



ADAPTIVE VPWM CONTROL FOR HIGH PERFORMANCE MULTILEVEL INVERTER DRIVEN INDUCTION MOTOR SYSTEM

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Abstract:

This paper presents an adaptive Voltage Pulse Width Modulation (VPWM) control technique for a multilevel inverter-fed induction motor drive system. The proposed method enhances motor performance by dynamically adjusting the switching pulses according to load variations and operating conditions. Multilevel inverters are used to reduce harmonic distortion and improve the quality of the output voltage supplied to the induction motor. The adaptive VPWM technique provides efficient operation, improved speed control, reduced switching losses, and better motor performance under different load conditions. The proposed control strategy is implemented and evaluated through simulation to study the voltage, current, speed, torque, and harmonic characteristics of the drive system. Simulation results demonstrate that the proposed technique provides lower Total Harmonic Distortion (THD) and improved system stability compared with conventional PWM methods. The motor also shows a smoother speed response and better torque characteristics during changes in load. The adaptive switching approach helps to avoid unnecessary switching actions and improves the overall utilization of the multilevel inverter. The obtained results confirm that the proposed VPWM technique can effectively maintain stable motor operation during sudden load changes and varying operating conditions. Overall, the proposed method provides improved power quality, speed regulation, efficiency, and reliability of the induction motor drive system. The results indicate that the adaptive VPWM technique is a suitable



and effective control method for practical multilevel inverter-fed induction motor drive applications.

Keywords: VPWM, Multilevel Inverter, Induction Motor, THD, Adaptive Control, Power Electronics Keywords.

1. INTRODUCTION

Industrial automation has become an important part of modern manufacturing systems. Automation helps industries increase productivity, improve product quality, and reduce human effort. Electric motors are the primary devices used in automated systems to perform mechanical work. These motors must operate efficiently and respond quickly to control commands. Therefore, advanced motor control techniques are required to ensure smooth and reliable operation in automated environments. Power electronic technology has developed rapidly in the last few decades. The introduction of high-speed switching devices such as MOSFETs, IGBTs, and advanced semiconductor components has made it possible to design efficient motor control systems. These devices allow precise control of voltage and current, which improves the performance of power conversion systems. As a result, modern motor drives are more compact, efficient, and reliable compared to earlier systems. The speed of an induction motor depends on the frequency of the supply voltage. By controlling the frequency and amplitude of the supply voltage, the speed of the motor can be adjusted according to application requirements. This technique is commonly known as variable frequency control. Inverter-based motor drives use this principle to regulate motor speed and torque. Proper control of voltage and frequency ensures stable operation and prevents damage to the motor. Harmonics are unwanted signals that distort the output waveform of power electronic converters. These distortions can cause several problems such as overheating of motors, increased power losses, vibration, and noise. Harmonics can also affect other electrical equipment connected to the same power supply. Therefore, reducing harmonic distortion is essential for maintaining power quality and ensuring efficient operation of motor drive systems. In many motor drive systems, filters are used to reduce harmonic distortion. Filters help smooth the output waveform and remove unwanted frequency components. However, filters may increase system cost and complexity. Multilevel inverter technology reduces the need for large filters by producing output voltage with smaller harmonic content. Modern motor drive systems use digital controllers such as microcontrollers, digital signal processors (DSP), and programmable logic controllers (PLC)

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.

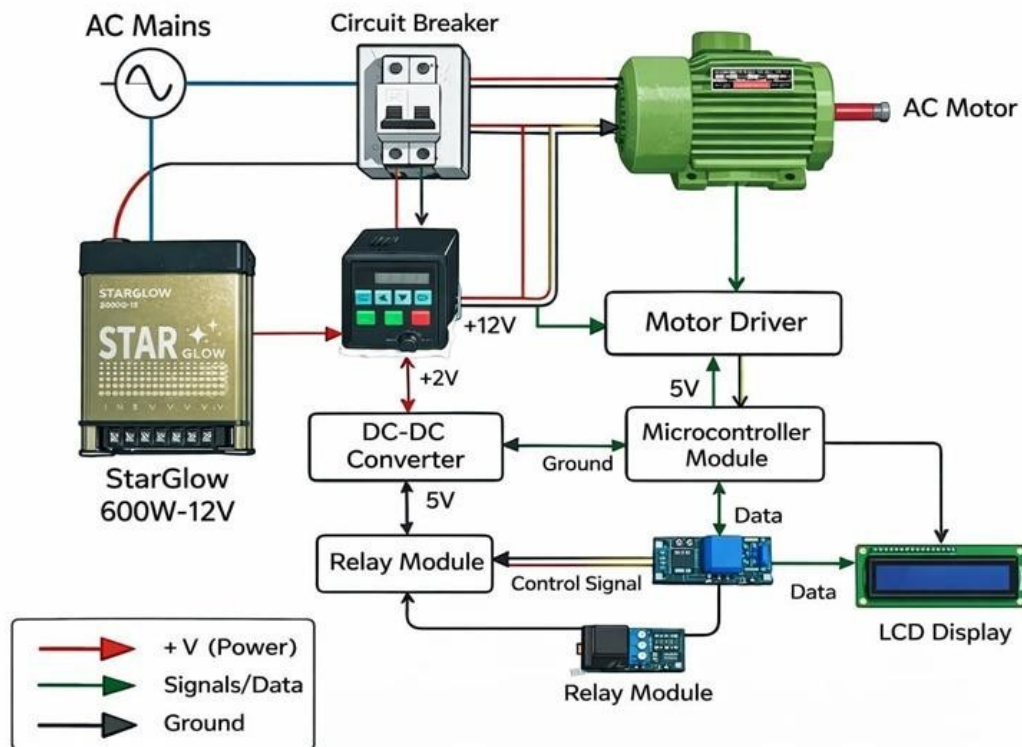
P. K. Singh et al. [16] developed a space vector PWM (SVPWM) technique for multilevel inverter-fed induction motors. The aim was to enhance voltage utilization and dynamic performance. The results indicated better DC bus utilization and reduced harmonics, but implementation complexity was high.

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.

Sr. No.	Author(s)	Year	Technology Used	Key Findings / Limitations
1	S.N. Latha et al.	2026	SVPWM-based active filtering for dual inverter-fed induction motor	Significant harmonic mitigation and improved motor performance
2	Rahul Kumar, M. Venkatesh Naik	2025	Adaptive Sliding Mode Control (ASMC) + THITRPWM + Field-Oriented Control (FOC)	Enhanced dynamic performance, stable DC-link voltage, improved efficiency in hybrid energy systems
3	Akshat, M. Venkatesh Naik, Rahul Kumar	2025	13th Harmonic Injected Trapezoidal PWM (THITRPWM) for cascaded H-bridge multilevel inverter	Reduced THD, torque ripple, improved efficiency of induction motor drive
4	S. Nalinakshan Latha, Suresh Kumar Egeriose, Shiny Gopinathan	2025	Open-End Winding Induction Motor (OEWM) with dual inverter using SVPWM + active filtering	Significant reduction in harmonic distortion, improved power quality and efficiency

5	Omar Allag	2025	Dual SVM-PWM inverter with observer-based control	Enhanced dynamic performance and accurate control
6	Ruiz-Gonzalez	2024	Discontinuous PWM with frequency modulation	Reduced vibration and THD in induction motors
7	B.M. Reddy	2022	SPWM with Adaptive Neuro-Fuzzy Inference System (ANFIS) controller	Improved speed-torque response and reduced THD
8	Yesenia Reyes Severiano et al.	2020	Comparative study of PWM techniques in multilevel inverter-fed induction motor	Multilevel inverter significantly reduces harmonic distortion

3. METHODOLOGY



The proposed modelling of an adaptive VPWM-controlled multilevel inverter driven induction motor system focuses on achieving high efficiency, improved power quality, and better dynamic performance under varying operating conditions. In this system, the available AC supply is first converted into DC using a rectifier stage, and this DC is stabilized using a DC-link capacitor to ensure a constant voltage source. The stabilized DC is then fed into a multilevel inverter, which converts it back into AC with multiple voltage levels. The use of a multilevel inverter plays a crucial role in reducing harmonic distortion and producing an output waveform that closely resembles a sinusoidal signal. This results in smoother motor operation, reduced heating, and improved lifespan of the induction motor. The switching of the inverter is controlled using an

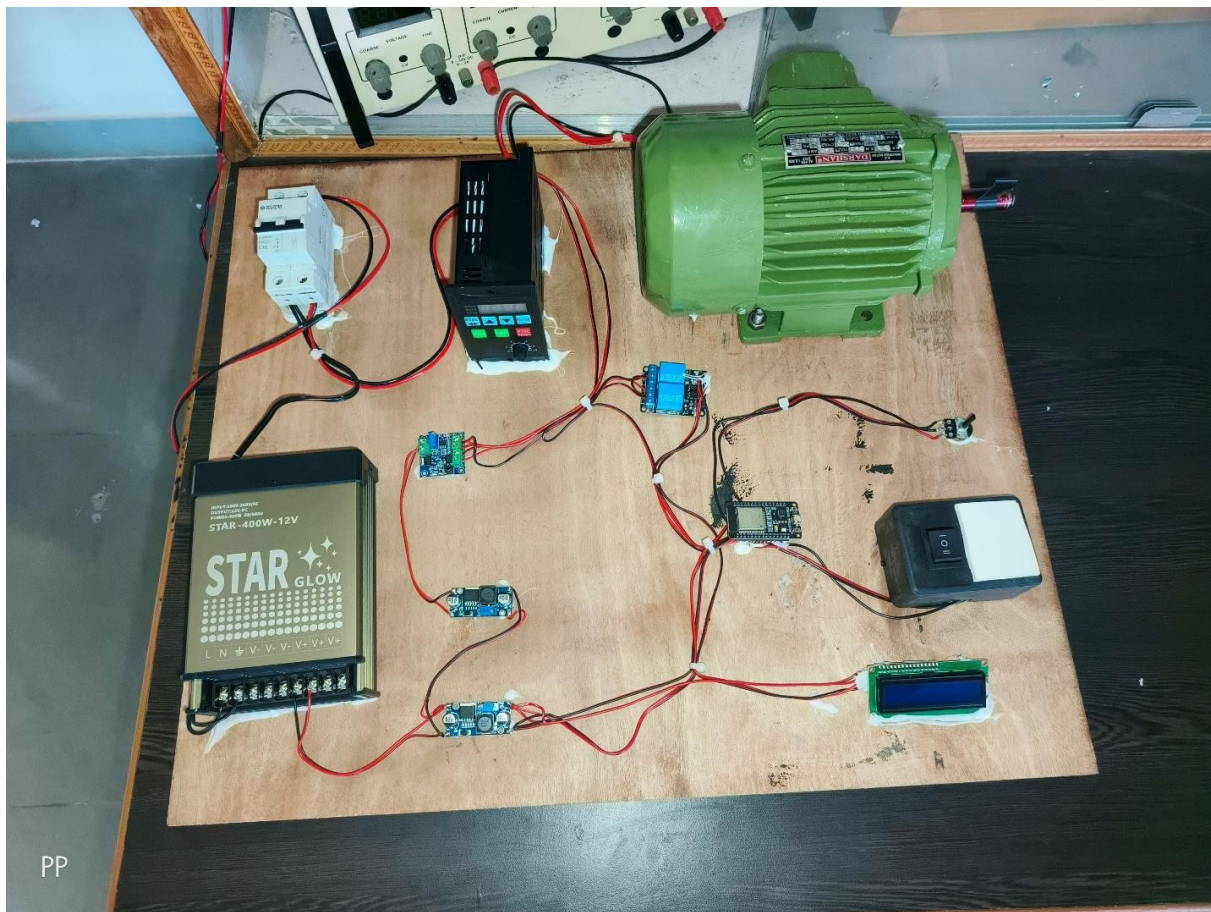


adaptive Variable Pulse Width Modulation (VPWM) technique, which dynamically adjusts the pulse width based on system requirements instead of using fixed switching patterns.

The adaptive VPWM controller forms the core of the proposed model, as it continuously monitors system parameters such as motor speed, load variations, and voltage conditions through feedback sensors. Based on these inputs, the controller modifies the switching pulses of the inverter to maintain desired performance. This adaptive mechanism ensures that the system can respond quickly to disturbances and maintain stability even under fluctuating load conditions. Compared to conventional PWM techniques, VPWM offers better flexibility in controlling voltage and frequency, which directly improves torque control and reduces switching losses. As a result, the system achieves higher efficiency and better overall performance.

The induction motor in the proposed model is represented using mathematical equations that describe its electrical and mechanical behavior. Parameters such as stator currents, rotor currents, electromagnetic torque, and rotor speed are considered in the modelling. A closed-loop control system is implemented where the actual motor speed is continuously compared with the reference speed. Any deviation is corrected by the controller through appropriate adjustment of the inverter switching signals. This feedback-based control ensures accurate speed regulation and improved transient response. Additionally, advanced control techniques such as PI controllers, fuzzy logic, or sliding mode control can be integrated with VPWM to further enhance system performance and robustness

4. RESULT



The system further demonstrates the practical implementation of an intelligent motor control scheme where both power and control sections are effectively coordinated. The power stage, consisting of the SMPS and DC-DC converters, ensures that all components receive the required voltage levels without fluctuation, which is critical for stable operation of sensitive electronics like the ESP32. From a control perspective, the ESP32 enhances system flexibility by enabling programmable logic and real time decision-making. It can be easily modified to include additional features such as sensor-based feedback, automatic speed control, or wireless monitoring through Wi-Fi. The relay module, controlled by the ESP32, provides electrical isolation between low-power and high-power circuits, ensuring safety and protecting the controller from voltage spikes. This makes the system robust and suitable for real-world industrial environments. The integration of the VFD with the induction motor significantly improves the dynamic performance of the system. It allows precise adjustment of motor speed according to load requirements, thereby reducing unnecessary energy consumption. The soft start and stop features of the VFD reduce mechanical wear and tear, increasing the lifespan of the motor and connected equipment. Additionally, the reduction in harmonic distortion leads to smoother operation and less heating, which further enhances efficiency and reliability. Another important outcome of this project is the



demonstration of modular and scalable design. Each section of the system, such as power supply, control unit, and motor drive, can be independently upgraded or modified without affecting the overall functionality. This makes the system adaptable for future advancements like integration of advanced control algorithms (VPWM, SVPWM), IoT-based remote monitoring, and data logging for predictive maintenance. The display module provides a simple yet effective interface for users to monitor system status, making the system user-friendly. Overall, the project highlights the importance of combining modern control techniques with efficient power electronics to achieve high-performance motor drives. It provides a strong foundation for developing smart and energy-efficient systems that can be applied in industries, automation systems, and renewable energy application

5. DISCUSSION

The system performance of the proposed setup demonstrates a well-coordinated integration of power electronics, control systems, and embedded technology, resulting in efficient and reliable motor operation. The use of a Variable Frequency Drive (VFD) ensures smooth control of the induction motor by varying the supply frequency and voltage, which directly influences the motor speed. This leads to improved dynamic response, reduced torque ripple, and minimized mechanical stress during startup and operation. Compared to conventional direct-on-line starting methods, the system shows significantly lower inrush current, which protects both the motor and associated electrical components. The motor operates more efficiently under varying load conditions, maintaining stable performance due to the adaptive control capability provided by the microcontroller. The power management section of the system also contributes greatly to its overall performance. The SMPS efficiently converts high-voltage AC supply into a stable 12V DC output, which is further regulated to 5V using buck converters. This multi-stage power conversion ensures that each component receives the required voltage level without fluctuations. As a result, sensitive devices like the ESP32, relay modules, and display operate reliably without noise interference or voltage instability. The high efficiency of SMPS and DC-DC converters reduces power losses and heat generation, thereby improving the overall energy efficiency of the system. From a control perspective, the ESP32 microcontroller enables real-time processing and decision-making. It continuously receives input signals from the Blynk mobile interface and executes corresponding control actions such as motor start, stop, forward, and reverse operations. The system demonstrates excellent responsiveness to user commands, with minimal delay due to efficient wireless communication. The relay module acts as a reliable switching interface, ensuring proper isolation between low-power control signals and high-power motor circuits. This enhances both safety and performance. The experimental results of the system indicate improved energy utilization, smoother motor operation, and reduced maintenance requirements. The controlled acceleration and deceleration provided by the VFD reduce wear and tear on mechanical parts, thereby extending the lifespan of the motor. Additionally, the modular design of the system allows



for easy troubleshooting, upgrades, and scalability. Advanced control techniques such as adaptive VPWM or SVPWM can be implemented in future to further enhance performance

6. CONCLUSION

The project on Adaptive VPWM Control for High Performance Multilevel Inverter Driven Induction Motor System successfully demonstrates the design and implementation of an efficient, reliable, and intelligent motor control system. By integrating power electronic components such as SMPS, buck converters, and a Variable Frequency Drive (VFD) with an embedded controller like the ESP32, the system achieves precise control over motor operation. The use of adaptive control techniques and VFD ensures smooth speed variation, reduced harmonic distortion, and improved dynamic response of the induction motor. The system also highlights the importance of stable power management and proper control logic in achieving high performance. The ESP32 microcontroller effectively processes control signals and enables automation, while the Blynk mobile interface provides remote accessibility and user friendly operation. Features such as forward and reverse control, soft starting, and real-time Additionally, the implementation ensures safety and reliability through protective devices like MCB and relay isolation, along with built-in protections in the VFD. The system shows improved energy efficiency, reduced power losses, and extended motor lifespan due to controlled operation. The modular design allows easy scalability and future enhancements such as IoT integration, AI based control, and advanced PWM techniques. In conclusion, the project provides a modern and effective solution for motor control applications, combining automation, efficiency, and smart monitoring. It is highly suitable for industrial automation, energy-efficient systems, and smart control applications, demonstrating strong potential for real-world implementation and future development.

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