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Z-Source Cascaded Multilevel Inverter Fed IM for Selective Harmonic Minimization & THD Reduction with PV Cell Input

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Abstract: ***This paper deals with a new hybrid multilevel inverter with Z-source converter fed induction motor drive which focuses. This paper approximates the reduction of total harmonic distortion and selective harmonic minimization using new model asymmetric cascaded multilevel inverter by PWM technique using MATLAB/SIMULINK. The switching angles are mathematically calculated. This method provides a lower total harmonic distortion and lower order harmonics are minimized drastically.6 level inverter input for the inverter is boosted using Z-source converter & the input for converter is from PV.***

Keywords: Z- source converter, THD, Selective Harimonic Minimization Multilevel Inverter

1. Introduction

The Z-source converter/inverter stage power conversion technology provides a great alternative with lower cost, higher reliability, and higher efficiency. System configurations, operating principles, features and results will be presented for advanced power conditioning of alternate energy systems. For any Grid connected applications we need to use inverters and converters, especially for renewable energy sources we use energy conversions. A number of technical papers for minimization of THD have been reported for fundamental frequency operation using the most common multilevel (ML) inverter topologies. The cascaded multilevel configuration has independent dc sources that have same voltage levels. Those dc sources might be capacitors, have experienced strong development over the past few years.

This study deals with the conversion line for a grid - connected photo voltaic system. It is assumed that the PV technology used is a crystalline one, because of its large spreading on the current market. These devices, with their strong building integration and their development in urban zones can be subjected to severe shadows. Under these conditions, the PV field works under mismatching conditions that can lead to important power losses. Due to the climatic conditions and location, the solar panels produce different power output. Therefore while cascading PV power loss and string current exists. To minimize the string current, string current diverter should be used. The proposed system should decrease the drawbacks and keep the system reliable. This work focuses on avoiding the string current and efficient conversion.

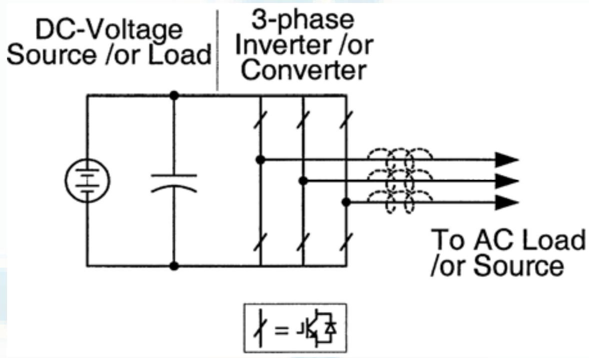

Figure 1: Traditional I-source converter.

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.

- 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 electromagnetic 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.
- 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.

Fig. 1 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. 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 produced 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.
- At least one of the upper devices and one of the lower de-vices 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.
- 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 (metal-oxide semiconductor field-effect transistor) (*MOSFET*). 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 con-verter 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, nor vice versa.
- They are vulnerable to EMI noise in terms of reliability.

2. Z-Source Converter

To overcome the above problems of the traditional V-source and I-source converters, this paper presents an impedance-source (or impedance-fed) power converter (abbreviated as Z-source converter) and its control method for implementing dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion. Fig. 3 shows the general Z-source converter structure proposed. It employs a unique impedance network (or circuit) to couple the converter main circuit to the power source, load, or another converter, for providing unique features that cannot be observed in the traditional V- and I-source converters where a capacitor and inductor are used, respectively. The Z-source converter overcomes the above-mentioned conceptual and theoretical barriers and limitations of the traditional V-source converter and I-source converter and provides a novel power conversion concept.

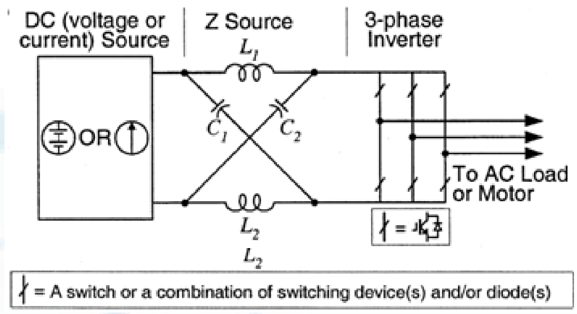

Figure 2: Z-source converter structure using the anti parallel combination of switching device and diode

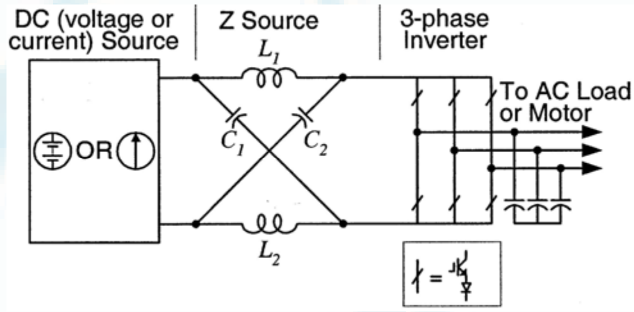

Figure 3: Z-source converter structure using the series combination of switching device and diode

In Fig. 3, a two-port network that consists 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 converter (or inverter) to the dc source, load, or another converter. The dc source/or load can be either a voltage or a current source/or load. Therefore, the dc source can be a battery, diode rectifier, thyristor converter, fuel cell, an inductor, a capacitor, or a combination of those. Switches used in the converter can be a combination of switching devices and diodes such as the anti parallel combination as shown in Fig. 1, the series combination as shown in Fig. 1, etc. As examples, Figs. 4 and 5 show two three-phase Z-source inverter configurations. The inductance L_1 and L_2 can be provided through a split inductor or two separate inductors.

The Z-source concept can be applied to all dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion. To describe the operating principle and control, this paper focuses on an application example of the Z-source converter: a Z-source inverter for dc-ac power conversion needed for fuel-cell applications.

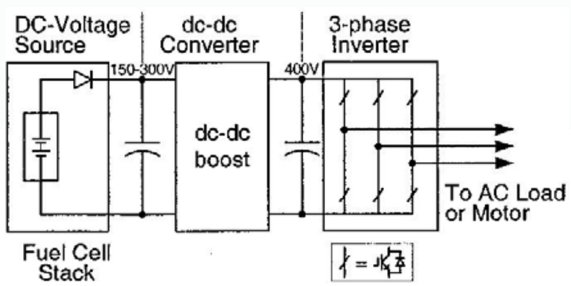

Figure 4: Traditional two-stage power conversion for fuel-cell applications

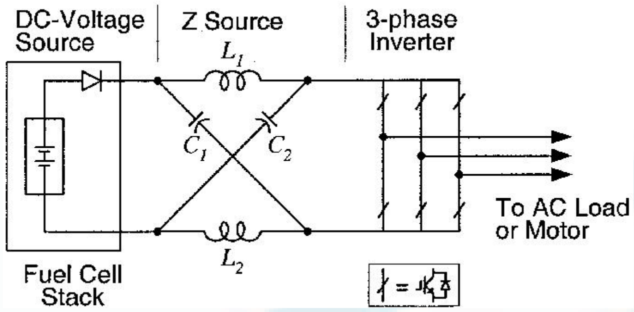

Figure 5: Z-source inverter for fuel-cell applications.

Fig. 4 shows the traditional two-stage power conversion for fuel-cell applications. 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. 5 shows a Z-source inverter for such fuel-cell applications, which can directly produce an ac voltage greater and less than the fuel-cell voltage. The diode in series with the fuel cell in Figs. 6 and 7 is usually needed for preventing reverse current flow.

3. Equivalent Circuit, Operating Principle, and Control

The unique feature of the Z-source inverter is that the output ac voltage can be any value between zero and infinity regard-less of the fuel-cell voltage. That is, the Z-source inverter is a buck–boost inverter that has a wide range of obtainable voltage. 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. 5, let us briefly examine the Z-source inverter structure. In Fig. 5, 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

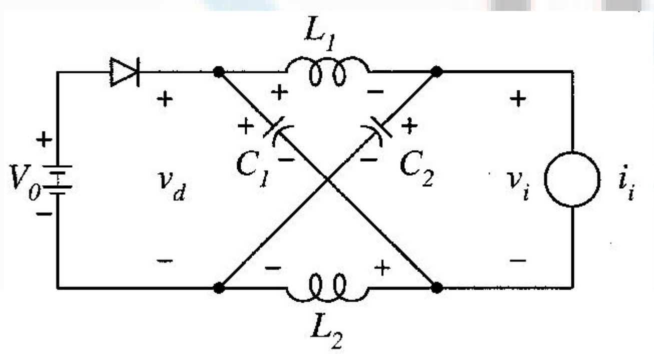

Figure 6: Equivalent circuit of the Z-source inverter viewed from the dc link

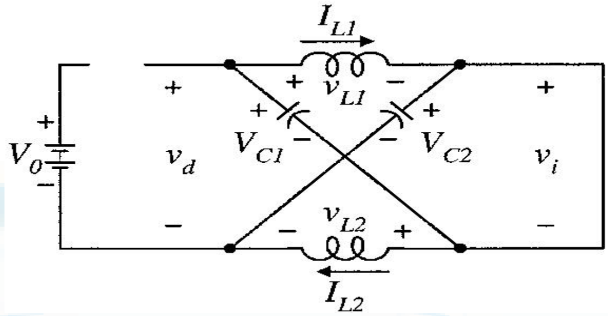

Figure 7: Equivalent circuit of the Z-source inverter viewed from the dc link when the inverter bridge is in the shoot-through zero state

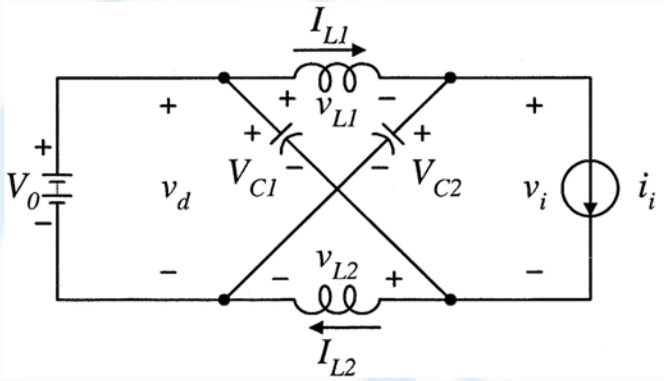

Figure 8: Equivalent circuit of the Z-source inverter viewed from the dc link when the inverter bridge is in one of the eight non shoot-through switching states.

(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. 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. 6 shows the equivalent circuit of the Z-source inverter shown in Fig. 5 when 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. 7, whereas the inverter bridge becomes an equivalent current source as shown in Fig. 8 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. 8 shows the 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.

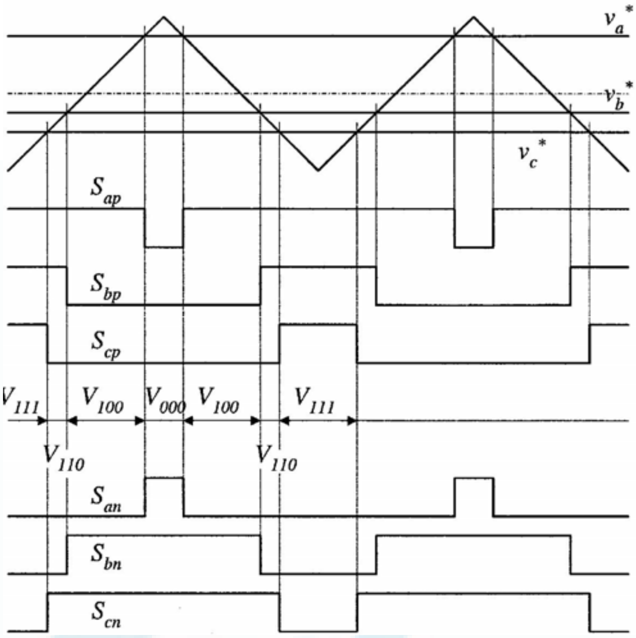

Figure 9: Traditional carrier-based PWM control without shoot-through zero states, where the traditional zero states (vectors) V_{111} and V_{000} are generated every switching cycle and determined by the references

All the traditional pulse width-modulation (PWM) schemes can be used to control the Z-source inverter and their theoretical input–output relationships still hold. Fig. 9 shows the traditional PWM switching sequence based on the triangular carrier method. In every switching cycle, the two nonshoot-through zero states are used along with two adjacent active states to synthesize the desired voltage. When the dc voltage is high enough to generate the desired ac voltage, the traditional PWM of Fig. 9 is used. While the dc voltage is not enough to directly generate a desired output voltage, a modified PWM with shoot-through zero states will be used as shown in Fig. 10 to boost voltage. It should be noted that each phase leg still switches on and off once per switching cycle. Without change the total zero-state time interval, shoot-through zero states are evenly allocated into each phase. That is, the active states are unchanged. However, the equivalent dc-link voltage to the inverter is boosted because of the shoot-through states. The detailed relationship will be analyzed in the next section. It is noticeable here that the equivalent switching frequency viewed from the Z-source network is six times the switching frequency of the main inverter, which greatly reduces the required inductance of the Z-source network.

4. Circuit Analysis and Obtainable Output Voltage

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.

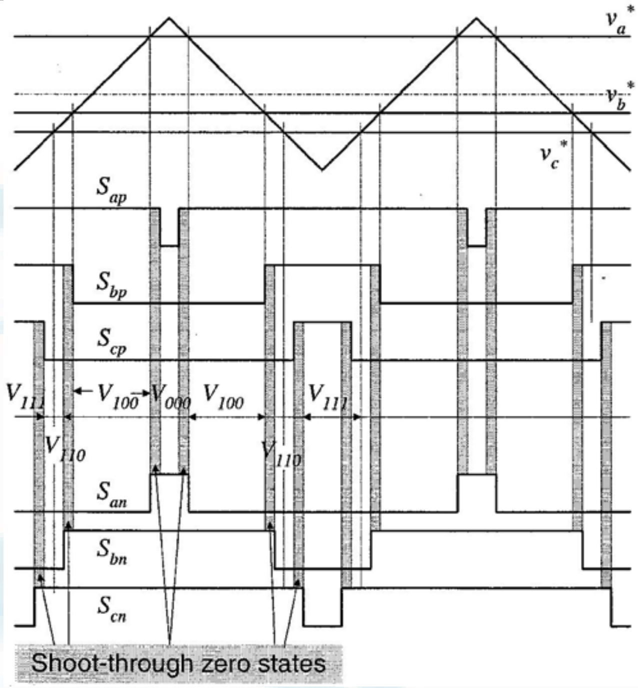

Figure 10: Modified carrier-based PWM control with shoot-through zero states that are evenly distributed among the three phase legs, while the equivalent active vectors are unchanged

From the symmetry and the equivalent circuits, we have

$$V_{C1} = V_{C2} = V_C \quad v_{L1} = v_{L2} = v_L. \tag{1}$$

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. 7, one has

$$v_L = V_C \quad v_d = 2V_C \quad v_i = 0. \tag{2}$$

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. 8, one has

$$v_L = V_0 - V_C \quad v_d = V_0 \quad v_i = V_C - v_L = 2V_C - V_0 \tag{3}$$

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

The average voltage of the inductors over one switching period (T) should be zero in steady state, from (2) and (3), thus, we have

$$V_L = \overline{v_L} = \frac{T_0 \cdot V_C + T_1 \cdot (V_0 - V_C)}{T} = 0 \tag{4}$$

or

$$\frac{V_C}{V_0} = \frac{T_1}{T_1 - T_0}. \tag{5}$$

Similarly, the average dc-link voltage across the inverter bridge can be found as follows:

$$V_i = \overline{v_i} = \frac{T_0 \cdot 0 + T_1 \cdot (2V_C - V_0)}{T} = \frac{T_1}{T_1 - T_0} V_0 = V_C. \tag{6}$$

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

$$\hat{v}_i = V_C - v_L = 2V_c - V_0 = \frac{T}{T_1 - T_0} V_0 = B \cdot V_0 \quad (7)$$

where

$$B = \frac{T}{T_1 - T_0} = \frac{1}{1 - 2\frac{T_0}{T}} \geq 1, \quad (8)$$

is the boost factor resulting from the shoot-through zero state. The peak dc-link voltage $\hat{v}_i$ is the equivalent dc-link voltage of the inverter. On the other side, the output peak phase voltage from the inverter can be expressed as

$$\hat{v}_{ac} = M \cdot \frac{\hat{v}_i}{2} \quad (9)$$

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

$$\hat{v}_{ac} = M \cdot B \cdot \frac{V_0}{2}. \quad (10)$$

For the traditional V-source PWM inverter, we have the well-known relationship: $\hat{v}_{ac}=M.V_0/2$. Equation (10) shows that the output voltage can be stepped up and down by choosing an appropriate buck–boost factor B_B,

$$B_B = M \cdot B = (0 \sim \infty). \quad (11)$$

From (1), (5) and (8), the capacitor voltage can expressed as

$$V_{C1} = V_{C2} = V_C = \frac{1 - \frac{T_0}{T}}{1 - 2\frac{T_0}{T}} V_0. \quad (12)$$

The buck–boost factor B_B is determined by the modulation index M and boost factor B. The boost factor B as expressed in (8) 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.

Note that the shoot-through zero state does not affect the PWM control of the inverter, because it equivalently produce the same zero voltage to the load terminal. The available shoot-through period is limited by the zero-state period that is deter-mined by the modulation index.

5. Inductor and Capacitor Requirement of the Z-Source Network

For the traditional V-source inverter, the dc capacitor is the sole energy storage and filtering element to suppress voltage ripple and serve temporary storage. For the traditional I-source inverter, the dc inductor is the sole energy storage/filtering element to suppress current ripple and serve temporary storage. The Z-source network is a combination of two inductors and two capacitors. This combined circuit, the Z-source network is the energy storage/filtering element for the Z-source inverter. The Z-source network provides a second-order filter and is more effective to suppress voltage and current ripples than capacitor or inductor used alone in the traditional inverters. Therefore, the inductor and capacitor requirement should be smaller than the traditional inverters. Detailed design guide and formulas of the Z-source network will be presented in a near future paper. A brief discussion is given below in terms of physical sizes and requirements. When the two inductors (L_1 and L_2) are small and approach zero, the Z-source network reduces to two capacitors (C_1 and C_2) in parallel and becomes a traditional V-source. Therefore, a traditional V-source inverter's capacitor requirements and physical size is the worst case requirement for the Z-source network. Considering additional filtering and energy storage provided by the inductors, the Z-source network should require less capacitance and smaller size compared with the traditional V-source inverter. Similarly, when the two capacitors (C_1 and C_2) are small and approach zero, the Z-source network reduces to two inductors (L_1 and L_2) in series and becomes a traditional I-source. Therefore, a traditional I-source inverter's inductor requirements and physical size is the worst case requirement for the Z-source network. Considering additional filtering and energy storage by the capacitors, the Z-source network should require less inductance and smaller size compared with the traditional I-source inverter.

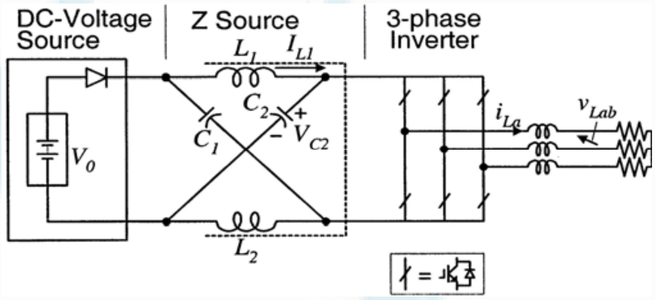

Figure 11: Simulation and prototype system configuration

6. Simulation Results, Prototype, and Experimental Results

Experimental work on a cascaded five level inverter and a Z-source inverter was carried out and the experimental set-ups are shown in Fig. 7 and Fig. 8. The procedure is repeated for different voltage for five, seven, nine and eleven levels and the corresponding waveforms are shown in Fig. 7 to Fig. 8. The steady state results for varying solar intensity and optimum MI to maintain the output voltage constant is presented in Tables 2 and 3 and the total harmonic distortion for different levels of cascaded multilevel inverter is shown in Fig. 7. The firing pulses to the gate circuit of five level inverter are shown in Fig. 7. The output voltage of a five level inverter for the input of 40V at MIs of 0.8 and 0.6 are 26.1V and 24.8, respectively. The output waveforms are shown in Fig. 7. The Z-parameters used in Z-source inverter are L=3mH, 5A and C=470micro F, 600V. The firing pulses to the gate circuit of Z-source inverter are shown in Fig. 7. The capacitor voltage and DC link voltage for Vin=40V are 60V and 104V for a shoot-through period of 1.2ms and 0.214ms, respectively. The waveforms are shown in Fig. 6 and Fig.9. The output voltage of Z-source inverter for the input of 40V at zero shoot-through state and the 1.2ms shoot through period are 24V(peak) and 100V(peak), Vrms=72V.

$$B = \frac{1}{1 - 2\frac{T_0}{T}} = 3.52 \quad (13)$$

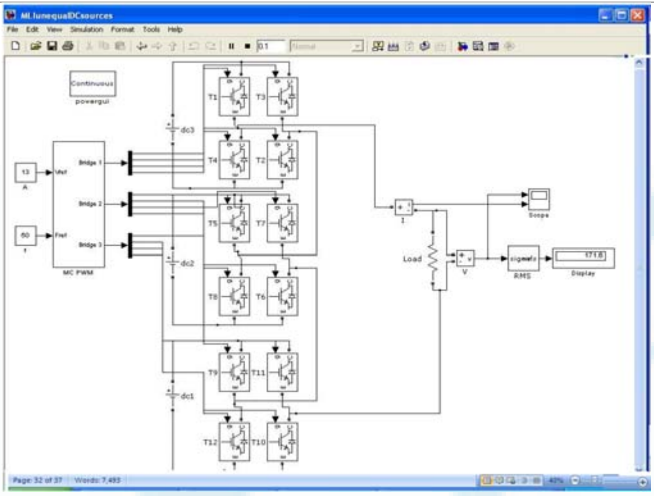

Figure 12: simulink diagram of the proposed system

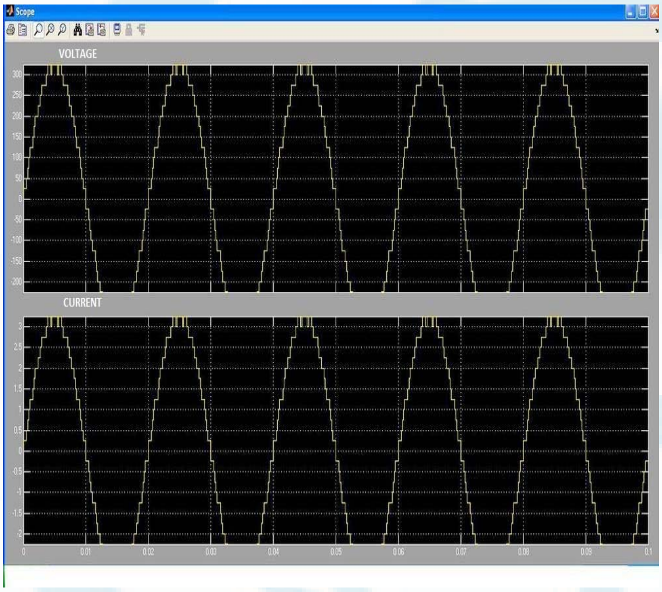

Figure 13: output waveforms

Equation (13) is the phase peak voltage, which implies that the line-to-line voltage is 208 V rms or 294 V peak. The above theoretical values are quite consistent with the simulation results. The simulation proved the Z-source inverter concept.

A prototype as shown in Fig. 11 has been constructed. The same parameters as the simulation were used. Show experimental results. When the fuel-cell voltage is low, as shown in Fig. 15, the shoot-through state was used to boost the voltage in order to maintain the desired output voltage. The waveforms are consistent with the simulation results. When the fuel-cell voltage is high enough to produce the desired output voltage, the shoot-through state was not used, as shown in Fig. 16, where the traditional PWM control without shoot-through was used. By controlling the shoot-through state duty cycle T_0/T or the boost factor B, the desired output voltage can be obtained regardless of the fuel cell voltage.

7. Conclusions

This paper has presented an impedance-source power converter for implementing dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion. The Z-source converter employs a unique impedance network (or circuit) to couple the converter main circuit to the power source, thus providing unique features that cannot be observed in the traditional voltage-source and current-source 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 converter and current-source converter and provides a novel power conversion concept. The Z-source concept can be applied to almost with harmonic to reduce 30%. This paper focused on an example—a Z-source inverter for fuel-cell applications. Through the example, the paper described the operating principle, analyzed the circuit characteristics, and demonstrated its concept and superiority. Analytical, simulation, and experimental results have been presented. The Z-source inverter can boost–buck voltage minimizes component count, increase efficiency, and reduce cost.

References

[1] K. Thorborg, Power Electronics. London, U.K.: Prentice-Hall International (U.K.) Ltd., 1988.
[2] M. H. Rashid, Power Electronics, 2nd ed. Englewood Cliffs, NJ: Prentice-Hall, 1993.
[3] N. Mohan, W. P. Robbin, and T. Under land, Power Electronics: Converters, Applications, and Design, 2nd ed. New York: Wiley, 1995.
[4] M. Trzynadlowski, Introduction to Modern Power Electronics. New York: Wiley, 1998.
[5] K. Bose, Modern Power Electronics and AC Drives. Upper Saddle River, NJ: Prentice-Hall PTR, 2002.
[6] P. T. Krein, Elements of Power Electronics. London, U.K.: Oxford Univ. Press, 1998.