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Voltage Vigilance: Ensuring Balance and curbing Theft in Power Distribution Networks

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Abstract

This project proposes a system for detecting electrical overload and earth faults using an Arduino Uno controller. The system uses a current sensor to identify overloads and a voltage sensor to detect earth faults. An ESP8266 module allows users to switch between the two fault detection modes. When an overload is detected, the Arduino turns off AC bulbs using a relay and sends an alert message via a GSM module. Similarly, for an earth fault, the Arduino switches off the bulbs and sends an alert. The system includes an LCD screen to display status. This design enhances safety, provides real-time alerts, and is user-friendly. It is suitable for homes, industries, and commercial spaces, ensuring electrical safety, protecting equipment, and promoting efficient energy use. Efficient power distribution is critical for the sustainability and reliability of modern energy systems. However, challenges such as load imbalances and electricity theft significantly hinder operational efficiency, escalating costs, and undermine grid stability. This paper explores a comprehensive framework for ensuring balance and mitigating theft in power distribution networks using advanced monitoring, data analytics, and smart grid technologies. A two-pronged approach is proposed: first, employing real-time load balancing through dynamic demand-response mechanisms to optimize energy allocation; second, leveraging machine learning algorithms and Internet of Things (IoT)-based smart meters to detect anomalies indicative of theft. Case studies and simulation results demonstrate significant reductions in distribution losses and improved grid efficiency.

Keywords: *Arduino Uno controller, ESP8266 module, fault detection, and Internet of Things.*

INTRODUCTION

This project proposes a system for detecting electrical overload and earth faults using an Arduino Uno controller. The system uses a current sensor to identify overloads and a voltage sensor to detect earth faults. An ESP8266 module allows users to switch between the two fault detection modes. When an overload is detected, the Arduino turns off AC bulbs using a relay and sends an alert message via a GSM module. Similarly, for an earth fault, the Arduino switches off the bulbs and sends an alert. The system includes an LCD screen to display the status. This design enhances safety, provides realtime alerts, and is user-friendly. It is suitable for homes, industries, and commercial spaces, ensuring electrical safety, protecting equipment, and promoting efficient energy use. Manual monitoring requires constant human presence and attention to identify faults. This dependence on human operators introduces the possibility of errors and oversight. Manual monitoring is a time consuming process that requires operators to physically inspect and analyze the electrical system The proposed method ensures enhanced safety by promptly detecting overload faults and earth faults, allowing for immediate action to prevent potential hazards such as electrical fires or equipment damage. The integration of a GSM module enables real-time alert messages to be sent to a registered mobile number, ensuring that the user is promptly notified of any detected faults, allowing for quick response.

LITERATURE SURVEY

The existing literature explores diverse strategies for voltage vigilance ensuring balance and curbing theft in power distribution network with by Inam Ullah Khan, et al investigated how a highly imbalanced class distribution dataset can be arranged to train a classifier for the identification of normal and abnormal electricity consumption patterns.[1]
Another relevant work by Inam Ullah Khan et al has proposed a DL-based multi-model ensemble approach, PFSC, to capture abnormal electricity consumption patterns in smart grids. This methodology has been evaluated using realistic electricity consumption data issued by SGCC, the largest power utility in China. [2] The study by Eddin et al investigated FIT generation ET attack detection in renewable energy-based DG units. We proposed efficient detectors with high detection rates, and we used a realistic energy profile dataset that includes the reported injected energy for three years.[3] Towards an Electricity Theft Detection Method by Sun et al, explained to restrain these economic losses, power enterprises often assign their workers to check the meter of suspicious customers or update the protective device of meter. However, inevitably, these traditional methods have obvious disadvantages.[4]
Lastly, Zhang et al explained that the traditional means of electricity theft prevention is mainly through regular investigations by professionals and the installation of monitoring or alarm instruments systems in the meter box. However, these methods not only waste considerable human and material resources but also have very low efficiency. Together, these studies provide valuable insights into the voltage vigilance, and which would help in preventing the theft from the power distribution network.[5]

BLOCK DIAGRAM

The block diagram of the system contains several components as shown in Figure 1
1. Power Supply
2. Arduino Uno
3. Voltage Sensor
4. Current Sensor
5. Four Channel Relay
6. Lamp (2)
7. Esp8266

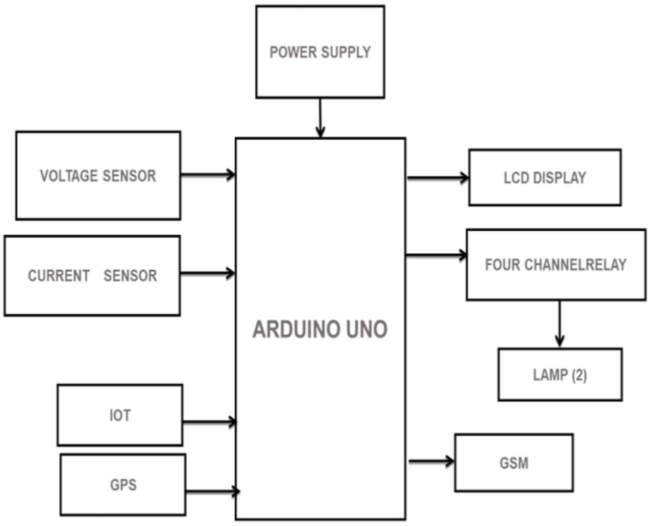

Figure 1: Block Diagram of the proposed system

PROPOSED SYSTEM

The proposed method utilizes a current sensor and a voltage sensor to detect overload faults and earth faults, respectively. The current sensor continuously monitors the electrical current flowing through the system, while the voltage sensor checks for the presence of voltage on the earth. The Arduino Uno detects an overload fault [6-8], activates the relay to turn off AC lamps, and sends a GSM alert. In the case of an earth fault, it repeats the process, ensuring safety and notifying the user via GSM. his work proposes a dual-layered approach to ensure balance and mitigate theft in power distribution networks. The first layer focuses on real-time load balancing through dynamic demand-response systems that use predictive algorithms to optimize energy distribution based on consumption patterns and grid conditions. [7-10] Advanced optimization techniques, such as machine learning-based predictive modeling, will be integrated with smart grid infrastructure to manage fluctuations and prevent overloading. The second layer targets theft detection by deploying IoT-enabled smart meters and implementing advanced anomaly detection systems. These systems will analyze consumption data using machine learning algorithms, such as clustering and classification, to identify irregularities that suggest unauthorized usage or tampering. [11-15] The framework will be validated through simulations and case studies using real world datasets, highlighting its effectiveness in reducing losses, enhancing grid stability, and promoting energy efficiency.

WORKING PRINCIPLE

Basically, this system works upon the following three modules:
Overload Detection Module.
Earth Fault Detection Module.
Alert Module.

The heart of this system is the Arduino Uno, functioning as the central con-troller, tasked with detecting both overloads and earth faults. Monitoring electrical current is achieved through the use of a current sensor. The ESP8266, an IoT module, provides the capability to select between modes for identifying either an earth fault or an overload fault. Initially, the system includes two AC bulbs connected via a four-channel relay. When the first bulb is activated, the current remains within safe limits, indicating no overload. However, upon activating the second bulb, the current surpasses the acceptable threshold. This prompts the Arduino to automatically deactivate both bulbs using the relay, thus preventing further overload. Concurrently, a GSM module dispatches an alert message to a preregistered mobile number, notifying the occurrence of an overload fault. In addition to overload detection, the system incorporates a voltage sensor to detect voltage on the earth. If voltage is detected, signalling an earth fault, the Arduino intervenes by cutting power to the AC bulbs to ensure safety. Once again, the GSM module sends an alert message to the designated mobile number, indicating the identification of an earth fault. For visual status updates, an LCD display is integrated. The LCD screen provides essential information, including current system status (normal operation, overload fault, or earth fault), detected fault type, and alerts transmitted via GSM.

Overload detection Module:

The Overload Detection Module is a critical component of the system, tasked with preventing electrical overloads. It employs a current sensor to continuously monitor the electrical current, feeding this data to an Arduino Uno acting as the central controller. The Arduino, in conjunction with an ESP8266 module, allows users to select the overload detection mode. Two AC bulbs are connected through a relay, and when the system detects an overload, the Arduino automatically deactivates both bulbs through the relay, preserving the system's safety. Simultaneously, it triggers a GSM module to send an alert message to a registered mobile number, notifying of the overload occurrence. GPS for finding a location.

Earth fault detection Module:

The Earth Fault Detection Module plays a crucial role in electrical system safety. It employs a voltage sensor to identify voltage presence on the earth, which indicates an earth fault. When an earth fault is detected, the Arduino Uno, acting as the central controller, triggers a relay to disconnect the power supply to AC bulbs, ensuring safety. The ESP8266 module facilitates mode selection for earth fault detection. In parallel, a GSM module sends alert messages to a registered mobile number to promptly notify users of the earth fault. This module enhances electrical system safety in residential, industrial, and commercial settings.

Alert Module:

The Alert Module in the system is responsible for sending alert messages via SMS through the GSM module to a registered mobile number whenever overload or earth faults are detected. Additionally, an LCD display is integrated into this module to provide a visual representation of system status, including information about the current state (normal, overload fault, or earth fault), the type of detected fault, and any alert messages transmitted via GSM. This combination of alert notifications and real-time information displayed on the LCD screen ensures comprehensive monitoring and effective response to electrical faults in the system.

SIMULATION

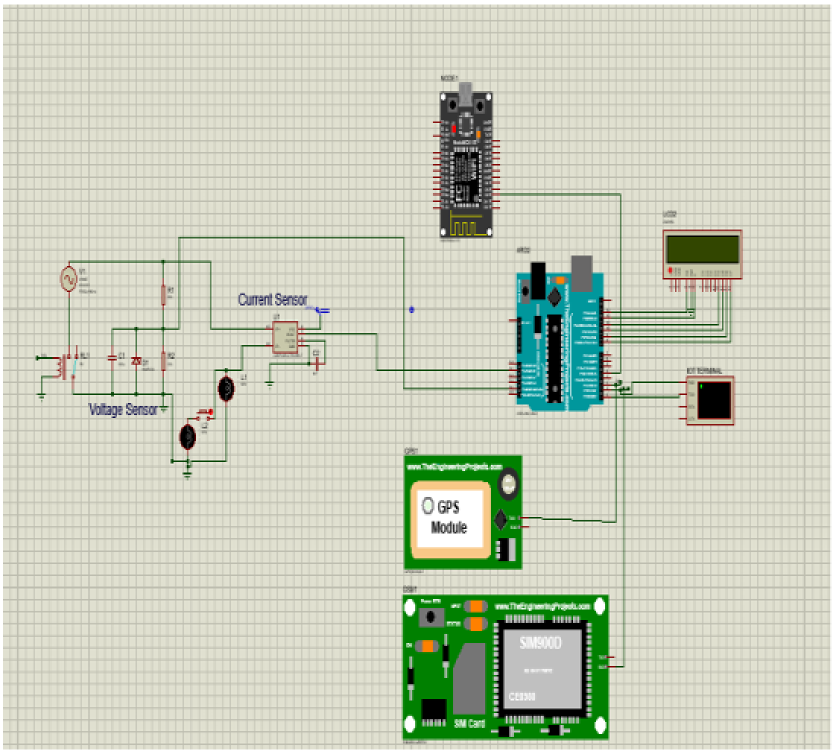

Figure 2: Simulation Circuit of the proposed system

According to the figure 2 by using Protecus Software The integration of GSM modules for alert notifications and an LCD screen for visual feedback adds to the user-friendliness of the system. This project's working principle not only addresses safety concerns in residential, industrial, and commercial environments but also contributes to efficient energy management. By continually evolving and incorporating future enhancements, this system can further revolutionize fault detection and prevention in electrical systems, ultimately improving the reliability and sustainability of the electrical infrastructure

RESULT & DISCUSSIONS

A Voltage Vigilance System is essential for ensuring balance in power distribution networks and addressing one of the critical challenges in the energy sector: power theft. By integrating smart technologies, monitoring devices, and predictive analytics, the system continuously tracks and analyzes voltage levels, current flows, and patterns across the network. The primary goal of this setup is to maintain stability in the power grid by detecting anomalies, identifying possible theft, and pinpointing areas with high loss rates. Power theft disrupts the balance of the network and leads to inefficiencies, increased costs, and strain on resources. Left unchecked, it can contribute to severe operational and financial losses for utility companies, as well as potential blackouts for consumers. Where the battery low condition is shown in figure 3.

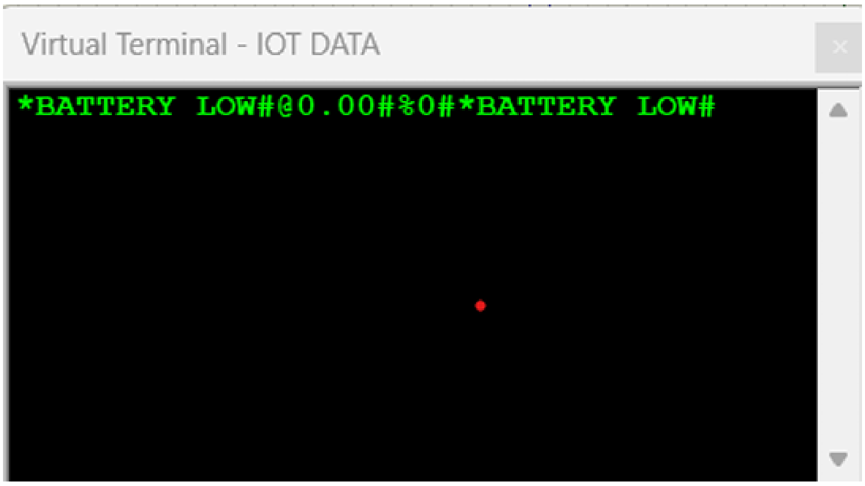

Figure 3: Low Battery Condition

The Voltage Vigilance System uses advanced sensors and Internet of Things (IoT) devices that collect real-time data, which is then processed through machine learning algorithms to detect unusual activities. When irregular voltage or current levels are detected, the system triggers an alert for immediate investigation. For example, an unusual spike in power consumption in a specific area can indicate tampering or unauthorized access, while an unexpected drop might point to equipment failure or maintenance needs. This system not only detects theft but also helps in identifying potential faults in the network, enabling proactive maintenance, reducing downtime, and ensuring more reliable service delivery. Additionally, the system aids in balancing the load across different areas, optimizing power distribution and preventing overloads that could lead to equipment damage. Through this vigilant approach, utility companies can improve efficiency, lower operational costs, and ensure a more equitable distribution of power resources. In the long term, such systems build trust with consumers and contribute to a more sustainable energy ecosystem by reducing wastage and improving overall grid resilience. The total output page will be represented below as the figure 4

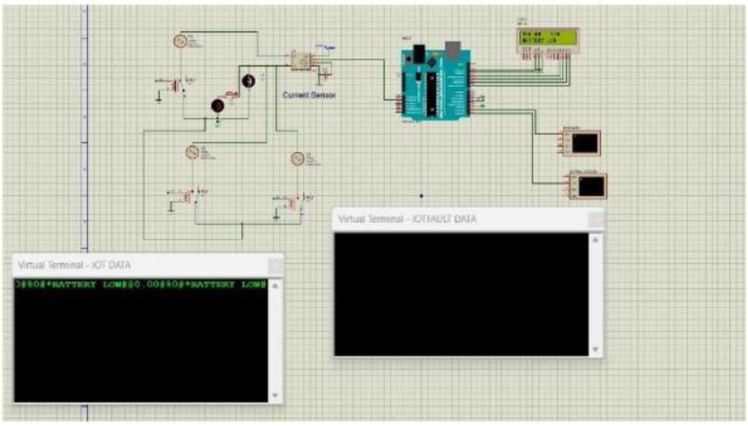

Figure 4: Output Page of the system

APPLICATIONS

The system can be installed in residential buildings to enhance electrical safety. It provides protection against overload faults and earth faults, minimizing the risk of electrical accidents, fires, and equipment damage. In industrial environments, the system can be integrated into machinery and equipment to monitor current and voltage levels. It ensures that the machinery operates within safe limits, preventing overloads and potential damage to critical components. The system can be deployed in commercial establishments such as offices, hotels, or shopping centers. It helps maintain the electrical system integrity, reduces downtime due to faults, and provides an additional layer of safety to protect occupants and property

FUTURE ENHANCEMENT

A promising future enhancement for this system could involve the implementation of machine learning algorithms for predictive maintenance. By continuously collecting data on electrical system behavior, including current and voltage patterns, the system can establish baseline parameters and usage patterns. Machine learning models can then analyze this data to predict potential overload or earth fault occurrences before they happen. This proactive approach would not only prevent electrical faults but also optimize energy usage, reducing downtime and maintenance costs. Furthermore, incorporating remote monitoring and control through an internet connected interface could provide users with realtime insights and the ability to remotely manage electrical systems, enhancing overall safety, efficiency, and convenience, especially in complex industrial or commercial environments where quick responses to faults are crucial.

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