Impact of Sine PWM on Voltage THD in 5-Level Vs 7-Level Inverters: A Comparative Analysis

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Abstract: This study focuses on THD and various modulation strategies while analyzing 5-level and 7-level multilevel inverters for grid systems. As they enable effective DC-to-AC conversion with advantages like lower switching losses, improved output quality, and compact design, multilevel inverters are essential in renewable energy applications. These inverters, which are widely used in industrial motor drives, PV systems, and electric vehicle charging, promote sustainable energy solutions. According to simulation data, the 7-level inverter provides the best performance with the lowest THD and outperforms the 5-level in terms of THD. POD is the most successful SPWM approach for reducing THD, according to a comparison analysis. These results highlight how advanced SPWM techniques and creative inverter designs can enhance grid integration and power quality.

1 INTRODUCTION

An inverter is a device that converts direct current (DC) electricity into alternating current (AC) electricity, enabling the use of DC power sources, like batteries or solar panels, to power AC appliances. . This process involves converting a steady DC input into a switching AC waveform, smoothing it into a usable sine wave, and adjusting the output voltage as needed. Inverters are widely used in solar systems, UPS, electric vehicles, and industrial applications to provide reliable AC power.

Multilevel Inverters (MLIs) are advanced inverters designed for high-power and high-voltage applications (Munawar, Iqbal, et al. , 2024). Unlike conventional inverters that generate simple two-level waveforms, MLIs produce a stepped AC output resembling a sinusoidal waveform. This reduces harmonic distortion, improves power quality, and enhances efficiency.

Types of Multilevel Inverters (Singh and Mohaney, 2024):

Diode-Clamped MLI: Uses diodes for voltage balancing. Ideal for medium-voltage applications but complex for high levels.

Flying Capacitor MLI: Balances voltage using capacitors, offering redundancy and flexibility but requiring complex balancing circuits.

Cascaded H-Bridge MLI: Uses multiple H-bridge units powered by independent DC sources. It is modular but needs isolated power sources.

Advantages of MLIs:

Power Quality: Reduced Total Harmonic Distortion (THD) minimizes external filter requirements.

Efficiency: Lower switching losses improve energy efficiency.

Scalability: Easily adaptable to medium and high-power applications.

Reduced Stress: Lower voltage stress enhances component reliability.

Applications include renewable energy systems, industrial drives, electric vehicles, and HVDC transmission (José, Sheng, et al. , 2002). Despite their complexity, MLIs offer unmatched efficiency,

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making them essential for modern high-power systems.

Challenges include higher costs, control complexity, and space requirements, but these are outweighed by their performance benefits (Susheela, Chandra, et al. , 2024), (Leon, Vazquez, et al. , 2017).

2 MODULATION TECHNIQUE

SPWM is a modulation technique used to control the output voltage and frequency of inverters (Akshay, Rakshith, et al. , 2024), (Susheela and Kumar, 2017). It generates switching signals by comparing a sinusoidal reference waveform (desired output) with a high-frequency triangular carrier waveform. Sinusoidal Pulse Width Modulation (SPWM) is a widely used technique for generating AC waveforms, particularly in inverters and motor drive systems. It modulates the width of pulses based on a sinusoidal reference waveform to approximate a sinusoidal output voltage.

There are many advantages of SPWM like Improved Efficiency, Lower switching losses compared to other modulation methods, Better Harmonic Profile (By increasing the carrier frequency, higher-order harmonics are shifted away from the fundamental frequency, making filtering easier) and Scalability (Output voltage and frequency can be easily controlled by adjusting the reference waveform).

In pulse-width modulation (PWM) techniques, different switching methods are used to control the inverter's output waveform. PD (Phase Disposition), POD (Phase Opposition Disposition), and APOD (Alternate Phase Opposition Disposition) are multi-carrier PWM techniques, primarily used in multilevel inverters to manage how the carrier signals are arranged. In multilevel inverters, several carriers are needed because multiple levels of voltage are generated. The arrangement of these carriers determines the type of modulation technique (Abbas, Majid, et al. , 2017), (Susheela and Kumar, 2017).

2.1 Phase Disposition

All carrier waves are in phase. Carriers are stacked vertically as depicted in Figure 1, with each carrier covering a specific range of the output voltage. The reference sinusoidal waveform is compared against all these carriers.

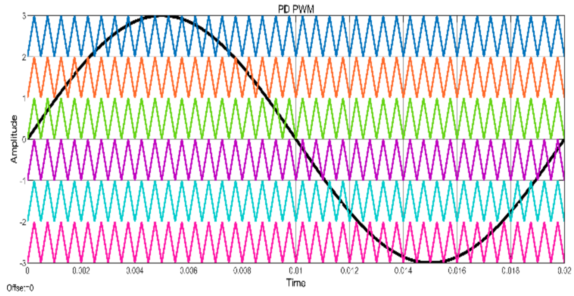

Figure 1: PD PWM Technique

2.2 Phase Opposition Disposition

Carriers are divided into two groups: The carriers above the reference sinusoidal wave are in phas e (Susheela and Kumar, 2020). The carriers below the reference wave are 180° out of phase with those above it as illustrated in Figure 2.

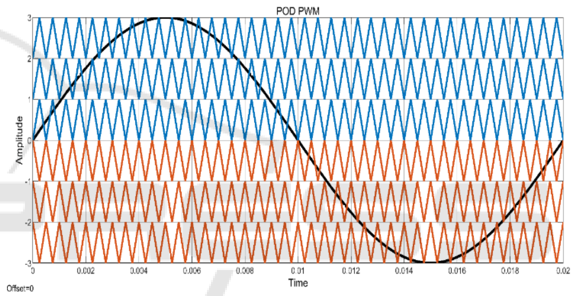

Figure 2: POD PWM Technique

2.3 Alternate Phase Opposition Disposition

Each adjacent carrier is 180° out of phase with the neighbouring carrier (Susheela and Kumar, 2019). This alternating phase arrangement applies to all carrier waves as indicated in Figure 3.

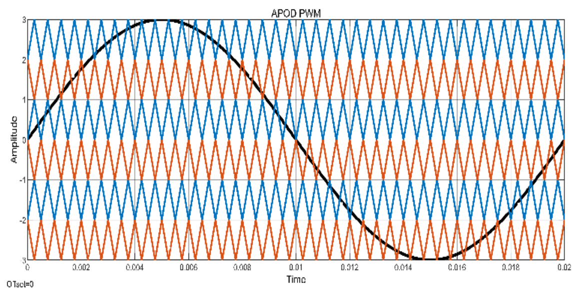

Figure 3: APOD PWM Technique

3 TOPOLOGY

The Cascaded H-Bridge (CHB) method is a widely used topology in multilevel inverters due to its modularity, scalability, and simplicity in implementation (Ramaprabha, 2022), (Deshmukh, Chaturvedi, et al. , 2022). It consists of multiple H-bridge inverter units connected in series, each producing a separate voltage level. By combining these voltage levels, a stepped waveform approximating a sinusoidal output can be generated, which reduces total harmonic distortion (THD) without requiring bulky filters (Babaei, 2008).

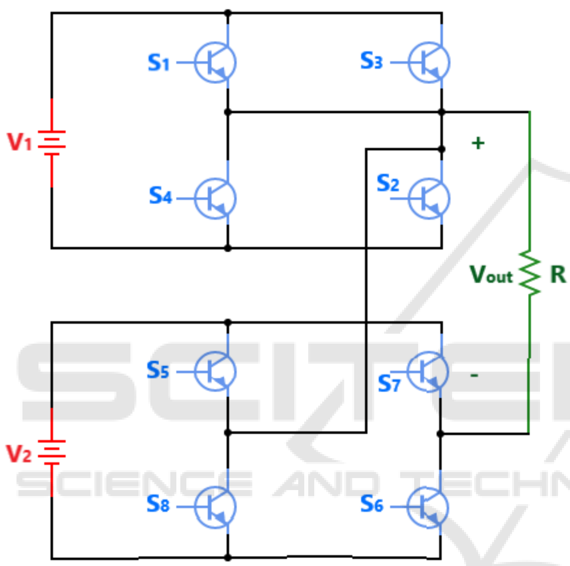

Figure 4: Inverter Topology

The topology shown in Fig. 4 is same for 5-Level and 7-Level Inverter. For a 5-Level Inverter voltages are symmetrical such that V1 = 10 V and V2 = 10 V whose switching table is provided in Table 1. H-Bridges produce five levels in the output: +20 V, +10 V, 0, -10 V and -20 V.

Table 1: Switching table for 5 – Level Operation.

Mode	Output	Switching State							
		S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
1	**+20 V**	1	1	0	0	1	1	0	0
2	**+10 V**	1	1	0	0	1	0	1	0
3	**0 V**	1	0	1	0	1	0	1	0
4	**-10 V**	0	0	1	1	1	0	1	0
5	**-20 V**	0	0	1	1	0	0	1	1

Similarly, for 7-Level Inverter operation mentioned in Table 2, H-Bridges produce 7 levels: +30 V, +20 V, 10 V, 0, -10 V, -20 V, -30 V for asymmetric voltages : V1 = 10 V and V2 = 20 V. Symmetrical setups offer simpler design and control, while asymmetrical configurations provide more levels with fewer components, improving harmonic performance.

Table 2: Switching table for 7 – Level Operation.

Mode	Output	Switching State							
		S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
1	**+30 V**	1	1	0	0	1	1	0	0
2	**+20 V**	1	0	1	0	1	1	0	0
3	**+10 V**	1	1	0	0	1	1	0	0
4	**0 V**	1	0	1	0	1	0	1	0
5	**-10 V**	0	0	1	1	0	0	1	1
6	**-20 V**	1	0	1	0	0	0	1	1
7	**-30 V**	0	0	1	1	0	0	1	1

4 SIMULATION RESULTS

4.1 5 – Level Inverter

The Inverter is implemented in Matlab Simulink as illustrated in Figure 5. V1 and V2 are chosen as 10 V. The output has 5 levels ranging from +20 V to -20 V, with an RMS value of voltage being 15.2 V.

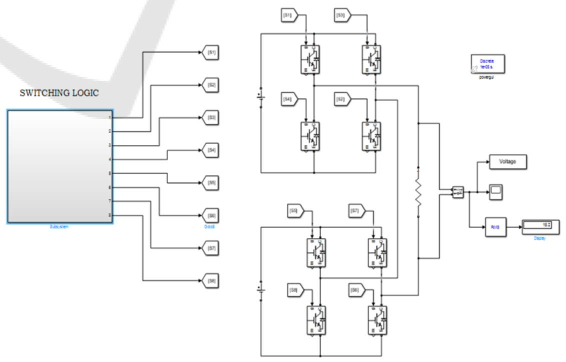

Figure 5: Simulink Model of 5 – Level Operation

4.1.1 PD PWM

The output shown in Figure 6 is obtained for the 5-level operation using PD PWM technique with its respective THD in Figure 7.

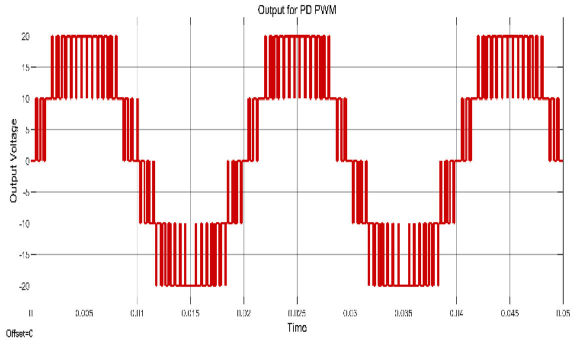

Figure 6: Output using PD PWM

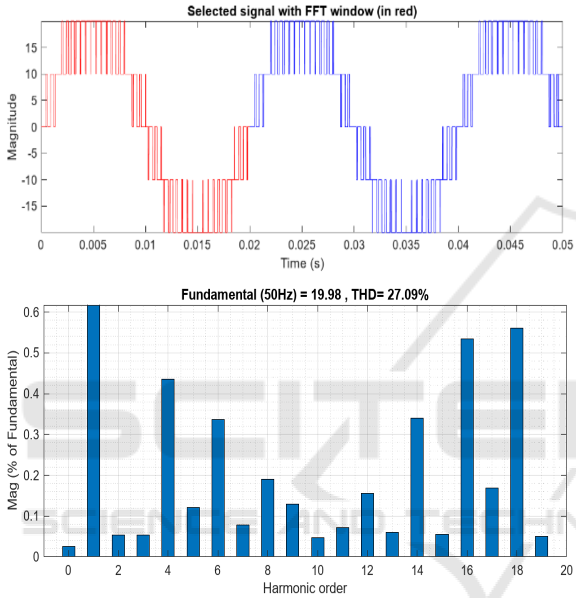

Figure 7: Voltage THD using PD PWM

4.1.2 POD PWM

Using the POD PWM approach, the result seen in Figure 8 is produced for the 5-level operation, with the corresponding THD displayed in Figure 9.

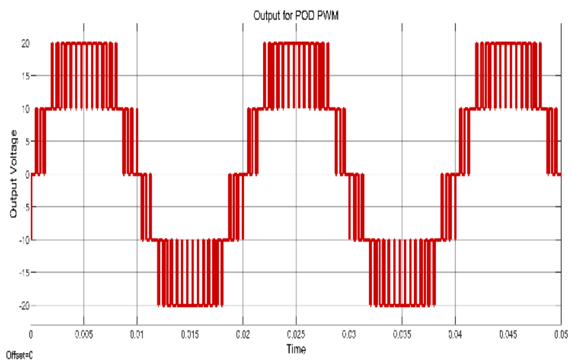

Figure 8: Output using POD PWM.

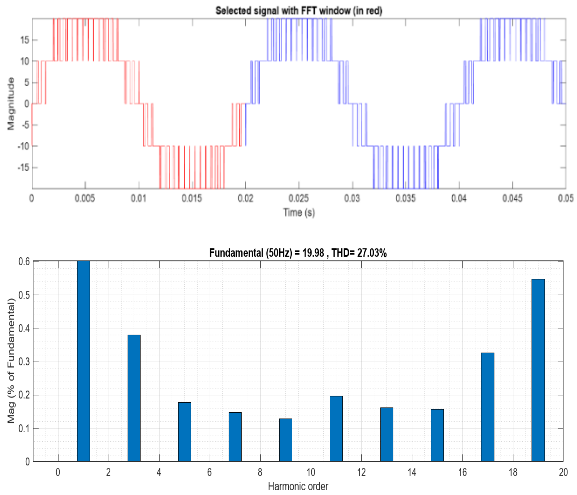

Figure 9: Voltage THD using POD PWM.

4.1.3 APOD PWM

With the application of APOD PWM, the voltage waveform obtained is in Figure 10 with its THD in Figure 11.

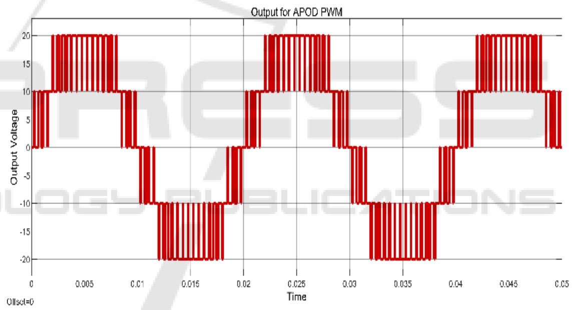

Figure 10: Output using APOD PWM.

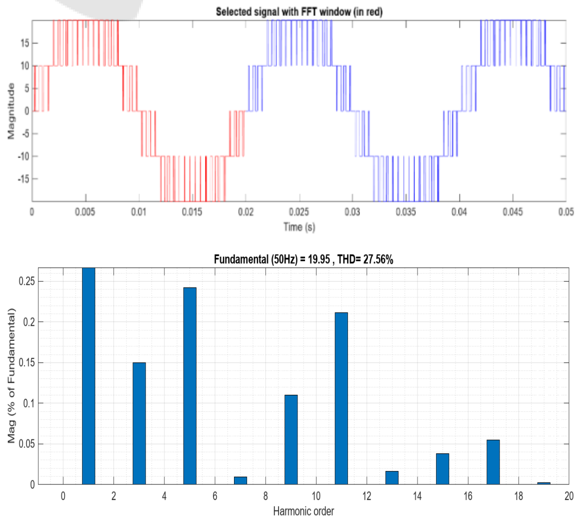

Figure 11: Voltage THD using APOD PWM.

4.2 7 – Level Inverter

Figure 12 shows how the inverter is configured in Matlab Simulink. V1 and V2 have been set to 10 V and 20 V respectively. The output contains seven voltage levels, from +30 V to -30 V, and its RMS value is 22.4 V.

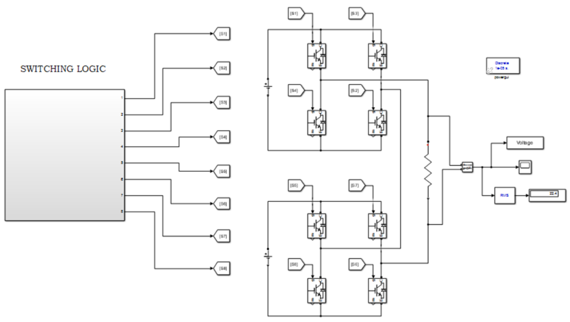

Figure 12: Simulink model of 7 - Level Operation.

4.2.1 PD PWM

By using the PD PWM technique, the output obtained is depicted in Figure 13 with the voltage THD in Figure 14.

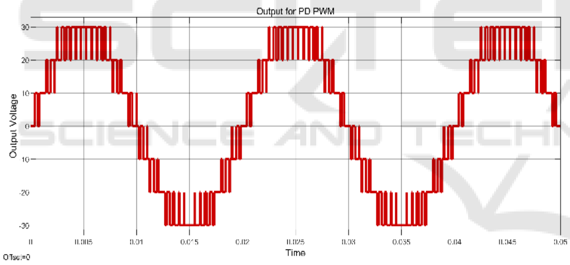

Figure 13: Output using PD PWM

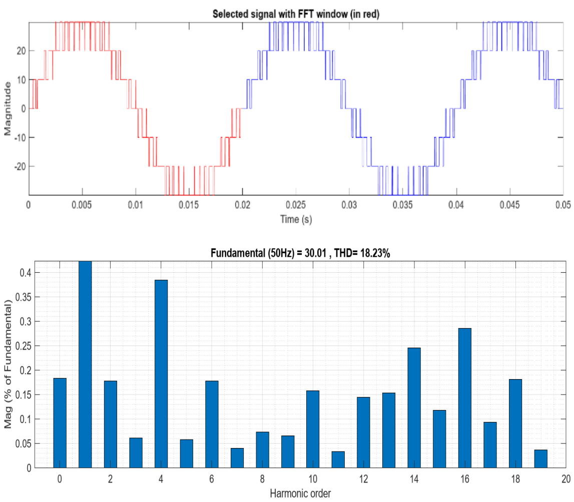

Figure 14: Voltage THD using PD PWM.

4.2.2 POD PWM

Using the POD PWM, the result seen in Figure 15 is produced for the 7-level operation, with the corresponding voltage THD displayed in Figure 16.

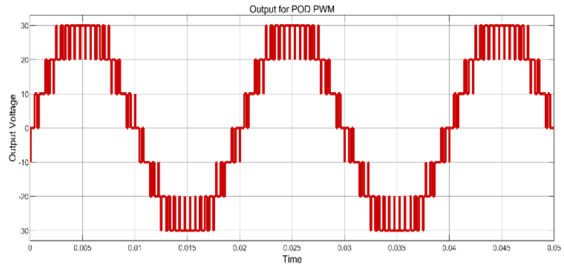

Figure 15: Output using POD PWM.

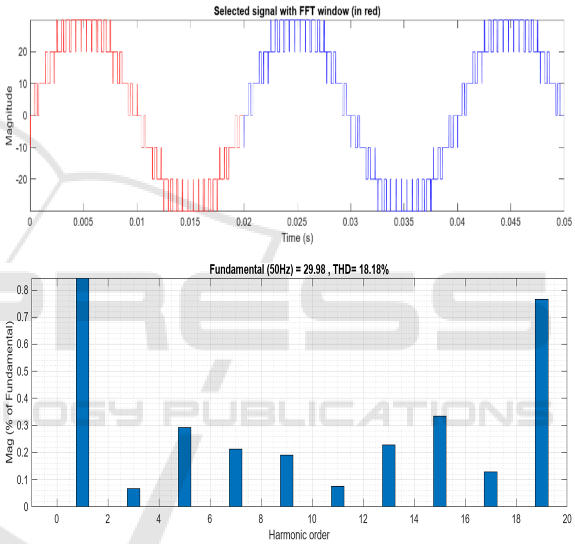

Figure 16: Voltage THD using POD PWM

4.2.3 APOD PWM

The output shown in Figure 17 is obtained for the 7-level operation using APOD PWM technique with its respective voltage THD in Figure 18.

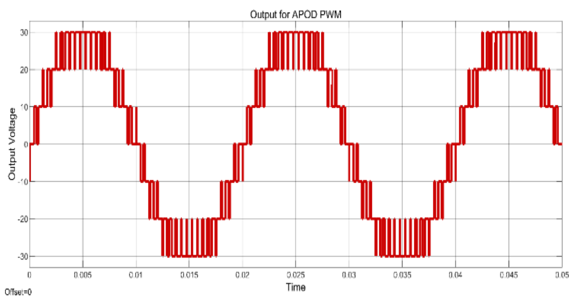

Figure 17: Output using APOD PWM.

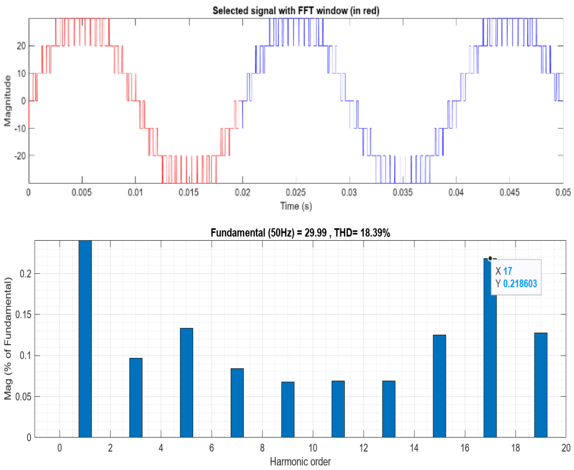

Figure 18: Voltage THD using APOD PWM.

Table 3 shows the comparison of voltage THD among the PD, POD and APOD modulation techniques for 5-level and 7-level operation of the inverter. It is evident from the table that the POD modulation technique is optimal to use, since it is able to produce less THD in comparison to other techniques. It can be observed that increment in the number of levels is causing the lower value of THD.

Table 3: Comparision of Voltage THD.

Modulation Technique	Voltage THD (%)	
	5-level operation	7-level operation
PD	27.09	18.23
POD	27.03	18.18
APOD	27.56	18.39

5 CONCLUSION

This study highlights the significance of multilevel inverters, particularly 5-level and 7-level configurations, in improving grid integration and power quality for renewable energy applications by focusing on Total Harmonic Distortion and various modulation strategies. The comparative analysis reveals that the 7-level inverter demonstrates superior performance with the lowest THD, making it a more efficient choice over the 5-level counterpart for achieving optimal power quality. Furthermore, the investigation of SPWM strategies identifies POD as the most effective approach for minimizing THD. These findings emphasize the potential of advanced SPWM techniques to further enhance the performance of multilevel inverters in grid systems. These characteristics make them indispensable in applications such as industrial motor drives, photovoltaic systems, and electric vehicle charging stations. Overall, the study underscores the critical role of innovative inverter designs and sophisticated modulation strategies in advancing sustainable energy solutions. The results provide a strong foundation for future research aimed at optimizing multilevel inverters to meet the evolving demands of modern power systems.

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