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Performance analysis of seven level multilevel inverter for power quality improvement

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ABSTRACT

Power conversion systems for demanding applications requiring high power and power quality are increasingly using multi-level converters. Due to its many advantages, such as low harmonic content, low electromagnetic interference (EMI) output, and low power consumption in power switches, the multilayer inverter (MLI) topology is more commonly used in medium and high power applications. The chosen switching technique of the inverter for operation significantly contributes to the suppression of harmonic components while creating the optimal output voltage. A single-phase 7-level cascaded H-bridge multilevel inverter (CHB-MLI) with fewer switches and alternative control algorithms is available in MATLAB-based simulation on the SIMULINK platform. In this research, the total harmonic distortion (THD) of several control techniques is compared. From the simulation results, it was found that the proposed artificial neural network (ANN) controller outperforms the proportional-integral (PI) controller. With a lower THD value and a comparatively better sinusoidal waveform, the ANN controller produces an output voltage. It is also more suitable for improving the quality of electricity. The efficiency and performance of the proposed 7-level CHBMI system are demonstrated by the improved sinusoidal output waveform and reduced output voltage THD.

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1. INTRODUCTION

Multilevel inverters are commonplace in excessive voltage and medium power programs because of their blessings of low voltage pressure in strength semiconductor devices, low harmonic distortion, amazing electromagnetic compatibility, decreased switching losses, and better fault tolerance reliability. To prevent inductive or discharge faults in loads, multilayer inverters even have a lower dv/dt ratio [1]. Multilevel inverters are currently being researched for use in low-voltage applications including photovoltaic (PV) system power inverters and uninterruptible power supplies (UPS) [2]. The impartial factor clamp multilevel inverter (NPC-MLI), flying capacitor multilevel inverter (FC-MLI), cascaded H-bridge multilevel inverter (CHB-MLI), and others are multilevel inverters for converting DC to AC. They have various because each CHB-MLI module requires a distinct DC power source, which may be easily supplied from different PV arrays, it is utilized primarily for PV applications. H-bridge modules connected in series allow for an increase in the output waveform's level count. Total harmonic distortion (THD) drops as the number of levels increases [3]. In comparison to the other two, the cascaded H-bridge inverter provides greater benefits. Clamping diodes and flying capacitors are not present in a cascaded H-bridge inverter. The fundamental disadvantage of a cascaded

H-bridge inverter is that as levels are added, more devices are utilized, increasing the need for gate drive circuits at the control stage itself, which raises the cost and switching losses. A hybrid multilevel inverter, which is created from cascaded H-bridge inverters, is the option to address the aforementioned drawbacks. Using multiple carrier pulse width modulation (PWM), the switching losses in the inverter circuit are reduced, so it can be used for high switching frequency applications [4]. In most research, a cascaded MLI arrangement is used. The development of updated multilevel inverters is still influenced by new trends, nevertheless. The internal structure has undergone modifications [5]. However, the primary issue with multilevel inverters is harmonic rejection. A multilevel inverter produces a sine wave that is closer to reality. The waveform grows in size as the number of DC volts rises. A greater amount of harmonic content can be filtered out because to the increased number of DC voltages [6]. The MLI output voltage can be controlled using a variety of methods. The most effective approach uses sinusoidal PWM methods, such as those in [7]. The beautiful improvement of recent MLI topologies on current ones multiplies their potential to stimulate greater output degrees with fewer additives. In addition, the trendy MLI topologies use balanced DC components to provide similar output tiers with fewer solid-nation switches, lowering funding costs and enhancing system reliability. Basically, the values of unbalanced DC assets can be acquired from numerous non-traditional electricity sources, together with sun, and wind. As a result, various topologies with asymmetrical structures have been designed to equalize unequal DC voltage sources and convert them to AC voltage with balanced situations [8].

2. CASCADED H-BRIDGE MULTILEVEL INVERTER

A single-phase cascaded 7-level converter topology with independent DC sources is depicted in Figure 1. A series connection is made between numerous single-phase full-bridge inverters to create a cascaded multilevel inverter. This multi-level inverter's job is to combine the many DC voltage sources linked to separate inverter units to provide the necessary AC output voltage. The advantages mentioned in [9] apply to cascading multilevel inverters. Note that each cell needs an isolated DC voltage source in each phase, unlike the flying capacitor and diode clamp topologies. The cascaded multi-level inverter has an output phase voltage level count of 2 seconds plus 1, where s is the total number of DC voltage sources. Figure 2 demonstrates the 7-level inverter's half-cycle phase voltage. Recently, the number of switches in MLI has been reduced by introducing a polarity generation module This topology provides a DC voltage suitable as a stairwell violin that approximates the rectified sine wave state to an expanding inverter that swaps the end to deliver an AC voltage with low THD and switching losses [10].

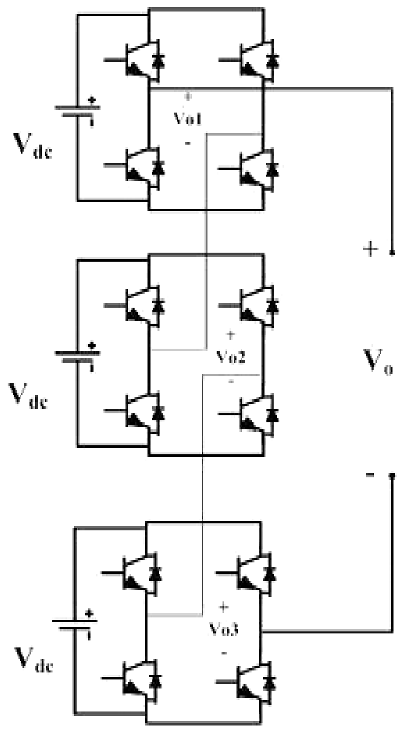

Figure 1. Configuration of single phase 7-level cascaded inverter

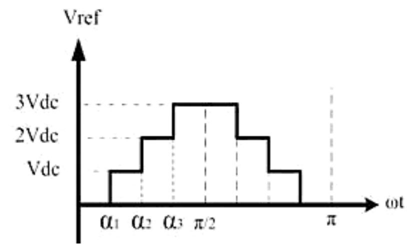

Figure 2. The half cycle of the phase voltage of 7-level inverter

3. PROPOSED METHODS

The incorporation of PWM control inside the inverter, as explained in [11], [12], is the most effective method of controlling the output voltage. This method involves providing the inverter with a consistent DC voltage and controlling the inverter on and off times to produce a controlled AC voltage. In many new industrial applications that demand greater performance, pulse width modulation techniques are being used more and more. Recent improvements in semiconductor and power electronics technologies have improved power electronics systems. As a result, several circuit topologies, such as PWM inverters, have gained popularity and the interest of researchers. To provide sources of changing voltage and frequency, a variety of pulse width modulation (PWM) techniques are used. Sinusoidal PWM, as shown in [13], is the PWM method for voltage source inverters that is most frequently employed.

3.1. Pulse width modulation technique

Switching power converters are used in industrial applications to convert the necessary energy and send it to a motor or load thanks to improvements in solid-state power devices and microprocessors. A strong PWM control method is safely utilized to decrease the extent of leakage current and improve the strength of a multilevel switched capacitor inverter. This approach creates developed reference signals from the principal signal to generate the circuit diagram for the converter circuit. In addition, the proposed manipulate approach works with best a small number of carrier alerts, ensuing in a quick system response and an easier controller algorithm, as in [14].

Both symmetrical and asymmetrical PWM pulses are displayed in Figure 3. PWM signals with pulse symmetry are always symmetrical at the middle of each PWM period irregular pulse. The same side of the PWM signal is always aligned with one end of the PWM period. It was established that fewer harmonics are produced in the output currents and voltages by balanced PWM signals. For the most typical three-phase power inverter applications, this literature takes into consideration three well-liked PWM approaches. Pulse width modulation (PWM) Control is the most often used technique for regulating the output voltage.

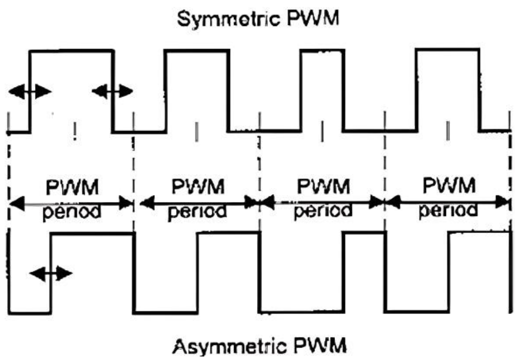

Figure 3. Symmetric and asymmetric PWM signals

3.2. Sinusoidal pulse width modulation technique

One of the more basic methods for suppressing harmonics in a quasi-square wave is the SPWM approach. The carrier wave in SPWM to the reference wave [15], [16] for comparison. The triangle wave specifies the frequency at which the values are swapped, and the reference wave corresponds to the desired one fundamental frequency at the output. Higher switching frequencies could be attained by altering the frequency of the carrier waves. The carrier frequency must always be an odd multiple of three to prevent throwing away the even harmonics. The proportional-integral (PI) controller has gained popularity in the control applications sector due to its straightforward implementation and structure. In Figure 4, the control circuit is displayed. The PI controller's regulation action law has the following equation [17].

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt \quad (1)$$

3.3. ANFIS

The adaptive network fuzzy inference system (ANFIS) is a fusion system that combines an artificial neural network's learning capabilities with fuzzy logic. The artificial neural network (ANN) is a fantastic example of knowledge and fuzzy logic inference capabilities, demonstrating its capacity to self-adjust membership roles to produce desired results. It is conceivable that the adaptive network is aware of the fuzzy inference system, which consists of practically every type of neural network model. ANFIS uses the hybrid learning rule to produce complicated result diagrams for diagnosis or decision-making. ANFIS was presented as a crucial tool for debugging systems using fuzzy inference membership functions. The ANFIS method for small-scale data learning creates a fuzzy inference system that is perfect for translating subjective effort into objective productivity. Membership functions, fuzzy logic operators, and if-then rules are all included in this forecast. However, there are two different categories of fuzzy systems.

In ANFIS operation, there are five primary processing phases: input fuzzification, fuzzy operator application, application strategy, output accumulation, and defuzzification [18]. Because of issue backpropagation into an organized network to mechanism parametric tuning fuzzy controller and fuzzy systems, ANFIS employs the display of the foregoing knowledge is interested in fixed restrictions in the network topology to moderate the optimization of the rifle bay. Fuzzy driver development involves learning to recognize distractions and uncertainty and to drive safely in their presence [19]. Modeling the membership functions with an ANFIS batch learning technique leads to set-based FIS tweaking input-output data pairs with a backpropagation process. ANFIS is frequently a multilayer feedforward network in which each node has a distinct function arriving signals as depicted in Figure 5.

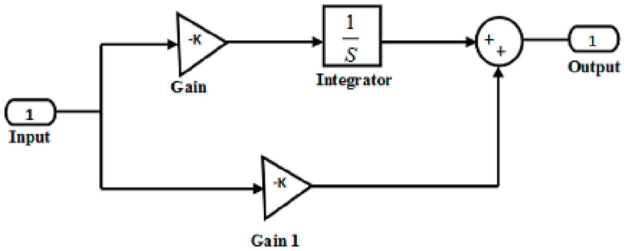

Figure 4. The control circuit of PI controller

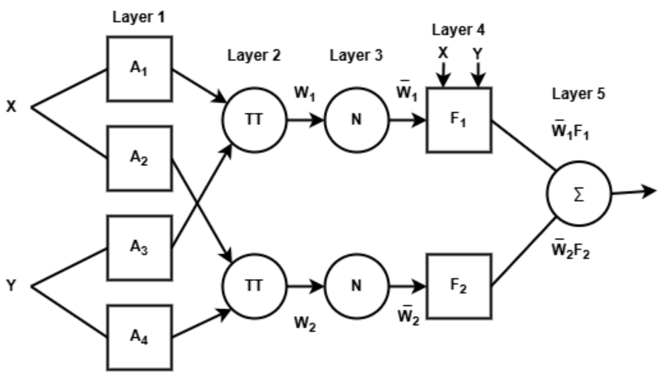

Figure 5. ANFIS architecture

4. SIMULATION RESULTS

The large number of components and the transformer increase the cost, size, weight and losses of the MLI, thereby reducing the efficiency of the system. This modular nature of the proposed MLI is used to increase the power processing capacity without introducing additional converters [20]. We can utilize any switch type, including MOSFET, IGBT, and other types, for modelling purposes, though MOSFETs typically offer the best results. Figure 6 demonstrates that it has twelve switches and produces an output with seven levels. Here, the modulation indices of the switches are used to determine which switch should be turned ON and OFF. Basically, we use R or RL load through in this situation, from which we obtain the output. A sample of the measured current and voltage waveforms is shown in Figure 7.

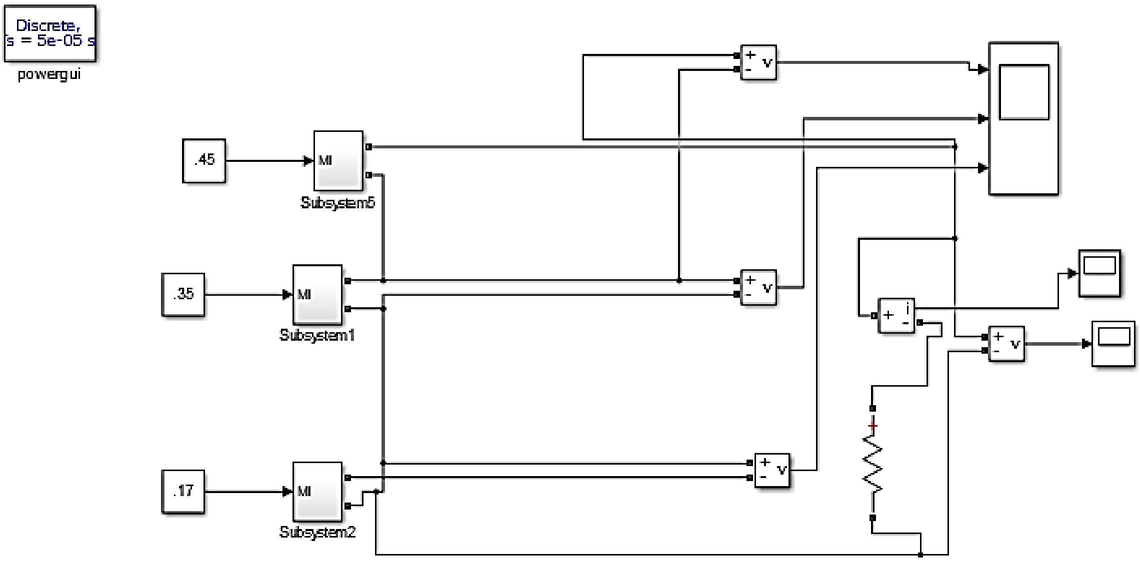

Figure 6. Simulation of 7-level MLI

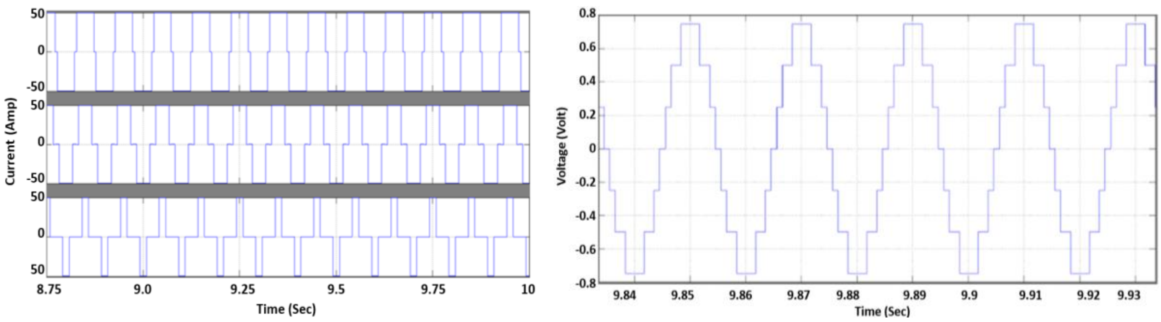

Figure 7. Output current and voltage waveform for seven-level inverter

In the context of multilevel inverters, particularly while using pulse width modulation (PWM) techniques, total harmonic distortion (THD) is a critical parameter that indicates the quality of the output waveform. THD quantifies the distortion in the output waveform, indicating how closely the inverter output resembles a pure sine wave. It is expressed as a percentage and is calculated based on the amplitudes of the harmonics relative to the fundamental frequency [21]. The proportional-integral (PI) controller is commonly used in the control strategy of multilevel inverters to regulate the switching of the power device, MOSFETs to achieve the desired output voltage waveform [22]. The quality of the PWM control, which is influenced by the PI controller parameters (such as gains and reference values), directly affects THD. A well-tuned PI controller can ensure that the output voltage closely follows the reference waveform, reducing the amplitude of harmonics and thereby lowering THD [23]. In this case, a PI controller is used, from which the gate signals are formed and fed to the inverter switches are represented in Figure 8. Figure 9 displays the output voltage and current waveforms. the PI controller in multilevel inverters plays a crucial role in minimizing THD by optimizing the PWM control strategy. Through careful design and tuning of the PI controller parameters, engineers can achieve low THD percentages, ensuring high-quality output waveforms suitable for various applications like renewable energy systems, motor drives, and grid-tied inverters. THD analysis of a seven-level inverter with a PI controller is shown in Figure 10.

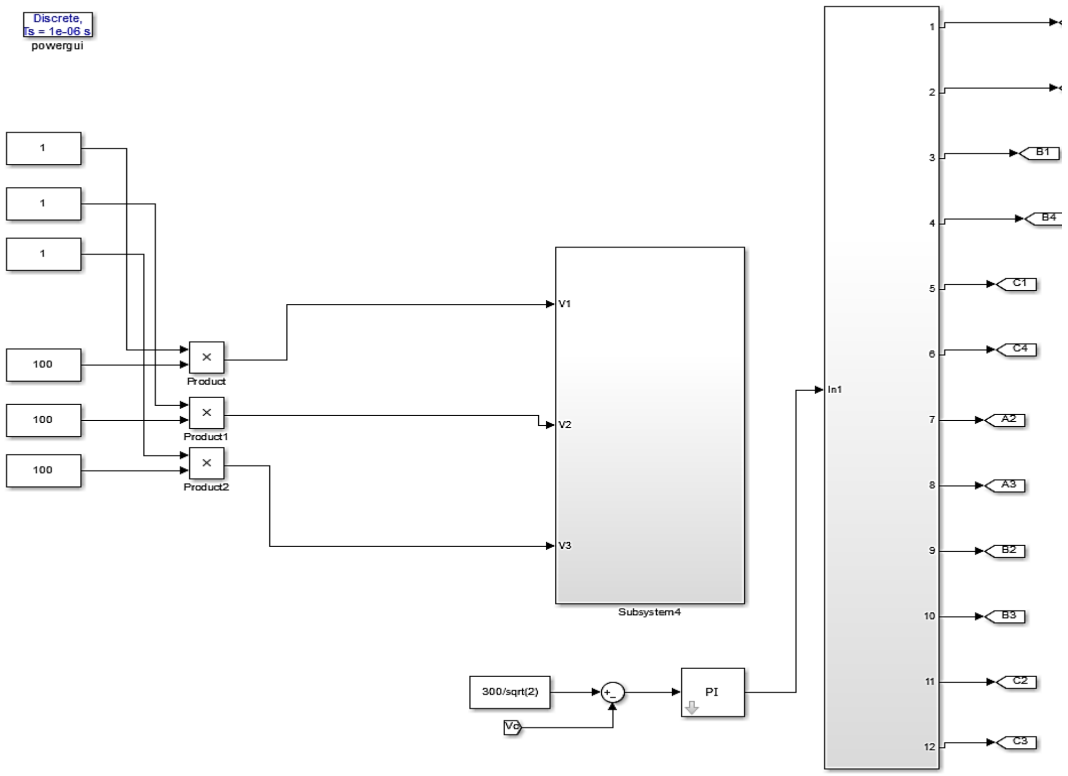

Figure 8. Simulation of 7 level MLI using PI controller

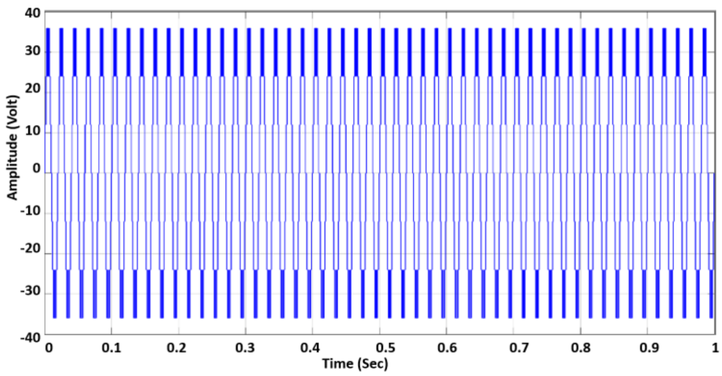

Figure 9. Output waveform for seven level inverter with PI controller

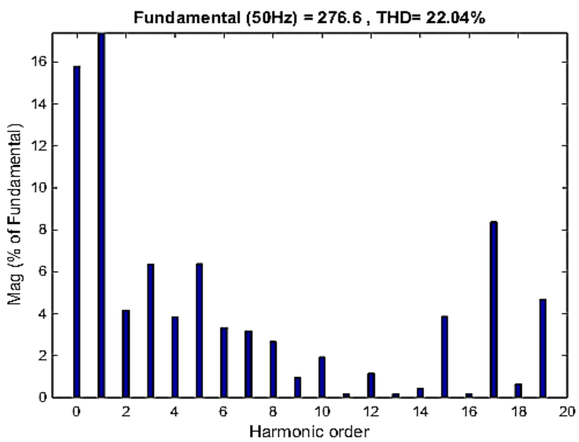

Figure 10. THD analysis seven level inverter with PI controller

An ANFIS controller with a multilevel inverter enhances control capabilities, allowing for efficient and adaptive management of output waveform characteristics as shown in Figure 11. This approach leverages the strengths of both fuzzy logic and neural networks to achieve superior performance in various applications requiring precise and dynamic control of power conversion systems [24]. By dynamically adjusting the modulation strategy, ANFIS can minimize total harmonic distortion (THD) in the output waveform is shown in Figure 12, thereby improving power quality [25]. THD analysis of a seven level inverter with PI controller is shown in Figure 13.

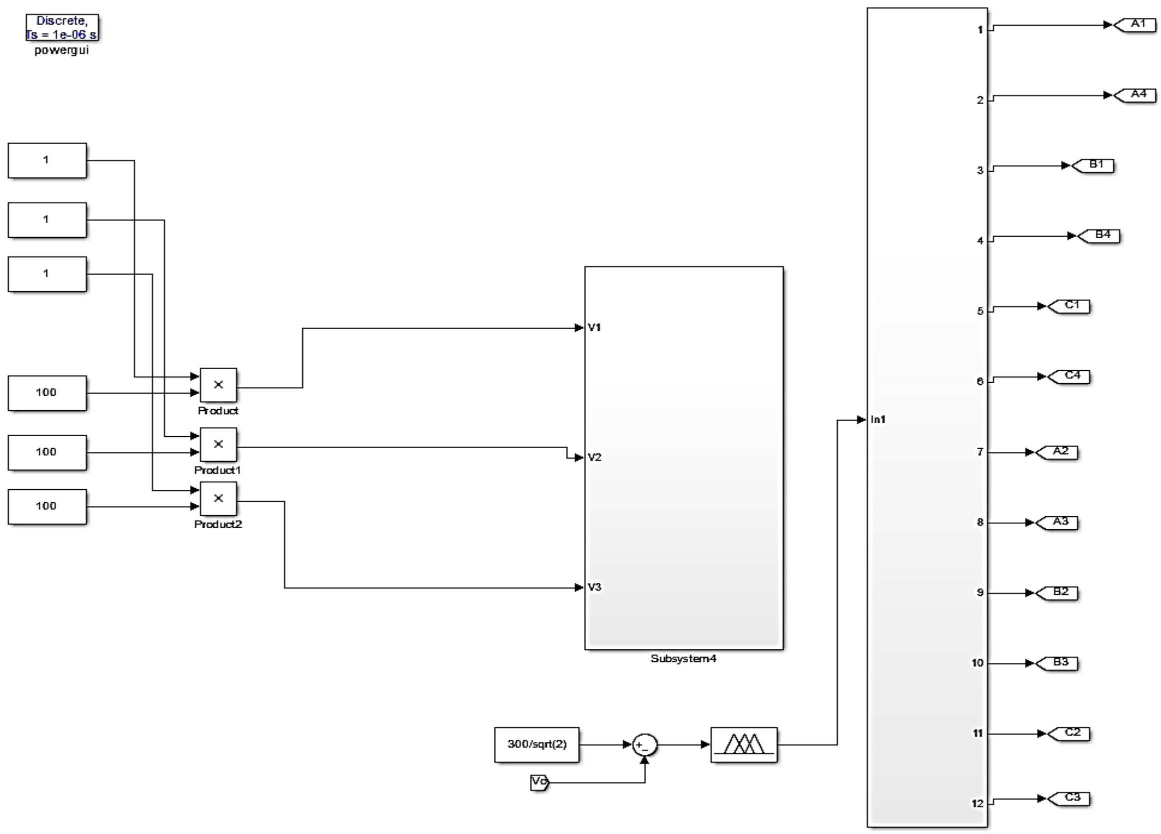

Figure 11. Simulation of 7-level MLI using ANFIS controller

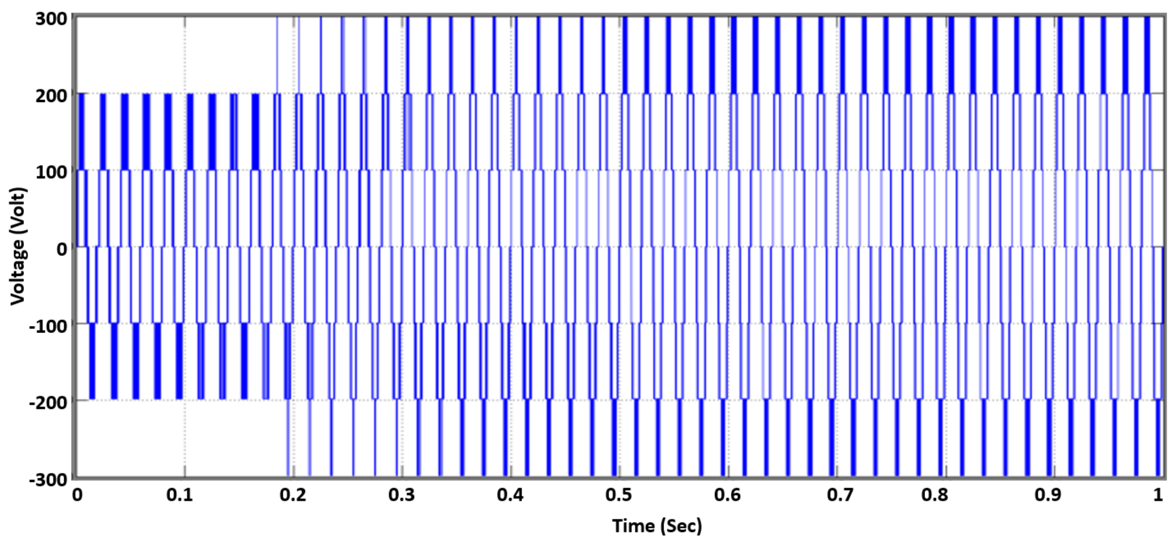

Figure 12. Output waveform of 7-level MLI using ANFIS controller

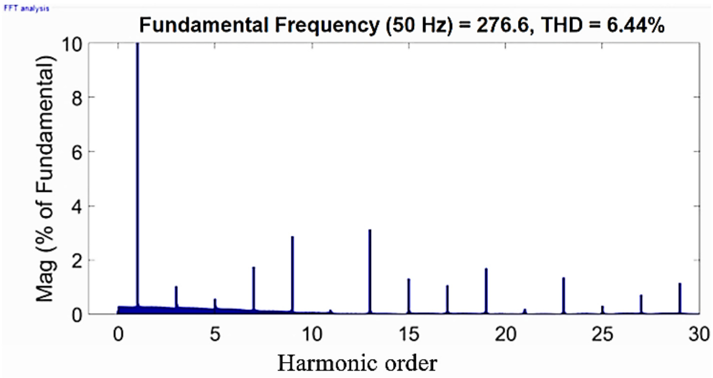

Figure 13. THD analysis seven level inverter with ANFIS controller

5. CONCLUSION

This study examined the performance of the suggested PI and ANN controllers using seven levels of CHB-MLI. It overcomes the shortcomings based on the ANN controller's capacity for self-learning. The proposed PI and ANN controller based on the general 7-level CHBMI were tested in a simulation together with the general 7-level CHB-MLI, and the simulation results were compared and examined. It is discovered from the simulation results that the suggested ANN controller outperforms the PI controller. With a smaller THD value and a comparatively superior sinusoidal waveform, the ANN controller produces the output voltage. Because it learns from experience and is trained through a dataset in supervised learning based on a neural network backpropagation model, the ANN controller is more sensitive than a PI controller in feedback and error modulation. It is also better suited for power quality improvement. The suggested 7-level CHBMI system's efficacy and performance are demonstrated by its improved sinusoidal output waveform and reduced THD output voltage.

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