Real-Time Monitoring & Controlling of Single-Phase Induction Motor Using IOT

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Abstract— This work introduces a dual-controller architecture designed for real-time supervision and control of a single-phase induction motor. The system consists of two separate modules: a monitoring unit powered by the Node MCU (ESP8266) and a control unit utilizing the Arduino Uno. The monitoring section collects essential electrical parameters—voltage, current, power, power factor, and frequency—via the PZEM-004T sensor. Additionally, it monitors the motor's temperature using a DHT11 sensor and determines rotational speed (RPM) through an infrared (IR) sensor. These readings are shown on a 16x2 LCD with I2C interface and are also transmitted to the Blynk platform for remote access over Wi-Fi. The control unit is responsible for adjusting the motor's speed using a TRIAC-based AC dimmer, with dimming levels (ranging from 0 to 100%) provided through the Serial Monitor. Directional control is achieved using command characters: 'F' for forward, 'R' for reverse, and 'S' for stop. To safeguard the motor, a 30-second delay is enforced during direction changes to minimize mechanical strain. The developed system offers an effective approach for smart motor management, combining both on-site display and remote control capabilities

Keywords— Induction motor, real-time monitoring, speed control, Arduino Uno, NodeMCU ESP8266, PZEM-004T, DHT11 sensor, IR sensor, AC dimmer, TRIAC, LCD display, Blynk IoT, motor direction control, dual controller system, single-phase motor.

1.INTRODUCTION

Induction motors are widely recognized for their robustness, cost-effectiveness, and maintenance-friendly design, making them indispensable in industrial automation, agricultural machinery, and domestic appliances. However, prolonged and unmonitored usage may result in hazardous conditions such as excessive voltage, current surges, overheating, or imbalanced phases, ultimately compromising motor health and operational reliability. To mitigate such risks, various researchers have developed intelligent condition monitoring systems that ensure safe, efficient, and prolonged operation of these motors. For instance, Khan et al. [1] proposed an IoT-based monitoring solution using ESP32 and the Blynk platform, which enabled real-time data visualization of electrical parameters. Similarly, Patil and Gudadhe [2] integrated smart sensing modules with cloud communication to monitor motor conditions remotely, focusing on predictive maintenance. Rao and Naik [3] employed a Raspberry Pi framework to not only measure critical electrical characteristics but also respond to abnormal behaviors through automated control mechanisms.

Inspired by these developments, the present project proposes a dual-microcontroller-based system combining the capabilities of NodeMCU ESP8266 and Arduino Uno to monitor, control, and protect a single-phase induction motor in real time. The ESP8266 module is responsible for acquiring electrical data such as voltage, current, power, power factor, and frequency through the PZEM-004T sensor, while the temperature and speed (RPM) are measured using a DHT11 sensor and an IR sensor, respectively. This information is displayed on a local 16x2 LCD via I2C interface and simultaneously transmitted to the Blynk IoT platform for real-time remote access over Wi-Fi. This dual visibility—local and cloud-based—allows users to track motor performance from anywhere.

Motor control is handled through the Arduino Uno, which operates a TRIAC-based AC dimmer module to regulate speed based on user input through the serial monitor, with dimming values ranging from 0 to 100%. In addition to speed modulation, the system includes a direction control mechanism via a two-channel relay setup, where serial commands (‘F’ for forward, ‘R’ for reverse, and ‘S’ for stop) define the direction of rotation. To prevent damage caused by immediate direction reversal, a safety delay of

30 seconds is implemented before switching directions. This protection mechanism is critical in reducing wear and tear on mechanical components and ensuring operational safety. The system also features a fault detection logic with dynamically configurable thresholds for parameters like over-voltage, over-current, and temperature, thereby allowing users to tailor protection settings based on specific motor requirements or environmental conditions. Unlike conventional motor management systems that rely on manual inspection or isolated control circuits, this integrated solution offers a comprehensive, automated, and remotely accessible approach to motor management. By combining real-time parameter tracking, remote interface through Blynk, local display, and user-defined safety controls, the system provides a scalable and efficient platform suitable for both academic research and industrial applications. Furthermore, the modular nature of the hardware allows easy upgrades and integration with more advanced analytics or predictive maintenance algorithms in future implementations.

2.SINGLE PHASE INDUCTION MOTOR WORKING PRINCIPLE

A Single-Phase Induction Motor is one of the most commonly used types of AC motors, especially in household and low-power industrial applications. It operates on the principle of electromagnetic induction, where alternating current (AC) supplied to the stator windings produces a pulsating magnetic field. Unlike three-phase motors, single-phase induction motors are not self-starting and require an external mechanism such as a start winding with a capacitor to initiate rotation. Once started, the motor continues to run using the main winding.

The rotor, usually a squirrel-cage type, is placed within the stator and is not electrically connected to any external power source. Instead, it rotates due to the interaction between the rotating magnetic field generated in the stator and the induced current in the rotor bars, in accordance with Faraday's Law of Induction and Lenz's Law. As the stator's magnetic field cuts across the rotor conductors, a current is induced, and a magnetic field is produced in the rotor, which then interacts with the stator field to generate torque and rotation.

Single-phase induction motors are favored for their simple construction, reliability, and low maintenance. However, their efficiency and starting torque are generally lower compared to three-phase motors. These motors are widely used in ceiling fans, pumps, compressors, washing machines, and other domestic or light industrial equipment. The following figure (Fig. 1) illustrates the internal structure of a typical single-phase induction motor.

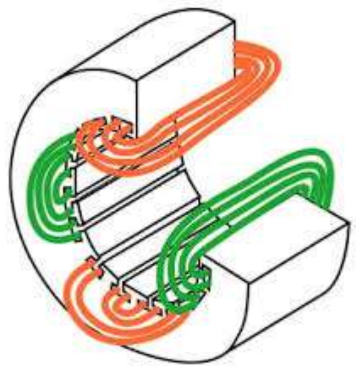
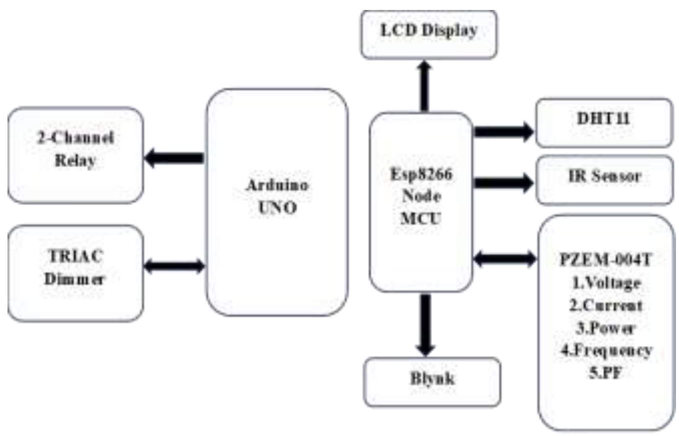


Fig.1 Constructional features of Single phase induction motor.

3.METHODOLOGY FOR REAL-TIME MONITORING AND CONTROL OF SINGLE-PHASE INDUCTION MOTOR USING IOT

This project entails the development of an IoT-based system for the real-time monitoring and control of a single-phase induction motor, integrating both local and remote functionalities. The system employs the ESP8266 microcontroller to collect real-time data on electrical parameters—voltage, current, power, power factor, and frequency—via the PZEM-004T sensor. Additionally, it monitors the motor's temperature using a DHT11 sensor and measures rotational speed (RPM) through an infrared (IR) sensor. The collected data is displayed locally on a 16x2 I2C LCD and transmitted over Wi-Fi to the Blynk IoT platform, enabling remote access and monitoring. For

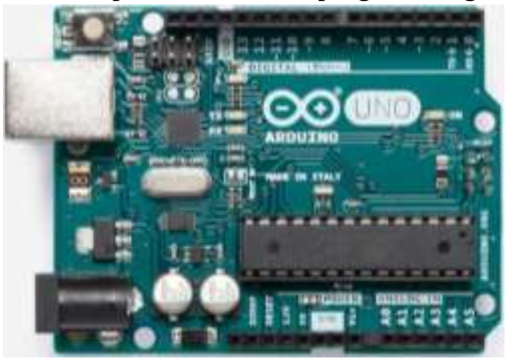


control operations, an Arduino Uno microcontroller manages the motor's speed and direction. Speed regulation is achieved using a TRIAC-based AC dimmer module, allowing adjustments from 0% to 100% via PWM signals. Direction control is facilitated through a two-channel relay module, with commands ('F' for forward, 'R' for reverse, and 'S' for stop) input via the Serial Monitor. To safeguard the motor, a 30-second delay is implemented when switching directions, preventing mechanical stress. The system also incorporates protective measures against over-voltage, over-current, and over-temperature conditions, automatically disconnecting the motor when thresholds are exceeded. This integrated approach ensures efficient, safe, and flexible operation of the induction motor, suitable for various applications.

Fig.2 Block diagram of Monitoring & Controlling

3.1 Arduino Uno board

The Arduino Uno is an open-source microcontroller board based on the ATmega328P microchip, widely used in embedded systems and IoT applications due to its simplicity, affordability, and flexibility. It features 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, USB connection, power jack, and reset button. The board operates at 5V and can be powered through a USB cable or an external adapter. The ease of programming through



the Arduino IDE and its extensive library support make it a popular choice for students, hobbyists, and researchers alike.

Fig.3. Arduino Uno

In the context of motor control and monitoring, the Arduino Uno acts as the central controller that reads data from various sensors, processes the inputs, and executes control actions such as regulating speed or triggering safety mechanisms. Its reliable performance and compatibility with a wide range of modules and sensors make it ideal for developing real-time embedded control systems. The Arduino Uno circuit board has 14 digital input and output pins out of which 6 can be used as PWM outputs and another 6 as analog inputs. It also consists a 16 MHz ceramic resonator, a power jack and USB connection on the circuit board..

3.2 ESP8266 Node MCU:

The ESP8266 is a low-cost Wi-Fi-enabled microcontroller module that has gained popularity for its integration in Internet of Things (IoT) applications. It is designed to offer full TCP/IP stack functionality, enabling microcontrollers to connect to a Wi-Fi network and make simple TCP/IP connections using Hayes-style commands. In many embedded projects, the ESP8266 serves either as a standalone microcontroller or as a communication bridge between a primary microcontroller, such as the Arduino Uno, and the cloud.

Fig.4. ESP8266

With its built-in Wi-Fi capability, GPIO pins, and support for UART, I2C, and SPI protocols, the ESP8266 is capable of both data acquisition and wireless communication. In real-time motor monitoring and control systems, the ESP8266 plays a crucial role in uploading sensor data to cloud platforms, enabling remote access, and receiving control commands. Its compact size, cost-effectiveness, and versatility make it an essential component for implementing wireless control and data logging in smart electrical applications.

3.3 PZEM-004T Sensor:

The PZEM-004T is a compact and reliable energy monitoring sensor widely used in electrical projects for measuring essential parameters of AC power systems. It is capable of accurately measuring voltage, current, active power, energy consumption (kWh), frequency, and power factor.

Fig.5. PZEM-004T Sensor

The sensor communicates via a serial interface, making it easy to integrate with microcontrollers like Arduino and ESP8266. Its built-in voltage and current sensing circuits eliminate the need for external sensors, simplifying circuit design. The PZEM-004T is particularly useful in IoT-based applications, where real-time electrical monitoring is required for safety, efficiency, and automation. In this project, the PZEM-004T plays a crucial role in monitoring the electrical performance of the single-phase induction motor, providing continuous feedback that is used for analysis, control, and protection purposes. Its precise readings contribute significantly to the overall reliability and effectiveness of the motor management system.

3.4 TRIAC Dimmer Module:

The TRIAC dimmer module is an electronic circuit used for controlling the power delivered to AC loads such as lamps, fans, and motors by adjusting the conduction angle of the TRIAC. In this project, the dimmer module is used to regulate the speed of a single-phase induction motor by varying the RMS voltage supplied to it.

Fig.6. TRIAC Dimmer Module

The module works by detecting the zero-crossing points of the AC waveform and triggering the TRIAC at calculated delay intervals to achieve the desired power output. This method of phase angle control allows for smooth and efficient speed regulation. The zero-cross detection (ZVC) input of the module is connected to the microcontroller, which calculates the appropriate delay based on the user’s input or automated control logic. The TRIAC dimmer module plays a vital role in enabling precise motor speed control while maintaining electrical efficiency and system stability.

3.5 Connection Diagram:

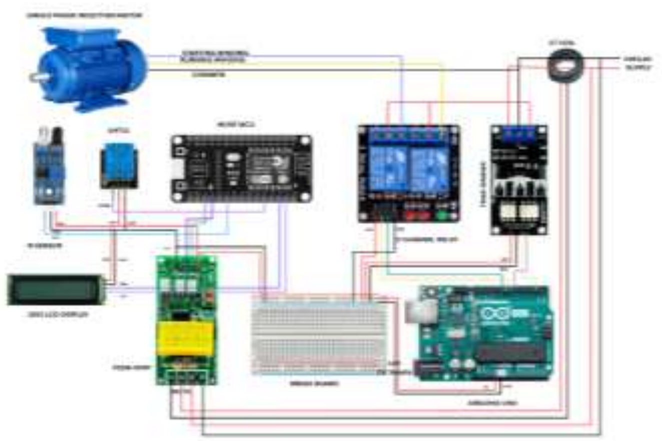


Fig.7 Connection Diagram

4 Results and Discussions

The developed IoT-based system for real-time monitoring and control of a single-phase induction motor was successfully implemented and tested. Utilizing an Arduino Uno microcontroller in conjunction with an ESP8266 Wi-Fi module, the system effectively integrated various sensors to monitor critical motor parameters. The PZEM-004T sensor provided accurate measurements of voltage, current, power, power factor, and frequency. Temperature monitoring was achieved using the DHT11 sensor, while an infrared (IR) sensor facilitated the measurement of the motor's rotational speed (RPM). These real-time readings were displayed locally on a 16x2 I2C LCD and simultaneously transmitted to the Blynk IoT platform, enabling remote monitoring and control via a mobile application.

The system's control capabilities were validated through the successful regulation of motor speed using a TRIAC-based AC dimmer module, which adjusted the phase angle of the AC supply based on user inputs received through the Blynk interface. Direction control was implemented using a two-channel relay module, with appropriate delay logic to prevent relay conflicts and ensure safe operation. The system's protection mechanisms were tested under various fault conditions, including over-voltage, over-current, and over-temperature scenarios. In each case, the system promptly detected the anomaly and activated the relay to disconnect the motor, thereby preventing potential damage.

The integration of dynamic threshold settings allowed users to define specific protection limits, enhancing the system's adaptability to different operational requirements. The successful implementation and testing of the system demonstrate its reliability and effectiveness in providing comprehensive monitoring, control, and protection of a single-phase induction motor. This approach offers significant advantages for industrial, agricultural, and domestic applications where remote monitoring and efficient motor management are essential.

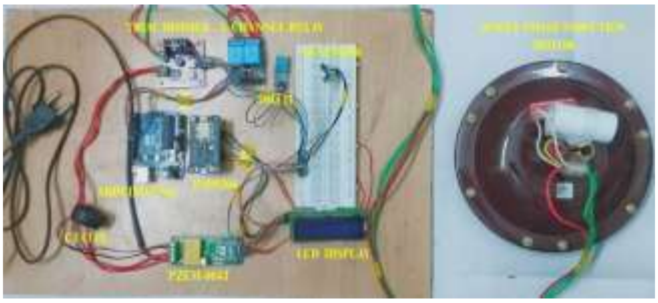


Fig.8 Controlling & Monitoring Hardware model

4.1 Web & Mobile Dashboard:

The proposed system successfully demonstrates a real-time monitoring, controlling, and protection mechanism for a single-phase induction motor using IoT technologies. By integrating various sensors like the PZEM-004T, DHT11, and IR sensor, the system provides accurate measurement of critical parameters including voltage, current, power, frequency, temperature, and motor speed.

Fig.9 Web Dashboard

Fig.10 Mobile Dashboard

5 CONCLUSIONS:

The implementation of an IoT-based system for real-time monitoring and control of a single-phase induction motor has demonstrated significant advancements in operational efficiency and safety. By integrating sensors such as the PZEM-004T for electrical parameters, DHT11 for temperature, and an IR sensor for speed measurement, the system effectively captures and displays critical motor data both locally and remotely via the Blynk IoT platform. The incorporation of a TRIAC-based dimmer module allows for precise speed control, while a two-channel relay facilitates safe direction changes. User-defined threshold settings enhance the system's protective capabilities against over-voltage, over-current, and over-temperature conditions. The web dashboard provides an intuitive interface for users to monitor and control motor operations in real-time, ensuring adaptability across various applications. Overall, the project successfully integrates hardware and software components to deliver a reliable, scalable, and user-friendly solution for intelligent motor management.

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