PERFORMANCE ANALYSIS OF MULTI CARRIER BASED PULSE WIDTH MODULATED THREE PHASE CASCADED H-BRIDGE MULTILEVEL INVERTER

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Abstract - *A Multilevel inverter is a power electronic device built to synthesize a desired A.C voltage from several levels of DC voltages. Multilevel inverters have been an important development in recent years, owing to their capability to increase the voltage and power delivered to the motor with semiconductor switches which are available today. There are many methods available to control the cascaded multilevel inverter. In this paper, comparison of various multi carrier Sine Pulse Width Modulation (SPWM) control like Alternative Phase Opposition Disposition (APOD), Phase Opposition Disposition (POD), Phase disposition (PD), Phase shifted (PS) and Hybrid-carrier techniques in both uni polar and bipolar mode of three phase cascaded H-bridge 5- level inverter have been analyzed. Effective results have been demonstrated by simulation using mat lab 7.6.. Total harmonic distortion and distortion factor (DF) have been estimated for different modulation indices and the comparative results indicate that the cascaded multi level inverter triggered by the developed phase shifted SPWM strategy exhibits reduced total harmonic distortion. Hardware implementation has been carried out for the phase shifted SPWM strategy which has exhibited better performance*

Keywords *- Multi level inverter, Three phase cascaded H bridge inverter, Total harmonic Distortion, Sine pulse width modulation, Carrier control technique, Modulation index.*

1. Introduction

Multilevel inverters have gained more attention in high power applications because it has got many advantages [1-4]. It can realize high voltage and high power output by using semiconductor switches without the use of transformer and dynamic voltage balance circuits. When the number of output levels increases, harmonics of the output voltage and current as well as electromagnetic interference decrease.

The basic concept of a multilevel inverter is to achieve high power by using a series of power semiconductor switches with several lower dc voltage sources to perform the power conversion by synthesizing a staircase voltage waveform [1,5]. To obtain a low distortion output voltage nearly sinusoidal, a triggering signal should be generated to control the switching frequency of each power semiconductor switch [3,5,14]. In this paper the triggering signals of multi level inverter (MLI) are designed by using the sinusoidal PWM scheme. A three phase cascaded H-bridge multi (five) level inverter has been taken to prove the simulation results for the APOD, POD, PS, PD and Hybrid control techniques.

Fig.1 shows a three-phase five-level cascaded multilevel inverter. It requires a total of six D.C voltage sources (for each phase, two D.C voltage sources) arranged in a star fashion.

2. Control Techniques for Multilevel Inverter

There are different control techniques available for a cascaded H-bridge MLI [15,19]. Among all those techniques, PWM control technique which produces less total harmonic distortion (THD) values is

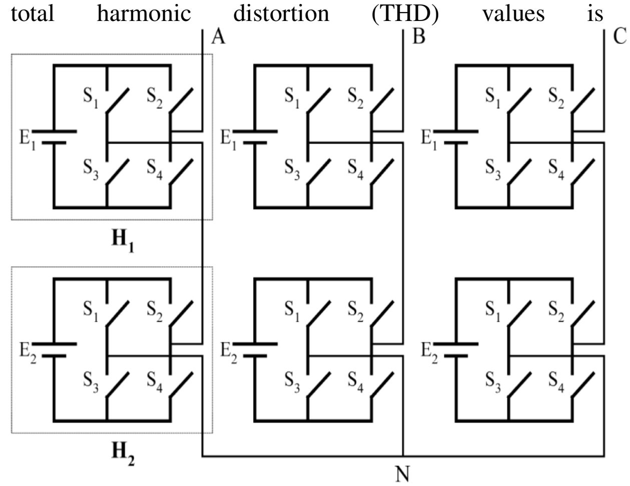

Fig.1 Conventional 3-phase 5-level Cascaded MLI

most preferable. In PWM technique, modulated signal can be of pure sinusoidal, third harmonic injected signals and dead band signals. The carrier signal is a triangular wave. For generating triggering pulses of MLI, pure sinusoidal wave as modulating signal and multi carrier signal which is of triangular in shape have been considered [10,14,15]. For a m-level MLI, m-1 carrier signals are required. For generation of triggering pulses to the cascaded MLI, carrier signals are constructed for different modulation indices using APOD, POD, PD, PS and Hybrid control techniques. Output phase voltage has been measured using all the techniques. THD analysis for the APOD, POD, PD, PS and Hybrid carrier control techniques in both bipolar, unipolar mode of operation for different modulation indices have been presented in this paper.

Multilevel sinusoidal PWM can be classified as shown in Fig.3 [14-19].

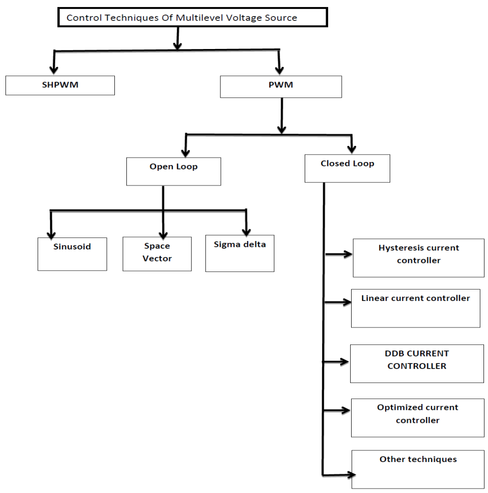

Fig. 2 Control techniques for a cascaded H-bridge MLI

3. Sinusoidal PWM

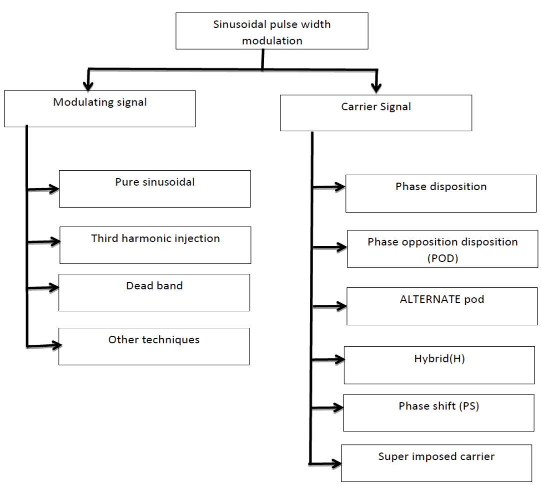

Fig 3. Classification of Sinusoidal PWM

a) Multicarrier PWM Techniques

Multi carrier pwm techniques have sinusoidal signal as reference wave and triangular which is four in number as carrier signals [6-7].

Frequency modulation ratio (m_f) is defined as the ratio of carrier frequency (f_c) and modulating frequency (f_m)

$$m_f = f_c / f_m \quad (1)$$

Amplitude modulation ratio (m_a) is defined as the ratio of amplitude of modulating signal and amplitude of carrier signal

$$m_a = A_m / (n\text{-}1) A_c \quad (2)$$

b) Modes of operation of generating triggering pulses

In bipolar mode, to generate the firing pulses to IGBT four (level-1) carrier signals of triangular in nature and one sine wave are used.

In the case of unipolar mode of operation, two reference sine waves and two carrier signals (level-1)/2 which are triangular in nature are used to generate the pulses [6,15].

c) Alternative phase opposition Disposition (APOD)

This technique requires m-1 carrier signals, for a m-level inverter, to be phase disposed from each other by 180 degree alternatively as shown in Fig4. For bipolar mode of operation four carrier signals have been taken. In the upper half two signals are 180 degrees out of phase with each other and the same case will repeat for lower half also. APOD control technique for bipolar mode and unipolar mode is shown in Fig.4 , Fig.5 respectively.

In APOD control technique, most significant harmonics appear as sidebands around the carrier frequency fc. There will not be any harmonics at fc.

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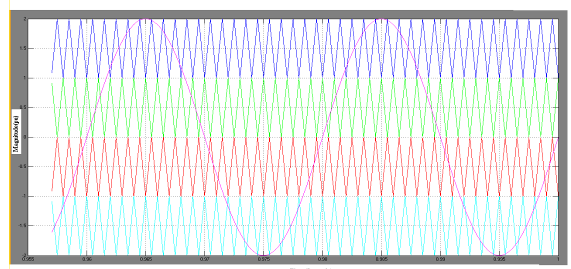

Fig 4 Carrier arrangement for bipolar mode of APOD technique

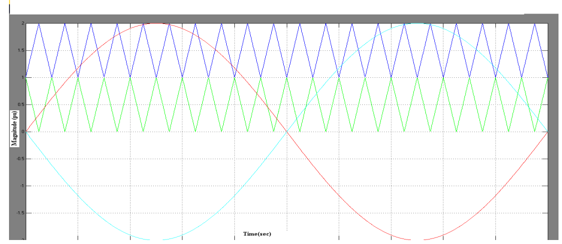

Fig 5 Carrier arrangement for unipolar mode of APOD technique

d) Phase opposition Disposition (POD)

This technique also requires m-1 carrier signals which are triangular in nature for a five-level MLI and the reference signal to be of sinusoidal. In the upper half two signals are in same phase and the lower half two signals will be 180 degree out of phase with the upper half signals.

In bipolar mode, carrier signals and the reference are generated as shown in Fig.6. But in the case of unipolar mode, two carrier signals are in same phase as shown Fig.7

In POD control technique, most significant harmonics is centered at fc and other harmonic components appear as sidebands around the carrier frequency fc.

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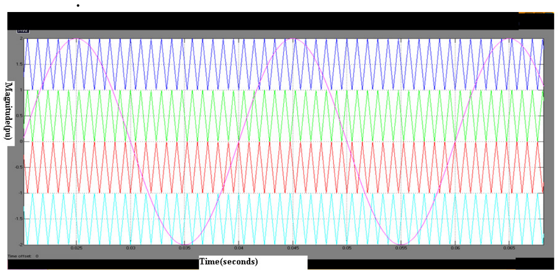

Fig.6. Carrier arrangement for bipolar mode of POD technique

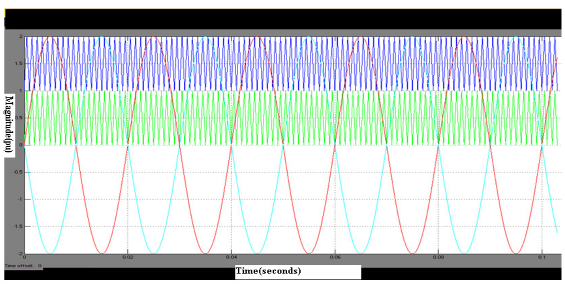

Fig.7. Carrier arrangement for unipolar mode of POD technique

e) Phase disposition carrier control technique (PD)

For a five level MLI, this technique also requires four carrier signals which are triangular in nature and the reference signal is of sinusoidal. Here all carrier signals are in phase but level shifted [13].

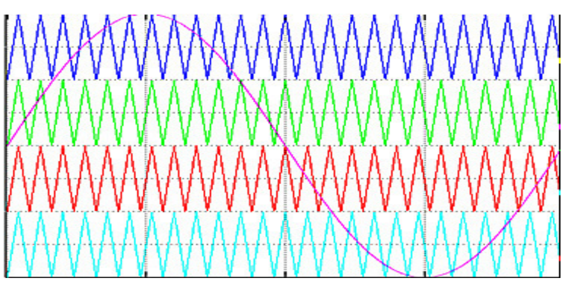

Fig.8. Carrier arrangement for bipolar mode of PD technique

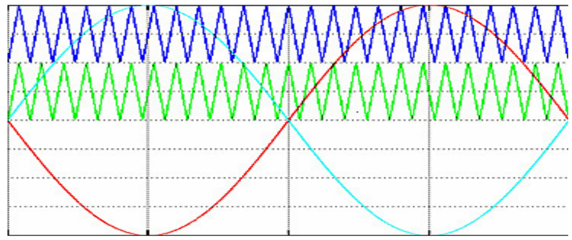

Fig.9. Carrier arrangement for unipolar mode of PD technique

f) Phase shifted carrier control technique (PS)

This technique employs four numbers of carriers which are all phase shifted by 90 degree accordingly as shown in Fig.10 [18].

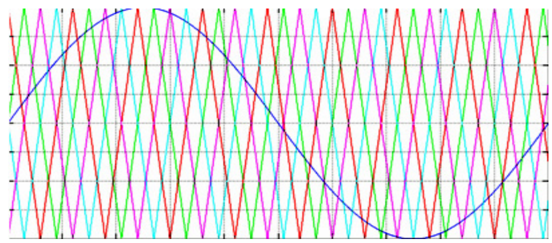

Fig.10. Carrier arrangement for bipolar mode of PS technique

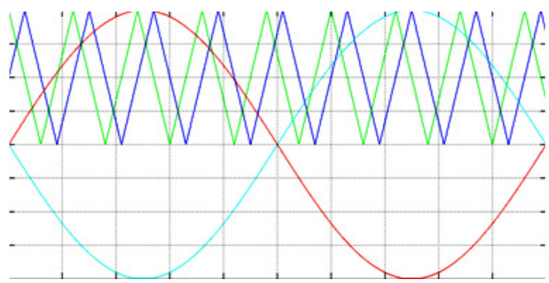

Fig.11. Carrier arrangement for uni polar mode of PS technique

g) Hybrid carrier control technique (H-carrier)

In hybrid carrier control technique dealt here, carrier waveforms are generated by the combination of PD and PS technique.

In bipolar mode of operation only one reference sine wave and four carrier waves are used to generate pulses. In the case of unipolar mode of operation two reference sine waves and two carrier waves are used to generate the pulses. The two sine waves are 180 degrees out of phase with each other. Hybrid carrier technique in both bipolar and unipolar mode of operation are shown in Fig.12 & 13.

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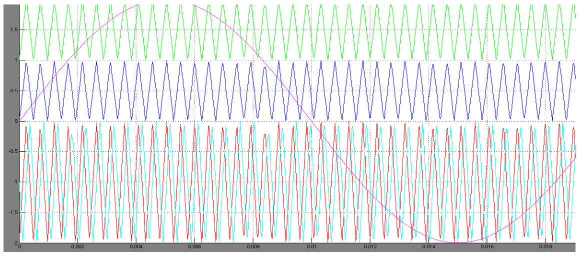


Fig.12. Carrier arrangement for bipolar mode of Hybrid technique

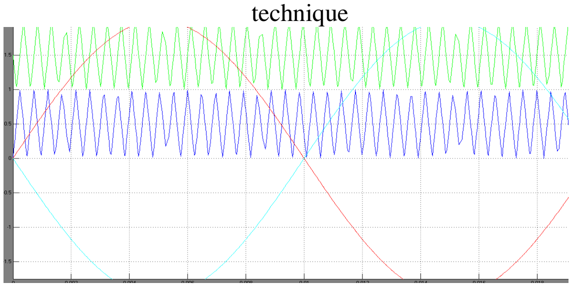


Fig.13. Carrier arrangement for uni polar mode of Hybrid technique

4. Matlab / Simulink Model

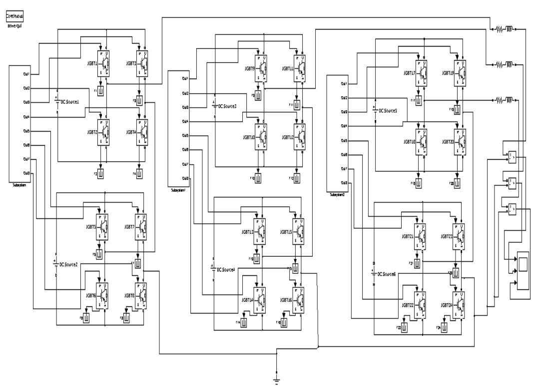


Fig.14.Simulation circuit for the 3-phase cascaded H-bridge MLI fed with R-L load

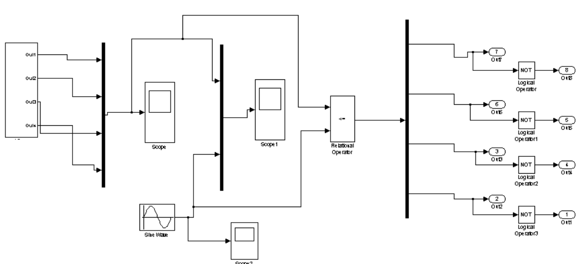


Fig.15.Simulink model for multi-pulse generation for bipolar mode

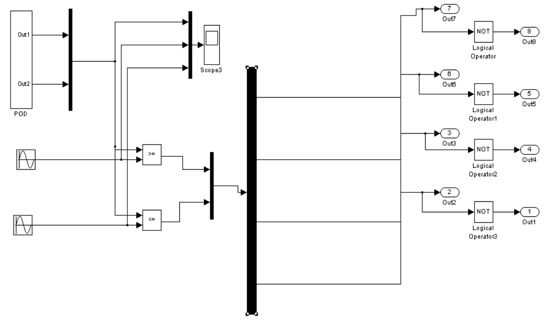
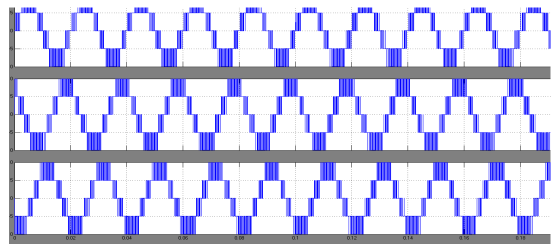


Fig.16. Simulink model for multi pulse generation for uni polar mode

5. Simulation Results and Discussion



Time (sec)

Fig.17.Phasevoltage using APOD technique in bipolar mode for mi = 0.8

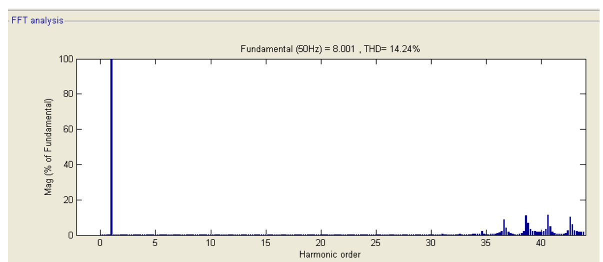


Fig.18 Frequency spectrum for APOD technique in bipolar mode for mi = 0.8

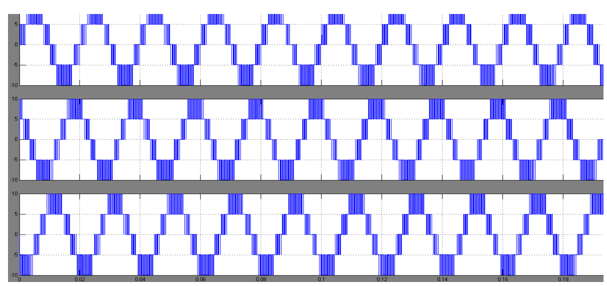


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Fig.19. Phase voltage using APOD technique in uni polar mode for mi = 0.8

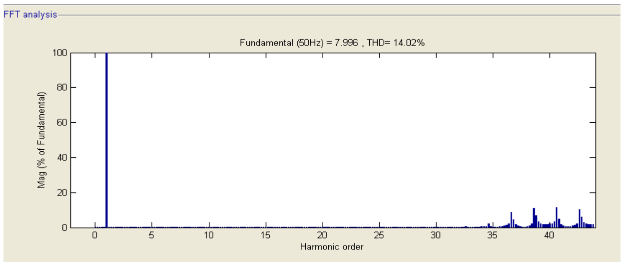
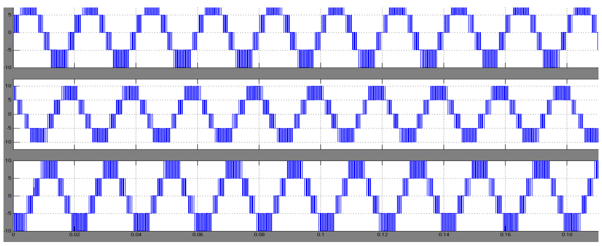


Fig.20 Frequency spectrum for APOD technique in uni polar mode for mi = 0.8



Time (sec)

Fig.21 Phase voltage using POD technique in bipolar mode for mi = 0.8

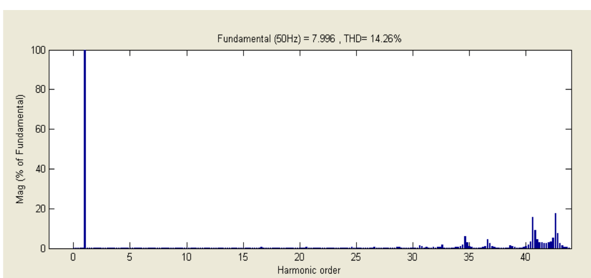
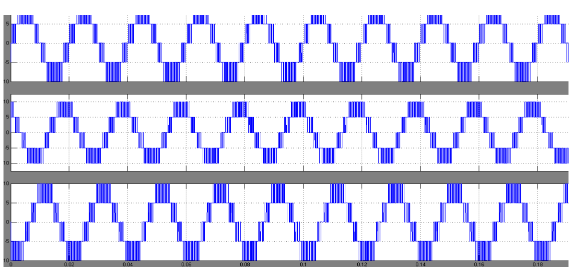


Fig. 22 Frequency spectrum for POD technique in bipolar mode for mi = 0.8



Time (sec)

Fig.23 Phase voltage using POD technique in uni polar mode for mi = 0.8

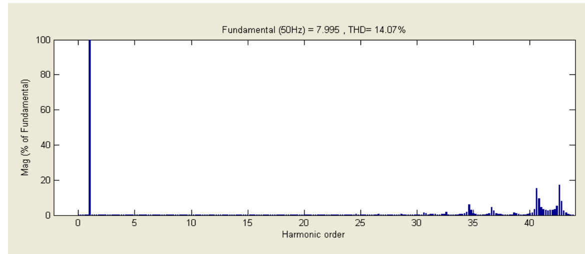
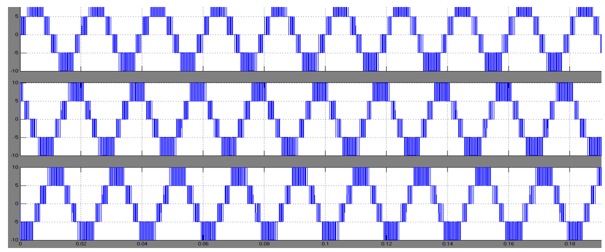


Fig.24. Frequency spectrum for POD technique in unipolar mode for mi = 0.8



Time (sec)

Fig.25.. Phase voltage using PD technique in bipolar mode for mi = 0.8

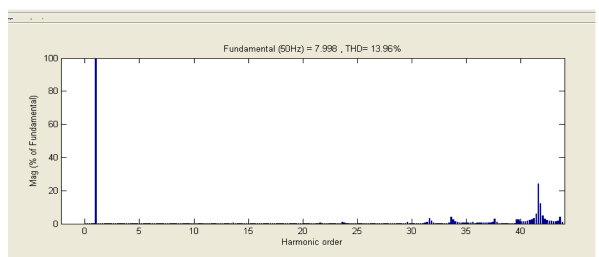
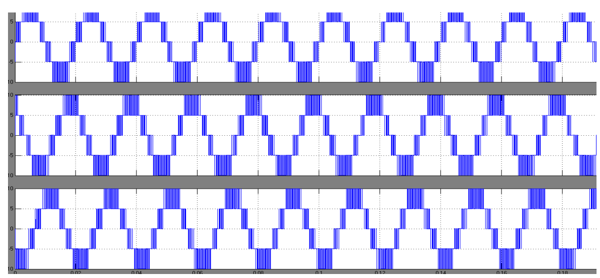


Fig.26 Frequency spectrum for PD technique in bipolar mode for mi = 0.8



Time (sec)

Fig.27. Phase voltage using PD technique in unipolar mode for mi= 0.8

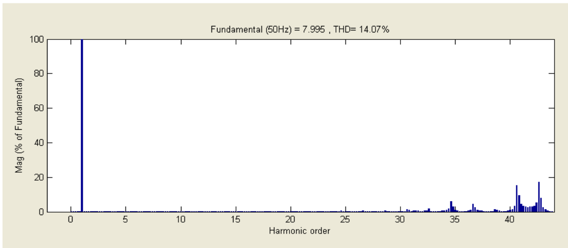


Fig.28. Frequency spectrum for PD technique in uni polar mode for mi = 0.8

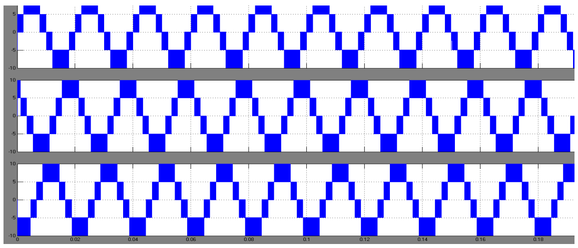

Time (sec)

Fig.29 Phase voltage using PS technique in bipolar mode for mi = 0.8

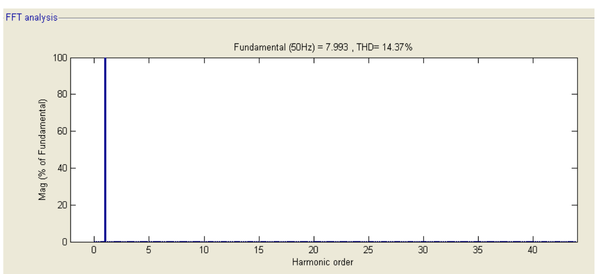


Fig.30 Frequency spectrum for PS technique in bipolar mode for mi = 0.8

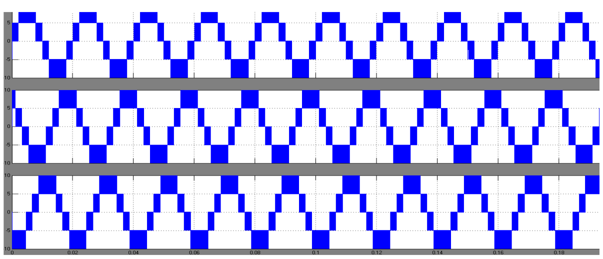

Time (sec)

Fig.31 Phase voltage using PS technique in unipolar mode for mi = 0.8.

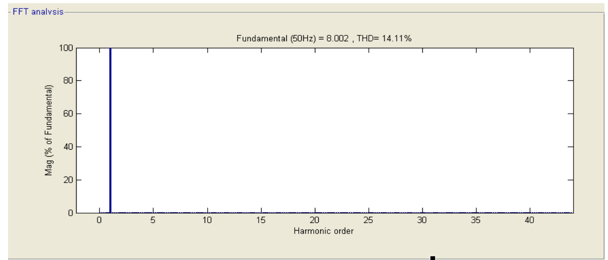


Fig.32 Frequency spectrum for PS technique in Uni polar mode for mi = 0.8

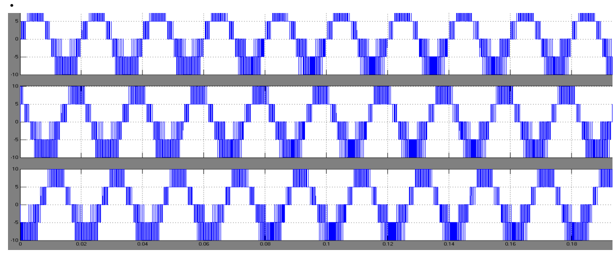

Time (sec)

Fig.33 Phase voltage using Hybrid technique in bipolar mode for mi = 0.8

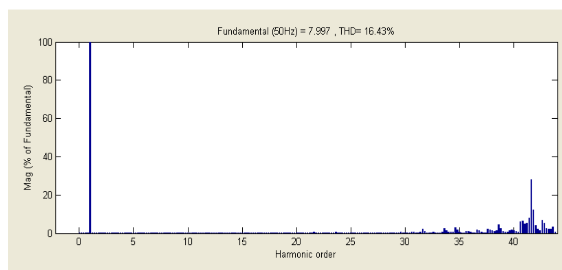


Fig.34.Frequency spectrum forHybrid technique in bipolar mode for mi = 0.8

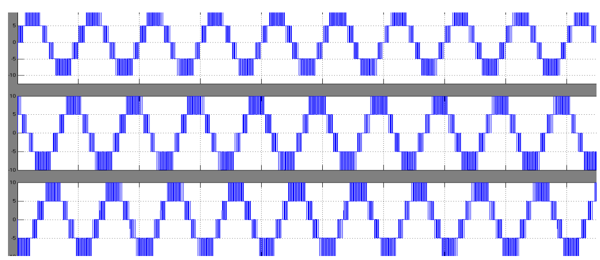

Time (sec)

Fig.35 Phase voltage using Hybrid technique in unipolar mode for mi= 0.8

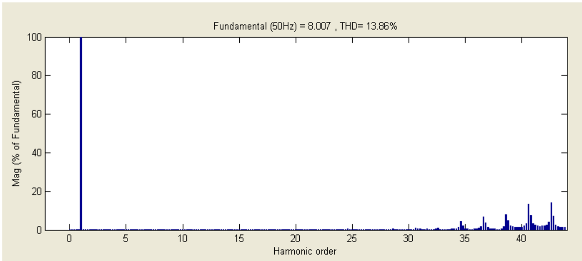


Fig.36. Frequency spectrum for Hybrid technique in unipolar mode for mi = 0.8

To obtain the above simulated results, Inverter was simulated using simulink matlab 7.6. Parameters used for simulation are as follows : V_{dc}=5 v, f_m = 50hz, f_c= 2100 hz (mf=42). Load is assumed to be of RL load where R=100 Ohms, L=20 mH.

THD analysis has been done for the modulation indices of 0.8, 0.9 and 1.0. Fig 14 shows the simulation circuit of three phase cascaded H- bridge multilevel inverter. Fig 15, 16 prove the method of multi pulse generation for bipolar and uni polar mode of operation. Fig 17 to 36 shows the output voltage and frequency spectrum for mi = 0.8 of various SPWM techniques such as POD, APOD, PD, PS, Hybrid. Fig 37 and Fig 38 depict the graphical analysis of percentage of THD versus modulation indices for bipolar and unipolar mode.

The results obtained from simulations have been tabulated in Table1 and Table 2 for various modulation indices for easy reference. Analysis of various factors like distribution factor, THD has been done using the Phase output voltage of the inverter and has been tabulated in Table 3 and Table 4. It is found that phase shifted bipolar control technique with mi=1 has shown better performance, therefore this technique has been used for hardware implementation.

Table 1. MI vs Total harmonic distortion for bipolar mode

MI	PD	POD	APOD	PS	HYBRID
0.8	13.96	14.26	14.24	14.37	16.43
0.9	12.32	12.14	12.21	12.31	14.54
1	9.87	10.08	10.23	9.67	11.76

Table.2 MI vs Total harmonic distortion for unipolar mode

MI	PD	POD	APOD	PS	HYBRID
0.8	13.86	14.07	14.02	14.11	13.86
0.9	12.21	12.09	12.22	12.11	12.35
1	10.17	10.17	10.02	9.96	9.96

Table.3 % DF for various modulation indices using bipolar technique

MI	PD	POD	APOD	PS	HYBRID
0.8	7.15	6.995	7.005	6.94	6.1
0.9	8.09	8.209	8.1633	8.097	6.86
1	10.08	9.872	9.7288	10.28	8.473

Table.4 % DF for various modulation indices using uni polar technique

MI	PD	POD	APOD	PS	HYBRID
0.8	7.2	7.1	7.115	7.1	7.2
0.9	8.1633	8.243	8.156	8.23	8.064
1	9.786	9.786	9.931	9.999	9.960

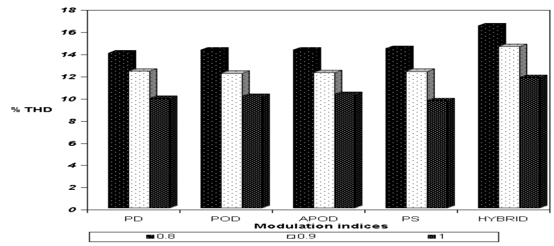


Fig.37. % THD for various modulation indices for bipolar mode.

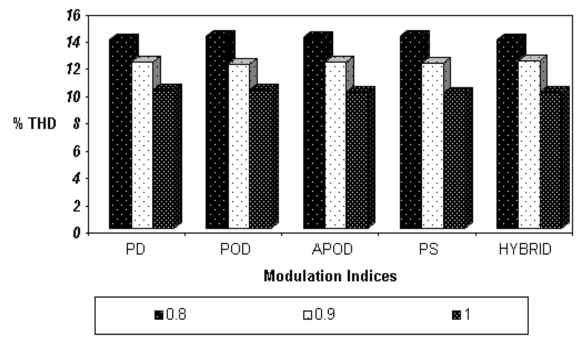


Fig.38. % THD for various modulation indices for unipolar mode

6. Experimental Results and Discussion

Fig.39. Hardware setup for three phase cascaded MLI

A hardware setup of three phase five level cascaded inverter has been built (shown in Fig.39) to validate the simulated results. The hardware parameters for MLI are as follows : Inverter rating = 5KW, three phase load R = 100 ohms, L = 20mH, each source Vdc = 5V, fundamental frequency 50HZ, switching frequency 2KHZ and Xilinix Spartan – DSP controller (FPGA).

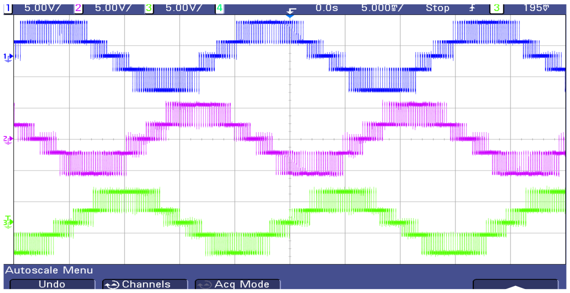


Fig.40. Output voltage using hardware setup

The three phase output voltage waveform obtained using the hardware setup is shown in Fig.40

7. Conclusion

In this paper, various pwm control strategies for three phase cascaded multilevel inverter has been presented. THD analysis and distortion factor have been estimated for different modulation indices. From the analysis we can say that the THD for PS technique for MI =1 is less when compared with APOD, PD, POD and Hybrid control techniques. In that PS technique also, bipolar mode of operation has given less THD values compared to uni polar.

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