



Cascaded Connection of Single-Phase & Three-Phase Multilevel Bridge Type Inverter

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Abstract: - The function of this work is to minimize total harmonics distortion and number of switch and improve level in output voltage waveform. In conventional method, needed five H-bridge units to used 11-echelon inverter but in this proposed method for a 28-echelon cascaded H-bridge multilevel inverter required only three H-bridge unit per phase. By using this proposed idea it reduces the total harmonics distortion through the appending of echelons. In this work both single phase and three phase total harmonics distortion and number of switch has reduced. Simulation result is providing for 14-echelon and 28-echelon cascaded H-bridge multilevel inverter to validate the accuracy of computational result.

Keywords—14-echelon and 28-echelon cascaded H-bridge multilevel inverter, single phase and three phase 14 echelon and 28-echelon cascaded H-bridge multilevel inverter, harmonics distortion, DC and AC voltage, Cascaded Connection

I. INTRODUCTION

Present-day power electronics apparatus uses power semiconductor devices that have made the H-bridge cascaded multilevel inverters, patented in 1975 and microelectronics that have the power and intelligence of a brain. For practically use as medium and high level voltage inverters, the output voltage and minimized the undesirable harmonics, different sinusoidal pulse width modulation and space-vector pulse width modulation schemes are suggested for cascaded multilevel inverters however, Pulse Width Modulation (PWM) techniques are not able to eliminate low-order harmonics completely [1]. This work discusses about the Cascaded H-Bridge Multilevel Inverter (CHMLI) and how to minimize the Total Harmonic Distortion (THD) using the control of conduction angle (switching angle) control method. Conventional 28-echelon

pulse width-modulated inverters offer improved output voltage waveform, lower electromagnetic interference, lower total harmonic distortion, smaller filter size, and others. In addition, several modulation and control strategies have been improved or adopted for cascaded H-bridge multilevel inverters, including multilevel sinusoidal pulse width modulation, multilevel selective harmonic reduction, and space vector pulse width modulation.

➤ Objective of the Work

A single phase and three-phase 28-echelon cascaded H-bridge multilevel inverter topology for DC systems with a novel Pulse width-modulated control scheme is used. It is main reason to easy of control of switches and a cascade multilevel inverter is design to synthesize inclined AC voltage from several echelons of DC voltages. The main function of this work is to minimize total harmonics distortion, number of switch and improve the output voltage level for single phase and three phase inverters. Researchers have proposed that this method is effectively reduces a large number of specific harmonic, and the output voltage result in low total harmonic distortion and switching frequency. This work is used cascaded H-bridge multilevel inverter [1].

II. LITERATURE SURVEY

In [1] C. Gnanavel, N. Kamalamoorthy, V. Prabhu, cascaded H-bridge multilevel inverter have an attracted a great deal of attenuation in different applications like that medium voltage and high power, due to their less switching losses, electromagnetic interference, and high efficiency. Among the several cascaded inverters topology it is more attractive due to the simplicity of control.

In [2] M. Abolhassani, Applying an approach for the power quality improves of medium voltage applications. A modular transformers strategy in combination with modular power electronics cubes is improved.

In [3] A. Kavousi, Behrooz Vahidi, et al., the author applying bee optimization method for reduce harmonic in the cascaded H-bridge multilevel inverter. This algorithm is used to solving the non-linear equations for seven levels H-bridge inverter. The most function of this algorithm is reducing low-order harmonics by using nonlinear equations, while the fundamental component is satisfied. This algorithm is working based on the food foraging behavior of a crowd of a honeybees and it complete a neighborhood find combined with a random search.

III. MULTILEVEL INVERTER STRUCTURES

A voltage level of three is considered to be the smallest number in multilevel converter topologies. Due to the bi-directional switches, the multilevel voltage source converter can work in both rectifier and inverter modes. This is why most of the time it is referred to as a converter instead of an inverter in this dissertation. A multilevel converter can switch either its input or output nodes (or both) between multiple (more than two) levels of voltage or current. As the number of levels reaches infinity, the output total harmonic distortion approaches zero. The number of the achievable voltage levels, however, is limited by voltage-imbalance problems, voltage clamping requirements, circuit layout and packaging constraints complexity of the controller, and, of course, capital and maintenance costs.

In a multilevel voltage source inverter, the DC-link voltage V_{dc} is obtained from any equipment which can yield stable DC source. Series connected capacitors constitute energy tank for the inverter providing some nodes to which multilevel inverter can be connected. Primarily, the series connected capacitors will be assumed to be any voltage sources of the same value. Each capacitor voltage V_c is given by $V_c = V_{dc} / (n-1)$, where n denotes the number of level.

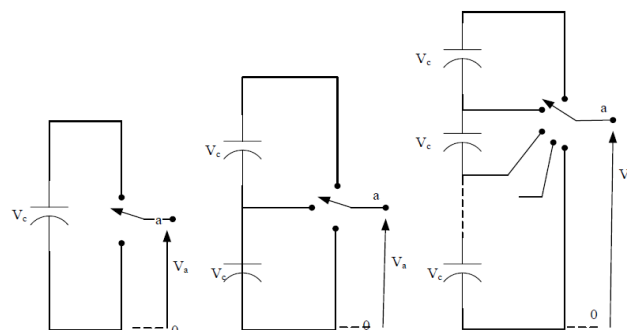


Figure 1: One Phase Leg of an Inverter with (a) Two Levels, (b) Three Levels, and (c) n Levels.

Figure 1, shows a schematic diagram of one phase leg of inverters with different number of levels, for which the action of the power semiconductors is represented by an ideal switch with several positions. A two-level inverter generates an output voltage with two values (levels) with respect to the negative terminal of the capacitor, while the three-level inverter generates three voltages, and so on.

➤ Cascaded multilevel inverter

With its modularity and flexibility, the cascaded multilevel inverter shows superiority in high-power applications, especially shunt and series connected flexible AC transmission system (FACTS) controllers. The cascaded multilevel inverter synthesizes its output nearly sinusoidal voltage waveforms by combining many isolated voltage levels. By adding more H-bridge converters, the amount of volt ampere reactive can simply increase without redesign the power stage, and build-in redundancy against individual H-bridge converter failure can be realized. A series of single-phase full bridges makes up a phase for the inverter. A three-phase cascaded multilevel inverter topology is essentially composed of three identical phase legs of the series-chain of H-bridge converters, which can possibly generate different output voltage waveforms and offers the potential for AC system phase-balancing. This feature is impossible in other voltage source converter topologies utilizing a common DC link

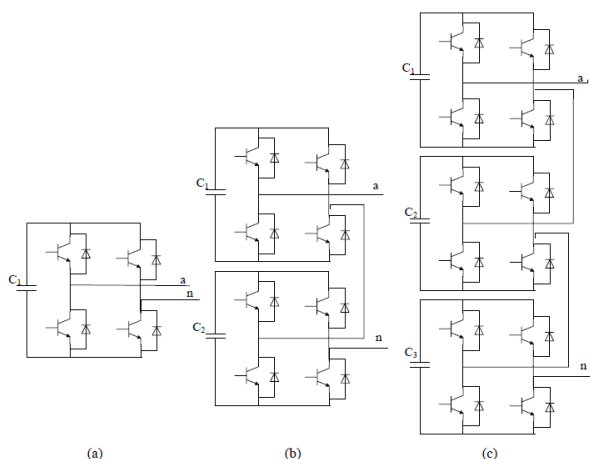


Figure 2: Single Phase Structures of Cascaded Inverter (a) 3-Level, (b) 5-Level, (c) 7-Level

For real power conversions, (AC to DC and DC to AC), the cascaded-inverter needs separate DC sources. The structure of separate DC sources is well suited for various renewable energy sources such as fuel cell, photovoltaic, and biomass, etc.

Connecting separated DC sources between two converters in a back-to-back fashion is not possible because a short circuit will be introduced when two back-to-back converters are not switching synchronously.

IV. PROPOSED TECHNOLOGY

By using this introduced consideration it reduces the total harmonic distortion through the appending of echelons. In this work both single and three phase total harmonic distortion has reduces [1]. A cascaded multilevel inverter consists of a series combination of single phase fully H-bridge inverter units. The main function of this multilevel inverter is to synthesize a desired voltage from several isolated DC sources, which is connect with the each H-bridge unit, and may be produced from batteries, fuel cells, or solar cells. Figure 1.1 shows the basic block diagram of a single phase cascaded multilevel inverter with isolated DC voltage sources. Each H bridge inverter connected to a separate DC voltage source. The output AC terminal voltages of multilevel inverters are connected in series. The cascaded multilevel inverter does not used any type of voltage balancing capacitors and voltage clamping diodes, unlike the flying capacitors and diode clamped.

One multilevel inverter topology inclusive single phase cascaded H-bridges with separate DC voltage sources from

the transformer secondary. This importance makes renewable energy sources such as fuel cells or photovoltaic a temperament (natural) preference for the separate DC voltage sources required for the cascade multilevel inverter. Figure shows a single-phase block diagram of an m-level cascade inverter. Each isolated DC voltage source is connected to a single phase fully H-bridge inverter. Each H-bridge inverter level can produce three different voltage outputs, that are $+V_{dc}$, 0, and $-V_{dc}$, by connecting the DC voltage source to the AC output by various combinations of the four switches S1, S2, S3 and S4. One of the main advantages of the cascaded multilevel inverter is that the series connection of H-bridges makes for modularized layout and packaging. This will enable the manufacturing development to be done more quickly and inexpensively. Also, redundant voltages level can be presented in a consumption plan so that the multilevel inverter can stable operate even with the shortage of one level. This enables the multilevel inverter to continue to function even when there is a problem with one of the DC sources or with one of the power electronics devices that make up the H-bridge.

This work discusses about the cascaded multilevel inverter and how to minimize the total harmonic distortion using the conduction angle control i.e. switching angle control method. The cascaded multilevel inverter is constructed depends on the number of echelons. For the production m-level inverters, totally it needs $(m-1)$ capacitors and $2(m-1)$ switches. And also it requires $2(m-1)$ diodes to clamp the voltage at difference voltage level. Gate signal is produced by using the comparator. The ramp signal is compared with DC voltage. By adjusting the DC magnitude the pulse width is controlled. Here the bottom switch conducts for large time than the upper switch.

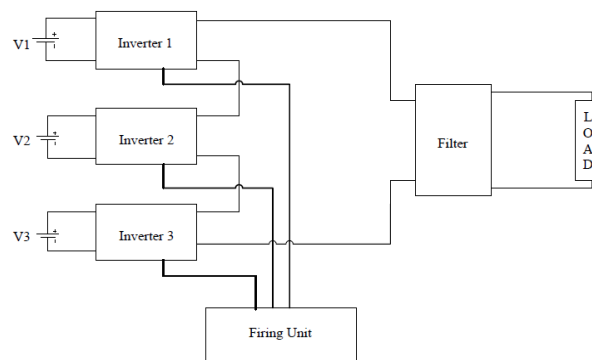


Figure 3:- Block Diagram of Cascaded Multilevel Inverter

➤ Proposed Harmonic Reduction Technique



There are some equations to calculate the conduction angles to minimize low order harmonics i.e. 5th, 7th and 11th in the AC output voltage waveform. At the same time period we also can manage the expected output RMS voltage by using the utilization to minimize the fifth, seventh and eleventh order harmonics. Finally the total harmonic distortion is minimized.

The four equations utilization to minimize the harmonics are

$$\cos\alpha_1 + \cos\alpha_2 + \cos\alpha_3 + \cos\alpha_4 = m$$

$$\cos 5\alpha_1 + \cos 5\alpha_2 + \cos 5\alpha_3 + \cos 5\alpha_4 = 0$$

$$\cos 7\alpha_1 + \cos 7\alpha_2 + \cos 7\alpha_3 + \cos 7\alpha_4 = 0$$

$$\cos 11\alpha_1 + \cos 11\alpha_2 + \cos 11\alpha_3 + \cos 11\alpha_4 = 0$$

Using MathCAD program, the conduction angles were determined to completed the above equations and they are

$$\alpha_1 = 12.834^\circ; \alpha_2 = 29.908^\circ; \alpha_3 = 50.993^\circ; \alpha_4 = 64.229^\circ;$$

The total harmonic distortion is calculated by the relation:

$$THD = \frac{\sqrt{(V_3^2 + V_5^2 + V_7^2 + \dots + V_{21}^2)}}{V_1}$$

A cascaded multilevel inverter consists of a series of single phase fully H-bridge inverter modules. The output voltage is synthesize with the output voltage waveform from several separate DC sources connected with H-bridge inverters, which may be batteries, solar cells, or fuel cells, that is general function of this multilevel inverter. Figure 4 shows the single phase basic structure of cascaded H-bridge multilevel inverter with separate DC sources. Each separate DC source connected with H-bridge inverter. The cascaded H-bridge multilevel inverter does not consists any voltage balancing capacitors or voltage clamping diodes, unlike the flying capacitors or diode clamp inverters. The output terminal voltages of different level inverters are connected in series.

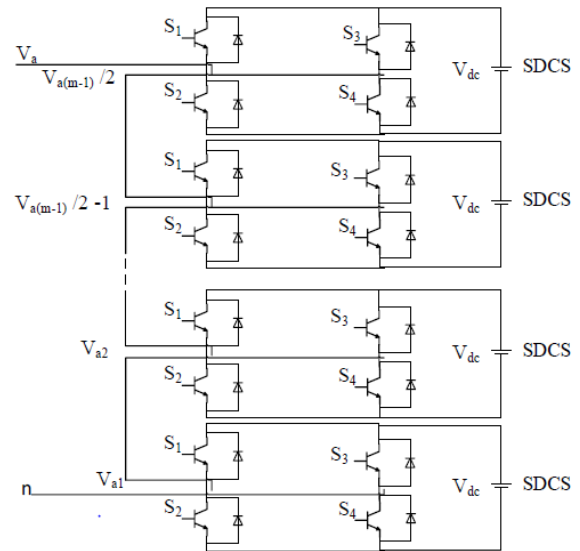


Figure 4: Structure of a Single-Phase Cascaded H-Bridges Multilevel Inverter

V. SIMULATION RESULTS

The control of the proposed method for a 14-echelon and 28-echelon single phase and three phase cascaded multilevel inverters is simulated by using the MATLAB/SIMULINK software. The simulation results of single phase and three phase for the developed 14-echelon and 28-echelon cascaded multilevel inverters are show that has many advantages such as decrease number of switches, lower electromagnetic interference, low harmonic distortion and the total harmonic distortion of the proposed inverter is consider by alleviated and the dynamic response are also improved significantly.

➤ 14-Echelon Cascaded H-Bridge Multilevel Inverter

The simulation results of single phase and three phase for the developed 14-echelon cascaded multilevel inverter proposed to minimize the total harmonic distortion with using of reduced number of switches and increase level in the output voltage waveform. There are connected three H-bridge inverters in the cascaded form and each H-bridge inverter is supplied by separate DC voltage source. The ratio of the separate DC voltage sources (V_{dc1} , V_{dc2} and V_{dc3}) that used in single phase and three phase 14-echelon cascaded H-bridge multilevel inverter, as given by-
 $V_{dc1} : V_{dc2} : V_{dc3} = 1V_{dc} : 2V_{dc} : 3V_{dc}$

The simulation model for single phase 14-echelon cascaded multilevel inverter is show in the Figure 5. The switching



system is controlled by firing unit, each H-bridge having separate firing unit to control the switching system in the cascaded H-bridge multilevel inverter.

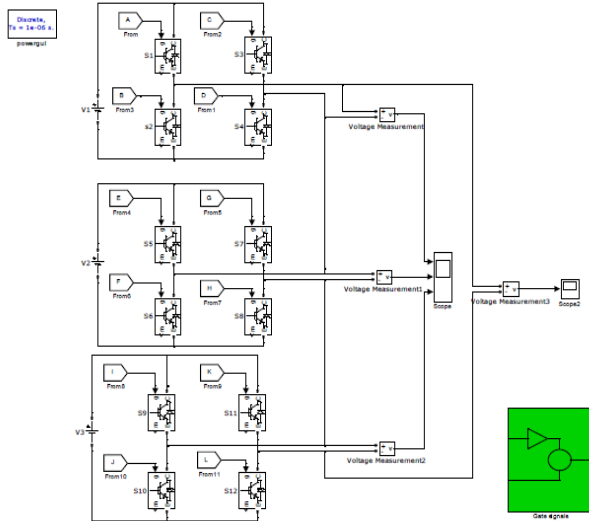


Figure 5: Single Phase 14-echelon Cascaded H-Bridge Multilevel Inverter

Voltage V_o	Switch State											
	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}
$V_o = 0V$	1	0	1	0	1	0	1	0	1	0	1	0
$V_o = 1V_{dc}$	1	0	0	1	1	0	1	0	1	0	1	0
$V_o = 2V_{dc}$	1	0	1	0	1	0	0	1	1	0	1	0
$V_o = 3V_{dc}$	1	0	1	0	1	0	1	0	1	0	0	1
$V_o = 4V_{dc}$	1	0	0	1	1	0	1	0	1	0	0	1
$V_o = 5V_{dc}$	1	0	1	0	1	0	0	1	1	0	0	1
$V_o = 6V_{dc}$	1	0	0	1	1	0	0	1	1	0	0	1
$V_o = -1V_{dc}$	0	1	1	0	1	0	1	0	1	0	1	0
$V_o = -2V_{dc}$	1	0	1	0	0	1	1	0	1	0	1	0
$V_o = -3V_{dc}$	1	0	1	0	1	0	1	0	0	1	1	0
$V_o = -4V_{dc}$	0	1	1	0	1	0	1	0	0	1	1	0
$V_o = -5V_{dc}$	1	0	1	0	0	1	1	0	0	1	1	0
$V_o = -6V_{dc}$	0	1	1	0	0	1	1	0	0	1	1	0

Table 1: 14-Echelon CMLI Voltage Level and Corresponding Switch States

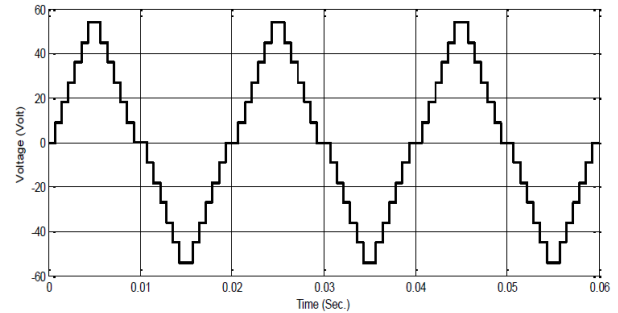


Figure 6: Simulation Output Voltage Waveform for Single Phase 14-Echelon MLI

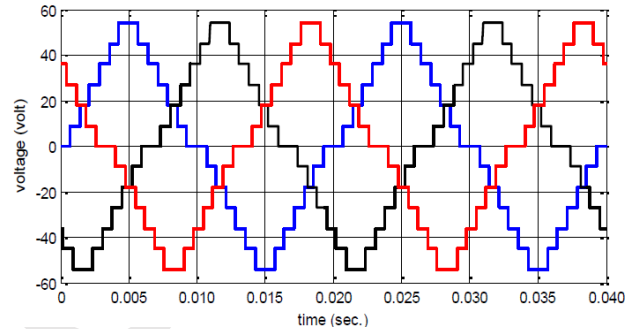


Figure 7: Simulation Output Voltage Waveform for Three Phase 14-Echelon MLI

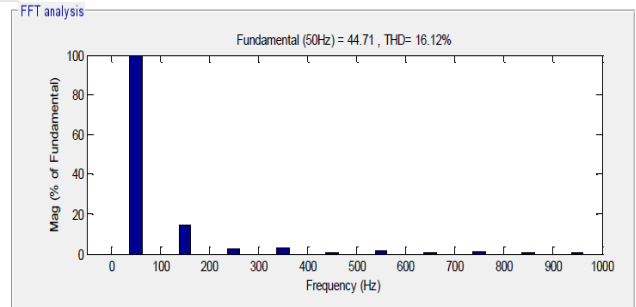


Figure 8: FFT Analysis for three Phase 14-Echelon MLI

The simulation result gives the total harmonic distortion level for three phase 14-echelon cascaded H-bridge multilevel inverter that is 16.12%. Therefore the total harmonic distortion in three phase inverter is same as compare to single phase inverter.

➤ 28-Echelon Cascaded H-Bridge Multilevel Inverter

The simulation results of single phase and three phase for the developed 28-echelon cascaded H-bridge multilevel inverter proposed to minimize the total harmonic distortion with using of reduced number of switches and increase level in the output voltage waveform. There are connected three H-bridge inverters in the cascaded form and each H-bridge inverter is supplied by separate DC voltage source. The ratio of the separate DC voltage sources (V_{dc1} , V_{dc2}

and Vdc3) that used in single phase and three phase 28-echelon cascaded H-bridge multilevel inverter, as given by-

$$V_{dc1}: V_{dc2}: V_{dc3} = 1V_{dc} : 3V_{dc} : 9V_{dc}.$$

The simulation model for single phase 28-echelon cascaded multilevel inverter is shown in the Figure 5.1. The switching system is controlled by firing unit, each H-bridge having separate firing unit to control the switching system in the cascaded H-bridge multilevel inverter.

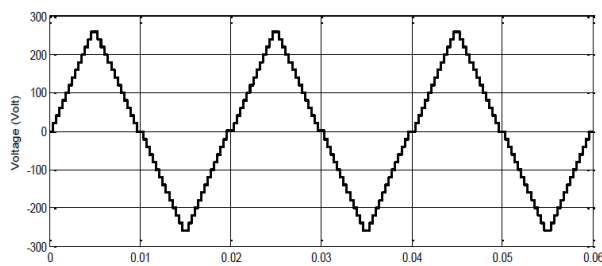


Figure 9: Simulation Output Voltage Waveform for Single Phase 28-Echelon MLI

Simulation is done the simulation result shown in single phase and three phase cascaded multilevel inverters and calculate the total harmonic distortion by using the FFT analysis.

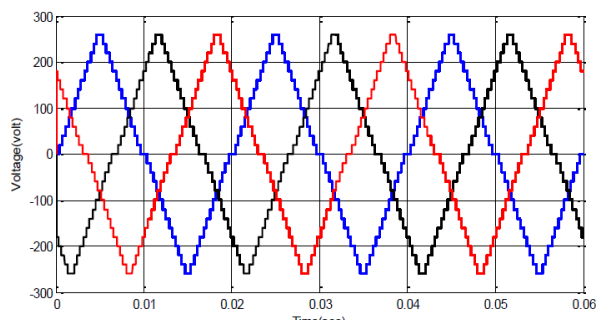


Figure 10: Simulation Output Voltage Waveform for Three Phase 28-Echelon MLI

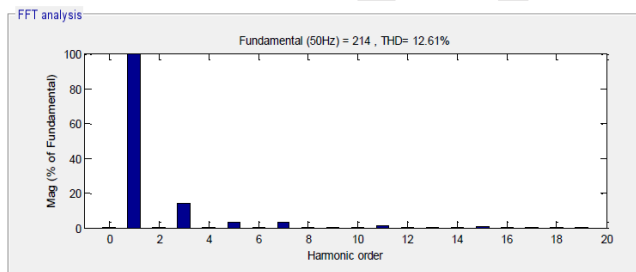


Figure 11: -FFT Analysis for Single Phase 28-Echelon MLI

Each H-bridge have separate firing unit to control the switching system in the cascaded multilevel inverter. Figure 5.8 show the simulation output voltage waveform for single phase 28-echelon cascaded H-bridge multilevel inverter and the FFT analysis of that voltage waveform

shown in Figure 5.9, that FFT analysis gives the magnitude in terms of percentage of fundamental with respect to frequency order. The FFT analysis is required to calculate the total harmonic distortion. The simulation result gives the total harmonic distortion level for single phase 28-echelon cascaded H-bridge multilevel inverter that is 12.61%.

The simulation result gives the total harmonic distortion level for three phase 28-echelon cascaded H-bridge multilevel inverter that is 12.61%. Therefore the total harmonic distortion in 28-echelon inverter is less by 3.51% with respect to 14-echelon inverter. The study can further be analysis by employing control schemes to have advance dynamic response and by using high level inverters.

VI. CONCLUSION

The function of this work is to minimize total harmonics distortion and number of switch and improve level in output voltage waveform. In conventional method, needed five H-bridge units to used 11-echelon inverter but in this proposed method for a 28-echelon cascaded H-bridge multilevel inverter required only three H-bridge unit per phase. By using this proposed idea it reduces the total harmonics distortion through the appending of echelons. In this work both single phase and three phase total harmonics distortion and number of switch has reduced. Simulation result is providing for 14-echelon and 28-echelon cascaded H-bridge multilevel inverter to validate the accuracy of computational result. Single phase and three phase simulation result was 14-echelon cascaded H-bridge multilevel inverter the total harmonics distortion level is 16.12%. The simulation result gives the total harmonic distortion level for single phase and three phase 28-echelon cascaded H-bridge multilevel inverter that is 12.61%. Therefore the total harmonic distortion in 28-echelon inverter is less by 3.51% with respect to 14-echelon inverter. Comparison of result with active harmonics reduction techniques indicates that the total harmonics distortion and switching frequency of output voltage reduced dramatically.

The Study can future be underscored by design of filters between Cascaded multilevel inverter and load and utilize control schemes to have advanced dynamic response by using high level inverters and also can implemented in hardware.

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