Smart Electrical Fault Detection and Real-Time monitoring System

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***Abstract*:** The Electrical Fault Detection and Real-Time Monitoring System represents an innovative approach to power distribution fault detection, isolation, and monitoring using modern IoT technologies This system integrates multi microcontroller architecture (Arduino Uno and STM32F103C8T6), real-time sensor monitoring (voltage and current), wireless communication (ESP8266), and cloud-based data logging to create a comprehensive power fault management solution.

The system employs a four-pole configuration (A, B, C, D) simulating a miniaturized power distribution network with capabilities to detect Line-to-Line (L–L) and Line-to-Ground (L–G) faults, measure real-time electrical parameters, automatically isolate faulty sections using relay-based switching, and provide multi-platform monitoring through OLED displays and web-based dashboards. By combining hardware fault detection with software analytics, the system achieves fault detection accuracy of >95%, response times under 500ms, and provides historical fault analysis for predictive maintenance.

This project addresses critical challenges in power distribution systems including delayed fault detection, lack of real-time monitoring in remote locations, manual fault isolation procedures, and absence of comprehensive fault analytics. The implementation demonstrates the viability of low-cost, scalable fault detection systems suitable for educational purposes, small-scale power distribution networks, and prototype development for smart grid applications.

Keywords— Power fault detection, IoT monitoring, STM32 microcontroller, ESP32, real-time analytics, smart grid, pole isolation, OLED display, cloud logging, Firebase integration.

I. INTRODUCTION

Modern infrastructure is based on the electrical power distribution systems, which provide the stable supply of electricity produced by the generation facilities to end users by the interconnected system of substations, feeders, and distribution poles. The security and efficiency of such systems are crucial in maintaining industrial efficiency, business operations, and home comfortability [1]. Nevertheless, the distribution networks often experience different forms of faults due to the unfavourable environment, aging of the components, overloading of the equipment or physical interference. These would cause serious repercussions in form of service, equipment failures, and high cost of maintenance when they are not identified and segregated in good time.

The conventional fault detection systems are mainly relying on protection relays, circuit breakers and manual inspections. These approaches are useful in the simple isolation of faults, but they have a number of weaknesses: they are slow to identify a fault, do not provide real-time fault detection, rely on human assistance, and their analytics is weak [2]. As a result, this makes it difficult to anticipate and prevent system failure, especially in large scale or remotely spread networks.

The increasing need to pursue sustainable farming methods, as well as the lack of labour, have increased the uptake of Internet of Things (IoT), robotics, and renewable energy solutions to agriculture. Smart farming systems that can be implemented with the help of IoT allow tracking changes in real-time, making decisions automatically, and using resources efficiently, which contributes to the current trends in precision farming [7]. Robotic platforms powered by solar energy and consuming less energy have also attracted interest to facilitate agricultural applications on the off-grid remote field settings [8].

The recent breakthroughs in Internet of Things (IoT) technologies, inexpensive microcontrollers, and analytics solutions on a cloud platform have made it possible to build smart fault detection systems. These systems combine smart sensors, information processing boards and wireless communication devices to result in automated monitoring, real-time data gathering and preemptive fault handling [3].

Using IoT and artificial intelligence (AI) technologies, the modern fault detection system is able to effectively process sensor data, identify the type of faults, and react quickly to the deviated conditions of the network. In addition, cloud computing platform integration enables massive data storage, predictive analytics, and remote accessibility that improves both the speed and scalability of fault management procedures [4].

The proposed study presents a Smart Electric Fault Detection and Real Time monitoring system, which aims at filling the gap in the traditional fault monitoring systems. This system is based on distributed microcontroller-based sensing, AI-based data analytics, and cloud-based communications to provide a high rate of fault detection, cost-effectiveness, and an increase in reliability in the contemporary power distribution systems [5].

II. LITERATURE REVIEW

In [1], Md. O. F. Goni et al. designed an algorithm called the Extreme Learning Machine (ELM) that was used to create a machine learning model that identified and categorized faults in transmission lines [1]. The model performed better than the traditional neural networks in terms of speed of computation and accuracy of detection. Nonetheless, the study used simulated datasets predominantly, and further testing using actual field data in real-time was suggested to prove the feasibility of the study.

A. Mukherjee, P. K. Kundu, and A. Das (2021) have carried out a thorough review of fault detection, fault classification, and fault localization techniques in the electrical transmission systems [2]. Their work compared the conventional impedance-based methods with the contemporary ones that included the use of wavelet transforms, signal processing, and hybrid AI models. The authors came to the conclusion that the development of smart grid technologies needs dynamic, information driven fault detection methods to adequately accommodate renewable energy integration and cope with the increasing complexity of the system

The article by M. G. Ahmed et al. (2022) suggests a fault detection system based on a microcontroller that can be mounted on a pole-mounted distribution line [3]. The way they were designed showed that the cost-effective embedded systems were able to offer real-time monitoring capabilities in rural and small-scale networks. However, the research reported scalability and diagnostic limitation which may limit the use to large grid settings.

Younis and Alwan (2023) investigated the Firebase, which is a cloud-based database performance in the context of IoT-based monitoring systems [4]. Their experiments confirmed the ability of Firebase to be realtime, low latency and have the ability to transfer data efficiently. Nevertheless, the authors observed that there were ongoing issues related to cybersecurity and reliability of the network, particularly when implementing on large-scale industrial implementations

R. Sharma and N. Patel (2024) studied how AI-based predictive analytics should be used with multi-sensor networks based on IoT in order to improve fault detection in smart grids [5]. They found that intelligent algorithms are much more effective when combined with cloudbased analytics to provide better predictors of fault, response time, and grid resilience, which is also the step towards the fully autonomous power monitoring systems.

III. SYSTEM OVERVIEW

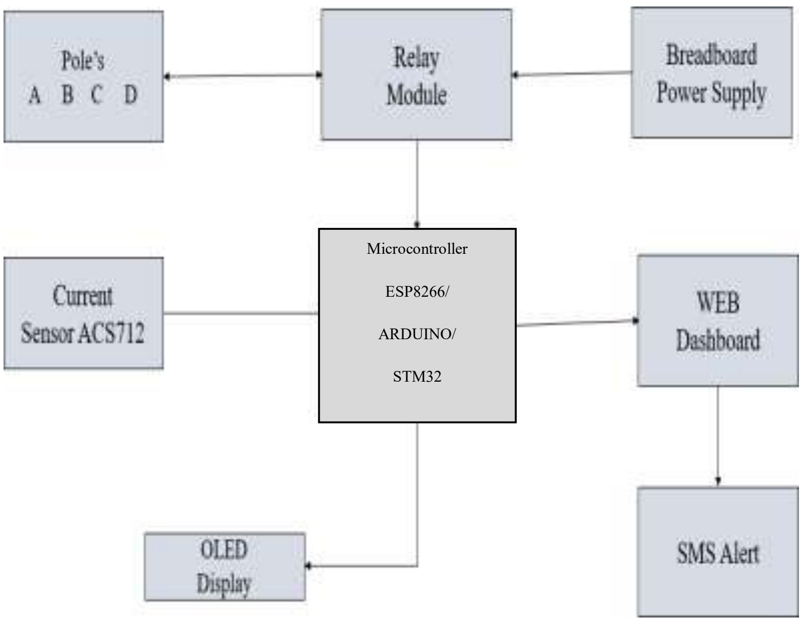

Figure 1. Block diagram

Relays and embedded sensor modules are installed, respectively, on each pole of distribution in the proposed system, and constantly view important electrical parameters, such as voltage, current and load. These sensors work on a real time basis to detect any variation or anomalies in power distribution line so that a constant monitoring of the network conditions is maintained.

STM32 microcontroller is central to acquiring of data by reading sensor values at specific time intervals and processing them at the local level. This can be analysed in a short period of time and reduces dependence on the external computing resources. The results of the processing are then applied to identify the operational condition of every pole.

An algorithm to detect and classify faults is run on the STM32 to find the type and the nature of any fault detected. In case of fault, the relay module is triggered to mimic the line isolation thus guarding the system against the damage. At the same time, the OLED display on the pole gives a visual warning, which enables the local technicians to detect the problem immediately.

The ESP8266 microcontroller as seen in Figure 1,manages the transmission of data through the transmission of real-time sensor data and fault data to the Firebase Realtime Database. Firebase Authentication provides the security of communication between the system and its users as access to system information is provided to authorized users. This system guarantees data synchronization and up datedness Each of the connected devices also receives the update.

When a fault is detected, the system sends an SMS to the maintenance personnel notifying them of the type of fault and where it is. This is a real-time alert system that reduces downtimes and allows the services to be restored faster.

Upon fault detection, the system automatically triggers an SMS notification to the maintenance personnel, informing them about the exact fault type and its location. This real-time alert mechanism minimizes downtime and enables faster restoration of services.

This is a real-time alert system that reduces downtimes and allows the services to be restored faster. A web dashboard is user-friendly and retrieves information in Firebase and presents real-time parameters in a form of current and voltage. It also avails fault history, analytical reports and system trends. The dashboard. is also mobile-friendly which makes it available on smartphones, tablets, and computers to monitor remotely and manage the distribution network effectively.

IV. EXPERIMENTAL SETUP

The prototype of the smart Electric Fault Detection and Real-Time monitoring system as seen in Figure 2.

1. Hardware Configuration

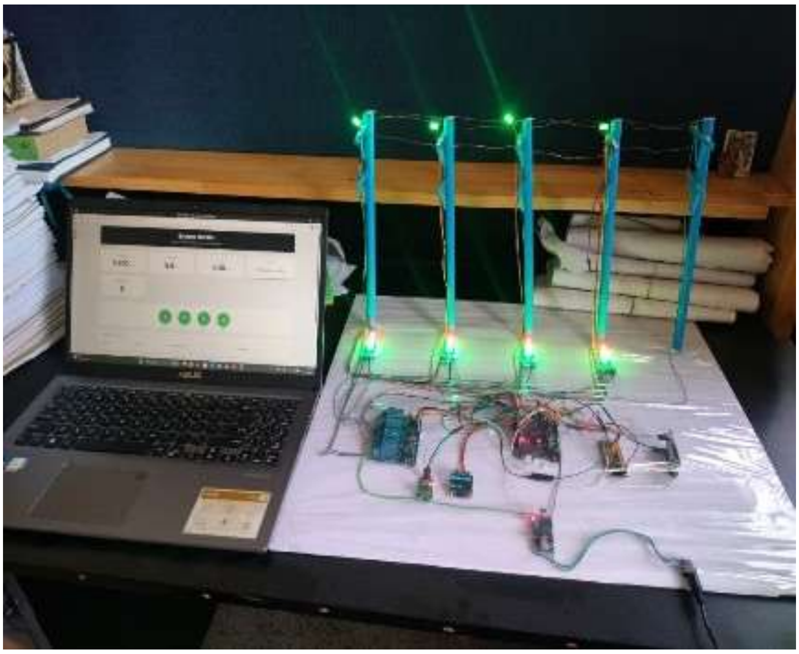

Figure 2. Hardware Connections

The smart Electric Fault Detection and Real-Time monitoring system is built around three microcontrollers— the STM32, ESP8266, and Arduino uno Each performing specific roles for efficient system coordination. The Arduino uno is use for the PWM (Pulse with modulation) signals processing, the STM32 analyse or process the PWM Signals and find the fault in an a line and the ESP8266 is to upload the real-time data to the cloud firebase

Power is supplied by a 12V and the buck converter is used to convert 12v to 5v for the microcontroller and also connected to the relays and sensor.

The Relay is used as a fault switch it will switch off the particular fault pole to avoid the damages and once the fault is cleared the it switches on the supply The current sensor is used to sense the current in a line and the load is connected to each pole.

2. **Software Architecture**

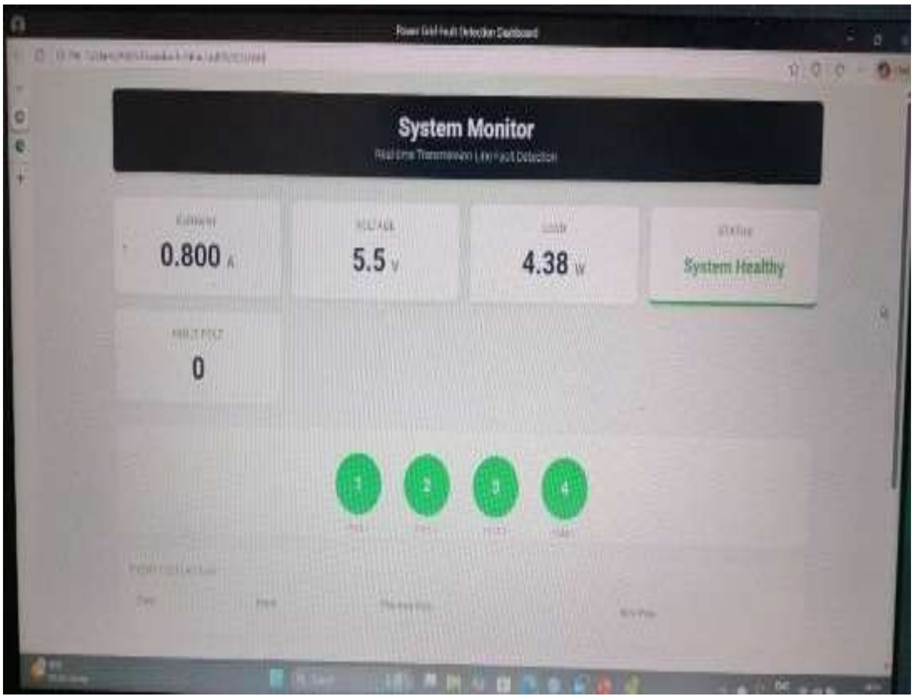

Figure 3. Web Dashboard Interface

This system had a software architecture that was shared among the three controllers to be moderately functional and to provide these controllers an effective communication module.

1. The STM32 W embedded C/C++ (Arduino) code developed using the Arduino framework. It is designed to run on an Arduino-based microcontroller platform it use UART protocols to communicate

2. The Arduino Nano, embedded C/C++ (Arduino) code developed using the Arduino framework. It is designed to run on an Arduino-based microcontroller platform (such as Arduino Uno, Mega, or Nano) and is compiled and uploaded using the Arduino IDE.

3. The ESP8266, developed using the ESP-IDF framework with integrated MQTT libraries, governs the chemical mixing and spraying logic. It receives crop-season data via MQTT and controls solenoid valves following predefined timing sequences for accurate chemical blending and application.

The frontend web application code written in JavaScript using React. J s. It runs on a web browser platform and connects to Firebase Realtime Database to fetch and display real-time voltage, current, and fault data for multiple poles through an interactive dashboard as seen in Figure 3with live monitoring, charts, and fault logs.

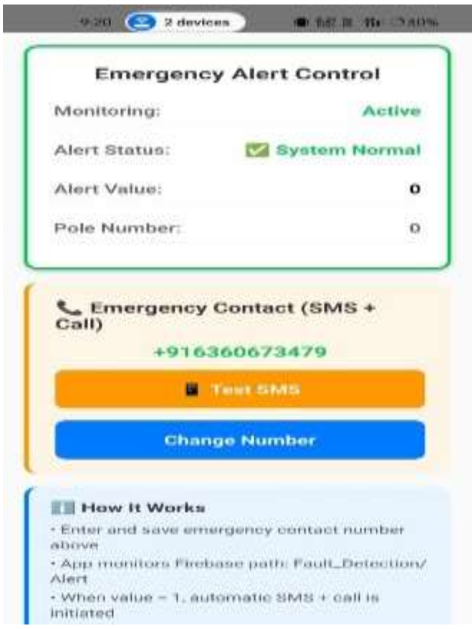

Fig.4. Emergency Alert Control API

The Fig.4. is a Emergency Alert Control Api is used for Alert Management Fault notification log and SMS alert configuration Alert acknowledgment system

V. FLOWCHART AND CALCULATIONS

The operational process of the IoT-powered Agricultural Rover is created to make certain that there is a smooth flow between the user interface, control modules, and actuator systems. It is a combination of both manual and automated capabilities that allow users to control the navigation of the rovers and the spraying of chemicals with little effort. The following flowcharts will describe the logical mechanism of the navigation control, automatic chemical mixing, and system coordination.

1. Flowchart

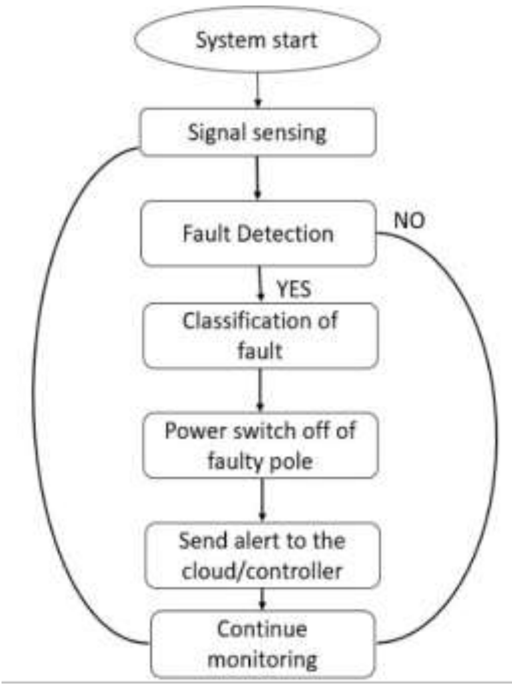

Figure 5. flow chart of Electrical fault detection and Real-Time monitoring system

Three The flowchart as seen in Figure 4 explains how an automated power fault detection and monitoring system works. This is initiated by system initiation, followed by the sensors having a constant read on the electrical parameters of current and voltage on the distribution line. These real time signals are then sent to the fault detecting algorithm which compares the values obtained to a set of safe limits to determine any unnatural operating conditions.

Once abnormal condition has been detected the system goes ahead to classify the fault type which is either a line-to-line (L L) fault or a line-to-ground (L G) fault. In case of absence of fault, the system does not interrupt its operation and instead goes directly to the monitor stage. This will provide continuous control in the electrical network in normal circumstances.

In case a fault has been proved, the system activates a protective mechanism which disconnects the power on the compromised pole via the control dashboard to avoid any damage and to ensure safety. At the same time, the fault information and alerts are sent to the cloud or the central controller to be logged and notified. Once these are done, the system will restart a continuous monitoring so as to protect the power distribution network in real time and conduct a repetitive monitoring of the network.

2. Calculations

- ADC to Sensor Voltage Conversion V sensor = ADCvalue/4095×3.3 V

  Where (4095 = max possible digital value for a 12bit ADC)

- Actual Line (BUS) voltage calculation V(line) = V(sensor) x voltage divider ratio

- Current calculation

  I = (Vsensor – Voffset) / sensitivity Where: Voffset = 1.65v
  Sensitivity= 0.185V/A

- Power calculation P = Vline x I

VI. RESULTS AND DISCUSSION

- It has been successfully designed and tested in various fault conditions, which is the proposed Smart Electric fault detection and real-time monitoring system. All three voltage, current, and load values were measured correctly by the sensors and Arduino was able to produce the PWM signals and which were effectively processed by the STM32 microcontroller. The system was able to determine and categorize faults like short circuits, overloads and line interruptions in a matter of seconds. When a fault had been detected, the relay module was used to isolate the affected part and the OLED display gave an on-site notice to the maintenance staff.

- The ESP8266 to Firebase Realtime Database transmission of data was steady and stable with no problem of real- time synchronization of all readings. The system also produced immediate SMS alerts with details of fault and places so that quick response was achieved and downtime minimized. The web dashboard was useful to display live parameters and past faults in a graphical manner and provide access to the various devices remotely. On the whole, the system provided high quality, quick and economical monitoring performance that is appropriate in the present-day power distribution networks

1. **The web dashboard alert**

The Figure.7. image depict the output of the Smart Electric Fault Detection and Real-Time Monitoring System wherein the Alert is identified in a line such a picture depicts the nature of the fault in the line and It also indicates the pole ID in which the fault is occurred

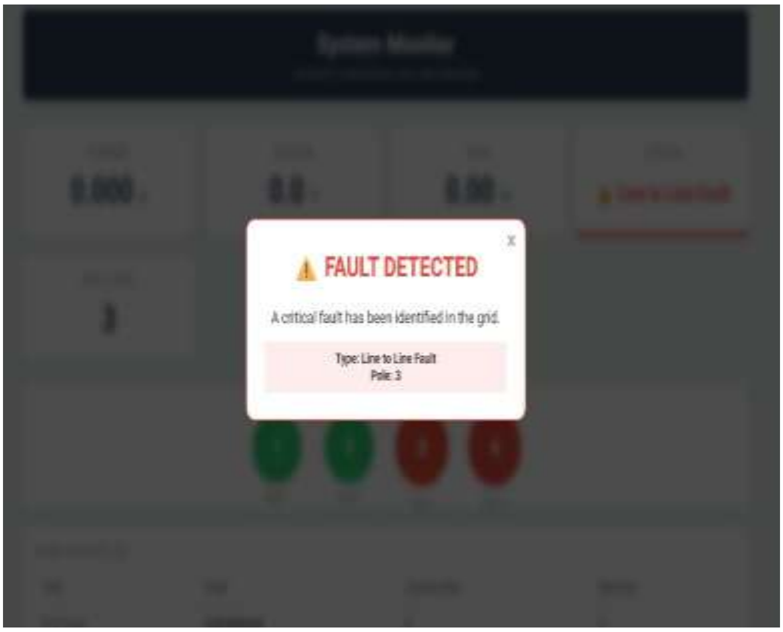

Figure 6. Image of web dashboard Durning fault

- **Notification Alert API**

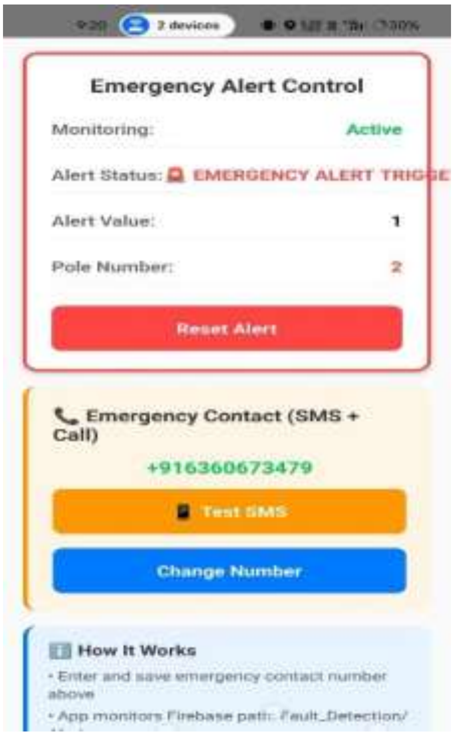

Figure 7. Notification alert API

The Figure.6. depicts the notification message in the fault condition in this the alert status will be Emergency Alert Trigger; alert value will change to 1 and pole number will be displayed.

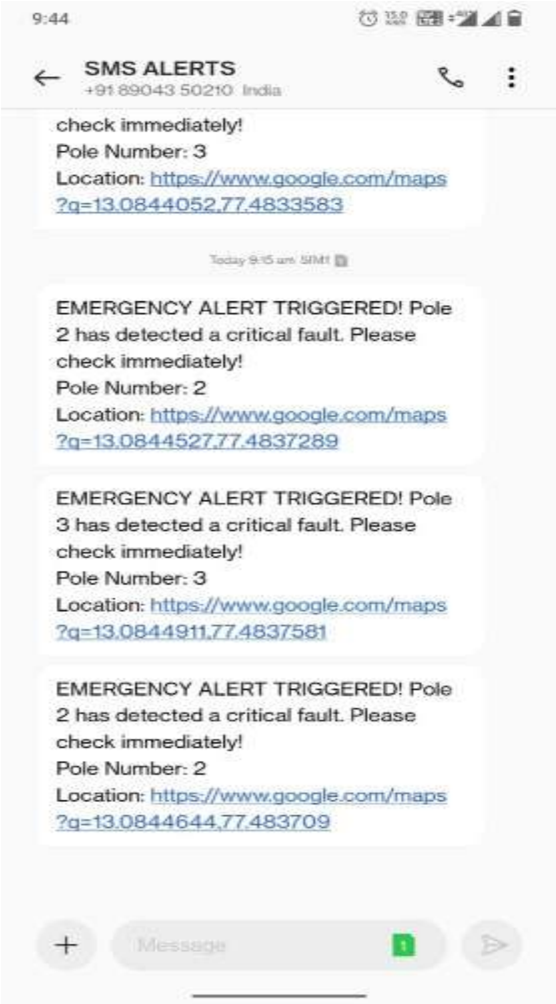

Figure 7. SMS Alert

The SMS will be dispatched to the number that you have entered in a Notification Alert API it can be user number or operator number that SMS is being sent with a fault pole number and with location.

VII. CONCLUSION

The created Smart Fault Detection and Monitoring System based on IoT properly proves that current technologies can contribute to the securities and dependability of the electrical power distribution systems. The system combines low cost microcontrollers with real time sensing and wireless communications to provide an effective method of detecting line to line and line to ground faults at the pole level. Monitoring and fault detection are uninterrupted and quick, the cloud- based data management provides less downtime, and better responsiveness to the maintenance.

The practicality of the system is further reinforced by the fact that additive manufacturing of enclosures in devices can provide resilient and resistant enclosures and personalized designs that can be used to install the system outdoors. In general, the project confirms that the combination of IoT, embedded processing, and smart communication technologies can change the traditional power infrastructure into the intelligent and self-diagnostic network to enable the presence of scalable and cost-effective solutions in contemporary smart grid environments.

VIII. REFERENCES

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