



A Real-Time Transmission Power Line Monitoring and Fault Detection Embedded System Using Internet of Things Technology

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Abstract: Electric power distribution is a critical infrastructure component; its reliability is paramount to the effective functionality of the modern society and how it is transmitted through power line. The reliability of electrical power transmission networks is crucial to the stability and efficiency of modern power systems. Conventional manual fault detection methods are often slow, labour-intensive, and inadequate for addressing real-time challenges in large-scale transmission grids. The demand for stable electricity is growing across various sectors such as industry, agriculture, banking, education, etc and has led to a significant increase in the requirement for effective electric power transmission. Nigeria power sector faces major challenges, particularly frequent electrical cable faults, cutting of electric cable, stealing of the cable when they discover no current flowing through it. Hence, an IoT-based electrical cable fault detection system to address these problems in Nigeria power sector would be the right solution. This paper presents a real-time power transmission line monitoring and fault detection system based on the Internet of Things (IoT) technology. The proposed system integrates smart sensors, microcontrollers, and wireless communication modules to monitor key parameters such as voltage, current, temperature, and line vibration. Data is transmitted to a cloud-based platform for analysis and visualization, enabling remote fault diagnosis and early warning notifications. Experimental results demonstrate that the IoT-based solution achieves high accuracy in fault detection, minimizes downtime, and significantly improves grid reliability and operational efficiency.

KEYWORDS: ESP8266 microcontroller board, Power Transmission, Fault detection, IoT, Real-time monitoring, Smart grid, Cloud computing

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I. INTRODUCTION

Power transmission systems are critical infrastructures responsible for delivering electricity from power generation plants to distribution networks and consumers. These systems consist of high-voltage transmission lines, substations, and distribution networks that span vast geographic areas and distances, that are subject to various environmental and operational stresses that can lead to faults such as short circuits, line breaks, or insulation failures [1]. The reliability and efficiency of power transmission are essential to ensure a continuous supply of electricity, which is vital for both industrial and residential sectors, as failures can cause widespread power outages, economic losses, and even pose safety risks to staff and end-users [2].

Transmission power lines are exposed to various environmental and operational stressors, such as weather conditions, aging infrastructure, and physical damage. These factors can lead to faults, including short circuits, line breaks, and insulation failures, which can disrupt the power supply, cause equipment damage, and even lead to large-scale blackouts. Traditionally, fault detection and monitoring were performed using manual inspections, supervisory control and data acquisition (SCADA) systems [2-4]. However, these methods have limitations, such as delayed fault detection, high maintenance costs, and limited real-time capabilities.

The traditional power transmission systems relied on periodic inspections and routine maintenance schedules to identify and address potential faults. However, these methods are often inadequate because they

cannot detect issues as they arise on site. Real-time monitoring of power transmission lines has emerged as a critical solution to enhance system reliability, reduce downtime, and ensure the continuous delivery of electricity [2]. By constantly tracking key parameters such as voltage, current, temperature, and line sag, real-time monitoring systems can detect anomalies and trigger alerts before minor issues escalate into significant faults. Therefore, there is a growing need for more advanced, automated systems that can monitor the health of transmission lines in real-time and detect faults promptly [4, 20].

Fault detection is a crucial aspect of maintaining the integrity of power transmission systems. Faults can occur due to a variety of reasons, including lightning strikes, equipment failures, weather conditions, and physical damage to the lines [3]. When a fault occurs, it is essential to quickly and accurately identify the location and nature of the fault to minimize disruption and facilitate timely repairs. So, fault should be monitor frequently and isolate faulty line immediately fault occurred. Traditional fault detection methods include impedance-based techniques, traveling wave methods, and the use of phasor measurement units (PMUs) [12].

However, these methods often require complex computations, may not provide real-time data, and can be limited in their ability to pinpoint the exact location of a fault [5-6]. This is where IoT-based solutions offer significant advantages by accurately locate fault location that can help personnel rectify the faults and locate the areas where the faults regularly occur. The sensors can take accurate measurement of an electrical parameters and transfer information to IoT-based medium provided for easy and prompt response to the faulty detected [7]. This would reduce the occurrence of fault and minimize the time of power outages and improve economics activities.

The traditional power line fault detection methods are often slow and labour-intensive, relying on manual inspections that delay repairs, prolong outages, and increase operational costs. This research develops an IoT-based power line fault monitoring system that continuously monitors distribution lines, detects faults in real time, and promptly notifies maintenance teams to expedite response and minimize downtime. This will enhance the reliability and efficiency of power distribution networks by providing real-time detection and reporting of various power line faults. With cloud-based platform to monitor and report power line fault in real-time to the engineer and the community user end [8].

Internet of Things (IoT) technology provide a promising approach for real-time condition monitoring and intelligent fault detection in power systems. IoT enables continuous data acquisition from distributed sensors, real-time analytics, and remote management through cloud-based interfaces. By leveraging IoT-enabled devices, utilities can minimize outage duration, improve maintenance scheduling, and ensure grid stability [9]. The remain section of paper are structures as follows. Section 2 reviews the related works. Section 3 presents the role of IoT in fault detection and monitoring. Section 4 is the system design and implementation. Section 5 is the result evaluation and analysis. The conclusion of the paper is in section 6.

II. LITERATURE REVIEW

The transmission power lines are a vital part of the electrical grid, carrying electricity from generation points to distribution networks. Monitoring these lines in real-time is crucial for maintaining the reliability and safety of the power grid. Recent advancements in Internet of Things (IoT) technology offer new opportunities for enhancing power line monitoring and fault detection. Some literature review explores recent research and developments in IoT-based systems for real-time monitoring and fault detection in transmission power lines.

Authors [10] in their study on IoT-based smart power line monitoring systems present a framework that integrates various sensors with IoT technology to provide real-time data on transmission lines. The authors highlight the use of sensors to monitor voltage, current, and temperature, and discuss the benefits of using IoT for continuous data collection and remote access. The study emphasizes the potential of IoT to improve the accuracy and efficiency of power line monitoring. Also, author [2] proposed a real-time fault detection system for power transmission lines using IoT. The system leverages data from various sensors and employs machine learning algorithms to detect faults. The study demonstrates how IoT-based systems can enhance fault detection capabilities and reduce response times compared to traditional methods but the author did not include real-time monitoring and alert system.

According to author [11], they explore the use of IoT for real-time monitoring and fault detection in power systems. They proposed a method that combines sensor data with advanced algorithms to accurately detect and locate faults. Their research indicates that IoT-based systems can significantly improve fault detection accuracy and localization by providing continuous monitoring and real-time data analysis. Moreover, a work proposed by [13] on an IoT-enabled smart grids and their applications in fault detection. The authors highlight the role of IoT in enhancing the precision of fault detection and localization, and they address challenges such as data integration and processing. The study provides insights into how IoT can be utilized to address common issues in fault detection and improve overall system reliability.

Authors [14] works wireless sensor networks for real-time monitoring and fault detection of transmission lines. Their research focuses on communication protocols and network architectures that are

essential for reliable and secure data transmission. The study provides a comprehensive overview of the challenges in maintaining connectivity and suggests solutions for improving communication in IoT-based monitoring systems. Automated alerts and notifications are critical for the timely response to faults. Research proposed by [2, 10] indicates that IoT systems can effectively generate real-time alerts based on predefined criteria. These alerts help in reducing response times and improving the efficiency of fault resolution. The studies also discuss the integration of alert systems with existing infrastructure to ensure effective communication and timely intervention.

III. ROLE OF THE IOT IN REAL-TIME MONITORING AND FAULT DETECTION IN POWER TRANSMISSION SYSTEM

The Internet of Things (IoT) is a network of interconnected devices that can collect, transmit, and analyze data in real-time. IoT has revolutionized various industries by enabling remote monitoring, predictive maintenance, and automation [15]. In the context of power transmission, IoT can be leveraged to develop embedded systems that monitor the condition of transmission lines continuously, detect faults as they occur, and provide actionable insights for preventive maintenance [7, 13, 16].

An IoT-based real-time monitoring and fault detection system typically includes sensors, microcontrollers, communication modules, and cloud-based platforms. Sensors are deployed along the transmission lines to measure various parameters such as current, voltage, temperature, and vibration [16-17]. These sensors are connected to microcontrollers that process the data and send it to a central server via communication networks like Wi-Fi, Zigbee, or LoRaWAN. The data is then analyzed using algorithms to detect anomalies or faults, and alerts are sent to operators for immediate action [18].

In the context of power transmission systems, IoT would enable the deployment of smart sensors and embedded systems along transmission lines that can continuously monitor various parameters in real-time. These sensors collect data and transmit it to centralized servers or cloud-based platforms where it can be analyzed for signs of faults or anomalies [2, 20]. An IoT-based real-time monitoring system typically involves:

- i. **Sensors:** Devices that measure physical parameters like voltage, current, temperature, humidity, and vibration.
- ii. **Communication Modules:** Components that enable data transmission using protocols like Zigbee, LoRa, or MQTT.
- iii. **Embedded Systems:** Microcontrollers or microprocessors that process sensor data locally before sending it to the cloud.
- iv. **Cloud Platform:** A centralized system that stores, analyzes, and visualizes data, often using machine learning algorithms to predict faults.
- v. **User Interface:** Dashboards or mobile applications that allow operators to monitor the system in real-time and receive alerts.

IV. SYSTEM DESIGN IMPLEMENTATION

The designing of an IoT-based power line fault monitor has two parts, namely the software part and the hardware part.

4.1 The Software Part

This research design, uses three different softwares. The first is the firebase cloud platform, the second is the MIT App Inventor and the third is the Arduino IDE.

4.1.1 Firebase Cloud Platform

The firebase cloud platform, is a software application used to host other mobile or web applications and store data. The four steps required for the firebase cloud platform to be deployed are stated as follows:

- i. Sign in to the Firebase Console – Firebase console (google.com)
- ii. Click “Add project”
- iii. Enter the project name.
- iv. Click “Continue”

When the firebase cloud platform sign-up was successful using a personal email, a welcome page for creating a project popped up. The diagram in figure 1 and 2 shows the welcome page of the firebase and the start up. Machine learning models on cloud platforms to predict transmission line failures using temperature and current data [19]



Figure 1. The firebase welcome

In addition, after successfully signing up with a personal email, the Firebase welcome page will appear, allowing to start creating a project. Figure 2 illustrates this welcome page, once the project setup steps are completed, the next step is to authenticate the account to obtain an Application Programming Interface (API) key and Database Secret key. After successful authentication, a database page will be displayed, and a unique database link will be assigned to the project.

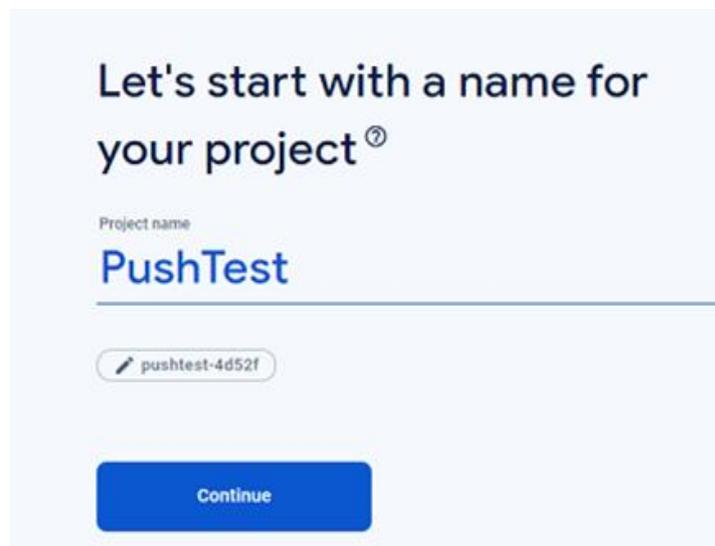


Figure 2. Start up page

Moreover, either API or database Secret key and the database link are needed in the coding of the micro-controller as well as the linking of the developed mobile app with the database. The diagram in figure 3 and figure 4 shows the database secret key and database link respectively.

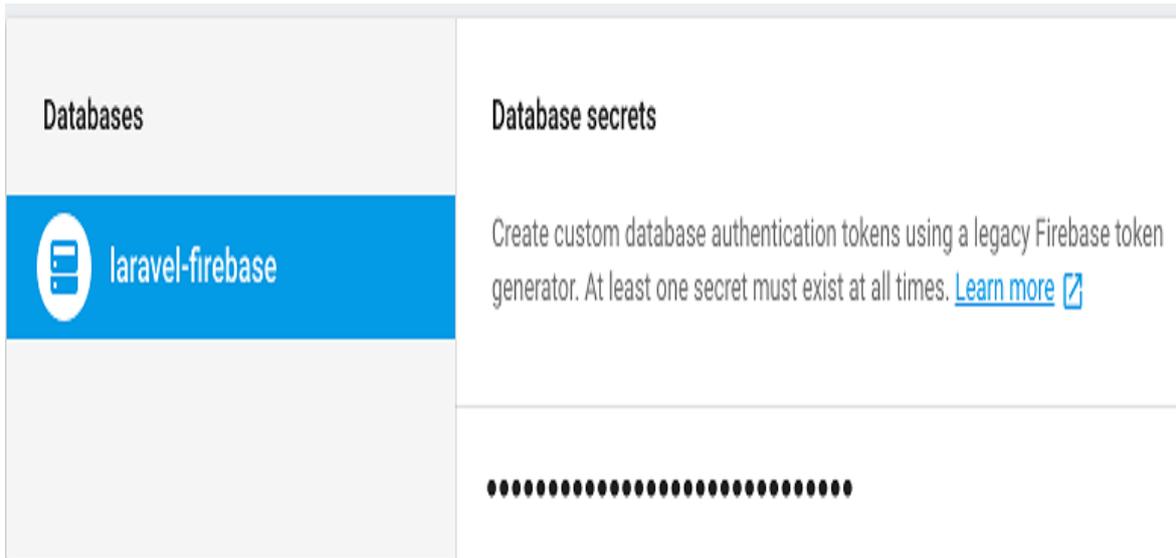


Figure 3. The firebase database secret key setup page

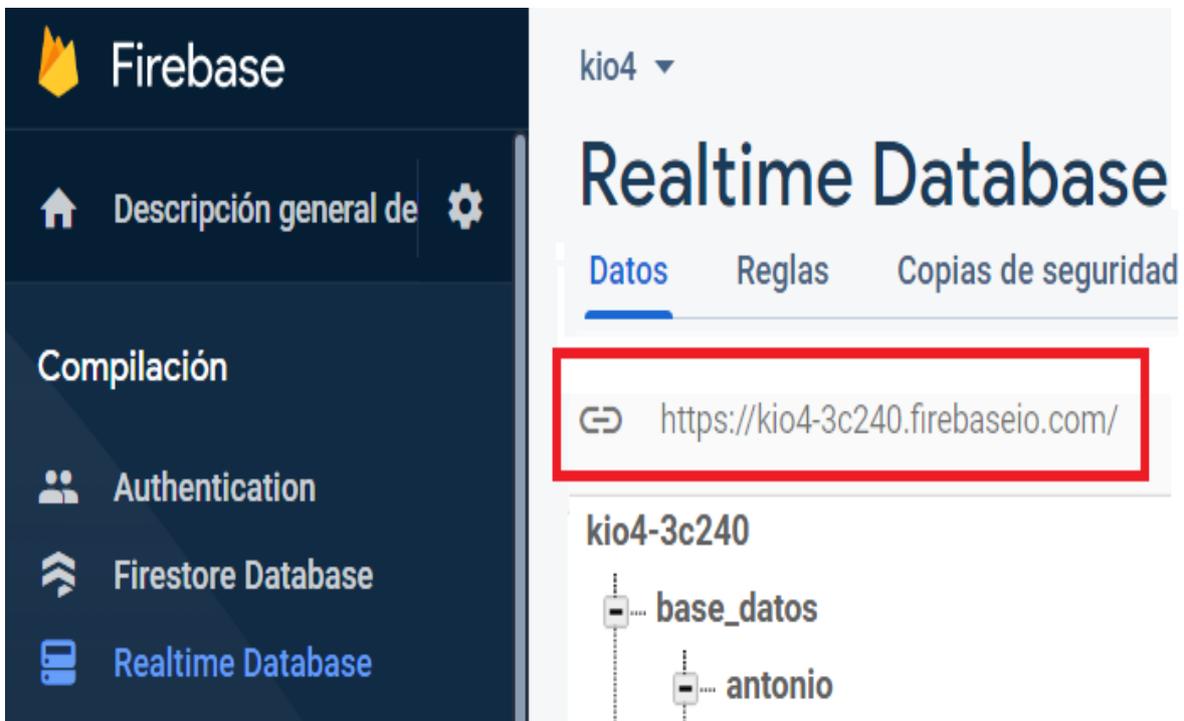


Figure 4. A typical database link needed for the mobile app

4.1.2 MIT App Inventor 2

The other software used in this design is MIT app inventor 2, it is one of the most popular app inventor software. It was employed in this design to create a mobile app for easy access to the data on our developed firebase real time database. To get started, a signup on the MIT app inventor is required. After a successful signup, a page for creating a mobile app popped up. The diagram in figure 5 shows the MIT App Inventor. After clicking on create an app button, it is required to also create a project name as shown in figure 6.



Figure 5. Sign up page on MIT app inventor

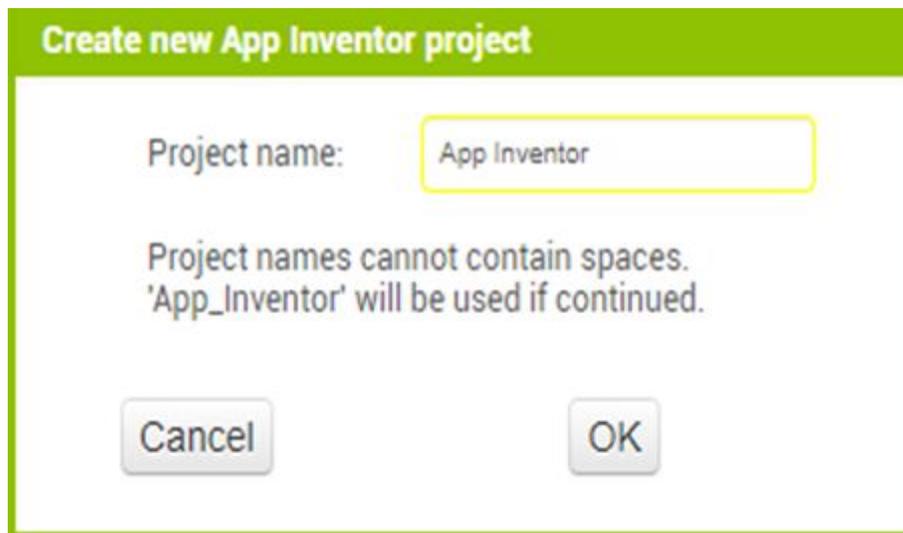


Figure 6. Project name formulation for a new project on MIT app inventor

Moreover, after successfully assigning a name to a new project, we dragged and dropped buttons, labels and layouts needed in the new screen. The MIT App Inventor has tools such as buttons, labels, etc. which we can use to add preferred features that perform certain functions on the app being developed. It is important to note that the app inventor has two phases, namely the designer phase and the block phase:

- i. The designer phase is for designing the user interface that appears on the screen, this includes the layouts, button sizes, label colour, background colour or image.
- ii. The block phase on the other hand is for coding the component of the app such as the function a button, label, textbook and layouts.

The diagram in figure 7 shows a typical designer phase where two buttons has been dragged and dropped from the user interface to the screen. In the block phase, the desired functions of the dragged buttons are defined. The diagram in figure 8 shows the assigning of functions to components of an app using the block phase.

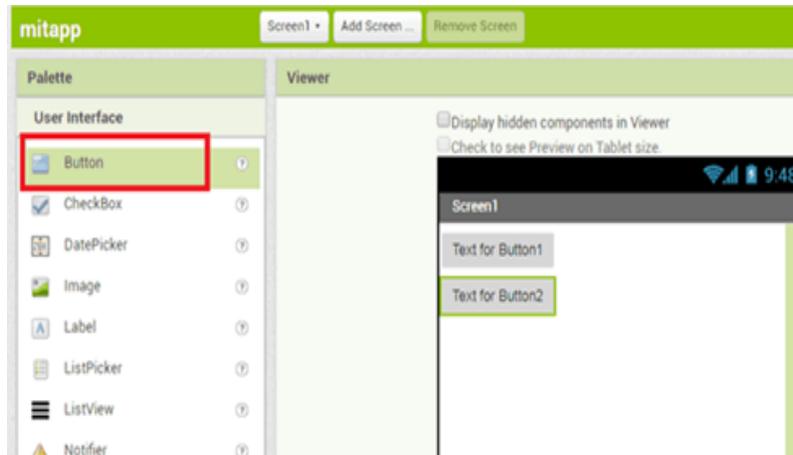


Figure 7. A typical designer phase

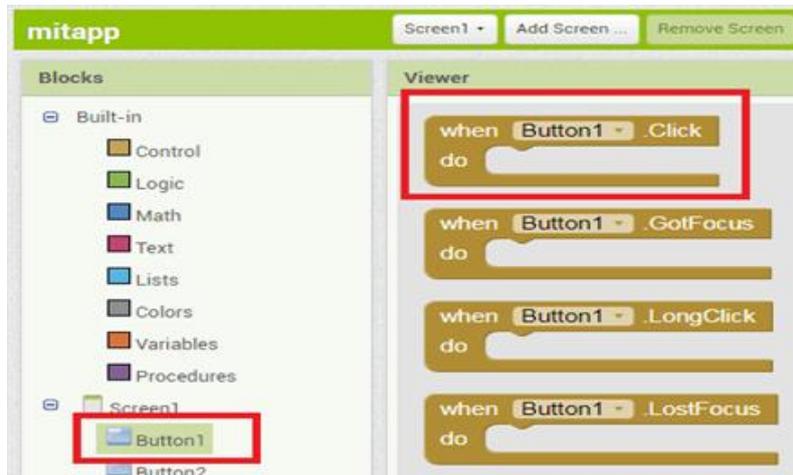


Figure 8. The assigning of functions to components

4.1.3 Arduino Integrated Development Environment

The third software used in this design is the Arduino Integrated Development Environment (IDE). The Arduino IDE was employed for the coding of the ESP8266 microcontroller used. The software was downloaded from the Arduino official website arduino.cc and it was installed on the local drive of the PC. The diagram in figure 9 shows the arduino IDE interface.

The Arduino version has many MENUS with many functions, but before the Arduino IDE can be used for programming ESP8266 which is not an Arduino product, the ESP8266 board file must be added to the Arduino IDE. To add the ESP8266 board to the Arduino IDE, the PC on which the Arduino IDE was installed would be connected to the internet, new reference link would be inputted at the reference link under file menu and then the board was downloaded through the board manager under the Tools menu.



Figure 9. Arduino IDE Interface

4.1.4 Connecting the Developed Mobile to Firebase Database

In order to link the developed app with the database, the component called firebase on the MIT app inventor must be linked to the designer phase of the screen. The features of the components must be inputted as appropriate. The “FirebaseToken” label is the database secret pin that we got when setting up the firebase database while the “FirebaseURL” is the path link we got on the real time database. The diagram in figure 10 below shows where the information will be inputted on the MIT app inventor firebase component dragged to the designer phase.

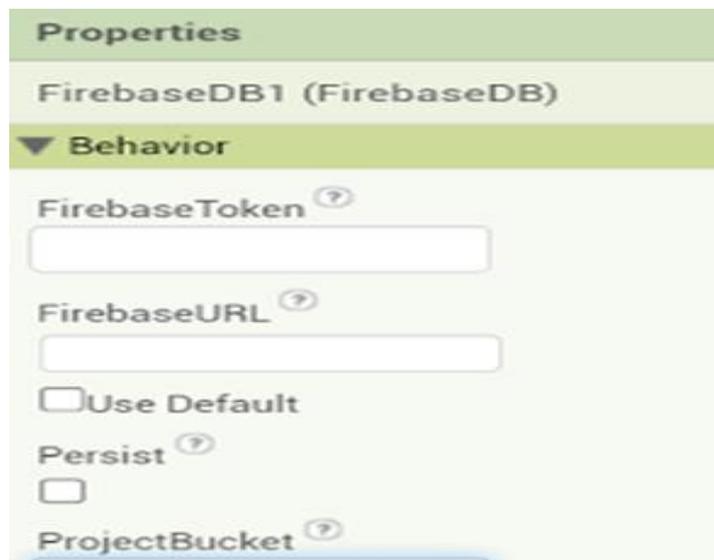


Figure 10. Firebase component for connecting the mobile app with firebase cloud

4.2 The Hardware Part

The hardware part of this design has to do with the assembling of the electronic components and the casing. It includes the implementation of the LCD with the microcontroller, development of the voltage divider, development of the voltage sensors and interfacing it with the microcontroller and the general connection of the aforementioned components.

4.2.1 General Connection

In this design, a 2x16 liquid crystal was employed as one of the user interface through which the activities of the ESP8266 can be viewed. The LCD has two pins for communication and two pins for powering the LCD. The power pins were connected to the ESP8266 on board power pins accordingly (Vcc to Vcc and GND to GND). An ESP8266 microcontroller interfacing with the voltage sensor.

The VCC and GND pins of the LCD were connected to the 5V and GND power out pin of the ESP8266. An illustration of the general circuit connection is displayed in figure 11. The developed voltage sensor too was connected as described above. The ground of the voltage sensor was connected to the GND pin of the ESP8266 while the Vout of the voltage sensor was connected to pin D3 of the ESP8266 which was configured as an analog pin in the code.

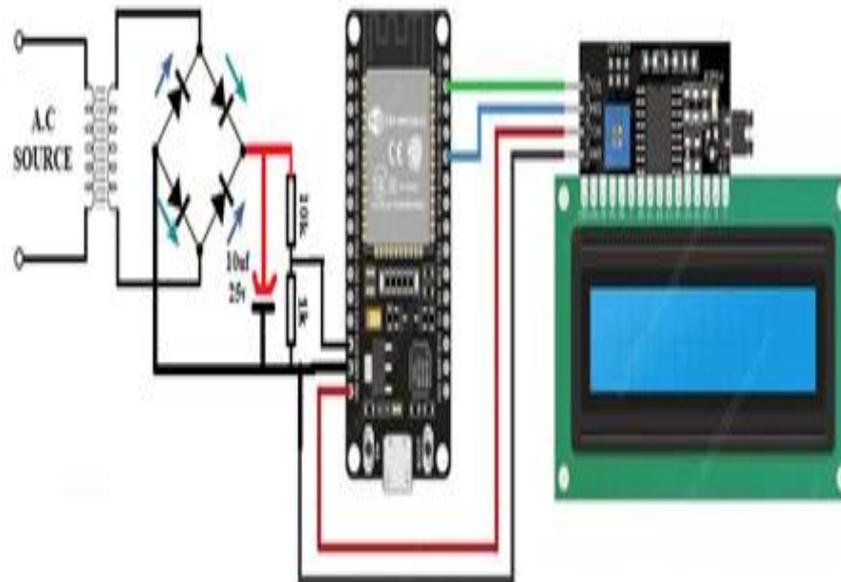


Figure 11. General connection of the system hardware

V. RESULT DISCUSSION, EVALUATION AND ANALYSIS

This section outlines the testing procedures and criteria used to evaluate the embedded system transmission line fault detector, presenting the performance data and the observed outcomes. The results not only confirm the effectiveness of the fault detection system but also provide insights into areas where the design could be enhanced to ensure long-term reliability and accuracy. Analyzing the testing outcomes, designers gain valuable feedback, which can be used to refine and optimize the device for future implementations.

5.1 Testing the ESP8266 Microcontroller Used

An ESP8266 microcontroller use in this design is also known as Node MCU8266, it is tasked with the responsibility of reading the voltages at the eight voltage sensors used in this design, it is also tasked with the responsibility of updating the measured voltages on the designed firebase based database. It is very important to check and ensure that the ESP8266 is in good working condition.

5.2 Testing of the Firebase Database

The cloud employed in this design is the firebase real time database cloud. It was setup as described in section 4.1. In this design, the test carried out on the firebase on a real time database and ESP8266 can write on the firebase database on real time successfully. A void loop code was written as shown below for the ESP8266 to upload three integer numbers on three different paths on the real time database created.

```
int phase_I, phase_II, phase_III
void set(){
// lengthy code for wifi and firebase database connections
}
void loop(){
yellow = 100 + 103;
blue = 90 + 123;
```

```
red = 97 + 50 + 50;  
Firebase.RTDB.setInt(&fbdo, "PHASE_I", yellow);  
Firebase.RTDB.setFloat(&fbdo, "PHASE_II", blue);  
Firebase.RTDB.setFloat(&fbdo, "PHASE_III", red);
```

The result in figure 12 shows that the ESP8266 was able to update data to the firebase real time database with ease. It should however be noted that this operation is network dependent.

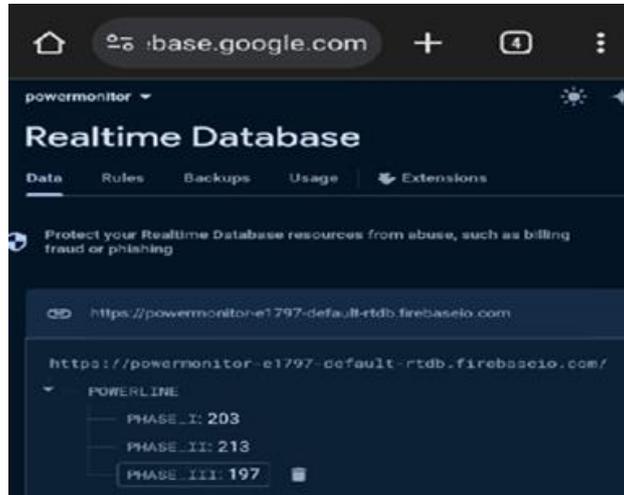


Figure 12. Result obtained from the testing of the firebase real time database

5.3 Testing of the Developed MIT App Inventor Based Mobile App

In this design, a mobile app was design to display the values uploaded to the database by the ESP8266. After deploying the developed mobile app to the firebase database as described in section 4.1. The developed MIT app is an open-source application and it worked based on user specification. The testing of the developed app showed “0.0” when no connection was established as shown in figure 13. The data on the firebase as uploaded by the ESP8266 was also retrieved and displayed as seen in the second figure 14.

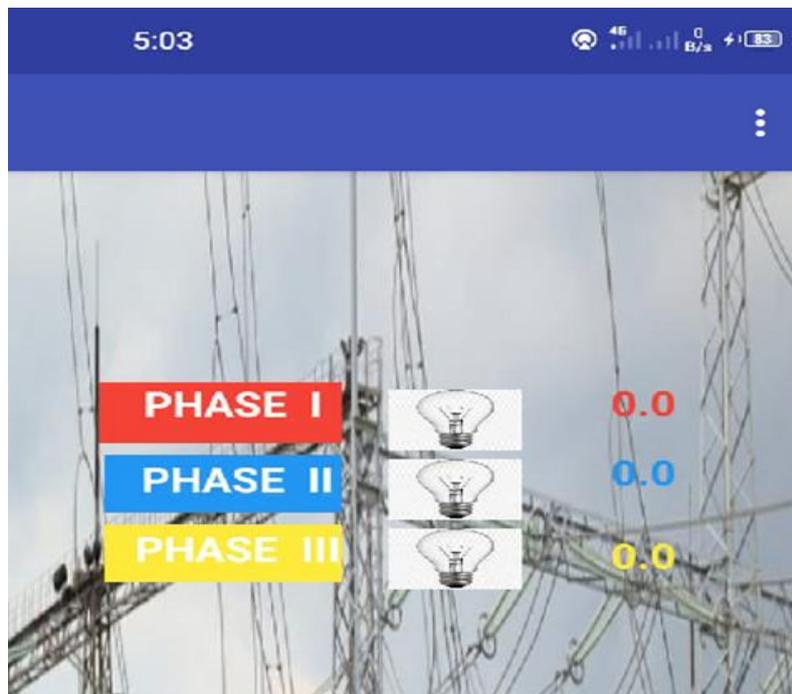


Figure 13. Initiating current

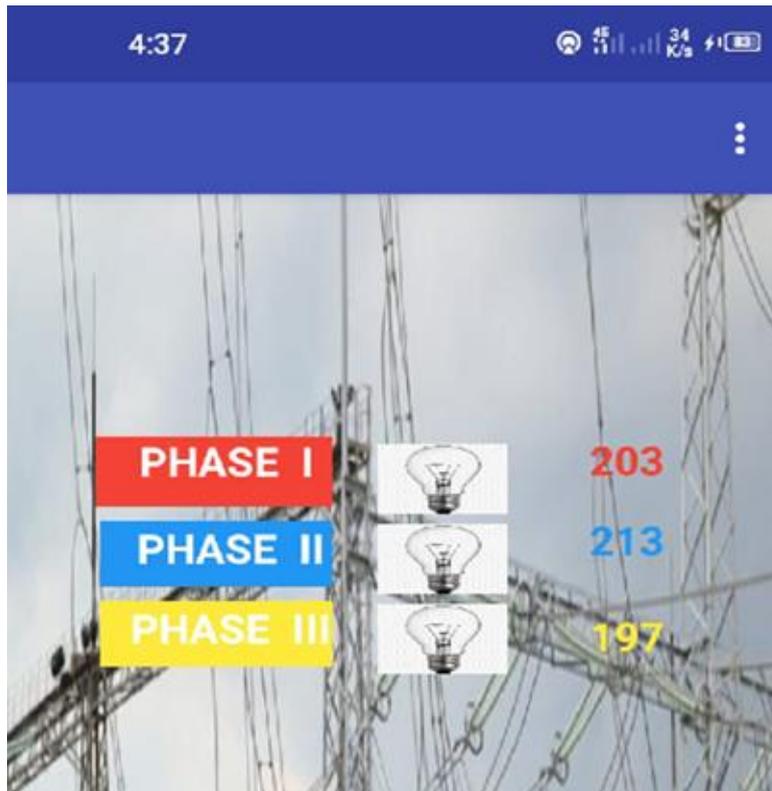


Figure 14. Connection established These systems consist of high-voltage transmission

VI. CONCLUSION

The research design and developed an embedded system for transmission line fault detection system that accurately detects and identifies electrical faults such as open-circuit and short-circuit conditions. Each defined zone's actual voltage levels were accurately monitored and displayed on the customized mobile application, which provided a user-friendly interface for real-time fault information. The research design results indicate that the developed fault detector system operates with high optimal efficiency in transmission line monitoring. Future work can expand the deployment of IoT-enabled power line fault monitoring devices that can enhance the capability for real-time fault tracing across wider geographic areas, improve power grid reliability and reducing downtime.

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