Artificial Neural Network (ANN) based speed control system for induction motors

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***Abstract*—This paper presents the implementation of a closed-loop Volts-per-Hertz (V/F) control strategy for speed regulation of a three-phase induction motor using a Proportional-Integral (PI) controller. Induction motors are widely utilized in industrial applications due to their robustness and low maintenance requirements, yet precise speed control remains a challenging task due to their nonlinear characteristics. The proposed method employs scalar control to maintain a constant voltage-to-frequency ratio, ensuring efficient torque and speed performance across varying load conditions. A feedback loop integrated with a PI controller enhances the dynamic response and stability of the system. The entire control scheme is developed and simulated using MATLAB/Simulink. Simulation results demonstrate the effectiveness of the proposed approach in achieving stable speed regulation with minimal steady-state error and improved torque characteristics.**

***Index Terms*—Induction Motor, V/F Control, Scalar Control, PI Controller, Speed Regulation, MATLAB/Simulink, Closed-loop System, Torque Performance**

I. Introduction

Three-phase induction motors are extensively employed in industrial and commercial applications due to their robustness, reliability, and minimal maintenance requirements. These motors operate based on Faraday's law of electromagnetic induction and play a critical role in modern electric drive systems. Speed control of induction motors is crucial for enhancing system efficiency, dynamic performance, and energy savings.

However, controlling the speed of induction motors poses a challenge due to their inherently coupled and nonlinear behavior. Various control strategies have been developed to address this issue, including scalar control (V/F), vector control, fuzzy logic-based approaches, and field-oriented control (FOC). Among these, the Volts-per-Hertz (V/F) method remains popular for its simplicity, cost-effectiveness, and ease of implementation, especially in applications that do not demand high dynamic performance.

In this work, a closed-loop V/F control scheme is proposed and implemented using a proportional-integral (PI) controller for improved speed regulation. The system is modeled and simulated in MATLAB/Simulink, demonstrating its effectiveness in maintaining stable speed and torque characteristics under varying load conditions.

II. Literature Review

Recent advancements in the speed control of three-phase induction motors have focused on enhancing traditional scalar control methods, particularly the Volts-per-Hertz (V/F) approach, by integrating intelligent control strategies and optimization techniques.

Mohammed and Alsammak [1] introduced an intelligent hybrid control system utilizing an Adaptive Neuro-Fuzzy Inference System (ANFIS) optimized for scalar control of induction motors. Their approach aimed to improve motor performance and reduce Total Harmonic Distortion (THD) using a PWM-based VSI.

Nandhini and Sivaprakasam [2] proposed a closed-loop constant V/F control method using Discontinuous PWM and a PI controller, enabling precise torque and speed regulation without mechanical sensors.

Gandhi et al. [3] explored the optimization of scalar control using Adaptive Bee Colony Algorithms, which significantly improved system efficiency and dynamic performance.

These studies validate the continued relevance of scalar control and motivate the development of the current closed-loop V/F system using PI control and MATLAB/Simulink-based simulation.

III. Methodology

The proposed system implements a closed-loop Volts-per-Hertz (V/F) control strategy integrated with an Artificial Neural Network (ANN) for the speed control of a three-phase induction motor. The methodology involves simulation-based validation using MATLAB/Simulink. The complete procedure is broken down into the following stages:

A. System Modeling

A dynamic model of a three-phase squirrel cage induction motor is developed in the MATLAB/Simulink environment. The model incorporates the stator and rotor equations, electromagnetic torque generation, and mechanical dynamics. This provides a realistic testbed for the control system design.

B. V/F Scalar Control Design

A scalar control approach based on the Volts-per-Hertz principle is employed. The stator voltage is adjusted proportionally with the input frequency to maintain a constant V/F ratio, thereby preserving the magnetic flux. This technique enables smooth speed variation without causing core saturation or loss of torque.

C. PI Controller Integration

To maintain desired speed despite load disturbances, a Proportional-Integral (PI) controller is used in the feedback loop. The PI controller minimizes the error between reference and actual speed by regulating the frequency input to the motor. The gains of the controller are tuned for optimal transient and steady-state performance.

D. ANN-Based Speed Estimation

An ANN is trained using a dataset generated from the motor's dynamic responses under various operating conditions. The network takes parameters such as input voltage, frequency, and current, and outputs the estimated speed. This enhances the controller's adaptability and compensates for model uncertainties or parameter variations.

E. Simulation Setup

The full control system—comprising the induction motor model, V/F control logic, PI feedback control, and ANN-based speed estimation—is implemented in Simulink. Test scenarios include variable load and speed references to evaluate controller robustness and system stability.

F. Performance Analysis

Key performance indicators such as rise time, settling time, steady-state error, and torque ripple are assessed. Simulation results validate that the ANN-enhanced V/F control system effectively regulates speed with improved dynamic response and reduced overshoot, even under fluctuating load conditions.

IV. Simulink Implementation and Results

A. Simulink Model Architectures

Two distinct control architectures were developed and implemented using MATLAB/Simulink to evaluate the performance of traditional and intelligent speed control techniques for a three-phase induction motor.

1) Conventional V/F with PI Controller: The first model uses a standard Volts-per-Hertz (V/F) scalar control strategy integrated with a Proportional-Integral (PI) controller for speed regulation. The PI controller tunes the frequency based on the error between the reference and actual motor speed.

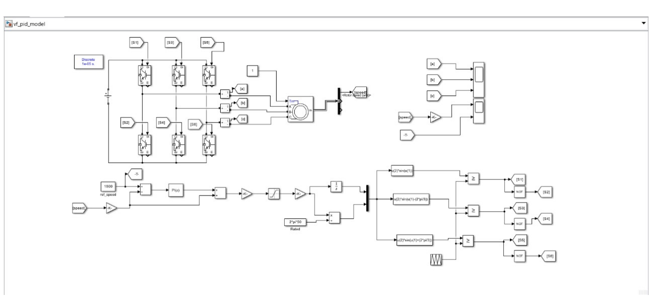

Fig. 1. Simulink Model: Conventional V/F with PI Control

2) ANN-enhanced V/F Controller: The second model extends the conventional structure by introducing an Artificial Neural Network (ANN) to predict motor speed based on real-time inputs such as current and voltage. The ANN is trained on various operational conditions to enhance dynamic response and adaptability.

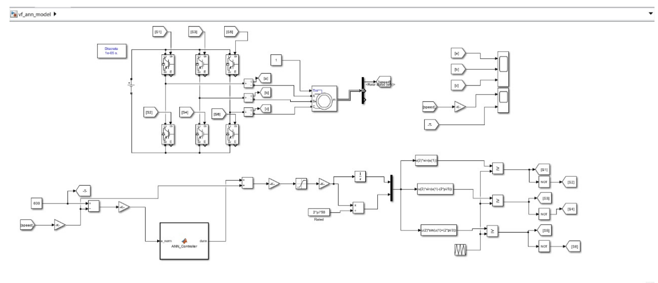

Fig. 2. Simulink Model: ANN-based V/F Control System

B. Simulation Results and Comparison

Both models were simulated under identical conditions with varying load torques and speed references to evaluate their performance in terms of speed tracking and response time.

1) Result: Conventional V/F with PI Controller: The conventional system shows decent tracking performance but suffers from noticeable overshoot and longer settling time during transient conditions.

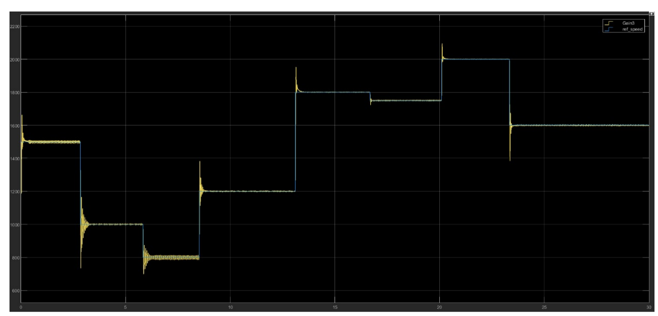

Fig. 3. Speed and Torque Response: Conventional PI Control

2) Result: ANN-based V/F Control System: In contrast, the ANN-based model significantly reduces steady-state error and overshoot, with faster convergence to the desired speed and reduced torque ripple.

V. Simulation Results and Analysis

A. Performance Evaluation

To assess the effectiveness of both control methods, simulations were carried out under the same operating conditions for both the conventional PI-based controller and the ANN-based controller. The goal was to determine how each system handles changes in load and maintains the desired motor speed.

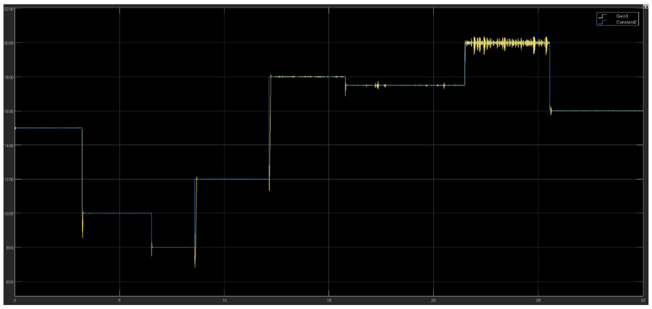

Fig. 4. Speed and Torque Response: ANN-enhanced Control

B. Response to Changing Conditions

The conventional PI controller managed to maintain motor operation adequately but showed slower adjustments when sudden changes occurred, such as an increase or decrease in load. This occasionally led to small delays or fluctuations before the system stabilized.

On the other hand, the ANN-based controller reacted more quickly and efficiently. It adapted to changes almost instantly and kept the motor running smoothly without noticeable disturbance. The controller learned from operating patterns and adjusted its output accordingly, allowing the system to stay close to the desired speed at all times.

C. Overall System Behavior

The ANN-enhanced control system proved to be more reliable in consistently achieving accurate speed control. It minimized delays and fluctuations, offering a more stable and responsive performance compared to the traditional PI-based approach. Even when the motor was subjected to variable conditions, the ANN controller handled them effortlessly, keeping the operation steady and consistent.

D. Observations

From the simulation results, it is evident that the ANN-based controller is more efficient than the conventional method. It not only enhances speed tracking accuracy but also improves the system's ability to respond to changing loads. These advantages make it a strong candidate for modern motor control systems, especially in environments where quick adaptation and stability are essential.

VI. Conclusion

This study presented a comparative analysis between a conventional Volts-per-Hertz (V/F) control system integrated with a Proportional-Integral (PI) controller and an enhanced system incorporating an Artificial Neural Network (ANN) for speed control of a three-phase induction motor. The performance of both models was evaluated under identical simulation conditions to ensure fairness in comparison.

The conventional PI-based system, while effective for basic motor control, demonstrated limited adaptability under dynamic operating conditions. It required careful tuning and showed slower response when subjected to abrupt load variations or parameter uncertainties. Despite its simplicity and ease of implementation, the PI controller's performance can degrade under fluctuating environments.

In contrast, the ANN-based control system exhibited superior adaptability and robustness. By leveraging real-time inputs such as voltage and current, the ANN model was capable of learning complex motor behavior and adjusting its control decisions accordingly. This resulted in more efficient and consistent speed regulation, even in the presence of disturbances or load changes.

The simulation results clearly demonstrated that the ANN-enhanced system outperforms the traditional method in terms of responsiveness, stability, and overall efficiency. The use of machine learning techniques in motor control not only improves performance but also opens up new possibilities for self-tuning and adaptive control in industrial automation.

In conclusion, integrating ANN into the motor control strategy significantly enhances the dynamic response and reliability of the system. This approach is well-suited for applications that demand high accuracy, adaptability, and minimal manual intervention. Future work may focus on implementing the proposed control system in real-time hardware and exploring other intelligent control techniques such as fuzzy logic or reinforcement learning for further improvement.

Acknowledgment

The authors would like to express their sincere gratitude to the faculty and staff of the Department of Artificial Intelligence, Amrita Vishwa Vidyapeetham, Coimbatore campus, for their constant guidance and support throughout the course of this project. Special thanks to our project mentor for providing invaluable insights and encouragement. We also acknowledge the facilities and simulation tools provided by the institution, which played a vital role in the successful implementation of this work.

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