



A COMPREHENSIVE REVIEW OF PWM TECHNIQUES FOR MULTILEVEL INVERTER-FED INDUCTION MOTOR DRIVES

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Abstract:

Induction motors are widely used in industrial applications because they are simple, reliable, and economical. However, controlling the speed and torque of an induction motor efficiently is an important challenge. Power electronic inverters are commonly used to control the voltage and frequency supplied to the motor. Conventional inverters may produce harmonic distortion, switching losses, torque ripple, and poor output voltage quality. Multilevel inverters have been developed to overcome many of these problems by producing an output voltage with multiple levels. This results in a waveform closer to a sinusoidal waveform and reduces harmonic distortion. Pulse Width Modulation (PWM) techniques play an important role in controlling multilevel inverters. Different techniques such as Sinusoidal PWM (SPWM), Space Vector PWM (SVPWM), Trapezoidal PWM, harmonic-injection PWM, discontinuous PWM, adaptive PWM, and intelligent control-based PWM have been studied for induction motor drives. The reviewed studies show that multilevel inverter systems can provide better voltage quality, lower Total Harmonic Distortion (THD), improved speed response, and better motor performance. However, advanced techniques may increase controller complexity and computational requirements.

This review presents a simple comparison of different PWM techniques used with multilevel inverter-fed induction motor drives. The advantages, limitations, harmonic performance, switching losses, speed control, and dynamic response of different methods are discussed. The



review also identifies adaptive PWM as a promising approach for achieving better performance under varying load conditions.

Keywords: Induction Motor, Multilevel Inverter, Pulse Width Modulation (PWM), Sinusoidal PWM (SPWM), Space Vector PWM (SVPWM), Adaptive PWM, Total Harmonic Distortion (THD), Harmonic Reduction, Switching Losses, Speed Control, Motor Drive, Power Quality.

1. INTRODUCTION

Induction motors are one of the most commonly used electrical machines in industrial applications. They are used in pumps, fans, compressors, conveyors, machine tools, electric vehicles, and many automation systems. Their simple construction, low maintenance requirement, and good reliability make them suitable for many applications. In modern industries, the motor should operate at different speeds and loads according to the application requirement. Directly connecting an induction motor to a fixed-frequency supply does not provide flexible speed control. Therefore, inverter-based variable frequency drives are commonly used. By changing the supply voltage and frequency, the speed and torque of the induction motor can be controlled.

One of the major problems in inverter-fed motor drives is harmonic distortion. Harmonics cause waveform distortion, additional heating, power losses, vibration, and noise. They may also affect other equipment connected to the same electrical system. Multilevel inverter technology is an important solution to this problem. Instead of producing only two voltage levels, a multilevel inverter produces several voltage levels. The staircase-shaped output waveform is closer to a sinusoidal waveform. Therefore, harmonic distortion can be reduced and the motor can operate more smoothly. PWM is used to control the switching devices of the inverter. The proper selection of PWM technique has a direct effect on motor performance, THD, switching losses, voltage utilization, and dynamic response. A multilevel inverter converts DC power into AC power using several voltage levels. Compared with a conventional two-level inverter, a multilevel inverter can generate a better-quality output voltage. The main advantages of multilevel inverters are reduced harmonic distortion, better output voltage waveform, lower voltage stress on switching devices, reduced electromagnetic interference, improved motor performance, lower requirement for large filters, and better voltage control. Common multilevel inverter topologies include diode-clamped, flying-capacitor, and cascaded H-bridge multilevel inverters. Multilevel inverter technology has received considerable attention because it provides better control of voltage and current compared with conventional two-level inverters. By increasing the number of voltage levels, the output waveform becomes closer to a sinusoidal waveform. This helps in reducing harmonic components and improves the overall quality of power supplied to the induction motor. Multilevel inverters are therefore suitable for medium- and high-power motor drive applications where high performance and reliable operation are required. Different multilevel inverter topologies have different advantages and limitations. Diode-clamped inverters provide multiple voltage levels using clamping diodes, while flying-capacitor inverters use capacitors to generate different voltage



levels. Cascaded H-bridge inverters use a number of H-bridge cells connected in series and provide a modular structure. However, increasing the number of voltage levels can also increase the number of switches, capacitors, diodes, and control requirements. Therefore, proper selection of inverter topology is important for achieving a balance between performance, cost, and system complexity. PWM techniques are equally important because they determine the switching pattern of the inverter. A suitable PWM method can improve the output voltage waveform, reduce THD, minimize torque ripple, and improve motor speed response. Conventional SPWM is simple and easy to implement, while SVPWM provides better voltage utilization and dynamic performance. Other advanced methods, such as harmonic-injection PWM, discontinuous PWM, adaptive PWM, and intelligent control-based PWM, are being studied to further improve motor drive performance. Adaptive PWM is particularly useful when the motor operates under varying load conditions. In this approach, the switching pulses can be adjusted according to changes in motor speed, load, voltage, or other system parameters. This provides better flexibility and can improve stability, efficiency, and overall motor performance. Therefore, the study and comparison of different PWM techniques are important for developing efficient and reliable multilevel inverter-fed induction motor drives.

2. LITERATURE SURVEY

S. N. Latha et al. [1] proposed an SVPWM-based active filtering technique for a dual inverter-fed induction motor system to improve overall performance and reduce harmonic distortion. The main objective was to enhance motor efficiency and minimize total harmonic distortion (THD). The results showed significant harmonic mitigation and improved motor performance, although the system required complex control coordination between inverters.

R. Kumar et al. [2] developed an Adaptive Sliding Mode Control (ASMC) combined with THITRPWM and Field-Oriented Control (FOC) for multilevel inverter-fed induction motors. The aim was to improve dynamic response and system stability. The results demonstrated enhanced dynamic performance, stable DC-link voltage, and improved efficiency, but increased computational complexity was a limitation.

Akshat et al. [3] introduced a 13th harmonic injected trapezoidal PWM (THITRPWM) technique for cascaded H-bridge multilevel inverters. The objective was to reduce harmonic distortion and torque ripple. The system achieved lower THD and improved efficiency, though implementation complexity and switching stress were noted limitations.

S. N. Latha et al. [4] designed an open-end winding induction motor system using a dual inverter with SVPWM and active filtering control. The main goal was to improve power quality and reduce harmonic distortion. The results showed enhanced efficiency and reduced THD, but the dual inverter configuration increased system complexity.

O. Allag et al. [5] proposed a dual SVM-PWM inverter with observer-based control for induction motor drives. The objective was to achieve accurate control and improved system dynamics. The



system showed enhanced dynamic performance and precise control, though it depended heavily on accurate system modelling.

J. Ruiz-Gonzalez et al. [6] presented a discontinuous PWM technique with frequency modulation to reduce vibration and harmonics in induction motors. The results indicated reduced THD and improved motor smoothness, but sensitivity to parameter tuning was a limitation.

B. M. Reddy et al. [7] developed an SPWM-based control using an Adaptive Neuro-Fuzzy Inference System (ANFIS) for induction motor drives. The aim was to improve speed–torque characteristics and reduce harmonics. The results showed improved performance and reduced THD, though computational complexity increased.

Y. Reyes Severiano et al. [8] conducted a comparative study of PWM techniques for multilevel inverter-fed induction motors. The objective was to analyze harmonic performance. The study concluded that multilevel inverters significantly reduce harmonic distortion, but performance depends on the selected PWM technique.

K. Neelshetty et al. [9] developed a PWM-based multilevel inverter system for induction motor drives. The system aimed to reduce THD and improve motor performance. Results showed better efficiency and waveform quality, though system complexity increased.

S. F. V. Rose et al. [10] implemented a multilevel inverter-based induction motor drive to improve power quality. The results demonstrated reduced harmonic distortion and improved efficiency, but higher cost and circuit complexity were challenges.

T. A. Ahmed et al. [11] studied PWM-controlled multilevel inverter-fed induction motors to enhance efficiency and harmonic performance. The results showed improved output quality, though the number of switching devices increased.

V. Srinath et al. [12] proposed an open-end winding induction motor using multilevel inverter topology to improve voltage levels and reduce THD. The results showed improved waveform quality, but required dual inverter configuration.

C. Manasa et al. [13] implemented a PWM-based multilevel inverter system for induction motor drives through simulation and hardware. The results showed reduced harmonic distortion and improved performance, but hardware implementation was complex.

M. M. Handge et al. [14] developed a PWM-controlled multilevel inverter for induction motor drives. The results showed improved efficiency and waveform quality, though switching losses increased.

S. K. Mishra et al. [15] proposed a cascaded H-bridge multilevel inverter using sinusoidal PWM for induction motor drives. The objective was to improve output voltage quality and reduce harmonic distortion. The results showed reduced THD and improved efficiency, though the system required more switching devices.

P. K. Singh et al. [16] developed a space vector PWM (SVPWM) technique for multilevel inverter-fed induction motors. The aim was to enhance voltage utilization and dynamic performance. The results indicated better DC bus utilization and reduced harmonics, but implementation complexity was high.

R. K. Gupta et al. [17] implemented a diode-clamped multilevel inverter using PWM control for induction motor applications. The objective was to improve waveform quality and efficiency. The results showed reduced distortion, though capacitor balancing remained a challenge

3. RESEARCH GAP

From the reviewed studies, several research gaps can be identified. Many advanced PWM techniques provide good harmonic performance but require complex control algorithms. Intelligent controllers can improve dynamic response but require greater computational resources. Some multilevel inverter topologies require a large number of switches, capacitors, or isolated DC sources. Another important research area is the development of simple adaptive control methods that can provide good performance without significantly increasing controller complexity. The adaptive VPWM approach addresses this area by changing the switching pulses according to system operating conditions. This approach can provide a balance between performance and implementation complexity.

Proposed Methodology:

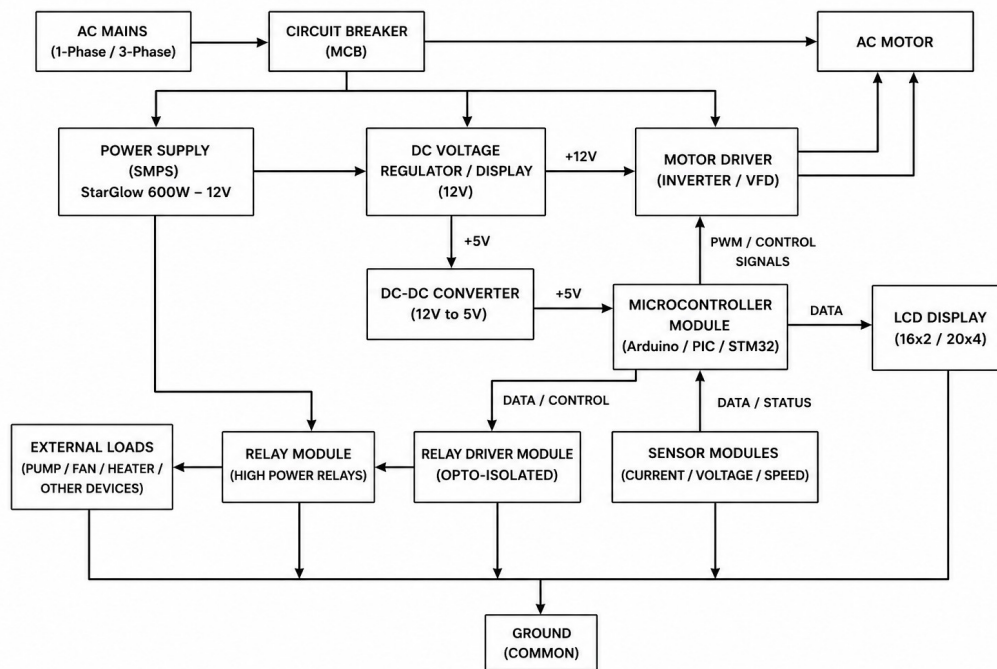


Figure 1 Proposed Block Diagram of a Comprehensive Review of PWM Techniques for Multilevel Inverter-Fed Induction Motor Drives



The proposed methodology for this review paper is based on a systematic study, classification, and comparison of different Pulse Width Modulation (PWM) techniques used in multilevel inverter-fed induction motor drives. The main purpose of the methodology is to understand how different inverter topologies and PWM control techniques affect the performance of an induction motor. The review focuses mainly on harmonic reduction, speed control, torque response, switching losses, efficiency, voltage utilization, and system stability. The first stage of the methodology is to identify the major problems associated with conventional induction motor drives. These problems include harmonic distortion, torque ripple, switching losses, poor output voltage quality, and difficulties in maintaining stable motor speed during load variations. The induction motor and its variable-speed requirements are therefore studied as the basic application area. In the second stage, different multilevel inverter topologies are reviewed. The major topologies considered are diode-clamped, flying-capacitor.

Their operating principles, advantages, limitations, number of switching devices, voltage levels, and suitability for induction motor applications are analyzed. Multilevel inverter technology is considered important because it can produce a stepped output voltage waveform that is closer to a sinusoidal waveform and can reduce harmonic components. The third stage focuses on the study of different PWM techniques. Conventional methods such as Sinusoidal PWM (SPWM) and trapezoidal PWM are first analyzed. Advanced methods such as Space Vector PWM (SVPWM), harmonic-injection PWM, and discontinuous PWM are then considered. Finally, adaptive and intelligent control methods such as Adaptive PWM, ANFIS-based PWM, and sliding-mode-based PWM are reviewed. The source result paper similarly discusses these PWM approaches and their effects on induction motor performance.

In the fourth stage, common performance parameters are selected for comparison. These parameters include Total Harmonic Distortion (THD), motor speed response, electromagnetic torque, torque ripple, switching losses, efficiency, voltage utilization, dynamic response, and stability. These parameters provide a common basis for comparing conventional and advanced PWM techniques. The result paper also considers voltage, current, speed, torque, harmonic characteristics, and switching losses while evaluating the proposed system.

4. CONCLUSION

This review presents an overview of PWM techniques used in multilevel inverter-fed induction motor drives. Multilevel inverters provide improved output voltage quality and help reduce harmonic distortion. Different PWM techniques such as SPWM, SVPWM, harmonic-injection PWM, discontinuous PWM, adaptive PWM, and intelligent control-based PWM have been developed to improve motor performance.

SPWM is simple and easy to implement, while SVPWM provides better voltage utilization and dynamic performance. Harmonic-injection techniques can reduce THD and torque ripple. Discontinuous PWM can reduce switching losses. Intelligent controllers such as ANFIS and



sliding-mode control can provide improved dynamic performance but increase computational complexity. Among these techniques, adaptive VPWM is a promising approach because the switching pulses can be changed according to load and operating conditions. The result paper reports smoother speed response, improved torque characteristics, reduced harmonic distortion, and stable operation during load changes.

Overall, future induction motor drives should focus on balancing low THD, low switching losses, fast dynamic response, simple implementation, and high efficiency. Adaptive and intelligent PWM techniques have strong potential for developing efficient and reliable motor drive systems for industrial applications.

Keywords: Multilevel Inverter, Induction Motor, PWM, SPWM, SVPWM, Adaptive PWM, THD, Harmonic Reduction, Motor Drive.

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