Design and Implementation of a Microcontroller-Based AC Current and Voltage Monitoring System

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Abstract

Reliable monitoring of electrical parameters is essential to ensure safe and efficient operation of industrial power systems. In industrial environments, manual measurement of electrical parameters such as voltage and current is often time-consuming and lacks real-time capabilities, which may increase the risk of undetected overloads and equipment failure. This study presents the design and implementation of a microcontroller-based AC current and voltage monitoring system developed as part of an industrial internship program at PT Hume Sakti Indonesia, a precast concrete manufacturing company. The proposed system utilises an ESP8266 microcontroller as the main processing unit, combined with an SCT-013 current sensor and a ZMPT101B voltage sensor to measure AC electrical parameters in real time. The acquired sensor data are processed to obtain effective RMS values of current and voltage, which are then displayed on a 16×2 LCD module using I²C communication. The system is powered by a portable Li-ion battery supported by a charging and voltage regulation module. Experimental testing results demonstrate that the developed prototype is capable of measuring AC current and voltage reliably under different load conditions. The system provides stable readings, clear visualisation, and safe non-invasive measurement, making it suitable as a low-cost monitoring tool for electrical maintenance applications. The proposed system contributes to improving operational awareness, preventive maintenance, and electrical safety in industrial environments.

Keywords: *AC monitoring, current sensor, voltage sensor, ESP8266, industrial electrical maintenance.*

I. INTRODUCTION

Industrial electrical systems play a critical role in supporting manufacturing processes, particularly in facilities that rely on heavy machinery and continuous power operation. Electrical parameters such as current and voltage must be maintained within safe limits to prevent equipment damage, production downtime, and safety hazards [1], [2]. However, in many industrial settings, electrical parameter monitoring is still performed manually using conventional measuring instruments, which limits real-time observation and early fault detection [3], [4].

The integration of microcontroller-based monitoring systems offers an effective solution to overcome these limitations. Embedded systems equipped with electrical sensors enable continuous measurement, data processing, and real-time visualisation of electrical conditions. Such systems support preventive maintenance strategies and improve operational reliability [5].

PT Hume Sakti Indonesia is a national company engaged in precast concrete manufacturing, where various electrical machines such as motors, mixers, hoist cranes, and control panels operate continuously. Electrical maintenance activities in this environment require accurate monitoring of current and voltage to ensure safe and efficient system performance. Therefore, this study focuses on the development of a simple and portable AC current and voltage monitoring prototype based on a microcontroller platform, designed to support electrical maintenance activities in industrial environments.

II. THEORY

A. AC Electrical Parameters in Industrial Systems

Alternating current (AC) electrical systems are widely used in industrial environments due to their efficiency in power transmission and compatibility with high-power electrical equipment [6], [7]. Key electrical parameters such as voltage and current play a crucial role in determining system performance, power quality, and operational safety. Voltage represents the electrical potential difference that drives current flow, while current reflects the amount of electrical charge flowing through a conductor.

In industrial applications, monitoring AC voltage and current is essential to detect abnormal operating conditions such as overload, undervoltage, overcurrent, and unbalanced loads [2], [8]. Continuous deviation of these parameters from their

nominal values may lead to excessive power losses, equipment overheating, insulation degradation, and reduced system reliability. Therefore, accurate and continuous monitoring of AC electrical parameters is a fundamental requirement for effective industrial electrical maintenance

B. RMS Measurement of AC Voltage and Current

AC electrical signals vary sinusoidally with time, making direct interpretation of instantaneous values impractical for power analysis. To represent the effective value of an AC signal, the root mean square (RMS) method is commonly used [8]. RMS values provide an equivalent DC value that produces the same heating effect in a resistive load.

For a sinusoidal AC waveform, the RMS value of voltage or current is calculated using the square root of the mean of the squared instantaneous values over one complete cycle. RMS measurement is widely adopted in industrial monitoring systems because it accurately reflects actual electrical power consumption and load conditions. In this study, RMS voltage and current values are used as the primary monitoring parameters to evaluate electrical system performance [3].

C. Microcontroller-Based Monitoring Systems

Microcontroller-based monitoring systems have become increasingly popular in industrial and academic applications due to their flexibility, compact size, and cost efficiency [5], [9]. A microcontroller integrates a processor, memory, and input/output peripherals into a single chip, enabling real-time data acquisition and processing.

The ESP8266 microcontroller is widely used in embedded systems because of its adequate processing capability, low power consumption, and built-in Wi-Fi module. These features allow the ESP8266 to perform data processing tasks while also supporting future expansion toward Internet of Things (IoT) applications. In electrical monitoring systems, microcontrollers serve as the core unit that processes sensor data, performs calculations, and displays measurement results.

D. SCT-013 Current Sensor

The SCT-013 is a non-invasive current transformer (CT) sensor designed to measure AC current without direct electrical contact [9], [10]. This sensor operates by detecting the magnetic field generated by current flowing through a conductor, thereby inducing a proportional current in the secondary coil.

The non-invasive nature of the SCT-013 sensor offers significant advantages in industrial environments, including improved safety, ease of installation, and minimal disruption to existing electrical systems. The sensor is suitable for measuring moderate to high AC currents and is commonly used in energy monitoring and electrical maintenance applications. However, accurate measurement requires proper calibration and burden resistor configuration to ensure linearity and precision[11], [12]

E. ZMPT101B Voltage Sensor

The ZMPT101B voltage sensor is a low-cost module designed for AC voltage measurement. It employs a precision voltage transformer to step down high-voltage AC signals into safe, low-level analog signals that can be processed by a microcontroller's analog-to-digital converter (ADC) [11], [13].

This sensor provides electrical isolation between the high-voltage input and low-voltage control circuit, enhancing system safety. The ZMPT101B is widely used in voltage monitoring applications due to its simplicity and adequate accuracy for non-critical industrial measurements. Calibration is required to minimize measurement error caused by component tolerances and signal noise [3], [10], [13].

F. Signal Conditioning and Data Processing\

Signal conditioning is a critical process in microcontroller-based measurement systems. It ensures that sensor output signals are compatible with the input requirements of the microcontroller's ADC. In AC monitoring systems, signal conditioning may involve scaling, offset adjustment, filtering, and noise reduction.

After signal conditioning, the microcontroller processes the acquired data to compute RMS values of voltage and current. Digital filtering techniques may also be applied to reduce noise and improve measurement stability. Proper data processing ensures that the displayed values accurately represent actual electrical conditions [4], [8].

G. LCD Display for Real-Time Visualization

Real-time visualization of measurement results is essential for practical monitoring applications. Liquid Crystal Display (LCD) modules are commonly used due to their low power consumption, readability, and ease of integration with microcontrollers [14]. A 16×2 LCD display provides sufficient resolution to display voltage and current values simultaneously.

In industrial maintenance applications, local visualization allows technicians to observe electrical parameters directly without additional

measurement tools. This feature enhances operational efficiency and supports quick decision-making during inspection and troubleshooting activities.

H. Application of Electrical Monitoring in Industrial Maintenance

Electrical parameter monitoring plays a vital role in preventive maintenance strategies. By continuously observing voltage and current levels, maintenance personnel can identify early signs of abnormal operation and take corrective actions before failures occur. Microcontroller-based monitoring systems offer a practical solution for implementing such strategies at a relatively low cost.

In industrial environments such as PT Hume Sakti Indonesia, where electrical equipment operates continuously, the availability of portable and reliable monitoring tools improves safety, reduces downtime, and enhances overall system reliability. Therefore, the development of microcontroller-based AC monitoring systems contributes directly to sustainable industrial operation and maintenance efficiency.

III. METHOD

A. Field Observation

Field observations were conducted during an industrial internship at PT Hume Sakti Indonesia, a company engaged in precast concrete manufacturing. The observations aimed to identify electrical system conditions, maintenance practices, and challenges related to monitoring electrical parameters in industrial equipment. Several electrical panels and machines were observed operating continuously under varying load conditions. It was found that measurements of AC voltage and current were still performed manually using conventional measuring instruments, which limited real-time monitoring and early detection of abnormal electrical conditions. These findings indicated the need for a portable and real-time electrical monitoring system to support maintenance activities.

B. System Design

The AC current and voltage monitoring system was designed as an integrated hardware configuration capable of measuring electrical parameters in real time and presenting the results through a local display. The system architecture, as shown in Figure 1, consists of an ESP8266 microcontroller as the main processing unit, an SCT-013 non-invasive current sensor for AC current measurement, a ZMPT101B voltage sensor for AC voltage measurement, and a 16×2 LCD display for real-time visualisation.

The SCT-013 current sensor is clamped around the load conductor to measure the magnetic field generated by the flowing current without direct electrical contact, ensuring measurement safety. The ZMPT101B voltage sensor is connected in parallel with the AC source to scale down the high-voltage signal into a low-level analog signal suitable for the microcontroller's analog-to-digital converter. Both sensors provide analog output signals that are processed by the ESP8266.

The ESP8266 reads the sensor signals continuously and performs data processing to calculate the effective root mean square (RMS) values of current and voltage. These RMS values represent the actual operating conditions of the electrical system and are updated in real time. The calculated values are displayed on the 16×2 LCD using an I²C communication interface, which reduces wiring complexity and improves system reliability.

The system is powered by a portable power supply, allowing flexible deployment during electrical inspection and maintenance activities. This system design emphasises portability, safety, and ease of implementation, making it suitable as a practical monitoring tool for industrial electrical maintenance at PT Hume Sakti Indonesia.



Figure 1. hardware configuration of the Otomatic Fan Cooler

C. Hardware Assembly and Software Development

Hardware assembly involved connecting the SCT-013 current sensor and the ZMPT101B voltage sensor to the ESP8266 microcontroller according to the designed circuit configuration. Signal conditioning components were implemented to ensure that sensor outputs were compatible with the microcontroller's analog-to-digital converter. The LCD display was connected using the I²C communication interface to reduce wiring complexity.

Software development was carried out using the Arduino IDE. The program was designed to acquire sensor data, perform RMS calculations for

voltage and current, and display the processed values on the LCD. Calibration routines were applied to improve measurement accuracy and stability. The software operates continuously to provide real-time monitoring without interruption.

D. System Testing

System testing was conducted under various load conditions to evaluate measurement accuracy, system stability, and response behavior. Tests were performed using different electrical devices commonly found in the industrial environment. The measured voltage and current values were observed for consistency and reliability during continuous operation. The testing results were used to assess the system's suitability as a practical tool for electrical maintenance and monitoring in industrial applications.

IV. RESULTS AND DISCUSSION

A. Implementation Results

The AC current and voltage monitoring system was successfully implemented using an ESP8266-based control unit, an SCT-013 current sensor, a ZMPT101B voltage sensor, and a 16×2 LCD display. The system was tested under various electrical load conditions to evaluate its operational performance and measurement reliability. The microcontroller processed sensor readings effectively and displayed the measured voltage and current values in real time through the LCD interface.

The system operates by continuously acquiring analog signals from the SCT-013 current sensor and the ZMPT101B voltage sensor connected to the monitored electrical line. The collected data are processed by the ESP8266 microcontroller to calculate the effective root mean square (RMS) values of current and voltage. These values are used to determine the operating condition of the electrical system. The real-time measurement results are then displayed on the LCD, providing clear and direct information for electrical monitoring and maintenance purposes. This implementation demonstrates a low-cost and practical solution for real-time electrical parameter monitoring and preventive maintenance in industrial environments [2], [9], [15].

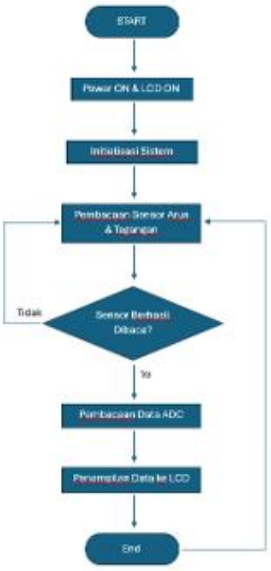


Figure 2. Operational workflow of the AC current and voltage monitoring system

This figure illustrates the operational workflow of the AC current and voltage monitoring system developed in this study. The process begins when the system is powered on, and the LCD display is initialised. The ESP8266 microcontroller then reads analog input data from the current and voltage sensors. The acquired sensor signals are processed to calculate RMS values of current and voltage. The calculated values are continuously displayed on the LCD, allowing real-time observation of electrical conditions. This process runs continuously to ensure stable and uninterrupted monitoring of AC electrical parameters during system operation.

B. Monitoring Results

The system was tested under normal operating conditions to evaluate the accuracy of AC voltage measurement and the stability of the monitoring system. Measurements were taken repeatedly to ensure consistency and reliability of the voltage readings displayed on the LCD. The results show that the system is capable of measuring AC voltage accurately and presenting stable values in real time.



Figure 3. LCD display showing real-time AC voltage

measurement.

This figure shows the information displayed on the LCD, which represents the real-time AC voltage value measured by the ZMPT101B voltage sensor and processed by the ESP8266 microcontroller. The displayed voltage value of approximately 219.34 V indicates normal operating conditions of the electrical system. This result confirms that the voltage sensor and microcontroller function correctly in detecting and processing AC voltage signals, enabling reliable real-time monitoring for electrical inspection and preventive mai



Figure 4. LCD display showing real-time AC current (Irms) measurement
(Source: Author's implementation)

This figure shows the information displayed on the LCD, which represents the real-time AC current value measured by the SCT-013 current sensor and processed by the ESP8266 microcontroller. The displayed current value of approximately 0.023 A (Irms) indicates a low-load operating condition of the electrical system. This result confirms that the current sensor and microcontroller function properly in detecting and processing AC current signals, enabling reliable real-time current monitoring for electrical inspection and preventive maintenance applications.

Table I.
Teleprotection Monitoring Parameters and Alarm Configuration

No	Testing Scenario	Expected Result	Actual Result	Status
1	System Powered On	LCD turns on and the system enters the main display	LCD turns on and displays the main menu	Succesful
2	Voltage measurement without load	Measured voltage value is close to the utility grid voltage	Voltage reading is stable and close to the reference value	Succesful
3	Current measurement without load	Measured current value is close to 0 A	Current reading is very low (close to 0 A)	Succesful
	Voltage measurement	Voltage value decreases	Voltage variation is	Succesful
4	with test load	or changes according to load conditions	detected according to load conditions	
5	Current measurement with test load	Current value increases according to load power	Increase in current is detected according to load variation	Succesful
6	Data display on LCD	Voltage and current values are displayed clearly and readable	Data are displayed clearly and easy to read	Succesful
7	Sensor reading stability	Data do not fluctuate excessively	Readings are relatively stable after calibration	Succesful
8	Sensor reading stability	System operates without external power supply	System operates normally using battery power	Succesful

Table 1 summarizes the results of system testing conducted to evaluate the performance and reliability of the AC current and voltage monitoring system. The test results indicate that all defined testing scenarios were completed successfully. The system was able to initialize properly, as evidenced by the LCD display turning on and entering the main menu upon power-up. Voltage and current measurements without load produced values close to the expected reference, confirming correct sensor operation under no-load conditions.

When tested under load conditions, the system successfully detected variations in voltage and corresponding increases in current, demonstrating its ability to respond accurately to changes in electrical load. The voltage and current values were displayed clearly on the LCD, ensuring good readability for maintenance personnel. In addition, sensor readings remained relatively stable after calibration, indicating reliable measurement performance with minimal fluctuation.

The system also operated normally using a Li-ion battery without an external power supply, confirming its portability and suitability for field use during electrical inspection and maintenance activities. Overall, the testing results confirm that the proposed system performs reliably and meets the expected functional requirements for real-time electrical parameter monitoring in industrial environments.

V. CONCLUSION

This study has successfully designed and implemented a microcontroller-based AC current and voltage monitoring system intended to support industrial electrical maintenance activities. The proposed system utilises an ESP8266 microcontroller in combination with an SCT-013 non-invasive current sensor and a ZMPT101B voltage sensor to perform real-time measurement of electrical parameters. Root mean square (RMS) values of current and voltage are processed and displayed locally using a 16×2 LCD module, providing clear and immediate visualisation for maintenance personnel.

Experimental results demonstrate that the system is capable of measuring AC voltage and current reliably under various load conditions. The use of non-invasive current sensing enhances operational safety, while the portable Li-ion battery-based power supply allows flexible deployment in industrial environments. The system shows stable performance during steady-state operation and is suitable for single-point electrical parameter monitoring tasks.

Despite its effectiveness, the proposed system has several limitations. Measurement accuracy is influenced by sensor calibration and analog-to-digital converter resolution, and the system does not include features such as data logging or remote monitoring. Future work may focus on improving measurement accuracy, integrating data storage, and expanding the system to support multi-point monitoring.

Overall, the developed monitoring system provides a practical, low-cost, and portable solution for real-time AC current and voltage monitoring, and serves as a valuable foundation for applied research and practical implementation in industrial electrical maintenance.

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