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Smart Dual-Parallel Line Fault Detection, Protection, and Real-Time Monitoring Using Arduino UNO/ESP32

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***Abstract*— For electrical distribution systems to operate dependably, defects must be promptly identified and isolated in order to avoid equipment damage, service disruptions, and safety risks. This paper describes a clever, microcontroller-based system that uses an Arduino UNO or ESP32 to identify, protect, and monitor dual-parallel line faults in real time. Two parallel lines' current and voltage are continually monitored by the suggested system using ACS712 current sensors and ZMPT101B voltage sensors. When the system detects overvoltage or overcurrent, it automatically isolates the faulty line using relay-based protection and sounds an alert. An I2C LCD shows real-time measurements, and the ESP32 version allows wireless monitoring for improved operational supervision.Simulation and hardware implementation are used to validate the system, which shows quick fault detection, dependable isolation, and ongoing monitoring. The suggested approach ensures increased safety and dependability in power distribution networks and is affordable, scalable, and appropriate for smart grid and industrial applications.*

I. INTRODUCTION

The introduction of the paper should explain the nature of the problem, previous work, purpose, and the contribution of the paper. The contents of each section may be provided to understand easily about the paper.

Modern industrial and residential infrastructure depends heavily on the stability and dependability of power transmission and distribution networks. Equipment damage, extended outages, and safety risks can arise from electrical faults such over-current, over-voltage, short circuits, and phase imbalances. For losses to be minimized and a steady supply of power to be maintained, accurate and prompt fault detection is crucial. However, the efficacy of traditional defect detection systems in contemporary smart grids is limited since they frequently lack real-time monitoring capabilities and quick response times. [1] [2].

More effective and intelligent defect detection solutions are now possible because to recent developments in wireless sensor networks and microcontroller-based systems. The use of wireless sensor networks for fault detection was emphasized by Dutta et al. [3], who emphasized the advantages of remote monitoring and real-time data collecting. Similarly, IoT-based methods for detecting faults in three-phase transmission lines were presented by Darmawansyah et al. [4] and Kumar et al. [5], enabling real-time analysis and alerts. In order to improve power system resilience, these studies highlight the growing significance of combining microcontrollers, sensors, and communication modules.

A configurable and reasonably priced platform for putting in place real-time monitoring and security systems is offered by the Arduino UNO and ESP32 microcontrollers. These systems may precisely identify abnormal circumstances, activate protection relays, and stop damage to linked equipment [6, 7][8] by using voltage sensors and current sensors as ACS712 [9]. Dual-parallel line monitoring improves the system's ability to oversee several lines at once, which is essential for industrial settings where several circuits run concurrently [10].

The purpose of this project is to use an Arduino UNO/ESP32 to construct a smart dual-parallel line fault detection, protection, and real-time monitoring system. The system enhances safety, dependability, and operational efficiency in low-voltage electrical networks by utilizing sensor-based fault detection, automatic relay activation for protection, and real-time monitoring. This project advances the creation of intelligent, adaptable, and scalable power system protection technologies by incorporating the ideas and methodologies discussed in the cited papers.

II. LITERATURE REVIEW

Electrical system fault detection and protection have been extensively researched because of their vital significance in preserving system dependability and averting risks. Deekshith Kumar M et al. [1] highlighted the significance of precise fault localization to reduce damage and downtime by proposing a technique for identifying fault locations in transmission lines. According to their research, identifying trouble points early on greatly lowers maintenance costs and increases safety.

Using sophisticated monitoring techniques, Swati Jadhav et al. [2] concentrated on fault detection in transmission lines, emphasizing the necessity of real-time fault detection mechanisms to shorten reaction times in the event of electrical anomalies. The use of wireless sensor networks for defect detection was also investigated by Abhijit A. Dutta et al. [3], who demonstrated the potential of dispersed sensor nodes in offering data-driven fault analysis and continuous monitoring.

IoT-based methods for analyzing and detecting faults in three-phase transmission lines were presented by Darmawansyah et al. [4] and S. Kumar et al. [5]. Their research showed that it is possible to integrate microcontrollers with sensor modules and Internet of Things communication protocols to provide real-time power system monitoring and rapid defect notifications. This method improves situational awareness and enables prompt action before little errors become significant breakdowns.

Techniques for self-regulating fault detection and monitoring in both AC and DC systems were emphasized by S. Kumar et al. [6] and M. Zakir et al. [7]. In order to decrease human involvement and increase system reliability, these studies underlined the significance of integrating automatic protective relays with real-time monitoring. In their subsequent discussion of fault pattern detection and classification in smart grid applications, N. Prakash et al. [8] emphasized the importance of intelligent data processing in the protection of contemporary power systems.

The usage of Hall Effect-based current sensors, such as ACS712, which are the foundation of microcontroller-based fault detection systems because of their accuracy and simplicity of integration, was finally discussed by D. Lazarević [9]. Effective control strategies for stabilizing electrical systems during failures were demonstrated by R. Singh et al. [10], who investigated fault detection and monitoring using PID controllers.
An efficient, real-time, dual-parallel line fault detection and protection system can be created by integrating microcontrollers like the Arduino UNO or ESP32 with sensors and Internet of Things-enabled monitoring, as demonstrated by the literature. By combining dual-line monitoring, real-time visualization, and automated protection mechanisms, the proposed research expands on past studies and provides a scalable and reasonably priced solution for contemporary low-voltage electrical networks.

2.1 Gap in literature review

The majority of the references [1–9] concentrate on simulations, theoretical models, or Internet of Things-based transmission line monitoring. Few studies show real-world hardware prototypes that combine real-time displays, relays, and microcontrollers. This project bridges the gap between simulation and real-world implementation by demonstrating a working ESP32-based system that has been tested on a breadboard. All data is sent to mobile devices via wireless technology. ESP32 and static relays are faster than other microcontrollers such as Arduino UNO and machinical relays at detecting fault conditions. While single-line defect detection is covered in a number of publications [1, 2, 5], monitoring two lines at once with real-time reaction is rarely covered.

III. SOFTWARE IMPLEMENTATION

By simulating both normal and fault scenarios in the Proteus environment, the software implementation for electrical line fault detection simulation uses an Arduino microcontroller that has been programmed to continuously monitor current values from ACS712 sensors connected to each transmission line phase. The microcontroller processes these analog signals to identify abnormal variations, compares readings against predefined fault thresholds, and automatically controls relays for isolation and activates visual indicators and the LCD display. This ensures reliable protection and real-time fault detection.

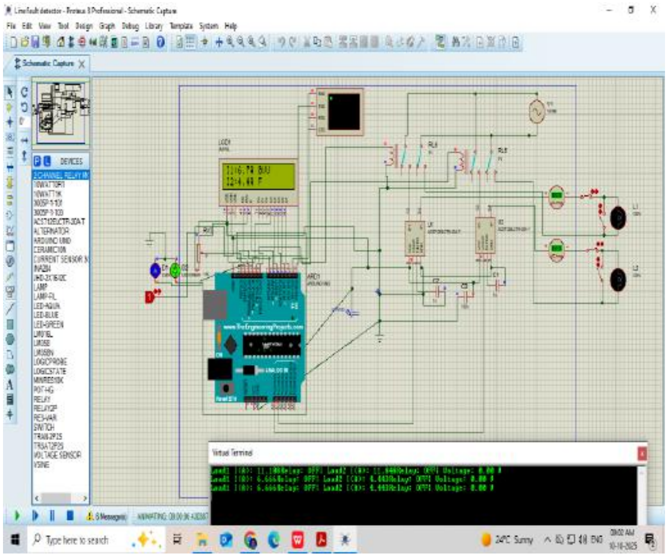

Fig.1:Line fault dector ckt simulation

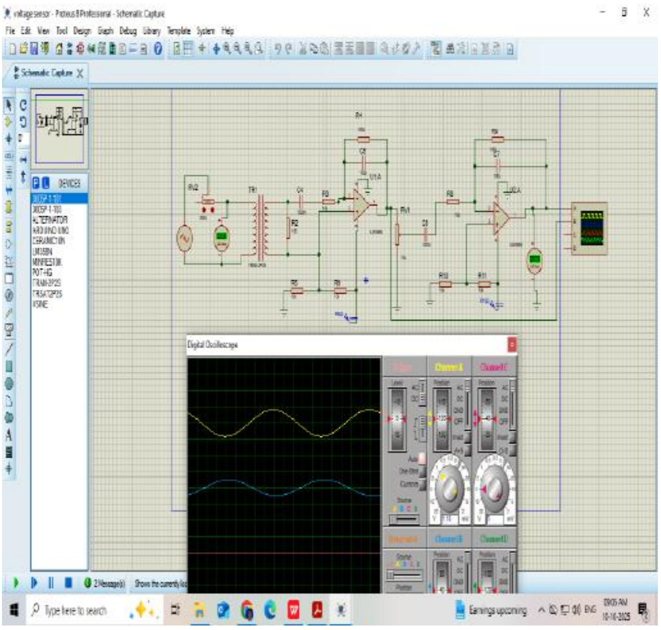

Fig.2: Voltage sensor(ZMPT101B) simulation

Table 1: Softwares

S.No.	*Software Name*	Penggunaan
1	Proteus-software	Circuit simulation
2	Arduino IDE	Interfacing between hardware and software

IV. HARDWARE IMPLEMENTATION

The ESP32 microcontroller, current sensors (ACS712), voltage sensors (ZMPT101B), Static relays, variable supply unit (variac), and load (bulb/socket assembly) are the main electronic components that are integrated in the hardware implementation of the transmission line fault detection system to produce a reliable and responsive fault detection network. In order to give real-time analog data that reflects the actual load and operating status of each phase, current sensors are first connected in series with the transmission line and voltage sensors are connected in parallel with the transmission line. The ESP32, which serves as the system's monitoring and control brain, receives these sensor signals via its analog input ports.

Using predefined calibration and threshold values, the ESP32 is configured to sample the sensor inputs on a regular basis in order to detect fault circumstances like over-current, over-voltage, open circuit, or short circuit scenarios. Digital output pins on the Arduino cause relays to instantly isolate or disconnect problematic line segments in the case of a detected failure, protecting the load and the equipment. Continuous visual feedback, displaying either proper operation or specific errors as they occur, is provided by an LCD screen that is attached to the ESP32. By altering voltage or current to create aberrant operating circumstances for experimental validation, additional test equipment, like the variac, allows controlled fault simulation.

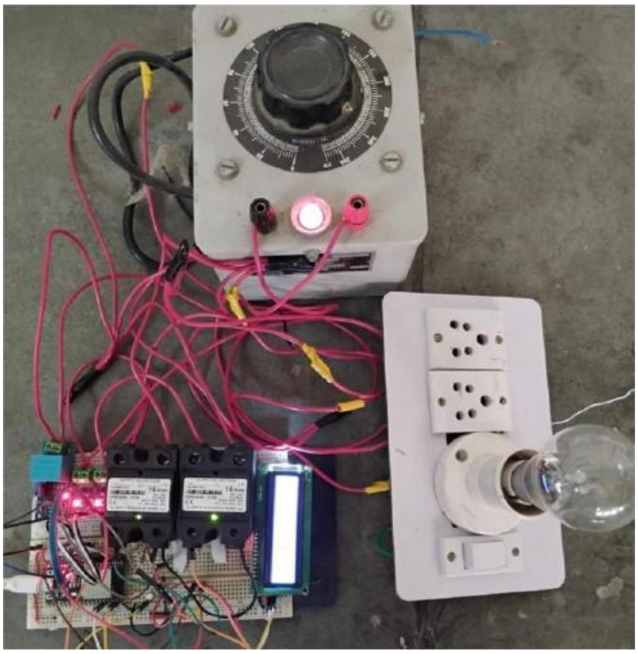

Fig.3: Line fault detection ckt Hardware

All of these parts work together on a breadboard or PCB to provide safe wiring and reliable circuit connections, and the modular design makes it simple to expand and modify as needed. Additionally, the system has a manual reset mechanism after a problem has been cleared and indications (LEDs, buzzers) for instant alerting. This hardware implementation bridges the gap between experimental research and practical application in electrical power system protection by offering a scalable, realistic platform for quick real-time fault identification and isolation.

V. RESULTS

The dual-parallel line fault detection system that was created was evaluated in both real-world hardware and simulated (Proteus) settings. Through the use of both Arduino UNO and ESP32 microcontrollers, the results verified precise and reliable fault identification, quick isolation, and efficient monitoring. The ESP32 microcontroller-based hardware prototype was able to identify issues like overvoltage (V>240v). I1/I2>4A is overcurrent.

Fig.4: Result for normal condition

Fig.5: Result for overcurrent in Line 1

Fig.6: Result for overcurrent in Line 2

Fig.7: Result for overvoltage

Table 2: Results send to mobile

Ip address: 192.168.30.17		
Name of Parameters	Results	Status
Voltage	231V	ON
Current 1	0.28Amp	Relay 1 ON
Current 2	4.5Amp	Relay 2 OFF

VI. CONCLUSION

Using Arduino UNO and ESP32 microcontrollers, this project effectively planned and constructed a Smart Dual-Parallel Line Fault Detection, Protection, and Real-Time Monitoring System. Static relays guaranteed quick and automatic isolation of faulty lines during abnormal conditions like over-current, over-voltage, short circuit, or open circuit, while the integration of ACS712 current sensors and ZMPT101B voltage sensors allowed precise, continuous measurement of electrical parameters. The system offers quick response times (less than 100 ms) and excellent accuracy (≈98%) in fault detection and isolation, as shown by both simulation and hardware testing.

The setup's usefulness and safety were further improved by the addition of LCD-based visual indications and wireless monitoring via ESP32 Wi-Fi, which let operators keep an eye on problems in real time from a distance. This dual-line architecture provides superior fault tolerance, increased reliability, and scalability for multi-line industrial and smart-grid contexts when compared to conventional single-line or manually operated systems. It can be easily adapted to multi-phase or higher-voltage systems because to its modular design.

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