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Performance Analysis of T-Type Three- Level Inverter under Different Modulation Indices

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***Abstract:** In recent years, multi-level converters have emerged as a potentially useful solution for medium- and high-power applications. This is primarily owing to their capacity to create output voltages of superior quality, while simultaneously minimizing harmonic distortion and switching stress. Recently developed T-type converters, have been subjected to extensive research for the purpose of application in renewable energy systems, electric vehicles, motor drives, and grid-connected applications. In this work, a complete comparative performance analysis is presented. The analysis is based on important a performance indicator such as total harmonic distortion (THD) is presented.*
***Keywords**: Multilevel Converter, NPC, T-type, line-line voltage, THD*

I. INTRODUCTION

The development of multilevel converter topologies has been rushed as a result of the growing demand for high-efficiency power conversion systems in applications including renewable energy, electric vehicle (EV) charging infrastructure, motor drives, and smart grid technologies. Multilevel converters offer greater output voltage quality, decreased electromagnetic interference (EMI), reduced switching losses, and improved power conversion efficiency when compared to standard two-level converters [1]. Additional benefits include these. They are appealing for medium- and high-power applications because of these characteristics, which are particularly useful in situations where power quality and efficiency are essential design requirements.

Among the many different configurations of multilevel converters, three-level converters have garnered a large amount of attention due to the fact that their structure is reasonably straightforward and they have the capacity to effectively reduce harmonics. Three-level converters lessen the voltage stress that is placed across semiconductor devices and limit the size of output filters. They accomplish this by creating multiple voltage levels at the output. Consequently, they offer a sensible balance between the complexity of the converter and the performance of the converter.

Because of its capacity to create high-quality output voltages with reduced harmonic distortion and lower switching stress, the development of multilayer inverter (MLI) technology has garnered a significant amount of interest in recent years. Recent research has investigated the possibility of incorporating computational intelligence and smart control approaches in order to improve the efficiency of power converters and renewable energy systems [1]. There has been a lot of discussion about advanced control approaches for AC drives and power electronic converters in order to increase efficiency and dynamic response under a variety of different operating circumstances [2]. Improvements in harmonic suppression and power quality enhancement have been established by comparative research on cascaded H-bridge inverters that make use of a variety of DC-link voltage controllers [3]. The problem of voltage balancing in flying-capacitor multilevel inverters has been effectively handled by the utilization of carrier-based pulse width modulation (PWM) techniques, which has caused an improvement in the regulation of capacitor voltage [4]. In a number of researches, harmonic performance in multilevel inverters has been examined under a variety of modulation indices and operating situations. These investigations have shed light on the impact that modulation techniques have on output quality [5]-[6]. Comprehensive evaluations of multilevel inverter topologies, control techniques, and applications have provided significant insights into the characteristics of various converter systems, including their advantages and drawbacks [7]. The T-Type three-level inverter has garnered a significant amount of interest for hybrid renewable energy applications among the various topologies that are available. This is primarily owing to the fact that it has decreased switching losses and improved efficiency [8]. As a result of its higher voltage waveform quality and longer control range, the neutral-point-clamped (NPC) inverter continues to be one of the multilevel converter topologies that is most extensively utilized [9]. In addition, grid-connected photovoltaic systems have been explored by researchers, with a particular focus on the significance of robust inverter functioning under both steady-state and dynamic settings [10]. Furthermore, advanced modulation schemes such as space vector PWM and zero-voltage-switching PWM have been proposed to reduce switching losses and enhance converter efficiency [11].

On the other hand, techniques for programmed PWM have been critically evaluated for the purpose of eliminating harmonics in power electronic systems [12]. It has been established that the utilization of modular multilevel converters in active power filtering has resulted in significant gains in power quality compensation [13]. In addition, grid-connected multilevel converters have been created in order to assist the effective conversion of electricity between single-phase and three-phase systems [14]. Recent research has concentrated on enhancing the efficiency of diode-clamped multilevel inverters as well as the distribution of power loss through these devices, particularly when they are operating at high frequencies [15]. Furthermore, strategies that are based on artificial intelligence and are used to track the greatest power point have been successfully used in freestanding photovoltaic systems in order to maximize the amount of energy that is extracted [16]. The implementation of intelligent power electronic converters in contemporary power systems has been further expedited by the incorporation of smart energy management systems and renewable energy resources [17], [18]. In spite of these advancements, there is still a lack of a comprehensive comparative analysis of T-Type and F-Type three-level converters operating under identical conditions. This necessitates additional research into the performance characteristics, efficiency, harmonic distortion, and suitability of these converters for medium-voltage applications.
It has become increasingly common for grid-connected converters and industrial drives to use the T-Type three-level converter as their topology of choice nowadays. It is vital to conduct a detailed comparison analysis of the performance of NPC and T-Type converters under identical operating conditions, despite the fact that both types of converters have been subjected to extensive research. Therefore, it is difficult to determine which converter is the most appropriate for a certain power conversion requirement because the majority of the research that are now available concentrate on particular topologies or applications. Therefore, it is required to conduct a comprehensive comparison based on key performance indicators such as the quality of the output voltage [2] and the total harmonic distortion (THD. The purpose of this article is to provide a comparative performance analysis of three-level converters of the NPC and T-Type converter.

II. METHODOLOGY

The proposed block diagram considered for the simulation study is depicted in Fig.1. A three-level converter-fed RL load system is depicted in the block diagram shown in the figure. A DC input source (V_{dc}) is used to supply the system with the necessary input power. This source makes the system available. A DC-link capacitor arrangement, which is comprised of capacitors C_1 and C_2, is connected to the DC source. In order to implement the three-level converter, which can be built using either the T-Type, Neutral Point Clamped (NPC), or F-Type topology, the regulated DC-link voltage is applied to the converter. When compared to conventional two-level converters, the converter is able to convert the direct current (DC) input into a controlled alternating current (AC) output voltage [3]. Additionally, the converter suffers from less harmonic distortion and less voltage stress across the switching devices. It is a PWM controller that is responsible for generating the necessary gate signals for the converter switches. This allows the controller to regulate the output voltage and current in accordance with the preferred operating conditions. An RL load, which consists of a resistor (R) and an inductor (L), is linked to the output of the converter. This load is a representation of practical electrical loads, such as motor drives and industrial power systems. Taking everything into consideration, the layout illustrates the flow of power from the DC supply to the RL load, passing through the DC-link stage and the three-level converter. Meanwhile, the PWM controller ensures that the switching and output voltage is regulated appropriately. PDPWM is considered for the PWM control.

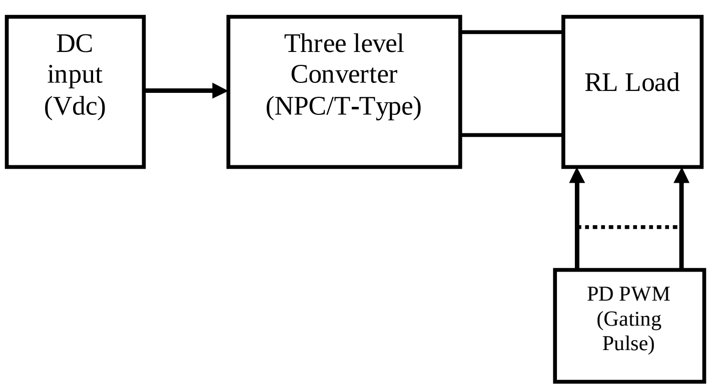

Fig. 1 Block diagram considered for the simulation work

A. NPC three Level Converter

In order to implement the N-level Neutral Point Clamped (NPC) inverter topology, it is necessary to have (n − 1) capacitors linked in series on the DC voltage side. Across the DC voltage source V dc, these capacitors are connected in a bridge configuration. As well as divide the voltage that is being input into several voltage levels. When functioning under ideal conditions, the entire direct current voltage is distributed evenly across the (n−1) capacitors, resulting in each capacitor having a voltage of V dc / (n−1). Additionally, each phase leg of an N-level NPC inverter is comprised of two power semiconductor switches, each of which is equipped with an antiparallel diode. Additionally, there are two pairs of clamping diodes that are also included in each phase leg. The switching devices are connected to the neutral points [4] of the DC-link capacitors by the use of clamping diodes, which enables the generation of different output voltage levels. Additionally, it is worth noting that every phase leg is comprised of (n − 1) complementary switch pairs. These switch states are responsible for determining the working modes of the inverter. Additionally, they ensure the synthesis of a stepped output voltage waveform that is characterized by less harmonic distortion and lower voltage stress on individual switching devices. Three-level [5] NPC/Diode clamped inverter is depicted in Fig.2 which is considered for the simulation.

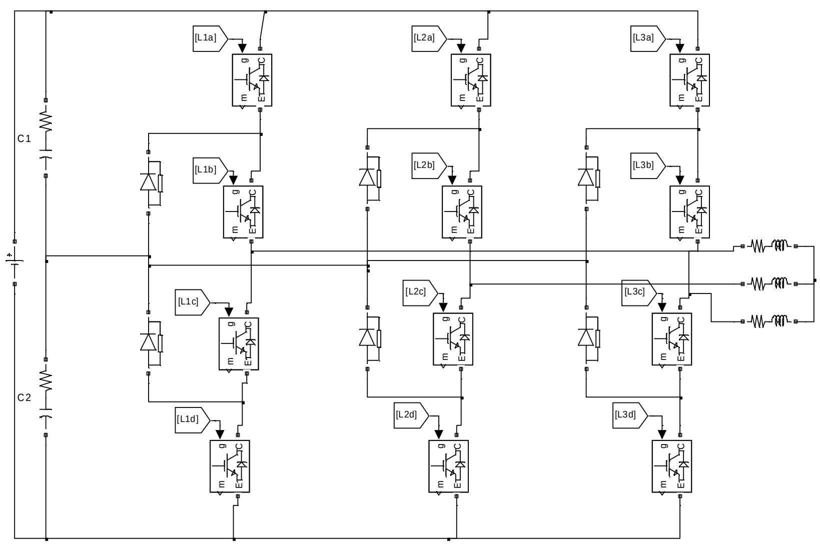

Fig. 2 Three level (3L) NPC/diode clamped Inverter [2]

B. T-Type Three Level Converter

The T-type inverter does not contain any clamping diodes in its circuitry. When it comes to switch pairs that are complementary, if one switch is turned on, the other switch should be turned off. Complementary switch pairs are connected by connecting the emitters of one switch to the emitters of another switch. The anti-parallel diodes are two in number, and there are ‘n’ different switching states for each phase of an n-level direct current converter (DCC). At the voltage node, the value "0" represents the reference voltage, and the switching combinations are used to generate a variety of voltage configurations. The technique known as pulse width modulation (PWM) is one of the most widely used strategies for controlling the alternating current (AC) output of power electronic converters [5]-[6]. This technique involves varying the duty cycle of the converter switches at a high switching frequency in order to achieve a target average low frequency output voltage or current. There is a significant relationship between the PWM method that is employed and the performance characteristics of power converters. Pre-calculated programmed PWM schemes and carrier-modulated sine PWM are two major categories that can be used to categorize the various PWM techniques that are currently available. The significant first carrier harmonic is the most prominent characteristic of the phase voltage spectrum in the PD-PWM modulation technology. As a result of the fact that this carrier harmonic is a common-mode component that is present across the phase voltages of a three-phase inverter, it is eliminated from the output line voltage. This characteristic enables the PD-PWM [3], [7]-[8], [10] and [13] to produce line voltage performance that is of an exceptionally high quality.

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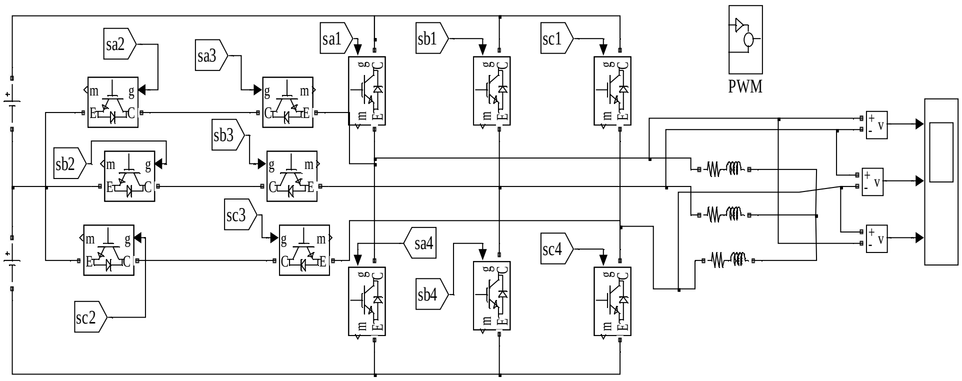


Fig. 3 Three level (3L) T-Type Inverter

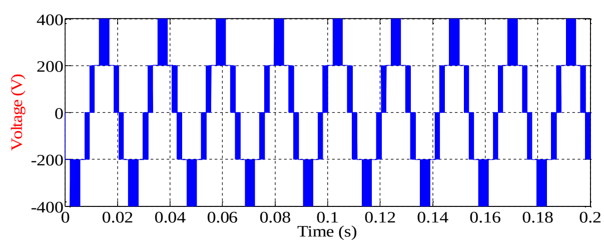
III. SIMULATION RESULT ANALYSIS

To assess the efficacy of the proposed three-level converter topologies, comprehensive simulations were conducted in the MATLAB/Simulink environment under uniform operating conditions. The research examines a comparative analysis of the Three-Level Neutral Point Clamped (NPC) [8] converter and the Three-Level T-Type converter. The performance evaluation relies on the line-to-line output voltage waveform [9], fundamental voltage magnitude, and harmonic attributes derived from Fast Fourier Transform (FFT) analysis.

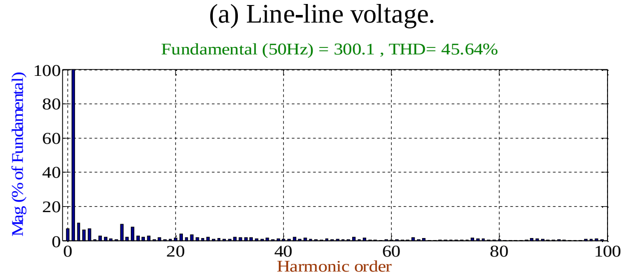
The modulation index is crucial in influencing the output voltage quality and harmonic content of multilevel converters. Consequently, simulations were performed for modulation indices of M = 1.0, 0.9, and 0.8 to examine the effect of modulation depth on converter performance. The simulation parameters are listed in Table I.

Table I
Simulation parameters

Parameter	Value
Input Voltage	400 Volts
R, L	0.1Ω, 5mH
Switching frequency	5000 Hz
Switches	IGBT



(a) Line-line voltage.



(b) FFT spectrum

Fig.4 Response curves of 3L NPC for MI=1

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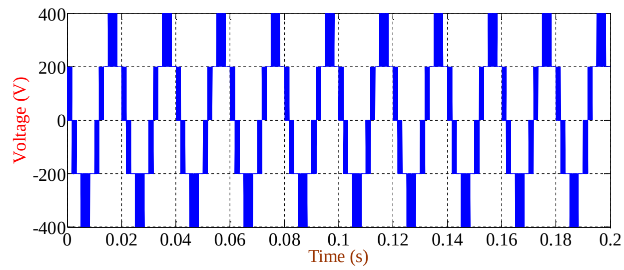
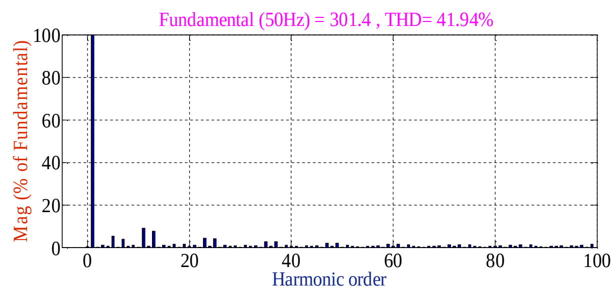
Fig.4 and Fig.5 illustrates the response characteristics of two different three-level inverter topologies, namely the Neutral Point Clamped (NPC) inverter and the T-Type inverter [10], both of which are operating with a modulation index of M = 1. The line-to-line output voltage waveform of the 3L NPC inverter displays a stepped three-level structure with voltage levels of +Vdc, 0Vdc, and –Vdc. This demonstrates the converter's capabilities to transition between multiple levels of voltage. There are considerable harmonic components present in the output waveform, as seen by the matching FFT spectrum, which reveals the presence of a fundamental voltage component of about 300.1 V at 50 Hz and a Total Harmonic Distortion (THD) of 45.64%. Similar to the previous example, the 3L T-Type inverter is capable of producing a line-to-line voltage waveform that is symmetrical and three-level, and it has amplitude and frequency characteristics that are equivalent. The FFT analysis, on the other hand, reveals a fundamental voltage of around 301.4 V at 50 Hz and a THD that is significantly lower than the previous value of 41.94%. This indicates that the harmonic performance is superior and that the output voltage quality has improved. A comparison of the two topologies reveals that the T-Type inverter experiences a large reduction in harmonic distortion in comparison to the NPC inverter. This is the case despite the fact that both converters produce fundamental output voltages that are almost equal to one another. As a result of this reduction in total harmonic distortion (THD), power quality is improved, filtering needs are reduced, and overall converter performance is enhanced. As a result, the T-Type architecture is a more appealing option for applications that demand high-quality power conversion.

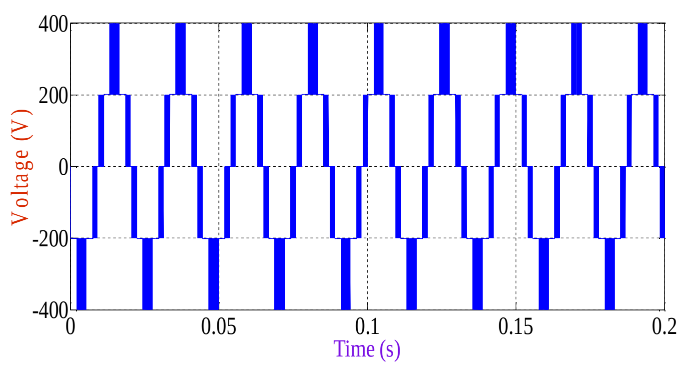


(a) Line-line voltage [11]



(b) FFT spectrum [11]

Fig.5 Response curves of 3L TTI for MI=1



(a) Line-line voltage [11]

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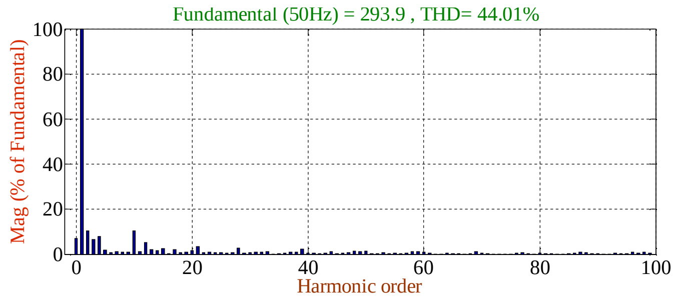
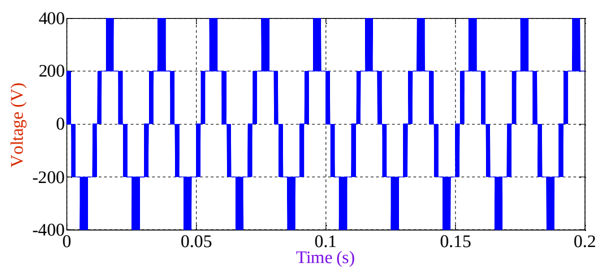
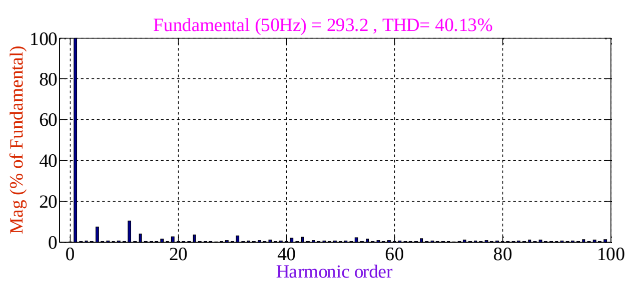


(b) FFT spectrum [11]
Fig.6 Response curves of 3L NPC for MI=0.9

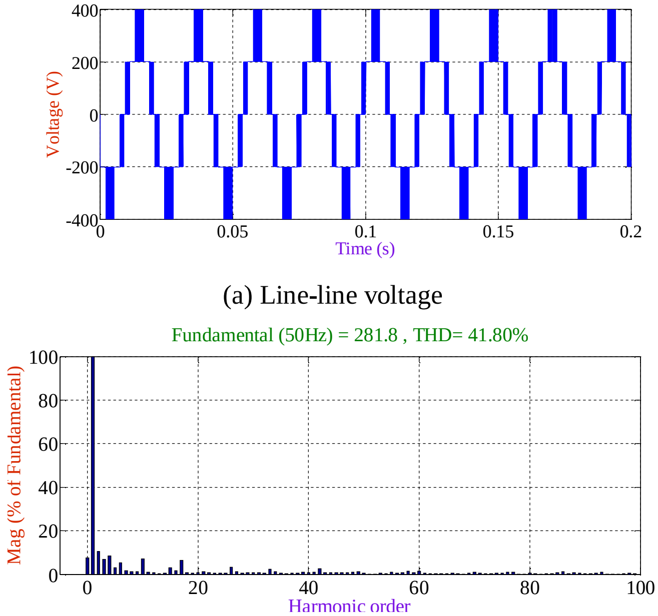
The performance characteristics of the three-level Neutral Point Clamped (NPC) inverter and the three-level T-Type inverter [8] that are both operating at a modulation index of M = 0.9 are depicted in the figure to illustrate their respective characteristics. In comparison to the scenario in which the modulation index is equal to one, the line-to-line output voltage [12] waveform of the NPC inverter as shown in Fig. 6 displays a stepped multilayer structure with lower amplitude. With the help of pulse width modulation (PWM) switching, the waveform keeps its typical three-level operation and generates an output that is nearly sinusoidal. A fundamental voltage component of roughly 293 V at 50 Hz is shown by the associated FFT spectrum, which also reveals a Total Harmonic Distortion (THD) of 44.01%. Despite the fact that the major component is focused at the fundamental frequency, the presence of considerable lower-order harmonics is a contributing factor to the comparatively high amount of distortion. In addition, the line-to-line voltage waveform of the T-Type inverter as shown in Fig. 7 exhibits a balanced three-level stepped profile, and the fundamental output voltage is approximately 293 V at 50 Hz. The FFT analysis reveals that the total harmonic distortion (THD) is just 40.13%, which is a significant reduction from the THD of the NPC inverter. The harmonic spectrum demonstrates that the majority of undesirable harmonics are efficiently suppressed, which leads to a cleaner waveform out of the output and an improvement in the quality of the power. The T-Type inverter has a greater fundamental voltage and much lower harmonic distortion than the NPC inverter when both topologies are compared at M = 0.9 [5].



(a) Line-line voltage



(b) FFT spectrum
Fig.7 Response curves of 3L TTI for MI=0.9



(a) Line-line voltage

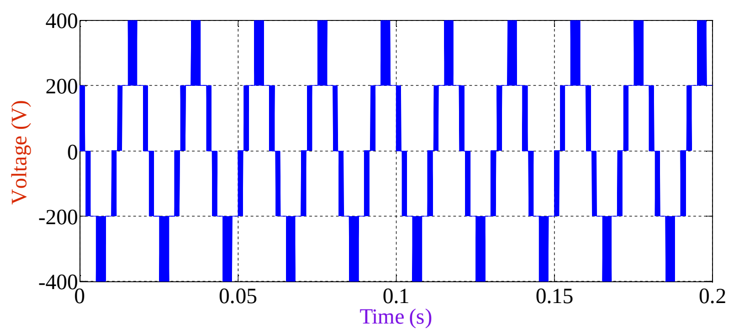
(b) FFT spectrum

Fig.8 Response curves of 3L NPC for MI=0.8

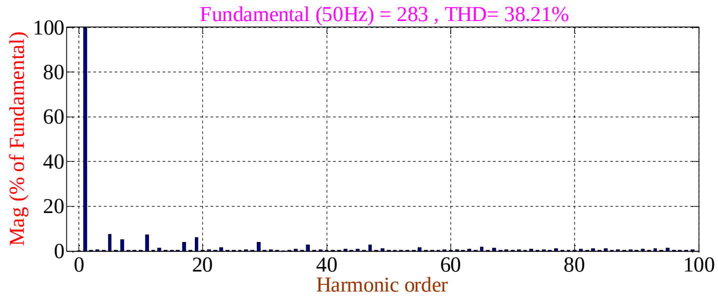
Fig.8 and Fig.9 illustrates the output voltage and harmonic performance of two different types of inverters: the three-level Neutral Point Clamped (NPC) inverter and the three-level T-Type inverter. Both of these inverters are operating with a modulation index of M = 0.8. Figure 8 depicts the line-to-line voltage waveform of the 3L NPC inverter, which displays a stepped three-level structure with reduced amplitude as a result of the lower modulation index. A fundamental voltage component of roughly 281 V at 50 Hz is displayed in the matching FFT spectrum, along with a Total Harmonic Distortion (THD) value of 41.80%. A rather high amount of distortion is produced as a consequence of the presence of multiple lower-order harmonics, despite the fact that the fundamental component continues to be the dominant one.

The performance of the 3-Level T-Type inverter [8] using the same modulation index is depicted in Fig. 9, which is similar to the previous figure. A fundamental voltage component of about 283 V at 50 Hz is maintained by the line-to-line voltage waveform, which also maintains a balanced three-level stepped profile. According to the FFT study, the total harmonic distortion (THD) is 38.21%, which is lower than the THD of the NPC inverter. The harmonic spectrum demonstrates that the magnitude of harmonic components has decreased, which has resulted in an improvement in the quality of the output voltage.

A comparison of the two topologies at M = 0.8 reveals that both converters experience a decline in fundamental output voltage when the modulation index decreases. This is demonstrated by the fact that the topologies are very similar. In contrast, the T-Type inverter obtains a lower harmonic distortion (38.21%) compared to the NPC inverter (41.80%), which indicates that the T-Type inverter has a higher capability to suppress harmonic frequency. Because of this, the T-Type topology offers higher output waveform quality and enhanced power conversion performance in comparison to the NPC inverter, even when the modulation indices are smaller. The comparative performance values are listed in Table II.



(a) Line-line voltage



(b) FFT spectrum

Fig.9 Response curves of 3L TTI for MI=0.8

Table II
% THD COMPARISON

Modulation index	3L NPC		3L T-Type	
	Voltage (V)	%THD	Voltage (V)	%THD
M=1	300	45.64	301.4	41.94
M=0.9	293.9	44.01	293.2	40.13
M=0.8	281.8	41.80	283	38.21

IV. CONCLUSIONS

This research conducted a comparative performance analysis of the Three-Level Neutral Point Clamped (NPC) converter and the Three-Level T-Type converter across various modulation indices. The converters were assessed according to their line-to-line output voltage waveforms and harmonic performance by FFT analysis. Simulation results indicated that both topologies may produce multilayer output voltages while minimizing voltage stress on the power semiconductor devices. However, their harmonic properties exhibited considerable variation in response to alterations in the modulation index.

Future research may concentrate on experimental validation, loss assessment, thermal performance evaluation, and sophisticated modulation approaches to further improve converter performance in dynamic operating settings.

REFERENCES

[1] Sharma, B., Kose, U., Singh, V.P., & Kumar, A. (Eds.). (2025). Computational Intelligence, and Smart Technologies in Solar Thermal Systems: Principles and Applications (1st ed.). CRC Press. https://doi.org/10.1201/9781003634737.

[2] Haitham Abu-Rub, Atif Iqbal, JaroslawGuzinski. "High Performance Control of AC Drives with MATLAB®/Simulink", Wiley, 2021.

[3] V. Narasimhulu, G. J. Rani and N. Jyothi, "Comparative Exploration of a Seven-Level Cascaded H-Bridge Shunt Active Power Filter using Diverse DC-Link Voltage Controllers," 2026 International Conference on Electronics and Renewable Systems (ICEARS), Tuticorin, India, 2026, pp. 689-694, doi: 10.1109/ICEARS67481.2026.11416801.

[4] Dae-Wook Kang, Byoung-Kuk Lee, Jae-Hyun Jeon, Tae-Jin Kim and Dong-Seok Hyun, "A symmetric carrier technique of CRPWM for voltage balance method of flying-capacitor multilevel inverter," in IEEE Transactions on Industrial Electronics, vol. 52, no. 3, pp. 879-888, June 2005, doi: 10.1109/TIE.2005.847574.

[5] V. Narasimhulu, D. V. Ashok Kumar, and Ch. Sai Babu, "Comparative Simulation Analysis of Harmonics in Line-Line Output Voltage of Multilevel Inverters for Different Modulation Indices," International Journal of Control Theory and Applications, vol. 10, no. 5, pp. 289–296, Jan. 2017.

[6] V. Narasimhulu, et al., “State of Art Review of Various Control Methods for Cascade H-Bridge 5-Level Inverter to Mitigate Harmonics,” International Journal of Control Theory and Applications, vol. 9, no. 49, pp. 1–9, 2016.

[7] A. El-Hosainy, H. A. Hamed, H. Z. Azazi and E. E. El-Kholy, "A review of multilevel inverter topologies, control techniques, and applications," 2017 Nineteenth International Middle East Power Systems Conference (MEPCON), Cairo, Egypt, 2017, pp. 1265-1275, doi: 10.1109/MEPCON.2017.8301344.

[8] J. G. K and N. V, “Performance Analysis Of T-Type 3-Level Inverter In PV-Fuel Cell Hybrid Generation System,” 2023 International Conference on Ambient Intelligence, Knowledge Informatics and Industrial Electronics (AIKIIE), Ballari, India, 2023, pp. 1–6, doi: 10.1109/AIKIIE60097.2023.10390403.

[9] R. Rojas, T. Ohnishi and T. Suzuki, "Neutral-point-clamped inverter with improved voltage waveform and control range," in IEEE Transactions on Industrial Electronics, vol. 42, no. 6, pp. 587-594, Dec. 1995, doi: 10.1109/41.475499.

[10] Narasimhulu, V., Jithendra Gowd, K. (2021). Performance Analysis of Single-Stage PV Connected Three-Phase Grid System Under Steady State and Dynamic Conditions. In: Gunjan, V.K., Suganthan, P.N., Haase, J., Kumar, A. (eds) Cybernetics, Cognition and Machine Learning Applications. Algorithms for Intelligent Systems. Springer, Singapore. https://doi.org/10.1007/978-981-33-6691-6_5.

[11] A. De and M. Barai, "An improved zero voltage switching SVPWM for three phase inverter," 2017 11th IEEE International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG), Cadiz, Spain, 2017, pp. 169-174, doi: 10.1109/CPE.2017.7915164.

[12] P. N. Enjeti, P. D. Ziogas and J. F. Lindsay, "Programmed PWM techniques to eliminate harmonics: a critical evaluation," in IEEE Transactions on Industry Applications, vol. 26, no. 2, pp. 302-316, March-April 1990, doi: 10.1109/28.54257.

[13] V. Narasimhulu, D. V. Ashok Kumar, and Ch. Sai Babu, "Recital Analysis of Modular Multilevel Converter Based Shunt Active Power Filter," Journal of Mechanics of Continua and Mathematical Sciences, Special Issue 5, pp. 181–192, Jan. 2020. DOI: https://doi.org/10.26782/jmcms.spl.5/2020.01.00016

[14] A. Kumar, M. V. Aware, B. S. Umre and M. A. Waghmare, "Grid Connected Multilevel Single to Three Phase Power Converter with Improved Performance," TENCON 2019 - 2019 IEEE Region 10 Conference (TENCON), Kochi, India, 2019, pp. 1535-1540, doi: 10.1109/TENCON.2019.8929411.

[15] Stala, R.; Folmer, S.; Penczek, A.; Hachlowski, J.; Mikoś, Z. Efficiency and Power Loss Distribution in a High-Frequency, Seven-Level Diode-Clamped Inverter. Energies 2023, 16, 7866. https://doi.org/10.3390/en16237866.

[16] V. Narasimhulu et al., "Maximum Power Extraction of PV Panel Adopting AI-MPPT Scheme in Standalone System," 2024 International Conference on Smart Systems for applications in Electrical Sciences (ICSSES), Tumakuru, India, 2024, pp. 1-4, doi: 10.1109/ICSSES62373.2024.10561358.

[17] G. P. Rao et al., "Smart Home Management System utilizing ESP32 Controller and Solar Power," 2026 IEEE International Conference on Emerging Computing and Intelligent Technologies (ICoECIT), Hyderabad, India, 2026, pp. 1-6, doi: 10.1109/ICoECIT68303.2026.11497927.

[18] P. Voleti, Vandna, B. P. Reddy, G. J. Rani, B. R. S. Reddy and N. Jyothi, "A Hybrid Neuro-Fuzzy Model for Power Quality and Stability Enhancement in EV Charging with Grid-PV Integration," 2025 International Conference on Information, Implementation, and Innovation in Technology (I2ITCON), Pune, India, 2025, pp. 1-7, doi: 10.1109/I2ITCON65200.2025.11210743.