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DESIGN OF Z SOURCE INVERTER TO IMPROVE EFFICIENCY OF A SOLAR POWER SYSTEM

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Abstract

The Z-source inverter (ZSI) employs a unique impedance network (or circuit) to couple the converter main circuit to the power source, thus providing unique features that cannot be obtained in the traditional voltage-source (or voltage- fed) and current-source (or current-fed) converters where a capacitor and inductor are used, respectively. The Z-source converter overcomes the conceptual and theoretical barriers and limitations of the traditional voltage-source inverter (VSI) and current-source inverter (CSI) and provides a novel power conversion concept. This impedance source inverter can provide a single stage power conversion concept where as the traditional inverter requires two stage power conversion. The Z-source concept can be applied to all dc-to-ac, ac-to-dc, ac-to-ac, and dc- to-dc power conversion.

Introduction

The oil, coal and gas price is rising and global warming becoming more severe due to environmental pollution. Therefore, countries are now looking for alternative energy sources to partially replace fossil fuels. Due to environmental concerns, more efforts are now being put into green power sources like solar power, wind power, geothermal, fuel cell etc. Solar cells or photovoltaic (PV) cells directly use the energy from the sun to generate electricity. As the energy from the sun is free, the major cost of PV generation is the installation cost. The installation cost mainly consists of the costs of solar modules and the converter interface i.e. the power conditioning system (PCS). With the development of PV technology, the price of solar modules has dropped dramatically. A recent worldwide survey shows that in the last three years, the retail price of solar modules has dropped by 16.95%. However, at the same time, the prices for the solar power system almost remain the same. Furthermore, compared with converters used in drive systems, the prices for the converters used in solar power systems are still up to 50% higher [1]. Reducing the cost of these systems has become a major issue in deploying residential solar power systems. Solar power system converts the DC output from PV cell to 230V, 50Hz AC output for residential use in India. By utilizing the Z-source inverter, the number of switching components and the total volume of the system can be minimized. Thus, the overall cost of the system is minimized.

Basics of PCS for residential use

In order to transfer the energy from solar PV array into residential circuits, the converter systems must fulfill the following requirements:

- To convert the D.C voltage to A.C voltage.
- To boost the voltage if the PV array voltage is less than the utility voltage.
- To insure maximum power utilization from the PV array.

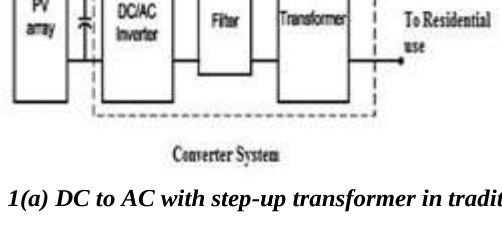

Fig. 1(a) DC to AC with step-up transformer in traditional PV system.

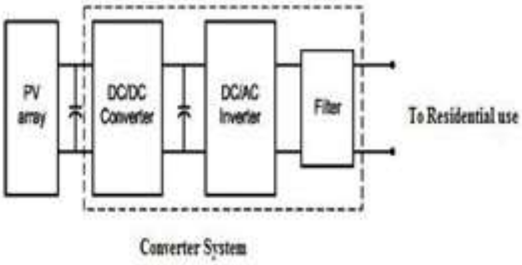

Fig. 1 (b) DC to AC with DC–DC boost in traditional PV system

Fig. 1 shows the two most commonly used converter system configurations in practice. In the system shown in Fig. 1(a), a transformer at line frequency is utilized to boost the voltage after the dc–ac inverter. Usually, a line frequency transformer is associated with huge size, loud acoustic noise, and high cost. In addition, the inverter has to be oversized to cope with the wide PV array voltage change[. The KVA rating of the inverter is doubled if the PV voltage varies at a 1 2 range. So in order to eliminate the transformer and to minimize the required KVA rating of the inverter, in many applications, a high frequency dc-dc converter is used to boost the voltage to a constant value as shown in Fig. 1(b).
Unfortunately, the switch in the dc–dc converter becomes the cost and efficiency killer of the system [2], [3].

Traditional voltage source inverter

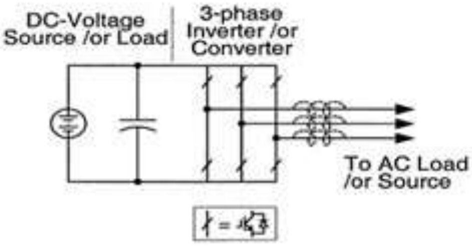

Fig. 2. Traditional V-source converter

Fig. 2 shows the traditional three-phase voltage-source converter (abbreviated as V-source converter) structure. A dc voltage source supported by a relatively large capacitor feeds the main converter circuit, a three-phase bridge. The dc voltage source can be a battery, fuel-cell stack, diode rectifier, and/or capacitor. Six switches are used in the main circuit; each is traditionally composed of a power transistor and an antiparallel (or freewheeling) diode to provide bidirectional current flow and unidirectional voltage blocking capability.[4] The V-source converter is widely used. It, however, has the following conceptual and theoretical barriers and limitations

- The ac output voltage is limited below and cannot ex-ceed the dc-rail voltage or the dc-rail voltage has to be greater than the ac input voltage. Therefore, the V-source inverter is a buck (step-down) inverter for dc-to-ac power conversion and the V-source converter is a boost (step-up) rectifier (or boost converter) for ac-to-dc power conversion. For applications where over drive is desirable and the available dc voltage is limited, an additional dc-dc boost converter is needed to obtain a desired ac output. The additional power converter stage increases system cost and lowers efficiency[4].
- The upper and lower devices of each phase leg cannot be gated on simultaneously either by purpose or by EMI noise. Otherwise, a shoot-through would occur and destroy the devices. The shoot-through problem by elec- tromagnetic interference (EMI) noise's misgating-on is a major killer to the converter's reliability. Dead time to block both upper and lower devices has to be provided in the V-source converter, which causes waveform distortion, etc[4].
- An output LC filter is needed for providing a sinusoidal voltage compared with the current-source inverter, which causes additional power loss and control complexity[4].

Traditional current source inverter

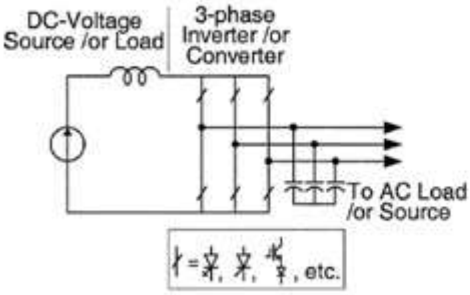

Fig 3. Traditional I-source converter

Fig. 2 shows the traditional three-phase current-source converter (abbreviated as I-source converter) structure. A dc current source feeds the main converter circuit, a three-phase bridge. The dc current source can be a relatively large dc inductor fed by a voltage source such as a battery, fuel-cell stack, diode rectifier, or thyristor converter. Six switches are used in the main circuit, each is traditionally composed of a semiconductor switching device with reverse block capability such as a gate-turn-off thyristor (GTO) and SCR or a power transistor with a series diode to provide unidirectional current flow and bidirectional voltage blocking[5].

However, the I-source converter has the following conceptual and theoretical barriers and limitations

- The ac output voltage has to be greater than the original dc voltage that feeds the dc inductor or the dc voltage pro- duced is always smaller than the ac input voltage. There- fore, the I-source inverter is a boost inverter for dc-to-ac power conversion and the I-source converter is a buck rectifier (or buck converter) for ac-to-dc power conversion. For applications where a wide voltage range is desirable, an additional dc–dc buck (or boost) converter is needed. The additional power conversion stage increases system cost and lowers efficiency[5].
- At least one of the upper devices and one of the lower devices have to be gated on and maintained on at any time. Otherwise, an open circuit of the dc inductor would occur and destroy the devices. The open-circuit problem by EMI noise's misgating-off is a major concern of the converter's reliability. Overlap time for safe current commutation is needed in the I-source converter, which also causes wave- form distortion, etc[6]
- The main switches of the I-source converter have to block reverse voltage that requires a series diode to be used in combination with high-speed and high- performance transistors such as insulated gate bipolar transistors (IGBTs). This prevents the direct use of low-cost and high-performance IGBT modules and intelligent power modules (IPMs)[6].

In addition, both the V-source converter and the I-source converter have the following common problems[6].

- They are either a boost or a buck converter and cannot be a buck–boost converter. That is, their obtainable output voltage range is limited to either greater or smaller than the input voltage.
- Their main circuits cannot be interchangeable. In other words, neither the V-source converter main circuit can be used for the I-source converter, nor vice versa.
- They are vulnerable to EMI noise in terms of reliability

Z source inverter

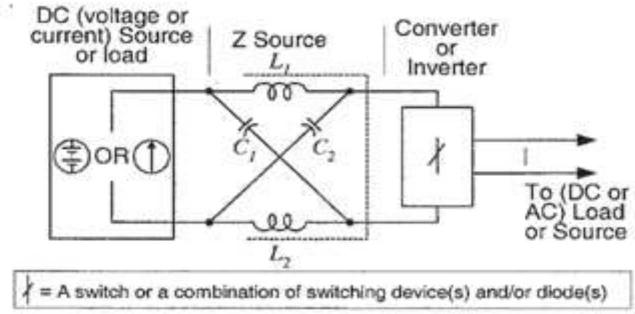

Fig. 4. General structure of the Z-source converter.

The unique feature of the Z-source inverter is that the output ac voltage can be any value between zero and infinity regardless of the fuel-cell voltage. That is, the Z-source inverter is a buck–boost inverter that has a wide range of obtainable voltage [3]. The traditional V- and I-source inverters cannot provide such feature. To describe the operating principle and control of the Z-source inverter in Fig. 4, let us briefly examine the Z-source inverter structure.

In Fig. 3, the three-phase Z-source inverter bridge has nine permissible switching states (vectors) unlike the traditional three-phase V-source inverter that has eight. The traditional three-phase V-source inverter has six active vectors when the dc voltage is impressed across the load and two zero vectors when the load terminals are shorted through either the lower or upper three devices, respectively. However, the three-phase Z- source inverter bridge has one extra zero state (or vector) when the load terminals are shorted through both the upper and lower devices of any one phase leg (i.e., both devices are gated on), any two phase legs, or all three phase legs[8]. This shoot- through zero state (or vector) is forbidden in the traditional V- source inverter, because it would cause a shoot-through. We call this third zero state (vector) the shoot-through zero state (or vector), which can be generated by seven different ways: shoot-through via any one phase leg, combinations of any two phase legs, and all three phase legs. The Z-source network makes the shoot-through zero state possible. This shoot- through zero state provides the unique buck-boost feature to the inverter. Fig. 4 shows the equivalent circuit of the Z-source inverter shown in Fig 4 when viewed from the dc link.

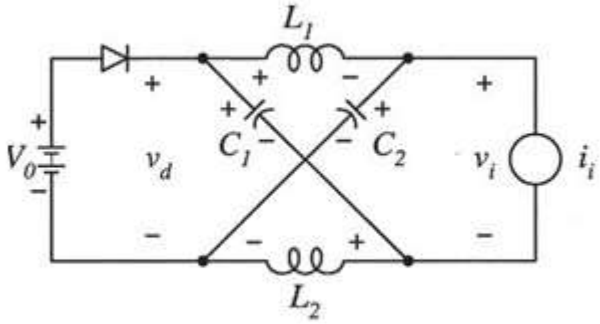

Fig. 5. Equivalent circuit of the Z-source inverter viewed from the dc link.

The inverter bridge is equivalent to a short circuit when the inverter bridge is in the shoot-through zero state, as shown in Fig. 5, whereas the inverter bridge becomes an equivalent current source as shown in Fig. 6 when in one of the six active states. Note that the inverter bridge can be also represented by a current source with zero value (i.e., an open circuit) when it is in one of the two traditional zero states. Therefore, Fig. 6 shows the equivalent circuit of the Z-source inverter viewed from the dc link when the inverter bridge is. in one of the eight non shoot through switching states[7].

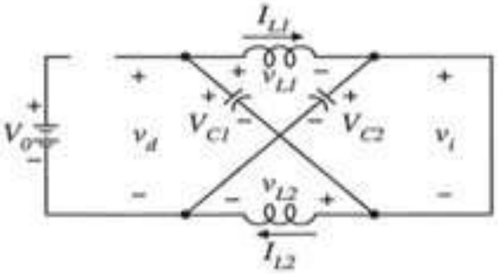

Fig. 6. Equivalent circuit of the Z-source inverter viewed from the dc link when the inverter bridge is in the shoot- through zero state

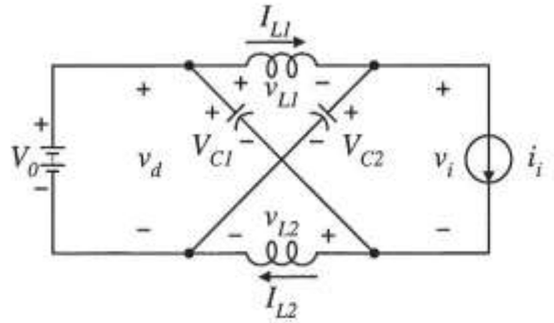

Fig. 7. Equivalent circuit of the Z-source inverter viewed from the dc link when the inverter bridge is in one of the eight nonshoot-through switching states.

Advantage of Z-source inverter over conventional inverters

The following are the advantages of Z- source inverter when compared to the two traditional inverters i.e. voltage source inverter and current source inverter[8].

- Secures the function of increasing and decreasing of the voltage in the one step energy processing. (lower costs and decreasing losses)
- Resistant to short circuits on branches and to opening of the circuits.
- Improve resistant to failure switching and EMI distortions.
- Relatively simple start-up (lowered current and voltage surges).
- Provide ride-through during voltage sags without any additional circuits. Improve power factor reduce harmonic current and common-mode voltage.
- Provides a low-cost, reliable and highly efficient single stage for buck and boost conversions.
- Has low or no in-rush current compared to VSI

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