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DEVELOPMENT OF EARLY WARNING SYSTEM FOR 3-PHASE ELECTRIC MOTOR MALFUNCTION DETECTION BASED ON LORA

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ABSTRACT

This study aimed to develop an early warning system for detecting malfunctions in three-phase electric motors using a LoRa-based microcontroller. Three-phase electric motors are vital components in industry, and their failure can cause significant downtime and financial losses. This system was designed to improve operational reliability and efficiency through remote monitoring and early detection of potential failures. Various sensors, including current, voltage, temperature, and RPM sensors, was installed on the motor to monitor its operational conditions. The collected data was sent via the LoRa network to the processing unit for further analysis and early warning. The study used Research and Development (R&D) approach with a prototyping development model, which included gathering requirements, designing, prototyping, and evaluating the system. Each stage was designed to ensure that the developed system can meet the expected operational and functional needs. It is expected that this system can prevent greater damage, reduce maintenance costs, and increase overall industrial productivity.

Keywords: Early Warning System; LoRa; 3 Phase Electric Motor.

1. Introduction

Three-phase electric motors are essential components in various industrial applications, functioning as prime movers in mechanical systems. The reliability and operational efficiency of these motors are crucial, considering that damage to electric motors can result in significant downtime and substantial financial losses for companies. Electric motors contribute about 70% of the total energy consumption in the industrial sector [1], so optimizing electric motor performance is a top priority.

Electric motor failures are often caused by several factors, such as overcurrent, overheating, and mechanical wear, which if not handled properly can lead to detrimental consequences. In this context, the implementation of a proactive maintenance system becomes very important. One approach that can be applied is the development of an early warning system (EWS) that is able to detect malfunctions in electric motors before damage occurs. This system is designed to improve operational reliability and efficiency through real-time monitoring of motor conditions. By applying early detection of potential damage, companies can take necessary preventive measures, reducing the risk of further damage and unexpected maintenance costs.

LoRa (Long Range) technology offers an efficient wireless communication solution for remote monitoring systems. LoRa enables long-distance data transmission with low power consumption, making it optimal for industrial applications that require continuous monitoring [2]. Integration of a LoRa-based microcontroller into an early warning system enables data collection from various sensors mounted on an electric motor, including current, voltage, temperature, and RPM (Revolutions Per Minute) sensors. The collected data will be sent via the LoRa network for further analysis and early warning to operators if any anomalies are detected. The research used a Research and Development (R&D) approach with a prototyping development model. This model was deemed the most suitable candidate owing to its demonstrated proficiency in expeditiously identifying and rectifying errors, as well as provide better feedback during the development process.

The research methodology comprised the stages of requirement elicitation, system design, prototyping, testing, and system evaluation. Each stage was designed to ensure that the developed system can meet the expected operational and functional requirements. It was projected that the early warning system resulting from this research will serve to prevent substantial damage to three-phase electric motors, diminish maintenance costs, and improve overall industrial productivity. This research contributes to the development of monitoring and detection technology and provides valuable references for further research in the same field. By applying the latest technology and systematic methodology, this research aimed to create effective and efficient solutions in electric motor maintenance management, which will ultimately improve industrial competitiveness.

2. Materials and Procedures

a. System Designing and Component Procurement

The design process commenced with the careful selection of components to guarantee optimal system performance. A LoRa-based microcontroller was selected due to its superior long-range, low-power wireless communication capabilities. The electric motor was instrumented with current, voltage, temperature, and RPM sensors to facilitate real-time monitoring of its operational parameters. The selection of these sensors aimed to measure important variables that can indicate potential damage to the motor, such as overheating and overcurrent.

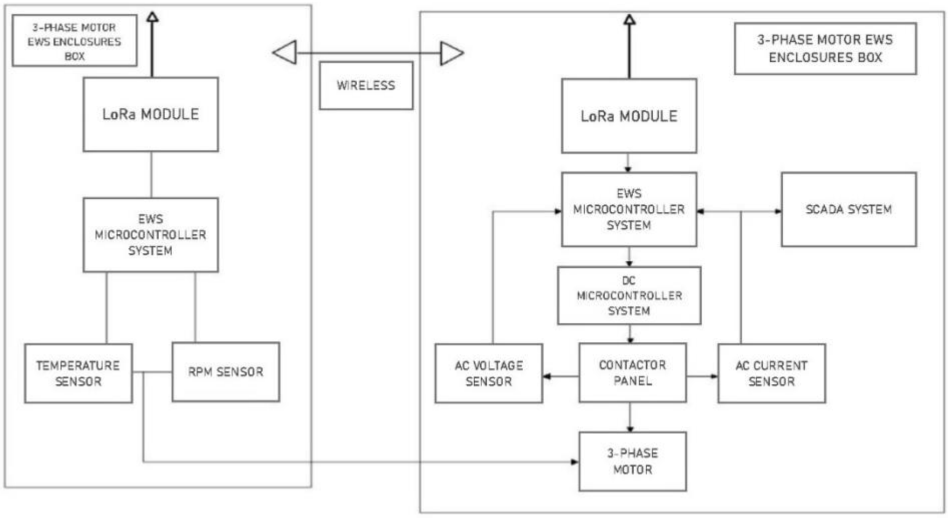

Figure 1. Device Design

b. Research Procedures

The experimental procedure involved interfacing relevant sensors with the microcontroller, which was subsequently configured for real-time data collection. Real-time sensor data was wirelessly transmitted to the data center via the LoRa network for in-depth analysis. Concurrently, all measurement result and motor conditions during the testing phase were meticulously documented.

Data analysis was performed using appropriate statistical methods to evaluate the system's accuracy and reliability. Following data acquisition, conducted a thorough analysis to quantify the measurement error associated with each sensor. This test aimed to evaluate the effectiveness of the early warning system in detecting malfunctions in electric motors. Data collection was conducted systematically, ensuring that each stage of the experimental process was comprehensively documented. It facilitated a more comprehensive assessment and verification of the experimental findings.

Figure 2. EWS Measurement

c. Data Analysis and Data Interpretation

The collected data was analyzed to identify patterns and anomalies that may indicate a malfunction. The analytical findings indicated that the early warning system is capable of effectively identifying anomalous conditions, such as temperature elevations surpassing established parameters. The application of this system demonstrates the potential to mitigate downtime and unexpected maintenance costs through early detection of potential damage.

Each experimental procedure was specifically designed to quantify variables influencing electric motor performance. Current and voltage data were collected to assess the risk of overload. Motor temperature was measured to assess the risk of overheating, and rotational speed (RPM) was monitored to confirm operation within the specified range.

3. Results

The following information was derived from data measurements conducted on three-phase electric motors.

Table 1. Current Measurement Results

No	Time (Minutes)	Current Sensor (A)	Amperemeter R-S-T (A)	Current Error (%)	EWS Operational Status	Resistance Load (W)
1	0	5.0	5.1 R	2.0	Normal	1100
2	1	6.5	6.4 S	1.5	Normal	1500
3	2	8.0	8.24 T	3.0	Normal	1900
4	3	9.5	9.4 R	1.1	Normal	2300
5	4	11.0	10.9 S	0.9	Not Normal	2400
6	5	12.5	12.3 T	1.6	Not Normal	2500

Table 2. Voltage Measurement Results

No	Time (Minutes)	Voltage Sensor (V)	Voltmeter R-S-T (V)	Voltage Error (%)	EWS Operational Status	Resistance Load (W)
1	0	234	231 R	1.30	Normal	1100
2	1	231	227 S	1.76	Normal	1500
3	2	228	224 T	1.79	Normal	1900
4	3	223	219 R	1.83	Normal	2300
5	4	192	190 S	1.05	Not Normal	2400
6	5	187	189 T	1.06	Not Normal	2500

Table 3. Temperature Measurement Results

No	Time (Minutes)	Temperature Sensor (°C)	Thermometer (°C)	Temperature Error (%)	Operational Status	Power Resistance (W)
1	0	60.7	59.5	2.02	Normal	1100
2	1	63.4	62.2	1.93	Normal	1500
3	2	67.0	65.5	2.29	Normal	1900
4	3	72.0	70.2	2.56	Normal	2300
5	4	76.9	74.8	2.81	Not Normal	2400
6	5	81.8	79.5	2.89	Not Normal	2500
7	6	80	79.5	0.63	Not Normal	1100

Table 3. RPM Measurement Results

No	Time (Minutes)	RPM Sensor (RPM)	Tachometer (RPM)	RPM Error (%)	Operational Status	Power Resistance (W)
1	0	1535	1505	2.00	Normal	1100
2	1	1635	1595	2.51	Normal	1500
3	2	1750	1705	2.64	Normal	1900
4	3	1860	1795	3.62	Normal	2300
5	4	1970	1905	3.41	Not Normal	2400
6	5	2075	1995	4.00	Not Normal	2500

Table 3. LoRa Measurement Results

No	LoRa Communication Distance (m)	Operational Status	EWS Status
1	10	Normal	Active
2	12	Normal	Active
3	14	Normal	Active
4	15	Normal	Active
5	17	Not Normal	Inactive
6	18	Not Normal	Inactive

a. Instrumentation Error Equation

To ensure data integrity, each sensor's data was subjected to error analysis using the following equation:

1) Percentage of Temperature Sensor Errors on Tools

The test was conducted to determine the temperature comparison in the use of tools, especially thermometers and temperature sensors. The equation used to determine the accuracy of thermometer measurements with temperature sensors is as follows:

$$Error = \frac{\text{Reading value deviancy}}{\text{Thermometer value}} \times 100\% \quad [3]$$

2) Percentage of AC Voltage and Current Sensor Error

Percentage error analysis of AC voltage and current sensors is a crucial step in evaluating system performance. Measurement errors can affect the accuracy of the data obtained, so it is important to calculate the deviation between the value measured by the sensor and the reference value of the standard measuring instrument. The analytical results provided the necessary data for optimal calibration.

$$Error = \frac{(\text{Design measurement} - \text{Multimeter measurement})}{\text{Multimeter measurement}} \times 100\% \quad [4]$$

3) Percentage of RPM Sensor Error on Tools

The RPM sensor error percentage represented the relative deviation of the RPM value measured by the sensor to the reference RPM value from the tachometer. The calculation of error percentage facilitated an assessment of the sensor's precision in determining rotational speed.

$$Error = \frac{\text{RPM Sensor} - \text{RPM Tachometer}}{\text{RPM Tachometer}} \text{ X } 100\% \quad [5]$$

4. Discussion

A comprehensive analysis of the EWS performance on the 3-phase electric motor can be conducted based on the measurement results presented in five tables. A five-minute observation period was conducted to monitor current, voltage, temperature, RPM, and LoRa communication distance under resistive loads ranging from 1100W to 2500W. Throughout the measurement period, a consistent trend was evident in all parameters. The electric current exhibited a gradual increase from 5.0 A to 12.5 A, while the voltage displayed a corresponding decrease from 234 V to 187 V. As expected, the observed increase in load led to a commensurate increase in current draw and a decrease in voltage, in accordance with Ohm's Law [6]. Simultaneously, the generator temperature experienced an increase from 60.7°C to 81.8°C. This rise in temperature is a direct consequence of the increased electrical load, which necessitated a corresponding increase in electric current, thereby elevating the thermal energy dissipation within the three-phase electric motor [7]. A corresponding increase in generator RPM, from 1535 to 2075 RPM, was observed as the three-phase electric motor adjusted its output to counteract the escalating load and preserve the system's electrical frequency.

The EWS system demonstrated satisfactory sensor performance. Measurement errors for current, voltage, and temperature remained within a 3% margin, indicating sufficient precision for effective monitoring. The RPM sensor showed a slightly higher error variation, reaching 4%, but still within acceptable limits for this application. The critical point in generator operation was seen at the 4th and 5th minutes, where the operational status changed to "Not Normal" for all measured parameters. The system transitioned to a failure state when the resistive load reached 2400 W and 2500 W, respectively. This critical state was accompanied by a significant voltage drop from 223 V to 192 V, a temperature increased to 76.9 °C and 81.8 °C, and an RPM increased to 1970 RPM and 2075 RPM. This condition indicated that the safe operational limit of the system is around 2300W. LoRa communication distance measurement showed that the EWS system can operate normally up to a distance of 15 meters. At a distance of 17 meters and 18 meters, the operational status changed to "Not Normal" and the EWS was inactive, indicating the effective limit of LoRa communication in this system.

5. Conclusion

The EWS system sensors demonstrated high precision, exhibiting minimal measurement deviation. The system effectively identified and signaled anomalous operating conditions when critical parameters are reached. The 3-phase electric motor system had a safe operating limit at a load of around 2300W. Exceeding this limit caused performance degradation and potential operational risks. The LoRa communication system was effective up to a distance of 15 meters, which is sufficient for monitoring generators in a limited working area.

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