac-to-ac, and dc-to-ac power conversion. To describe the operating principle and control, this paper focuses on an application

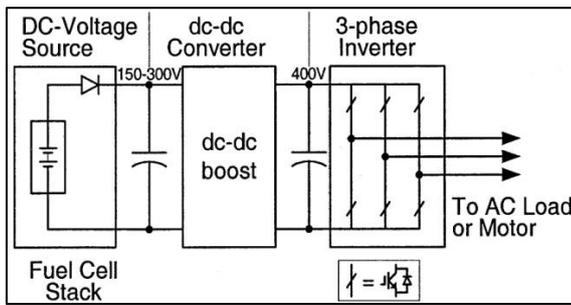


Fig. 4. Traditional two-stage power conversion for fuel-cell applications.

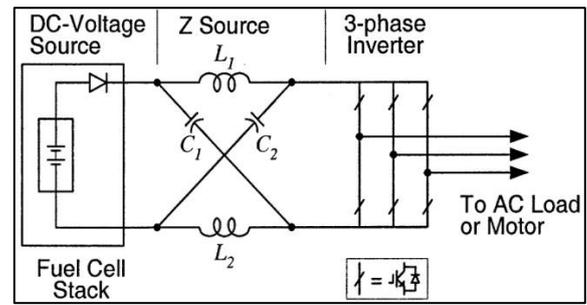


Fig. 5. Z-source inverter for fuel cell applications

An example of the Z-source converter: a Z-source inverter for dc-ac power conversion required for fuel-cell applications. Fig. 6 depicts the traditional two-stage power conversion for fuel-cell applications. Fuel cells generally produce a voltage that changes widely (2:1 ratio) depending on current drawn from the circuit. For fuel-cell vehicle and distributed power generation, a boost dc-dc converter is required because the VSI cannot produce an ac voltage that is greater than the DC voltage. Fig. 7 depicts a ZSI for such fuel-cell applications, which can directly produce an AC voltage greater or less than the fuel cell voltage. The diode in series with the fuel cell in Figs. 6 and 7 are generally required for preventing reverse current flow.

a. 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, because of series diode embedded in the source side, the input dc source can be effectively disconnected from the Z-source network by naturally reverse-biasing the diode during its unique shoot-through period, 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 are analysed, it can be differentiated as shoot-through and non-shoot-through states with six actives and two null states. In its active state, the inverter circuit and load can be treated as a constant CS (Current Source), where the diode is naturally conducting as the capacitor discharging process and the need for powering load from input source resulting in the following voltage relationships between the dc source, inductors, capacitors and dc-link by assuming $C_1=C_2$ and $L_1=L_2$. For optimally controlling the Z-source inverter, the shoot-through stage should be inserted in the general switching sequence without disturbing the normalized voltage and introducing any additional switching.

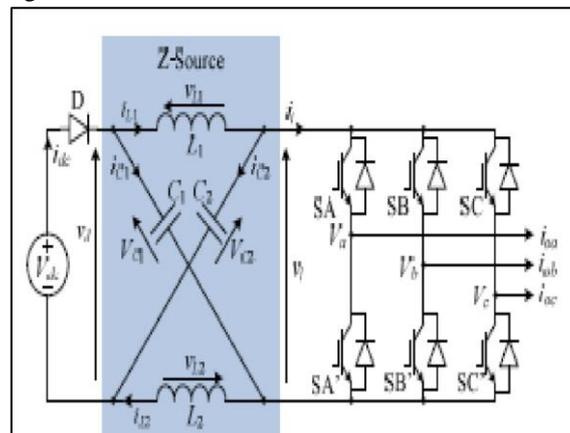


Figure 6. Traditional Z-source inverter

Single stage Z-source inverter

These types of inverters are capable of boosting voltage and delivering power in a single stage structure and thus are suitable for photovoltaic applications. The design comprises of three important parts; PV array, DC link, which is a typical Z-source network and an inverter bridge (Fig. 2). In the design, the PV array is a group of many 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 to the main inverter circuit before the power source. The impedance network accepts the DC voltage from the PV source and according to the boosting factor required the impedance network will boost or buck the input voltage. In the design of the impedance network a two-port network with split inductors L_1 & L_2 , two capacitors C_1 & C_2 , which are connected to each other in such a

manner 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 (suggested by 32) used MOSFET as switches with the assumption that $L1=L2=L$ and $C1=C2=C$, thus making the single stage Z-source inverter a symmetrical device.

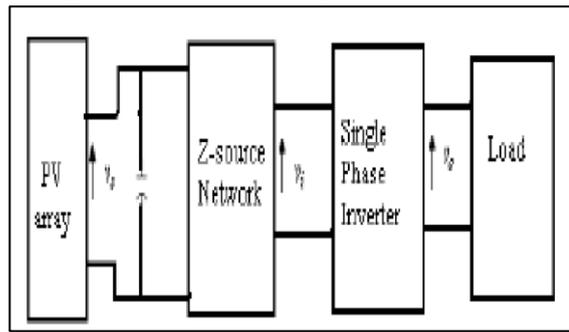


Figure 7. Block diagram of Z-source single phase Inverter

The basic concept of control is to turn zero states to shoot through state 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 reliable energy system, especially for households. The proposed system uses only a single stage inverter for direct DC-AC conversion, with less number of switches.

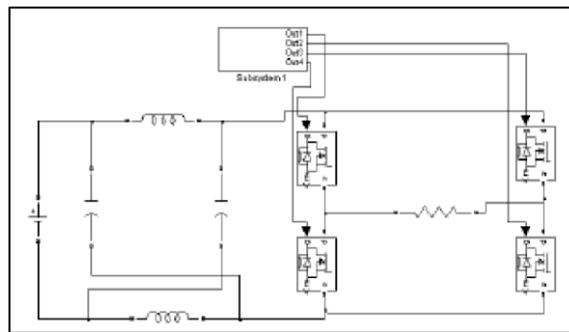


Figure 8. Single phase ZSI

b. Embedded Z-source inverters

(10) Studied the step-up-step-down impedance network and suggested a new type of inverter with embedded features and came to known as were referred to as embedded Z-source inverter. Also (16) suggested voltage type Z-source inverter with an approximately shunt-embedded battery applied in a fuel cell powered the hybrid electric vehicle. Fig.4 gives the topology with dc sources placed into the X-shaped network, where the two isolated dc sources are embedded with each other connecting to the inductor L2 or L1. The principle of operation the inverter can easily be understood by studying its behavior in different switching cycles. Apart from this 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 perfect alternatives for the traditional Z-source inverters, as it cannot optimize the components and also become difficult to avoid the circulation of current in the system. But the fully parallel embedded Z-source inverters can be comfortably used in PV applications. The voltage rating of shunt capacitors is reduced to a great extent when the designed maximum boost voltage deviates from infinite. Even for using it where only single dc-source is available, the embedded Z-source inverters are advantageous in relation to smooth source current and reduced capacitor rating.

1.1. Switched-inductor Quasi-Z-source Inverter

A number of workers (17, 23, 26) suggested a class of quasi-Z-source inverters resolve the drawbacks of the classical Z-source which had various advantages such as, reducing passive component ratings and improving input profiles. The inverters suggested by (25,28) added inductors, diodes and capacitors to the Z-impedance network to produce a high dc-link voltage for the main power circuit from a low input dc-voltage, whereas (27) replaced two inductors of the impedance Z-network with a transformer to obtain high voltage gain. Therefore applying switched inductor, switched-capacitor, hybrid switched-inductor /switched-capacitors structures, voltage-multiplier cells and voltage lift techniques (18,20,22) to dc-dc conversion provides a high boost in transformer-less and cascade structures with high efficiency and high power density. They named this combo as switched-inductor-ZSI or SL-ZSI (28). Further (29) proposed a modified inverter with improved input current, reduced passive component count and become more reliability and called it as a switched-inductor quasi-Z-source inverter (SL-qZSI). The proposed inverter as given in Fig. 5 has two capacitors, C1 and C2; three inductors, L1, L2 and L3; and four diodes Din, D1, D2, D3.

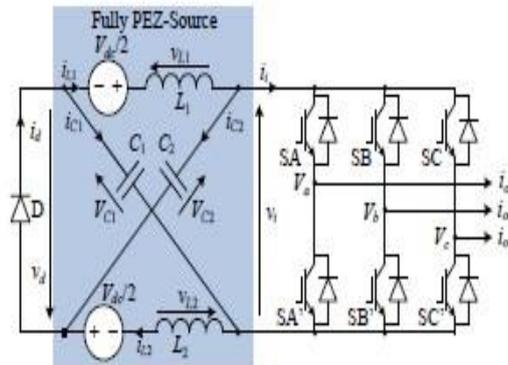


Figure 4 Fully parallel-embedded Z-source inverter

The combination of inductors L2-L3 with diodes D1-d2-D3 is used as switches. The suggested topology provides inrush current suppression, unlike the SL-ZSI, so 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 two zero states and six states in the traditional inverters. In comparison to the traditional Z-source inverters and the SL-ZSI's the proposed inverter gives continuous input current, high boost voltage inversion ability 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.

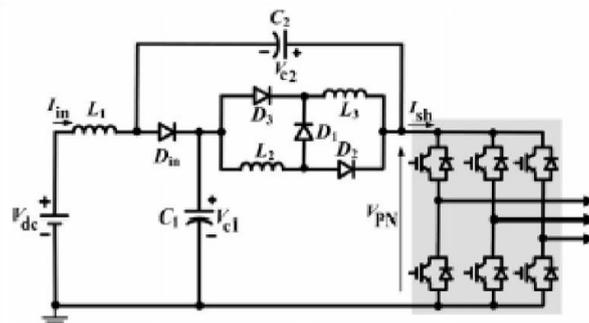


Figure 5 SL-qZSI with continuous input current

CONCLUSION

The basic Z-source inverter performs buck-boost functions, as compared to the old voltage-source inverter. Apart from this, the two switches in the same phase leg can be gated on simultaneously. So, there is no dead time required hence the output distortion is minimized and becomes more reliable (31). In addition to, the Z-source inverters have many limitations, 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.
- Various researchers are working towards the modification of these inverters to increase its performance and applicability.
- 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.

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