Simulation and Modelling of 5-Level Single Phase 
Z-Source based Cascaded Inverter 

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Abstract 

Objectives: This paper illuminates simulation and modelling of 5-level single phase Z-source based cascaded scheme inverter and its progress for output voltage twice the applied input voltage. 

Methods/Analysis: Z-source network utilizes a unique impedance network (L-C) combinations to connect with 5-level cascaded inverter, which gives unique features that cannot be obtained from the conventional inverter circuits. Z-source network trounce the various restrictions of conventional voltage source inverter and current source inverters like reduced losses, voltage stress, improved output voltage. By using the shoot-through conditions the duty ratio of the proposed system can be speckled to achieve better output source voltage compare to conventional methods. This method is imitation using matlab - simulink with experimental results are verified using dsPIC controller. 

Findings: Z-source cascaded type H-bridge inverter facilitates to boost functional source voltage without any conservative dc - dc boost converters. The output source voltage of the planned system increased twice that of conventional inverter system and better current control is achieved.SPWM technique used to control the power switches placed in the proposed system. 

Novelty/ Improvement: The total harmonic level in the proposed system diminished and voltage stress in the each power switches also reduced. The method keeps away from the convention of dc/dc converter, diminishes the expenditure of the scheme and reduces voltage stress in the switches. 

Keywords: Cascaded Type H-Bridge Inverter (CHBI), Matlab/simulink, Sinusoidal based Pulse Width Modulation (SPWM), Z-source Network 

1. Introduction 

Multilevel type inverters comprise fascinated greatly attention from the researchers predominantly in requests concerning high source voltage and high power as the usefulness and bulky motor drive purposes. Abundant industrial claims encompass instigate to demand privileged power equipment for the period of current-duration. For average voltage applications multilevel inverters are used to reduce voltage stress and switching loss in the power circuit. For a usual voltage grid, which offensive to attach just one power semiconductor device unwaveringly. The commutation of the power switches communal these numerous dc sources instruct to attain high voltage source at the output side; the voltage value across the each power semiconductor switches are based on how much is the applied input voltage and number of switches used in the exacting power circuit. Z-source network is utilised to conquer shoot through problem and to advancement the dependability of cascaded h-bridge inverter. Z-source network is a unique impedance network connection of 2 capacitors and 2 inductors in X shape, which is used to boost the output voltage and which keeps away from the tradition of conventional dc/dc boost converter. For getting better the output voltage value of Z-source inverter depends on the design value of inductors and capacitors. To control the any converter power semiconductor switches the control technique places an important role and which generates the gating pulses to switched on and switched off the devices.
In this proposed work, the simulation and modeling of 5-level single phase Z-source based cascaded inverter. To control the projected scheme, the sinusoidal pulse width modulation (SPWM) technique is used and maximum boosting concept implemented to improve better output voltage source and current control.

2. Review of Multilevel Inverter

2.1 Multilevel Inverter

The conservative two level inverters like current source inverter type (CSI) and voltage source inverter type (VSI) construct the output voltage value or current value that has levels of +V or –V and 0. But two level inverters cannot be used to knob high power and high voltage applications. Consequently as a result of their incapability to organize high voltage and high power, the multilevel inverters were introduced. Multilevel inverters are much suitable for renewable sources like photovoltaic (PV) scheme, the wind energy, fuel cells and battery.

Multilevel inverter has an incomparable structure permits them to attain higher voltage with absolutely less number of harmonics. Increasing the levels will further decrease the harmonic distortion level and switching losses, which can improve the efficiency of inverter circuit. Multilevel have some features like strategy of less rating can be used thus facilitate the plan to be used for high voltage source applications, concentrated total harmonic distortion, \( \frac{dv}{dt} \) is minimum, very lower EMI problems, lower switching frequencies can be used to reduce the switching losses.

The multilevel inverter used in various applications such as petrochemical industry with pumps, fans with cement industry, STATCOM, UPFC, power quality applications, grid connected systems, reactive power compensators, power conditioners, DC-DC converters, fuel cell utilizations, renewable energy sources, etc.

2.2 Cascaded Type H-Bridge Inverter

An substitute multilevel inverter structure with minimum power devices obligation evaluated to other a variety of multilevel structure is well-known as cascaded type H-bridge inverter (CHBI) and method is used on the sequence association of H bridge cell with split dc sources, which is shown in Figure 1. Because output incurable of the H bridges associated in sequence, DC resource should be inaccessible from each other. Owing to these belongings, CHBI also been projected to be among renewable sources like the fuel cells, photovoltaic (PV) arrays in order to accomplish higher voltage source levels.

![Figure 1. single phase 5-level Cascaded H-bridge inverter](image-url)
Z - Source Network

3.1 Conventional Z-source VSI Network

Z-source system which is mixture of 2 inductors and 2 capacitors. It is the energy storage device or straining device working as band pass filter for the Z-source inverter. It is further efficient to reduce voltage value and ripple current in the circuit. The design value of inductor and capacitor decides the energy storage amount and as well as to improve the output voltage range. Conventional Z-source VSI network is shown in Figure 2. Based on the shoot-through state concept Z-source inverter network operated.

![Figure 2. conventional Z-source VSI network.](image)

The corresponding switching frequency from the impedance network scheme is five times the switching frequency of the conventional VSI inverter, which required combination of L-C network system. From Figure2 the voltage equations can be written as,

\[ V_{\text{in}} = V_{\text{L1}} \quad (1) \]
\[ V_{\text{Vin}} = V_{\text{L1}} + V_{\text{C2}} \quad (2) \]
\[ V_{\text{out}} = V_{\text{C2}} - V_{\text{L2}} \quad (3) \]

The shoot through state condition will occur when the both switches turned on in a leg, the short circuit condition will happen. So during this condition the amount voltage stored in the particular inductor and capacitor starts to discharge. Then the output voltage of the scrupulous mode, the stored energy is additional with applied input voltage.

3.2 Single Phase 5level Z-Source Cascaded Type H-Bridge Inverter

Cascaded type H-bridge multilevel inverter uses the several numbers of units to produce more ac voltages by back to back connection of H-bridge cells in sequence manner. Each h-bridge cell contains 4 switches with different combinations of switch positions find the different voltage levels such as +V, -V and 0. Two switching combinations are contains for producing 0 output voltage. 5 level single phase Z-source cascaded type H-bridge inverter is shown in Figure3. in that switches S1 and S3 are connected to positive voltage and S2 and S4 are associated to negative voltage side. The amount of output voltage level from a cascade type H-bridge inverter depends on the number of disconnect dc sources placed to it. Equation (4) shows to find the voltage level in CHBI circuit.

\[ P = 2K + 1 \quad (4) \]

Where, K-number of dc sources, P-number of levels.

![Figure 3. Single phase 5-level Z-source cascaded H-bridge inverter.](image)

While using the multilevel inverter the amount harmonic in the particular system starts reducing and voltage stress in the each switching devices also minimizing. To produce better output voltage and improved current control the Z-source network is added in front of CHBI system. By adding this impedance network and using shoot through state condition the output voltage can be improved 2 times of conventional system.

The amount of voltage in the capacitors C1 and C2 is,

\[ V_{\text{C1}} = V_{\text{C2}} = \frac{1 - \frac{T_2}{T}}{1 - 2\frac{T_2}{T}} V_{\text{out}} \quad (5) \]
So the boosting factor can be derived by,

$$G = \frac{1}{1 - 2 \frac{T_a}{T}}$$  \hspace{1cm} (6)

Where, G-boosting factor, Ta- turns on time period and T-total time period.

The L-C network combinations are mentioned with equal conditions like C1=C2 and L1=L2. Based on these conditions the amount of output voltage generation in the proposed system determined. In this proposed system for generating 5 level output voltages the 2 cascaded H-bridge cells are related with separated Z-source network and detach dc sources. Based on these intended condition and L-C combinations the output voltage generated is 2 times of the applied input and much greater than the conventional methods.

4. Sinusoidal Pulse Width Modulation (SPWM) Technique

SPWM technique is one of the pulse width modulation (PWM) used to manage power semiconductor switches, which generate the gating pulses by comparing the reference signals with carrier signals. Here the sinusoidal waveform acts as reference signal and triangular waveform act as carrier waveform, by comparing these two signals the required gating pulses generated. Each gating pulse width diverse proportionally to the peak value of the sine wave assessed at the centre of the similar pulse is shown in Figure4.

The output frequency (fo) of Z-source inverter can be ascertain by using frequency of reference signal (fr). The rms output voltage value can be inhibited by accent index and in turn accent index is controlled by peak amplitude (Ar). The voltage can be embarrassed by the generate gating pulses from the controller. Carrier frequency of the scheme used to recognize the number of pulses per half cycle.

$$M_c = \frac{V_c}{V_{car}}$$  \hspace{1cm} (7)

Where, Vc – Peak magnitude of reference control signal, Vcar- Peak magnitude of carrier signal.

5. Simulation Results

The imitation of the projected scheme was verified using matlab - simulink 11.b. Z-source inverter received the dc source voltage of 100V. The simulation parameters are inductors L1=L2=5 mH and capacitors C1=C2=270 micro Farad and the various switching frequency of the inverter scheme is 10 kHz. In general simulation illustration of the projected scheme exposed in Figure5.

The proposed system operating under the 2 conditions shoot through and non-shoot through conditions. During non-shoot through condition the system will act as normal conventional inverter and during shoot through condition the system will produce output as 2 times of conventional inverter. In Figure6 shows the switching pulses generation for 5 level cascaded inverter using SPWM method. The output voltage waveform of z-source CHBI is 185 V shown in the Figure7.

The controlled output current waveform for z-source CHBI of 5.808 A is shown in Figure8 and the THD analysis of the planned system, in that for output voltage with 0.68% and for output current 0.98% is shown in Figure9a and Figure9b respectively.
6. Experimental Results

To authenticate the imitation results of the projected scheme, experimental setup for 5 level single phase Z-source based cascaded type inverter was intended and practised. Staircase output voltage of 185 V is acquired at the inverter output side is exposed in Figure 10. The yield waveforms are acquired on Digital Storage Oscilloscope (DSO) device. Sinusoidal pulse width modulation control is realized using DSPIC2813F microcontroller fed with 7V dc voltage and Figure 11 illustrates the experimental setup for the projected scheme.

7. Conclusion

The projected scheme simulated with matlab simulink environment, and it was examination that the system
efficiency and reliability was improved by place the shoot through condition. The Z-source cascaded type H-bridge inverter facilitates to boost the functional voltage without any conservative dc/dc boost converters. The output voltage value of planned system increased twice that of conformist inverter system and better current control is accomplished. The harmonic content level in the system also diminished and voltage stress in the power switches also abridged.

- The proposed system achieved the THD of output voltage with 0.68% and for current with 0.98% which is less than IEEE standard. And this work will be extended with space vector modulation controller to minimize common mode voltage problem.

8. References