Multicarrier PWM Strategies for Hybrid Symmetrical Multilevel Inverter with Reduced Switch Count

Ujwala Gajula, Gouthami Eragamreddy

Abstract: Multilevel inverters are widely used for high power and high voltage applications. The performance of multilevel inverters are superior to conventional two level inverters in terms of reduced total harmonic distortion, higher dc link voltages, lower electromagnetic interference and increased quality in the output voltage waveform. This paper presents a single phase hybrid eleven level multilevel inverter topology with reduced switch count to compensate the above mentioned disadvantages. This paper also presents various high switching frequency based multi carrier pulse width modulation strategies such as Phase Disposition PWM Strategy (PDPWM), Phase Opposition and Disposition PWM Strategy (PODPWM), Alternate Phase opposition Disposition PWM (APODPWM), Carrier Overlapping PWM (COPWM), Variable frequency carrier PWM (VFPWM), Third Harmonic Injection PWM (TFIPWM) applied to the proposed eleven level multilevel inverter and is analyzed for RL load. FFT analysis is carried out and total harmonic distortion, fundamental output voltage are calculated. Simulation is carried out in MATLAB/SMULINK.

Keywords: Multi Carrier Pulse Width Modulation, Total Harmonic Distortion, Hybrid Multilevel Inverter, High Switching Frequency PWM.

I. INTRODUCTION

In recent years, there has been a lot of increase in interest on the concept of multilevel power conversion. The theory of power conversion multilevel inverters has gained lot of advantages [1]-[3]. Recent researches have evolved in the introduction of novel inverter topologies and unique modulation techniques. However the mostly addressed multilevel inverter topologies are neutral-point clamped (NPC) inverter, the flying capacitor inverter, and the cascade inverter. Among these cascaded H Bridge configuration is more attractive because of its simplicity in design. Conventional H-Bridge inverters have applications in industrial side because of easy way of controlling and simple switching configuration. However the number of components and switching losses are quite high. "Although the above mentioned conventional MLI finds number of applications, all these topologies need more number of switches to produce higher voltages. So in the recent years the research focuses on reducing the number of components. Reducing the number of diodes used, voltage sources, switches and capacitors can improve the quality as well as reduce the switching losses, overall cost etc.," [5].

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In this paper a new symmetrical 11 level hybrid multilevel inverter topology is proposed with different PWM techniques to obtain more accurate waveform with minimal switching losses and lower harmonic distortion. This paper analyzes a comparative study carried out on different high switching frequency based carrier Pulse width modulation Techniques.

II. PROPOSED HYBRID INVERTER TOPOLOGY

The proposed hybrid eleven level multilevel inverter mainly eliminates higher number of switches that are helpful in producing the output voltages when compared to the existing multilevel inverters. The fundamental structure of the proposed hybrid inverter topology is given in fig.1 (a). It consists of two isolated DC sources and six unidirectional switches (T_1, T_2, T_3, T_4, S_1 and S_2). The basic unit generates five level of output voltage ($2V_{dc}$, V_{dc}, 0, $-V_{dc}$, $-2V_{dc}$). The switching states are given in Table 1. Fig.1 (b) gives the proposed 11 level symmetrical novel inverter topology with reduced switch count.
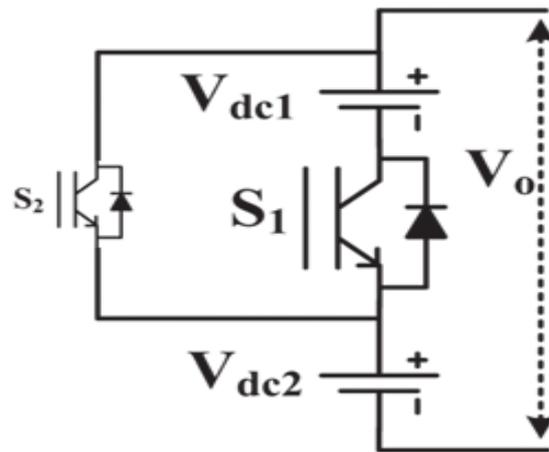

Fig.1. a) Basic Structure

Table1. Switching States for Basic Unit

S.No.	Level of Combined Signal	Switches in ON State	Output Voltage
1	2	S_1, T_1, T_2	$+2V_{dc}$
2	1	S_2, T_1, T_2	$+V_{dc}$
3	0	T_1, T_3	0
4	-1	S_2, T_3, T_4	$-V_{dc}$
5	-2	S_1, T_3, T_4	$-2V_{dc}$

3	$S_{2a}, S_{1b}, H_1, H_4, S_{4b}, S_{3b}$	$+3V_{dc}$
4	$S_{3a}, S_{2b}, S_{1b}, H_1, H_4, S_{4b}$	$+4V_{dc}$
5	$S_{4a}, S_{3b}, S_{2b}, S_{1b}, H_1, H_4$	$+5V_{dc}$
6	H_1, H_4	0
7	$S_{4b}, S_{3b}, S_{2b}, S_{1b}, H_2, H_3$	$-V_{dc}$
8	$S_{1a}, H_2, H_3, S_{4b}, S_{3b}, S_{2b}$	$-2V_{dc}$
9	$S_{2a}, S_{1b}, H_2, H_3, S_{4b}, S_{3b}$	$-3V_{dc}$
10	$S_{3a}, S_{2b}, S_{1b}, H_2, H_3, S_{4b}$	$-4V_{dc}$
11	$S_{4a}, S3_b, S2_b, S_{1b}, H_2, H_3$	$-5V_{dc}$
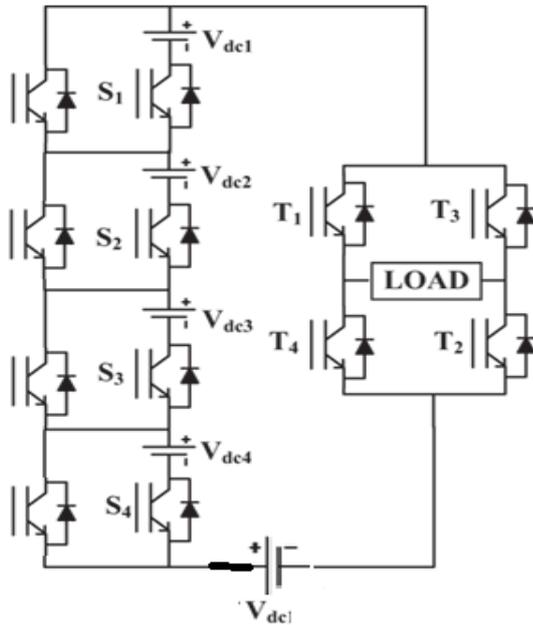
Fig.1. b) proposed MLI Topology

In the propose hybrid Multilevel Inverter topology the number of switches (N_S) required to produce number of levels (N_L) is given by eq (1) & (2) and the maximum output voltage is given by eq (3).

$$Ns = 2n+2 \text{ ----- (1)}$$

Where n is the number of DC sources used

$$N_L = 2Ns - 5 \text{ ------- (2)}$$

$$V_{Max,O} = n\, Vdc \text{ ----- (3)}$$

The switching states of the proposed hybrid multilevel inverter from the Simulink model Fig 8. are given in Table 2.

Table 2. Switching States of the Proposed MLI

S.No	Conducting Switches	Output Voltage
1	$S_{4b}, S_{3b}, S_{2b}, S_{1b}, H_1, H_4$	$+V_{dc}$
2	$S_{1a}, H_1, H_4, S_{4b}, S_{3b}, S_{2b}$	$+2V_{dc}$

III.   PULSE WIDTH MODULATION STRATEGIES

In the literature of MLI's various pulse width modulation strategies are proposed. A classification of these strategies is proposed in reference [4] and is updated in reference [6]. These strategies are classified based on the switching frequency as:

1. Low Switching Frequency PWM Techniques (selective harmonic elimination (SHE), space vector control, and nearest level control)
2. High Switching Frequency PWM Techniques (Multicarrier PWM and space vector pulse-width modulation [SVPWM]).

Multi carrier based PWM methods depending on different carrier signals is selected for the proposed topology. Carrier PWM based methods have more than one carrier wave it can be either triangular wave or saw tooth wave. As far as the carrier signals are concerned there are multiple control parameters of freedom, which includes amplitude, offset between carriers, frequency and phase of each carrier. In this paper the following multicarrier based modulation strategies are proposed.

➢ Phase Disposition PWM (PDPWM)
➢ Phase Opposition and Disposition PWM (PODPWM)
➢ Alternate Phase opposition Disposition PWM (APODPWM)
➢ Carrier Overlapping PWM (COPWM)
➢ Variable frequency carrier PWM (VFPWM)
➢ Third Harmonic Injection PWM (TFIPWM)

A. Phase Disposition PWM Strategy: In this method, the entire carrier signals above and below zero reference are in same phase. Carrier and reference wave arrangement is shown in fig. 2(a) & (b).
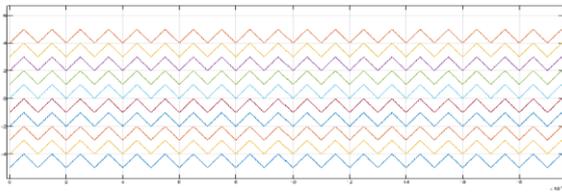
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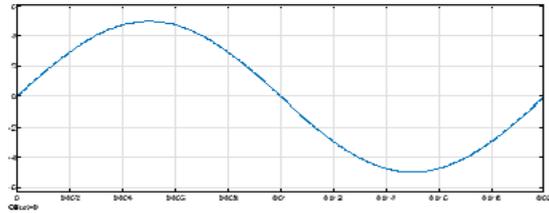**Fig.2 (a) Multi carrier signals for PD-PWM**

Fig.2 (b) Reference signal of PD-PWM

Phase Opposition and Disposition PWM Strategy: In this method, all the carriers have same amplitude and frequency. All the carriers above zero reference are in same phase and all the carriers below zero reference are in same phase but 180 degrees phase shifted with respect the above carriers. The arrangement is shown in fig. 3(a) & (b).
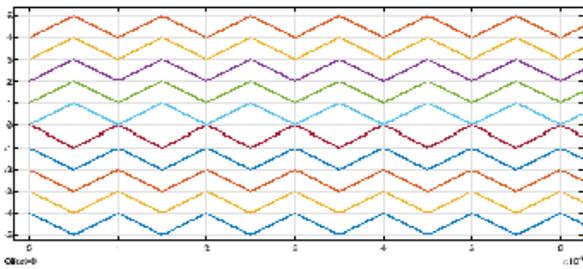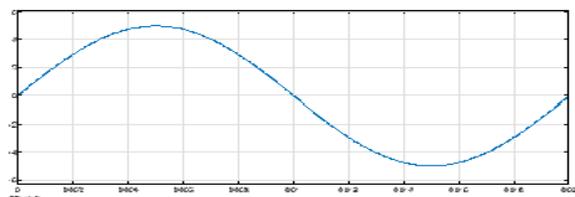

Fig.3 (a) Multi carrier signals for POD-PWM

Fig.3 (b) Reference signal of POD-PWM

B. Alternate Phase opposition Disposition PWM Strategy: In this method, all the carriers have same amplitude and frequency. All the alternate carriers are in same phase and the others are phase shifted by 180 degrees. The arrangement is shown in fig. 4(a) & (b).
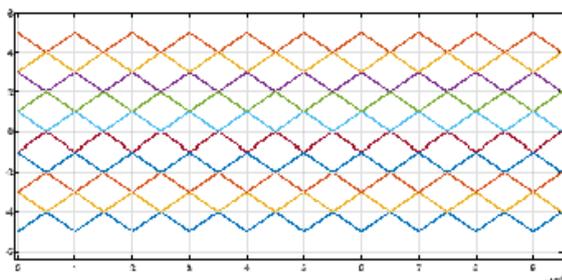
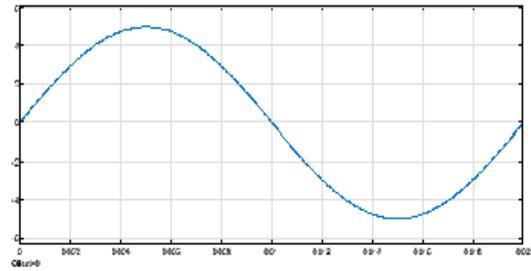
Fig.4 (a) Multi carrier signals for APOD-PWM

Fig.4 (b) Reference signal of APOD-PWM

C. Carrier Overlapping PWM Strategy: In this method, the carriers are overlapped with each other as shown in fig. 5(a) & (b). The amount of overlapping decides the quality of the output waveform.
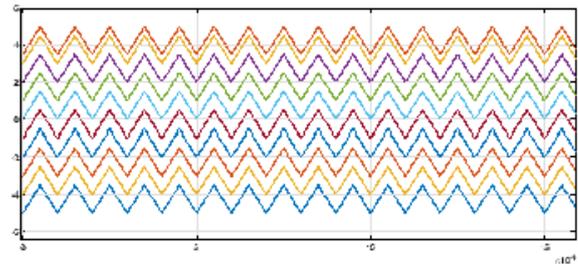

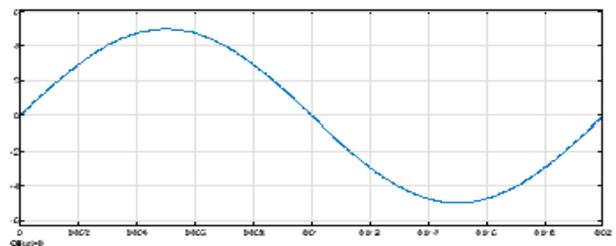**Fig.5 (a) Multi carrier signals for CO-PWM**

Fig.5 (b) Reference signal of APOD-PWM

D. Variable frequency carrier PWM Strategy: In this method, the frequency of the carriers is not same. Some carriers have same frequency others have different frequency. The arrangement is shown in 6(a) & (b).
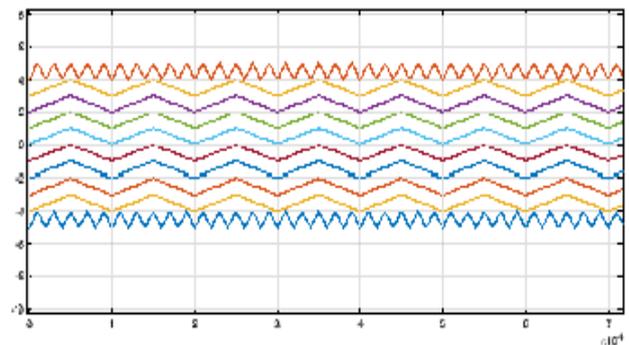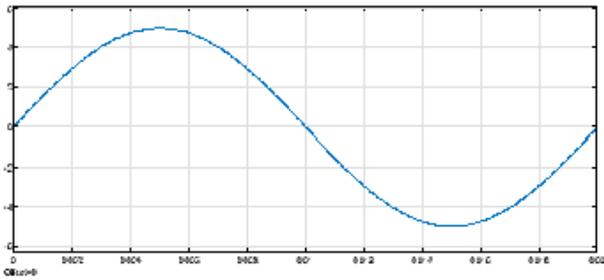

Fig.6 (a) Multi carrier signals for VF-PWM

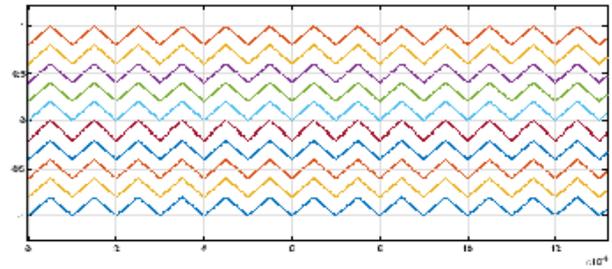**Fig.6 (b) Reference signal of VF-PWM**

Fig.7 (a) Multi carrier signals for Third Harmonic Injection –PWM

Third Harmonic Injection PWM Strategy: In this technique the effect of third harmonic is cancelled in the output voltage spectrum. The gain is increased by the addition of third harmonic component to the fundamental. The arrangement is shown in 7(a) & (b).
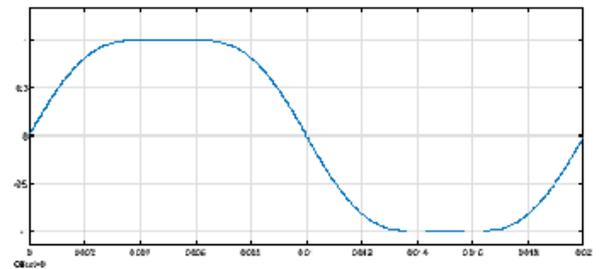

Fig.7 (b) Reference signal of Third Harmonic Injection –PWM

IV. RESULTS AND SIMULATION

Fig.8 gives the simulation model of the proposed eleven level multilevel inverter topology and fig.9. Shows the eleven level output voltage generated.
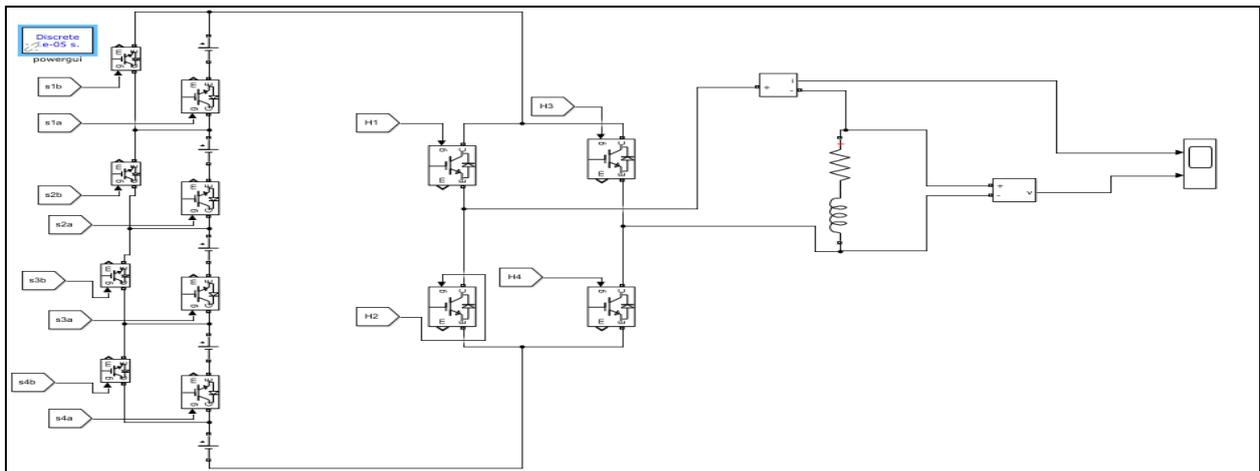

Fig.8 Simulink Model of Eleven Level Hybrid Multilevel Inverter with Reduced Switch Count
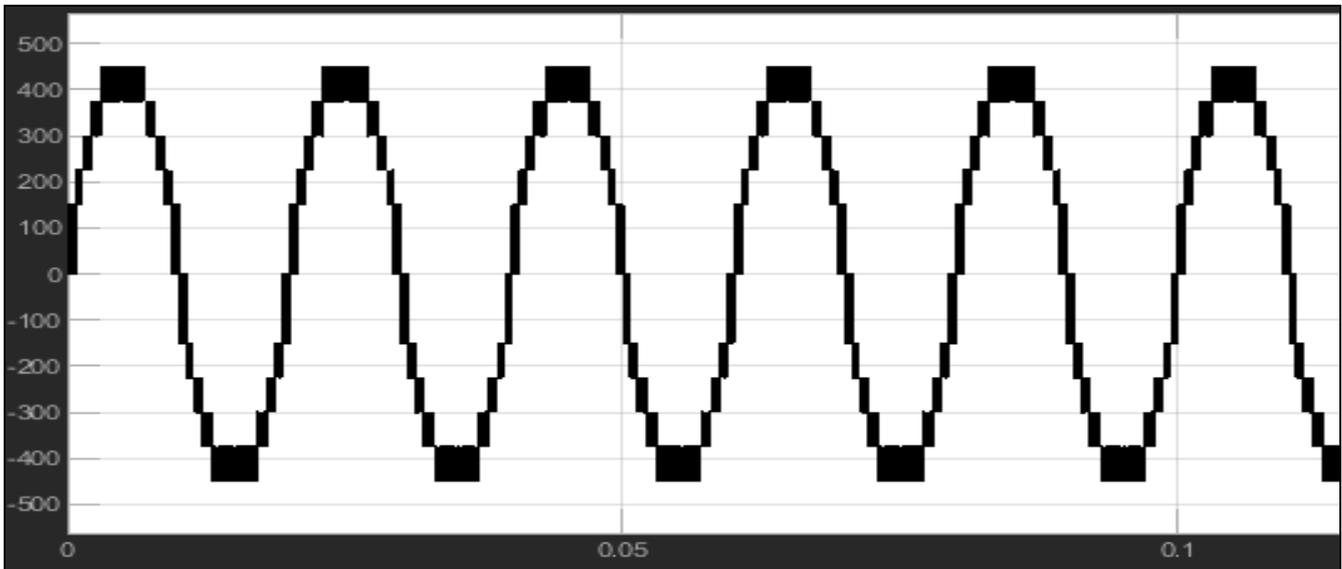
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Fig.9. Output Voltage of Eleven Level Hybrid Multilevel Inverter with Reduced Switch Count

Fig.10, Fig.11, Fig.12, Fig.13, Fig.14 and Fig.15 shows the FFT analysis of PD, POD, APOD, CO and THI PWM. Table 3 gives the comparison between different pulse width modulation techniques versus % THD and Vrms.

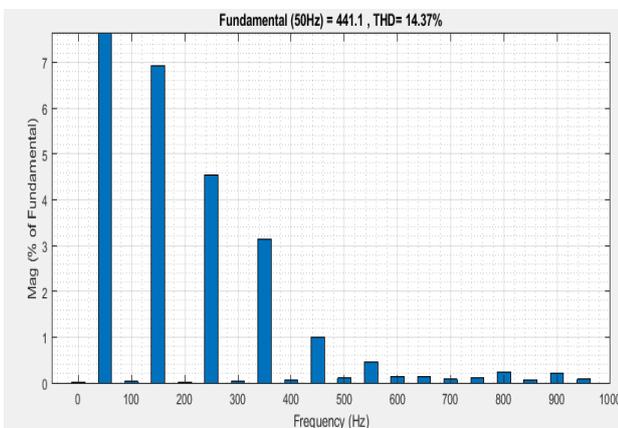**A. Phase Disposition Pulse Width Modulation:**

Fig.10. Frequency Spectrum of Output Voltage of PD-PWM

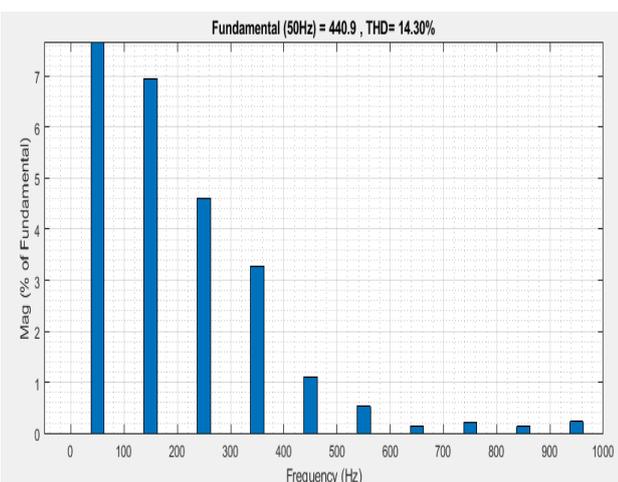**B. Phase Opposition Disposition Pulse Width Modulation**

Fig.11 Frequency Spectrum of Output Voltage of POD-PWM

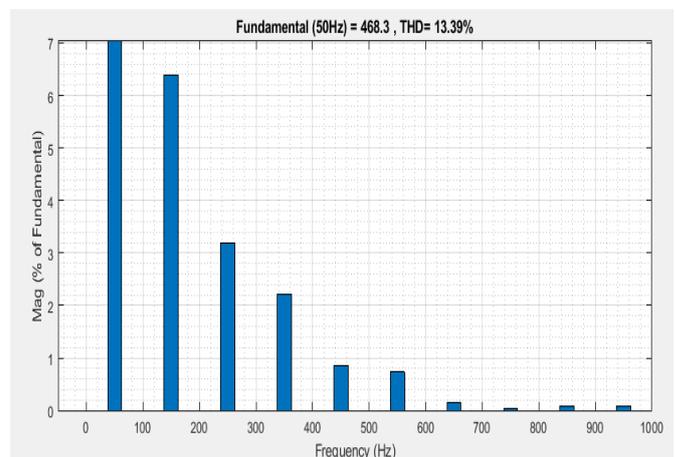**C. Alternate Phase Opposition Disposition Pulse Width Modulation**

Fig.12 Frequency Spectrum of Output Voltage of APOD-PWM

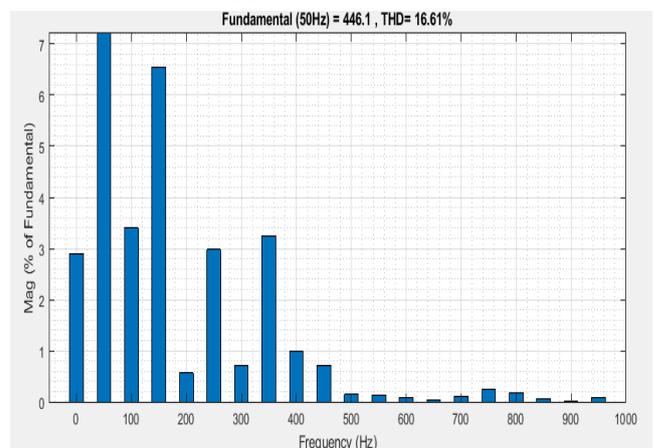**D. Carrier Overlapping Pulse Width Modulation**

Fig.13 Frequency Spectrum of Output Voltage of CO-PWM

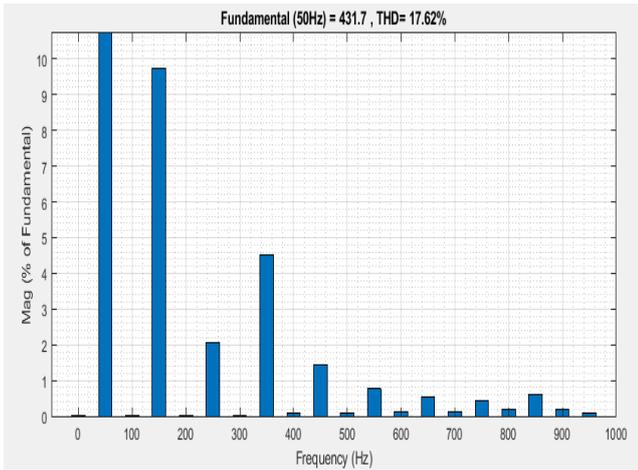## E. Variable frequency carrier Pulse Width Modulation

Fig.14 Frequency Spectrum of Output Voltage of VF-PWM
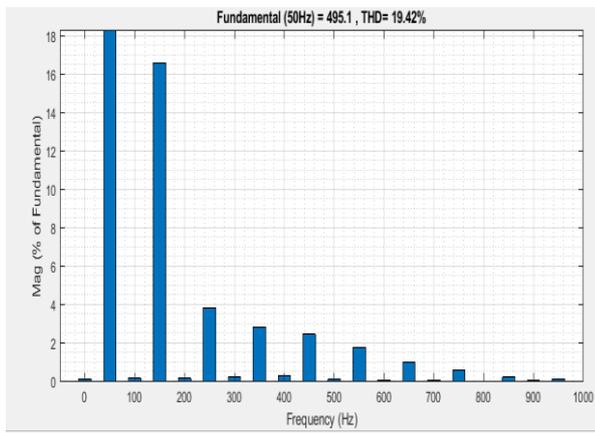
F. Third Harmonic Injection Pulse Width Modulation

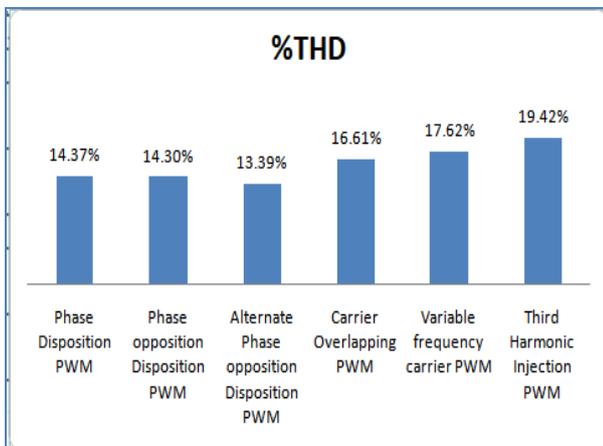**Fig.15 Frequency Spectrum of Output Voltage of Third Harmonic Injection –PWM**

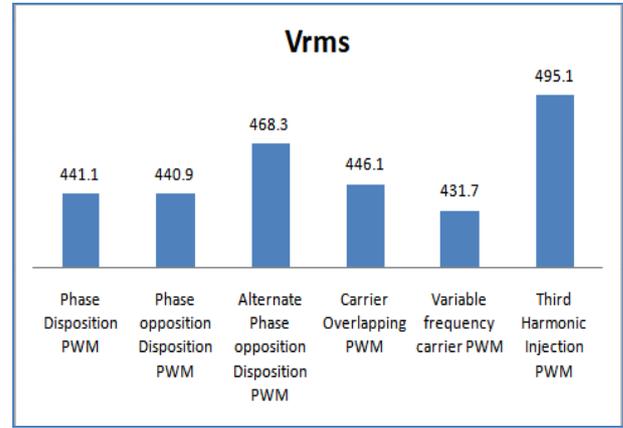**Fig.16 Graph of Different PWM Techniques versus % THD**

Fig.17 Graph of Different PWM Techniques versus Vrms

Table 3: Comparison Table of different PWM Techniques versus THD & RMS Output Voltage

S.No	PWM Technique	% THD	Vrms
1.	Phase Disposition PWM	14.37%	441.1V
2.	Phase opposition Disposition PWM	14.30%	440.9V
3.	Alternate Phase opposition Disposition PWM	13.39%	468.3V
4.	Carrier Overlapping PWM	16.61%	446.1V
5.	Variable frequency carrier PWM	17.62%	431.7V
6.	Third Harmonic Injection PWM	19.42%	495.1V

V. CONCLUSION

The performance analysis of any power converter depends on the pulse width modulation technique employed and so the multilevel inverters. In this paper the results of single phase eleven level hybrid symmetrical multilevel inverter with reduced switch count with RL load is obtained through MATLAB/SIMULINK, various performance indices like total harmonic distortion and V_{rms} associated with power quality issues are measured, analyzed and tabulated. From the fig.16 and fig.17 it is observed that APOD PWM provides output with relatively lower distortion and Third Harmonic Injection PWM provides high fundamental output voltage achieving maximum DC utilization.

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