ISSN: 2582 - 6379
IJISEA Publications
International Journal for Interdisciplinary Sciences and Engineering Applications
IJISEA - An International Peer- Reviewed Journal
2026, Volume 7 Issue 2
www.ijisea.org

CONTROL OF SQUIRREL CAGE INDUCTION MOTOR USING CONVENTIONAL CONTROLLERS AND FUZZY LOGIC

1.Alladi Mydhili, 2.Gentem Charan, 3.Konda Purna Kumar, 4.Duvva Gopal,5.N.Chaitanya

Author Affiliations

1,2,3,4 .UG Students ,Department of Electrical & Electronics Engineering, RVR&JC College Of Engineering, Chowdavaram, Guntur, Andhra Pradesh

5.Associate Professor,Department of Electrical & Electronics Engineering , RVR&JC College Of Engineering, Chowdavaram, Guntur, Andhra Pradesh

ABSTRACT

Induction motors, particularly squirrel cage induction motors, are widely used in industrial applications due to their robustness, low cost, simple construction, and minimal maintenance requirements. However, achieving precise and efficient speed control of these motors remains a significant challenge because of their nonlinear characteristics, parameter variations, and sensitivity to external disturbances such as load changes. Conventional control techniques like Proportional-Integral (PI) and Proportional-Integral-Derivative (PID) controllers are commonly employed, but their performance is limited due to fixed gain parameters and poor adaptability under dynamic conditions. This work presents an advanced control strategy for improving the speed control performance of a three-phase squirrel cage induction motor using a hybrid Fuzzy-PID controller integrated with vector (field-oriented) control. The system is modeled mathematically and implemented using MATLAB/Simulink to analyze its dynamic behavior under various operating conditions. The proposed method combines the advantages of conventional PID control with the adaptability of fuzzy logic, enabling real-time tuning of controller parameters. Simulation results are evaluated based on key performance metrics such as rise time, settling time, overshoot, and steady-state error. Comparative analysis with PI, PID, and standalone fuzzy logic controllers demonstrates that the Fuzzy-PID controller provides superior performance with faster response, reduced overshoot, and improved stability. Additionally, it shows strong robustness against parameter variations and load disturbances. Therefore, the proposed approach is highly suitable for modern industrial applications requiring high precision, reliability, and efficiency in motor speed control systems.

Keywords: Induction Motor, Speed Control, PID Controller, Fuzzy Logic, Fuzzy-PID Controller, Vector Control, SMATLAB/Simulink

1.INTRODUCTION

Induction motors are among the most widely used electrical machines in industrial and commercial applications due to their rugged construction, high efficiency, low cost, and minimal maintenance requirements [1]. In particular, squirrel cage induction motors are extensively used in applications such as conveyor systems, pumps, compressors, electric vehicles, and manufacturing industries where reliable and continuous operation is essential [2]. Despite these advantages, achieving precise speed control of induction motors remains a complex challenge due to their nonlinear characteristics, strong coupling between torque and flux, and sensitivity to parameter variations [3].

Unlike DC motors, where speed control is relatively simple due to independent control of armature and field currents, induction motors require more sophisticated control strategies [4]. Traditional control methods such as Proportional-Integral (PI) and Proportional-Integral-Derivative (PID) controllers have been widely used due to their simplicity and ease of implementation [5]. The PI controller is effective in eliminating steady-state error, while the PID controller improves transient response by introducing a derivative component [6]. However, these controllers rely on fixed gain parameters and fail to perform efficiently under varying operating conditions such as sudden load changes and parameter variations [7].

The limitations of conventional controllers include higher overshoot, longer settling time, reduced accuracy, and poor adaptability [8]. These drawbacks make them unsuitable for modern industrial applications that require high precision and fast dynamic response [9]. To address these issues, advanced control techniques have been developed, among which vector control or Field-Oriented Control (FOC) plays a significant role [10].

Vector control enables decoupled control of torque and flux by transforming three-phase motor quantities into a rotating reference frame using Clarke and Park transformations [11]. This approach makes the induction motor behave similarly to a DC motor, allowing independent control of torque and flux components [12]. As a result, it significantly improves dynamic performance and response speed [13]. However, the effectiveness of vector control depends heavily on the accuracy of the mathematical model and controller design [14].

In recent years, intelligent control techniques such as Fuzzy Logic Control (FLC) have gained considerable attention due to their ability to handle nonlinear systems and uncertainties without requiring precise mathematical models [15]. Fuzzy logic controllers use linguistic rules and human-like reasoning to make control decisions, making them highly adaptable to changing system conditions [16]. They offer advantages such as reduced overshoot, improved stability, and robustness against disturbances [17]. However, fuzzy controllers may exhibit steady-state errors and require careful design of membership functions and rule bases [18].

To overcome the limitations of both conventional and intelligent control techniques, hybrid approaches such as the Fuzzy-PID controller have been introduced [19]. This approach combines the precision of PID control with the adaptability of fuzzy logic, allowing dynamic tuning of controller parameters based on system conditions [20]. The Fuzzy-PID controller enhances system performance by reducing overshoot, improving response time, and increasing robustness under varying load and speed conditions.

In this work, a comprehensive study of different control techniques is carried out for the speed control of a squirrel cage induction motor. The system is modeled and implemented using MATLAB/Simulink, where controllers such as PI, PID, Fuzzy Logic, and Fuzzy-PID are analyzed and compared under different operating conditions. Performance parameters such as rise time, settling time, overshoot, and steady-state error are evaluated to determine the effectiveness of each controller.

The primary objective of this study is to develop an efficient and reliable control strategy that can overcome the limitations of conventional methods and provide superior performance in dynamic environments. The

ISSN: 2582 - 6379
IJISEA Publications
International Journal for Interdisciplinary Sciences and Engineering Applications
IJISEA - An International Peer- Reviewed Journal
2026, Volume 7 Issue 2
www.ijisea.org

results demonstrate that the hybrid Fuzzy-PID controller significantly outperforms other controllers in terms of speed response, stability, and robustness. Thus, this research contributes to the development of advanced motor control systems that are suitable for modern industrial applications, automation systems, and electric drive technologies.

2.LITERATURE SURVEY

The control of induction motor speed has been an active area of research for several decades due to its importance in industrial applications [1]. Various control strategies have been developed to improve performance, stability, and efficiency of induction motor drives. This section reviews the major contributions in the field, focusing on conventional control techniques, vector control, fuzzy logic control, and hybrid control approaches.

Initially, conventional control techniques such as PI and PID controllers were widely used due to their simple structure and ease of implementation [2]. The PI controller is effective in eliminating steady-state error and is commonly used in industrial motor drives [3]. However, it suffers from slow response and poor performance under dynamic conditions [4]. The PID controller improves transient response by adding a derivative term, but it often introduces overshoot and oscillations if not properly tuned [5]. Several researchers have reported that fixed gain controllers are not suitable for nonlinear systems like induction motors [6].

To overcome these limitations, vector control or Field-Oriented Control (FOC) was introduced as an advanced control technique [7]. This method allows independent control of torque and flux by transforming three-phase quantities into a rotating reference frame [8]. Studies have shown that vector control significantly improves dynamic performance and provides fast response and accurate speed control [9]. However, it requires precise mathematical modeling and accurate parameter estimation, which can be challenging in practical applications [10].

In recent years, intelligent control techniques such as fuzzy logic have been widely explored for induction motor control [11]. Fuzzy Logic Control (FLC) does not require an exact mathematical model and can handle nonlinearities and uncertainties effectively [12]. It uses linguistic rules and membership functions to make control decisions, mimicking human reasoning [13]. Researchers have demonstrated that fuzzy controllers reduce overshoot and improve system stability compared to conventional controllers [14]. However, the design of fuzzy systems requires careful selection of rules and membership functions, and they may exhibit steady-state errors in some cases [15].

To enhance performance further, hybrid control techniques such as Fuzzy-PID have been proposed [16]. In this approach, fuzzy logic is used to tune the PID controller parameters dynamically based on system conditions [17]. This combination leverages the advantages of both methods, providing improved adaptability and precision [18]. Studies indicate that Fuzzy-PID controllers offer superior performance in terms of faster response, reduced overshoot, and better robustness under varying operating conditions [19].

Additionally, researchers have explored optimization techniques such as genetic algorithms and neural networks to improve controller performance [20]. These methods aim to optimize controller parameters automatically, further enhancing system efficiency and adaptability.

ISSN: 2582 - 6379
IJISEA Publications
International Journal for Interdisciplinary Sciences and Engineering Applications
IJISEA - An International Peer- Reviewed Journal
2026, Volume 7 Issue 2
www.ijisea.org

From the literature, it is evident that while conventional controllers are simple and widely used, they are not suitable for nonlinear and dynamic systems. Vector control improves system performance but requires accurate modeling. Fuzzy logic provides adaptability, and hybrid Fuzzy-PID controllers combine the strengths of both approaches, making them the most effective solution for induction motor speed control. Therefore, the present work focuses on implementing and analyzing a Fuzzy-PID controller integrated with vector control to achieve efficient and reliable speed control of a squirrel cage induction motor.

3.METHODOLOGY

The methodology adopted in this work focuses on designing, modeling, and implementing an efficient speed control system for a three-phase squirrel cage induction motor using conventional and intelligent control techniques. The overall approach involves mathematical modeling, vector control implementation, controller design, simulation, and performance evaluation.

The first step in the methodology is the mathematical modeling of the induction motor. The motor is represented using its electrical and mechanical equations, which include stator and rotor voltage equations, flux linkage equations, and electromagnetic torque equations. Parameters such as stator resistance, rotor resistance, inductance, moment of inertia, and friction coefficient are considered. Since the induction motor is a nonlinear system with complex dynamics, accurate modeling is essential to analyze its behavior under different operating conditions.

The second step involves the implementation of vector control (Field-Oriented Control - FOC). This technique is used to achieve decoupled control of torque and flux, making the induction motor behave similarly to a DC motor. Clarke transformation is applied to convert three-phase quantities into two-phase stationary reference frame components (α-β). Then, Park transformation converts these components into a rotating reference frame (d-q axes). In this frame, the d-axis controls the flux while the q-axis controls torque. This transformation simplifies the control strategy and enhances dynamic performance.

The third step is the design of controllers. Initially, conventional controllers such as PI and PID are implemented. The PI controller reduces steady-state error, while the PID controller improves transient response by including proportional, integral, and derivative actions. However, these controllers are limited by fixed gain parameters. To overcome these limitations, a Fuzzy Logic Controller (FLC) is designed. The fuzzy controller uses inputs such as speed error and change in error and processes them using membership functions and a rule base to generate a control signal. It provides better adaptability to nonlinear systems.

To further enhance performance, a hybrid Fuzzy-PID controller is developed. In this approach, the fuzzy logic system dynamically tunes the PID parameters based on system conditions. This combination improves response speed, reduces overshoot, and enhances stability under varying load conditions. The hybrid controller effectively integrates the advantages of both conventional and intelligent control methods.

The fourth step involves the simulation of the complete system using MATLAB/Simulink. The induction motor model, vector control mechanism, and controllers are integrated into a closed-loop feedback system. The reference speed is compared with the actual speed to generate an error signal, which is processed by the controller. The simulation is carried out under various operating conditions such as step changes in speed, load variations, and transient disturbances.

ISSN: 2582 - 6379
IJISEA Publications
International Journal for Interdisciplinary Sciences and Engineering Applications
IJISEA - An International Peer- Reviewed Journal
2026, Volume 7 Issue 2
www.ijisea.org

The final step is the performance evaluation and analysis. The system performance is evaluated using parameters such as rise time, settling time, peak overshoot, and steady-state error. Graphs and plots are generated to compare the performance of PI, PID, Fuzzy, and Fuzzy-PID controllers. From the analysis, it is observed that the Fuzzy-PID controller provides superior performance with faster response, minimal overshoot, and improved robustness. Thus, the methodology provides a systematic approach to designing and evaluating an advanced induction motor control system, ensuring high efficiency, accuracy, and reliability suitable for modern industrial applications.

4.PROPOSED SYSTEM

The proposed system focuses on improving the speed control performance of a three-phase squirrel cage induction motor by integrating an intelligent hybrid control strategy based on a Fuzzy-PID controller with vector control (Field-Oriented Control). The system is designed as a closed-loop feedback control system in which the reference speed is continuously compared with the actual motor speed to generate an error signal. This error and its rate of change are used as inputs to the controller, enabling dynamic adjustment of control parameters. Unlike conventional systems that rely on fixed gain controllers such as PI or PID, the proposed system adapts to varying operating conditions, ensuring improved performance, accuracy, and robustness. The main objective is to achieve precise speed tracking, reduced overshoot, faster settling time, and enhanced stability under different load conditions.

At the core of the proposed system is the vector control mechanism, which plays a crucial role in achieving high-performance motor operation. Vector control enables independent control of torque and flux by transforming three-phase stator currents into a two-axis rotating reference frame using Clarke and Park transformations. In this transformed domain, the d-axis component controls the magnetic flux while the q-axis component controls the electromagnetic torque. This decoupling simplifies the control process and allows the induction motor to behave similarly to a DC motor, where torque and flux can be controlled independently. As a result, the system achieves faster dynamic response, improved efficiency, and better controllability compared to scalar control methods. The implementation of vector control also enhances the system's ability to respond quickly to sudden changes in load and speed.

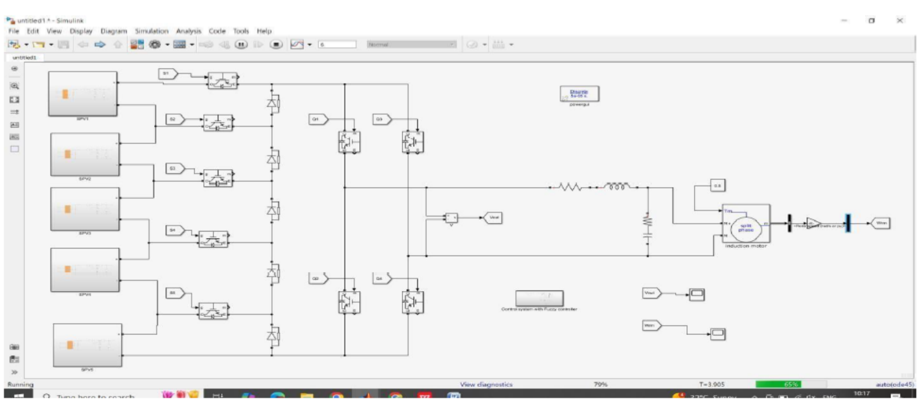

Fig 1. Proposed simulation diagram

The controller used in the proposed system is a hybrid Fuzzy-PID controller, which combines the advantages of both conventional PID control and fuzzy logic control. The PID controller provides a structured approach to minimizing error through proportional, integral, and derivative actions, while the fuzzy logic system introduces adaptability and intelligence into the control process. The fuzzy controller takes two inputs—speed error and change in error—and processes them using predefined membership functions and a rule base consisting of IF-THEN rules. Based on these inputs, the fuzzy system dynamically tunes the PID controller parameters (Kp, Ki, and Kd) in real time. This adaptive tuning allows the controller to respond effectively to nonlinearities, parameter variations, and external disturbances. As a result, the system achieves improved transient and steady-state performance, reduced oscillations, and better robustness compared to standalone PI, PID, or fuzzy controllers.

The complete system is implemented and tested using MATLAB/Simulink, where all components—including the induction motor model, vector control mechanism, Fuzzy-PID controller, and feedback system—are integrated into a unified simulation environment. The system is evaluated under various operating conditions such as sudden changes in reference speed, load disturbances, and transient scenarios to analyze its performance. The results demonstrate that the proposed system significantly outperforms conventional control methods by providing faster response, minimal overshoot, reduced settling time, and high accuracy in speed tracking. Additionally, the system exhibits strong robustness against parameter variations and external disturbances, making it highly suitable for real-world industrial applications such as electric drives, automation systems, robotics, and electric vehicles. Thus, the proposed Fuzzy-PID-based vector control system offers an efficient, reliable, and intelligent solution for advanced induction motor speed control.

5.RESULTS AND DISCUSSION

The results of the proposed induction motor speed control system are obtained through simulation using the MATLAB/Simulink environment. The performance of the system is evaluated under different operating conditions, including startup, steady-state operation, and sudden changes in reference speed. The simulation model integrates the induction motor, vector control mechanism, and different controllers such as PI, PID, Fuzzy Logic, and Fuzzy-PID. The evaluation is carried out using key performance parameters such as rise time, settling time, peak overshoot, and steady-state error. These parameters provide a comprehensive understanding of the dynamic and steady-state behavior of the system.

ISSN: 2582 - 6379
IJISEA Publications
International Journal for Interdisciplinary Sciences and Engineering Applications
IJISEA - An International Peer- Reviewed Journal
2026, Volume 7 Issue 2
www.ijisea.org

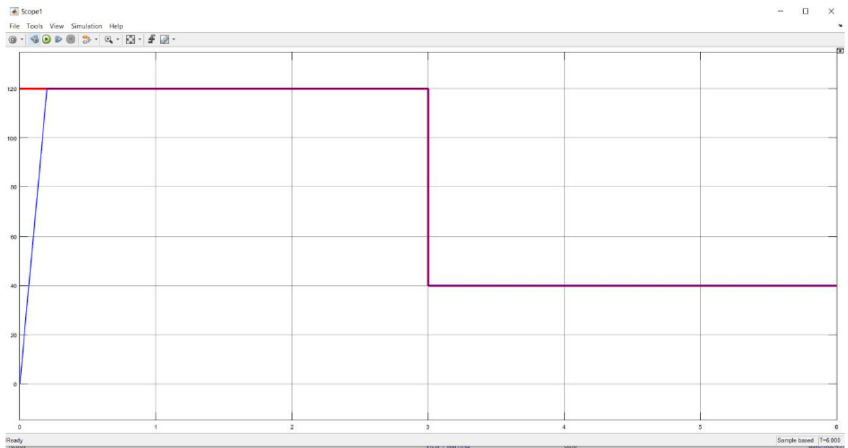

Fig 2. Ideal/Reference Tracking Response

In the first analysis, the reference speed tracking performance is observed. The motor starts from zero speed and quickly accelerates to the desired reference speed without significant delay. The response is smooth and stable, with minimal oscillations during the transient period. When the reference speed is suddenly changed, the system adapts quickly and reaches the new setpoint with high accuracy. This demonstrates the effectiveness of the control system in handling dynamic changes. The tracking performance indicates that the system maintains excellent synchronization between reference and actual speed, which is essential for applications requiring precise control.

Fig 3. Controlled Speed Response

The comparison between actual speed and reference speed further highlights the accuracy of the system. The actual speed closely follows the reference signal with very small deviation, indicating minimal steady-state error. During transient conditions, a slight deviation may occur, but the system quickly stabilizes and maintains the desired speed. This behavior confirms that the controller is capable of providing accurate speed regulation

ISSN: 2582 - 6379
IJISEA Publications
International Journal for Interdisciplinary Sciences and Engineering Applications
IJISEA - An International Peer- Reviewed Journal
2026, Volume 7 Issue 2
www.ijisea.org

even in the presence of disturbances. The close overlap between reference and actual speed curves indicates that the control strategy is highly effective in achieving reliable performance.

Fig 4. Dynamic Performance Analysis

The dynamic performance analysis reveals the differences between various controllers used in the system. The PI controller provides stable operation but exhibits slower response and longer settling time. The PID controller improves response speed but introduces noticeable overshoot and oscillations, especially during sudden changes in speed. The fuzzy logic controller reduces overshoot and improves stability but may result in minor steady-state error due to its rule-based nature. In contrast, the hybrid Fuzzy-PID controller combines the strengths of both approaches and delivers superior performance. It minimizes overshoot, reduces settling time, and provides a faster and smoother response compared to other controllers.

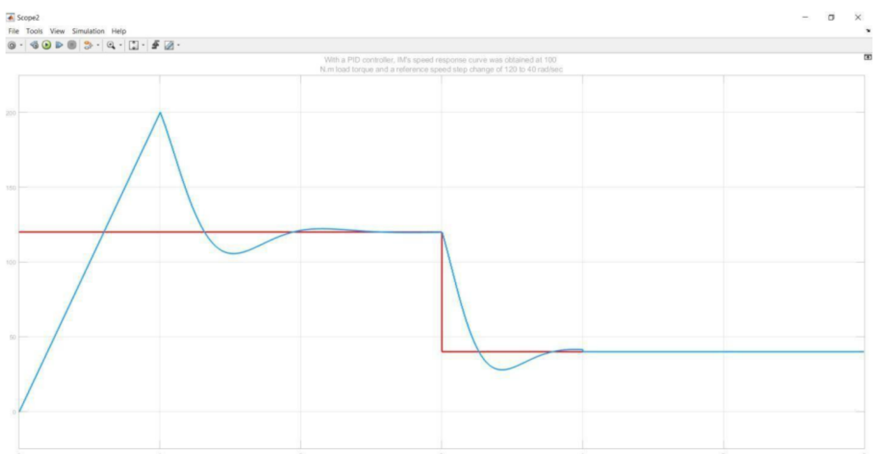

Fig 5. Comparative Performance Analysis

The overall comparative analysis clearly demonstrates that the Fuzzy-PID controller is the most effective control strategy among all the methods considered. It offers improved dynamic response, high accuracy, and strong robustness against load variations and parameter changes. The system maintains stable operation under different conditions, making it suitable for real-time industrial applications. The results confirm that integrating fuzzy logic with PID control significantly enhances the performance of induction motor speed control systems. Therefore, the proposed approach provides a reliable and efficient solution for advanced motor control applications in modern industries.

6.CONCLUSION

The present work successfully demonstrates the design, modeling, and simulation of an advanced speed control system for a three-phase squirrel cage induction motor using conventional and intelligent control techniques. The study primarily focused on comparing the performance of PI, PID, Fuzzy Logic, and hybrid Fuzzy-PID controllers integrated with vector control (Field-Oriented Control). From the simulation results, it is evident that conventional controllers such as PI and PID provide acceptable performance under steady-state conditions but suffer from limitations like slower response, higher overshoot, and poor adaptability under dynamic operating conditions. The fuzzy logic controller improves system stability and reduces overshoot but may exhibit slight steady-state errors due to its rule-based nature. However, the proposed Fuzzy-PID controller effectively combines the advantages of both PID control and fuzzy logic, resulting in superior overall performance. It provides faster rise time, reduced settling time, minimal overshoot, and improved accuracy in speed tracking even under varying load and speed conditions. Additionally, the system demonstrates strong robustness against parameter variations and external disturbances, making it highly reliable for practical applications. The implementation using MATLAB/Simulink validates the effectiveness of the proposed approach in achieving precise and efficient motor control. Therefore, the Fuzzy-PID-based vector control system can be considered a highly suitable and efficient solution for modern industrial applications, including automation systems, electric drives, robotics, and electric vehicles, where high performance, reliability, and adaptability are essential requirements.

REFERENCES

1. Bose, B. K. (2002). Modern power electronics and AC drives. Prentice Hall.
2. Krause, P. C., Wasynczuk, O., Sudhoff, S. D., & Pekarek, S. (2013). Analysis of electric machinery and drive systems (3rd ed.). Wiley-IEEE Press.
3. Leonhard, W. (2001). Control of electrical drives (3rd ed.). Springer.
4. Vas, P. (1998). Sensorless vector and direct torque control. Oxford University Press.
5. Mohan, N. (2012). Advanced electric drives: Analysis, control, and modeling using MATLAB/Simulink. Wiley.
6. Krishnan, R. (2001). Electric motor drives: Modeling, analysis, and control. Prentice Hall.
7. Ogata, K. (2010). Modern control engineering (5th ed.). Prentice Hall.
8. Dorf, R. C., & Bishop, R. H. (2017). Modern control systems (13th ed.). Pearson.
9. Zadeh, L. A. (1965). Fuzzy sets. Information and Control, 8(3), 338–353.
10. Mamdani, E. H. (1974). Application of fuzzy algorithms for control of simple dynamic plant. Proceedings of the Institution of Electrical Engineers, 121(12), 1585–1588.

ISSN: 2582 - 6379
IJISEA Publications
International Journal for Interdisciplinary Sciences and Engineering Applications
IJISEA - An International Peer- Reviewed Journal
2026, Volume 7 Issue 2
www.ijisea.org

11. Jang, J. S. R., Sun, C. T., & Mizutani, E. (1997). Neuro-fuzzy and soft computing. Prentice Hall.
12. Kosko, B. (1992). Neural networks and fuzzy systems. Prentice Hall.
13. Takagi, T., & Sugeno, M. (1985). Fuzzy identification of systems and its applications. IEEE Transactions on Systems, Man, and Cybernetics, 15(1), 116–132.
14. El-Sousy, F. F. M. (2010). Hybrid fuzzy-PI control for induction motor drives. IEEE Transactions on Industrial Electronics, 57(2), 452–460.
15. Hazzab, A., Bousserhane, I. K., Hadjeri, S., & Fellah, M. K. (2006). Speed control of induction motor using fuzzy logic technique. Serbian Journal of Electrical Engineering, 3(1), 139–150.
16. Kassem, A. M. (2010). Robust speed control of induction motor using fuzzy logic control. International Journal of Electrical Power & Energy Systems, 32(5), 520–525.
17. Li, H., & Xu, L. (2000). Fuzzy logic control of induction motor drives. IEEE Transactions on Energy Conversion, 15(2), 163–168.
18. Holtz, J. (2002). Sensorless control of induction motor drives. Proceedings of the IEEE, 90(8), 1359–1394.
19. Rashid, M. H. (2013). Power electronics: Circuits, devices, and applications (4th ed.). Pearson.
20. MATLAB. (2021). MATLAB and Simulink for control systems. The MathWorks, Inc.