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Real time data monitoring in smart grid

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Abstract—The Real-Time Grid Monitoring System is an IoT-based project designed to continuously monitor and control electrical parameters in a power distribution setup. The system utilizes a NodeMCU (ESP8266) microcontroller for real-time data acquisition, processing, and wireless communication. A potentiometer is used to simulate and monitor voltage variations, while an LM324 operational amplifier serves as a crucial component for detecting short-circuit and open-circuit faults in the grid. In the event of such abnormalities, or when undervoltage conditions occur, a buzzer is activated to provide an immediate alert.The system incorporates two relays, enabling remote switching of connected loads through an IoT-based web interface, allowing users to manually control devices from anywhere using a smartphone or computer. Additionally, a 16×2 LCD display presents real-time voltage status, load condition, and fault information locally. This integration of hardware monitoring and IoT control ensures improved reliability, safety, and user convenience. The proposed system provides a cost-effective and scalable approach to enhance smart grid management, offering real-time visibility and quick response to faults. It demonstrates the potential of IoT in modern electrical systems by bridging automation, monitoring, and fault detection into a unified platform. Keywords: NodeMCU, RELAYS, BUZZER, LOADS, LCD, VOLTAGE MONITOR, LM324, OC, SC.

Keywords- NodeMCU (ESP8266), IoT-Based Grid Monitoring, Voltage Monitoring, Relay Control, LM324 Operational Amplifier, Short Circuit Detection, Open Circuit Detection, Undervoltage Protection, Buzzer Alert System, Smart Grid, Load Control, Wireless Monitoring, LCD Display, Fault Detection, Remote Switching, Embedded Systems, Real-Time Monitoring, Power Distribution Automation.

I. INTRODUCTION

Electric power systems form the backbone of modern civilization, supplying energy to residential, industrial, and commercial sectors. With the rapid growth in electricity demand and the increasing complexity of power networks, ensuring the reliability, stability, and efficiency of the grid has become a critical challenge [1], [2]. Traditional power systems often lack real-time monitoring capabilities, making them vulnerable to faults such as short circuits, open circuits, and undervoltage conditions. These faults can lead to equipment damage, energy losses, reduced power quality, and potential safety hazards [3], [4]. Therefore, the development of intelligent monitoring systems capable of providing continuous supervision and instant fault detection is essential for modern smart grid infrastructures.

In recent years, the evolution of the **smart grid** has introduced advanced communication and automation technologies into conventional power systems. Among these, the **Internet of Things (IoT)** has emerged as a key enabler for real-time data acquisition, remote monitoring, and intelligent decision-making [5], [6]. IoT-based smart grid systems allow seamless integration of sensors, controllers, and communication networks to monitor electrical parameters such as voltage, current, and power quality in real time [7]. These systems significantly enhance grid visibility and enable faster response to abnormal operating conditions [8].

The proposed Real-Time Grid Monitoring System utilizes an IoT-based architecture centered around the NodeMCU (ESP8266) microcontroller for data acquisition, processing, and wireless communication. The system incorporates LM324 operational amplifiers for accurate detection of fault conditions such as short circuits and open circuits. By integrating sensing circuits, relay-based control mechanisms,

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and IoT platforms, the system provides a unified solution for monitoring, fault detection, and remote operation [9], [10]. Furthermore, the system enables users to remotely control connected loads through a web-based interface, improving operational flexibility and energy management. In the event of abnormal conditions such as undervoltage, short circuit, or open circuit, an alert mechanism using a buzzer ensures immediate notification for preventive action. A 16×2 LCD display provides local visualization of system parameters, including voltage levels and fault status, ensuring both on-site and remote situational awareness [11].

Compared to conventional monitoring approaches, the proposed system offers a cost-effective, scalable, and efficient solution for real-time grid supervision. It demonstrates the potential of IoT-enabled technologies in enhancing the reliability, safety, and automation of modern power distribution systems [12][15].

II. BACKGROUND AND LITERATURE REVIEW

Nowadays, power systems require continuous monitoring to avoid faults and ensure smooth operation. Traditional methods are not efficient because they do not provide realtime information and require manual checking. With the help of IoT, it is now possible to monitor electrical parameters like voltage and detect faults instantly. Devices like the NodeMCU (ESP8266) make it easy to send data wirelessly and control systems remotely. So, developing a smart system that can monitor, detect faults, and control loads in real time is very useful for improving safety and reliability.

Many researchers have worked on IoT-based monitoring systems for electrical applications. Most of them used microcontrollers and sensors to measure voltage and current and send the data to online platforms. Some systems focused on fault detection using components like the LM324 Operational Amplifier, while others worked on remote control using relays. However, many existing systems only focus on either monitoring or control. Very few combine monitoring, fault detection, and remote operation in one system. This project tries to bring all these features together in a simple and cost-effective way.

III. PROBLEM STATEMENT AND OBJECTIVES

In many existing grid systems, there is no real-time monitoring or fault alerting mechanism. When a short circuit or open circuit occurs, the detection and response depend on manual inspection, which can be timeconsuming and unsafe. Additionally, users often have no control over the loads remotely, limiting flexibility and quick fault response.

Thus, there is a clear need for an automated, IoT-enabled system capable of monitoring voltage variations, detecting faults, and alerting users immediately. The system should also provide the ability to control loads remotely to isolate faulty circuits or manage energy usage effectively.

The main objectives of this project are as follows:

1. To design and develop a real-time grid monitoring system capable of detecting voltage variations and fault conditions.
2. To implement short circuit and open circuit detection using the LM324 op-amp.
3. To enable manual switching of loads via an IoT web interface using NodeMCU.
4. To alert users through a buzzer in case of undervoltage, short circuit, or open circuit faults.
5. To display real-time information, such as voltage and system status, on a 16×2 LCD.

IV. SYSTEM ARCHITECTURE

A. Overview

The Real-Time Grid Monitoring System is an IoT-based solution designed to monitor and control electrical parameters in a power distribution system. It uses the NodeMCU (ESP8266) to collect data, process it, and send it wirelessly for remote access.

The system continuously monitors voltage and detects faults such as open circuit, short circuit, and undervoltage conditions using appropriate sensing and signal processing circuits like the LM324 Operational Amplifier. When any abnormal condition occurs, a buzzer provides an immediate alert.

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It also includes relay modules for controlling electrical loads remotely through an IoT interface, while a 16×2 LCD displays real-time system status locally. Overall, the system improves safety, reliability, and user convenience by combining monitoring, fault detection, and remote control in a single platform.

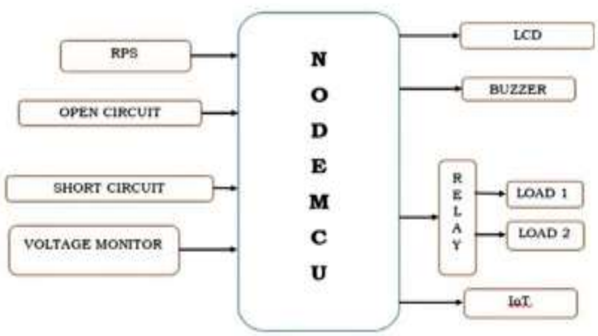

Fig. 1. System block diagram of real time data monitoring in smart grid

The system is built around the NodeMCU (ESP8266), which acts as the main controller for monitoring and control operations.

The input side includes a regulated power supply (RPS), voltage monitoring unit, and fault detection circuits for identifying open circuit and short circuit conditions. These inputs continuously send data to the NodeMCU for processing. The voltage monitoring section measures the supply voltage, while the fault detection circuit (using components like the LM324 Operational Amplifier) detects abnormal conditions such as faults in the system. On the output side, a 16×2 LCD display shows real-time voltage values and system status. A buzzer is used to provide alerts whenever a fault or undervoltage condition occurs.

The system also includes relay modules, which control connected loads (Load1 and Load2). These loads can be switched ON/OFF automatically or through IoT. Finally, the IoT module enables remote monitoring and control of the system through a web interface, allowing users to access the system from anywhere.

V. HARDWARE COMPONENTS AND SPECIFICATIONS

Table-1 summarises the principal hardware components with their rated specifications as used in the experimental prototype.

Table-1 Hardware components and specifications used in the experimental prototype.

components	specifications	purpose
AC power source	230V,50Hz	Provides the main supply voltage for the system and grid monitoring
U11(Bridge)	diode	Offers over-voltage protection and rectifies AC to DC power for circuit.
C5, C6(Capacitors)	1000 µF,50V	Smooth and filters the rectified voltage for stable DC supply.
LCD9(16*2 LCD)	HD-216-OC Display	Displays real-time status, voltage, and fault messages locally
NodeMCU-ESP3	ESP8266 Module	Central Wi-Fi enabled microcontroller, processes data controls outputs.
U12B,U12D(Op amps)	LM324(QUAD Op-Amp IC)	Compares monitored voltages to thresholds for open/short detection
BUZZ9(Buzzer)	5V Electronic Buzzer	Sounds alarms for detected faults or abnormal conditions.

2 channel Relay Module	5V Relay board	Allows NodeMCU to switch two loads (LAMP, L4) ON/OFF, isolating circuits.

VI. MATHEMATICAL ANALYSIS AND MODELLING

The system relies on converting physical electrical parameters into digital data. The following models describe the core functionality of the monitoring system.

1. Voltage Divider and ADC Modelling The ESP8266 ADC (Analog-to-Digital Converter) measures voltages between 0V and 3.3V. Since grid-scaled voltages (even stepped down) may exceed this, a voltage divider is employed. The relationship between the actual input voltage V_{in} and the voltage at the ADC pin V_{adc} is given by:

$$V_{adc} = V_{in} * \left(\frac{R_2}{R_1 + R_2}\right)$$

this is simplified using the VOLTAGE_DIVIDER_FACTOR:

$$V_{actual} = V_{adc} * \text{factor}$$

2. Digital Quantization: The ADC converts the analog voltage into a digital integer. The ESP8266 has a 10-bit resolution (2^{10} = 1024 levels). The mathematical mapping is:

$$\text{Digital Value(raw)} = \frac{V_{adc}}{V_{ref}} * (ADC_{res} - 1)$$

Where: V_{ref}=3.3v, ADC_{res}=1023

Combining these, the software calculates the real voltage as:

$$V_{measured} = \left(\frac{raw * 3.3}{1023}\right) * 2$$

3. Fault Detection Logic (Boolean Modelling) The system monitors for three specific fault conditions. We can model the state of the Buzzer (B) as a Boolean function of the Short Circuit sensor (S), Open Circuit sensor (O), and Undervoltage condition (U):

Where:

$$B = U + S + O$$

- U = 1 if V{measured} < 5.0V
- S = 1 if SHORT_PIN is LOW (Logic 0 via Pull-up)
- O = 1 if OPEN_PIN is HIGH (Logic 1)

4. Power Management and Load Control The loads are controlled via relays. The state of the grid can be represented by a simple efficiency or status matrix. However, for your specific implementation, the Sampling Rate (fs) is a critical parameter for real-time performance:

$$f_s = \frac{1}{\Delta t} = \frac{1}{1.0s} = 1\text{Hz}$$

While 1 Hz is sufficient for human monitoring via a web interface, transient faults (spikes) occurring faster than 1000ms may not be captured by the current POLL_MS constant.

VII. EXPERIMENTAL RESULTS AND ANALYSIS

A. During Normal operation

The system was tested under normal operating conditions and showed stable performance. The measured voltage was around 5.26 V, which is within the safe range. The system status was displayed as "GOOD" on both the LCD and IoT interface. No short circuit or open circuit faults were detected, and the buzzer remained OFF. The NodeMCU (ESP8266) monitored the system continuously and updated the data in real time.

Both loads were operating normally through the relay module, and the IoT interface showed accurate results.

Fig. 2. During normal operation

B. During open circuit condition

The system was tested under open circuit conditions to evaluate its fault detection capability. The measured voltage

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was around 5.26 V, and the system status was still displayed as "GOOD." However, the open circuit condition was successfully detected and indicated on both the LCD display and the IoT interface.

The buzzer was activated immediately to alert the user about the fault. The NodeMCU (ESP8266) continuously monitored the system and accurately identified the fault condition.

The IoT interface clearly showed "Open-circuit: YES," and the LCD displayed the fault indication as "OC." The loads remained operational through the relay module. This result confirms that the system can effectively detect open circuit faults and provide timely alert**s.**

Fig. 2. During open circuit operation

C. During short circuit condition

The system was tested under short circuit conditions to verify its fault detection performance. The measured voltage was around 5.25 V, and the system status was displayed as "GOOD." The short circuit condition was successfully detected by the system.The buzzer was activated immediately to alert the user about the fault. The NodeMCU (ESP8266) continuously monitored the inputs and identified the fault accurately.The IoT interface displayed "Short-circuit: YES," and the LCD showed the indication as "SC." The relay modules continued to operate the loads as per control conditions. This result confirms that the system can effectively detect short circuit faults and provide quick alerts.

Fig. 4. During short circuit condition

D. During under voltage condition

The system was tested under undervoltage conditions with a measured voltage of approximately 4.9 V, which is below the predefined threshold. The system successfully detected the undervoltage condition and indicated it on both the LCD display and the IoT interface.

The buzzer was activated immediately to alert the user about the low voltage condition. The NodeMCU (ESP8266) continuously monitored the voltage and updated the system status in real time.

The IoT interface displayed the voltage along with an undervoltage warning, and the LCD also showed the same condition. This result confirms that the system can effectively identify undervoltage situations and provide timely alerts for safe operation.

Fig 5.During under voltage condition

IX. DISCUSSION

The developed Real-Time Grid Monitoring System successfully demonstrates how IoT can be used for continuous monitoring and control of electrical parameters. By using the NodeMCU (ESP8266), the system is able to collect voltage data, detect faults, and transmit information wirelessly in real time.

The system effectively identifies abnormal conditions such as undervoltage, short circuit, and open circuit. The use of components like the LM324 Operational Amplifier helps in reliable fault detection. Immediate alerts through the buzzer and real-time updates on the LCD display improve system responsiveness and safety.

The IoT-based web interface allows users to monitor system status and control loads remotely, which adds flexibility and convenience. The relay-based load control works efficiently and responds quickly to user commands.

However, the system has some limitations, such as dependence on internet connectivity and limited parameter measurement (mainly voltage). Despite this, the project proves to be a cost-effective and practical solution for smallscale smart grid applications.

B. Advantages and Limitations

Advantages

- Provides real-time monitoring of electrical parameters
- Enables remote control of loads using IoT
- Quick fault detection (short circuit, open circuit, undervoltage)
- Improves safety with instant buzzer alerts
- Cost-effective using components like NodeMCU (ESP8266)
- Easy to use with LCD display and web interface
- Reduces need for manual supervision

◇ Limitations

- Depends on internet connectivity for remote operation
- Limited accuracy due to use of basic sensors (like potentiometer)
- Suitable mainly for small-scale applications
- Power supply fluctuations may affect performance
- Security risks in IoT communication if not protected
- Limited parameters (only voltage, no detailed power quality analysis)

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Special thanks to my friends and classmates who offered valuable suggestions and feedback during the development and testing stages. Their ideas and discussions helped in improving the overall performance of the system. This project aims to contribute towards smarter and safer power distribution by integrating real-time monitoring, fault detection, and IoT-based control. I hope this work will be useful for future developments in smart grid systems and automation.

X. FUTURE WORK AND ENHANCEMENTS

Based on the experimental findings, the following enhancements are planned for the next development phase.

Table II
Planned Future Enhancements

Enhancement	Technical Approach	Expected Benefit
Advanced Fault Detection	AI/ML based analysis	Faster fault prediction
Current Monitoring	Use of current sensors	Full parameter monitoring
Cloud Storage	IoT cloud integration	Remote data access
Mobile App Control	Android/iOS app	Easy user control
Auto Load Control	Smart relay switching	Less manual work
Renewable Integration	Solar system connection	Sustainable usage
GSM Alerts	SMS notification module	Works without internet
Power Quality Analysis	Harmonics measurement	Better performance insight
System Scalability	Multi-node expansion	Large scale use

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