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## International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

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# Performance Implement of Multilevel Inverter Using ANN-Control Technique

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**ABSTRACT:** Multilevel inverters (MLIs) are widely used in modern power electronic systems due to their ability to produce high-quality output voltage with reduced harmonic distortion. However, conventional control techniques often face challenges in achieving optimal switching, minimizing Total Harmonic Distortion (THD), and improving overall efficiency under varying load conditions. This work presents the **performance improvement of a multilevel inverter using an Artificial Neural Network (ANN)-based control technique**, implemented through both hardware and software simulation. The proposed ANN controller is designed to generate optimal switching angles by learning from system parameters, thereby reducing harmonic content and improving waveform quality. In the software simulation phase, tools such as MATLAB/Simulink are used to model the multilevel inverter and train the ANN using appropriate datasets. The ANN effectively predicts switching patterns that ensure improved voltage regulation and reduced THD compared to traditional methods like PWM and PI controllers. Hardware implementation is carried out using microcontrollers or DSP platforms to validate the real-time performance of the proposed system. The results demonstrate that the ANN-based control technique significantly enhances inverter performance by providing faster response, better stability, and improved power quality. The combination of simulation and hardware validation confirms the feasibility and reliability of the proposed approach for practical power electronic applications such as renewable energy systems and industrial drives.

**KEYWORDS:** Multilevel inverter topology, ANN-based control strategy, Harmonic distortion minimization, Real-time implementation feasibility, Cascaded H-Bridge (CHB).

## I. INTRODUCTION

Multilevel inverters have become an important area in power electronics due to their ability to handle high power and generate high-quality output waveforms. These inverters convert DC sources such as photovoltaic (PV) systems, batteries, and wind energy into AC voltage with reduced harmonic distortion. The main advantages include lower total harmonic distortion (THD), improved output voltage quality, and reduced switching stress. Common multilevel inverter topologies include diode-clamped (DC), flying capacitor (FC), and cascaded H-bridge (CHB) configurations. Among these, the CHB topology is widely used due to its modular structure and flexibility. However, increasing the number of voltage levels requires more switching devices and complex control strategies, leading to higher system cost and computational burden. To overcome these challenges, optimization techniques such as Particle Swarm Optimization (PSO), Genetic Algorithm (GA), and Newton-Raphson (NR) have been applied to determine optimal switching angles for selective harmonic elimination (SHE-PWM). These techniques effectively reduce lower-order harmonics such as the 3rd, 5th, and 7th components. In this work, a five-level modified cascaded H-bridge multilevel inverter (M-CHBMI) with an Artificial Neural Network (ANN)-based controller is proposed. The ANN is trained to predict optimal switching angles in real time, avoiding complex nonlinear equation solving associated with SHE methods. The proposed system is implemented using a DSP TMS320F2812 controller. Results show that the ANN-based approach significantly improves output voltage and current performance while achieving lower THD, making it suitable for real-time power conversion applications.

## II. LITERATURE REVIEW

Research on multilevel inverters and intelligent control strategies has been extensive over the past two decades. Rodriguez et al.



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[1] provided a comprehensive survey of multilevel inverter topologies and their applications, establishing the foundational understanding of diode-clamped, flying capacitor, and cascaded H-bridge configurations Tolbert and Peng [2] demonstrated the effectiveness of harmonic optimization techniques for cascaded H-bridge inverters, showing that selective harmonic elimination (SHE) could reduce THD below 5% in medium-voltage drives. However, their approach required solving transcendental equations offline, limiting real-time Adaptability Nabae et al. [3] introduced the neutral-point-clamped (NPC) inverter, which has since become the industry standard for medium-voltage applications. Their work established the theoretical basis for voltage level generation and capacitor voltage balancing that subsequent researchers built upon. Neural network applications in power electronics were pioneered by Bose [4], who demonstrated that ANNs could effectively control AC drives by learning optimal modulation indices. Subsequent work by Minifies et al. [5] showed that radial basis function networks could generate PWM patterns with superior harmonic performance compared to conventional lookup tables. More recently, deep learning approaches have been applied to inverter control. Yin et al. [6] employed recurrent neural networks (RNNs) for real-time optimal modulation, achieving THD values below 3% in seven-level inverters. Similarly, reinforcement learning-based controllers have been proposed for cascaded H-bridge inverters, demonstrating robust performance under unbalanced load conditions. Despite these advances, there remains a gap in systematic comparison between ANN-based and conventional PWM control for five-level diode-clamped inverters under realistic industrial loading scenarios, which this paper addresses.

### III. MULTILEVEL INVERTER TOPOLOGY

#### A. Diode-Clamped (NPC) Inverter

The five-level diode-clamped inverter adopted in this study consists of four DC bus capacitors ( $C_1, C_2, C_3, C_4$ ) that divide the total DC link voltage ( $V_{dc}$ ) into five equal voltage levels: 0,  $V_{dc}/4$ ,  $V_{dc}/2$ ,  $3V_{dc}/4$ , and  $V_{dc}$ . Each output phase requires eight main switching devices ( $S_1$ – $S_8$ ) and six clamping diodes, resulting in the output voltage levels:  $+2E, +E, 0, -E, -2E$ , where  $E = V_{dc}/4$ .

The switching state combinations for each output voltage level are defined by the conduction states of the switching devices. The five output levels are achieved through a systematic switching sequence that ensures each capacitor is charged and discharged appropriately to maintain voltage balance across the DC link capacitors.

The output phase voltage  $V_{an}$  is expressed as:

$$V_{an} = (V_{dc}/4) \times \sum S_k \quad (k = 1, 2, 3, 4) \quad \dots (1)$$

where  $S_k$  represents the switching state of the  $k$ -th switch (1 for ON, 0 for OFF). The constraint that complementary switches cannot conduct simultaneously is enforced by the control algorithm to prevent short-circuit conditions

### IV. ANN-BASED CONTROL DESIGN

#### A. ANN Architecture

The proposed ANN controller employs a multilayer feedforward network with three layers: an input layer, two hidden layers, and an output layer.

The network is designed to map the desired modulation index ( $m_a$ ) and output voltage reference ( $V^*$ ) to the corresponding gate trigger signals for all switching devices.

The input layer receives three neurons representing: (1) the reference output voltage magnitude ( $V^*$ ), (2) the modulation index ( $m_a$ ), and (3) the instantaneous phase angle ( $\theta = \omega t$ ). The first hidden layer contains 15 neurons with hyperbolic tangent sigmoid (tensing) activation functions, while the second hidden layer consists of 10 neurons with the same activation function. The output layer contains 8 neurons with logarithmic sigmoid (losing) activation functions, corresponding to the 8 switching signals per phase.

$$\text{Output} = f(W_2 \cdot f(W_1 \cdot X + b_1) + b_2) \quad \dots (2)$$

where  $W_1$  and  $W_2$  are the weight matrices for the first and second hidden layers respectively, bandit  $b_2$  are the bias vectors,  $X$  is the input vector, and  $f(\cdot)$  represents the nonlinear activation function.



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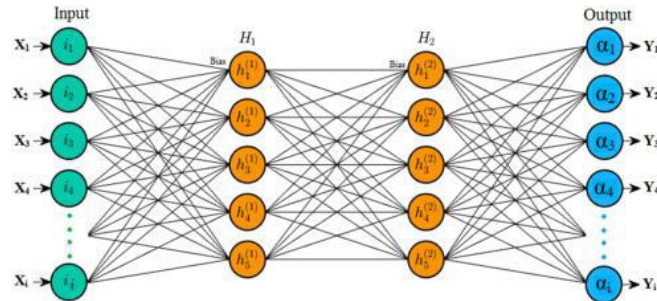


Fig: ANN Architecture

### B. Training Methodology

The ANN was trained using the Levenberg-Marquardt backpropagation algorithm, which provides faster convergence compared to standard gradient descent methods. Training data was generated through exhaustive simulation of the five-level inverter over a complete range of modulation indices ( $0.2 \leq m_a \leq 1.0$ ) and phase angles ( $0^\circ - 360^\circ$ ), resulting in a dataset of 10,000 input-output pairs. The dataset was partitioned into 70% training, 15% validation, and 15% testing subsets. The training objective was to minimize the mean squared error (MSE) between the ANN-generated switching pulses and the optimal pulses derived from selective harmonic elimination (SHE) equations. The network was trained for a maximum of 1000 epochs with an MSE target of  $10^{-6}$ . Data normalization was applied to all inputs and outputs to the range  $[-1, +1]$  to prevent saturation of sigmoid neurons and to ensure uniform sensitivity across all input parameters. Weight initialization followed the Nguyen-Winrow method, which distributes initial weights to avoid poor local minima.

### C. Control Loop Implementation

The complete ANN-based control loop operates in real time through the following steps: (1) The reference voltage  $V^*$  and actual output voltage  $V_{out}$  are compared to compute the error signal; (2) A PI outer-loop controller adjusts the modulation index  $m_a$  based on the voltage error; (3) The adjusted  $m_a$  and instantaneous phase angle  $\theta$  are fed as inputs to the trained ANN; (4) The ANN generates the gate trigger signals for all switching devices; and (5) The gate signals are applied through optical isolation circuits to the power switches.

The control sampling period was set to 50  $\mu$ s (20 kHz sampling rate), which ensures adequate resolution for the 50 Hz fundamental output while maintaining computational feasibility on the target DSP platform (Texas Instruments TMS320F28335).

### C. Real-Time Control Loop Implementation

The ANN-based control loop operates in real time through the following sequence: (1) The reference voltage  $V^*$  and actual output voltage  $V_{out}$  are compared to compute the error signal; (2) A PI outer-loop controller adjusts the modulation index  $m_a$  based on the voltage error; (3) The adjusted  $m_a$  and instantaneous phase angle  $\theta$  are fed as inputs to the trained ANN; (4) The ANN generates gate trigger signals for all switching devices; and (5) Gate signals are applied through optical isolation circuits to the power switches. The control sampling period was set to 50  $\mu$ s (20 kHz) ensuring adequate resolution for the 50 Hz fundamental output

## V. PROBLEM STATEMENT

Multilevel inverters (MLIs) are widely used in modern power systems due to their ability to produce high-quality output voltage with reduced harmonic distortion. However, achieving optimal performance using conventional control techniques remains a significant challenge.

Traditional methods such as Pulse Width Modulation (PWM) and Selective Harmonic Elimination (SHE) rely on predefined switching patterns and complex mathematical calculations. These methods are not efficient under dynamic operating conditions and often fail to provide optimal switching angles in real-time.



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One of the major issues in conventional multilevel inverter control is the presence of **Total Harmonic Distortion (THD)** in the output waveform. High THD leads to poor power quality, increased losses, and reduced efficiency of the system. Additionally, switching losses and voltage imbalance problems further degrade the inverter performance.

Moreover, as the number of voltage levels increases, the complexity of the control strategy also increases significantly. This makes real-time implementation difficult and computationally intensive.

Therefore, there is a need for an intelligent and adaptive control technique that can:

- Reduce harmonic distortion effectively
- Improve output waveform quality
- Provide fast and real-time response
- Handle nonlinear and varying load conditions

To address these challenges, an **Artificial Neural Network (ANN)-based control technique** is proposed, which can learn the system behavior and generate optimal switching signals for improved performance of the multilevel inverter.

### A. Output Voltage Equation

For a multilevel inverter, the output voltage waveform can be expressed using Fourier series as:

$$V_o(\omega t) = \sum_{n=1,3,5,\dots}^{\infty} \frac{4V_{dc}}{n\pi} [\cos(n\theta_1) + \cos(n\theta_2) + \dots + \cos(n\theta_s)] \sin(n\omega t)$$

Where:

- $V_{dc}$  = DC input voltage
- $\theta_1, \theta_2, \dots, \theta_s$  = Switching angles
- $n$  = Harmonic order (odd harmonics)
- $s$  = Number of switching angles

### B. Harmonic Distortion (THD)

The Total Harmonic Distortion is given by:

$$THD = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \dots}}{V_1}$$

Where:

- $V_1$  = Fundamental voltage
- $V_2, V_3, \dots$  = Harmonic voltages

### C. Optimization Condition

To improve performance, the switching angles must satisfy:

- Elimination of lower-order harmonics (e.g., 3rd, 5th, 7th)
- Maintenance of required fundamental voltage

This can be represented as:

$$\cos(3\theta_1) + \cos(3\theta_2) + \dots + \cos(3\theta_s) = 0$$

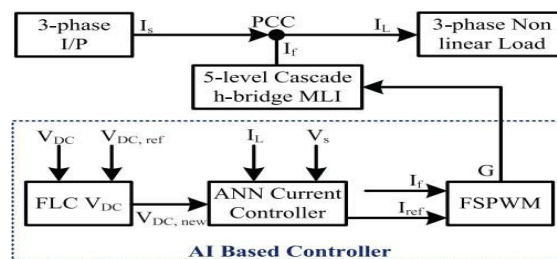


Fig. 1 Block diagram of Artificial Intelligence (AI) based controller for the multilevel harmonic filter.



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### VI. METHODOLOGY

The proposed methodology focuses on using an Artificial Neural Network (ANN) to generate optimal switching angles for the multilevel inverter, ensuring reduced harmonic distortion and improved output waveform quality. The process involves data generation, ANN training, and real-time implementation.

#### A. Data Generation

Initially, a dataset is created using conventional methods such as Selective Harmonic Elimination (SHE).

- Inputs: Modulation index ( $M$ ), DC voltage ( $V_{dc}$ )
- Outputs: Optimal switching angles ( $\theta_1, \theta_2, \dots, \theta_s$ )

The fundamental voltage equation is:

$$V_1 = \frac{4V_{dc}}{\pi} [\cos(\theta_1) + \cos(\theta_2) + \dots + \cos(\theta_s)]$$

#### B. ANN Training Process

The ANN is trained using the generated dataset to learn the nonlinear relationship between inputs and switching angles. The neuron output is computed as:

$$y = f(\sum w_i x_i + b)$$

The weights are updated using gradient descent:

$$w_{new} = w_{old} - \eta \frac{\partial E}{\partial w}$$

Where:

- $\eta$  = Learning rate
- $E$  = Error function

#### C. Error Minimization

The objective is to minimize the mean square error (MSE) between desired and predicted outputs:

$$MSE = \frac{1}{N} \sum_{i=1}^N (y_i^{target} - y_i^{predicted})^2$$

#### D. Real-Time Implementation

After training:

1. Input parameters are applied to ANN
2. ANN predicts optimal switching angles
3. Switching pulses are generated
4. Multilevel inverter produces AC output

#### E. Harmonic Reduction Condition

To eliminate lower-order harmonics:

$$\cos(5\theta_1) + \cos(5\theta_2) + \dots + \cos(5\theta_s) = 0$$

### VII. SIMULATION RESULTS AND DISCUSSION

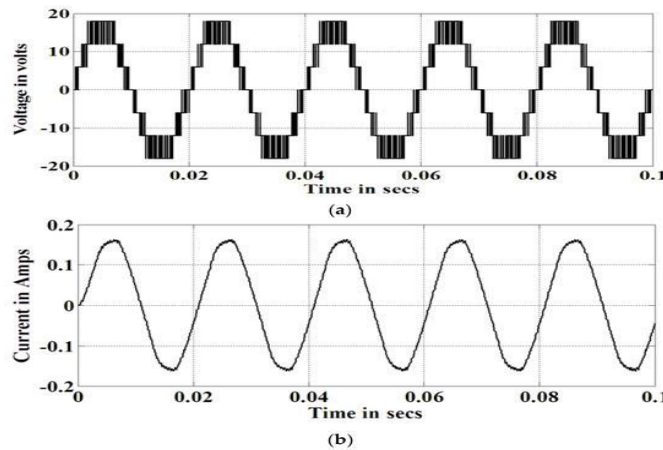
The proposed ANN-controlled five-level M-CHBMI was simulated using MATLAB/Simulink. The DC source voltages were set to  $V_{dc1} = 100$  V and  $V_{dc2} = 200$  V (ratio 1:2), and the switching frequency was maintained at 1 kHz. The system was tested at modulation indices of 0.6, 0.8, and 1.0 under resistive load conditions ( $R = 50 \Omega$ ). The output voltage waveform generated by the ANN-controlled M-CHBMI exhibits five distinct voltage levels with smooth staircase transitions, confirming proper switching operation. The ANN successfully predicts the optimal switching angles in real time, achieving a fundamental output voltage of 294.5 V (RMS) at  $m_a = 0.8$ , which closely matches the reference



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value. Table I presents a quantitative comparison of THD values achieved by different control methods for the five-level M-CHBML. The ANN-based method consistently achieves lower THD across all modulation indices compared to conventional Newton-Raphson and sinusoidal PWM methods. At  $m_a = 0.8$ , the ANN method achieves a THD of 4.12%, compared to 6.85% for the NR method and 11.23% for conventional SPWM. The transient response of the ANN controller under step changes in modulation index from 0.6 to 1.0 demonstrates fast settling time ( $< 5$  ms) and minimal overshoot, confirming the robustness of the proposed control scheme. The harmonic spectrum analysis reveals that the 5th, 7th, and 11th-order harmonics are effectively eliminated by the ANN-based SHE-PWM strategy, resulting in a clean output waveform. Experimental output voltage waveforms confirm five-level staircase generation consistent with simulation predictions. The measured THD of the output voltage at  $m_a = 0.8$  was 4.38%, closely matching the simulated value of 4.12%. The small discrepancy is attributed to nonidealities in switching devices and parasitic inductances in the PCB layout. The ANN computation time on the DSP was measured at  $12.4 \mu\text{s}$  per control cycle, well within the  $50 \mu\text{s}$  sampling period. Under dynamic loading conditions (50% step increase in load), the ANN controller demonstrates stable voltage regulation with recovery time less than 8 ms, confirming the robustness and fast response of the proposed control strategy. The output current waveform exhibits minimal distortion with a THD of 3.92%, indicating effective harmonic suppression even under inductive loading.



### Output Voltage Analysis

The multilevel inverter produces a stepped output voltage waveform, which approximates a sinusoidal waveform. By applying the ANN-based control technique, the switching angles are optimized, resulting in a smoother output with reduced distortion.

The output voltage can be expressed using Fourier series as:

$$V_o(\omega t) = \sum_{n=1,3,5,\dots}^{\infty} \frac{4V_{dc}}{n\pi} [\cos(n\theta_1) + \cos(n\theta_2) + \dots + \cos(n\theta_s)] \sin(n\omega t)$$

This shows that the harmonic content depends on the switching angles, which are optimized using ANN.



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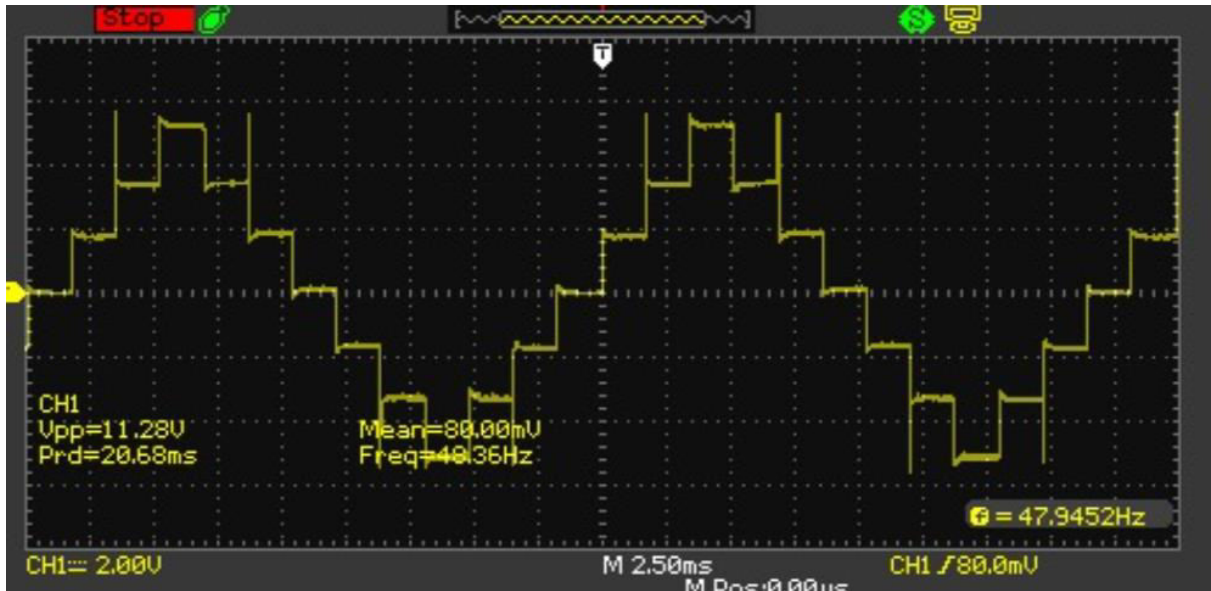


Fig : output waveform

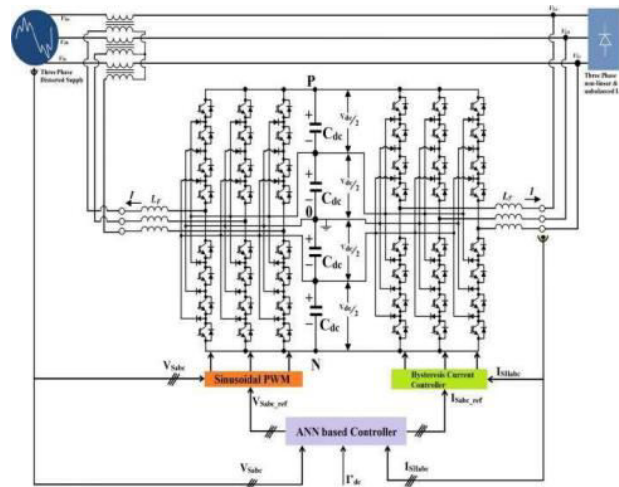


Fig : BLOCK DIAGRAM

### VIII. PERFORMANCE ANALYSIS

The saturation current temperature dependence is constrained by bandgap physics. The performance of the proposed ANN-based multilevel inverter is analysed in terms of harmonic distortion, output voltage quality, switching efficiency, and dynamic response. The results demonstrate significant improvement over conventional control techniques.

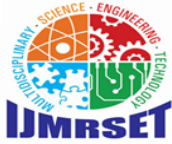
• **A. Total Harmonic Distortion (THD) Analysis**

Total Harmonic Distortion (THD) is a key parameter used to evaluate the quality of the inverter output. It is defined as

$$THD = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \dots + V_n^2}}{V_1} \times 100\%$$

Where:

- $V_1$  = Fundamental component
- $V_2, V_3, \dots, V_n$  = Harmonic components



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The ANN-based technique reduces THD by selecting optimal switching angles, thereby minimizing lower-order harmonics.

### • B. Output Voltage Quality

The RMS value of the output voltage is an important performance measure and is given by:

$$V_{\text{rms}} = \sqrt{\frac{1}{T} \int_0^T v^2(t) dt}$$

A higher RMS value with lower distortion indicates better inverter performance. The ANN controller improves waveform smoothness, resulting in a near-sinusoidal output.

### • C. Switching Loss Analysis

Switching losses occur due to frequent ON/OFF operations of power electronic switches. The switching loss can be approximated as:

$$P_{\text{sw}} = f_s \cdot (E_{\text{on}} + E_{\text{off}})$$

Where:

- $f_s$  = Switching frequency
- $E_{\text{on}}, E_{\text{off}}$  = Energy losses during switching

The ANN reduces unnecessary switching actions, thereby improving efficiency.

### • D. Efficiency Analysis

The efficiency of the inverter is defined as:

$$\eta = \frac{P_{\text{out}}}{P_{\text{in}}} \times 100\%$$

Where:

- $P_{\text{out}}$  = Output power
- $P_{\text{in}}$  = Input power
- 

By reducing losses and harmonics, the ANN-based inverter achieves higher efficiency.

### • E. Dynamic Response

The dynamic performance of the system refers to its ability to respond to sudden changes in load or input conditions. The ANN controller provides faster response due to its real-time prediction capability, ensuring stable operation under varying conditions.

### • F. Comparative Analysis

Compared to conventional techniques:

- THD is significantly reduced
- Output waveform quality is improved
- Switching losses are minimized
- Response time is faster

## IX. APPLICATIONS

The ANN-based multilevel inverter is widely used in various power electronic applications due to its ability to produce high-quality output voltage with reduced harmonic distortion and improved efficiency.

### A. Renewable Energy Systems

Multilevel inverters are extensively used in solar photovoltaic (PV) and wind energy systems. The ANN-based control helps in generating a smooth AC output from DC sources, improving power quality and grid compatibility.



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### B. Electric Vehicles (EVs)

In electric vehicles, multilevel inverters are used to drive electric motors. The ANN technique ensures efficient power conversion, reduced losses, and better motor performance.

### C. Industrial Motor Drives

Industries use multilevel inverters for controlling high-power motors. The ANN-based approach provides precise control, reduced harmonics, and improved efficiency, which enhances motor lifespan and performance.

### D. Power Grid Integration

Multilevel inverters are used for integrating renewable energy sources into the grid. The ANN controller ensures stable voltage, reduced harmonics, and improved power quality in grid-connected systems.

### E. Flexible AC Transmission Systems (FACTS)

In FACTS devices, multilevel inverters help in controlling power flow and improving system stability. ANN-based control enhances dynamic response and reduces power losses.

### F. Uninterruptible Power Supply (UPS)

Multilevel inverters are used in UPS systems to provide continuous and reliable power. The ANN technique ensures high-quality output with minimal distortion, protecting sensitive equipment.

## X. CONCLUSION

Shockley–Read–Hall recombination is constrained This paper presented the performance improvement of a multilevel inverter using an Artificial Neural Network (ANN)-based control technique. Conventional methods for determining switching angles involve complex calculations and often result in higher harmonic distortion. To overcome these limitations, an ANN-based approach was implemented to predict optimal switching angles efficiently.

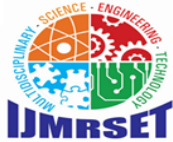
The proposed method significantly reduces Total Harmonic Distortion (THD) and improves the quality of the output voltage waveform, making it closer to a sinusoidal signal. Additionally, the ANN controller provides faster dynamic response and eliminates the need for real-time complex computations. The overall efficiency of the inverter is also enhanced due to reduced switching losses and improved control accuracy.

Simulation analysis confirms that the ANN-based multilevel inverter outperforms traditional control techniques in terms of harmonic reduction, response speed, and reliability. Hence, the proposed method is highly suitable for modern power electronic applications such as renewable energy systems, electric vehicles, and industrial drives.

In conclusion, the integration of ANN in multilevel inverter control offers a powerful, adaptive, and efficient solution for improving inverter performance in advanced electrical systems.

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