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(Research Article)

IOT based smart power system for fault detection in transmission lines with automated distribution transformer load sharing

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Abstract

The reliability of electrical power systems largely depends on the efficient operation of transmission networks, where faults such as ground faults, short circuits, and overcurrent conditions frequently occur due to environmental factors, equipment failures, or unforeseen disturbances. Conventional impedance-based fault detection methods are often time-consuming and lack real-time accuracy. This paper proposes an IoT-based smart power system for real-time fault detection in transmission lines with automated distribution transformer load sharing. The system employs IOT-based controllers integrated with current and voltage sensors to continuously monitor line parameters and detect faults with high accuracy. Fault data is transmitted via ESP8266 Node MCU Wi-Fi modules to a cloud platform, enabling remote monitoring, rapid fault isolation, and predictive analysis. Additionally, a relay-based adaptive load-sharing mechanism dynamically redistributes loads among transformers to prevent overloading and improve operational efficiency. Experimental validation under simulated fault conditions demonstrates reduced fault detection and clearance time, enhanced reliability, and improved power distribution performance. The proposed solution offers a scalable, cost-effective framework for modern smart grid applications.

Keywords: Smart Grid; Fault Detection; Transmission Line Protection; Internet of Things (IoT); Real-Time Monitoring;

1. Introduction

An electrical power system is a vital infrastructure responsible for generating, transmitting, and distributing electrical energy to consumers in a reliable and efficient manner. It consists of three primary components such as power generation, transmission, and distribution. Among these, the transmission system plays a crucial role by transporting high-voltage electrical power from generating stations to distribution substations over long distances. Transmission lines are typically constructed using conductors with uniform cross-sectional areas and are insulated by surrounding air, ensuring efficient power transfer while preventing electrical discharge.

Due to the presence of high-voltage equipment and exposure to environmental conditions, power systems are highly susceptible to faults. A significant percentage of these faults occur in the transmission sector and are commonly caused by lightning strikes, heavy rainfall, strong winds, insulation failure, or mechanical damage. Such faults disrupt the stability of the power system, leading to voltage fluctuations, loss of synchronism, equipment damage, and widespread power outages.

Faults in transmission lines, if not detected and cleared promptly, can have severe consequences. Prolonged fault conditions may result in irreversible damage to costly electrical equipment, reduced system reliability, and substantial economic losses. Traditional fault detection techniques rely on impedance-based methods using voltage and current

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measurements to estimate fault locations. Although widely used, these methods are computationally intensive, time-consuming, and often lack real-time responsiveness, making them unsuitable for modern smart grid applications.

With advancements in embedded systems and communication technologies, there is a growing need for intelligent fault detection solutions that offer real-time monitoring, precise fault localization, and rapid response. This paper introduces a smart fault detection and monitoring system using Node MCU and IoT technology. The proposed system continuously monitors transmission line conditions and immediately transmits fault data to a cloud-based server when abnormalities are detected. Also, the IoT integration allows operators to access real-time information through mobile and desktop platforms.

By enabling remote monitoring and faster fault isolation, the proposed system enhances the reliability, efficiency, and safety of transmission networks. This approach represents a significant step toward modernizing fault management practices in electrical power systems and supports the development of smart and resilient power grids.

2. Review of related literature

The research explains about the fault detection in electrical systems has seen significant advancements, particularly with the integration of microcontrollers and IoT technologies. Also, introduced a microcontroller-based fault detection system for transmission lines that emphasizes real-time monitoring and quick fault identification, thereby enhancing operational reliability [1]. Similarly, this work developed an IoT-based monitoring system that utilizes advanced sensors and cloud technology to provide timely alerts and data analytics, improving maintenance efficiency [2]. Singh and Sharma [3] focused on an Arduino-based approach for detecting and localizing faults in underground cables, highlighting cost-effectiveness and reliability in pinpointing fault locations. Bhagat and Reddy [4] further explored this area by implementing an underground cable fault detector using Arduino and GSM technology, facilitating immediate notifications and faster response times. This paper presented an automatic fault detection system that employs GSM technology to enhance operational efficiency through automated alerts [5]. Tariq et al. [6] introduced an optimized wavelet-based technique for underground power cables, demonstrating improved accuracy in fault identification. Sharma and Verma [7] emphasized the importance of sensor integration for real-time data monitoring in electrical power networks, enabling proactive maintenance. This research proposed a method for three-phase underground cable fault detection using Arduino and IoT, focusing on rapid identification and improved maintenance practices [8]. Khan and Joshi [9] discussed an automatic load-sharing system for transformers, aiming to optimize load distribution and prevent overloads. The review by Soni and Mehta [10] examined various smart grid-based fault monitoring systems, addressing current challenges and future directions. Patel and Kaur [11] investigated a microcontroller-based load balancing approach to enhance efficiency in power distribution networks. Verma and Gupta [12] presented an IoT and GSM-based automatic fault detection system designed for immediate alerts and remote monitoring. Additionally, Ahmed and Sultana [13] reviewed fault detection methods in power converters, providing insights into improving reliability and efficiency. Sharma and Bhatia [14] introduced an IoT-based smart transformer monitoring system, while Kumar and Rao [15] discussed an impedance-based fault location technique for high-voltage transmission systems. Singh and Patel [16] highlighted various fault detection methodologies using Proteus simulation and IoT technologies. Chaudhary and Sahu [17] presented an IoT-enabled transformer protection system that includes real-time load analysis, enhancing safety and operational efficiency. Reddy and Thomas [18] explored three-phase fault analysis using IoT and Arduino, aiming to improve detection accuracy. Finally, Wei and Han [19] proposed an advanced fault detection method utilizing wavelet transforms and artificial neural networks, while Park and Lee [20] focused on detecting invisible broken conductors with embedded sensors, improving safety in overhead power line maintenance. Collectively, these studies underscore the critical role of innovative technologies in enhancing fault detection and management in electrical systems.

3. Materials and Methods

3.1. Block Diagram of IOT based Smart Power System for Fault Detection in Transmission lines with Automated Distribution Transformer Load Sharing

Fig. 1 shows the block diagram that illustrates IOT based smart power monitoring and load control system integrated with IoT functionality. Multiple three-phase power lines are provided as inputs and are first connected to switching units, which ensure safe signal conditioning and phase selection before interfacing with the controller. The Arduino acts as the central processing unit, continuously monitoring the status of the incoming power lines and executing control logic based on predefined conditions. System information such as power availability and load status is displayed locally on an LCD for easy monitoring. Based on Arduino's decisions, a four-channel relay module is activated to switch electrical loads ON or OFF safely. For remote monitoring and communication, the Arduino interfaces with a NodeMCU module, which transmits system data to a cloud platform via Wi-Fi. In case of faults or abnormal conditions such as phase failure or power interruption, alert messages are generated and sent through the cloud to notify users promptly.

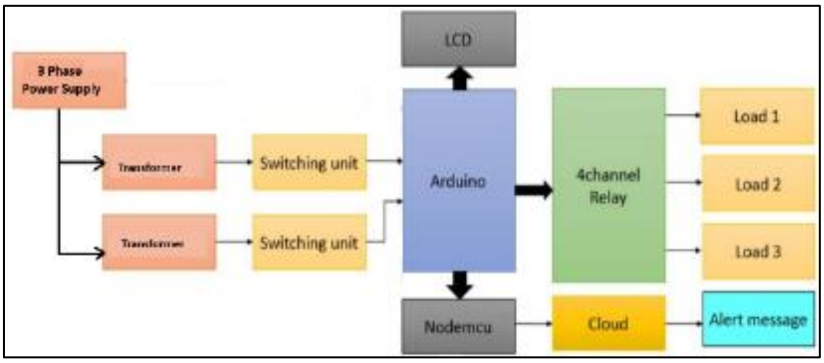

Figure 1 Block Diagram of IOT based Smart Power System for Fault Detection in Transmission lines with Automated

3.2. Distribution Transformer Load Sharing

Flow chart for Transmission Line Fault Detection and Indication System

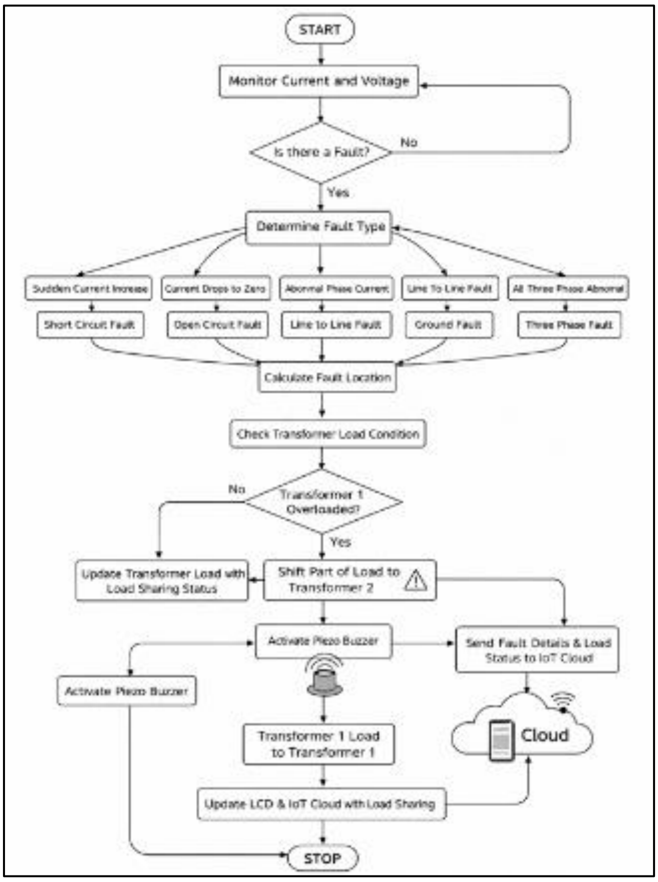

Figure 2 Flow chart for Smart Three-Phase Power Monitoring and Remote-Control System with Cloud Alerts

Fig. 2 presents the operational flow of the IOT based Smart Three-Phase Power Monitoring and Remote-Control System for transmission line fault detection and transformer load management. The sequence begins with system initialization, followed by continuous monitoring of voltage and current in all three phases to ensure stable power delivery. The controller then checks whether a fault condition exists; if no fault is detected, the system continues monitoring in a loop. When a fault is identified, it classifies the fault type based on current behavior, such as short circuit (sudden current rise), open circuit (zero current), line-to-line fault (abnormal current in one phase), ground fault (current leakage to ground), or three-phase fault (all phases abnormal). After classification, the system calculates the approximate fault location and evaluates the transformer load condition. If Transformer 1 is operating within safe limits, the load status is updated, a piezo buzzer alert is activated, and the transformer continues operation while the LCD and IoT cloud platform are updated with fault and load-sharing information. If Transformer 1 is overloaded, a portion of the load is automatically transferred to Transformer 2, a warning buzzer is triggered, and fault as well as load details are transmitted to the IoT cloud before updating the display and concluding the process.

3.3. Circuit Diagram of IOT based Smart Power System for Fault Detection in Transmission lines with Automated Distribution Transformer Load Sharing

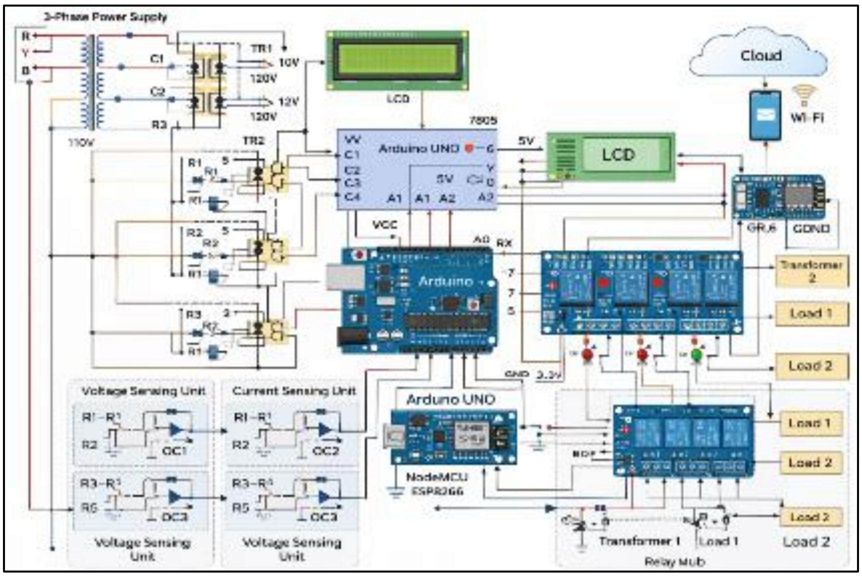

Figure 3 Circuit Diagram of IOT based Smart Power System for Fault Detection in Transmission Lines with Automated Distribution Transformer Load Sharing

Fig. 3 illustrates an IoT-based smart power system designed for transmission line fault detection and automatic transformer load sharing. A three-phase supply (R, Y, B) is stepped down through transformers (TR1 and TR2), rectified using diodes, filtered, and regulated by a 7805-voltage regulator to provide stable 5V DC for the control circuitry. Separate voltage sensing and current sensing units using resistor networks, signal conditioning circuits, and ACS712 current sensors continuously monitor phase voltage and line current, and their outputs are fed to the Arduino UNO's analog inputs. The Arduino processes these signals to detect abnormal conditions such as overcurrent or phase failure and displays system parameters on the LCD. A 4-channel relay module, controlled by the Arduino, switches load and enables automatic load sharing between transformers during overload conditions. The NodeMCU ESP8266 module communicates with the Arduino via serial interface and transmits real-time data to the cloud over Wi-Fi, allowing remote monitoring and sending alert messages when faults occur. Overall, the system integrates sensing, control, protection, load management, and IoT communication into a unified smart grid monitoring solution.

4. Simulation results

4.1. Proteus Simulation of Smart Load Monitoring System with Real-Time Display of Load 47% on LCD

Fig 4. shows a Proteus Simulation of Smart Load Monitoring System with Real-Time Display of Load 47.00% on LCD, that illustrates a well-structured electrical system designed for monitoring and controlling load conditions, featuring two input voltage sources, V1 and V2, which supply power to transformers TR1 and TR2 for voltage conversion. The setup includes several diodes (D1, D2, D8, D9, D11, D12, D13, and D14) that ensure unidirectional current flow and protect the circuit from potential reverse polarity issues. Capacitors (C1, C2, C3, and C4) are integrated into the design to filter out voltage spikes and stabilize the power supply, enhancing overall circuit reliability.

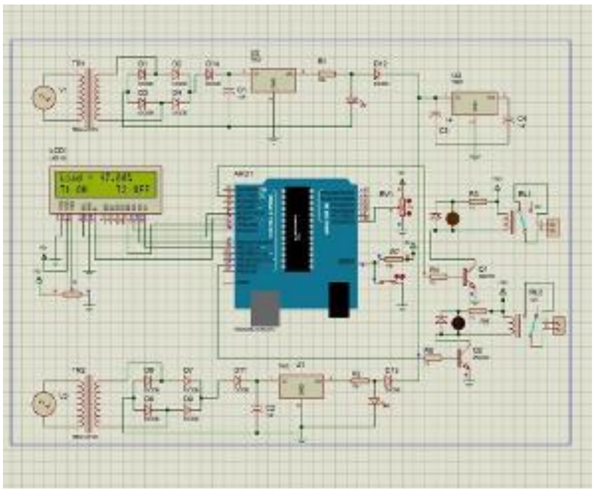

Figure 4 Proteus Simulation of Smart Load Monitoring System with Real-Time Display of Load 47.00% on LCD

The heart of the system is the Arduino microcontroller (ARD1), which processes input signals and controls the operation of connected components. An LCD display (LCD1) provides real-time feedback, showing critical information such as "Load = 47.00%", "T1 ON", and "T2 OFF", indicating the status of the load and the transformers. The circuit also incorporates multiple resistors (R1, R2, R3, R4, R5, R6, and R7) that regulate current flow and voltage levels, while transistors (Q1 and Q2) serve as switches or amplifiers for controlling larger loads. Additionally, relays (RL1 and RL2) are utilized to manage high-power devices, allowing for safe operation within the system. This comprehensive arrangement of components is meticulously designed to ensure efficient monitoring and control of electrical loads in various applications.

4.2. Proteus Simulation of Load Monitoring System with Real-Time Display of Load 59% on LCD

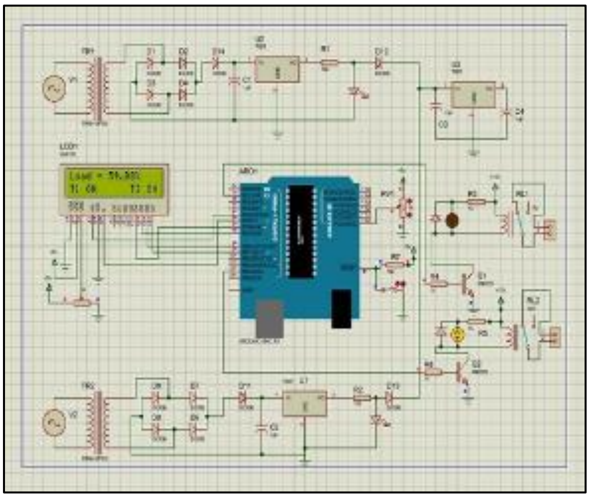

Figure 5 Proteus Simulation of Arduino-Based Load Monitoring System with Real-Time Display of Load 59.00% on LCD

Fig. 5. Shows the Proteus Simulation of Load Monitoring System with Real-Time Display of Load 59.00% on LCD which is a comprehensive representation of an electronic control system designed to monitor and manage electrical loads, prominently featuring an Arduino microcontroller (ARD1) as the central processing unit. Power is supplied through two voltage sources, V1 and V2, which connect to transformers (TR1 and TR2) for voltage adjustment. The diagram includes multiple diodes (D1 to D14) that ensure proper current direction and safeguard the circuit from reverse voltage, while capacitors (C1 to C4) are employed to smooth out voltage fluctuations, enhancing stability. Resistors (R1 to R7) are strategically placed to control current flow and protect sensitive components. The system also incorporates transistors (Q1 and Q2, specifically 2N2222) for switching applications, allowing for the control of larger loads through relays (RL1 and RL2). An LCD display (LCD1) provides real-time feedback, showing critical operational data such as a load percentage of "Load = 59.00%" and status indicators for transformers "T1 ON" and "T2 ON." Additionally, a

potentiometer (RV1) allows for adjustable resistance, enabling fine-tuning of circuit parameters. The logical arrangement of components, with power supply sections clearly delineated, facilitates an efficient flow of electricity throughout the system, making this circuit diagram a robust solution for load management applications.

4.3. Proteus Simulation of Load Monitoring System with Real-Time Display of Load 100% on LCD

Fig. 6. Shows the Proteus Simulation of Arduino-Based Load Monitoring System with Real-Time Display of Load 100% on LCD which illustrates a sophisticated system designed for load monitoring and control, prominently featuring an Arduino microcontroller (ARD1) that serves as the central processing unit. Power is supplied through two voltage sources, V1 and V2, which connect to transformers (TR1 and TR2) for appropriate voltage conversion. The circuit includes a series of diodes (D1 to D14) that ensure current flows in the correct direction while protecting against reverse polarity. Voltage regulators (U1, U2, U3) stabilize the output voltage, ensuring consistent performance across the system. Capacitors (C1 to C4) are integrated to filter out voltage spikes and smooth the power supply, enhancing circuit reliability. Resistors (R1 to R7) are strategically placed to manage current levels and protect sensitive components. The inclusion of transistors (Q1 and Q2) allows for efficient switching of larger loads, which are controlled by relays (RL1 and RL2). An LCD display (LCD1) provides real-time feedback on system status, indicating parameters such as "Load 100.00%" and the operational states of transformers "T1 OFF" and "T2 OFF." Additionally, a potentiometer (RV1) enables users to adjust resistance, allowing for fine-tuning of circuit parameters. The organized layout of components facilitates an efficient flow of electricity, making this circuit diagram a robust solution for various applications in load management and monitoring.

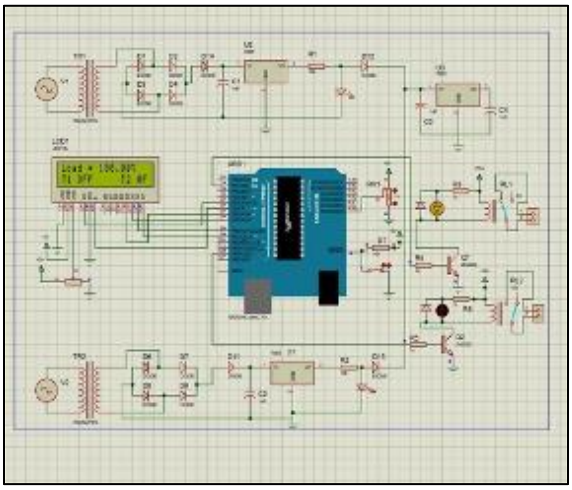

Figure 6 Proteus Simulation of Arduino-Based Load Monitoring System with Real-Time Display of Load 100% on LCD

4.4. Arduino-Based Single Line-to-Ground Fault Detection System with LCD Display and Virtual Monitoring

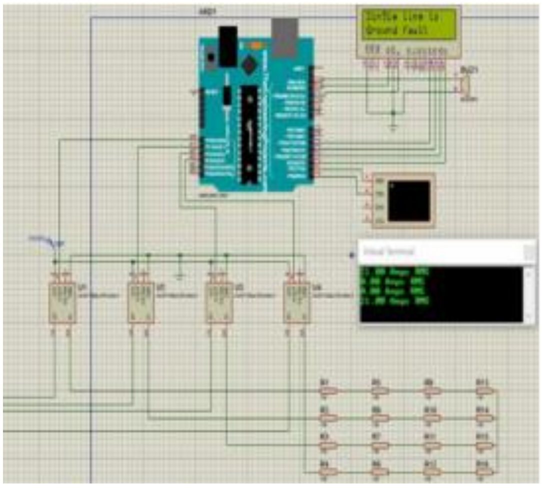

Figure 7 Arduino-Based Single Line-to-Ground Fault Detection and Monitoring System with LCD Alert and Virtual Terminal Output

Fig. 7. Shows the Arduino-Based Single Line-to-Ground Fault Detection and Monitoring System with LCD Alert and Virtual Terminal Output that illustrate an Arduino-based single-line to ground fault detection and monitoring system, simulated using a circuit design environment and demonstrated through an LCD output. In the circuit diagram, the Arduino Uno functions as the main controller, interfaced with multiple voltage sensing and signal conditioning components arranged using resistor networks and input modules to continuously monitor line parameters. These inputs allow the system to detect abnormalities such as leakage current, or voltage imbalance associated with a single line-to-ground fault. The processed data is displayed on an LCD module, which provides clear real-time fault messages, while a buzzer or indicator is activated to alert users when a fault occurs. The virtual terminal shows measured RMS values, confirming real-time monitoring and analysis, and the LCD image specifically indicates the detected fault condition (“Single line to Ground fault”), demonstrating the system’s ability to identify and communicate fault status effectively for protection and maintenance purposes.

4.5. Double Line-to-Ground Fault Detection System with Real-Time LCD Alert and Virtual Terminal Logging

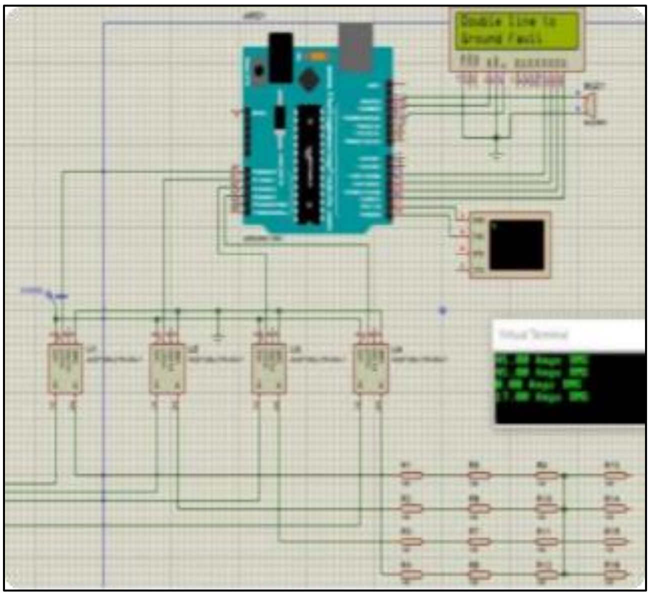

Figure 8 Double Line-to-Ground Fault Detection System with Real-Time LCD Alert and Virtual Terminal Logging

Fig 8. Shows the Double Line-to-Ground Fault Detection System with Real-Time LCD Alert and Virtual Terminal Logging that depicts a simulated microcontroller-based protection system designed to detect and respond to double line-to-ground faults in a three-phase electrical network, using an Arduino Uno as the central processing unit. Four voltage sensing modules (U_1–U_4), likely configured as analog input circuits or potential dividers, continuously monitor phase voltages; when two phases simultaneously experience a drop indicative of a ground fault such as during a double line-to-ground event the Arduino processes these signals and triggers a visual alert on a 16x2 LCD displaying “Double line to Ground fault,” while also activating a buzzer for audible warning. Simultaneously, the system transmits real-time RMS voltage readings via serial communication to a virtual terminal window, allowing engineers or students to log and analyze fault behavior remotely. The inclusion of multiple relay outputs (R_1–R_{15}) suggests the system is scalable for automated circuit isolation or load shedding under fault conditions. All components are powered by a regulated 5V supply, with clear grounding and signal routing ensuring stable operation.

4.6. Three phase Fault Detection System with Real-Time LCD Alert and Virtual Terminal Logging

Fig. 9. Shows the Arduino-Based Three phase Fault Detection System with Real-Time LCD Alert and Virtual Terminal Logging that illustrates a fault detection system utilizing an Arduino microcontroller, specifically labeled as 'ARD1'. Central to the design are four current sensors (U_1, U_2, U_3, and U_4) that monitor electrical currents across three phases, indicated by the 'Three Phase fault' message on the display. The system is designed to detect anomalies in current flow, with the virtual terminal displaying real-time readings of 79.00 Amps RMS for three sensors and 8.00 Amps RMS for one, suggesting a potential fault condition. Additionally, the circuit includes a series of resistors (R1 through R16) that likely play a role in signal conditioning or protection within the system. This configuration enables the Arduino to process current data effectively, facilitating timely fault detection and enhancing electrical system safety.

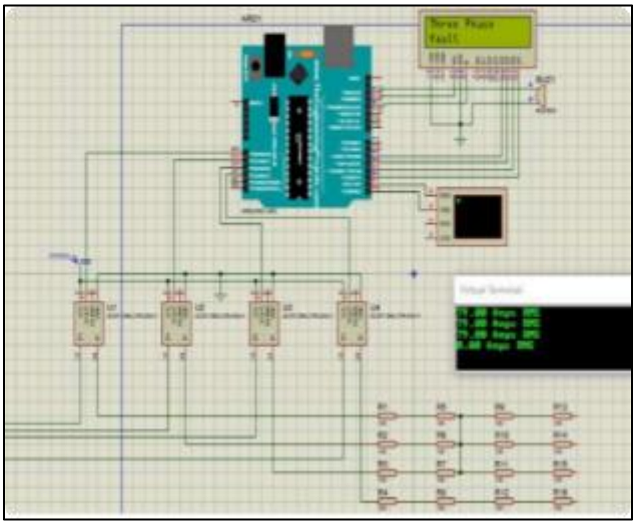

Figure 9 Arduino-Based Three phase Fault Detection System with Real-Time LCD Alert and Virtual Terminal Logging

5. Experimental results

5.1. Miniature Power Grid Circuit Model

Fig. 10. It shows a Power Grid Circuit Prototype that develop a reliable fault detection system for both overhead power transmission lines using an Arduino microcontroller and ACS712 current sensors. The system continuously monitors current flow to identify and classify various electrical faults such as outages, overloads, and abnormal current patterns. When a fault is detected, it triggers an audible alarm and automatically sends a text message with fault details. To maintain uninterrupted power supply, a load-sharing mechanism engages backup transformers during faults.

Figure 10 Power Grid Circuit Prototype

The design relies solely on programmed logic, excluding artificial intelligence to ensure simplicity, transparency, and reliability. The system can detect four main types of faults short circuit faults caused by sudden current surges, open circuit faults when current flow drops to zero, line-to-line faults due to irregular current between phases, and ground faults resulting from current flowing directly to the ground. By analyzing variations in current and voltage, the system can also estimate the fault's location, which, along with the fault type, is displayed on an LCD screen while a buzzer provides an audible warning. This approach is highly effective for monitoring long overhead transmission lines, allowing for quick fault detection and easier maintenance.

5.2. Load Real-Time Load Monitoring and Fault Detection Responses to the Proposed Smart Power System

Fig. 11 illustrates the real-time operational responses of the proposed Arduino-based smart power system under various load and fault conditions. In Case (a), a moderate load of 47% is detected, where Transformer T1 remains ON while T2 is OFF, indicating normal operation with a single transformer. In Case (b), as the load increases to 59%, both transformers are activated to share the load effectively, ensuring balanced distribution. Case (c) represents a critical condition where the load reaches 100%, resulting in the protective shutdown of both transformers to prevent system damage. Case (d) demonstrates the system's ability to detect and alert a single line-to-ground fault, enhancing operational safety. In Case (e), a double line-to-ground fault is identified and displayed, reflecting accurate fault classification. Finally, Case (f) shows successful detection of a three-phase fault, confirming the robustness and reliability of the proposed system in real-time monitoring, protection, and fault diagnosis of power distribution networks.

Figure 11 Real-time operational responses of the proposed Arduino-based smart power system under various load and fault conditions:

(a) 47% load, T1 ON T2 OFF (b) 59% load, T1 ON T2 ON (c) 100% load, T1 OFF T2 OFF (d) Single line-to-ground fault (e) Double line-to-ground fault (f) Three-phase fault detection

5.3. IoT Smart Power Monitoring for Load and Fault Management

Fig. 12. illustrates the real-time mobile notification interface of an IoT-enabled smart power monitoring system under different operating and faulty conditions. Each screen represents a distinct system state and demonstrates how load levels, transformer status, and fault conditions are communicated to operators through structured alerts.

In normal operating conditions, the system displays load percentages along with transformer operational status. At 47% load, Transformer 1 (T1) is ON and Transformer 2 (T2) is OFF, indicating single-transformer operation with no detected faults. At 59% load, both transformers are active (T1 ON, T2 ON), enabling load sharing to maintain system stability. At 100% load, both transformers are OFF, and a warning notification is generated, indicating the absence of active transformers and the need for immediate intervention.

The lower row presents fault scenarios. In the case of a single line-to-ground fault, the system detects the abnormal condition and automatically adjusts transformer loading while issuing an alert for inspection. For a double line-to-ground fault, the system redistributes load and triggers an emergency notification due to multiple fault occurrences. In the most severe case, a three-phase short circuit is detected, leading to transformer disconnection and a critical alert requiring immediate maintenance action.

Overall, the figure demonstrates the system's capability for continuous monitoring, intelligent fault detection, automated response, and real-time operator notification via a mobile interface, enhancing reliability, safety, and rapid decision-making in smart power distribution networks.

Smart Power Alert

Load Status: 47%

Transformer Status: T1 ON, T2 OFF

System operating normally. No faults detected.

Smart Power Alert

Load Status: 59%

Transformer Status: T1 ON, T2 ON

Load sharing active. System stable.

Smart Power Alert

Load Status: 100%

Transformer Status: T1 OFF, T2 OFF

Warning: No active transformers. Immediate action required.

(a) 47% Load, T1 ON, T2 OFF (b) 59% Load, T1 ON, T2 ON (c) 100% Load, T1 OFF, T2 OFF

Smart Power Alert

Fault Detected: Single line-to-ground

Transformer load automatically adjusted.

Alert: System response initiated. Check faulted line.

Smart Power Alert

Fault Detected: Double line-to-ground

Transformer load redistributed.

Emergency alert: Multiple fault lines detected. Protective measures activated.

Smart Power Alert

Fault Detected: Three-phase short-circu

Transformers disconnected to prevent damage.

Critical system alert! Immediate maintenance required.

(d) Single Line-to-Ground Fault (e) Double Line-to-Ground Fault (f) Three-Phase Fault Detection

Figure 12 Mobile interface of the proposed system showing real-time load status (47%, 59%, 100%) and detection of SLG, DLG, and three-phase faults with automated transformer control and alert generation

6. Conclusion

In conclusion, this paper presents an innovative approach to modernizing power distribution by implementing an automatic load-sharing system for distribution transformers using an Arduino microcontroller and underground cabling. By intelligently monitoring voltage and current, the system efficiently balances electrical loads across multiple transformers, reducing the risk of overheating, equipment failure, and energy loss. The use of underground cables enhances system reliability by protecting the network from adverse weather conditions while improving urban aesthetics and ensuring greater public safety. Overall, this paper represents a significant advancement toward developing smart, resilient, and efficient power distribution networks capable of adapting dynamically to real-time load demands.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that there is no conflict of interest.

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