Research Paper
Impact Factor: 3.567
Peer Reviewed Journal

IJMDRR
E- ISSN –2395-1885
ISSN -2395-1877

MULTILEVEL Z-SOURCE INVERTER PHASE VOLTAGE FORMULATION AND CALCULATION OF ITS THD

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Abstract
Multilevel inverters have recently been received more attention in the power industry. Two traditional types of multilevel inverters are multilevel voltage-source inverter and multilevel current-source inverter. Despite this widespread use, multilevel Z-source inverter (ML-ZSI) has not been regarded enough, because a unique approach to voltage control of ML-ZSI has not yet been presented. Besides, the phase voltage and its total harmonic distortion (THD) have not been calculated for ML-ZSI so far. This study proposes two new methods for the formulation of phase voltage in ML-ZSI. The first method is based on Fourier series analysis of the phase-voltage waveform, and the second utilizes the staircase waveform of the phase voltage. In addition, two new methods are introduced for computing the phase-voltage THD in ML-ZSI: approximate method and waveform-integration method. Although the waveform-integration method leads to the accurate answer, using this method is more difficult than an approximate method. The detailed description of suggested methods and comparison with each other are presented in this study. Simulation and experimental results are also given to demonstrate the new features of the proposed methods.

Keywords: Total Harmonic Distortion, Phase voltage, Z-source inverter, H-Bridges, Fourier series Analysis.

Introduction

A Z-source inverter is a type of power inverter, a circuit that converts direct current to alternating current. It capacities as a buck-support inverter without making utilization of DC-DC converter extension because of its one of a kind circuit topology .Impedance Z-Source systems give a productive method for force change in the middle of source and stack in a wide range of electric power conversion applications (DC-DC, DC-AC, AC-DC, AC-AC). The quantities of alterations and new Z-source topologies have become exponentially. Enhancements to the impedance systems by presenting coupled attractive have additionally been of late proposed for accomplishing significantly higher voltage boosting, while utilizing a shorter shoot-through time. They include the Γ-source, T-source, trans-Z source, TZ-source, LCCT-Z-source. . Among them, the Y-source network is more versatile and can in fact be viewed as the generic network, from which the Γ-source, T-source, and trans-Z-source networks are derived. Z-source inverter can support dc information voltage with no prerequisite of dc-dc boost converter or step up transformer, consequently overcoming yield voltage confinement of customary voltage source inverter and also bring down its expense. A comparison among conventional PWM inverter, DC-DC boosted PWM inverter, and Z-source inverter shows that Z-source inverter needs lowest semiconductors and control circuit cost, which are the main costs of a power electronics system . This results in increasing attention on Z-source inverter, especially for the application where the input DC source has a wide voltage variation range, such as the photovoltaic (PV) grid-tied generation and fuel cell motor drive system. Moreover, for Z-source inverter we have not to worry about EMI influence since shoot through are welcome and even exploited. This in turn enhances the inverter reliability. The Z-source converter employs a unique impedance network to couple the converter main circuit to the power source, thus providing unique features that cannot be obtained 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 inverter, both of the power switches in a leg can be turned on in the meantime, which dispenses with dead time and fundamentally enhances the unwavering quality while diminishing the yield waveform mutilation. The augmented help Z-source inverters add inductors, capacitors, and diodes to the Z impendence network in order to produce a high dc-link voltage for the main power circuit from a very low input dc voltage. A combination of the Z-source inverter and switched-inductor structure, called the switched-inductor Z-source inverter, provides strong step-up inversion to overcome the boost limitation of the classical Z-source inverter. In order to overcome the inconvenience of inrush current suppression at start-up of the switched-inductor Z-source inverter, a switched-inductor quasi- Z-source inverter is proposed which provides continuous input current, reduced passive component count, reduced voltage stress on the capacitors, lower shoot-through current, and lower current stress on inductors and diodes, in comparison to the switched-inductor Z-source inverter for the same input and output voltages. Like the conventional Z-source inverters, the enhanced inverter turns on both power switches in a leg to help the dc bus voltage. The current drawn from the dc source is continuous. In addition, the improved trans-Z-source inverter can suppress resonant current at start-up, which might destroy the devices. Both shoot-through states and the transformer turn ratio can be regulated to control the boost voltage gain. Thus, the output voltage can be adjusted over a wide range, and can be boosted to a higher value.

Literature Review

The modulation schemes of three-level multiphase Z-source inverters with either two Z-source networks or single Z-source network connected between the dc sources and inverter circuitry. With the best possible balance included for accomplishing both sought four-leg operation and improved harmonic execution, the proposed balance plans of four-leg three-level Z-source inverters can fulfil the normal buck-support operation under unequal modulation conditions. Except of the modulation complexity hidden in the four-leg inverters, five-phase three-level Z-source inverters show totally different modulation requirement and output performance. For obviously delineating the point by modulation process, time domain examination rather than the customary multi-dimensional space vector exhibition is accepted which uncovers the right approach to embed shoot-through lengths of time in the exchanging succession with negligible replacement check [1].On the basis of the classical Z-source inverter, this presents a developed impedance-type power inverter that is termed the switched inductor (SL) Z-source inverter. To enlarge voltage adjustability, the proposed inverter employs a unique SL impedance network to couple the main circuit and the power source. Compared with the classical Z-source inverter, the proposed inverter increases the voltage boost inversion ability significantly. Only a very short shoot-through zero state is required to obtain high voltage conversion ratios, which is beneficial for improving the output power quality of the main circuit. In addition, the voltage buck inversion ability is also provided in the proposed inverter for those applications that need low ac voltages. Similar to the classical Z-source inverter, the proposed concepts of SL Z-source inverter can be applied to various applications of DC–AC, AC–AC, DC– DC, and AC–DC power conversion [2].Compared to previous *Z*-source inverter topology, it can reduce the *Z*-source capacitor voltage stress greatly, and has an inherent limitation to inrush current. The control strategy is exactly the same as the previous one, so all existing control strategies can be used directly. Soft-start strategy is also proposed to avoid the inrush current and resonance between the *Z*-capacitors and the *Z*-inductors [3].

A desired AC voltage is achieved from several levels of DC voltages is done by multilevel inverters. These inverters are applied to high voltage and high power applications due to better harmonic spectrum and faithful output. In recent years a single X-shaped LC network is important development in multilevel inverters. The power quality improvement is obtained by reducing the harmonics present at the output voltage of the inverter [4].

It deals with a new family of high boost voltage inverters that improve upon the conventional trans-Z-source and trans-quasi-Z-source inverters. The improved trans-Z-source inverter provides continuous input current and a higher boost voltage inversion capability. In addition, the improved inverter can suppress resonant current at start-up, which might destroy the device. In comparison to the conventional trans-Z-source/-trans-quasi-Z source inverters, for the same transformer turn ratio and input and output voltages, the improved inverter has a higher modulation index with reduced voltage stress on the dc link, lower current stress flow on the transformer windings and diode, and lower input current ripple. In order to produce the same input and output voltage with the same modulation index, the improved inverter uses a lower transformer turn ratio compared to the conventional inverters. Thus, the size and weight of the transformer in the improved inverter can be reduced [5].Three-phase locomotives use voltage source inverter technology for the speed control of traction motors. The voltage source inverter is fed by single phase active front end converter connected in H Bridge in the locomotives .Since the voltage source inverter works in buck mode, a higher DC-link voltage is required to provide the rated voltage of traction motors increasing the size and cost of system. This study proposes a high-performance bi-directional Z-source inverter instead of voltage source inverter. Analysis is performed in all regions of operation of locomotive drive-acceleration, free running and regenerative braking. Both the speed control techniques-variable voltage variable frequency and field weakening are used for the drives. Simulation study of the system shows that the DC-link voltage gets reduced by 39% which in turn lower the voltage stress. This will decrease the traction transformer output voltage. Reduction in the harmonics at the output of Z-source inverter by 16% reduces the overheating of traction motor drive [6].Z-source impedance network is used to boost up the output voltage using shoot through state control. A new PWM technique is implemented by using three reference signals and a triangular carrier signal which are used to generate the PWM signals for inverter switches, and the shoot through state for Z-network is achieved by inserting DC reference signal. The advantage of proposed topology makes reduction in number of switches, and this new configuration is suitable for applications working at lower and medium power levels [7].The Z-source inverter is a type of converter that exhibits voltage buck and voltage boost capability. This type of concept applied to all dc to ac, dc to dc, ac to dc, ac to ac power conversion whether two level or multilevel. Multi-level converters offer many advantages for higher power applications. Generally in Z-source neutral point clamped inverter carrier based modulation technique is used for controlling. But in this paper presents the space vector modulation technique for controlling Z-source neutral point clamped inverter. This gives more advantages, in terms of harmonics performance and implementation [8].

Proposed Method

Unlike the other H-bridge inverters, H-bridge Z-source inverter (ZSI) can provide shoot-through states to boost the input dc voltage when both switches in the same leg are on, and because of this feature, the reliability of the inverter is greatly

IJMDRR
E- ISSN –2395-1885
ISSN -2395-1877

improved. In comparison with the traditional H-bridge inverters, H-bridge ZSI is more reliable and has lower costs and higher efficiency.

By combining cascaded multilevel inverter and H-bridge ZSI, features of both structures, such as shoot-through capability and ability of voltage increasing and harmonics decreasing can be achieved. Despite these useful features, a unified approach to voltage control of ML-ZSI has not been proposed so far. Also, although in recent year's different strategies are proposed for the formulation and calculation of phase voltage and its total harmonic distortion (THD) in traditional multilevel inverters, the phase voltage and its THD have not yet been calculated for ML-ZSI.

This paper proposes novel approaches for formulation of phase voltage and calculation of its THD in ML-ZSI. For this purpose, the phase voltage is formulated by two methods. The first method formulates phase voltage by applying Fourier series analysis, and the second method uses the staircase waveform of the phase voltage. Also, two new methods are introduced for calculation of phase-voltage THD, which have some differences in accuracy and difficulty of calculations. These methods are also compared with each other. The proposed methods are described in detail and verified by simulation and experiment.

Block Diagram

The block diagram of the proposed multi-level Z-source inverter is shown in Fig.1. This shows the structure of cascaded ML-ZSI. This multilevel inverter produces the desired voltage from several separate dc sources. These resources can be supplies from batteries, fuel cells or solar cells.

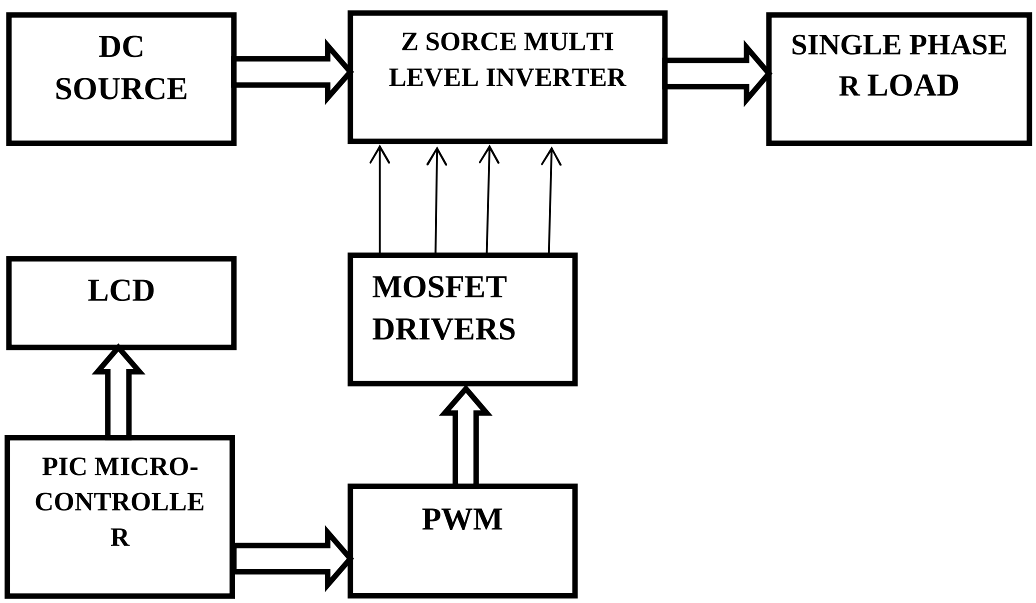

Fig.1, Block diagram of the proposed multi-level Z-source method

Where s is the number of dc voltage sources (or H-bridges) and v_{ok} is the output voltage of the K^{th} H-bridge ZSI. In traditional ML-VSI, phase voltage has only one typical configuration. However, as previously mentioned, because of the switching angles, the output voltage of H-bridge ZSI can be in three different configurations. Therefore, since ML-ZSI consists of several H-bridge ZSIs, its phase voltage does not have one typical configuration, and this makes it difficult to find a unique formula for phase voltage. For example, for a ML-ZSI with three dc sources which its first, second and third H-bridges are controlled according to the switching pattern of case 1, case 2 and case 3, respectively, there are 20 boundaries which can be defined as follows and the half cycle waveform of the traditional voltage source inverter waveform is shown in Fig.2.

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ISSN -2395-1877

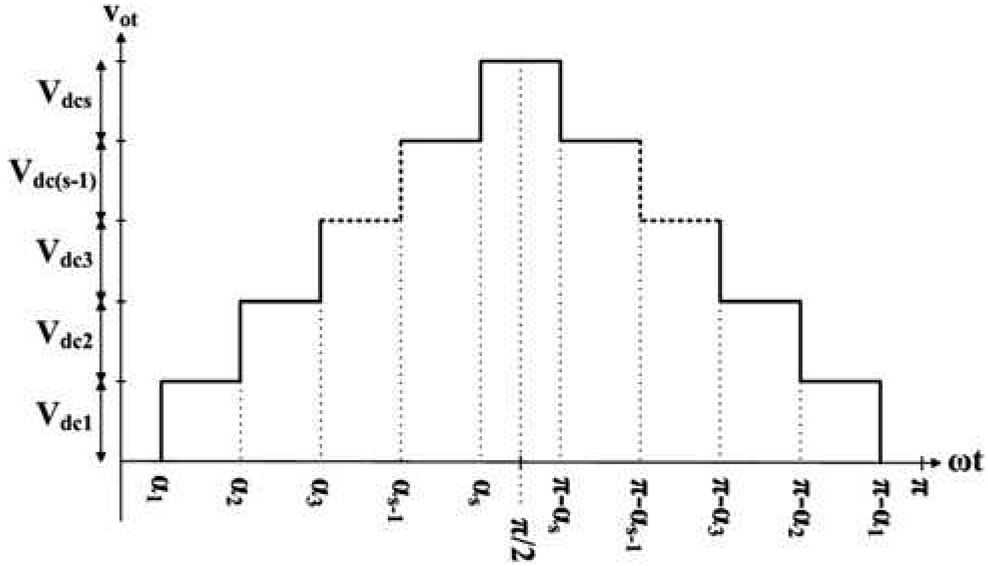

Fig .2 Half-cycle waveform of the phase voltage of traditional ML-VSI

Experimental Result

The simulation is done with the SVPWM technique and the carrier frequency is varied in between 3 to 35 kHz and after analysing the output parameters for the different frequencies the carrier frequency is fixed at 5 kHz where the output shows the optimum results in terms of output THD discussed by Yu Tang (2012). The simulation is done for the output supply frequency of 50Hz and the voltage of 100V. The same control technique is applied for different levels of three phase cascaded configurations. The phase sequence is A, B and C. The output waveform confirms the proper phase displacements and steady magnitude throughout the simulation profile without any transients.

The simulation is done for different levels in order to obtain the optimum solution on the quality of the output waveforms. The same control technique is used to simulate the different levels with different carrier frequencies irrespective of the levels, 5 kHz results better performance when compared to other carrier frequencies. Therefore the same carrier frequency is considered for the simulation irrespective of the levels of the cascaded configuration. The offset voltage waveform for the proposed five level cascaded configuration is as shown in Figure 3. Figure 4 shows the effective voltage waveforms obtained from the proposed SVPWM method for the individual phase. The phase sequence is A, B and C indicated in red, green and blue respectively.

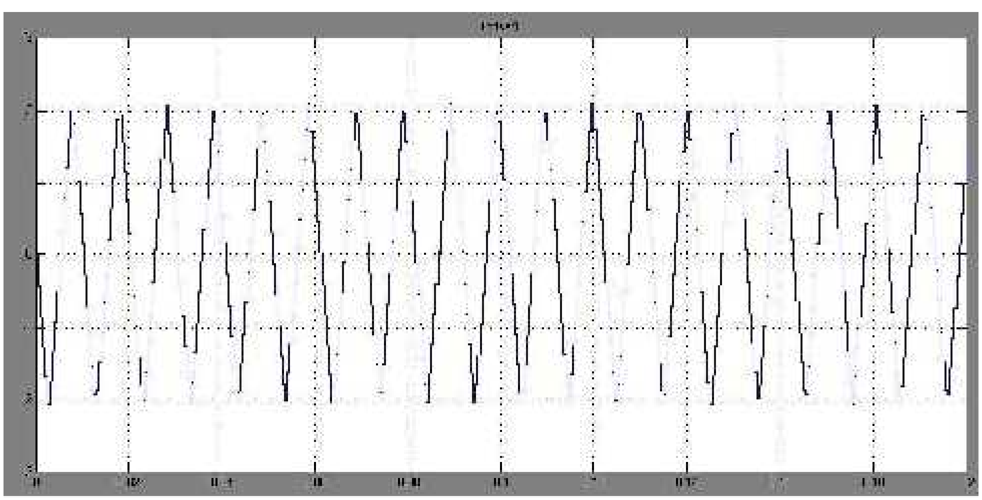

Fig.3 OFFSET voltage waveform

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ISSN -2395-1877

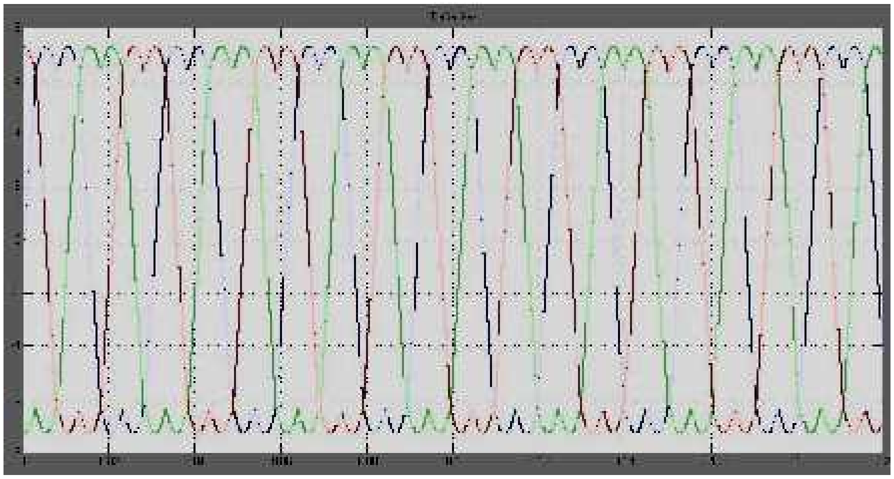

Fig.4 Effective voltage waveform for five levels with four carriers

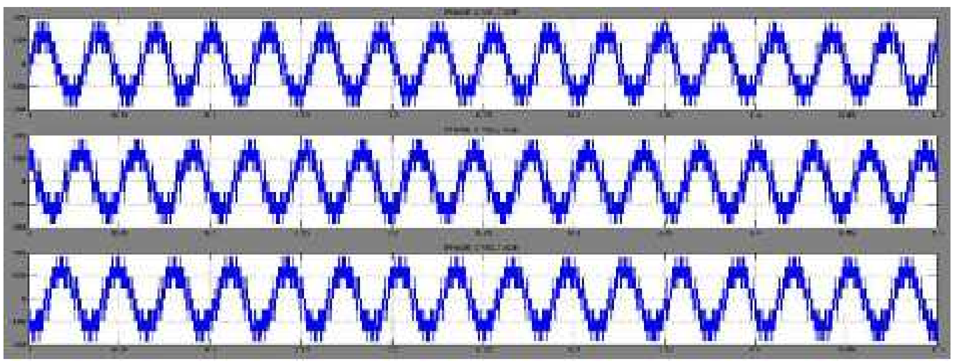

Fig.5 Output phase voltage waveforms

The obtained output phase voltages are as shown in Figure 5. The output waveform for individual phases confirms the constant magnitude over the wide **range of operation** and the phase displacements are apart from each other's

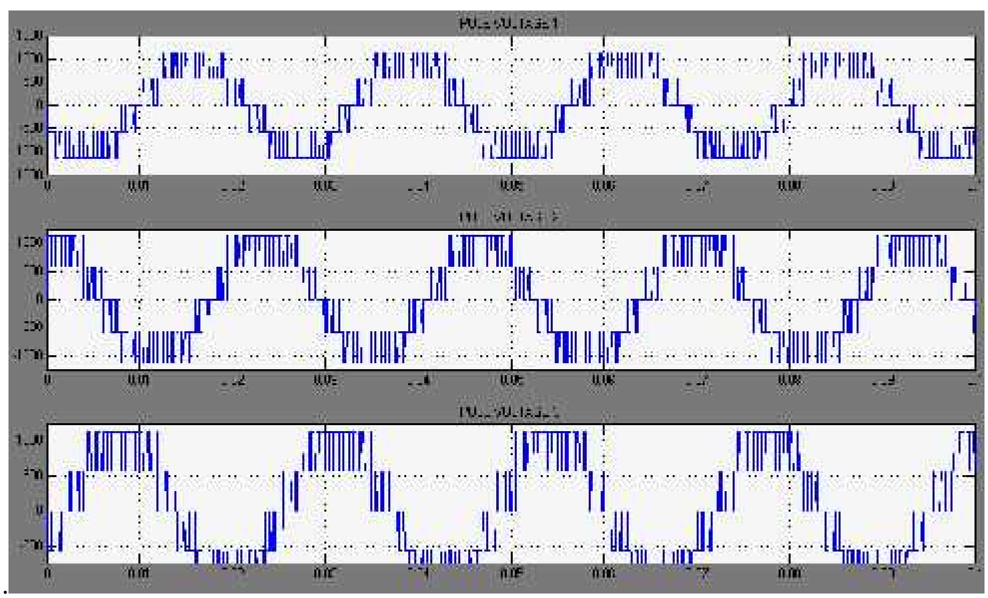

Fig.6 Output line voltage waveforms

Figures 5 and 6 shows the output phase voltage and line voltage waveforms respectively, for the three phase five level CMLI with the proposed space vector pulse width modulation technique. The phase voltages consist of five levels phase shifted by 120^0 apart from each other. The simulation is done for various frequency and voltage levels. The FFT analysis for 45Hz is as shown in Figure 7.

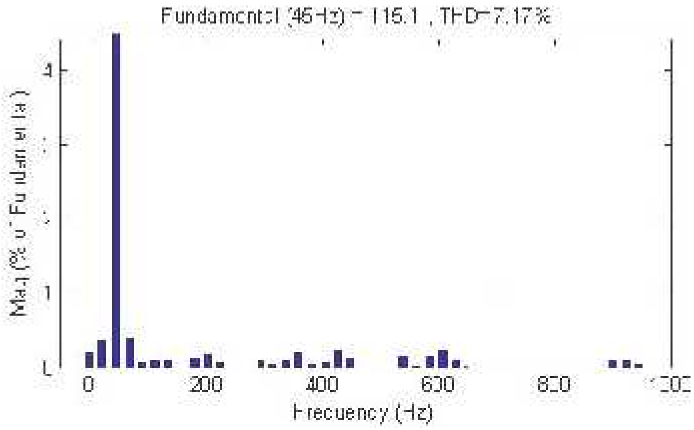

Fig.7 FFT spectrum for output THD at 45Hz output frequency

Similarly the output wave forms are obtained for three phase seven level, nine level and eleven level cascaded configurations, as level increases the number of power switches required to construct the power circuit will also get increased. The control of individual switches will become a complex issue and it is not an economical solution for the power quality issues.

Conclusion

In this paper, novel methods have been proposed for formulation of phase voltage and calculation of its THD in ML-ZSI. For this purpose, two new methods have been presented for phase-voltage formulation. In the first method, the phase voltage has been Formulated irrespective of the waveform type and by applying Fourier series analysis, whereas the second method has been used the staircase output voltages of H-bridge ZSI. After finding the phase-voltage formula, it has been verified that in comparison with traditional ML-VSIs, one of the advantages of ML-ZSI is ability of instantaneous elimination of more harmonics with fewer dc sources (or H-bridges). Two novel approaches have also been proposed for phase-voltage THD calculation: approximate method and waveform-integration method. Comparison between these methods has been indicated that although approximate method leads to an imprecise answer, its implementation is easier than waveform-integration method. Besides, for many values of switching angles, an increase in phase-voltage amplitude implies a decrease in THD. The simulation and experimental results have been provided for a ML-ZSI with three dc sources to validate the accuracy of computational results.

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