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Comparative Analysis of Cascaded Multilevel Inverter With Sine PWM and Inverted Sine PWM

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***Abstract*— Multi-level inverters possesses the capability of generating high quality of output and reduce the harmonic distortion in the output waveform. Hence, they are used in a variety of applications such as motor drives, photovoltaic systems, adjustable speed drives (ASD's). Cascaded multilevel inverter is most feasible topology with two DC sources for medium and high power applications. This paper presents the comparison of Sine PWM and Inverted sine PWM control strategy of a cascaded multilevel inverter.**

Inverted sine PWM control strategy offers improved efficiency and performance compared to SPWM. ISPWM control strategy generates very less THD, switching losses compared to conventional sine PWM. In this paper, the simulations for the single phase and three phase five level cascaded H-bridge using both inverted sine and sine PWM control strategy are carried out using MATLAB/SIMULINK software.

Keywords*— *Cascaded multilevel inverter, Sine PWM, Inverted Sine PWM.

I. INTRODUCTION

Multilevel inverters that synthesize a desired AC voltage from several levels of DC voltage has gained significant importance in medium to high power applications, with cost effective solution. Power electronics and microelectronics advancements in multilevel inverters, by increasing the number of levels instead of increasing the size of filters to improve the magnitude of output. Multilevel inverters have multiple voltage outputs, resulting in a stepped waveform rather than the square wave output of two-level inverters. This results in higher power quality, lower harmonic content, lower electromagnetic interference and improved efficiency. Additionally, multilevel inverters have higher power density and can handle higher voltages than two-level inverters. These inverters are essential in various industries, including renewable energy systems, electric vehicles, and high-voltage power transmission systems. The configurations of multilevel inverters are diode-clamped, flying capacitor, and cascaded H-bridge topologies, each with its own set of advantages and trade-offs.

II. FIVE LEVEL CASCADED MULTILEVEL INVERTER

Cascaded multilevel inverter is also called single-phase H-bridge inverter and it consists of series H-bridges. A single phase cascaded multilevel inverter consists of 2(N-1) switches, (N-1)/2 DC sources, and (N-1)/2 H-bridges, N=number of levels. Each H-bridge has its own DC source and produces three different voltage levels. Total output voltage is the sum of all the DC sources. Output voltage of five level is, V=Vdc1+Vdc2, V=total output voltage.

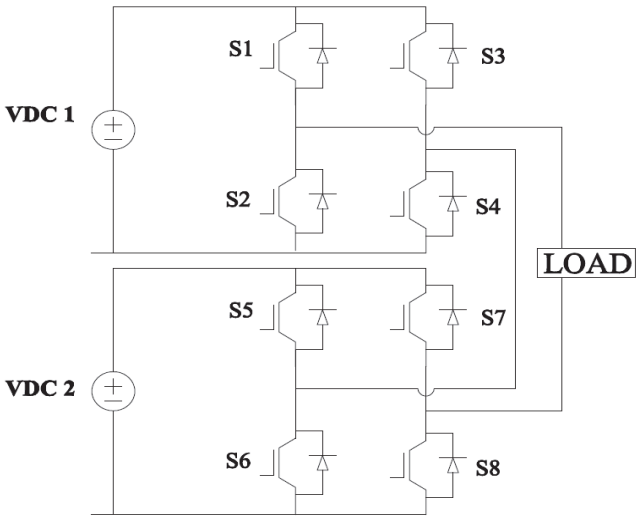

Fig. 1. Single phase five-level Cascaded H-Bridge Multilevel Inverter

This five-level inverter consists of 8 switches. The five-level output voltages are 0,+Vdc/2,+ Vdc,-Vdc/2 and -Vdc. First, the switches 1,8,4 ON then only one DC source is conduct, then +Vdc/2 level is generated. Next 1,8,4,5 these four switches ON, both DC sources conduct and +Vdc is generated. After that switches 2,6,3 ON, only one DC source is used and current flows in opposite direction, then -Vdc/2 is produced, later 2,6,7,3 switches conduct and both DC sources are used, current flows in opposite direction, -Vdc is produced.

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TABLE I. Switching sequence of five-level Cascaded H-Bridge inverter

S1	S2	S3	S4	S5	S6	S7	S8	V_o
ON	OFF	OFF	ON	ON	OFF	OFF	ON	V_{dc}
ON	OFF	OFF	ON	OFF	ON	OFF	ON	$V_{dc}/2$
OFF	ON	OFF	ON	OFF	ON	OFF	ON	0
OFF	ON	ON	OFF	OFF	ON	OFF	ON	$-V_{dc/2}$
OFF	ON	ON	OFF	OFF	ON	ON	OFF	$-V_{dc}$

Cascaded inverter does not require any voltage clamping diodes or voltage balancing capacitors, unlike the diode clamp or flying capacitors inverter.

III. SINUSOIDAL PULSE WIDTH MODULATION(SPWM)

The sine pulse width modulation (SPWM) technique is one of the most popular techniques used for converting a DC voltage to an AC voltage. It works by modulating the width of the pulses of a square wave to create a sine wave of adjustable amplitude and frequency.

In this technique sine signal is compared with triangular signals, if the amplitude of sine signal is greater than triangular then the pulse is generated for the positive half cycle and if the amplitude of triangular signal is greater than sine signal then the pulse is generated for negative half cycle.

In carrier based SPWM for MLI, (N-1) carrier waves are used to generate N level output in this scheme. The carrier based PWM schemes are of two types. They are: 1) Phase Shifted multi carrier modulation 2) Level shifted multi carrier modulation. Level shifted multi carrier modulation schemes are classified into three types i) Phase disposition ii) Phase opposition disposition iii) Alternate phase opposition disposition.

The frequency of reference signal is 50Hz and frequency of carrier signals is twenty times more than frequency of reference signal.

A. Phase Disposition (PD)

The carrier signals above the zero level and below the zero level are in phase but the level is changed.

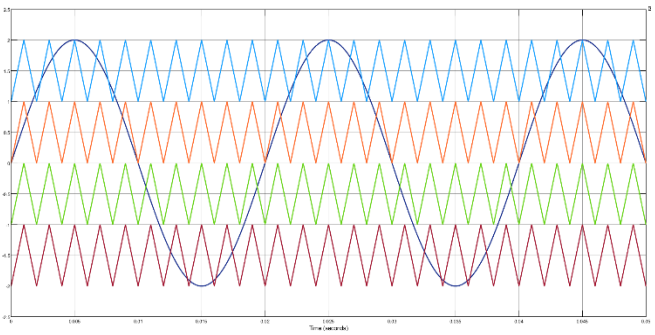

Fig.2. Carrier arrangement for PD PWM technique

B. Phase Opposition Disposition (POD)

The carrier signals above zero level are in phase whereas the carrier signals below zero level are in opposite phase to the carrier signals above the zero level. If the zero level is considered as mirror then it looks like a mirror image.

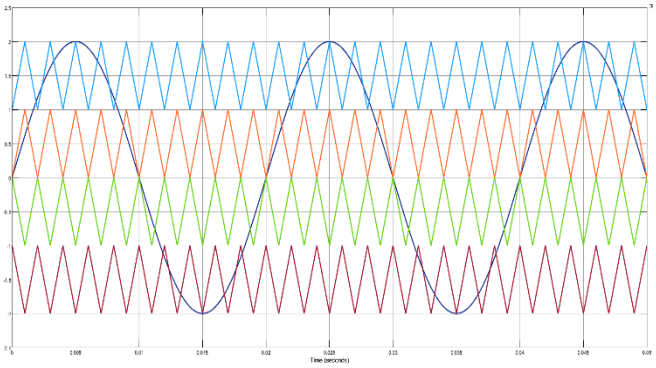

Fig.3. Carrier arrangement for POD PWM technique

C. Alternate Phase Opposition Disposition (APOD)

The two adjacent carrier signals are displaced by 180 degrees and they are like mirror images.

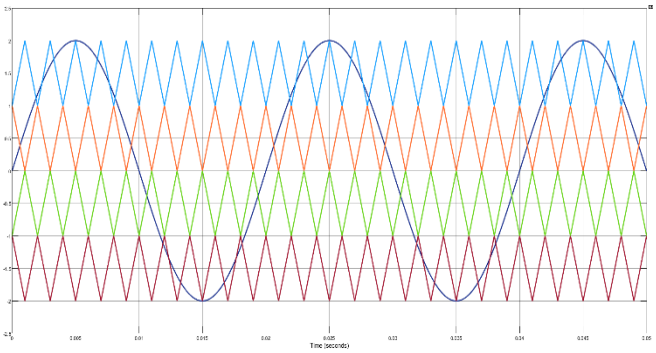

Fig.4. Carrier arrangement for APOD PWM technique

IV. INVERTED SINUSOIDAL PULSE WIDTH MODULATION(ISPWM)

In this strategy, triangular wave is replaced by inverted sine wave as carrier signal and sine signal as reference signal. The sine wave is compared with inverted sine wave and the switching signals are obtained when the amplitude of sine wave is greater than inverted sine wave. Output frequency is determined by the frequency of sine wave and the switching frequency is defined by the frequency of inverted sine wave.

The amount of THD generated in this technique is less compared to conventional SPWM.

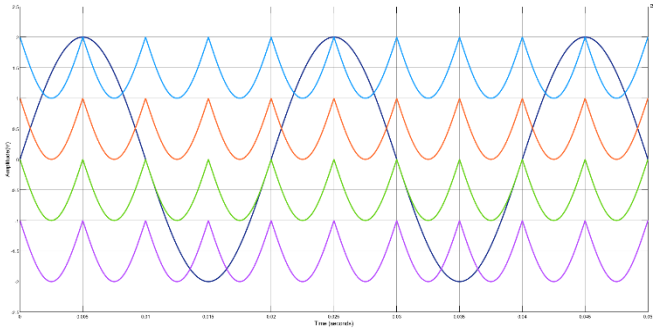

Fig.5. Inverted sine waveforms as carrier for ISPWM technique

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V. SIMULATION RESULTS AND ANALYSIS

a) Simulation of single-phase five-level cascaded H-bridge inverter

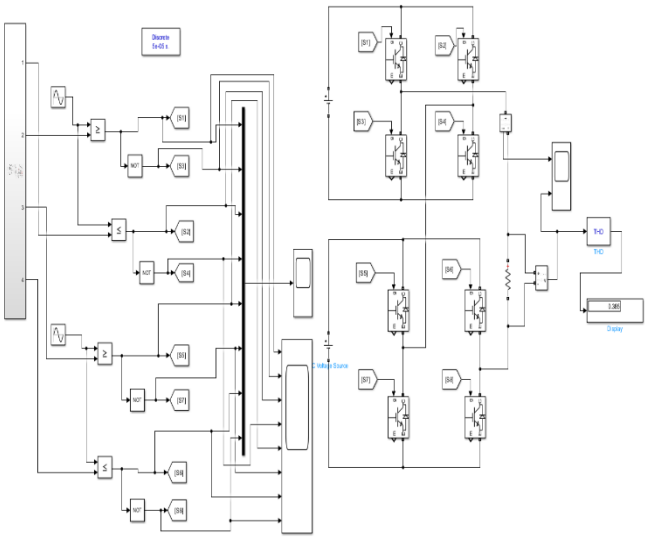

Fig.6. Simulation of single-phase Five-level cascade MLI using ISPWM technique

Fig.6 shows simulation of single-phase five level cascaded multilevel inverter employing ISPWM technique. The five-level output voltage is shown in Fig.9.

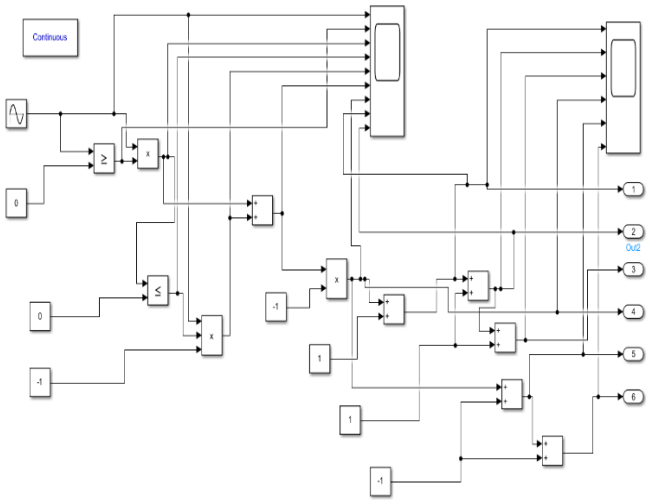

Fig.7. Simulation of ISPWM carrier signals generation in MATLAB

Fig.7 shows sub circuit for generation of inverted sinusoidal carrier signal. Six inverted sine waves are generated through this simulation circuit for seven level inverter. Only four inverted sine pulses are used for five level, in which two inverted sine waves are compared with the positive half cycle of reference sine wave and the other two inverted sine waves are compared with negative half cycle of reference sine wave.

In Fig.7 the strategy involves comparing the sine wave with the 0 constant and if the amplitude of sine wave is greater than or equal to zero, pulse is generated. The product of these pulses and the sine wave results in the positive half cycle of the sine wave. Again, this positive half cycle of sine wave is compared with the 0 constant and when the amplitude of positive half cycle is less than or equal to zero, pulse will be generated. The product of the sine wave, newly generated pulse and (-1) gives rise to a new carrier signal as shown in Fig.8 called inverted sine signal.

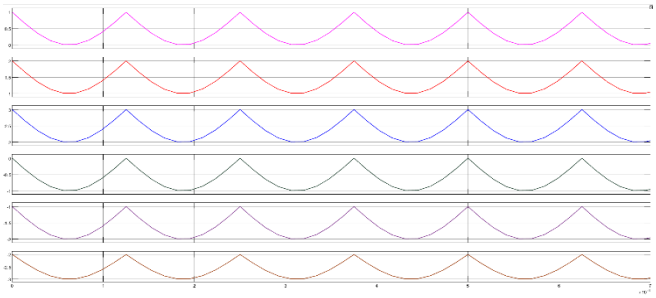

Fig.8. ISPWM carrier signals

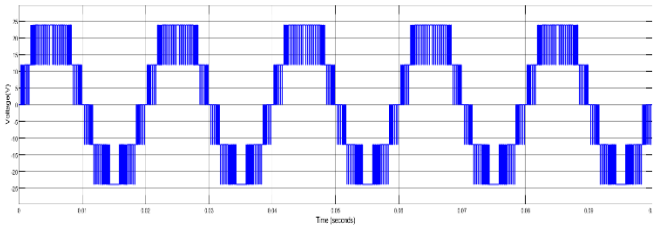

Fig.9. Five-level output voltage waveform for ISPWM technique

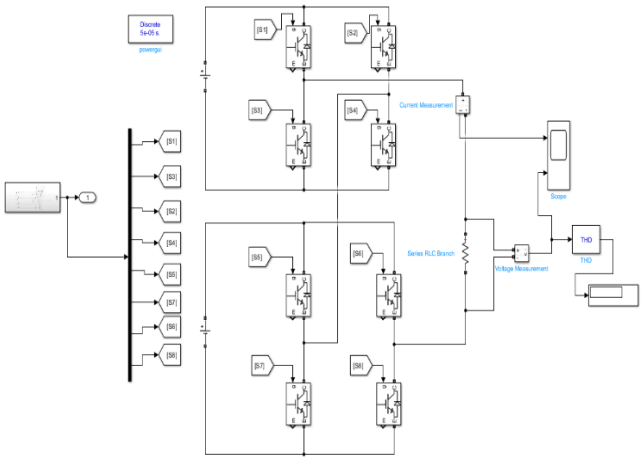

Fig.10. Simulation of single-phase Five-level cascaded MLI using SPWM technique

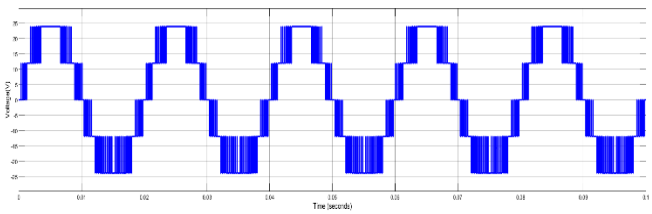

Fig. 11. Five-level output voltage waveform for SPWM technique

The FFT Analysis is done for single-phase five-level cascaded multilevel inverter with ISPWM and SPWM. Comparing THD obtained, we can observe that by using

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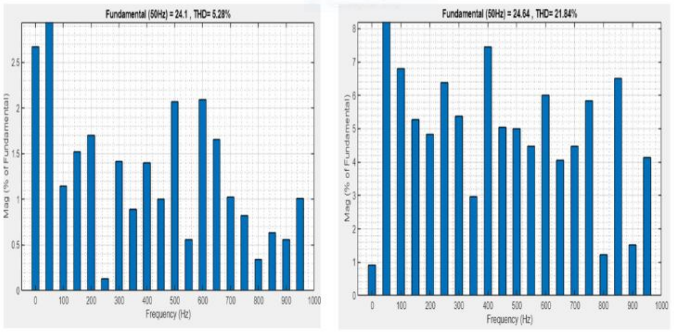
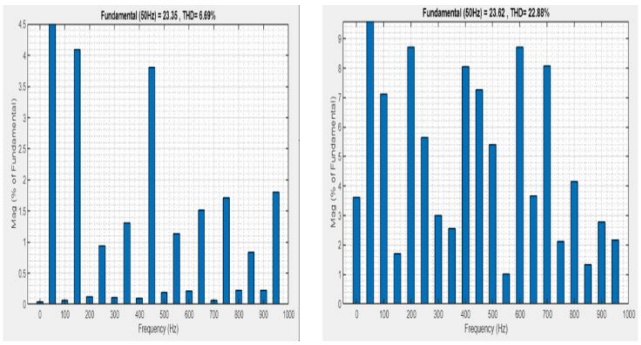
inverted sine PWM technique the THD generated is very less compared to SPWM.



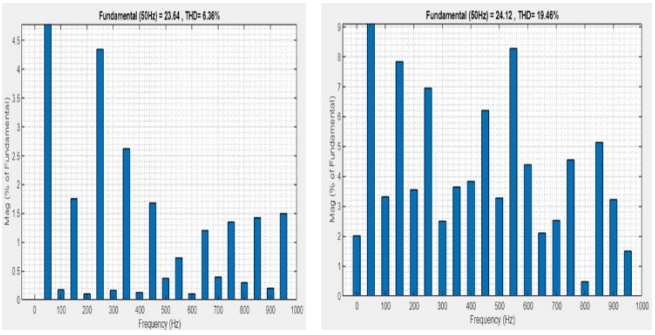
ISPWM(THD=5.28%) SPWM(THD=21.84%)

Fig.12. FFT analysis of ISPWM and SPWM for PD(Phase Disposition)



ISPWM(THD=6.69%) SPWM(THD=22.88%)

Fig.13. FFT analysis of ISPWM and SPWM for POD(Phase Opposition Disposition)



ISPWM(THD=6.36%) SPWM(THD=19.46%)

Fig.14. FFT analysis of ISPWM and SPWM for APOD(Alternate Phase Opposition Disposition)

From the FFT analysis, it is observed that THD is less in case of ISPWM when compared to SPWM. Also, it is proved that PD(Phase Disposition) technique results in less THD.

b) Simulation of three phase five-level cascaded H-bridge inverter

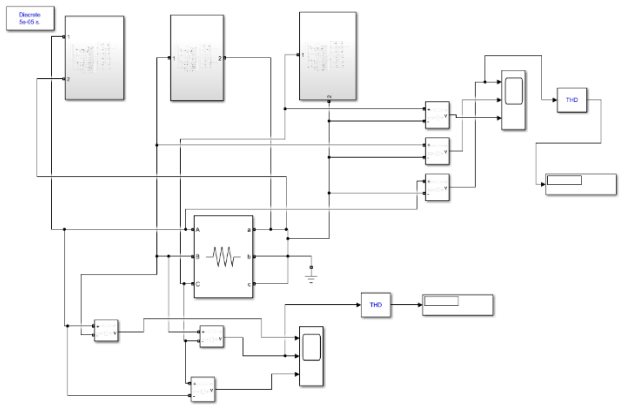


Fig.15. Simulation of three phase five-level cascaded MLI using ISPWM technique

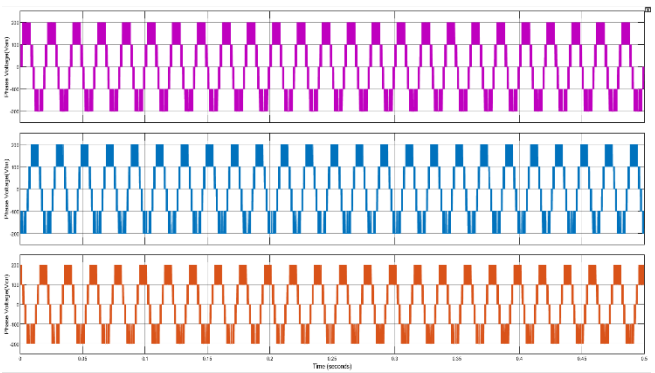


Fig.16. Phase Voltages of five-level cascaded MLI using ISPWM technique

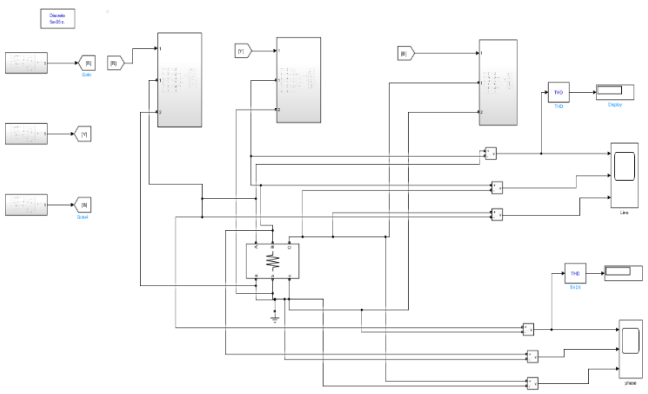


Fig.17. Simulation of three phase five-level cascaded MLI using SPWM technique

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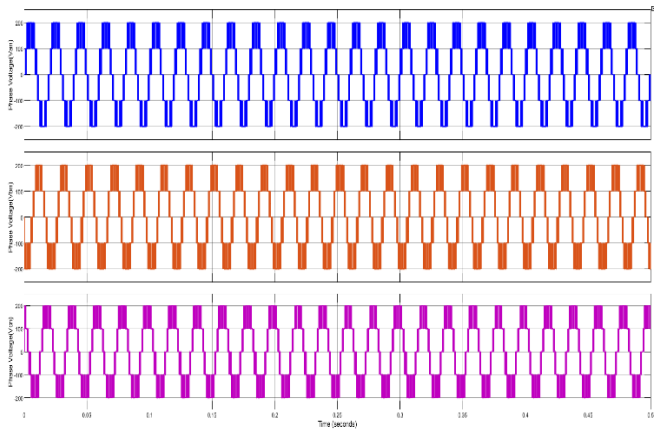
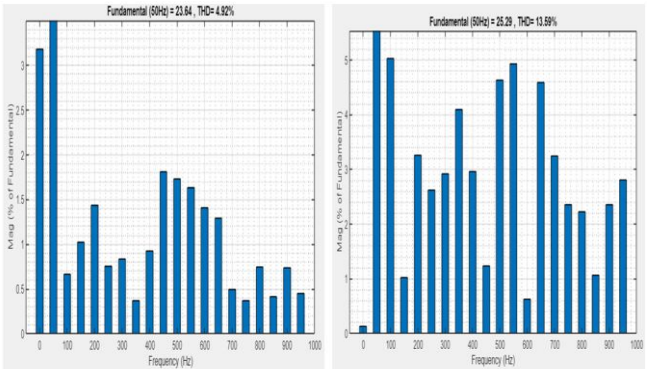


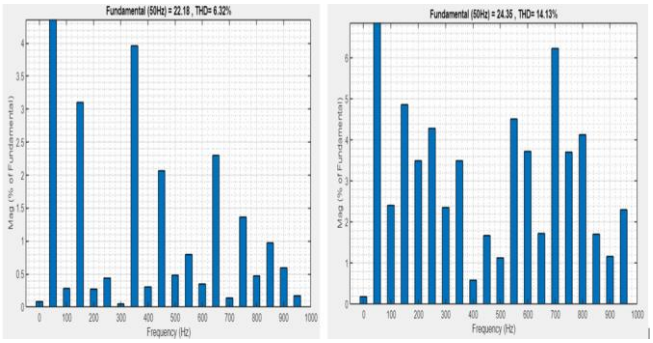
Fig.18. Phase Voltages of five-level cascaded MLI using SPWM technique

The THD in the output voltage of three phase inverter using ISPWM and SPWM is analyzed using FFT analysis.



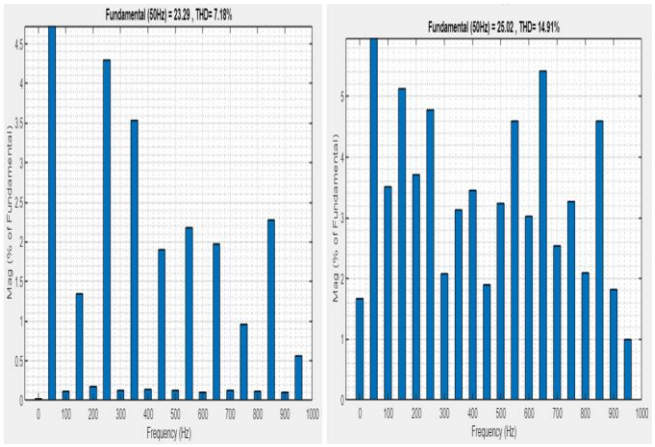
ISPWM(THD=4.92%) SPWM(THD=13.59%)

Fig.19. FFT analysis of ISPWM and SPWM for PD(Phase Disposition)



ISPWM(THD=6.32%) SPWM(THD=14.13%)

Fig.20. FFT Analysis of ISPWM and SPWM for POD(Phase Opposition Disposition)



ISPWM(THD=7.18%) SPWM(THD=14.91%)

Fig.21. FFT analysis of ISPWM and SPWM for APOD(Alternate Phase Opposition Disposition)

From the simulation results and FFT analysis, it is observed that THD in the output voltage of inverter using ISPWM is less when compared to SPWM technique.

C)ANALYSIS OF TOTAL HARMONIC DISTORTION

THD comparison for single-phase H-bridge inverter using ISPWM and SPWM is shown in Table-II and that for three-phase H-bridge inverter is given in Table-III. From the FFT analysis, it is observed that THD is less for five-level cascaded H-bridge multilevel inverter compared to conventional inverter. As number of levels increases, the THD will reduce and output waveform obtained is near to sinusoidal waveform. When compared to SPWM, ISPWM results in less THD in the output voltage.

TABLE II. THD Comparison for Single-Phase inverter with ISPWM and SPWM Techniques

	Modulation Index	Sine PWM	Inverted Sine PWM
Phase Disposition	1	21.84%	5.28%
Phase Opposition Disposition	1	22.88%	6.69%
Alternate Phase Opposition Disposition	1	19.46%	6.36%

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TABLE III. THD Comparison for Three-Phase inverter with ISPWM and SPWM Techniques

	Modulation Index	Sine PWM	Inverted Sine PWM
Phase Disposition	1	13.59%	4.92%
Phase Opposition Disposition	1	14.13%	6.32%
Alternate Phase Opposition Disposition	1	14.91%	7.18%

VI. CONCLUSION

The simulations for the five-level cascaded H-bridge using both inverted sine and sine PWM control strategy are carried out in MATLAB/SIMULINK software. The THD (Total Harmonic Distortions) for Sine PWM and Inverted Sine PWM are compared for single-phase and three phase five-level cascaded H-bridge inverter by using (Phase Disposition)PD, (Phase Opposition Disposition)POD, (Alternate Phase Opposition Disposition)APOD schemes through (Fast Fourier Transform)FFT analysis. As compared to SPWM, the harmonics obtained are least for ISPWM. It is concluded that Inverted sine PWM control strategy offers improved efficiency and performance compared to SPWM technique.

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