Journal of Power, Energy, and Control

Research article

IoT-Based Control, Monitoring, and Protection System for 3-Phase Induction Motors in Electric Motorcycles

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https://doi.org/10.62777/pec.v1i2.32

Received: 18 September 2024
Revised: 23 October 2024
Accepted: 28 October 2024
Published: 3 November 2024

Abstract: This study investigates the application of the Internet of Things (IoT) for wireless control and monitoring of a 3-phase electric motor using a smartphone. The system integrates PZEM-004T, DS18B20, and Hall Effect sensors to collect data on voltage, current, temperature, and rotational speed using the NodeMCU ESP8266 microcontroller. Measurements are displayed on an LCD and transmitted to the Blynk server for smartphone access. A comparative method evaluates the accuracy of sensor readings against standard measuring instruments. Results obtained an average percentage error of 0.5% for the R phase voltage, 0.2% for the S phase, and 0.1% for the T phase. Current measurements reveal errors of 5% for the R phase, 10.3% for the S phase, and 11.7% for the T phase. The control system's performance varies with internet speed, with an average delay of 0.99 seconds on a 4G network and 2.51 seconds on 3G. Additionally, the study evaluates three protection mechanisms, demonstrating that the motor stops within 4.03 seconds in the event of a phase failure, while overcurrent and overheating protections activate within 8.47 seconds and 3.64 seconds, respectively. Overall, the findings affirm the viability of IoT in motor monitoring and control, emphasizing accuracy and response times under varying conditions.

Keywords: 3-phase electric motor, Blynk, control, Internet of Things, monitoring, protection system

1. Introduction

Technological advances in electronics are accelerating rapidly, fostering increasingly interconnected and unrestricted communication. The Internet of Things (IoT) facilitates seamless integration into daily human activities, allowing tasks to be performed more practically, effectively, and efficiently [1]. IoT enables continuous connectivity, supporting capabilities like data sharing and remote control [2], [3].

The induction motor is one of the most widely used electric machines in industry, serving as a driving force in production equipment [2], [4], [5]. Given its essential role, induction motors must operate reliably and safely. However, various disturbances can compromise their function and performance, or even cause damage [6], [7]. Disturbances may arise from multiple sources, and identifying them requires analyzing key operational parameters of the motor—such as voltage, current, temperature, and rotational speed—during these disturbances [8], [9], [10].

These parameters can be monitored with a microcontroller. Modern technological developments have focused on automation across many aspects of life, replacing previously manual processes. This shift extends to the monitoring and control of 3-phase induction motors [11], [12]. In many industrial settings, inspections of induction motors still rely on manual methods. Typically, personnel check the electrical instrument panel periodically to record current and voltage readings. Additionally, temperature checks are performed on-site with handheld thermometers, such as thermoguns. These manual processes are susceptible to human error, which can impact data accuracy [13], [14].

To address these issues, this study presents the design of an IoT-based tool for monitoring voltage, current, temperature, and motor speed, using the PZEM-004T sensor. The system includes a protection mechanism and enables remote control via a smartphone running the Blynk application. The tool is managed by a NodeMCU ESP8266 microcontroller focusing on the design of an IoT-based control, monitoring, and protection system for 3-phase induction motors [15], [16].

2. Methods

2.1. System Overview

The system block diagram is shown in Figure 1. When the NodeMCU ESP8266 connects to the internet, the system is prepared to operate via the Blynk application installed on a smartphone. The PZEM-004T R sensor measures the voltage and current in phase R, while the PZEM-004T S and T sensors measure the voltage and current in phases S and T, respectively. The DS18B20 temperature sensor monitors the motor's temperature, starting from the ambient temperature, and tracking increases as the motor operates. Additionally, the Hall Effect sensor reads the motor's rotational speed. These measurements are displayed on an LCD and transmitted to the Blynk application [17], [18].

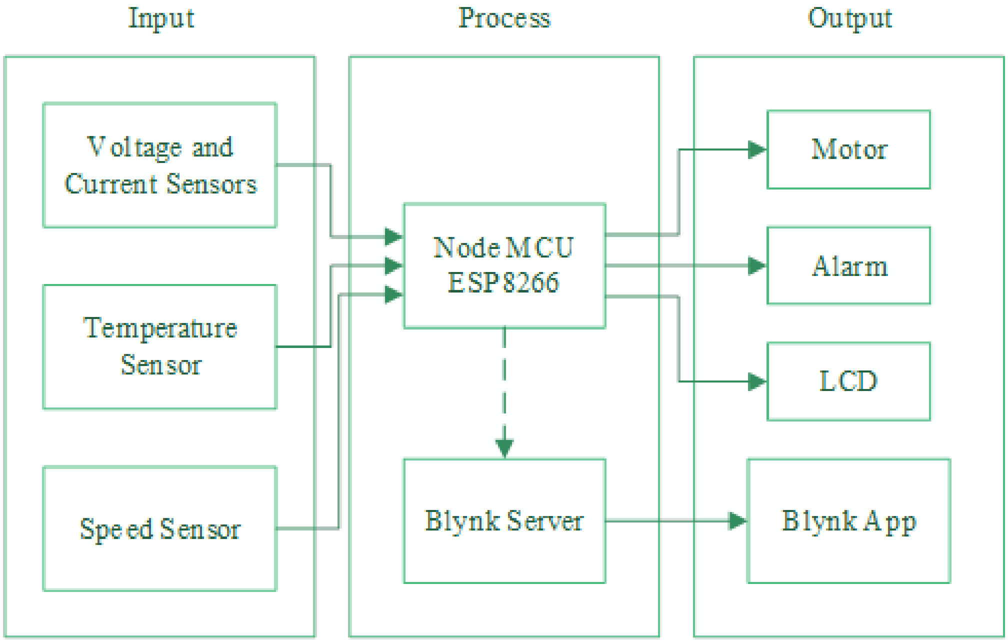


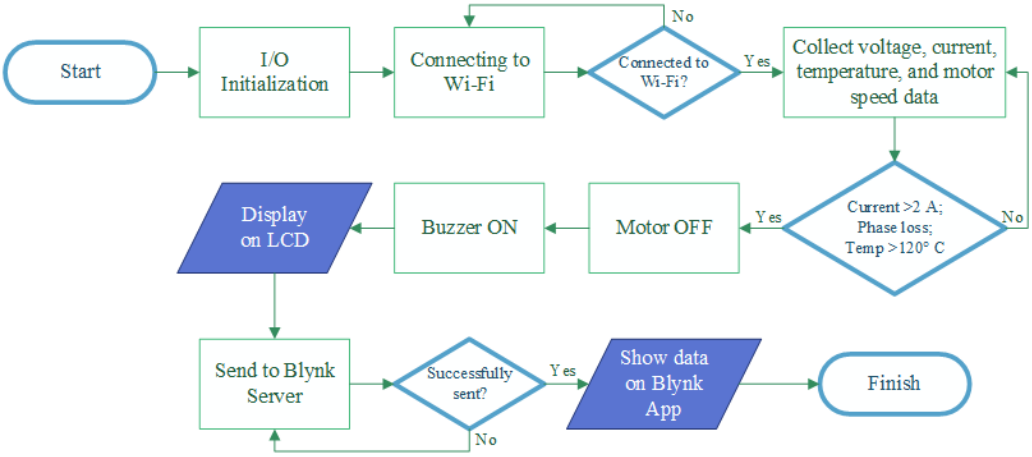
Figure 1. System block diagram.

In the Blynk interface, pressing the ON button activates the SSR, engaging the magnetic contactor and initiating the rotation of the 3-phase induction motor. Pressing the OFF button deactivates the SSR, stopping the motor [19]. If one of the PZEM sensors fails to read voltage, the system detects this as a phase failure, automatically stopping the motor and triggering an alarm. The temperature sensor, attached to the motor body, monitors temperature; if it exceeds a predetermined limit, the system halts motor operation and activates the alarm. The overcurrent protection system is set to engage if the current exceeds 2 Amperes, similarly stopping the system and activating an alarm [11], [20].

2.2. Operational Workflow

The flowchart outlines the system's operational workflow, with each step represented by symbols and directional arrows indicating the sequence of actions. This structured program plan details input and output requirements to ensure accurate data processing and effective information delivery. The flowchart diagrams can be seen in Figure 2.

Figure 2. Arduino UNO ATmega 328p.



The system begins by initializing its input/output components and preparing the hardware for operation. It then attempts to connect to a Wi-Fi network, a prerequisite for transmitting data to the Blynk application. If the Wi-Fi connection is unsuccessful, the system will continue trying to connect until successful. Once connected to Wi-Fi, the system starts collecting real-time data on key parameters, including voltage, current, temperature, and motor speed (RPM). Following data collection, the system checks for any abnormal conditions, such as current exceeding 2 amperes, phase loss in any of the R, S, or T phases, or motor temperature surpassing 120°C. If any of these conditions are met, the system takes protective actions: it shuts down the motor, activates a buzzer to alert users, and displays the issue on an LCD screen.

Assuming no abnormal conditions are detected, the system proceeds to send the collected data to the Blynk server. It verifies whether the data was successfully transmitted; if not, it continues to retry until the transmission is successful. Once the data reaches the server, it is displayed on the Blynk application, allowing remote users to monitor the motor's status. After completing these steps, the system concludes its cycle.

3. Results and Discussion

3.1. Testing of Blynk Application Performance

The purpose of testing the Blynk application is to evaluate its performance in controlling and monitoring the relay systems for two induction motors. This testing includes assessing the response time of the relay control system via the Blynk application, which is installed on a smartphone. The relay control test involves toggling the motors on and off within the application using a 4G and 3G hotspot network provided by Provider X to transmit data commands. The results of the response time tests based on data transmission speed are shown in Table 1 and Table 2.

Table 1. Control system test results using the 4G network.

Motorcycle	Test Iteration	Condition	Delay (seconds)
Motorcycle 1	Test 1	ON	0.66
	Test 2	OFF	2.36
	Test 3	ON	0.93
	Test 4	OFF	0.86
	Test 5	ON	2.52
	Test 6	OFF	0.93
Motorcycle 2	Test 1	ON	0.53
	Test 2	OFF	1.25
	Test 3	ON	0.47
	Test 4	OFF	0.47
	Test 5	ON	0.60
	Test 6	OFF	0.40
	Average		**0.99**

Table 2. Control system test results using the 3G network.

Motorcycle	Test Iteration	Condition	Delay (seconds)
Motorcycle 1	Test 1	ON	3.80
	Test 2	OFF	1.12
	Test 3	ON	5.36
	Test 4	OFF	6.99
	Test 5	ON	1.25
	Test 6	OFF	2.03
Motorcycle 2	Test 1	ON	1.25
	Test 2	OFF	1.97
	Test 3	ON	0.60
	Test 4	OFF	1.52
	Test 5	ON	1.58
	Test 6	OFF	2.73
	Average		**0.99**

The test results reveal that the control system responds effectively under favorable network conditions, while poor internet connectivity introduces delays in data transmission. Using a 4G network, the control system achieved an average delay of 0.99 seconds, whereas the 3G network resulted in a longer average delay of 2.51 seconds. This demonstrates that network connectivity significantly impacts the response time of the control system. The system can be accessed remotely at any time, provided the device is connected to an available Wi-Fi network.

3.2. Evaluation of Motor Protection Systems

The evaluation of motor protection systems includes analyzing the systems' effectiveness in safeguarding a three-phase induction motor when facing issues such as phase failure, overheating, and overcurrent.

3.2.1. Response to Phase Failure

The phase failure protection test was conducted to check if the system could detect a voltage loss in any of the three phases (R, S, or T) and respond accordingly by activating the power breaker. This test was performed by disconnecting power from one of the PZEM-004T sensors at a time to simulate a zero-voltage condition on the corresponding phase. The results of this test are presented in Table 3.

Table 3. Phase failure protection test results.

Motorcycle	Test Iteration	Failed Phase	Phase Voltage (V)			Delay (seconds)	Power Breaker Status
			R	S	T		
Motorcycle 1	Test 1	R	0	226.1	222.5	5,12	Trip
	Test 2	S	221.8	0	221.3	4.17	Trip
	Test 3	T	222.4	224.5	0	1.70	Trip
	Test 4	R	0	225.8	223.1	4.52	Trip
	Test 5	S	222.5	0	221.8	2.84	Trip
	Test 6	T	221.7	224.5	0	2.30	Trip
Motorcycle 2	Test 1	R	0	225.2	223.1	2.76	Trip
	Test 2	S	221.7	0	220.7	3.58	Trip
	Test 3	T	221.3	224.5	0	5.57	Trip
	Test 4	R	0	224.7	223	5.66	Trip
	Test 5	S	222.1	0	222.9	3.89	Trip
	Test 6	T	220.5	224.2	0	6.29	Trip

Based on the test results, the protection system was able to detect phase failures across all trials without any missed detections. However, there was a delay in response times, attributed to the intervals required for sensor readings and data transmission. The longest delay recorded was 6.29 seconds, while the shortest delay was 1.70 seconds. The quality of network connectivity influenced the sensor's reading speed: better connectivity resulted in faster response times.

3.2.2. Response to Overcurrent Conditions

The overcurrent protection test aimed to evaluate the system's response when the current exceeds a preset limit of 2 amperes in any of the three phases. The test was conducted by running the motor with a load of 0.9 kW, causing the current to exceed this threshold. When the sensor detects a current above 2 A, the system is expected to trip. The results, summarized in Table 4, show that the protection system responded appropriately in all six trials, but with varying response times due to sensor reading latency and network connectivity. The highest delay recorded was 10.12 seconds, while the lowest delay was 6.56 seconds, with an average delay of 8.47 seconds. Although response times fluctuated, the system consistently shut down as expected whenever the current limit was exceeded.

Table 4. Overcurrent protection test results. The current limit is set at 2 Ampere.

Motorcycle	Test Iteration	Phase Current (A)			Delay (seconds)	Power Breaker Status
		R	S	T		
Motorcycle 1	Test 1	2.45	2.46	2.19	8.82	Trip
	Test 2	2.47	2.46	2.16	10,12	Trip
	Test 3	2.45	2.48	2.16	7.34	Trip
Motorcycle 2	Test 1	2.45	2.48	2.19	9.70	Trip
	Test 2	2.41	2.45	2.21	6.56	Trip
	Test 3	2.38	2.45	2.22	8.31	Trip

3.2.3. Response to Overheat Conditions

The overheat protection system was tested by conditioning the system to trigger commands to the microcontroller when the temperature exceeds the set point. If the temperature surpasses this threshold, the power breaker is activated. The conditioning involved gradually applying heat to the DS18B20 sensor until it exceeded the predetermined set point based on the motor's insulation class. This study uses an induction motor with insulation class B. According to the NEMA insulation standard for class B insulation, the maximum temperature limit is 130°C. Since the tests were conducted in a room with an ambient temperature of approximately 30°C, the motor insulation temperature limit was set at 120°C. The results of the overheat protection test, based on the NEMA standard, are presented in Table 5.

Table 5. Phase failure protection test results.

Motorcycle	Test Iteration	Conditioning Duration (seconds)	Temperature Reached (°C)	Delay (seconds)	Power Breaker Status
Motorcycle 1	Test 1	6	40.8	2.33	No Trip
	Test 2	8	61.6	2.84	No Trip
	Test 3	10	127.9	2.30	Trip
	Test 4	12	127.9	2.76	Trip
	Test 5	14	127.9	4.52	Trip
Motorcycle 2	Test 1	6	41.2	5.57	No Trip
	Test 2	8	66.7	2.66	No Trip
	Test 3	10	127.9	3.89	Trip
	Test 4	12	127.9	4.29	Trip
	Test 5	14	127.9	5.30	Trip

Based on the overheat protection test results, it can be analyzed that temperature increases varied according to the duration of heating applied to the sensor. According to the NEMA standard with a temperature limit of 120°C, the system detected overheating and disconnected power after heating the sensor for 10 seconds, with an average delay of 3.64 seconds. The DS18B20 temperature sensor proved to be highly sensitive; occasional shocks, errors, or voltage losses may cause it to read a temperature of 127°C, indicating system malfunction.

4. Conclusion

Based on the obtained results, it can be concluded that the design and implementation of a control, monitoring, and protection system for two three-phase induction motors, integrated with IoT, effectively monitors voltage, current, temperature, and speed in real-time. The system's performance is notably influenced by the strength of the personal hotspot signal. The wireless control system for the two motors operates reliably; in testing, twelve trials on 4G and 3G personal hotspot networks showed an average delay of 0.99 seconds on 4G and 2.51 seconds on 3G, indicating that system responsiveness is directly linked to signal quality. Additionally, the motor protection system functions as expected, providing effective phase failure, overcurrent, and overheat protection. From our tests, the average delay was 4.03 seconds for phase failure protection, 8.47 seconds for overcurrent protection, and 3.64 seconds for overheat protection, with some variability in delay due to sensor reading speeds. Overall, the system demonstrates reliable control and protection capabilities for induction motors within the tested network conditions.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflicts of interest.

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