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Comparison Study of Modulation Techniques for a Three-Level NPC Inverter

Alhassan Musa Oruma[1], Ismaila Mahmud[2], Umar Alhaji Adamu[3], Simon Yakubu Wakawa[4], Mahmud Mustapha[5], Gambo Idris[6]

[1]University of Greenwich, London-United Kingdom
[2]Department of Electrical Engineering, Ahmadu Bello University, Zaria-Nigeria
[3]Department of Renewable Energy, Niger-Delta Power Holding Company, Abuja-Nigeria
[4]Department of Electrical/Electronic Engineering. Nile University, Abuja-Nigeria
[5]Department of Electrical/Electronic Engineering Nuhu Bamalli Polytechnic Zaria-Nigeria
[6]Ministry of Industry, Trade and Investment, Lagos-Nigeria.

Abstract: *In this study, the effectiveness of two well-known pulse width modulation (PWM) methods used on a three-level Neutral Point Clamped (NPC) inverter is compared. Given how crucial PWM is to the functioning of multilevel inverters, the two main PWM algorithms employed for multilevel inverters are Space Vector Pulse Width Modulation (SVPWM) and Sinusoidal Pulse Width Modulation (SPWM). The findings show that when the Modulation Index varies, the peak value of the fundamental component varies linearly for both approaches. The study explains how two PWM approaches' operational ability is impacted by variations in modulation indices. Moreover, the SVPWM technique revealed a lower Total Harmonic Distortion (THD) value than the SPWM technique. A three-level NPC inverter simulation was performed using MATLAB/SIMULINK.*

Keywords: *Neutral Point Clamped Inverter, Modulation Techniques, Total harmonic Distortion, Switches*

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I. INTRODUCTION

When electricity flows from a DC source to an AC source, an inverter is used to change the direction of the flow [1]. There are many different types and uses for inverters. Within the class of multilevel voltage source inverters, the 3-level neutral point clamped (NPC) inverter is the subject of this particular inquiry. In terms of application, it also performs as a variable speed drive (VSD). A VSD is a device used to modify a motor's speed. Using a VSD in pump and fan drives—which are frequently found in gas plants—proves to be a more energy-efficient option than connecting directly to the grid, where flow control is accomplished by less effective mechanical means [2]. To create an output waveform synthesized by recognized regulations.

Based on the switching frequency, several modulation strategies are used to control the switching action in inverters. In particular, the two pulse width modulation techniques on a 3-level NPC inverter, as shown in Fig. 1, are investigated in this article. Because of its very simple implementation, SPWM is the most often used modulation technique among them [3]. Another modulation method that has certain advantages over SPWM is SVPWM [4]. It is assumed that SVPWM produces a better Total Harmonic Distortion (THD). It is important to remember, nonetheless, that compared to SPWM, the computational complexity of SVPWM implementation is higher.

The purpose of this article is to investigate the aforementioned modulation techniques and assess their performance with respect to THD and the basic phase value at the output. These measures are used as performance indicators for different modulation indices of the Neutral Point Clamped (NPC) inverter.

II. MULTILEVEL INVERTER

Thanks to new topologies and semiconductor device improvements, multilevel converters remain essential to many industrial processes. Higher voltage, quicker switching rates, simpler switching, improved efficiency, snubberless operation, and lower losses are all made possible by these advancements [5]. An array of switches and voltage sources combine to form a multilayer inverter, which generates a stepped output voltage waveform. By controlling the commutation of switches and guaranteeing that power semiconductors are

subjected to lower voltages, capacitors are added to increase output [6]. In general, there are two types of high-power converter topologies: direct and indirect.
There are two types of indirect converters: voltage source inverter (VSI) and current source inverter (a). A fixed DC voltage is transformed into a variable-frequency, variable-magnitude AC voltage in the VSI [7]. Moreover, diode-clamped, capacitor-clamped, and cascaded multilevel inverters are the three main categories of multilevel voltage source inverters.

A. Neutral Point Clamped Inverter

The Neutral Point Clamped (NPC) inverter, also known as the diode-clamped inverter, is one of the most well-known multilevel inverter topologies and is frequently used. Its primary difference from a two-level inverter is that it achieves stepped output voltage levels by clamping the DC bus voltage using diodes. One of the first multilayer inverters to be introduced in the 1980s is the NPC inverter [8]. As seen in Figure 1, it is a combination of two pairs of switches and two clamping diodes. The inverter can access the neutral point thanks to the diodes' method of operation. Every switch pair adopts a complementary mode of operation in order to accomplish the switching sequence. There are three voltage levels in the waveform that the inverter produces. The three stages of the DC bus voltage are produced by the capacitors. In the case of the three-level inverter, two sets of switches are actively ON at any given time.

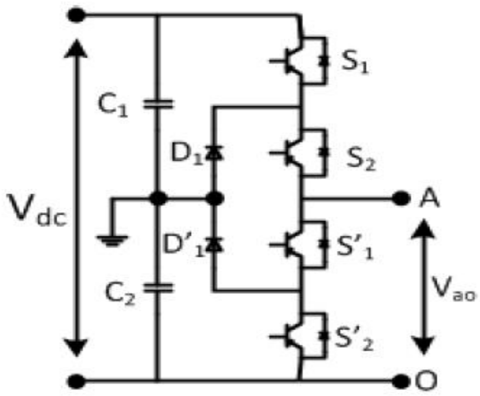


Figure 1: Three-level Neutral Point Clamped Inverter

B. Multilevel Modulation Techniques

In power electronics, transistors typically function in a "switched mode," wherein they are either in an ON or OFF state. In multilayer inverters, modulation techniques are used to regulate the switches that function in certain states. High power conversion efficiency is ensured when operating in switching mode [2]. One often used method for adjusting the AC output of power electronic inverters is pulse width modulation, or PWM. Using this method, pulse signals are created and used to operate the inverter's switches, usually at a frequency that guarantees the desired output voltage or current. PWM systems are classifiable depending on how reference and carrier frequencies relate to one another. They can also be categorized based on the type of control used, such as open-loop or closed-loop ideas. Space vector PWM, selective harmonic removal, and sinusoidal PWM are a few examples of PWM approaches.

1. Sinusoidal Pulse Width Modulation

One well-known and widely applied PWM method is sinusoidal pulse width modulation, or SPWM. This method generates PWM signals using two high-frequency triangular carrier waves with level shifts and three sine waves (vm). While the second triangular wave (vc2) only accepts negative numbers, the first wave (vc1) only accepts positive values. The desired PWM signals are then produced by combining these modulating signals with the triangle carrier waves [5].

$$v_A = m_a \sin(\omega t) \qquad (1)$$

$$v_B = m_a \sin(\omega t - 120°) \qquad (2)$$

$$v_C = m_a \sin(\omega t - 240°) \qquad (3)$$

The modulation index, or ma, has a value between 0 and 1. By comparing the triangular carrier waves with the sinusoidal waves, the switches function. This comparison establishes when the switches should be activated or deactivated, affecting the pulse width and therefore controlling the inverter's output.

2. Modulation of Space Vector Pulse Width

Space Vector Pulse Width Modulation (SVPWM) is a type of modulation strategy that makes use of the inverter's current switching signal state and digital voltage conversion technique. The vectors are chosen using the Q-d stationary reference frame. The commanded voltage vector is found using equation 4, and the space vector's d and q components are presented next to the inverter's supplied vectors in Figure 2. Finding the closest three vectors is the first stage in the SVPWM system. Equation (4) yields the numbers Vd and Vq, which aid in identifying the ideal voltage vector for accurate control.

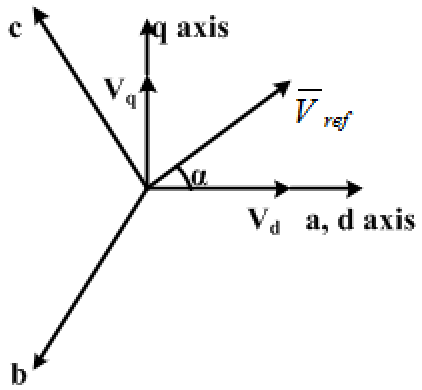


Figure **Error! No text of specified style in document.**: Voltage Space vector and its component in d, q.

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} \tag{4}$$

From Figure 2, $\overline{V}_{ref}$ and α can be obtained and are given in Eq. (5) and (6) respectively

$$\left|\overline{V}_{ref}\right| = \sqrt{V_d^{\,2} + V_q^{\,2}} \tag{5}$$

$$\alpha = \tan^{-1}\left({V_q}/{V_d} \right) = \omega_s t = 2\pi f_s t \tag{6}$$

where f_s is the fundamental frequency.

The duty cycle time is obtained through the command vectors for the selected switches in a sampling period of SVPWM [14] and is provided in Eqs. (7) – (10).

$$T_0 = T_{pwm} - T_1 - T_2 \tag{7}$$

$$T_1 = T_{pwm} a \sin({\pi}/{3} - \alpha) \tag{8}$$

$$T_2 = T_{pwm} a \sin(\alpha) \tag{9}$$

$$a = \frac{\sqrt{3}}{V_{dc}} V_{ref} \tag{10}$$

For a three-level inverter, the total switching state number that correlates to the voltage vectors is twenty-seven. Based on their magnitudes, the voltage vectors are divided into four segments. These 27 stationary space vectors are used in an approximate calculation to produce the reference vector [9]. Fig. 3 shows the space vector diagram, which shows how these vectors are arranged and related to one another.

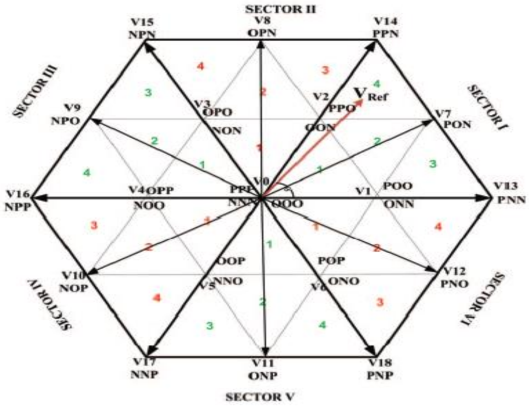


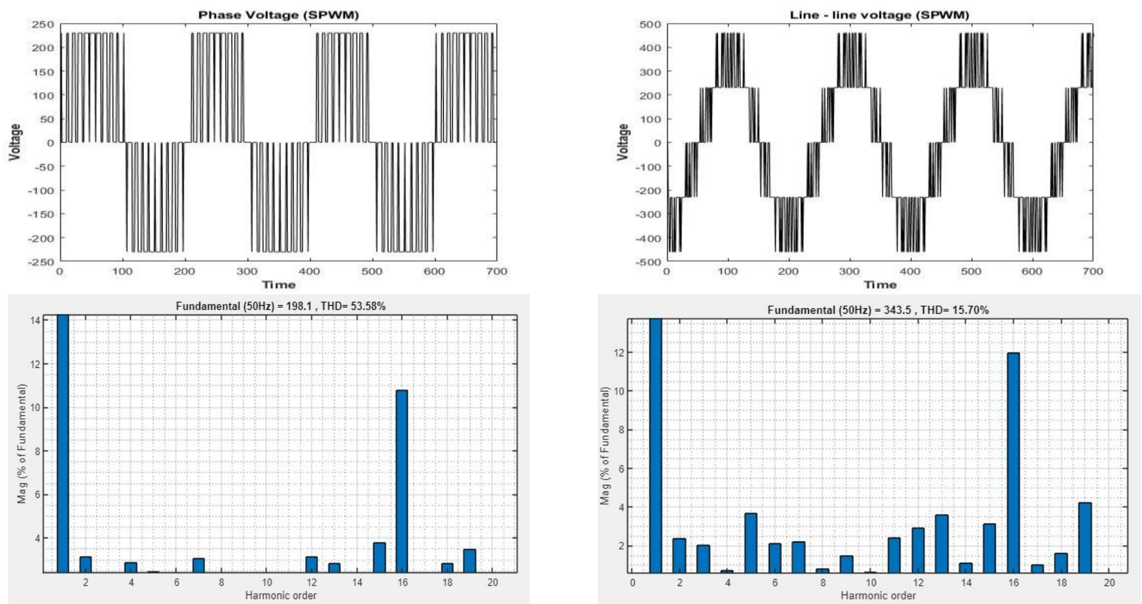
Figure 3: Space Vector PWM’s sectors and regions division

There are six sectors (I to VI) in the space vector diagram. As shown in Fig. 3, there are four triangular sections (1 to 4) within each sector. In the context of the three-level inverter, this segmentation helps with the viewing and study of the relationships and configurations of space vectors [10].

III. RESULTS AND DISCUSSION

Using MATLAB/Simulink and a resistive-inductive (RL) load, the three-level Neutral Point Clamped (NPC) inverter was simulated. In the simulation, 230 V was the DC connection voltage used, and 0.85 was the modulation index. With this method, the performance of the inverter under particular operating conditions and with the specified load characteristics may be thoroughly analysed and evaluated.

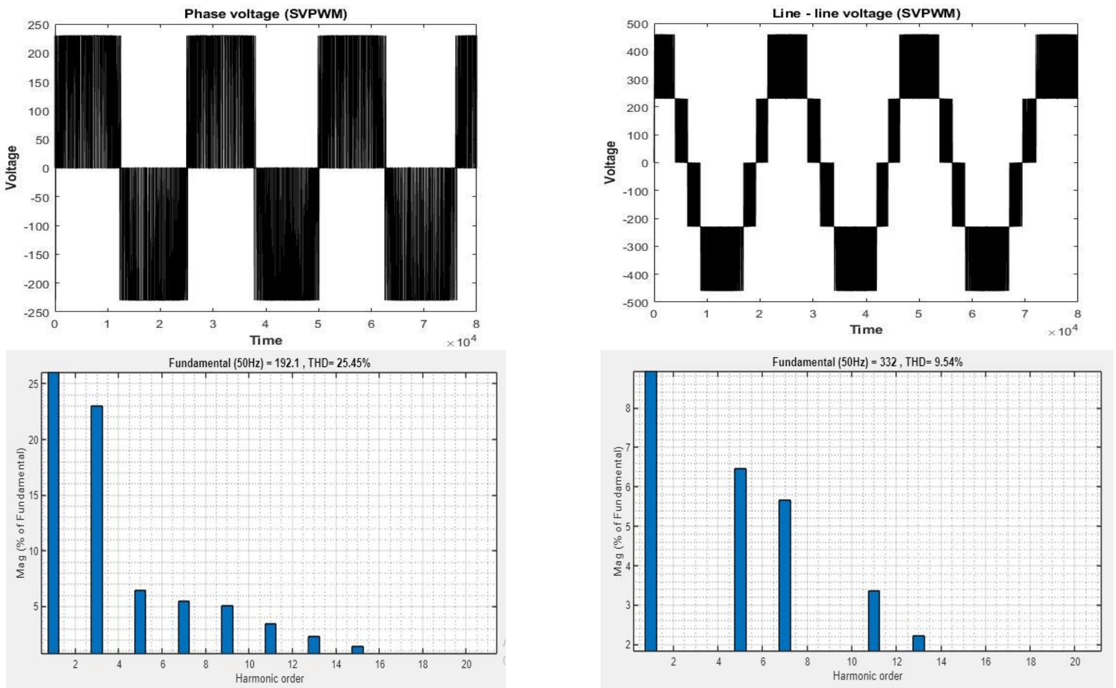
The 3-level Neutral Point Clamped (NPC) inverter using Sinusoidal Pulse Width Modulation (SPWM) is shown in Fig. 4 with its phase and line voltage displayed. As shown in Fig. 4(a), the phase voltage has a THD value of 53.58%. 198.1V is the measured peak voltage value for the phase voltage. However, as can be seen in Fig. 4 (b), the line voltage had a THD value of 15.70%, indicating that there were no triple harmonics because the three-phase system was balanced. The line voltage is measured at 343.5 V in magnitude.



a) Phase Voltage b) Line-line Voltage

Figure 4: Voltage waveform and harmonic contents of 3-level NPC inverter with R-L using SPWM

The 3-level Neutral Point Clamped (NPC) inverter employing Space Vector Pulse Width Modulation (SVPWM) is shown in Fig. 5 along with its line voltage and phase. Fig. 5(a) shows that the phase voltage has a THD value of 25.45%. 192.1 V is the observed peak voltage value for the phase voltage. As can be seen in Fig. 5(b), the line voltage had a THD value of 9.54%, indicating that there were no triple harmonics because the three-phase system was balanced. 332 V is the measured line voltage magnitude.



a) Phase Voltage b) Line-line Voltage

Figure 5: Voltage waveform and harmonic contents of 3-level NPC inverter with R-L using SVPWM

Table 1 displays alterations in the peak value of the fundamental component with variations in the amplitude modulation index across the range of 0.6 to 1.0 for both SPWM and SVPWM methods.

Table 1: Fundamental values with change of modulation index.

m_a	SPWM		SVPWM	
	Phase Voltage (V)	Line Voltage (V)	Phase Voltage (V)	Line Voltage (V)
0.6	126.6	220	140.8	244
0.7	163.1	283.6	156.6	271.5
0.8	180.1	296.6	179.2	310.1
0.9	206.6	362.3	205.2	355.9
1.0	220.4	377.2	233.9	405.1

According to Table 1's results, as the amplitude modulation index increases, so do the phase and line-line fundamental values for both SPWM and SVPWM. This variation in the phase and line-line fundamental values for both SPWM and SVPWM, as the amplitude modulation index is progressively modified from 0.6 to 1.0, is visually represented in Figures 6 and 7. Figures 6 and 7 both demonstrate how the peak values of the fundamental component in SVPWM vary more linearly with modulation index variation than in SPWM. This shows that SVPWM has a larger peak fundamental value for both phase and line-line voltage and is more consistent as the modulation index changes.

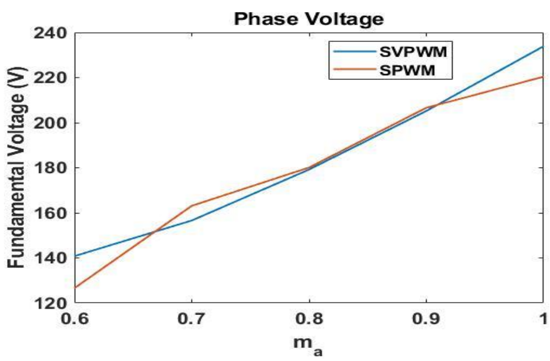


Figure 6: Modulation index vs Peak fundamental value (Phase voltage)

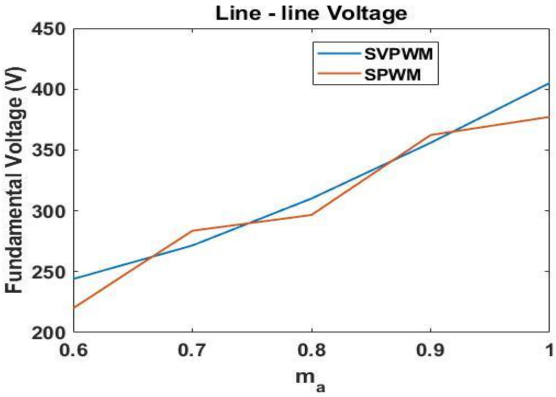


Figure 7: Modulation index vs Peak fundamental value (Line – line voltage)

IV. CONCLUSION

According to the findings derived from the data, an increase in the modulation index causes a linear rise in the fundamental peak voltages (phase and line) throughout this modulation index range ($0.6 < ma \leq 1$), as shown in Fig 6. In particular, it is shown that, when using the SVPWM technique, the fundamental peak phase voltage increases by 15% and the THD related to the output voltage decreases in comparison to the results obtained using the SPWM technique, as shown in Figures. 4 and 5.

These findings indicate that, in comparison to SPWM, SVPWM's greater output fundamental voltage indicates a more efficient use of the DC bus. The benefits of SVPWM over SPWM in obtaining reduced THD and greater fundamental voltages in the output voltage within the examined modulation range are highlighted in this conclusion.

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