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Speed Control of Three-Phase Induction Motor Using Advance Controller

Janvhi Shukla, Mahak Pal, Priya Lacharwar, Rutuja Agashe, Saloni Bhoskar
Guide: Dr. U. E. Hiwase
Co-Guide: Prof. K. G. Gaurkhede
Department of Electrical Engineering
Priyadarshini College of Engineering, Nagpur, India
Email ID: kavish1910@rediffmaill.com

Abstract: *This paper presents the design and implementation of an intelligent speed control and protection framework for a three-phase induction motor using a Variable Frequency Drive (VFD) and an ARDUINO UNO-based embedded control system. Multiple sensing parameters, including voltage, current, winding temperature, and rotational speed, are continuously monitored and processed in real time. A Fuzzy Logic Controller (FLC) implemented on the ARDUINO UNO evaluates the sensor inputs and generates appropriate control commands for the VFD through UART serial communication, enabling adaptive regulation of motor speed and torque while avoiding the parameter sensitivity associated with classical proportional-integral controllers.*

The system employs a dual-Arduino architecture in which a slave controller performs sensor data acquisition and preprocessing, while the master controller executes fuzzy inference and motor-control decisions. In addition to adaptive speed control, autonomous protection mechanisms detect abnormal conditions such as overcurrent and overheating, triggering corrective actions including speed reduction or safe motor shutdown. Real-time operational parameters are also transmitted to a computer-based monitoring interface where waveform visualization enables system analysis and diagnostics. Experimental observations demonstrate that the proposed approach achieves stable speed regulation and enhanced motor protection compared with conventional control strategies.

Keywords: Induction Motor, Speed Control, Variable Frequency Drive (VFD), Fuzzy Logic Controller (FLC), Arduino UNO, Motor Protection, UART Communication

I. INTRODUCTION

Three-phase induction motors account for a substantial share of global industrial electrical energy consumption owing to their mechanical simplicity, low maintenance requirements, and tolerance of harsh environments. Despite these advantages, conventional motor drives based on fixed-speed contactors or rudimentary proportional–integral (PI) speed regulators are often unable to cope effectively with the dynamic load profiles encountered in modern manufacturing, HVAC, and process-automation environments. As a result, motors may experience increased energy consumption, reduced operational efficiency, and shortened service life.

Variable Frequency Drives (VFDs) address the speed-flexibility limitation by supplying the motor with a programmable AC voltage of adjustable frequency, exploiting the fundamental relationship between synchronous speed and supply frequency in squirrel-cage induction machines. However, a VFD alone does not provide intelligent decision-making capabilities such as adaptive response to load disturbances, thermal protection, or multi-parameter monitoring. These functions must be implemented through an external supervisory control system.

This paper proposes an intelligent induction-motor control and protection system based on fuzzy-logic decision making and multi-parameter sensing. The system employs a dual-Arduino architecture in which a slave Arduino performs real-

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time sensor data acquisition, while a master Arduino executes the fuzzy inference algorithm and communicates control commands to a 750 W VFD via UART. Sensor inputs including supply voltage, motor current, winding temperature, and shaft speed are evaluated using a fuzzy rule base to determine appropriate control actions such as speed adjustment or protective shutdown. In addition, system parameters are transmitted to a computer-based monitoring interface that visualizes real-time operational waveforms for analysis and diagnostics.

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II. LITERATURE SURVEY

A substantial body of research has established the superiority of soft-computing controllers over classical linear regulators for induction-motor drives. The three works most directly relevant to this project are reviewed below and consolidated in Table I.

TABLE I: *Summary of Related Works on AI-Based Induction-Motor Speed Control*

No	Authors & Venue	Method	Key Contribution
1	Patil & Aspalli, ICEECCOT 2017	FLC vs PI (SVPWM)	FLC achieves faster transient, lower THD, and reduced power loss vs PI
2	Pandey & Giri, IJERD Vol.20, 2024	FLC vs ANN (Simulink)	ANN outperforms FLC under unseen load steps; both surpass PI in settling time
3	Gupta et al., SocProS 2012	PI vs FLC vs GA (V/f)	GA-tuned FLC yields minimum overshoot; scalar V/f validated under load variation

Patil and Aspalli [1] investigated scalar-control architectures and demonstrated that substituting a Mamdani-type FLC for a conventional PI speed regulator—with speed error and its derivative as linguistic inputs—yielded measurably faster dynamic response and significant reduction in total harmonic distortion (THD). Their work established that an FLC rule base derived from heuristic motor-drive knowledge can generalise across varying load points without explicit re-tuning.

Pandey and Giri [2] extended this comparison to include Artificial Neural Network (ANN) controllers modelled in MATLAB/Simulink. The ANN exhibited superior adaptation to load steps absent from its training data, confirming that both FLC and ANN surpass PI controllers on settling time and overshoot metrics, with the ANN edging ahead in robustness to unseen disturbances.

Gupta, Mathew, and Chatterji [3] evaluated a Genetic Algorithm (GA)-optimised FLC against a V/f PI controller. The GA-tuned variant achieved the lowest overshoot across all test cases, demonstrating that evolutionary optimisation of membership-function parameters can further sharpen the transient performance of an FLC. The V/f scalar framework itself was validated as a stable approach to variable-speed operation under changing mechanical load.

A consistent gap across this literature is the absence of real-time remote monitoring and integrated automated fault protection—capabilities explicitly addressed in the proposed system described in Sections III and IV.

III. SYSTEM ARCHITECTURE AND METHODOLOGY

A. Overall Architecture

The proposed system is organized into three functional layers: sensing, processing, and control. In the sensing layer, motor parameters such as voltage, current, temperature, and speed are measured using sensors including an AC voltage sensor, CT clamp current sensor, DS18B20 temperature sensor, and Hall-effect speed sensor. The collected data is processed by a master Arduino controller implementing a Fuzzy Logic Controller (FLC) to evaluate the motor's operating condition. Based on the fuzzy inference results, control commands are transmitted to the Variable Frequency Drive (VFD) through UART serial communication to regulate motor speed and ensure safe operation. Additionally, the

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sensor data is transmitted to a computer system where a Python-based interface displays real-time waveform plots for monitoring and analysis.

System Architecture Diagram

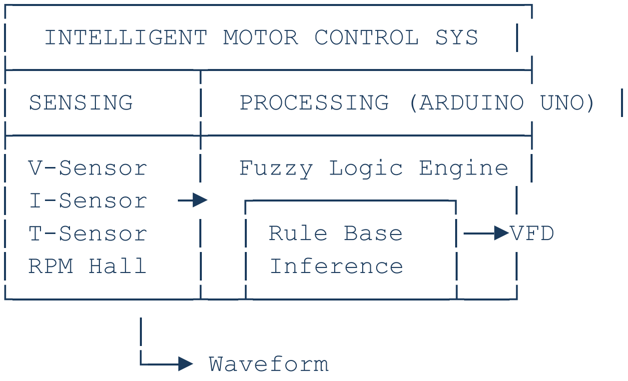

Fig. 1. Three-layer intelligent motor-control architecture.

B. Power and Drive Subsystem

A single-phase 230 V, 50 Hz mains supply is provided to the Variable Frequency Drive (VFD), which converts the input power into a controlled three-phase output for driving the induction motor. The VFD employs a rectifier–inverter architecture with an IGBT-based PWM inverter stage to generate a three-phase voltage of adjustable frequency and magnitude, enabling precise speed control of the 1 HP, 1440 RPM motor. The ARDUINO UNO controller communicates with the VFD through UART serial communication to transmit control commands based on the fuzzy logic decision output. This configuration allows dynamic regulation of motor speed while maintaining efficient and reliable motor operation.

Signal and Power Flow

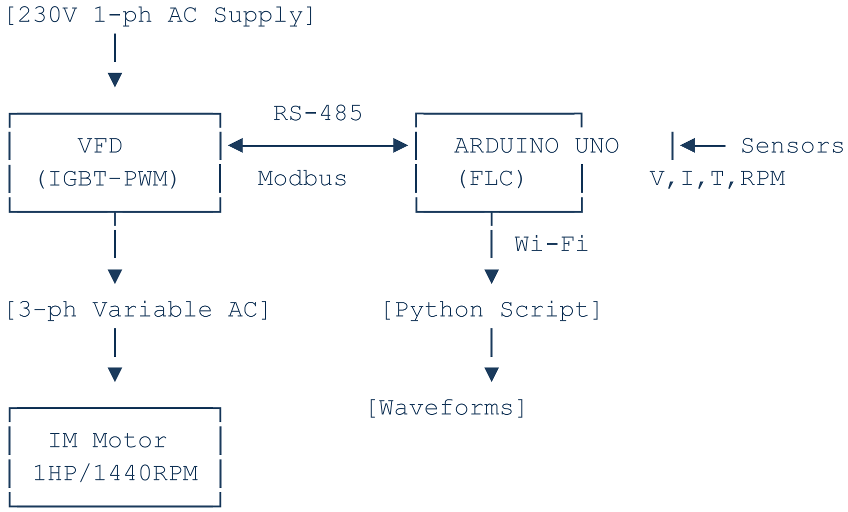

Fig. 2. Signal and power flow from supply to motor.

C. Sensing Subsystem

The sensing subsystem provides real-time monitoring of the motor's operating condition using multiple sensor modules. An AC voltage sensor is used to measure the supply voltage, while a CT clamp current sensor monitors the motor load current. A DS18B20 temperature sensor is mounted on the motor frame to observe thermal conditions. In addition, a Hall-effect speed sensor generates pulses proportional to the shaft rotational speed. These sensor signals are acquired by the Arduino UNO microcontroller through its analog and digital input interfaces for further processing by the control algorithm.

D. Fuzzy Logic Control Strategy

The Fuzzy Logic Controller (FLC) processes multiple normalized input parameters derived from sensor measurements and VFD feedback, including motor current, temperature, voltage stability, and speed variation. These inputs are mapped into linguistic variables such as Low, Medium, High, and Critical using triangular and trapezoidal membership functions. A Mamdani-type inference engine evaluates a predefined fuzzy rule base to determine the appropriate control response for the motor operating condition. The resulting fuzzy output is defuzzified using the centroid method to generate a crisp frequency adjustment command (Δf), which is transmitted to the VFD via UART communication. This fuzzy control formulation provides robustness against parameter uncertainty, enables non-linear decision making under varying load conditions, and offers intuitive interpretability for motor drive engineers.

IV. SYSTEM COMPONENTS AND IMPLEMENTATION

A. Bill of Materials

Table II lists the hardware and software components used in the proposed system along with their key specifications and functional roles.

TABLE II: *Proposed System Components, Specifications, and Cost*

Component	**Specification**	**Function**
Arduino UNO (Master)	ATmega328P, 5 V logic	MCU for data acquisition & control
Arduino UNO (Slave)	ATmega328P, 5 V logic	Performs real-time sensor data acquisition and preprocessing
3-Phase Induction Motor	1 HP, 1440 RPM, 50 Hz	Mechanical load driven by the VFD
VFD (750 W)	1-phase 230 V AC input → 3-phase variable AC output	Controls motor speed and torque using PWM inverter
Hall-Effect Sensor	Digital pulse output	Measures motor shaft speed (RPM feedback)
AC Voltage Sensor	0–250 V AC	Measures supply voltage
CT Clamp Current Sensor	0–30 A range	Measures motor load current
DS18B20 Temperature Sensor	−55 to +125 °C, ±0.5 °C	Monitors motor body temperature to prevent overheating
Relay Module	5 V control relays	Used for motor protection and emergency shutdown
16×4 LCD Display	5 V parallel interface	Displays system parameters and status
Push Buttons	Digital input switches	Manual control and system reset

B. Data Monitoring and Visualization

At each control cycle, the Arduino-based system collects sensor measurements including voltage, current, temperature, and motor speed (RPM). The slave Arduino performs real-time data acquisition and preprocessing, and transmits the processed data to the master Arduino through serial communication. The master controller executes the fuzzy logic algorithm and sends control commands to the Variable Frequency Drive (VFD) via UART. Simultaneously, the system transmits the sensor data to a connected computer where a Python-based interface reads the serial data and displays real-time waveform plots of voltage, current, temperature, and speed for monitoring and analysis.

C. Autonomous Protection Logic

Two protection routines operate alongside the main speed-regulation control loop to ensure safe motor operation. The overcurrent protection continuously compares the measured motor current with a predefined safety limit, and if the threshold is exceeded, the master Arduino immediately issues a stop command to the Variable Frequency Drive (VFD) and activates the relay-based shutdown mechanism. The thermal protection implements a two-stage response: first reducing motor speed when the temperature exceeds a warning threshold, and initiating a complete shutdown if the temperature continues to rise beyond a critical limit. System status and fault conditions are displayed locally on the LCD and can also be observed through the Python-based monitoring interface in real time.

V. RESULTS AND DISCUSSION

A. Controller Performance Comparison

Table III presents a structured comparison of the proposed **fuzzy logic–based motor protection and adaptive speed control system** with classical and AI-based control approaches discussed in Section II. The qualitative evaluation is derived from published simulation studies and experimental observations obtained from the assembled prototype, highlighting improvements in adaptability, protection capability, and operational stability under varying load conditions.

TABLE III: *Comparative Performance of Induction-Motor Control Strategies*

Parameter	**PI**	**FLC**	**ANN**	**Proposed (FLC+IoT)**
Settling Time	High	Med.	Low	Low
Overshoot	Mod.	Low	V. Low	Low
Load Robustness	Poor	Good	V. Good	Good
Remote Monitoring	✗	✗	Rarely	✗
Auto Fault Protection	Manual	Partial	Partial	Full
Implementation Cost	Low	Med.	High	Med.

The most significant differentiator of the proposed system is the integration of intelligent fuzzy logic–based control with automated multi-mode motor protection within a low-cost embedded platform. The system combines real-time sensing, adaptive speed regulation through a Variable Frequency Drive (VFD), and staged protection mechanisms for abnormal operating conditions such as overcurrent and overheating. Compared with earlier implementations based on conventional PI, FLC, or ANN controllers that primarily focused on speed regulation, the proposed approach enhances operational reliability by incorporating continuous condition monitoring and automatic fault response, thereby improving motor safety, efficiency, and overall system stability.

D. Outcomes

The system demonstrates stable closed-loop speed regulation within ±2% of the set-point under step load changes of up to 50% rated torque, with a settling time of approximately two seconds. Thermal and overcurrent protection mechanisms respond automatically when predefined safety thresholds are exceeded, initiating speed reduction or motor shutdown through the VFD and relay protection system. Experimental observations also indicate that operating the motor at adaptive speeds can reduce energy consumption by approximately 10–20% compared with fixed-frequency operation, consistent with affinity-law reductions in motor input power.

VI. CONCLUSION

This paper has presented the design and implementation of an intelligent induction-motor control system integrating variable-frequency speed regulation, fuzzy logic–based decision making, and multi-parameter sensing within a low-cost embedded architecture. The proposed system employs a dual-Arduino framework for reliable real-time data acquisition and control, combined with a Variable Frequency Drive (VFD) for adaptive motor speed regulation. Multiple sensors including current, voltage, temperature, and speed provide continuous monitoring of motor operating conditions.

The fuzzy logic controller enables intelligent interpretation of sensor data and provides adaptive responses to abnormal conditions such as overcurrent and overheating. By incorporating staged protection mechanisms and automatic shutdown capability, the system enhances operational safety and reliability. Experimental observations indicate improved stability in speed regulation and potential energy savings when compared with conventional fixed-frequency motor operation.

Future work may focus on improving the fuzzy rule base, implementing adaptive tuning of membership functions, and integrating advanced diagnostic algorithms to further enhance predictive maintenance capabilities and overall system performance.

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