Performance Improvement of Multilevel Inverter through Trapezoidal Triangular Carrier based PWM

Kishor Thakre
Department of Electrical Engineering
National Institute of Technology
Rourkela, India 769008
thakrekishor26@gmail.com

Kanungo Barada Mohanty
Department of Electrical Engineering
National Institute of Technology
Rourkela, India 769008
kbmohanty@nitrkl.ac.in

Abstract— In this paper a new SPWM technique using a trapezoidal triangular multicarrier for a 17 level cascaded H bridge multilevel inverter is simulated and compared with other types of carrier based PWM technique for performance evaluation. Different triangular carrier modulation techniques such as constant switching frequency level shift (LS) PWM technique viz, phase disposition (PD), phase opposition disposition (POD), alternative phase disposition (APOD), phase shift carrier (PSC) PWM, and variable switching frequency (VSF PWM) are compared with proposed technique for symmetric and asymmetric structure of cascaded H bridge MLI. Simulation for 17 level CHB inverter has been carried out in MATLAB/Simulink and simulation results for voltage waveform and harmonic spectrum are presented and compared. The variation of THD with modulation index for output voltages are analyzed.

Keywords— *Cascade H-bridge Multilevel Inverter; Level Shift PWM; Phase Shift PWM and Variable Switching Frequency PWM; Trapezoidal Triangular Multicarrier PWM (TTMC PWM); Total Harmonic Distortion*

I. INTRODUCTION

Multilevel inverters have achieved increasing acceptance in high power and high performance applications. Recently, multilevel inverters are widely used as static var compensators, active power filters and in motor drive applications. The advantages of multilevel inverters are good power quality, low switching loss and high voltage capability [1]-[3]. The topologies of multilevel inverters are classified into three types: the flying capacitor, diode clamped and cascaded multilevel inverters [4]-[7]. The cascaded H-bridge (CHB) multilevel inverter (MLI) is widely used due to the modularity and simplicity of the control. A single-phase five level cascaded multilevel inverter is shown in Fig. 1. Each dc source connected with its H-bridge generates three different output voltages, $+V_{dc}$, 0, and $-V_{dc}$ using various combinations of switching with the 4 switches. With two symmetric H-bridges in cascade, five level $+2V_{dc}$, $+V_{dc}$, 0, $-V_{dc}$, $-2V_{dc}$ of output voltage can be produced. The overall output voltage of CHB MLI is given by:

$$V_o = V_1 + V_2 + V_3 \ldots \ldots + V_n$$

The number of output phase voltage levels in cascaded inverter is given by m = 2n +1, where, n is the number of separate dc sources and m is the number of levels in inverter output voltage. Thus, with 8 such H-bridge in cascade, 2n+1 = 17 level inverter can be obtained. The cascaded H-bridge MLI are classified in two ways: symmetric and asymmetric structure. It depends on the magnitude of the DC source voltages. Symmetric CHBMLI is obtained with same magnitude of dc source voltages and asymmetric CHBMLI with different magnitude dc source voltages [9], all these properties of CHBMLI allow using various carrier based PWM techniques, Carrier-based PWM uses several triangular carrier signals, which can be modified in phase and/or vertical position in order to reduce the output voltage harmonic content.

In this paper, constant switching frequency and variable switching frequency based on carrier pulse width modulation methods are presented and compared. A new modulation method called trapezoidal triangular multi carrier (TTMC) SPWM is implemented and compared with other methods. This new modulation method gives advantages in multilevel inverter to minimize the percentage of total harmonic distortion (THD) and to increase the output voltage.
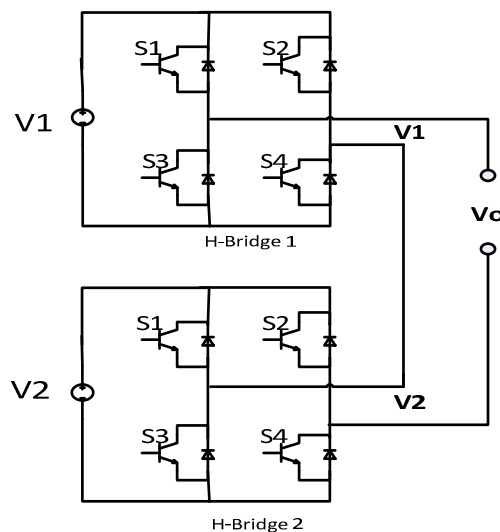

Fig.1 Circuit configuration of five level cascaded H-bridge MLI

II. Constant Switching Frequency PWM

A. Level Shift PWM (LS PWM) [10]

The level-shift pulse-width modulation technique is one of the most popular and very simple switching techniques for multilevel inverters. In m-level inverter, (m-1) carriers with the same frequency f_c and the same amplitude A_c are disposed such that the bands they occupy are continuous. The reference waveform has peak amplitude A_m, and the frequency f_m which is zero centred in the middle of the carrier set. The reference is continuously compared with each of the carrier signals. If the reference is greater than any carrier signal, then the active device corresponding to that carrier is switched off. In multilevel inverters, the amplitude modulation index M_i and the frequency ratio M_f are defined as

$$M_i = \frac{A_m}{(m-1)A_c} \quad (1)$$

$$M_f = \frac{f_c}{f_m} \quad (2)$$

In this level-shift constant switching frequency pulse width modulation, according to the way the triangular carrier waves are placed in relation to the reference signal, three cases can be distinguished. Fig. 2(a) shows the phase disposition pulse-width modulation (PDPWM), where all the carriers are in phase. Fig. 2(b) shows the phase opposition disposition pulse-width modulation (PODPWM), where the carriers above the zero reference are in phase, but shifted by 180 degree from those carriers below the zero reference. Fig. 2(c) shows the alternative phase opposition disposition (APODPWM), where each carrier band is shifted by 180 degree from the adjacent bands.

B. Phase shift carrier PWM [8]

Phase shift carrier (PSC) PWM is another type of constant switching frequency PWM technique. In this PWM scheme, all the triangular carriers have the same frequency and same peak amplitude, but there is a phase shift between any two adjacent carrier waves given by

$$\phi_{cr} = 360^o/(m\text{-}1) \quad (3)$$

For m-level voltage, each of (m-1) carrier signals are required and they are phase shifted by an angle of 22.5 degrees from the adjacent bands as shown in Fig. 3.
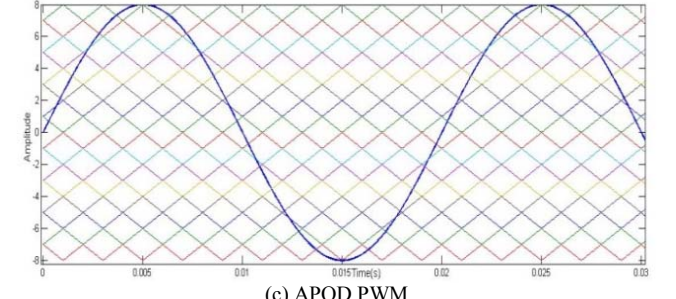
III. Variable Switching Frequency PWM

This technique uses the conventional sinusoidal reference signal and the (m-1) carrier signals with variable frequency. For the seventeen level inverter there are 16 distinct carriers with variable or different frequency and same amplitude. This modulation method signifies that harmonic energy is concentrated at carrier frequency. Carriers of the 17-level inverter with variable switching frequency have frequency between 2 kHz- 5 kHz and are shown in Fig. 4.
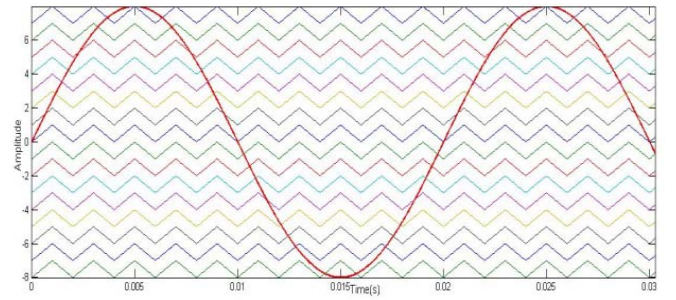
(a) PD PWM
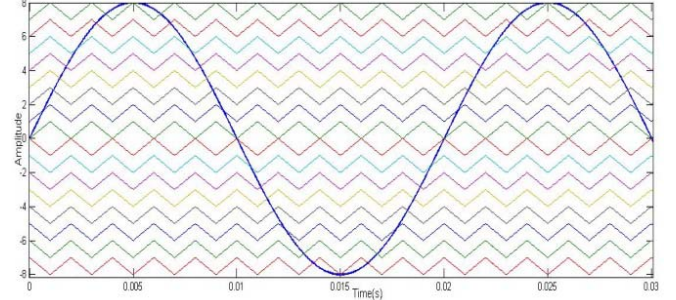
(b) POD PWM

(c) APOD PWM

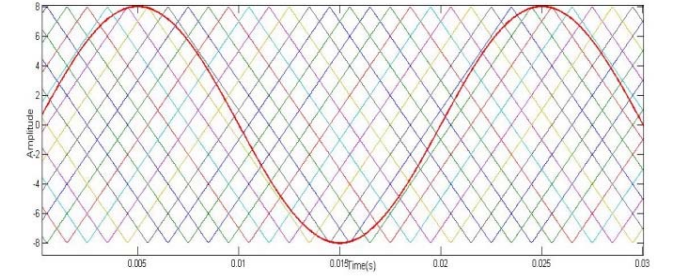Fig. 2 Level shift constant switching frequency PWM: (a) PD PWM, (b) POD PWM, (c) APOD PWM
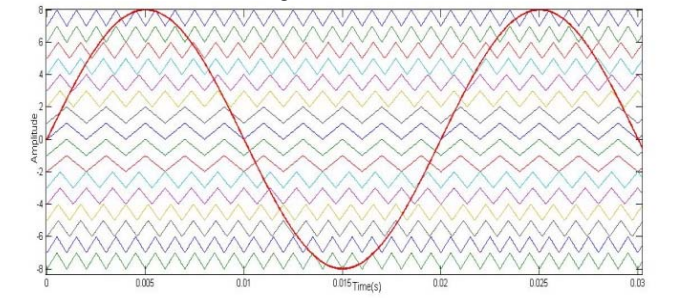

Fig. 3 PSC PWM

Fig. 4 Variable switching frequency pulse width modulation

IV. TRAPEZOIDAL TRIAUNGLAR MULTICARRIER PWM [11]

In trapezoidal triangular multicarrier (TTMC) PWM the carrier consists of two waveforms viz, a trapezoidal and a triangular wave as shown below in fig. 5 The lower part is trapezoidal and upper part is triangular wave. The amplitude modulation index and frequency ratio will be same as that of triangular multicarrier wave as given in equations (1) and (2) respectively
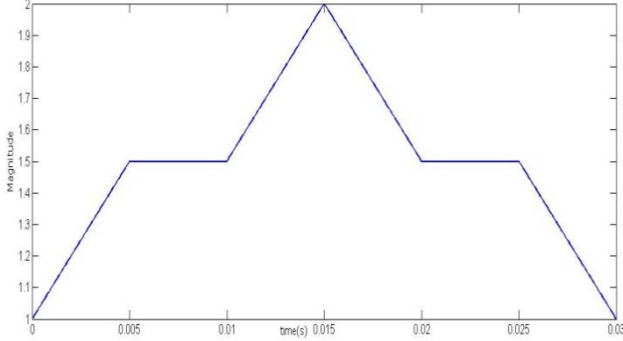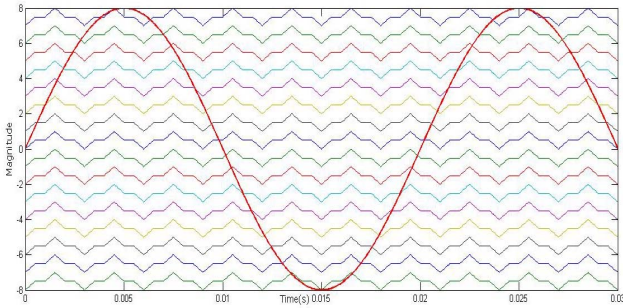

Fig. 5 A typical trapezoidal triangular multicarrier

Fig. 6 Sixteen TTMC with sinusoidal wave for 17 level inverter

V. RESULTS AND DISSCUSSION

The voltage and current waveform obtained using TTMC PWM technique for symmetrical and asymmetrical multilevel (17 level) inverters are shown in Fig. 7 and Fig. 8, respectively.
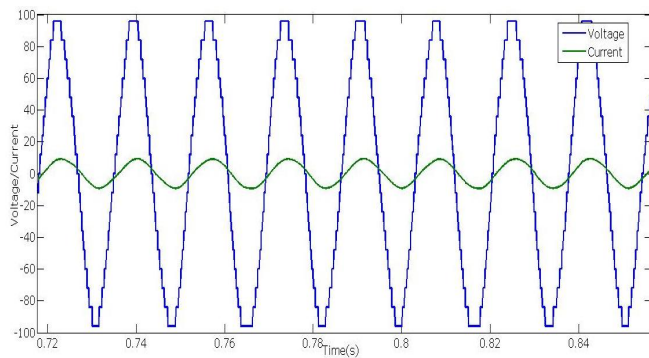
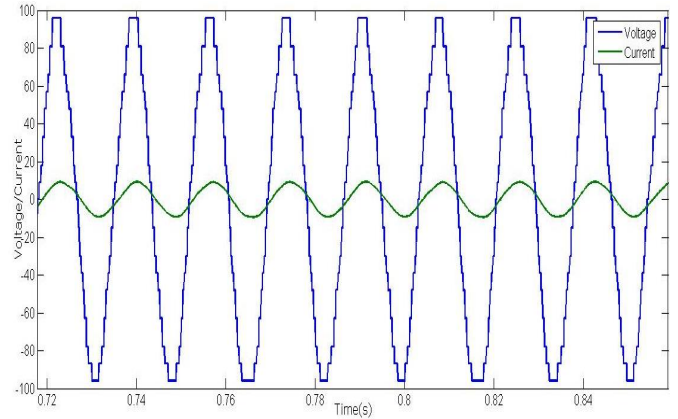Fig. 7 Voltage and current waveform for symmetrical MLI with TTMC

Fig. 8 Voltage and current waveform for asymmetrical MLI with TTMC

The percentage of THD of the output voltage can be calculate by

$$\text{THD} = \frac{\sqrt{\sum_{n=2,3,\dots}^{\infty} V_n^2}}{V_1}$$

Where V_1 and n are the fundamental component of voltage and order of the harmonics, respectively. The comparison in the percentage of THD, fundamental voltage and order of harmonics using three types of level shift constant switching frequency (viz. PD, POD, APOD) PWM, phase shift (PS) PWM and variable switching frequency (VSF) PWM and trapezoidal triangular multicarrier (TTMC) PWM for symmetrical and asymmetrical multilevel inverters based on results obtained from MATLAB/SIMULINK simulations are given in table 1 and table 2 respectively. The variation in THD of output voltage with the modulation index is also plotted for different modulation methods in fig. 9

TABLE. I HARMONICS AND % THD FOR DIFFERENT CARRIERS IN SPWM FOR SYMMETRICAL SEVENTEEN LEVEL CHB INVERTER

PWM Methods	Funda mental volt.	THD (%)	Order of harmonic (% of fundamental)					
			3rd	5th	7th	11th	13th	15th
PD	95.82	3.55	0.45	0.5	1.0	0.2	0.5	0.32
POD	96.12	3.51	0.08	0.08	0.04	0.15	0.03	0.01
APOD	96.02	3.52	0.03	0.09	0.05	0.13	0.06	0.07
PSC	97.74	6.09	0.59	1.19	1.46	0.4	3.05	0.66
VSF	95.91	4.78	1.63	1.39	1.01	0.41	0.11	0.27
TTMC	96.93	3.04	0.36	0.22	0.25	0.37	0.22	0.36

PWM methods	Fundamental Volt.	THD (%)	Order of harmonic (% of fundamental)					
			3rd	5th	7th	11th	13th	15th
PD	98.77	4.89	2.48	0.23	1.3	0.57	0.39	0.36
POD	96.12	4.55	0.13	0.16	0.44	0.2	0.02	0.14
APOD	96.02	4.52	0.09	0.12	0.08	0.9	0.06	0.21
PS	97.76	6.77	0.64	1.14	1.49	0.84	3.04	0.78
VSF	95.86	5.72	1.7	1.32	1.1	0.56	0.17	0.35
TTMC	96.82	4.32	0.37	0.21	0.13	0.46	0.12	0.33
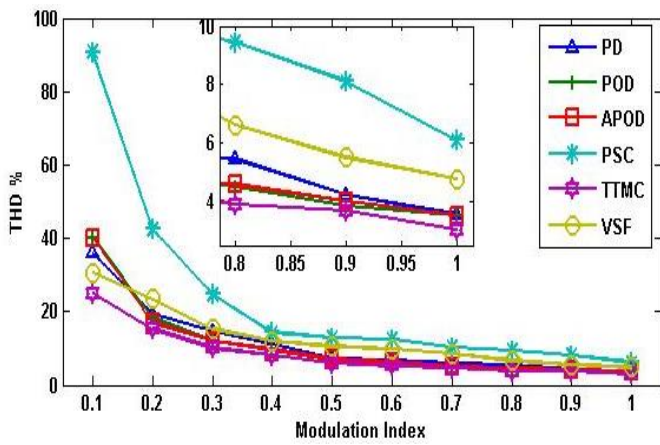
Fig. 9 Comparison of % THD at different modulation indices for different PWM techniques in 17 level CHB inverter
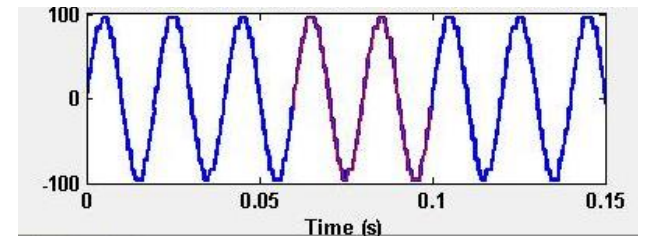
A. Simulation Results

To verify the effectiveness of carrier based PWM methods, they are applied to a single phase cascaded H-bridge seventeen level inverter in symmetrical and asymmetrical structure. Eight identical dc sources of 12V are used for symmetric structure, Eight different dc sources whose sum is 96V are used for asymmetric structure. The voltage waveforms and % of THD corresponding to different PWM schemes are using MATLAB/SIMULINK shown in Fig. 10 (a),(b),(c),(d),(e),(f) for symmetrical MLI and Fig. 11 (a),(b),(c),(d),(e),(f) for asymmetrical MLI, respectively.
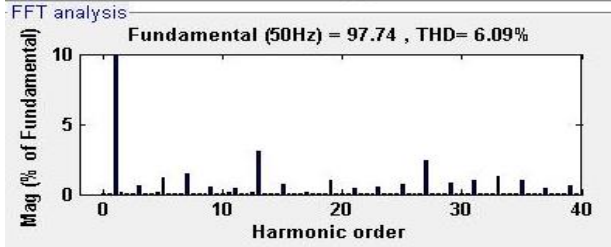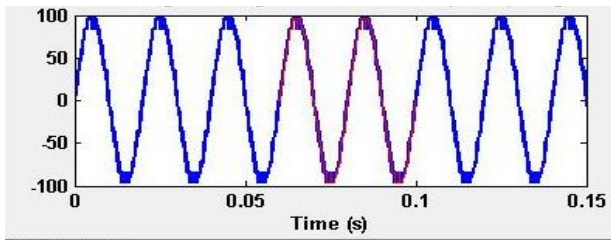

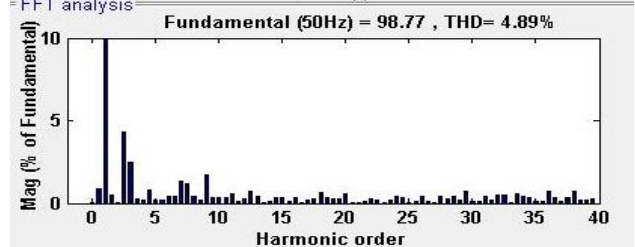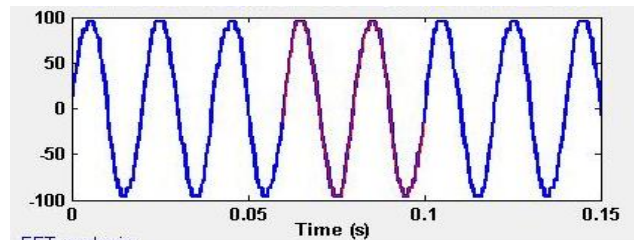Fundamental (50Hz) = 95.82 , THD= 3.55%

(a) PD PWM

Fundamental (50Hz) = 96.12 , THD= 3.51%

(b) POD PWM

Fundamental (50Hz) = 96.01 , THD= 3.52%
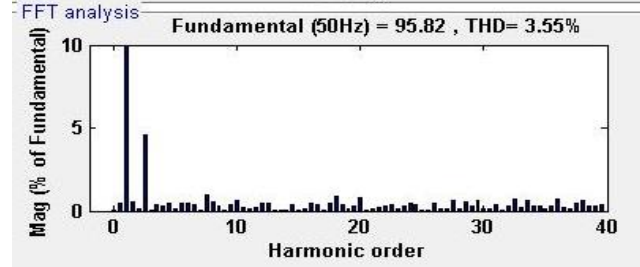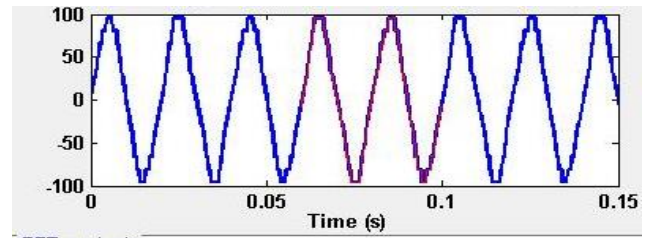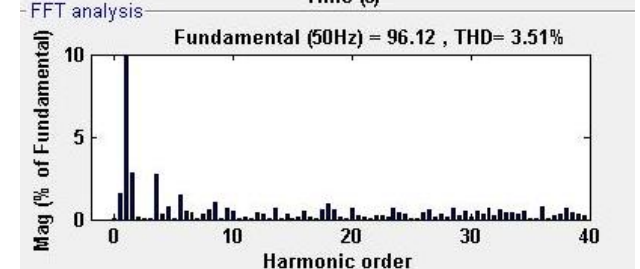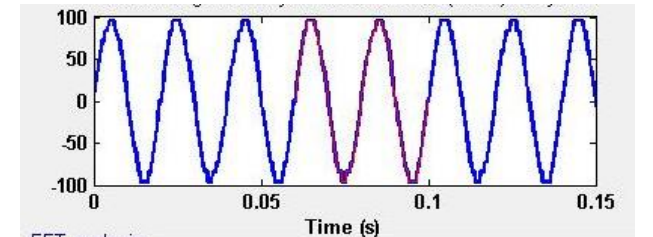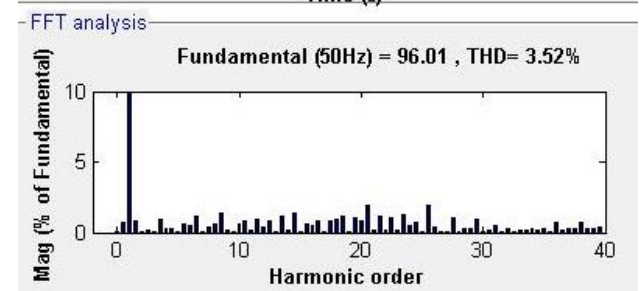
(c) APOD PWM

(d) PSC PWM

(a) PD PWM
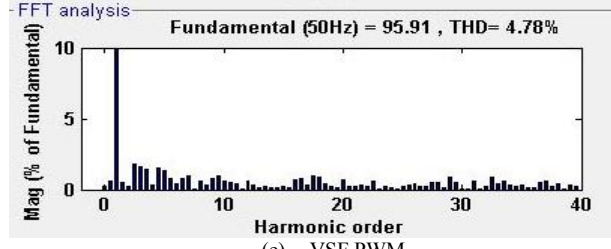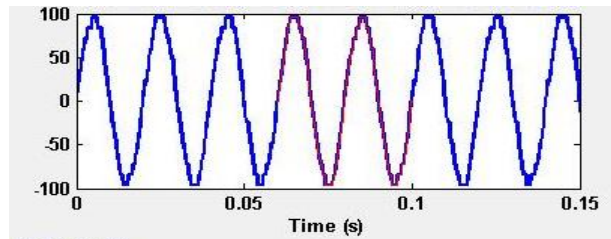
(e) VSF PWM
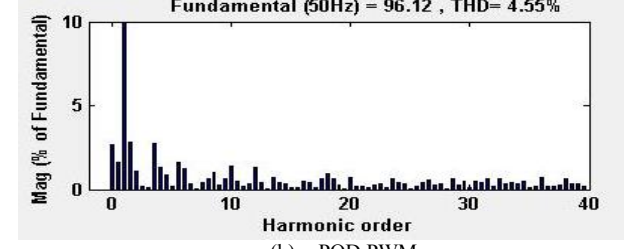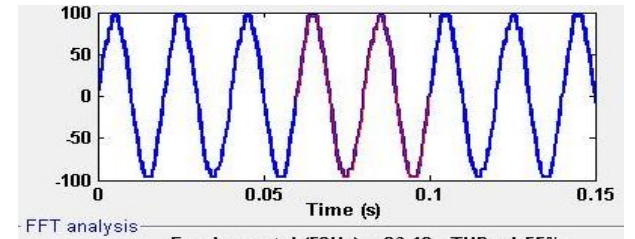
(b) POD PWM

(f) TTMC PWM

(c) APOD PWM

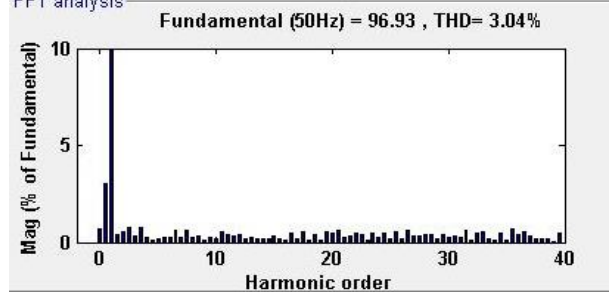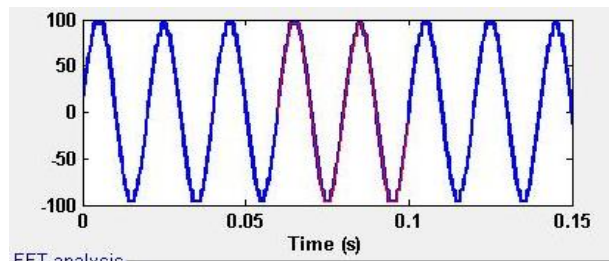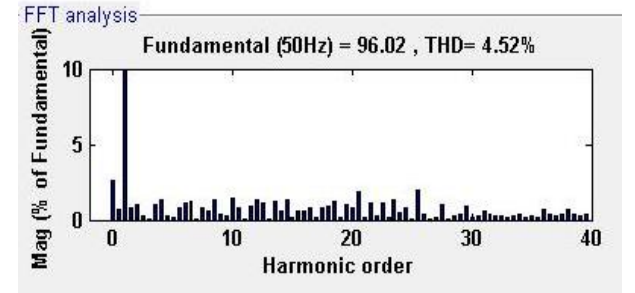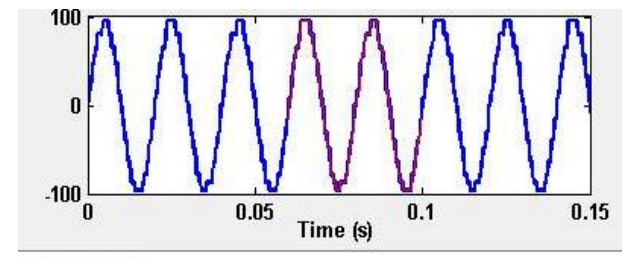Fig. 10 Voltage waveform and harmonic spectrum in symmetrical CHB 17 level inverter with different PWM techniques: (a) PD PWM, (b) POD PWM, (c) APOD PWM, (d) PSC PWM, (e) VSF PWM, (f) TTMC PWM
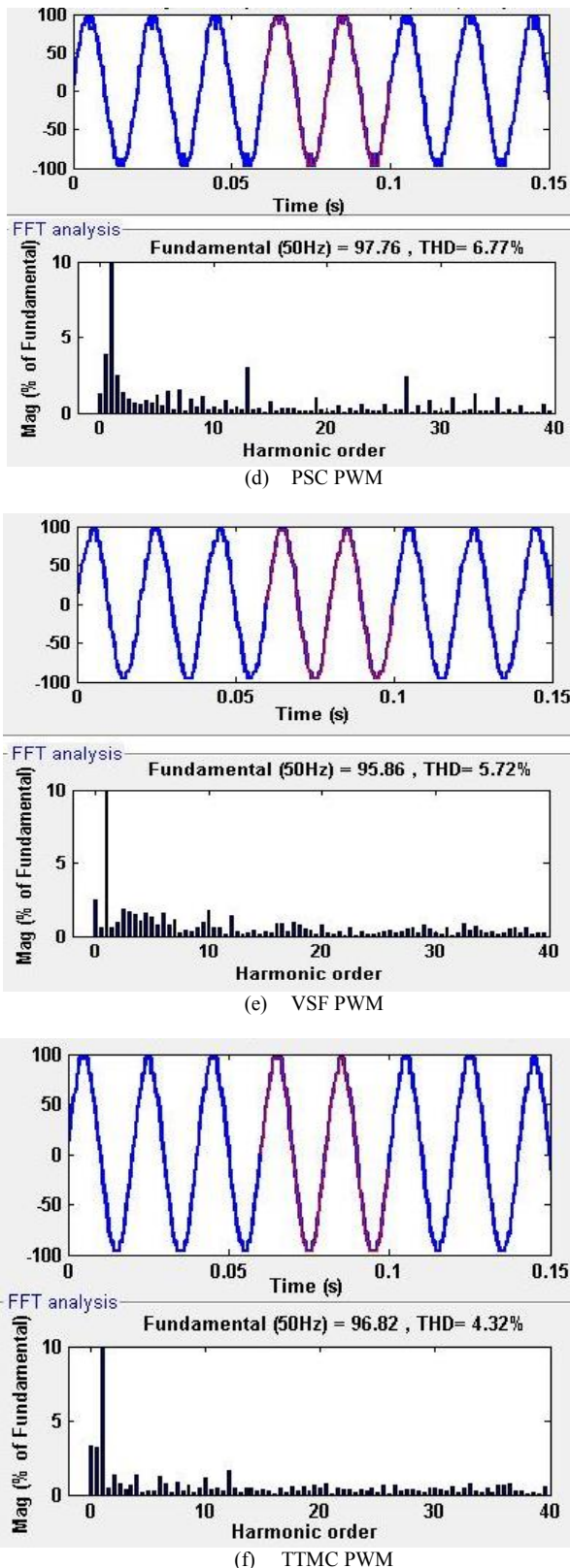
(d) PSC PWM

(e) VSF PWM

(f) TTMC PWM

Fig. 11 Voltage waveform and harmonic spectrum in asymmetrical 17 level CHB inverter with different PWM techniques: (a) PD PWM, (b) POD PWM, (c) APOD PWM, (d) PSC PWM, (e) VSF PWM, (f) TTMC PWM

VI. CONCLUSSION

This paper present simulation results for a Seventeen level cascaded H bridge inverter in symmetric configuration and also in asymmetric configuration using various types of PWM like level shift constant switching frequency (PD, POD, APOD) PWM, phase shift PWM, variable switching frequency PWM, and TTMC PWM, and simulation results are compared. The THD values are low in symmetric structure compared those in asymmetric MLI, but output voltage is higher in asymmetric MLI. The proposed trapezoidal triangular carrier wave as new multicarrier for sinusoidal pulse width modulation technique gave minimum THD of 3.04 %, whereas corresponding values are high in triangular LS PWM, PSC PWM and CSF PWM for both symmetrical and asymmetrical structure. The output voltage with the proposed TTMC PWM is also second highest, just next to phase shift PWM, but PSC PWM has major disadvantage of highest THD. So, the TTMC PWM is the best choice for minimum THD and maximum output voltage. The experiments will shortly start to verify the validity of above simulation results.

REFERENCES

[1] J.S. Lai, , F.Z. Peng, "Multilevel converters – a new bread of converters", *IEEE Trans. Ind. Appl.,vol. 32, pp. 509–517,1996*

[2] R. Teodorescu, F. Blaabjerg, J.K. Pedersen, E. Cengelci, P.N. Enjeti, "Multilevel inverter by cascading industrial VSI''*, IEEE Trans. Ind. Electron.,vol. 49, pp. 832–838,2002*

[3] P. Palanivel, S.S. Dash "Analysis of THD and output voltage performance for cascaded multilevelinverter using carrier pulse width modulation technique" *IET Power Electronics vol. 4, no. 8, pp. 951-958, 2010*

[4] J. Rodriguez, J.S. Lai, F. Zheng Peng, "Multilevel inverters; a survey of topologies, controls, and applications''*, IEEE Trans. Ind. Electron.,vol. 49, pp. 724–738,2002*

[5] L.M. Tolber, T.G. Habetler, "Novel multilevel inverter carrier based PWM method", *IEEE Ind. Appl., vol. 35, pp. 1098–1107, 1999.*

[6] B. P. McGrath, D. G. Holmes, T. Meynard "Reduced PWM harmonic distortion for multilevel inverter operating over a wide modulation range", *IEEE Trans. Power Electron., vol. 21, pp. 941–949,2006*

[7] S.Sirisukpraserl, J.S. Lai, T.H. Liu. "Optimum harmonic reduction with a wide range of modulation indices for multilevel converter"*, IEEE Trans. Ind. Electron.,vol. 49, pp. 875– 881,2002*

[8] R. Naderi, A. Rahmati, "Phase-shifted carrier PWM technique for general cascaded inverters", *IEEE Trans. Power Electron.,vol. 23, pp. 1257– 1269,2008*

[9] O. L. Jimenez, R. A. Vargas, J. Aguayo "THD in Cascade Multilevel Inverters Symmetric and Asymmetric" *2011ERAMC IEEE computer society. pp. 289-295,Mexico, Nov 2011.*

[10] Bin Wu "Cascaded H-bridge multilevel inverters" in *High-Power Converters and AC Drives*, Hoboken, NJ: John Wiley and Sons. Inc., Chaps. 7, pp. 119–142, 2006.

[11] A. Paikray, B. Mohanty " A new multicarrier SPWM technique for five level cascaded H-bridge inverter" *IEEE international conf.(ICGCCEE'14),pp. 1-6,Coimbatore, March 2014.*