International Journal For Technological Research In Engineering
Volume 3, Issue 9, May-2016 *ISSN (Online): 2347 - 4718*

MODELLING AND SIMULATION OF LOW FREQUENCY PULSE WIDTH MODULATION FOR CASCADED H-BRIDGE MULTILEVEL INVERTER USING SINGLE DC- SOURCE AND ISOLATION TRANSFORMER

Divyanka Chauhan[1], Prof. Vasant D.Chaudhary[2]
[1]PG Scholar, [2]Assistant Professor
Department of Electrical Engineering Shri satsangi saketdham “Ram-Ashram” group of institution
Faculty of Engineering, Vadasma, Mehsana, Gujarat, India

ABSTRACT: Cascaded H-Bridge multilevel inverter is a promising topology for generation of high power output. This can be done by cascading number of H-bridge modules. Though it has wide application area and merits, it has greater disadvantage that it use separate DC supply. CMI with single phase transformer and single DC source is proposed for ensure high quality output power waveform. Numerical methods like N-R method is presented where switching angles are computed such that a certain lower order harmonics are eliminated. The proposed topology provides minimisation in cost in terms of THD, losses and filter size. In this report, the modulation techniques SPWM, Fundamental frequency and SHE-PWM are proposed and comparison of them with each other for ensures effectiveness.

I. INTRODUCTION

Background

Numerous industrial applications have begun to require higher power apparatus in recent years. Some medium voltage motor drives and utility applications require medium voltage and megawatt power level. For a medium voltage grid, it is troublesome to connect only one power semiconductor switch directly. As a result, a multilevel power converter structure has been introduced as an alternative in high power and medium voltage situations. A multilevel converter not only achieves high power ratings, but also enables the use of renewable energy sources. Renewable energy sources such as photovoltaic, wind, and fuel cells can be easily interfaced to a multilevel converter system for a high power application.

Harmonics in Electrical Systems

Harmonics is one major problem in the electrical system. Harmonics is a concern because they can cause excessive heating and pulsating and reduced torque in motors and generators; increased heating and voltage stress in capacitors; and mis operation in electronics, switchgear and relaying.

Generally, two types of harmonics are:
1) Voltage harmonics, and
2) Current harmonics.

Current harmonics is usually generated by harmonics contained in voltage supply and depends on the type of load such as resistive, capacitive, and inductive load. Both harmonics can be generated by either the source or the load side. Harmonics generated by load are caused by nonlinear operation of devices, including power converters, arc-furnaces, gas discharge lighting devices, etc. Load harmonics can cause the overheating of the magnetic cores of transformer and motors. On the other hand, source harmonics are mainly generated by power supply with non-sinusoidal voltage waveform. Voltage and current source harmonics imply power losses, Electromagnetic Interference (EMI) and pulsating torque in AC motor drives. Any periodic waveform can be shown to be the superposition of a fundamental and a set of harmonic components. By applying Fourier transformation, these components can be extracted. The frequency of each harmonic component is an integral multiple of its fundamental. The method used to express harmonic content commonly used is Total Harmonic Distortion (THD), which is defined in terms of the amplitudes of the harmonics,H_n, at frequency $n_{\omega o}$, where $\omega o$is frequency of the fundamental component whose amplitude of H1 and n is integer.

The THD is mathematically given by,

$$\%\ \mathrm{THD} = \frac{\sqrt{\sum_{n=2}^{\infty} H^2(n)}}{H1}\%$$

The Concept of Multilevel Inverters

Conventional two-level inverters, seen in Figure 1.1, are mostly used today to generate an AC voltage from an DC voltage. The two-level inverter can only create two different output voltages for the load, $V_{dc}/2$ or $-V_{dc}/2$ (when the inverter is fed with V_{dc}). To build up an AC output voltage these two voltages are usually switched with PWM, see Figure 1.2. Though this method is effective it creates harmonic distortions in the output voltage. This may not always be a problem but for some applications there may be a need for low distortion in the output voltage.

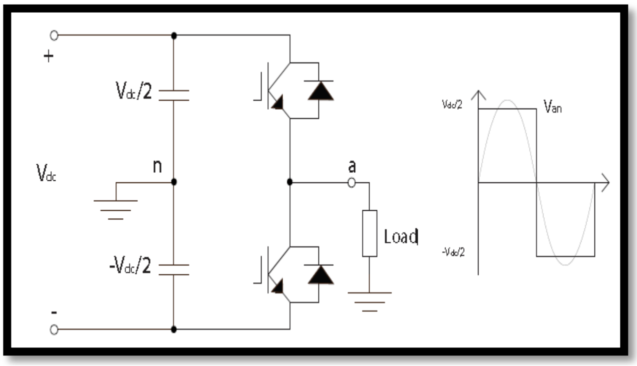


Figure-1.1: One phase leg of a two-level inverter and waveform without PWM

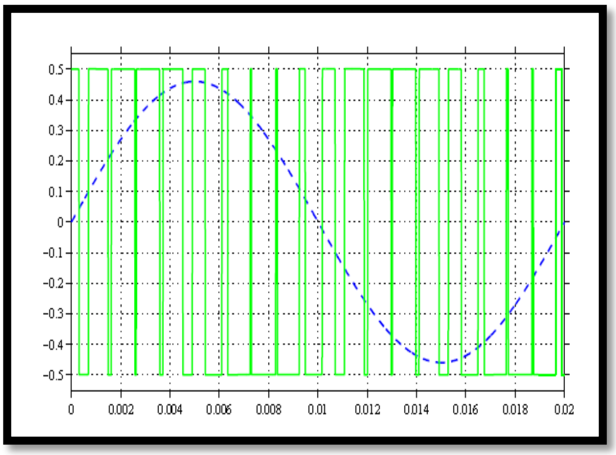


Figure 1.2: PWM voltage output, reference wave in dashed blue

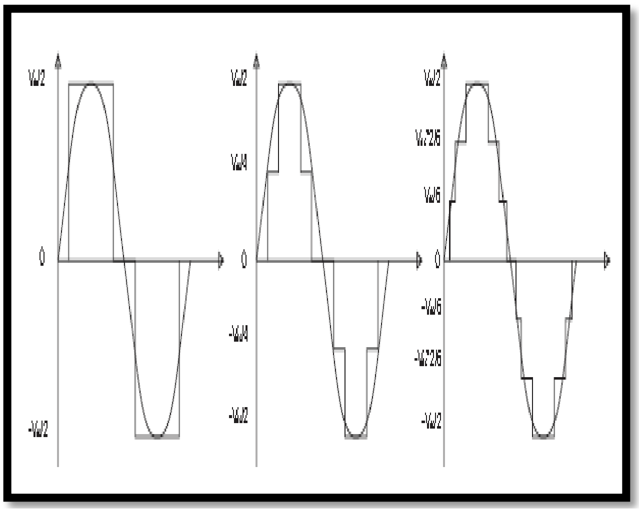


Figure1.3: A three-level, a five-level and a seven-level waveform

The concepts of Multi-Level Inverters (MLI) do not depend on just two levels of voltage to create an AC signal. Instead several voltage levels are added to each other to create a smoother stepped waveform, see Figure 1.3, with lower dv/dt and lower harmonic distortions. With more voltage levels, the waveform becomes smoother, but with many levels the design becomes more complicated, with more components and a more complicated controller for the inverter is needed.

Some of its most attractive features in general are as follows [1]:

- They can generate output voltages with extremely low distortion and lower dv/dt.
- They draw input current with very low distortion.
- They generate smaller common-mode voltage, thus reducing the stress in the motor bearings. In addition, using sophisticated modulation methods, voltages can be eliminated.
- They can operate with a lower switching frequency.

These all benefits, together with the ability to deal with high voltage levels, confer on multilevel converters a very important role in the field of high power applications.

There are also different topologies of multilevel inverters that can generate a stepped voltage waveform and that are suitable for different applications. By designing multilevel circuits in different ways, topologies with different properties have been developed. The Multilevel inverter topologies are: Neutral- Point Clamped Multilevel Inverter (NPCMLI), Capacitor Clamped Multilevel Inverter (CCMLI), and Cascaded Multi-level Inverter. The most dominant multilevel inverters use one or more voltage sources, as the three-level inverter, and topologies which are presented in this report will have voltage sources, so called Voltage Source Inverters (VSI).

Selective Harmonic Elimination Pulse Width Modulation (SHE-PWM)

The elimination of low-order harmonics is an important issue in many applications. When high switching efficiency is of utmost importance, it is desirable to keep the switching frequency much lower. Selective harmonic elimination (SHE)techniques were introduced and some other SHEPWM techniques were presented in [5] - [7].

Concept of SHEPWM

The SHE PWM technique is applicable to both a half-bridge and a full-bridge inverter [5].The output voltage of half bridge and full bridge can be synthesized by using SHE PWM technique. In this chapter, a three-level SHE-PWM generated by a full-bridge inverter is considered.

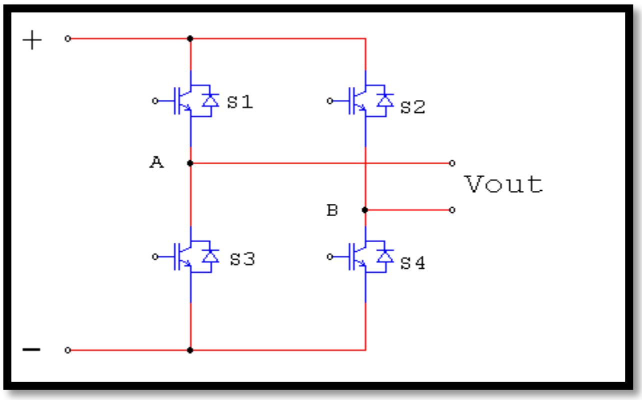


Figure-2.1:- A full-bridge voltage source inverter

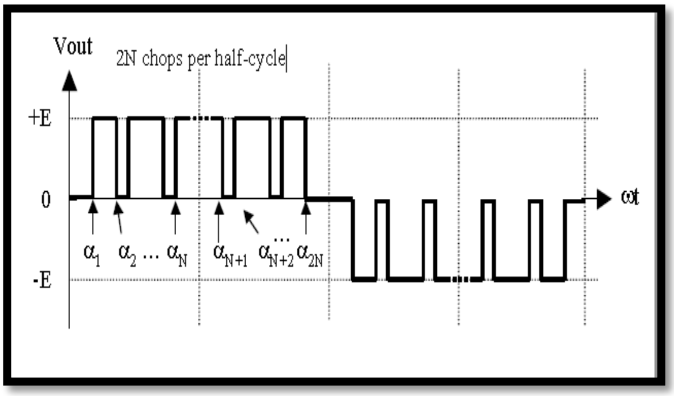


Figure-2.2:- Generalized three-phase SHE PWM waveform

A full-bridge or H-bridge voltage source inverter, which comprises four switches and one dc source, is shown in Fig. 2.1. Three states of an output voltage waveform can be obtained such as positive, negative, and zero. Fig 2.2 shows a generalized three-level SHE PWM waveform. The output waveform is chopped N times per quarter and therefore the switch is switched N times per cycle to generate such a waveform.

Fourier series analysis for the SHE-PWM

Consider the generalized three-level SHEPWM shown in Fig. The output waveform is assumed to be odd quarter wave symmetry, whose amplitude equals E. Because of odd quarter wave symmetry, the dc component and even harmonics are equal to zero. Thus, the generalized Fourier expression of the three-level SHEPWM can be written as

$$\text{Vout}(\omega t)=\sum_{n=1}^{\infty} a\text{nsin}(\text{n}\omega t) \qquad (1)$$

Where

$$a\text{n} = \frac{4E}{n\pi}\sum_{k=1}^{N}(-1)^{k+1}\cos(n\alpha_k), \text{ for odd n} \qquad (2)$$

N is the number of the switching angles per quarter.

α_k is the switching angles, which must satisfy the following condition:

$$\alpha_1 < \alpha_2 < \ldots.. < \alpha_n < \pi/2 \qquad (3)$$

E is the amplitude of the dc source.

And n is the harmonic order.

Newton-Raphson's method to solve SHE-PWM switching angles

From above calculation, the nonlinear equation system of SHE PWM waveform can be written as follows:

$$\cos(\alpha_1) - \cos(\alpha_2) + \ldots.. \pm \cos(\alpha_n) = \frac{\pi}{4}M \qquad (4.4a)$$

$$\cos(3\alpha_1) - \cos(3\alpha_2) + \ldots.. \pm \cos(3\alpha_n) = \frac{3\pi}{4E}h_3 \qquad (4.4b)$$

$$\cos(5\alpha_1) - \cos(5\alpha_2) + \ldots.. \pm \cos(5\alpha_n) = \frac{5\pi}{4E}h_5 \qquad (4.4c)$$

$$\vdots$$

$$\cos(N\alpha_1) - \cos(N\alpha_2) + \ldots.. \pm \cos(N\alpha_N) = \frac{N\pi}{4E}h_n \qquad (4.4n)$$

Where,

M is the modulation index and M = $\frac{h_1}{E}$

From equations (4.4a) to (4.4b), the cosine terms of α_N are negative with even N and positive with odd N. To control the amplitude of the fundamental component, the modulation index in (4.4a), M, is given. According to the above nonlinear system, N-1 order harmonic can be eliminated from the output voltage waveform by setting equations (4.4b) to (4.4n) equals to zero. Basically, the lowest odd harmonic components need to be eliminated from a single-phase system. For a three-phase system, the lower order harmonic components are eliminated. Generally, all triplen-harmonics in line-to-line voltage will be eliminated by 120 electrical degree phase shift characteristic [5]-[8].

II. ALGORITHM STEPSFOR NEWTON RAPHSON'S METHOD

[1] Guess a initial set of switching angle with j = 0

$$\alpha^\circ = [\alpha1 \ \ \alpha2 \ \ \alpha3\ ]^T$$

[2] Calculate the value of matrix F,

$$F^\circ = F(\alpha^\circ) = \begin{bmatrix} \cos(\alpha1) - \cos(\alpha2) + \cos(\alpha3) \\ \cos(3*\alpha1) - \cos(3*\alpha2) + \cos(3*\alpha3) \\ \cos(5*\alpha1) - \cos(5*\alpha2) + \cos(5*\alpha3) \end{bmatrix}$$

[3] Calculate matrix below,

$$[df/d\alpha]^\circ = \begin{bmatrix} -\sin(\alpha1) & \sin(\alpha2) & -\sin(\alpha3) \\ -3\sin(3*\alpha1) & 3\sin(3*\alpha2) & -3\sin(3*\alpha3) \\ -5\sin(5*\alpha1) & 5\sin(5*\alpha2) & -5\sin(5*\alpha2) \end{bmatrix}$$

[4] Corresponding harmonic amplitude matrix is,

$T = [\ M*(\pi/4) \ \ 0 \ \ 0\ ]^T$

Where, M is the modulation index.

[5] Solve $(d\alpha)^\circ$ = *INV* [$(df/d\alpha)]^\circ * (T - F^\circ)$

Where, *INV* $[(df/d\alpha)]^\circ$ is inverse matrix of $[(df/d\alpha)]^\circ$

[5] Update initial value,

$\alpha^{(j+1)} = \alpha^j + d\alpha^j$

[6] Repeat step from step-[2] to step-[5] until desired degree of accuracy achieved.

Fundamental frequency approach

In this technique the commutation angles are calculated and later they are transferred to a digital system [3]. This technique eliminates some harmonics in order to reduce the distortion in the output voltage.

Fig.2.3 shows converter characteristic waveform and its switching fashion. Nine single-phase transformers creates seven-level output voltage waveform by using three switching angles. In general, the minimum harmonic switching angle can be easily solved by the Newton–Raphson's approach [6].From fig. 4.8 the details of output characteristics of CMI with single-phase transformers and output waveform at each transformer terminal in phase 'a' are obtained. To determine the fundamental frequency approach, consider the theoretical output voltage waveforms V1, V2 and V3of each of the single-phase transformers. The output voltages are connected in series to produce a net output voltage. The net output voltage is V1 + V2 + V3 and this situation is shown in Fig. In a similar fashion V2 and V3 can be obtained. These output Voltages are not depend of switching angles, and the range of switching angles are from $0 < \alpha_k < \pi/2$. So output voltage can be represented as

$$Vout = 4Vdc \,/\, n\pi \,(cos(n\alpha 1) + cos(n\alpha 2) + cos(n\alpha 3))$$

Above-mentioned output voltages of converter are controlled by switching angles, which are represented by a1, a2, a3.All these switching angles lie between 0 and π/2 and it can represented as $0 \le \alpha 1 \le \alpha 2 \le \alpha 3 \le \pi/2$.

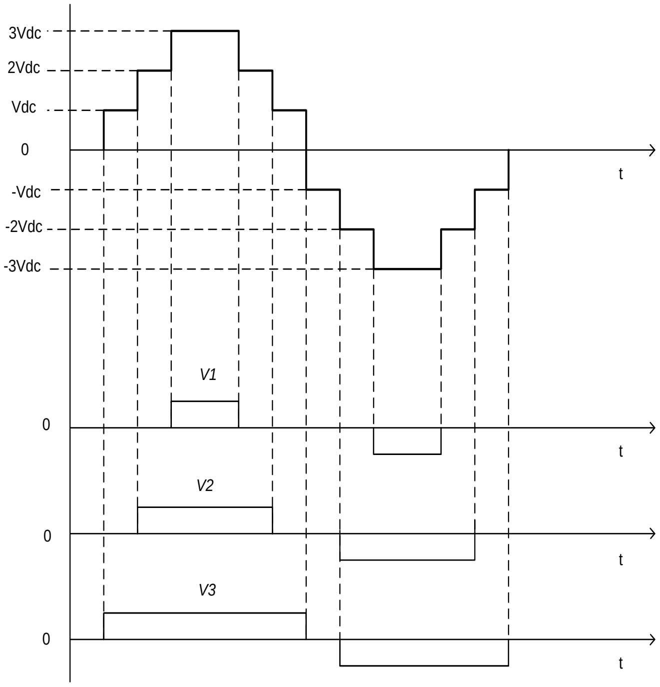


Fig.2.3-Details of waveform for seven level CHB MLI using fundamental frequency approach

By controlling the switching angles, the fundamental component can be synthesized and meanwhile, 5th and 7thorder harmonic components can be suppressed. The secondary side of the transformer is delta connected and so third harmonic component can be completely eliminated this is the main feature of fundamental frequency method. From this to find out the value of switching angles, a set of non-linear equation can be written as

$$\cos(\alpha_1) + \cos(\alpha_2) + \,\ldots\ldots + \cos(\alpha_n) = 3M\frac{\pi}{4}$$

$$\cos(3\alpha_1) + \cos(3\alpha_2) + \,\ldots\ldots + \cos(3\alpha_n) = 0 \qquad (4.5)$$

$$\cos(5\alpha_1) + \cos(5\alpha_2) + \,\ldots\ldots + \cos(5\alpha_n) = 0$$

Where m is the modulation index, which is varied from 0.1 to 1.By using the Newton–Raphson's method, switching angles of each switch are calculated on the basis of area of each switch [18]. All relay angles can be determined by applying the linearization method to each area. These prospects are useful in eliminating lower order harmonic components.

Table 2.1 calculation of switching angle based on modulation indexes

Modulation index (M)	a1	a2	a3
0.1	76.42	–	–
0.2	61.93	–	–
0.3	50.22	86.24	–
0.4	44.21	74.33	–
0.5	40.8	66.12	89.45
0.6	39.44	58.61	83.1
0.7	35.35	53.9	74.5
0.8	29.8	54.46	65.55
0.9	17.76	43.05	63.21
1	11.7	31.27	58.6

However, by solving the above limitation using the Newton–Raphson method three switching angles α1, α2, α3 can be predicted, which are less than π/2. At modulation index 1 the switching angle of transformer 1 is 11.70° and its extinction angle is 168.3°, which produces an output voltage V_{A1} shown in Fig. 4b. Similarly, for transformers two and three switching angles are 31.2° and 58.6° and there corresponding extinction angles are 148.8° and 121.4°.

III. MODELLING AND SIMULATIONS

Simulation of three-phase five-level cascaded H-bridge multilevel inverter using SPWM:

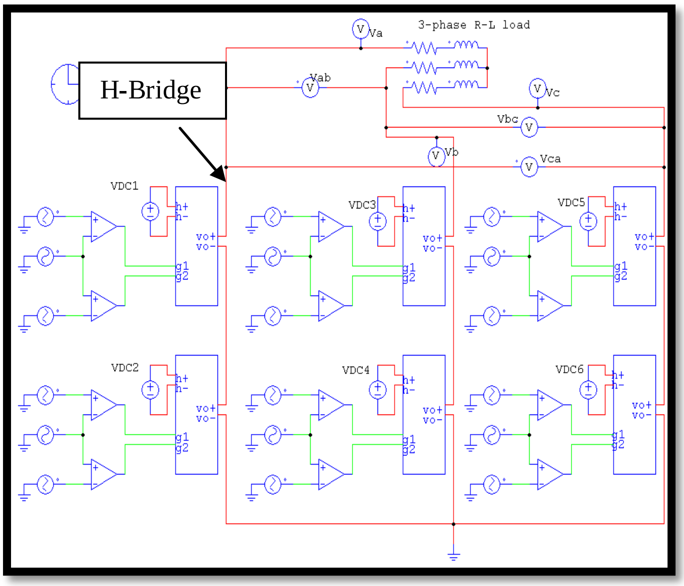
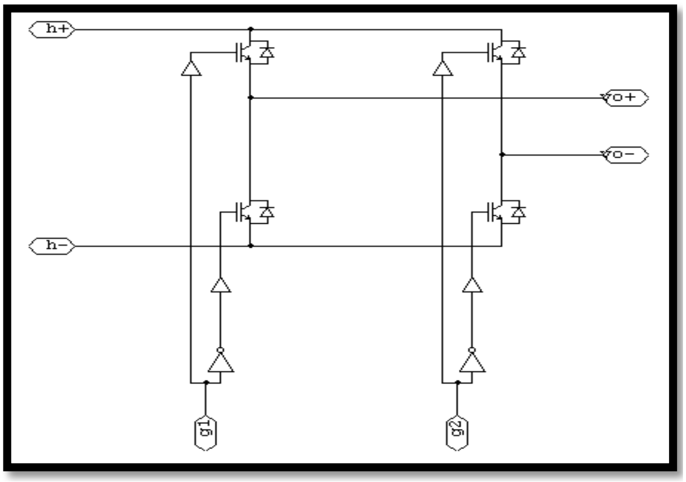


Fig.3.1 Simulation of three phase five level CHB MLI for Sinusoidal PWM



H-bridge block

Output Phase Voltage waveform (Va, Vb, Vc):-

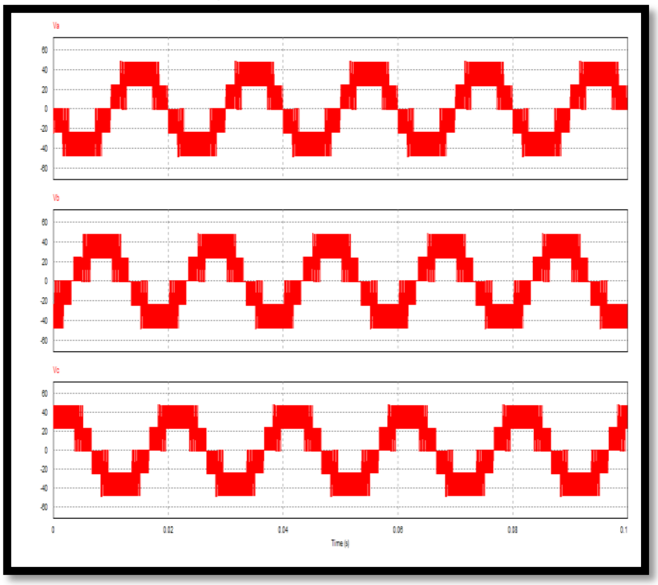


Fig.3.2 Output phase voltages of five level CHB MLI for SPWM

Output line voltages waveform (Vab, Vbc, Vca)

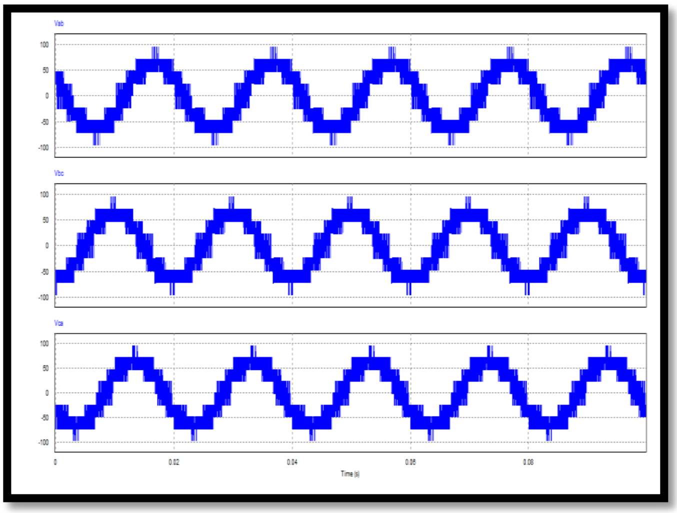
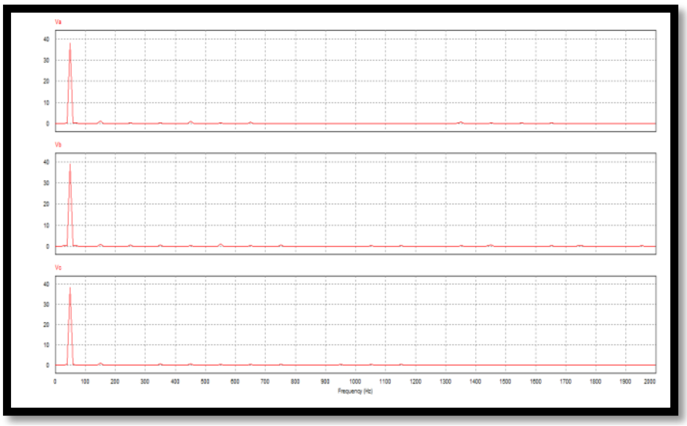


Fig.3.3 Output line voltages of five level CHB MLI for SPWM

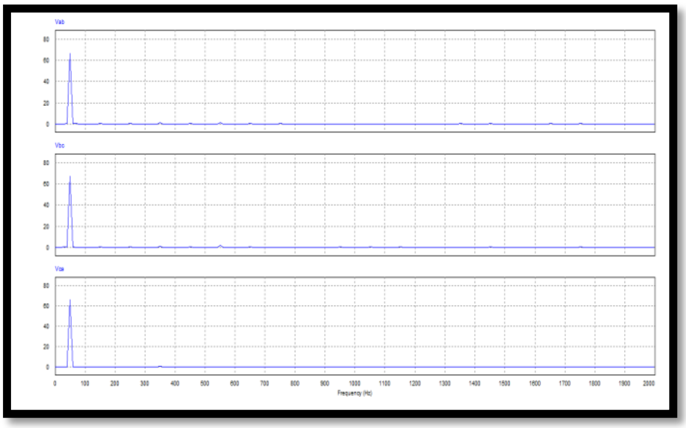
HarmonicSpectrum of phase voltages (Va, Vb, Vc):-



THD = 44.25%

Fig 2.4: FFT analysis of output phase voltages of CHB MLI for SPWM

Harmonic Spectrum of line voltages (Vab, Vbc, Vca):-



THD = 35%

Fig 2.5: FFT analysis of output line voltages of CHB MLI for SPWM

Simulation of three-phase seven-level cascaded H-bridge MLI inverter using SPWM:

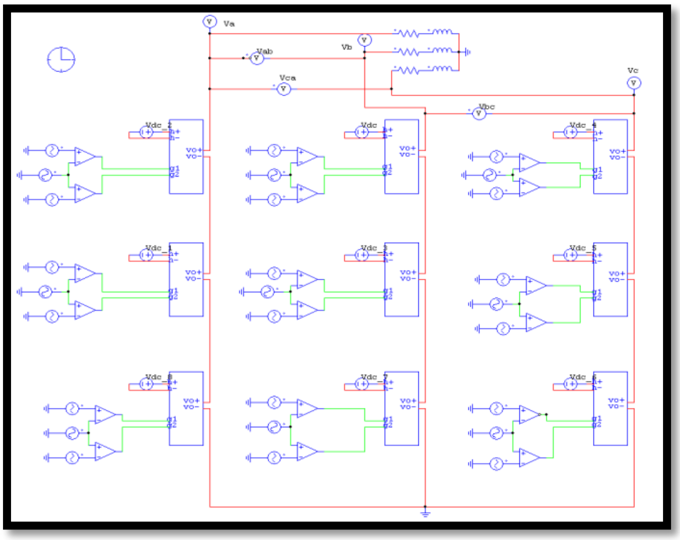


Fig.2.6 Simulation of three phase seven level CHB MLI for Sinusoidal PWM

Output phase voltages waveform (Va, Vb, Vc):-:

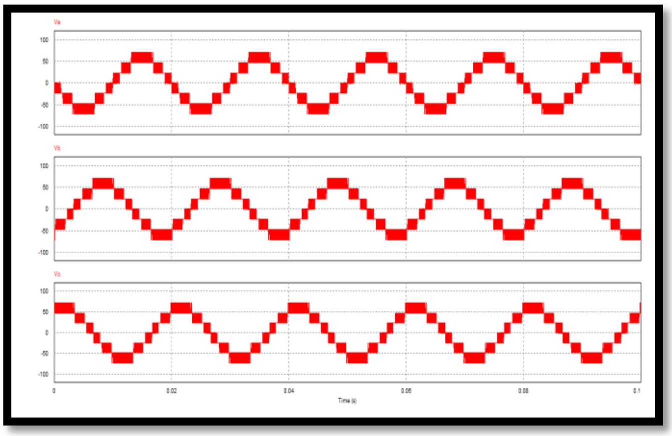


Fig.2.7Output phase voltages of seven level CHB MLI for SPWM

Output line voltages waveform(Vab, Vbc, Vca):-

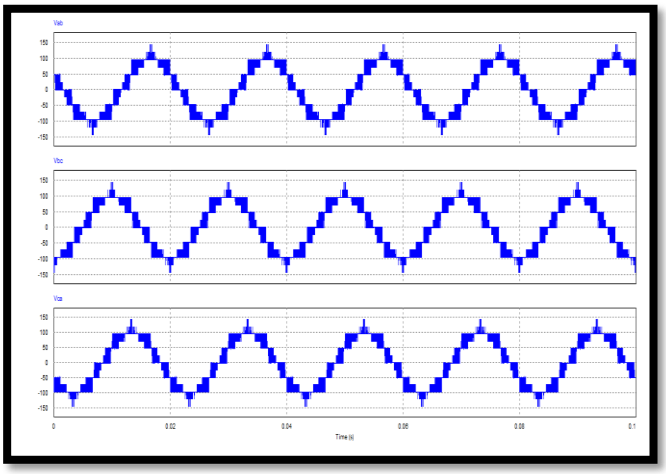
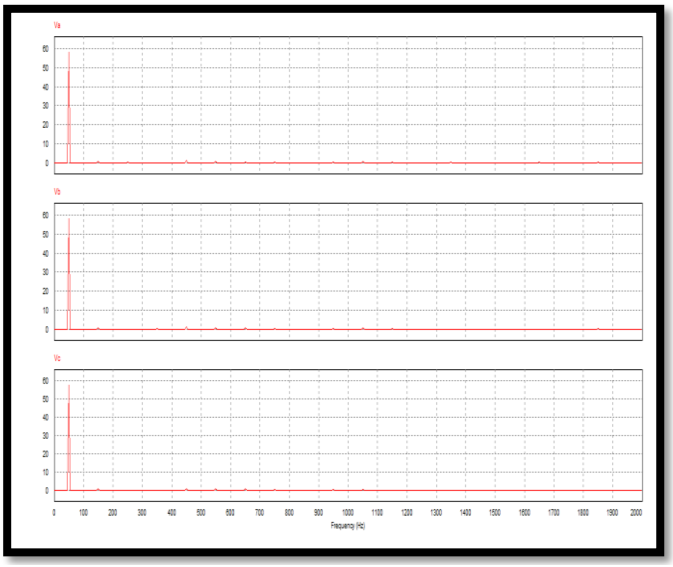


Fig.2.8Output line voltages of five level CHB MLI for SPWM

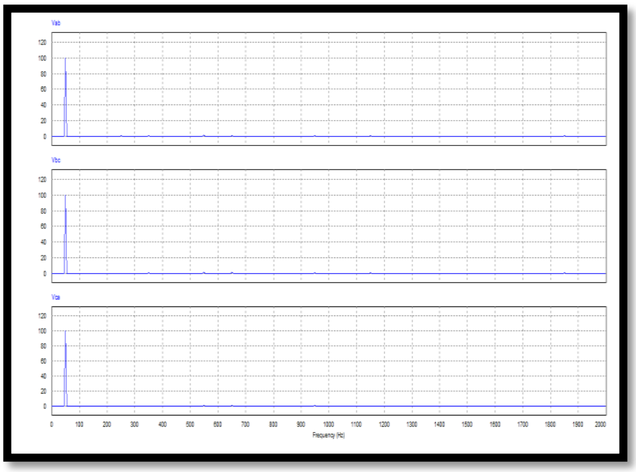
Harmonic Spectrum of phase voltage (Va, Vb, Vc):-



THD = 25.2%

Fig 2.9: FFT analysis of output phase voltages of CHB MLI for SPWM

Harmonic Spectrum of line voltage(Vab, Vbc, Vca):-



THD = 20%

Fig 2.10: FFT analysis of output line voltages of CHB MLI for SPWM

Simulation of three-phase seven-level cascaded H-bridge multi-level inverter using single DC source:

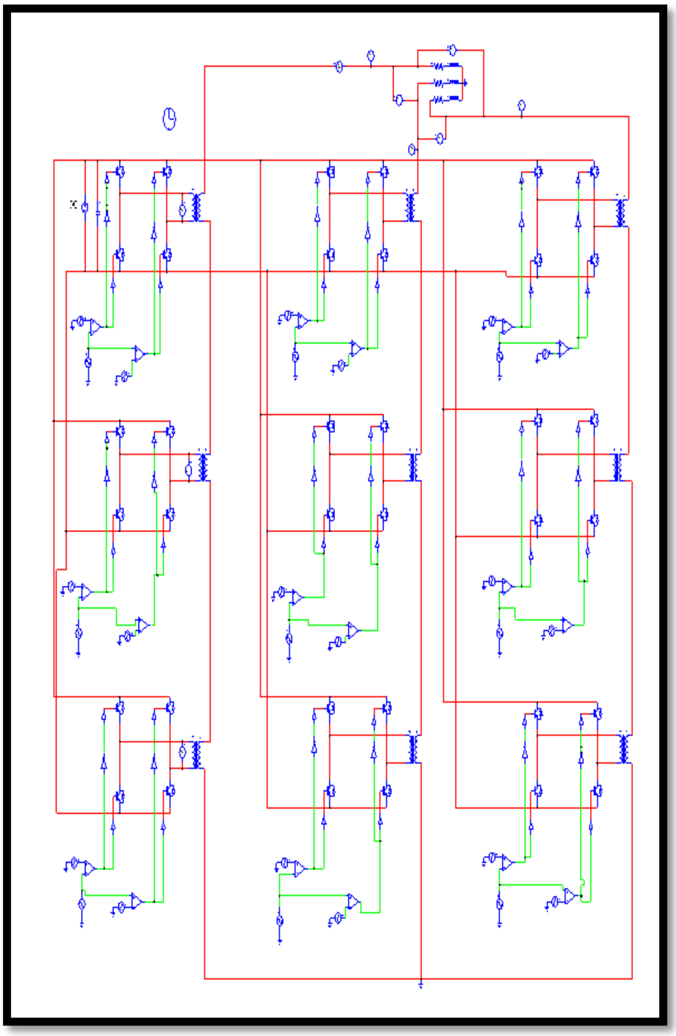


Fig.2.11 Simulation of three phase seven level CHB MLI using single DC source and single phase transformer for Sinusoidal PWM

Output Phase Voltages waveform (Va, Vb, Vc):-

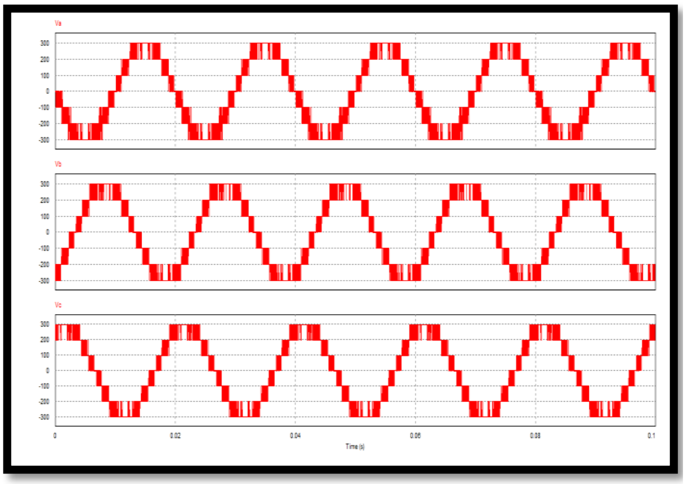


Fig.2.12 Output phase voltages of seven level CHB MLI using single DC source.

Output line Voltages waveform (Vab, Vbc, Vca):-

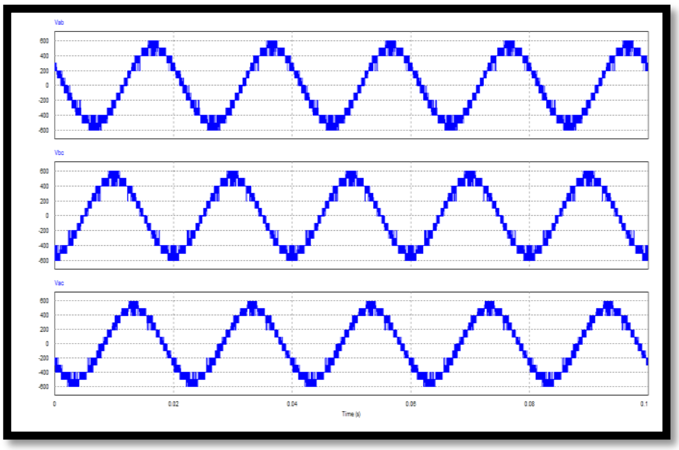
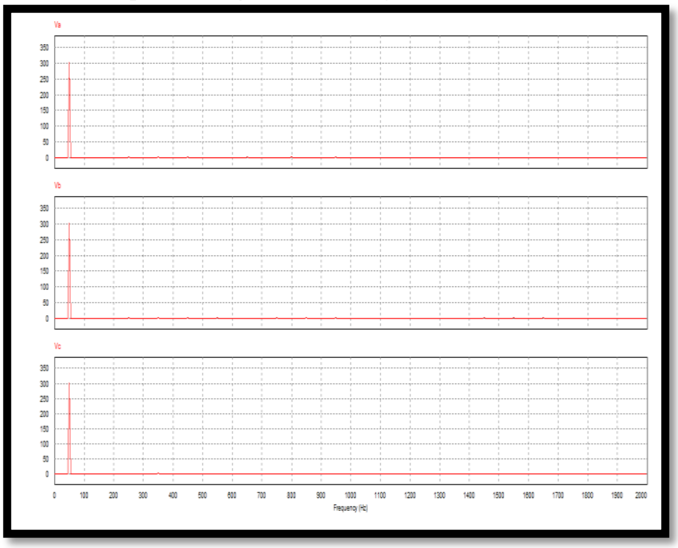


Fig.2.13 Output line voltages of seven level CHB MLI using single DC source.

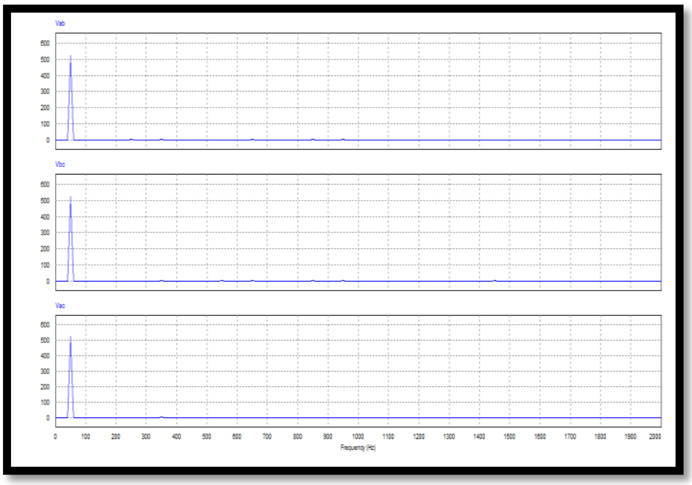
Harmonic Spectrum of Phase Voltage (Va, Vb, Vc):-



THD = 18%

Fig 2.14: FFT analysis of output phase voltages of seven level CHB MLI using single DC source.

HarmonicSpectrum of line Voltage (Vab, Vbc, Vca):-



THD = 14%

Fig 2.15: FFT analysis of output line voltages of seven levelCHB MLI using single DC source.

Simulation of single phase CHB MLI using single DC source and single phase transformer for Fundamental frequency approach

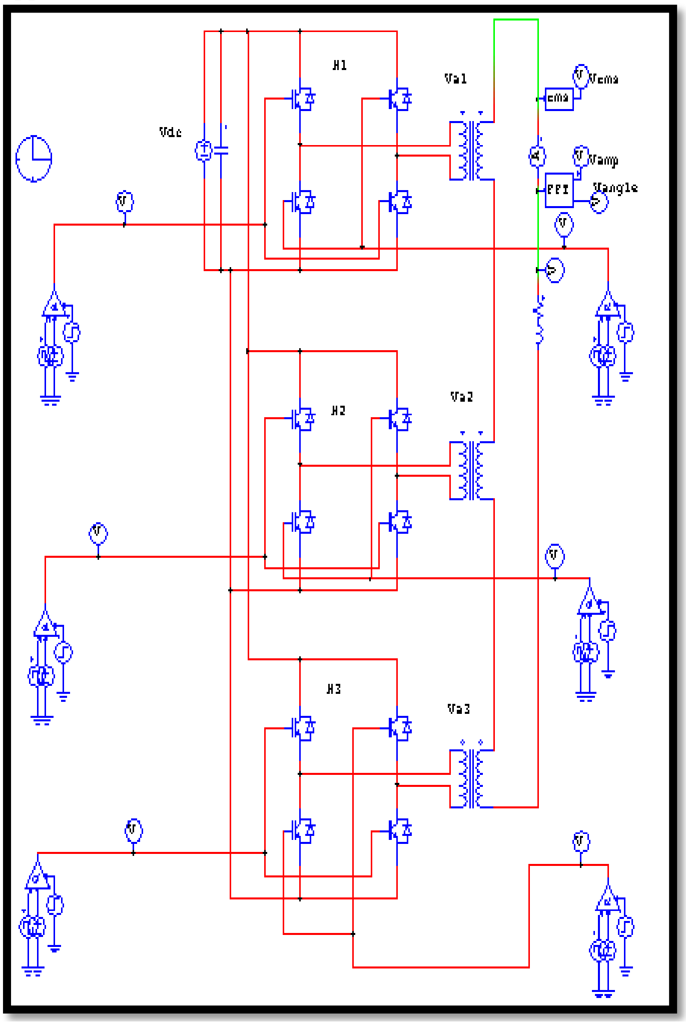
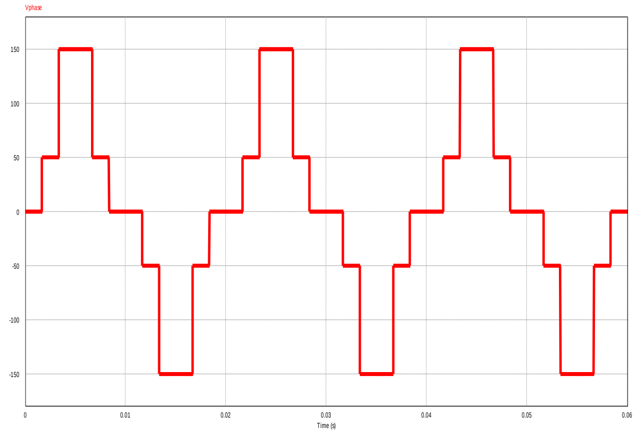


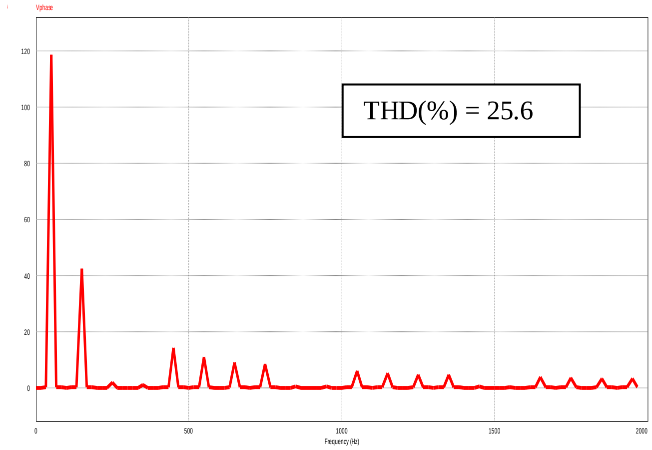
Fig.2.16- simulation of CHB MLI using single DC source applying fundamental frequency approach

Five level Output phase voltage of CHB MLI for fundamental frequency approach:-



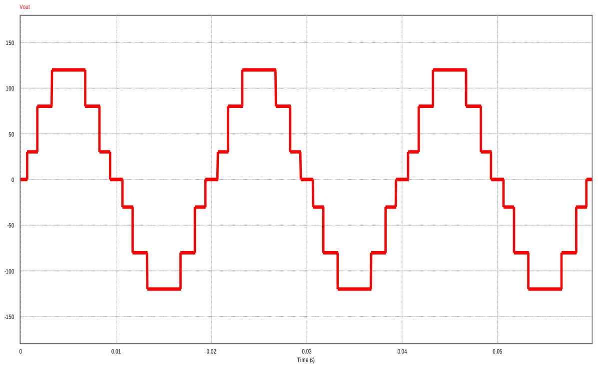
(X-axis: Time, 1ms/div & Y-axis: voltage, 50 volt/div)
Fig.2.17: five level Output of CHB MLI using single DC source applying Fundamental frequency approach

Harmonic spectrum of output phase voltage:-



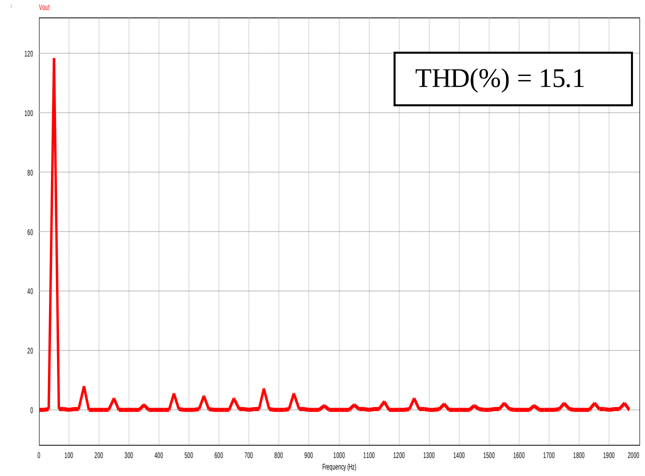
(X-axis: Frequency, 100Hz/div & Y-axis: amplitude, 20 volt/div)
Fig 2.18: FFT analysis of five level output of CHB MLI using single DC source applying Fundamental frequency approach

Seven level output phase voltage of CHB MLI using single DC source for fundamental frequency approach:-



(X-axis: Time, 1ms/div & Y-axis: voltage, 50volt/div)
Fig.2.19: Seven level Output of CHB MLI using single DC source applying Fundamental frequency approach

Harmonic spectrum of seven level output phase voltagefor fundamental frequency approach



(X-axis: Frequency, 100Hz/div & Y-axis: amplitude, 20volt/div)
Fig 2.20: FFT analysis of sevenlevel output of CHB MLI using single DC source applying Fundamental frequency approach

Comparison of PWM techniques for CHB MLI using single DC source:

Table-2.1 Comparisons of PWM techniques for CHB MLI using single DC source

Switching techniques	SPWM		Fundamental frequency		SHEPWM	
Modulation index	0.2	0.5	0.2	0.5	0.2	0.5
Phase Voltage level	3	5	3	5	3	5
THD (%)	35	30	39.7	25.6	35.2	24

IV. CONCLUSION

Cascaded H-bridge multilevel inverter has tremendous advantage in terms of harmonic contents, simple structure and low switching losses. From the comparison of SPWM, Fundamental Frequency approach and Selective harmonic elimination PWM methods it can be seen by simulation and THD analysis, as the voltage level is increased it lower the harmonic distortion from the output of the Cascaded H-bridge Multilevel inverter. Higher quality of waveform is achieved by using Recalculated switching angles in SHE-PWM and Fundamental frequency approach and desired lower order of harmonic can be eliminated.

REFERENCES

[1] José Rodríguez, Jih-Sheng Lai, "Multilevel Inverters: A Survey of Topologies, Controls, and Applications," IEEE Transactions on Industrial Electronics, vol. 49, no. 4,pp.724-738, AUG-2002.
[2] Zhong Du, Leon M.Tolbert, "A Cascade Multilevel Inverter Using a Single DC Source", Applied Power

Electronics Conference And Exposition, pp.426-430, OCT-2006.

[3] Ramirez S, Cardenas V, Rodolfo Echavarria, "Cascade Multilevel Inverter With Only One Dc Source",Power Electronics Congress, pp.171-176,OCT-2002.

[4] Sung Geun Song, Feel Soon Kang, and Sung-Jun Park, "Cascaded Multilevel Inverter Employing Three-Phase Transformers and Single DC Input",IEEE Transactions On Industrial Electronics, vol. 56, no. 6, JUNE 2009.

[5] Y. Suresh A.K. Panda, "Research On A Cascaded Multilevel Inverter By Employing Three-Phase Transformers", IET Power Electronics, vol.no.5, Iss.5, pp. 561–570, JULY 2012.

[6] Anup Kumar Panda, Y Suresh, "Research On Cascade Multilevel Inverter With Single Dc Source By Using Three-Phase Transformers", IET Power Electronics, Electrical Power And Energy System,vol-40,pp.9-20,2012.

[7] T Tang, J Han, X Tan, IEEE ISI 2006, "Selective Harmonic Elimination for a Cascade Multilevel Inverter", Industrial Electronics, IEEE International Symposium, pp.977-991, JULY 2006.

[8] J. Napoles, Member, A. J. Watson, P. W. Wheeler, "Selective Harmonic Mitigation Technique for Cascaded H-Bridge Converters with Non-Equal DC Link Voltages",IEEE Journal, vol. 23, no. 4, 2011.

[9] Nikolas Flourentzou, Member, and Vassilios G. Agelidis, "Multi-Module HVDC System Using SHE-PWM With DC Capacitor Voltage Equalization", IEEE Transactions on Power Delivery, vol. 27, no.1, JANUARY 2012.

[10] Muhammad H. Rashid, Power Electronics, circuit, devices, and application Third Edition,pp.253-255.2009.

[11] O. L. Jimenez, R. A. Vargas and J. Aguayo, "THD in Cascade Multilevel Inverters Symmetric and Asymmetric", Robotics and Automotive Mechanics Conference, IEEE computer society, pp.289-295, 2011.

[12] Li Li, DariuszCzarkowski, Member, Y Liu, and PragasenPillay, "Multilevel Selective Harmonic Elimination PWM Technique in Series-Connected Voltage Inverters", IEEE Transactions on Industry Applications, vol. 36, no.1, JAN/FEB 2000.

[13] Vassilios G. Agelidis, Anastasios I. Balouktsis, and Mohamed S. A. Dahidah, "A Five-Level Symmetrically Defined Selective Harmonic Elimination PWM Strategy: Analysis and Experimental Validation", IEEE Transactions On Power Electronics, vol. 23, no. 1, JANUARY 2008.

[14] Nikolas F, and V G. Agelidis, "Multimodule HVDC System Using SHE-PWM With DC Capacitor Voltage Equalization", IEEE Transactions On Power Delivery, vol. no.27, JANUARY 2012.

[15] J. Napoles, A. J. Watsonand M. A. Aguirre, "Selective Harmonic Mitigation Technique forCascaded H-Bridge Converterswith Non-Equal DC Link Voltages", IEEE Transaction on Power Quality,2011.

[16] Feel-soon Kang, "A modified cascade transformer-based multilevel inverter and its efficient switching function", Elsevier, Electric Power Systems Research vol.no.79 pp.1648–1654.

[17] N. AAzli, and Y. C. Choong, "Analysis on the Performance of a Three-phase Cascaded H-Bridge Multilevel Inverter", First International Power and Energy Coference NOVEMBER 28-29, 2006.

[18] Jagdish Kumar, Biswarup Das and PramodAgarwal, "Selective Harmonic Elimination Technique for a Multilevel Inverter", Fifteenth National Power Systems Conference (NPSC), IIT Bombay, December 2008.