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Simulation And Investigation On Z-Source Inverter

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Abstract:

The Z-source inverter employs a unique impedance network (or circuit) to couple the inverter main circuit to the power source, thus providing unique features that cannot be obtained in the traditional voltage-source and current-source inverters where a capacitor and inductor are used. The Z-source concept can be applied to all dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion.

1. Introduction:

The main objective of inverter is to convert a dc power supply to an ac output waveform. Flexible ac transmission system (FACTS), active filters, adjustable speed drives, static VAR compensator are some of the applications that require this type of conversion. if we have to design a circuit that produces AC output larger than the DC input, then a two stage converter has to be designed which consists of boost converter and inverter. This directly affects the overall efficiency and cost of the circuit. To overcome this problem Z-source inverter has been proposed.

2. Voltage-Source Inverter:

A dc voltage source supported by a relatively large capacitor feeds the main converter circuit, a three-phase bridge. Six switches are used in the main circuit; each is traditionally composed of a power transistor and a freewheeling diode to provide bidirectional current flow and unidirectional voltage blocking capability.

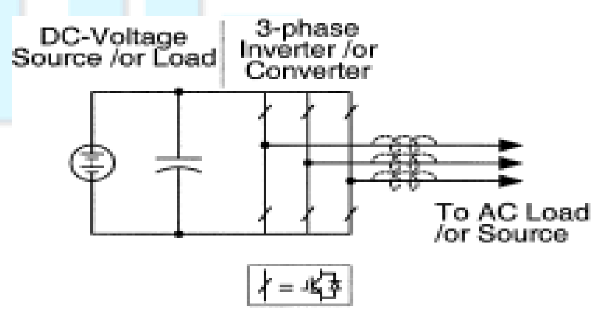

Fig.1 Traditional V – Source Converter

Fig. 1 shows the traditional three-phase voltage-source converter structure. The V-source converter is widely used.

However, it has the following conceptual and theoretical **barriers and limitations**.

- 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.
- Shoot-through is a major problem to converter's reliability. Dead time to block both upper and lower devices phase has to be provided in the V-source converter, which causes waveform distortion, etc.
- 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.

3. Current-Source Inverter:

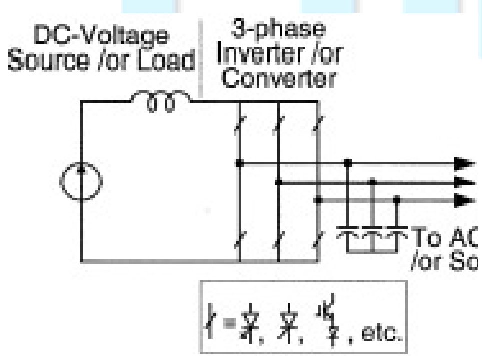

Fig.2 Traditional I – Source Converter

Fig. 2 shows the traditional three-phase current-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. 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. However, the I-source converter has the following conceptual and theoretical **barriers and limitations**.

- 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. This increases system cost and lowers efficiency.
- At list 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. Overlap time for safe current commutation is needed in the I-source converter, which also causes waveform distortion, etc.
- The main switches of the I-source converter have to block reverse voltage that requires a series diode

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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).

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

- 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, or vice versa.
- They are vulnerable to EMI noise in terms of reliability.

4. Z-Source Inverter:

Impedance-source or Z-source inverter overcomes the problems of the traditional VSI and CSI Fig. 3 shows the general Z-source inverter structure. It employs a unique impedance network (or circuit) to couple the converter main circuit to the power source, load, or another converter. The Z-source converter provides a novel power conversion concept.

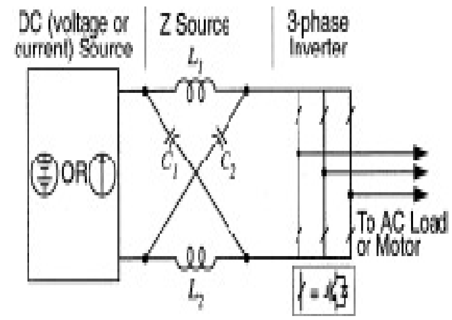

Fig.3 Z – Source Inverter

A two port network consisting of a split-inductor L_1 and L_2 and capacitors C_1 and C_2 connected in X shape is employed to provide an impedance source (Z-source) coupling the inverter to the dc source, Load, or another converter. Switches used in the converter can be a combination of switching devices and diodes such as the anti-parallel combination.

Fig. 4 shows the traditional two-stage power conversion for fuel-cell applications. Because fuel cells usually produce a voltage that changes widely (2:1 ratio) depending on current drawn from the stacks. For fuel-cell vehicles and distributed power generation, a boost dc–dc converter is needed because the V-source inverter cannot produce an ac voltage that is greater than the dc voltage.

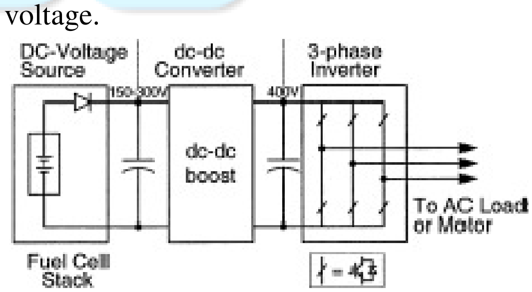

Fig.4 Traditional two-stage power conversion for fuel-cell applications

Fig. 5 shows a Z-source inverter for such fuel-cell applications, which can directly produce an ac voltage greater and less than the DC source. The diode in series with the DC source is usually needed for preventing reverse current flow.

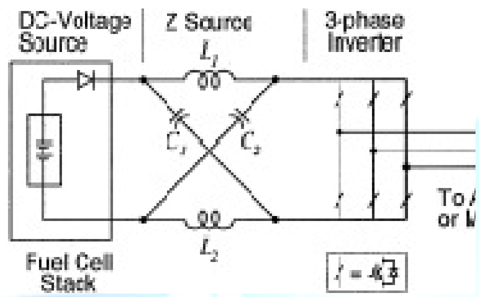

Fig.5 Z-source inverter for fuel-cell applications

5. CIRCUIT ANALYSIS:

Assuming that the inductors L_1 and L_2 and capacitors C_1 and C_2 have the same inductance (L) and capacitance (C) respectively, the Z-source network becomes symmetrical.

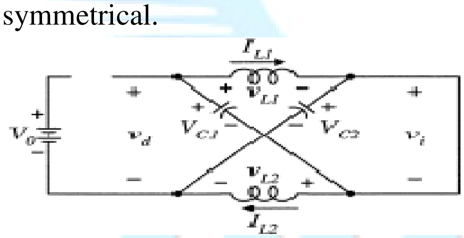

Fig.6 Equivalent circuit of Z-source inverter viewed from the dc link when the inverter bridge is in the shoot-through zero state.

From the symmetry and the equivalent circuits, we have

$$\mathrm{VC1 = VC2 = VC \;\; vL1 = vL2 = vL} \ldots.(1)$$

Given that the inverter bridge is in the shoot-through zero state for an interval of T_0, during a switching cycle, T and from the equivalent circuit, fig 6,

$$\mathrm{vL = Vc,} \quad \mathrm{vd = 2Vc,} \quad \mathrm{vi} = 0 \ldots..(2)$$

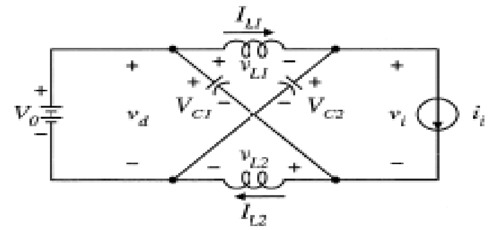

Fig.7 Equivalent circuit of the Z-source inverter viewed from the dc link when the inverter bridge is in one of the eight nonshoot-through switching states.

Now consider that the inverter bridge is in one of the eight non-shoot-through states for an interval of T_1, during the switching cycle, T. From the equivalent circuit, Fig. 7, one has

$$\mathrm{vL = V0 - Vc,} \qquad \mathrm{vd} = V0$$
$$\mathrm{vi = Vc - vL = 2Vc - V0} \ldots \ldots ..(3)$$

Where V_0 is the dc source voltage and $T = T_0 + T_1$

Average voltage of the inductors over one switching period (T) should be zero in steady state, from (2) and (3),

$$\frac{\mathrm{Vc}}{\mathrm{V0}} = \frac{\mathrm{T1}}{\mathrm{T1-T0}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

$$\mathrm{Vi}=\frac{\mathrm{T1}}{\mathrm{T1-T0}} V_0 = V_c \ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

The peak dc-link voltage across the inverter bridge is expressed in (3) and can be rewritten as

$$\mathrm{Vi} = \frac{T}{T1-T0} V_0 = B.\, V_0 \ldots\ldots\ldots\ldots\ldots(6)$$

$$\text{Where } B = \frac{\mathrm{T}}{\mathrm{T1-T0}} = \frac{1}{1-2\frac{\mathrm{T0}}{\mathrm{T}}} \geq 1 \ldots\ldots\ldots(7)$$

B is the boost factor resulting from the shoot-through zero state.
output peak phase voltage from the inverter can be expressed as

$$vac = M.\frac{vi}{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Where *M* is the modulation index.
Using (7), (9) can be further expressed as

$$vac = M.B\ \frac{v0}{2} \ldots\ldots\ldots\ldots\ldots (9)$$

Equation (10) shows that the output voltage can be stepped up and down by choosing an appropriate buck–boost factor B_B,

$B_B = M . B = (0 \sim \infty)$ …………(10)

The buck-boost factor B_B is determined by the modulation index M and boost factor B. The boost factor B as expressed in (7) can be controlled by duty cycle (i.e., interval ratio) of the shoot-through zero state over the nonshoot-through states of the inverter PWM.

6. SIMULATION RESULTS:

Simulink model of the z-source inverter designed for demonstration and result analysis is shown in Fig. 8 and output line-to-line voltage / current waveform is shown in Fig. 9

DC source voltage is $V_0 = 100$ V.

Shoot-through duty cycle $T_0/T = 0.421$

Modulation Index = 0.579

Boost Factor (B) = 6.32

Phase Peak Voltage (v_{ac}) = M . B . $\frac{V0}{2}$

$=0.579.\ 6.32.\frac{100}{2} = 183$V (11)

It implies that line-to-line voltage is 317 V peak or 224 V rms.

The simulation proved the Z-source inverter concept.

By controlling the desired shoot-through state duty cycle $\frac{T0}{T}$ or boost factor B, the desired output voltage can be obtained regardless of dc voltage source voltage.

Variation of output voltage and % third harmonic distortion vs Boost factor with 100 Volt DC Source is plotted in fig. 10

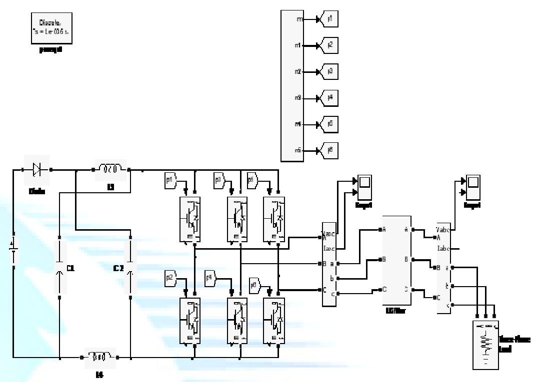

Fig.8 Simulink model of Z-source inverter

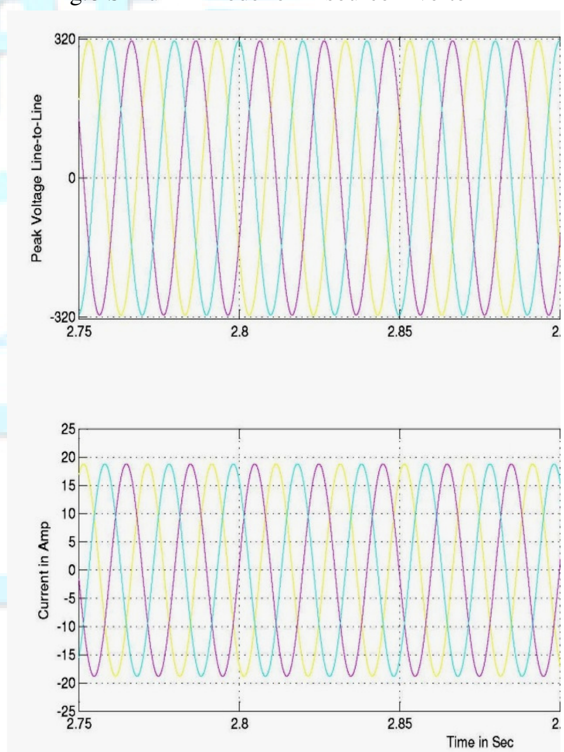

Fig.9 Waveforms output ac voltage and current

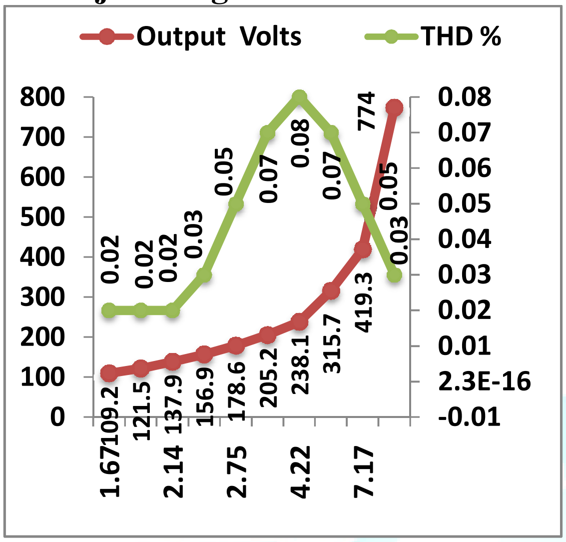

Fig.10 Variation of output voltage and % THD vs Boost factor with 100 Volt DC Source

7. CONCLUSIONS:

Z-source inverter can boost–buck voltage, minimizes component count, increase efficiency, and reduce cost.

The Z-source rectifier/inverter system can produce an output voltage greater than the ac input voltage by controlling the boost factor, which is impossible for the traditional ASD systems.

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