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IoT-Based Motor Protection and Control System Using PLC and ESP8266

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Abstract

Because of their straightforward design and affordable price, single-phase induction motors are frequently utilized in residential and small-scale industrial settings. However, conventional direct-on-line (DOL) control provides fixed-speed operation and offers limited protection against thermal overload and fault conditions. This article describes the design and implementation of an ESP8266 NodeMCU-based programmable logic controllers (PLC)-based closed-loop motor control system with Internet of Things (IoT) features. To increase operating flexibility and maintenance efficiency, the suggested system also incorporates sensor-based feedback control, wireless connection, and remote accessibility capabilities. Through a web-based interface, the suggested system allows for the continuous monitoring of motor temperature and operating status. To assist with predictive maintenance and improve system dependability, cloud-based data recording and trouble notification systems are also included. It also implements automatic thermal derating and shutdown mechanisms to prevent damage. Experimental results indicate a reduction in temperature rise by approximately 12–15%. The system also achieves an efficiency improvement of about 10–12% compared to conventional DOL control. During continuous operation, the developed prototype exhibits consistent performance, lower energy consumption, and enhanced protection against electrical failures and overheating. The suggested approach is affordable, scalable, and appropriate for Industry 4.0 applications provide improved long-term operating stability, sustainability, flexibility, safety, dependability, and connection.

Keywords: PLC, ESP8266, IoT, induction motor, thermal protection, speed control

INTRODUCTION

Single-phase induction motors are widely used in residential and light industrial applications. This is due to their reliability, simple construction, and low-maintenance requirements. However, conventional motor control techniques provide limited flexibility and protection [1]. Consequently, motors are more vulnerable to overheating, overcurrent, and insulation failure.

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One of the main causes of insulation life reduction is motor overheating. An excessive temperature increase can occur owing to overload, voltage imbalance, or poor cooling. Therefore, an efficient protection mechanism is essential for improving the motor lifespan.

Industrial automation systems extensively use programmable logic controllers (PLCs). They provide reliable control, modular designs, and real-time operations. PLC-based systems enable the effective implementation of speed control and fault detection logic.

In recent years, the Internet of Things (IoT) has enabled the remote monitoring and management of industrial equipment [2]. Microcontrollers, such as the ESP8266, provide cost-effective wireless communication. These devices support protocols such as HTTP and message queuing telemetry transport (MQTT) for data transmission.

Existing systems focus on either PLC-based control or IoT-based monitoring. Few systems integrate both into a unified architecture.

Despite their widespread use, conventional motor control techniques, such as direct-on-line (DOL) starters, provide only basic operational functionality and lack advanced protection, monitoring, and automation features [3].

In industrial automation, the integration of IoT with PLCs improves reliability, flexibility, and operational efficiency. PLCs are widely used in industrial control applications because of their robustness, fast response, and ability to perform automated control tasks efficiently. By combining PLC technology with IoT-enabled communication modules, such as the ESP8266 NodeMCU, it is possible to create smart motor control systems capable of remote supervision and intelligent protection.

The ESP8266 NodeMCU is a low-cost Wi-Fi-enabled microcontroller widely used in IoT applications because of its compact size, easy programming capability, and wireless communication support. This enables real-time data transmission between sensors, control systems, and cloud-based platforms. In motor protection applications, the ESP8266 can continuously monitor important parameters such as the motor temperature, current status, operating conditions, and fault signals [4]. The collected data can then be displayed through web servers or mobile applications, enabling operators to monitor the motor performance remotely from any location. This capability reduces the need for manual inspections and improves maintenance efficiency.

In conventional motor systems, thermal overload and overheating are the major causes of insulation damage and reduced motor lifespan. Excessive temperature increases can occur because of prolonged operation, overloading, or inadequate ventilation. Traditional protection methods often fail to provide accurate real-time monitoring and respond slowly to abnormal conditions [5]. The proposed IoT-based motor protection and control system addresses these limitations by implementing automatic thermal monitoring, fault detection, and shutdown. The sensors continuously monitor the motor condition, whereas the PLC processes the input signals and executes appropriate control actions whenever abnormal conditions are detected. This improves operational safety and minimizes the risk of equipment damage to the crane.

Another important advantage of integrating IoT with PLC-based systems is the ability to conduct predictive maintenance. Real-time data logging and continuous monitoring help identify the early signs of faults before severe failures occur. This reduces maintenance costs, minimizes downtime, and improves the overall system reliability [6]. Furthermore, remote accessibility allows operators to supervise industrial equipment without being physically present at the site, which is especially beneficial in large industrial plants and remote installations.

The proposed system also contributes to energy efficiency and smart industrial automation in the manufacturing process. Energy losses can be significantly reduced by optimizing motor operation and preventing unnecessary overheating [7]. The system supports Industry 4.0 concepts by enabling intelligent communication, automation and cloud-based monitoring. Its low implementation cost and scalable design make it suitable for both domestic and industrial applications [8].

Overall, the IoT-based motor protection and control system using PLC and ESP8266 offers an effective solution for intelligent motor monitoring, improved safety, remote accessibility, and enhanced operational efficiency of motors. The integration of automation and IoT technologies provides a modern approach to reliable motor protection and smart industrial control systems [9].

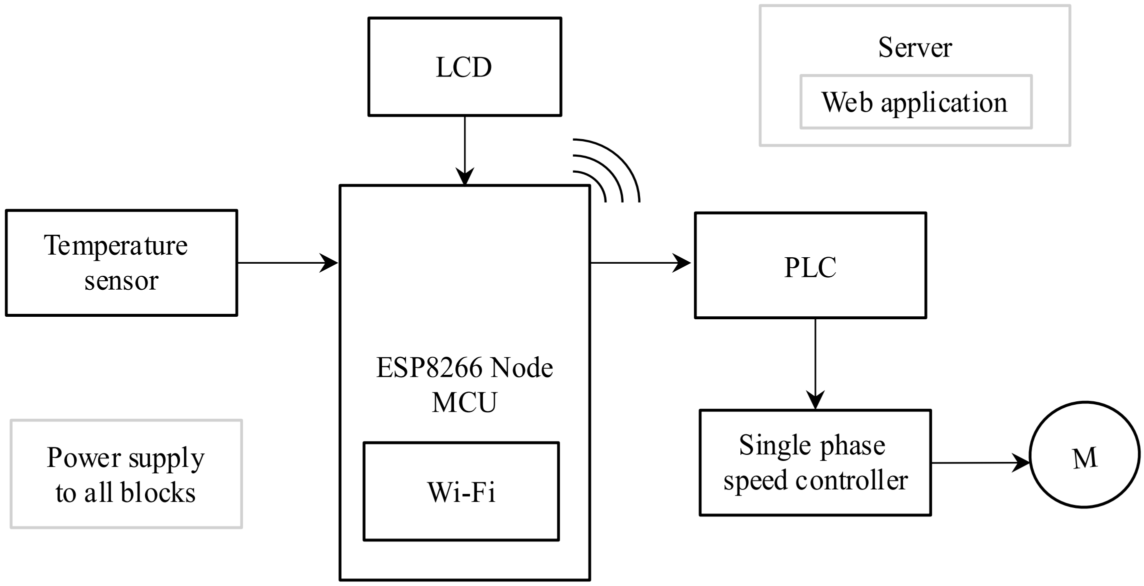

Figure 1. Block diagram of proposed system.

Contributions

- A PLC-based closed-loop motor control system is developed.
- Real-time thermal protection with automatic derating is implemented.
- IoT-based monitoring using ESP8266 is integrated.
- A web-based remote monitoring interface is designed.
- A hybrid PLC–IoT architecture is proposed for industrial applications.

SYSTEM ARCHITECTURE

The proposed system, as shown in Figure 1, consists of a PLC, ESP8266 module, temperature sensor, motor drive unit, and monitoring interface. The primary control unit is a PLC. It executes the ladder logic for motor operation and protection. The ESP8266 module handles wireless communication.

The temperature sensor continuously measures the motor temperature. The measured data were processed and transmitted to the monitoring interface. After receiving the control inputs, the PLC produces the necessary output signals to operate the motor [10].

METHODOLOGY

The system was developed using a structured approach. Initially, the system requirements were defined. A block diagram was prepared to represent the system architecture.

A PLC ladder logic was developed for motor control and protection. Separate modules were created for startup, speed control, and fault detection. The ESP8266 firmware was programmed to acquire and transmit data.

The hardware components were assembled based on the circuit design, as shown in Figure 2. Various operational scenarios were used to test the system. The performance was validated through experimental observations.

MATHEMATICAL MODELLING

The synchronous speed of the motor is given by:

$$Ns = 120f/P \tag{1}$$

Where, f is the supply frequency and P is the number of poles.

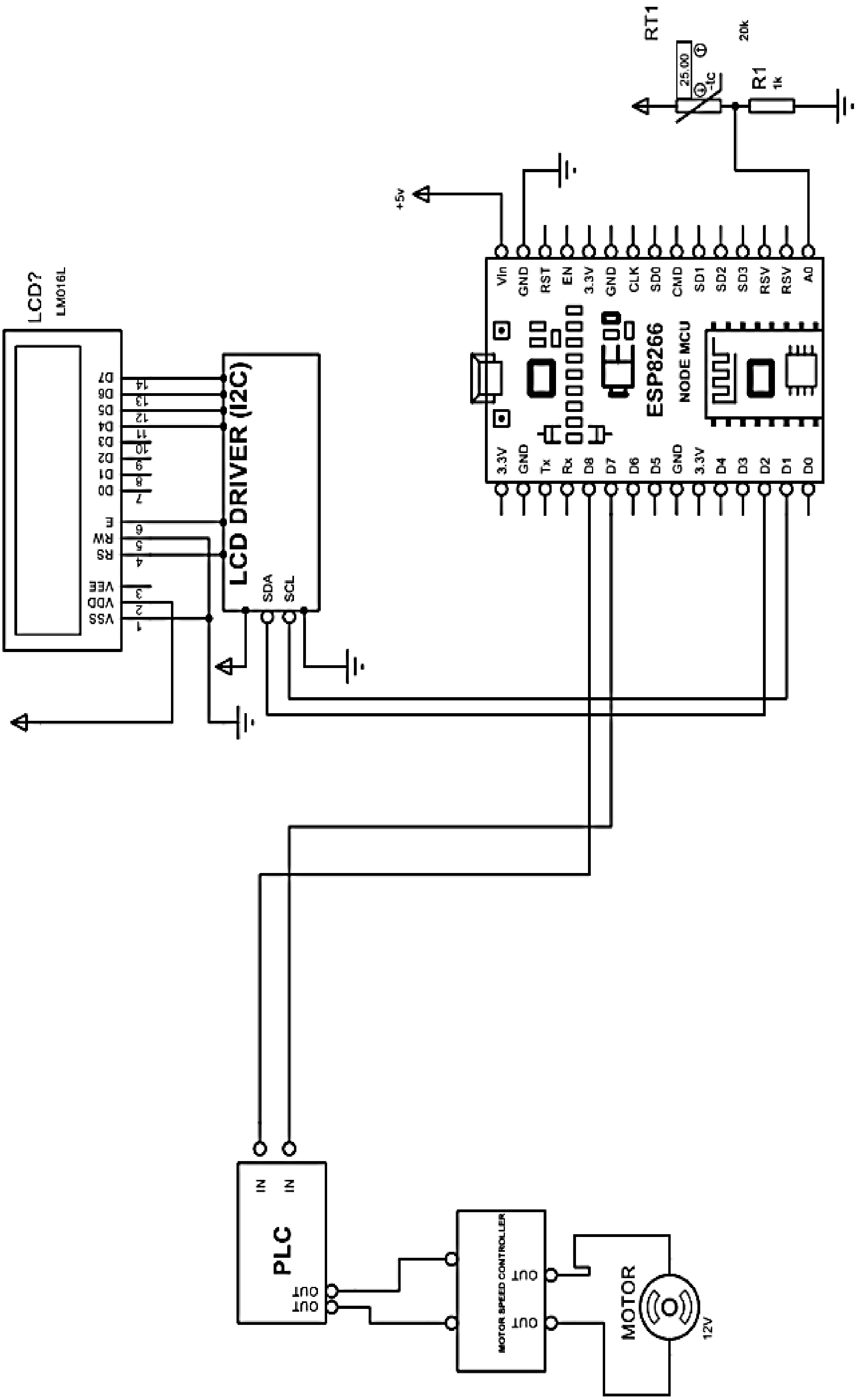

Figure 2. Circuit diagram.

The slip is defined as:

$$s = (Ns - Nr)/Ns \quad (2)$$

where, Nr is the rotor speed.

The torque relation is expressed as:

$$T \propto V^2/s \quad (3)$$

The proportional–integral–derivative (PID) control equation is given by:

$$u(\mathrm{t}) = K_p\, e(\mathrm{t}) + K_i \int e(\mathrm{t})\, \mathrm{dt} + Kd\, \mathrm{d}e(\mathrm{t})/\mathrm{dt} \quad (4)$$

The efficiency of the system is calculated as:

$$\eta = (\text{Output Power}/\text{Input Power}) \times 100 \quad (5)$$

HARDWARE IMPLEMENTATION

The hardware system, as shown in Figure 3, consists of a Delta PLC, an ESP8266 NodeMCU, a temperature sensor (LM35), as shown in Figure 4, a single-phase induction motor, and a variable frequency drive (VFD).

Control and protection functions are performed via the PLC. The ESP8266 module enabled wireless communication. The temperature sensor continuously monitored the motor temperature.

Proper grounding and electrical isolation were maintained. This ensures safe and reliable system operations.

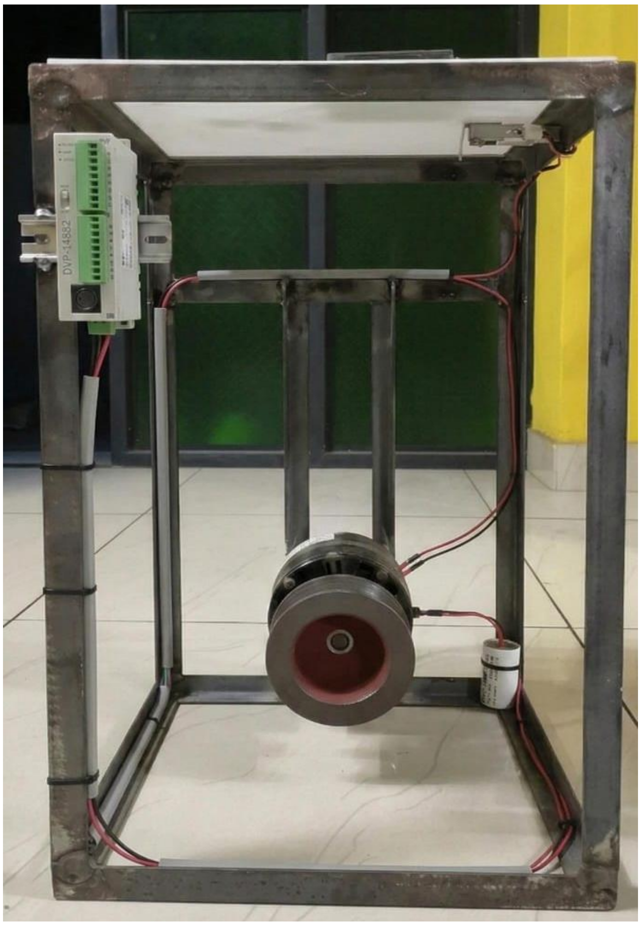

Figure 3. Hardware components.

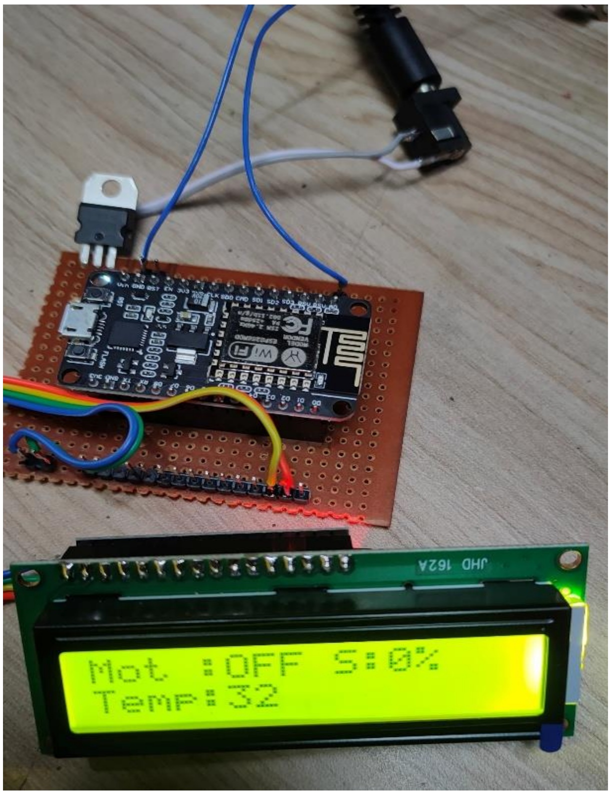

Figure 4. Temperature-controlling using ESP266.

Table 1. Comparison between DOL and proposed temperature.

Time (min)	Temperature (DOL) (°C)	Temperature (proposed) (°C)
0	30	30
5	45	40
10	60	52
15	75	65

Table 2. Comparison with different parameters.

Parameter	DOL	Proposed system
Efficiency	75%	86%
Temperature rise	High	Reduced
Control	Fixed	Variable
Protection	Limited	Advanced

RESULTS AND DISCUSSION

The system performance was assessed under various operating settings. The experimental results, as shown in Table 1, confirm stable motor operation and effective protection.

The proposed system shows reduced temperature rise compared to DOL operation.

The results indicate improved efficiency and reduce thermal stress as shown in Table 2.

Software Implementation

The software implementation consisted of PLC ladder logic programming and embedded firmware development for the ESP8266 module. The PLC control logic was developed using OpenPLC to ensure deterministic and real-time operation. It includes start/stop routines, PID-based speed control, temperature protection, and fault handling mechanisms. The control output is generated based on the error between the reference and measured speeds and transmitted to the VFD as an analog signal.

The Arduino IDE was used to build the ESP8266 firmware. It establishes Wi-Fi connectivity, acquires system parameters, and transmits data to a remote monitoring platform. It also supports remote setpoint updates and incorporates a watchdog mechanism for reliable communications.

A web-based interface developed using HTML and cascading style sheets (CSS)provides real-time visualization of motor parameters, such as temperature, speed, and system status. Data logging and user authentication features enhance monitoring and security.

PLC Configuration

The system uses a Delta DVP Series PLC operating at 24 V DC voltage. It provides eight and six digital input and output channels, respectively. The input interface with control devices, such as start/stop switches, while the outputs control actuators and motor drive signals. The PLC executes the ladder logic, as shown in Figure 5, to perform motor control, safety interlocking, and overall system automation.

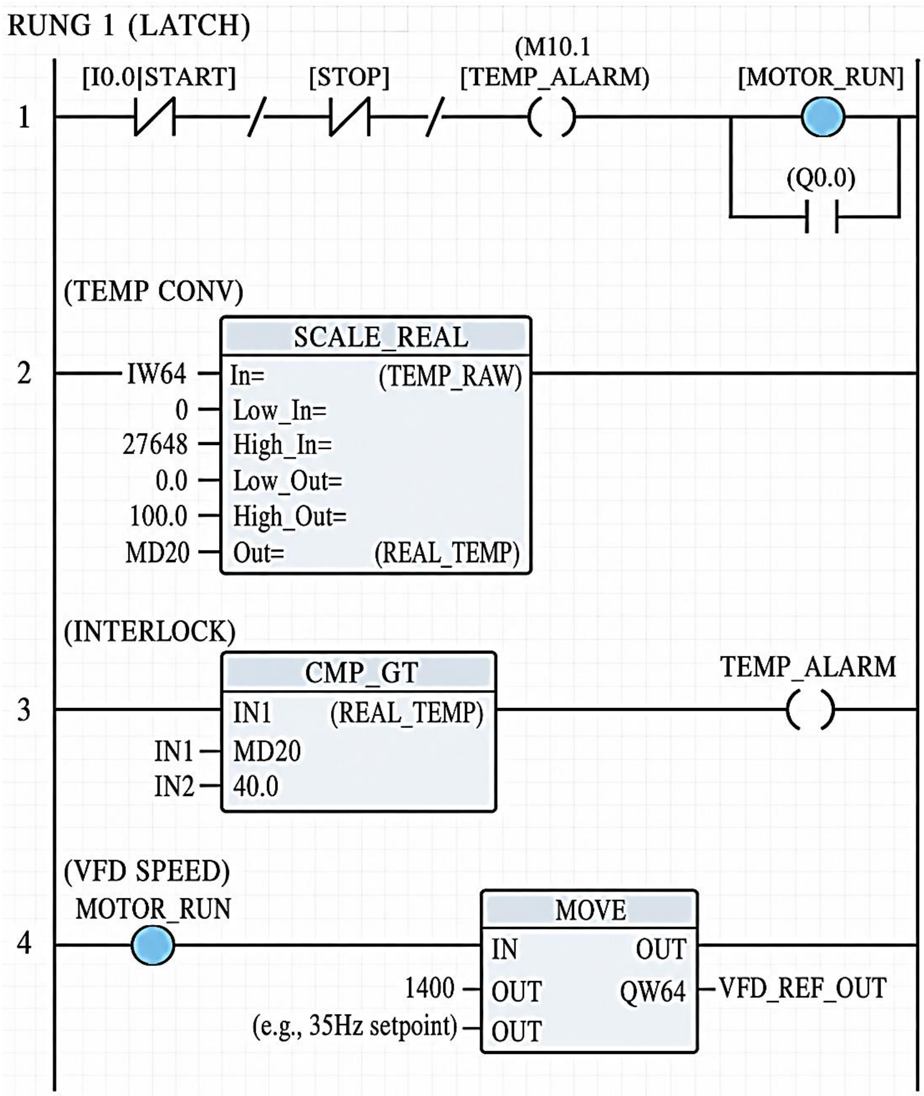

Figure 5. Ladder program.

APPLICATIONS

The proposed method has applications in smart buildings, agriculture, renewable energy, industrial automation, and water pumping systems.

CONCLUSION

The proposed system integrates PLC-based control with IoT monitoring capabilities. This increases dependability, efficiency, and safety. The efficacy of the system was confirmed using experimental data. The proposed IoT-based motor protection and control system using PLC and ESP8266 successfully demonstrates an efficient and intelligent approach for monitoring and protecting single-phase induction motors in modern industrial and domestic applications.

By integrating programmable logic control with IoT communication technology, the system provides reliable real-time monitoring of important motor parameters, such as temperature, operational status, and fault conditions, through a web-based interface. The implementation of automatic thermal protection and shutdown mechanisms significantly improves motor safety and minimizes the risk of overheating and equipment damage.

The developed system also enhances operational efficiency by enabling continuous supervision, remote accessibility, and faster fault identification compared with conventional DOL control methods. Experimental observations confirm that the proposed method reduces the temperature increase and improves the overall energy efficiency, thereby increasing the motor reliability and service life. The use of the ESP8266 NodeMCU offers a low-cost and flexible communication platform, making the system economically suitable for small-scale industries and smart automation environments.

Furthermore, the integration of cloud connectivity and real-time data logging supports predictive maintenance and reduces the need for manual inspection. The proposed design is scalable, energy-efficient, and compatible with the requirements of Industry 4.0. Overall, the system provides a practical and cost-effective solution for advanced motor protection, intelligent control, and remote industrial monitoring.

Future Scope

Future work will include cloud integration, predictive maintenance, and multi-motor system expansion. The future scope of IoT-based motor protection and control systems using PLC and ESP8266 is highly promising owing to the growing demand for smart automation and Industry 4.0 technologies. The system can be further enhanced by integrating artificial intelligence and machine learning algorithms for predictive fault analysis and automated decision making. Advanced sensors can be incorporated to monitor vibration, current harmonics, and power quality for improved condition monitoring. Cloud computing and mobile applications can provide better remote accessibility and real-time analysis. The system can also be expanded for three-phase motor applications, renewable energy systems, and large-scale industrial automation environments.

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