BINDURA UNIVERSITY OF SCIENCE EDUCATION (BUSE)

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FINAL YEAR PROJECT

PROJECT TITLE:

REAL TIME CABLE THEFT ALARM SYSTEM WITH GPS FOR FAULT LOCALIZATION

NAME(S) OF RESEARCHER(S)

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YEAR: 2024 - 2025

DECLARATION

This research project is my original work except where sources have been acknowledged. The work has never been submitted, nor will it ever be, to another university to award a degree or any other qualification.

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This achievement is not mine alone—it is the result of the combined support of all the incredible people in my life.

Abstract

Cable theft remains a persistent challenge in many power distribution systems, especially in developing regions, leading to severe power outages, revenue losses, and service interruptions. This project presents the design and implementation of a real-time cable theft alarm system integrated with GPS for fault localization. The system aims to detect cable tampering or faults promptly and notify the relevant authorities with precise geographical coordinates to enable swift response.

The proposed system is built around the ESP32 microcontroller, which coordinates data from multiple sensors, including vibration sensors and relay-based voltage monitoring circuits. When abnormal vibration is detected or voltage is lost due to cable theft or tampering, the ESP32 processes the input and activates the GSM module to send SMS alerts. Simultaneously, the NEO-6M GPS module retrieves the current location, which is embedded in the alert message for accurate fault pinpointing. The system monitors different zones—Zone A, B, and C—each representing separate sections of the cable line.

In addition to SMS alerts, the system includes a dashboard built using XAMPP, PHP, and MySQL. This interface displays real-time status updates of each zone and records fault history in a structured database. The integration of vibration detection, GPS-based localization, and a user interface dashboard makes the system comprehensive and practical for deployment.

Testing showed that the system can detect faults within seconds, accurately capture GPS coordinates, and display the status of cable zones in real time. Despite challenges such as GPS signal limitations indoors and initial vibration sensor sensitivity, the system performed reliably under various conditions. The outcome demonstrates a scalable, low-cost, and efficient solution for addressing the growing problem of cable theft in critical infrastructure.

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Chapter1 REAL TIME CABLE THEFT ALARM SYSTEM WITH GPS FOR FALT LOCALIZATION

1.1 Introduction

The proposed system for cable fault and theft detection is designed to efficiently identify and report faults in electrical cables using advanced technology. When a fault occurs, it disrupts the voltage continuity, indicating a potential issue in the cable. The system also detects cable theft and tempering through a vibration sensor which is mounted on the electrical cable. The system leverages these principles to detect faults and theft tempering thus promptly send alert messages through a GSM module, along with the precise coordinates of the fault location using a GPS module. This combination ensures rapid and accurate fault and theft detection, minimizing downtime and enabling quick repairs. The key components of this system include voltage sensors, a microcontroller, a GSM module, and a GPS module, all powered by a reliable power supply. Voltage sensors continuously monitor the voltage levels in the cable, and upon detecting a disruption, send data to the microcontroller. The microcontroller processes this data and determines if a fault has occurred. If a fault or theft is detected, the microcontroller triggers the GSM module to send an alert message to a predefined phone number. Simultaneously, the GPS module provides the exact coordinates of the fault location, which are included in the alert message. This system offers numerous benefits, including real-time fault and theft detection, accurate location reporting, and rapid notification, all of which contribute to minimizing downtime and enhancing the efficiency of cable maintenance operations. The application of this system is particularly valuable in industries where timely detection and repair of cable faults are critical, such as power distribution, telecommunications, and industrial automation. By integrating modern technology and leveraging the principles of voltage monitoring, this cable fault and theft detection system ensures reliable and efficient fault management, significantly improving operational efficiency and reducing maintenance costs.

1.2 Background Study

The increasing reliance on electrical cables for power distribution and communication highlights the critical need for efficient fault detection, theft detection and maintenance systems. Companies like Zimbabwe Electricity Transmission and Distribution Company(ZETDC) and Powertel rely on cable transmissions for their service. Cable faults and thefts can lead to significant disruptions, downtime, and maintenance costs. Traditional methods of cable fault detection often involve manual inspection and extensive testing, which can be time-consuming and labour-intensive. The proposed cable fault and theft detection system addresses these challenges by leveraging modern technology to automate the detection and reporting process.

The fundamental principle of the proposed system is based on monitoring the voltage continuity within the cable. Voltage sensors are strategically placed along the cable to continuously measure voltage levels. When a fault occurs, such as a break or short circuit, the voltage continuity is disrupted. This disruption is detected by the sensors and reported to the microcontroller. The microcontroller, serving as the central processing unit, analyses the sensor data to determine if a fault has occurred. Upon fault or theft detection, the microcontroller activates the GSM module to send an alert message to a predefined phone number, notifying the user of the fault. Additionally, the GPS module provides the precise coordinates of the fault location, enabling quick and accurate fault localization.

The integration of GSM and GPS modules into the system offers several advantages. The GSM module ensures that fault and theft alerts are promptly communicated to maintenance personnel and law enforcement, regardless of their location. This immediate notification allows for rapid response and reduces downtime. The GPS module enhances the system's effectiveness by providing accurate fault location coordinates. This feature is particularly valuable in extensive cable networks, where pinpointing the exact fault location can be challenging. The proposed system's design incorporates key components such as voltage sensors, a microcontroller, GSM and GPS modules, and a reliable power supply. The voltage sensors are responsible for real-time monitoring of the cable's voltage levels. The microcontroller processes the sensor data and makes decisions based on predefined thresholds. The GSM module transmits fault alerts, while the GPS module provides location data. The entire system is powered by a stable power supply, ensuring continuous operation.

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1.3 Problem Statement

Electrical cables are critical components in power distribution, telecommunications and various industrial applications. Faults and thefts in these cables can lead to significant disruptions, downtime and maintenance costs. Traditional methods of fault and theft detection often involve manual and extensive testing, which are time consuming, labor intensive and may not provide immediate fault localization. This delay in fault detection and repair can result in prolonged outages, affecting productivity and service quality.

1.4 Problem Solution

The cable fault and theft detection system is designed to address the challenges of identifying and reporting faults and thefts in electrical cables efficiently. The system operates on the principle that a fault disrupts voltage continuity, which is detected by strategically placed voltage sensors. It also caters for theft tempering detection through vibration sensor attached on the electrical cable. This automated process ensures real-time fault detection, accurate location reporting through GPS module and rapid notification through a GSM module, significantly minimizing downtime, reducing maintenance costs, and enhancing the efficiency of cable maintenance operations.

1.5 Aim

To develop an automated cable fault and theft detection system that efficiently identifies and report faults in electrical cables in real time, providing accurate location details via GPS and immediate notifications through GSM communication to minimize downtime and enhance maintenance and response operations.

1.6 Objectives

To design a system that is able to:

- ❖ autonomously detect cable faults.
- ❖ autonomously detect cable tempering and theft.

- ❖ To capture precise coordinates of the fault location, ensuring quick and accurate localization for efficient repair and maintenance.
- ❖ send immediate alert messages to predefined phone numbers upon fault detection, enabling prompt response and minimizing downtime.
- ❖ allow users to view real-time data, receive fault and theft alerts, and access historical reports, ensuring ease of use and effective monitoring.

1.7 Scope of Study

This capstone project endeavours to design and develop an automated cable fault and theft detection system that efficiently identifies and report faults and cable tempering in electrical cables in real time, providing accurate location details via GPS and immediate notifications through GSM communication to minimize downtime and enhance maintenance operations. The study will cover the following hardware and software key areas.

- **System Design**: Defining the architecture of the cable fault and theft detection system, including the selection of appropriate hardware and software components (microcontroller, voltage sensors, GSM module, GPS module and power supply).
- **System Integration**: Integrating the GSM, GPS and voltage sensor subsystems into a cohesive and functional cable fault detection system.
- **Software Development**: Writing and testing the necessary code to ensure seamless communication between the microcontroller and the various hardware components, enabling accurate cable fault detection. Create a web or mobile application interface for users to monitor real-time data, receive fault alerts, and access historical reports.
- **Testing and Calibration**: Conduct extensive testing of the system under various scenarios to validate its accuracy, reliability, and efficiency. Calibrate the sensors and modules to optimize performance and ensure consistent results.

1.8 Justification

The cable fault detection system is a crucial innovation designed to enhance the reliability and efficiency of electrical cable maintenance.

Minimizing Downtime: Cable faults can lead to significant disruptions in power distribution, telecommunications, and industrial processes. Traditional fault detection methods often involve time-consuming manual inspections, leading to prolonged outages. The proposed system provides real-time fault detection, enabling immediate response and minimizing downtime.

Accurate Fault and Theft Localization: Identifying the exact location of a fault in extensive cable networks can be challenging. Manual methods may require extensive testing and inspection, leading to delays. The integration of a GPS module in the proposed system ensures precise fault localization, allowing for quick and accurate repairs.

Rapid Notification: Timely notification of cable faults is essential for prompt action. The GSM module in the system sends immediate alert messages to predefined phone numbers, ensuring that maintenance personnel are quickly informed of the issue. This rapid notification system reduces the time between fault detection and repair.

Cost Efficiency: Frequent and prolonged cable faults can result in high maintenance costs and operational losses. By providing real-time fault detection and accurate localization, the system reduces the need for extensive manual inspections and decreases repair times, leading to significant cost savings.

Enhanced Reliability: The system's continuous monitoring of voltage levels ensures that faults are detected as soon as they occur, preventing potential escalation of issues. This proactive approach enhances reliability.

1.8 Project Organization

The dissertation is made up of five chapters directed to different scopes of the dissertation. Before the beginning of the five chapters there is an abstract, declaration, name of student and supervisor, dedication, list of tables, list of abbreviations, list of appendices and list of figures.

*Chapter one***:** Is introducing the topic of discussion which is a study on design of an IOT based Automatic cable fault detection system. It shows the importance of the system. A short background of study. The project objectives in their totality are listed including the expected results.

Chapter two: Studies the literature which made this dissertation possible to accomplish in two distinct groups which are, theoretical, conceptual framework and literature review. Books, journal, scholarly books, and any other material used in the research processes are mentioned. The engineering fundamentals used behind the study from choice of components and their construction is highlighted in this chapter.

Chapter three: Expands on the system design and implementation of the research carried out. The design of the project is subdivided into two groups which are hardware design and software design. Hardware design follows through the processes in the development of the project hardware from the capturing of the schematic drawings, PCB layout, track layout, fabrication and implementation of the components on the PCB as a finished board carrying out the desired functions. In the software design of the project, Proteus is used for capturing the schematics by the aide of huge component library it possesses. The programming software used is Arduino IDE compiler.

Chapter four: discusses and analyses the results from the testing of the project prototype. All the inputs of the system are initiated and the output is analysed and appropriate conclusions and recommendations are noted.

Chapter five: Concludes the research and also sitting the advantages and disadvantages of the process used to get the results including recommendations for future studies and research.

Chapter2 : LITERATURE REVIEW

2.0 Introduction

The literature review serves as a critical component of our Automated Cable Fault and Theft detection research project, offering a comprehensive analysis of existing research, technologies, and methodologies related to cable fault detection and theft prevention, focusing on the integration of voltage sensors, vibration sensors, GSM, and GPS modules. In recent years, the reliability and security of electrical cable systems have become increasingly important due to the growing demand for uninterrupted power supply and the rise in cable theft incidents. Automated cable fault and theft detection systems have gained significant attention as they offer a proactive approach to maintaining the integrity of electrical and communication infrastructure. The primary objective of this literature review is to evaluate the current state of knowledge in the field of automated cable fault and theft detection. By examining relevant studies and technologies, this review will identify the strengths and weaknesses of existing systems, highlight gaps in the literature, and propose potential areas for further research and development.

The literature review will cover key aspects such as analysing the use of voltage sensors for monitoring voltage continuity and identifying cable faults, exploring the application of vibration sensors in detecting tampering and theft attempts, reviewing the integration of GSM modules for sending notifications and GPS modules for providing real-time location data, and investigating the role of the Internet of Things (IoT) in enhancing real-time monitoring and control of cable systems. Additionally, it will compare and contrast similar systems developed by other researchers and companies, identifying areas for improvement and innovation.

2.1 Related Work

The field of automated cable fault and theft detection has seen significant advancements in recent years, with researchers and engineers developing innovative solutions to enhance the reliability and security of electrical infrastructure. One notable study by *Nuli Namassivaya et al. (2023) proposed an underground cable fault detection system using IoT.* Their system utilized an Arduino UNO and an ESP8266 IoT module to detect faults and display their locations on a web application. This approach streamlined the fault detection process, reducing the time and manpower required for repairs. The abstract of this system stressed on:

Underground cable lines can be susceptible to various issues, such as wear and tear, rodent damage, and environmental factors. It's crucial to detect the precise location of the fault to ensure a faster and smoother repair process. Detecting the exact location of the fault can be a daunting task, especially since the cables are hidden underground. However, with the use of an Arduino UNO, our team has developed a prototype that can help detect the fault location and direction (left or right) from the base station in kilometers. Our prototype utilizes the fundamental principle of Ohm's law. To make this possible, our system employs a fault sensing circuit module that contains set of switches with interconnected wiring. Fault creation is made by long closing a switch. switch indicates the cable's length in kilometres, and switches that generate faults at regular intervals, ensuring the accuracy of our system. In case of a fault, the distance and direction of the fault is fed to an Analog to Digital Converter (ADC), generating digital data for our Arduino UNO. The fault location and direction are displayed on a 16x2 LCD, which is also interfaced with an Internet of Things (IoT) module ESP8266 for broader reach. With the use of a web application, users can now view information regarding the occurrence of a fault with ease. In summary, our innovative system utilizes IoT web application to provide an efficient and accurate means of detecting faults in underground cables.

Another relevant study by *Chaitrashree S R et al. (2024) focused on an IoT-based cable fault detection system*. Their system integrated AC current and voltage sensors, GSM, and GPS moduless to provide real-time monitoring and proactive fault detection. Upon detecting abnormalities, the system sent automated SMS alerts with GPS coordinates to designated authorities, enabling swift intervention and minimizing downtime. The Underground Cable Fault Detection System outlined in this project represents a significant advancement in the field of electrical network management, addressing the pressing need for real-time monitoring and proactive fault detection. By integrating cutting-edge sensor technologies, including AC current and voltage sensors, alongside GSM and GPS modules, the system offers a comprehensive solution for identifying and responding to critical events in electrical infrastructure. The primary objective of this system is to enhance the reliability, safety, and efficiency of electrical networks by enabling swift detection and resolution of faults. Through continuous monitoring of current and voltage levels, the system can identify abnormalities such as over-voltage, under-voltage, and over-loading in real-time. Upon detection of these conditions, automated SMS alerts are promptly dispatched to designated authorities, providing instant notification of the issue and its precise location via GPS coordinates. This immediate response mechanism facilitates rapid intervention and maintenance, minimizing downtime and mitigating potential risks to the electrical system\'s integrity.

In addition to fault detection, theft prevention has also been a critical area of research. A study by *Celimpilo Lindani Zulu and Oliver Dzobo (2023) proposed a real-time power theft monitoring and detection system*. Their system utilized smart meters with Arduino microcontrollers and GSM modules to detect power theft and send alerts to authorities. The system's cloud storage capabilities allowed for continuous monitoring and analysis of power measurements. Power utilities worldwide are facing enormous challenges when it comes to the distribution of electricity. With these challenges, electricity theft is regarded as the most common challenge in the electrical distribution system. Electricity theft can be meter tampering done in consumer houses and illegal connections done using hook-ups from the distribution pole grids. These electricity theft challenges have caused power utilities to reconsider customer engagements focusing on feedback, putting loss detection systems in their distribution system networks, using artificial intelligence to schedule maintenance and other asset management activities, etc. The main focus of this paper is to design a real-time power theft monitoring and detection system that is able to detect power theft in distribution systems. This proposed system utilizes smart meters consisting of an Arduino ATMega328P microcontrollers with GSM modules (Global System for Mobile Communication) used for system communication. Cloud storage is created to store the smart meter data. Simulations of the proposed system were done using Proteus Design Suite v.8.10 SP3 software. The proposed system is practically constructed for prototype measurement results. Should power imbalances be measured by the system, the authority office will receive an SMS notification as an alert for power theft detected by a specific smart metering system. The authority office will analyse the power measurements sent to the cloud storage (MATLAB Online, ThingSpeak IoT channels display), and further action will be taken.

These studies collectively demonstrate the potential of integrating advanced sensor technologies, IoT modules, and communication systems to enhance the reliability and security of electrical infrastructure. By leveraging these innovations, automated cable fault and theft detection systems can significantly reduce downtime, operational costs, and the risk of theft, ultimately contributing to a more resilient and efficient electrical network.

2.2 Limitations of related work

2.2.1 Accuracy of Fault Location

Many existing systems struggle with accurately pinpointing the exact location of faults in underground cables. This can lead to delays in repairs and increased downtime. By integrating advanced voltage sensors and precise GPS modules, the proposed system will provide real-time, accurate fault location data, reducing repair time and minimizing downtime.

2.2.2 Detection of Tampering and Theft

Current systems often rely on a single type of sensor, which may not be sufficient to detect all forms of tampering or theft. By combining vibration sensors with voltage sensors, your system will be able to detect both electrical faults and physical tampering, offering a more comprehensive security solution.

2.2.3 Real-Time Notifications

Some systems lack the capability to send real-time notifications to authorities or maintenance teams, leading to slower response times. By incorporating GSM modules, your system will send immediate SMS notifications with GPS coordinates, enabling swift intervention and reducing the risk of prolonged outages or theft.

2.2.4 Integration with IoT

Many existing systems do not fully leverage IoT technologies for continuous monitoring and control. By integrating IoT modules, your system will allow for remote monitoring and control, providing real-time data analytics and enhancing overall system reliability and security.

2.2.5 Scalability

Existing systems may not be easily scalable to larger networks or different types of electrical infrastructure. The proposed system will be designed with scalability in mind, allowing for easy expansion and adaptation to various network sizes and configurations.
By addressing these limitations, the proposed automated cable fault and theft detection system will offer a more robust, efficient, and reliable solution for detecting cable faults and preventing theft, ultimately contributing to a more resilient electrical infrastructure.

2.3 Theoretical Framework and Design of System Components

2.3.1 Voltage Measurement

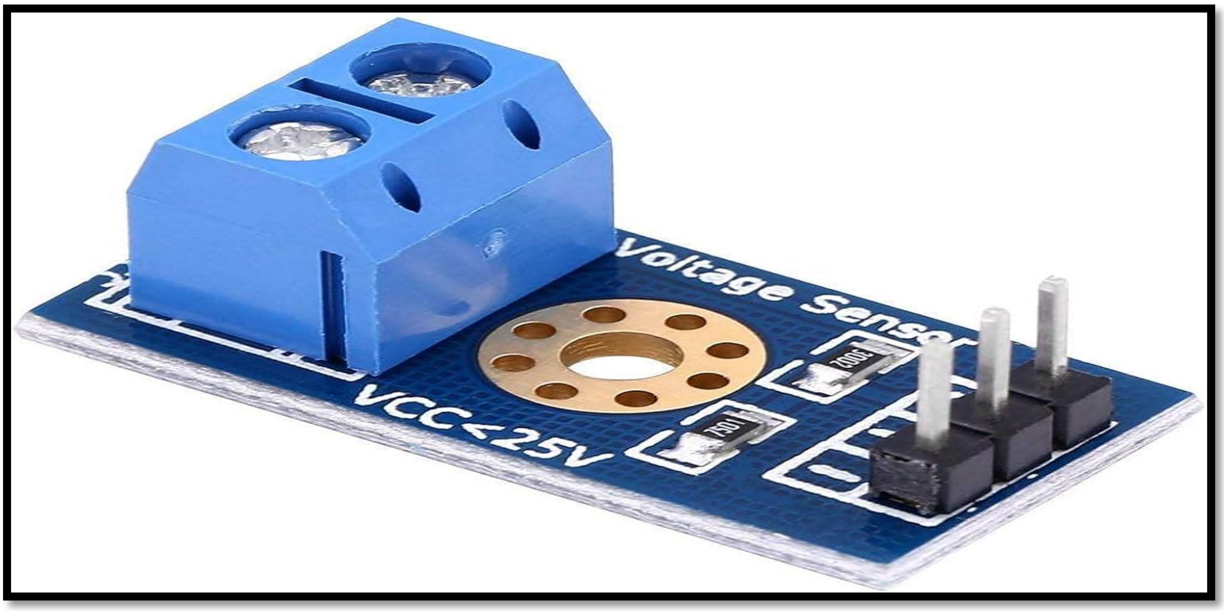

Figure 2-1: Voltage Sensor

Figure2.1: Voltage Sensor

The 25V voltage sensor is a highly efficient voltage sensor designed to measure and monitor DC voltage levels up to 25 volts. It is commonly utilized in applications such as battery monitoring, power supply testing, and voltage regulation systems. This sensor provides a convenient and accurate way to measure voltage levels and can be easily interfaced with microcontrollers like the Arduino UNO for real-time monitoring and data logging. The sensor's input voltage range spans from 0 to 25 volts, and it outputs a corresponding voltage of 0 to 5 volts DC, making it compatible with various microcontroller input levels. It boasts high measurement accuracy with a minimal error margin of ±1%, ensuring reliable and precise voltage readings. The 25V voltage sensor operates within a broad temperature range of -40°C to 85°C, maintaining consistent performance in diverse environmental conditions. Its compact dimensions (30mm x 20mm x 10mm) allow for easy integration into different projects. The sensor typically includes pins for power supply (VCC), ground (GND), positive voltage input (VIN+), and negative voltage input (VIN-).

These features make it an ideal choice for applications requiring accurate and efficient voltage level monitoring, such as in battery management systems, solar panel voltage measurement, and other critical voltage monitoring tasks.

2.3.2 Location capturing

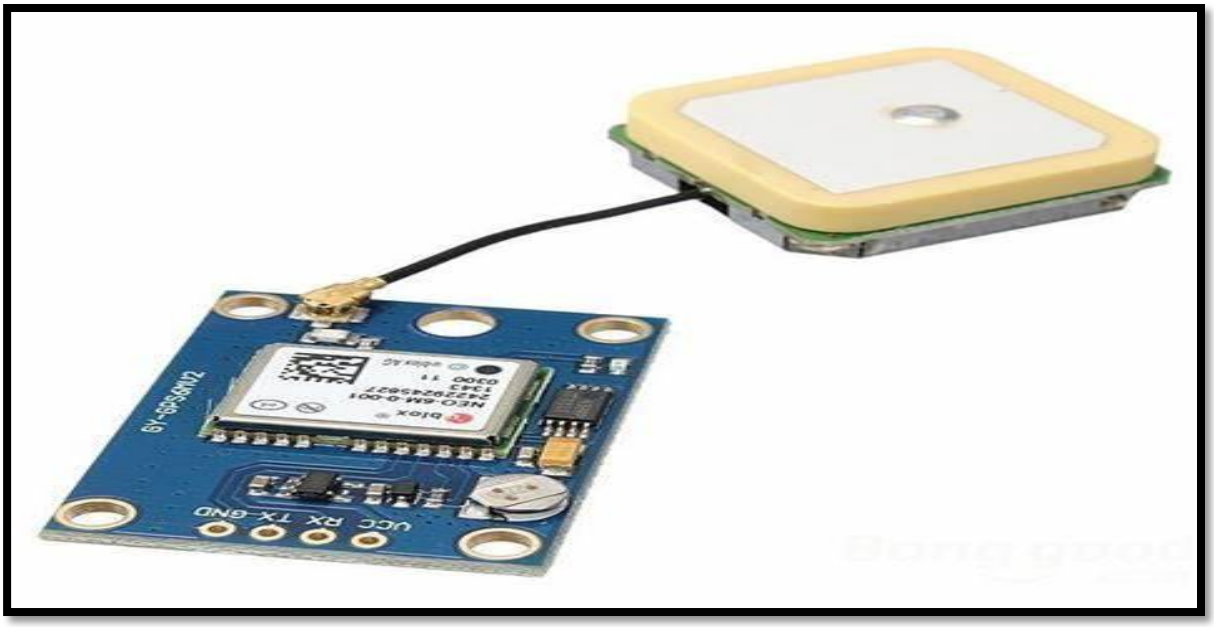

Figure 2-2: NEO6MV2 GPS module

Figure 2.2: NEO6MV2 GPS module

The NEO-6M GPS module is a compact and high-performance satellite positioning receiver based on the u-blox NEO-6 series chipset. Designed to provide simple integration of GPS functionality into various electronic projects, the module can track up to 50 satellites simultaneously, ensuring high sensitivity and improved accuracy. It features a 50-channel GPS L1 frequency receiver with a position accuracy of approximately 2.5 meters and an update rate of up to 5 Hz. The module boasts fast acquisition times, with cold starts taking 27 seconds, aided starts 3 seconds, and reacquisition 1 second. With a sensitivity of –161 dBm, it operates efficiently even in challenging conditions. It supports a wide operating temperature range from –40°C to 85°C and requires a supply voltage of 3.0V to 5.5V, consuming around 50mA at 5V. The NEO-6M GPS module includes essential pin configurations such as VCC (power supply), GND (ground), RX (UART receive), and TX (UART transmit). Its versatility and reliability make it suitable for applications like drones, vehicle tracking systems, personal navigation devices, and time synchronization, especially in battery-operated mobile devices where cost and space constraints are critical.

2.3.3 Liquid Crystal Display

*Figure 2-3: 16*2 LCD display*

*Figure 2.3: 16*2 LCD display*

A micro controller in one Gi manipulates this parallel 16-pin interface in order to control the display. The interface is made up consisting of eight data pins, a register select pin, a read or write pin, and an enable pin. The register select pin selects a data register in the LCD memory, which holds the memory and an instruction register from which the micro controller for the LCD searches for instructions on the next step to take. The read and write pin essentially plays the function of selecting between two modes, which are read and write mode respectively. The 8 data pins exist in two states which are high and low. These determine the bits one is writing to a register or reading from a register. The screen turns on due to the use of power supply pins that use 5volts and LED backlight pins, which can turn it off. The display contrast pin, controls the display of the screen. The screen will be used in the project to display real time measured parameters and location.

2.3.4 Microcontroller Unit(ESP32)

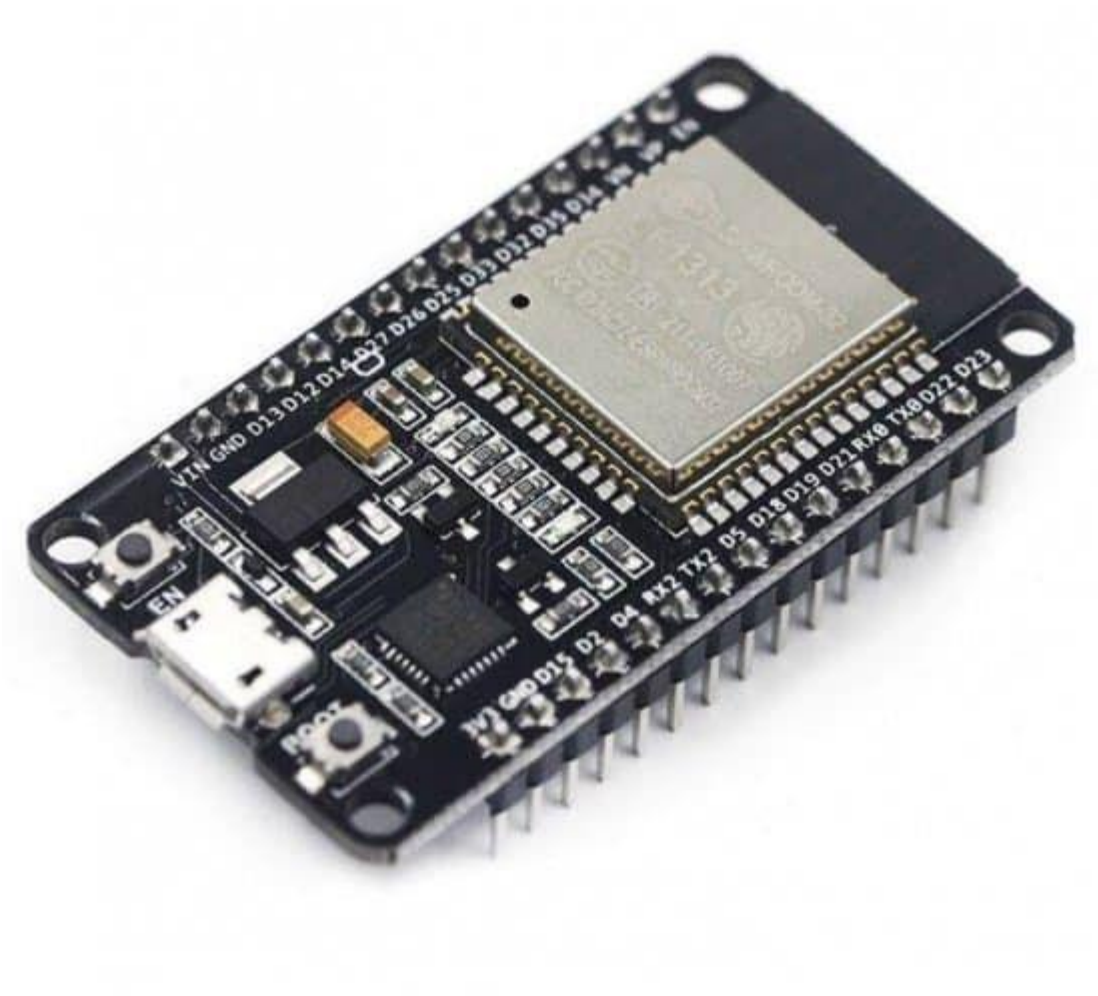

Figure 2-4: ESP32 microcontroller

Figure 2.4: ESP32 microcontroller

The ESP32 microcontroller is a versatile and powerful device developed by Espressif Systems, designed to cater to a wide range of applications. It features a dual-core Xtensa LX6 microprocessor running at up to 240 MHz, providing robust performance for multitasking and real-time processing. The ESP32 comes with 512 KB of SRAM, 448 KB of ROM and 4 MB of Flash memory, making it suitable for complex applications.

One of the standout features of the ESP32 is its built-in Wi-Fi and Bluetooth module, which allows for seamless integration into IoT projects, home automation, and remote monitoring systems. Additionally, it supports a variety of peripheral interfaces, including SPI, I2C, UART, PWM, and ADC, enabling easy communication with sensors, displays, and other devices. The ESP32 also includes touch sensors, capacitive touch GPIOs, and a real-time clock, further enhancing its functionality.

Reasons for Using ESP32 in Our System:

1. Dual-Core Processor: The dual-core architecture allows for efficient multitasking and improved performance, making it ideal for handling complex tasks.
2. Built-in Connectivity: With integrated Wi-Fi and Bluetooth, the ESP32 simplifies the process of connecting to networks and other devices, reducing the need for additional modules.
3. Rich Peripheral Set: The wide range of input/output options and peripheral interfaces makes it easy to integrate with various sensors and actuators.
4. Low Power Consumption: The ESP32 is designed to be energy-efficient, with various power modes and sleep options, making it suitable for battery-powered devices.
5. Arduino Compatibility: The ESP32 can be programmed using the Arduino IDE, providing access to a vast library of resources and community support.
6. Cost-Effective: Despite its advanced features, the ESP32 remains affordable, making it accessible for both hobbyists and professionals.

2.3.5 GSM Module

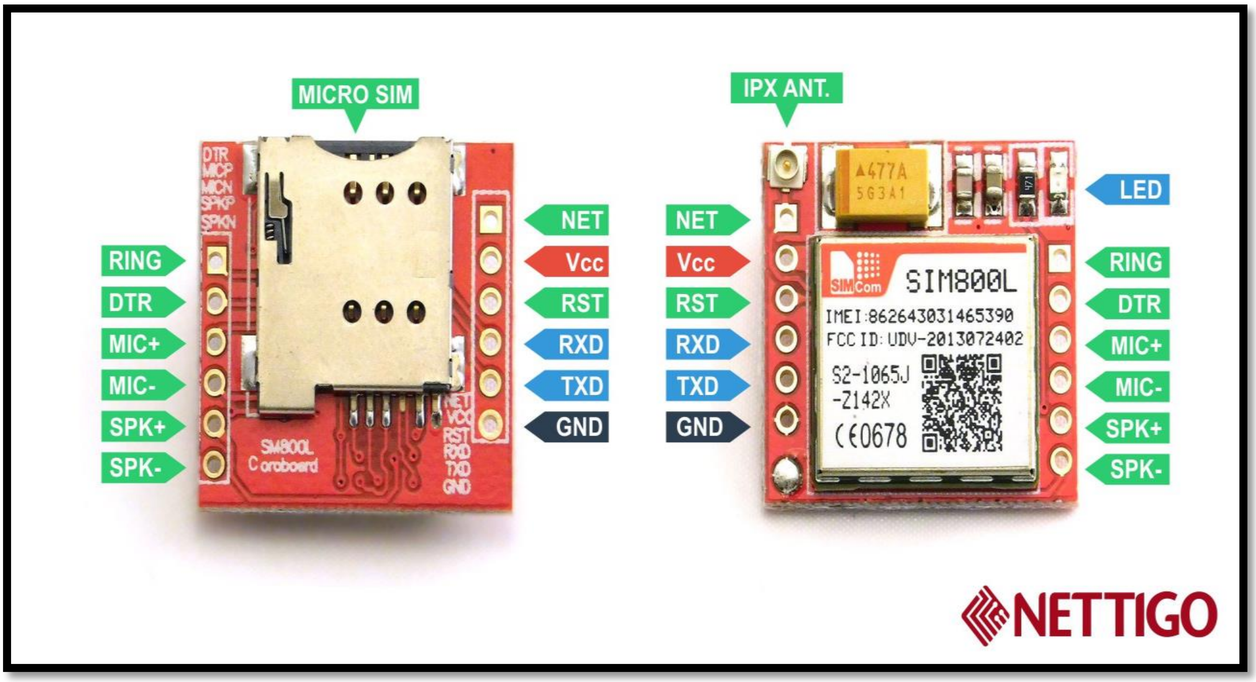

Figure 2-5: SIM800L gsm module

Figure 2.5: SIM800L gsm module

The SIM800L GSM module is a compact and versatile cellular modem from Simcom that provides GSM and GPRS functionality. It allows any microcontroller to connect to the mobile network to make or receive phone calls, send or receive SMS (text messages), and connect to the internet using GPRS, TCP, or IP. Here are some key features:

Quad-band support: Operates on frequencies 850MHz, 900MHz, 1800MHz, and 1900MHz, making it suitable for global use.

Power supply: Operates within a voltage range of 3.4V to 4.4V, making it compatible with various power sources, including LiPo batteries.

Low power consumption: Ideal for battery-operated applications.

Compact size: Measures just 17.6mm x 15.7mm x 2.3mm, making it easy to integrate into projects with limited space.

Serial interface: Uses AT commands for communication, which can be easily integrated with microcontrollers like Arduino.

Status indicators: Includes LED indicators to show network status and connection status.

2.3.6 VIBRATION SENSOR

Figure 2-6: Vibration sensor

Figure 2.6 Vibration sensor

The SW-420 vibration sensor is a simple yet highly effective device used to detect mechanical vibrations or shocks. It consists of a spring-type mechanism that closes or opens a circuit when vibrations exceed a set threshold, producing a digital output signal (either HIGH or LOW). The sensor module typically includes:

- **VCC pin** (connected to 3.3V or 5V power supply),
- **GND pin** (connected to ground),
- **DO (Digital Output) pin** (connected to a digital input pin on a microcontroller such as ESP32).

Key specifications of the SW-420 include:

- **Operating Voltage:** 3.3V to 5V DC

- **Sensitivity Adjustment:** Built-in potentiometer to set the vibration threshold
- **Output:** Digital (logic HIGH/LOW)
- **Compact Size:** Ideal for embedded and IoT projects

The sensor detects mechanical disturbances such as cutting, sawing, or shaking of the cable and is used in this project to identify tampering or theft attempts. When such vibrations are detected, it sends a digital signal to the ESP32, which then triggers an alarm response, logs the event, and sends an SMS notification with GPS location using the GSM and GPS modules.

Reasons for Using SW-420 in the System:

- **Tamper Detection:** Provides early warnings of possible theft by detecting unusual physical activity.
- **Digital Output:** Simplifies interfacing with microcontrollers**.**
- **Adjustable Sensitivity:** Allows tuning to filter out false positives (like wind or minor ground vibrations).
- **Low Cost and Easy Integration:** Suitable for scalable and budget-friendly designs.

2.4 Conclusion

Chapter 2 of the literature review focused on automated cable fault and theft detection systems. It began by outlining the importance of reliable and secure electrical infrastructure and the role of advanced technologies in achieving this goal. Key aspects covered include fault detection using voltage sensors, theft detection with vibration sensors, GSM and GPS for real-time notifications, and IoT integration for continuous monitoring. The review highlights limitations in existing systems, such as accuracy in fault location, detection of tampering, real-time notifications, power supply dependency, and scalability. The proposed automated cable fault and theft detection system aims to address these limitations by incorporating precise sensors, immediate notifications with GPS coordinates, IoT integration, and dual power supply.

Chapter3 METHODOLOGY

3.1 Introduction

The methodology chapter is a critical component of this project as it outlines the systematic approach adopted to design, develop, and implement the automated cable fault and theft detection system. This section aims to provide a clear and detailed description of the processes, tools, and techniques used to achieve the project objectives. The methodology will ensure that the system is built on a solid foundation of proven engineering principles and best practices, leading to a reliable and efficient solution. The development of the automated cable fault and theft detection system involves several key stages, including system design, component selection, hardware assembly, software development, integration, testing, and validation. Each stage is meticulously planned and executed to ensure the final system meets the desired performance criteria and addresses the limitations identified in the existing literature.

3.2 System Design

3.2.1 Overview of the system

The automated cable fault and theft detection system is designed to ensure the security and reliability of electrical and communication cable networks by detecting faults and tempering attempts. The system integrates multiple components, including voltage sensors, vibration sensors, GSM and GPS modules, and a microcontroller, to provide comprehensive monitoring and real-time notifications. Voltage sensors continuously measure the voltage levels along the cable to detect any disruptions, while vibration sensors detect physical tampering or theft attempts by measuring vibrations. The microcontroller serves as the central processing unit, receiving and analyzing data from the sensors to determine if a fault or tampering has occurred. Upon detection, the microcontroller activates the GSM and GPS modules to send real-time notifications with GPS coordinates to designated authorities.

The system architecture ensures seamless integration and efficient operation, with sensors strategically placed along the cable network, and communication modules providing accurate location data and immediate alerts. The hardware assembly involves installing and connecting the sensors to the microcontroller, integrating the GSM and GPS modules, and configuring the power supply for continuous operation. The software development process includes coding detection algorithms, processing sensor data, and sending notifications. The final step involves testing and validating the system to ensure it performs as expected under various scenarios. By combining advanced sensor technologies with real-time communication capabilities, the automated cable fault and theft detection system offers a robust solution for enhancing the security and reliability of electrical infrastructure.

3.3 SYSTEM ARCHITECTURE:

3.3.1 Block Diagram

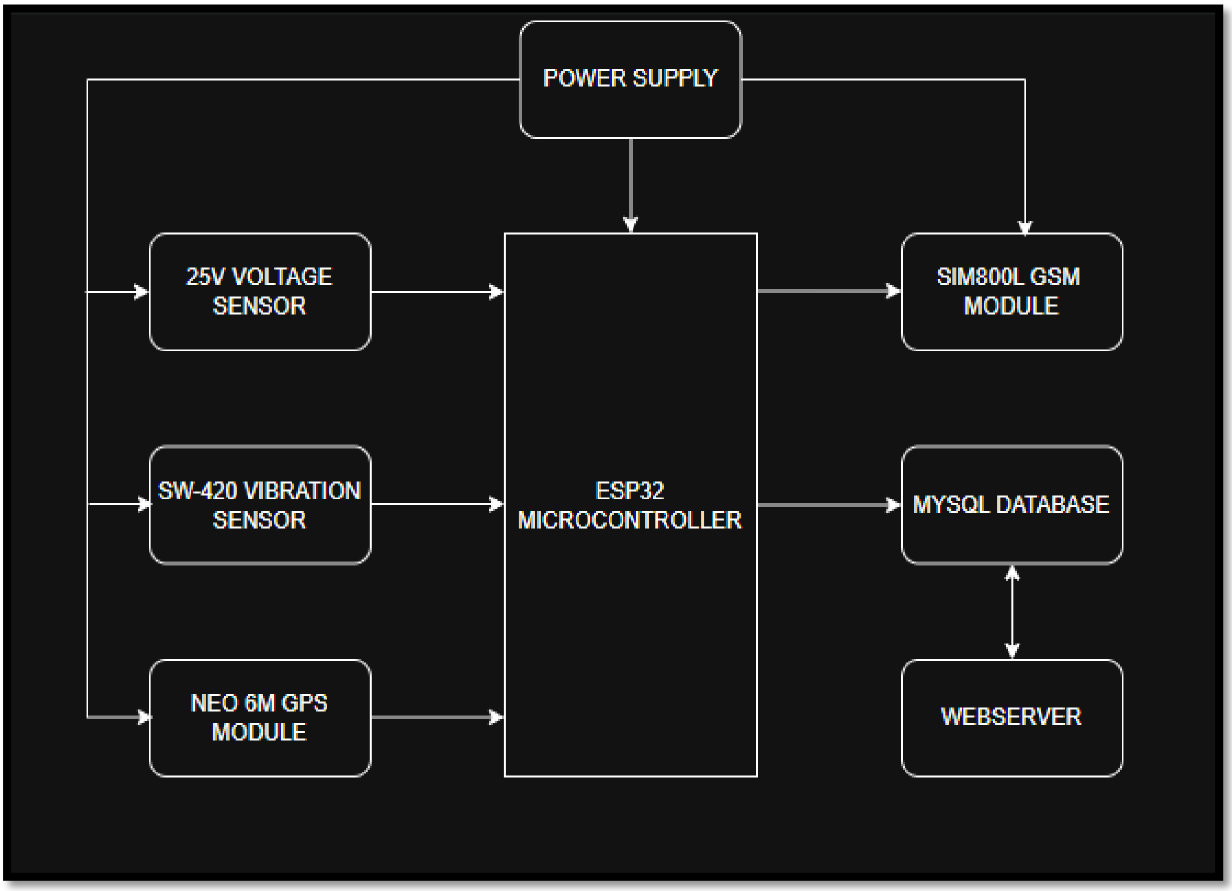

Figure 3-1: System Block diagram

The automated cable fault and theft detection system is designed to ensure the security and reliability of electrical cable networks through the integration of various components. Overall, the block diagram outlines a cohesive and efficient system where each component plays a crucial role in monitoring, detecting, and notifying authorities of cable faults and theft attempts. This integrated approach ensures that the electrical infrastructure remains secure and reliable, with swift intervention enabled through real-time notifications and accurate location data.

3.3.2 Block Diagram Description

1.Power Supply:

Consists of AC to DC power supply which converts 230V AC to the required 5V DC which is required by electronic components. There’s also a battery backup which ensures continuous operation during power outages.

2. Sensor Network:

Is made up of the input sensors to our automated cable fault detection system. It consists of multiple voltage sensors installed along the cable to monitor voltage continuity. There are also vibration sensors which are attached to the cable to detect physical tampering or theft. These sensors continuously send data to the central processing unit.

3. Microcontroller:

The ESP 32 microcontroller serves as the brain of the system, processing the incoming signals from the sensors. If necessary, an Analog-to-Digital Converter (ADC) is employed to convert analog sensor signals to digital format for further processing. A signal conditioning circuit ensures the sensor signals are accurately interpreted. Within the microcontroller, fault detection and tamper detection algorithms evaluate the data against predefined criteria to determine if a fault or tampering has occurred.

4. Communication Modules:

Consists of an output GSM Module (SIM800L) that is responsible for sending alert SMS notifications when faults or tampering are detected. There is also an input GPS module that provides real-time location data to include in SMS notifications.

5. User Interface Block:

The IoT Module (ESP8266) allows remote monitoring and control through a web server which communicates with the microcontroller over a wireless network. The webserver fetches data from the local database and displays the real time sensor data on a html webpage.

3.4 FUNCTION CIRCUITS

3.4.1 Voltage Sensor Circuit

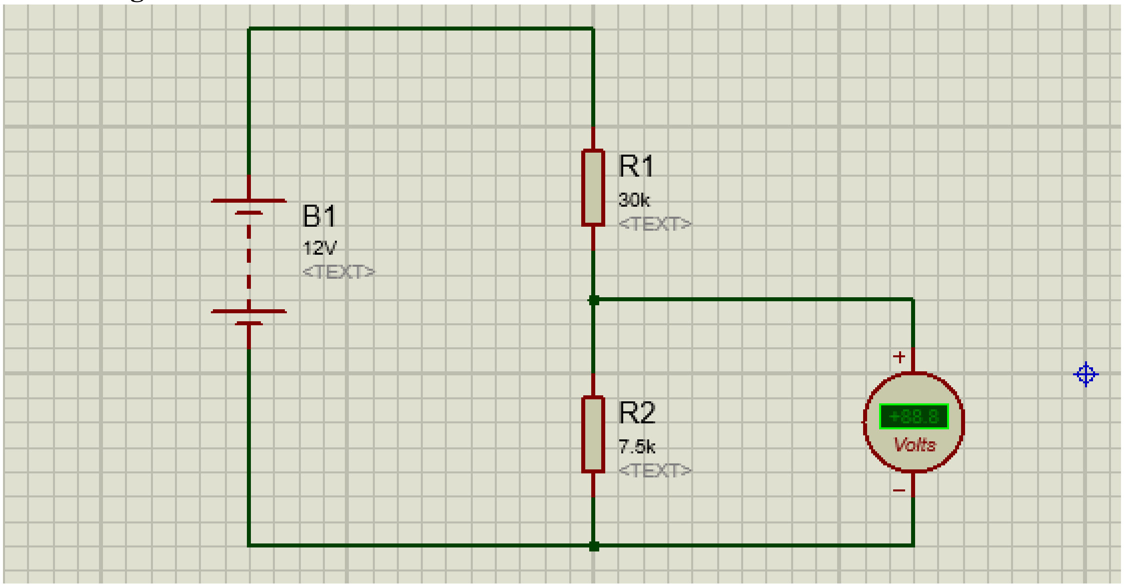

Figure 3-2: Voltage sensor circuit

Figure 3.2 above illustrates a simple **voltage divider circuit** used to scale down a higher input voltage to a lower level, which is particularly useful in microcontroller applications where analogue inputs are limited to 5V or 3.3V. In this circuit, a 12V DC supply (B1) is divided using two resistors in series: **R1 = 30kΩ** and **R2 = 7.5kΩ**. A voltmeter is connected across R2 to measure the output voltage.

Working Principle

A voltage divider works based on Ohm's Law and the principle of potential division in a series resistor network. When two resistors are connected in series across a voltage supply, the voltage drop across each resistor is proportional to its resistance.

The output voltage across R2 can be calculated using the voltage divider formula:

$$\mathbf{Vout} = \frac{R2}{R1+R2} \times \mathbf{Vin}$$

Voltage Sensor Pin Configuration

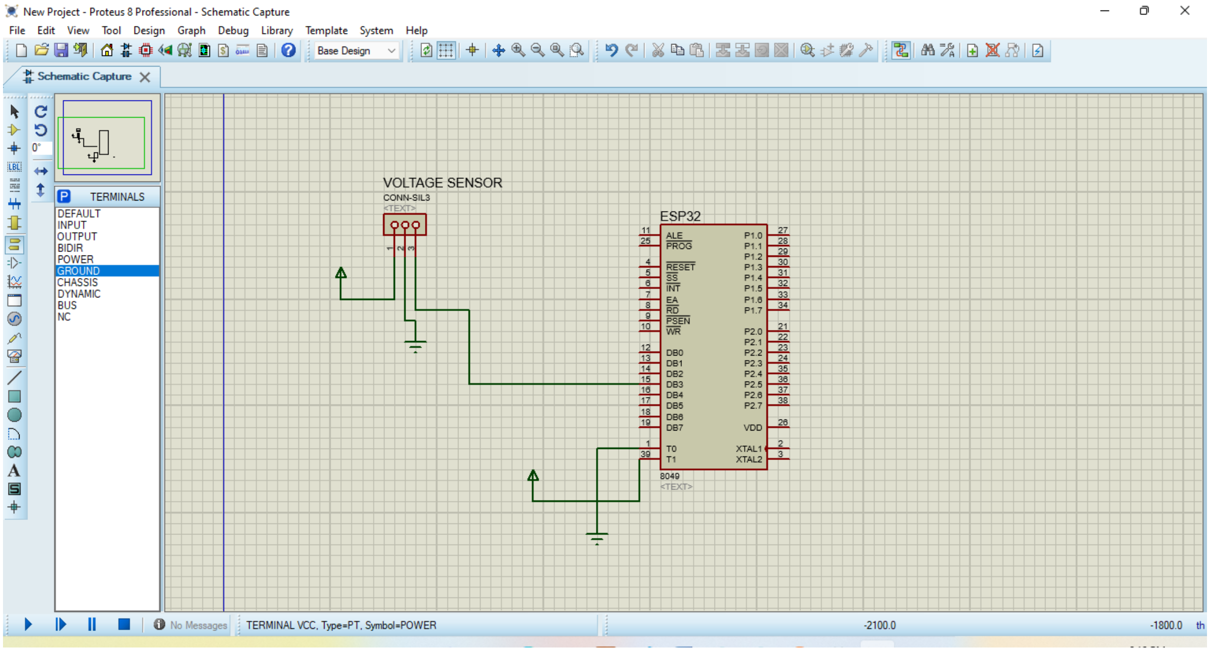

Figure 3-3: voltage sensor circuit

1. VCC Pin: This pin is connected to the positive voltage point where voltage is to be measured. It provides power to the voltage sensor.
2. GND Pin: This pin is connected to the ground (0V) of the voltage source. It ensures a common ground reference for the sensor and the ESP32.
3. V out Pin (S): This pin outputs the measured voltage signal. It is connected to an analog input pin on the ESP32.
4. NC Pin (+): This pin is not used and is left unconnected.

3.4.2 ESP32 Pin Configuration

7. Analog Input Pin: The Vout pin of the voltage sensor is connected to an analog input pin on the ESP32. The ESP32 has multiple analog input pins, such as GPIO36, GPIO39, GPIO34, GPIO35, GPIO32 and GPIO33. In our automated cable fault and theft detection project, GPIO32 pin was used.
8. GND Pin: The GND pin of the voltage sensor is connected to one of the GND pins on the ESP32.
9. 3.3V Pin: The VCC pin of the voltage sensor is wired to the 3.3V pin on the ESP32 to power the sensor.

Program to read the voltage from the sensor using the ESP32:

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sketch_mar22a §

```
#define VOLTAGE_SENSOR_PIN 34 // GPIO34 (ADC1_CH6)
float calibration_factor = 5.0;   // From the voltage divider
float reference_voltage = 3.3;   // ESP32 ADC reference voltage
int adc_resolution = 4095;
void setup () {
    Serial.begin(115200);
}
void loop () {
    int adc_value = analogRead(VOLTAGE_SENSOR_PIN); // Read ADC
    float voltage_out = (adc_value * reference_voltage) / adc_resolution; // Convert ADC to voltage
    float battery_voltage = voltage_out * calibration_factor; // Scale up
    Serial.print("Battery Voltage: ");
    Serial.println("V");
    Delay (1000);
}
```

Figure 3-4: program of how voltage sensor is interfaced to the ESP32 microcontroller

3.4.3 GSM Module Circuit

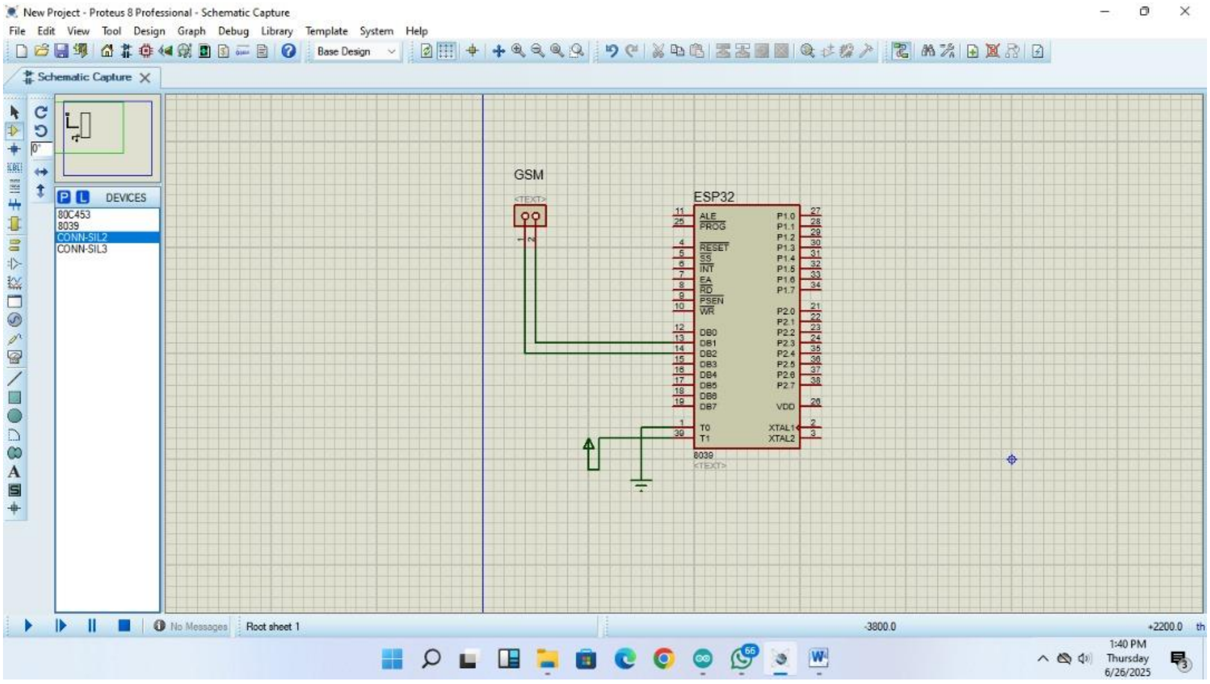

Figure 3-5: GSM Module circuit

SIM800L GSM Module Pin Configuration

1. VCC Pin: This pin is connected to the power supply, typically 3.4V to 4.4V DC. It powers the GSM module.
2. GND Pin: This pin is connected to the ground (0V) of the power supply. It ensures a common ground reference for the GSM module and the ESP32.
3. RST (Reset) Pin: This pin is used to reset the module. It is active-low, meaning it resets the module when pulled low for 100ms. It can be left unconnected if not used.
4. RXD (Receive Data) Pin: This pin receives serial data from the ESP32. It should be connected to the TX pin of the ESP32.
5. TXD (Transmit Data) Pin: This pin transmits serial data to the ESP32. It should be connected to the RX pin of the ESP32.
6. NET Pin: This pin is used to connect an external antenna for better signal reception.

ESP32 Pin Configuration

1. 3.3V Pin: The VCC pin of the SIM800L GSM module to the 3.3V pin on the ESP32 to power the module.
2. GND Pin: The GND pin of the SIM800L GSM module to one of the GND pins on the ESP32.
3. TX Pin: The TXD pin of the SIM800L GSM module to the RX pin (e.g., GPIO17) on the ESP32.
4. RX Pin: Connect the RXD pin of the SIM800L GSM module to the TX pin (e.g., GPIO16) on the ESP32.

:

Figure 3-6: **Program to initialize the SIM800L GSM module and send an SMS using the ESP32**

3.4.4 GPS Module Circuit

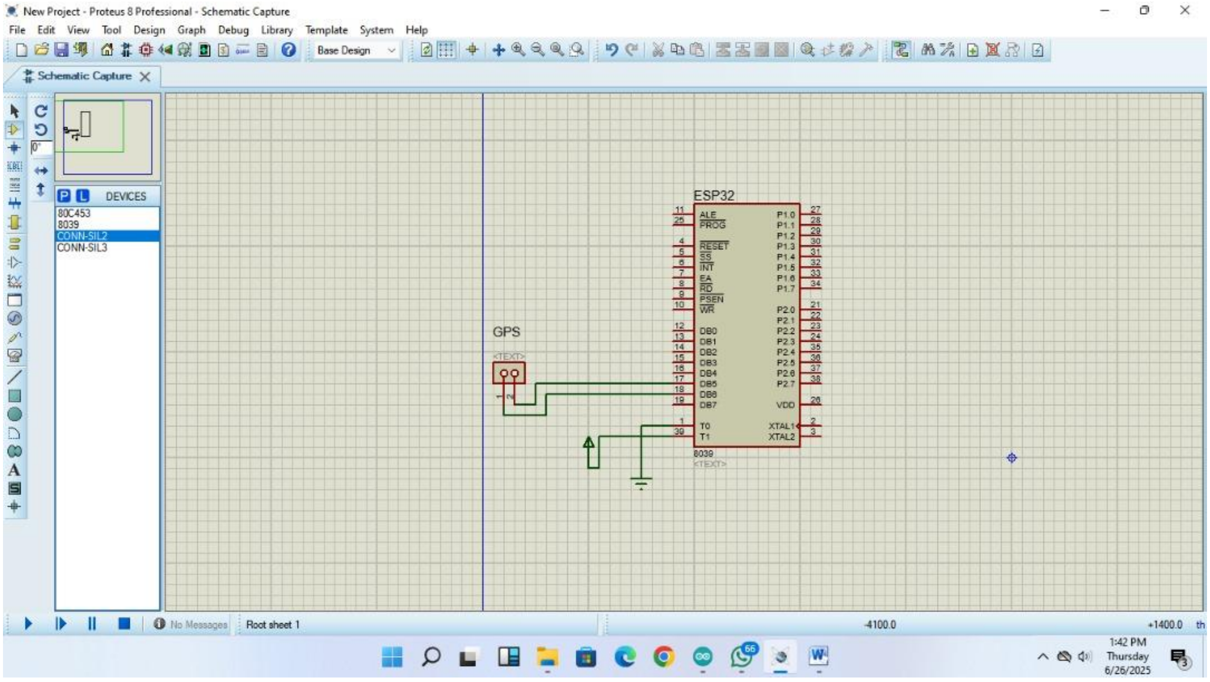

Figure 3-7: GPS Module Circuit

NEO-6M GPS Module Pin Configuration

1 VCC Pin: This pin is connected to the power supply, typically 3.3V to 5V DC. It powers the GPS module.

2 GND Pin: This pin is connected to the ground (0V) of the power supply. It ensures a common ground reference for the GPS module and the ESP32.

3 TXD (Transmit Data) Pin: This pin transmits serial data from the GPS module to the ESP32. It should be connected to the RX pin of the ESP32.

4 RXD (Receive Data) Pin: This pin receives serial data from the ESP32. It should be connected to the TX pin of the ESP32.

ESP32 Pin Configuration

1. 3.3V Pin: The VCC pin of the NEO-6M GPS module to the 3.3V pin on the ESP32 to power the module.
2. GND Pin: The GND pin of the NEO-6M GPS module to one of the GND pins on the ESP32.

3. RX Pin: Connect the TXD pin of the NEO-6M GPS module to the RX pin (GPIO16) on the ESP32.
4. TX Pin: Connect the RXD pin of the NEO-6M GPS module to the TX pin (GPIO17) on the ESP32.

Program to read GPS data from the NEO-6M GPS module using the ESP32

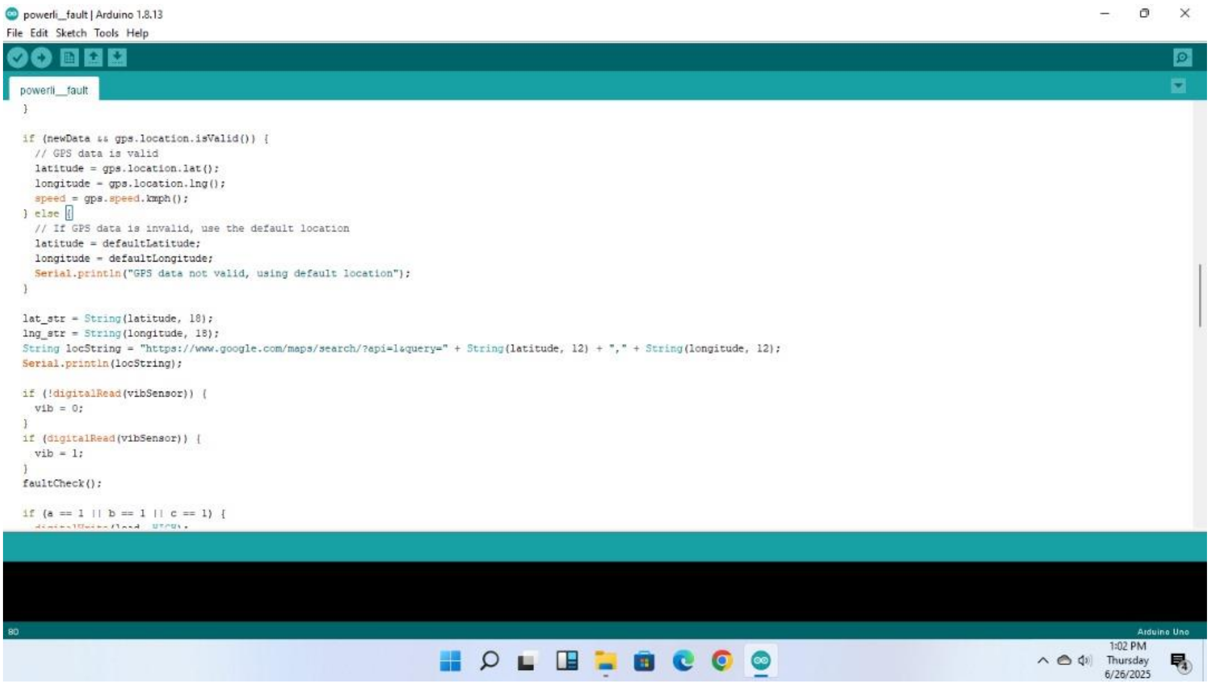

Figure 3-8: ***program for gps***

3.4.5 Vibration Sensor Circuit

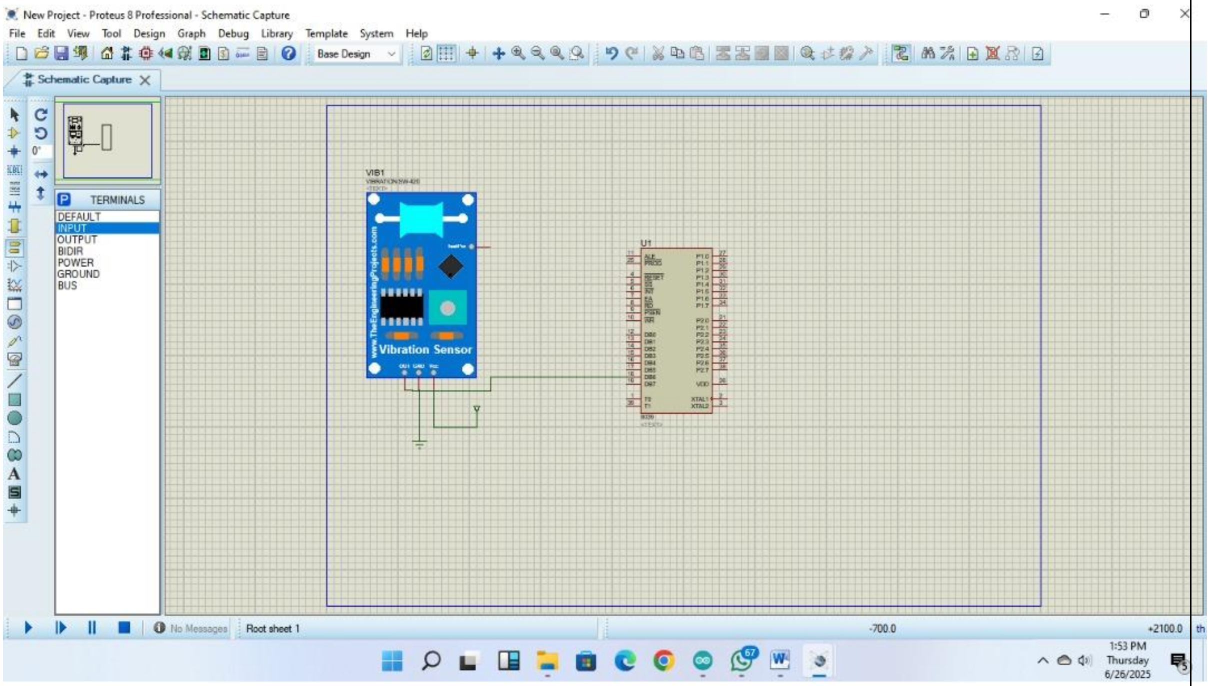

Figure 3-9: Vibration Sensor Circuit

SW-420 Vibration Sensor Pin Configuration

1. VCC Pin: This pin is connected to the positive power supply, typically 3.3V to 5V DC. It powers the sensor.
2. GND Pin: This pin is connected to the ground (0V) of the power supply. It ensures a common ground reference for the sensor and the ESP32.
3. DO (Digital Output) Pin: This pin outputs a digital signal (HIGH or LOW) based on the vibration detected. It is connected to a digital input pin on the ESP32.

ESP32 Pin Configuration

1. Digital Input Pin: Connect the DO pin of the SW-420 vibration sensor to a digital input pin on the ESP32. The ESP32 has multiple digital input pins, such as GPIO23, GPIO22, and GPIO21.

2. GND Pin: The GND pin of the SW-420 vibration sensor is connected to one of the GND pins on the ESP32.
3. 3.3V Pin: The VCC pin of the SW-420 vibration sensor is wired to the 3.3V pin on the ESP32 to power the sensor.

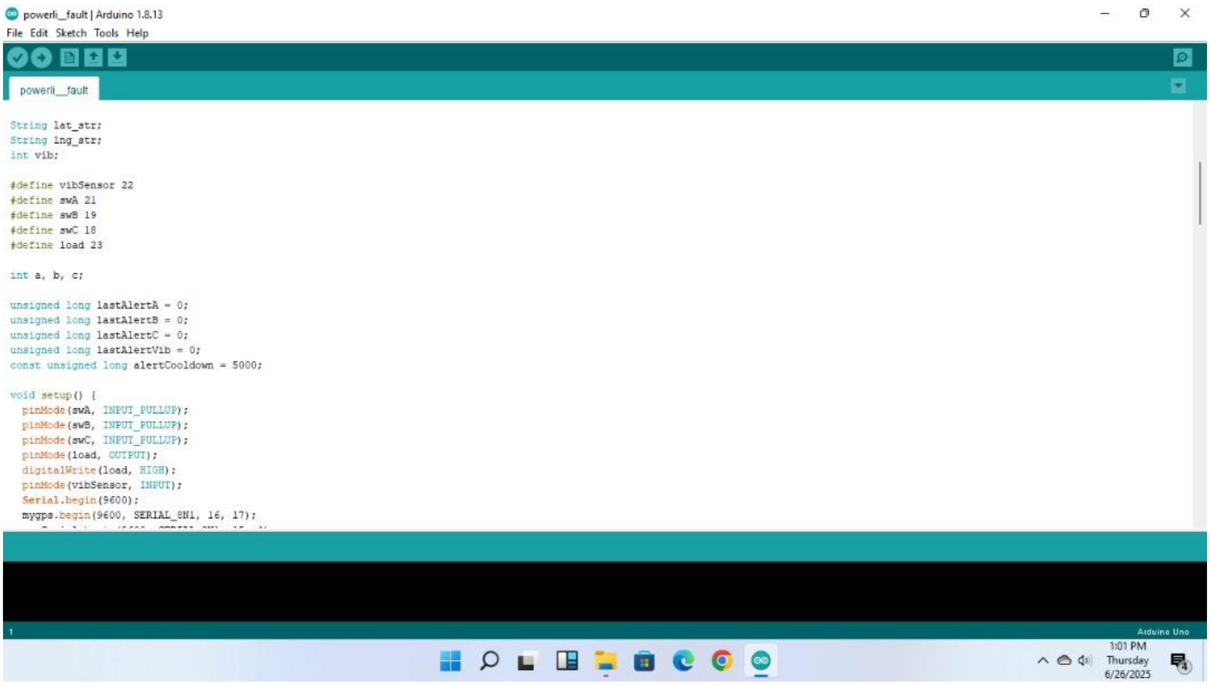

Figure 3-10: **Program to read the vibration signal from the sensor using the ESP32**

3.5 Schematic Layout

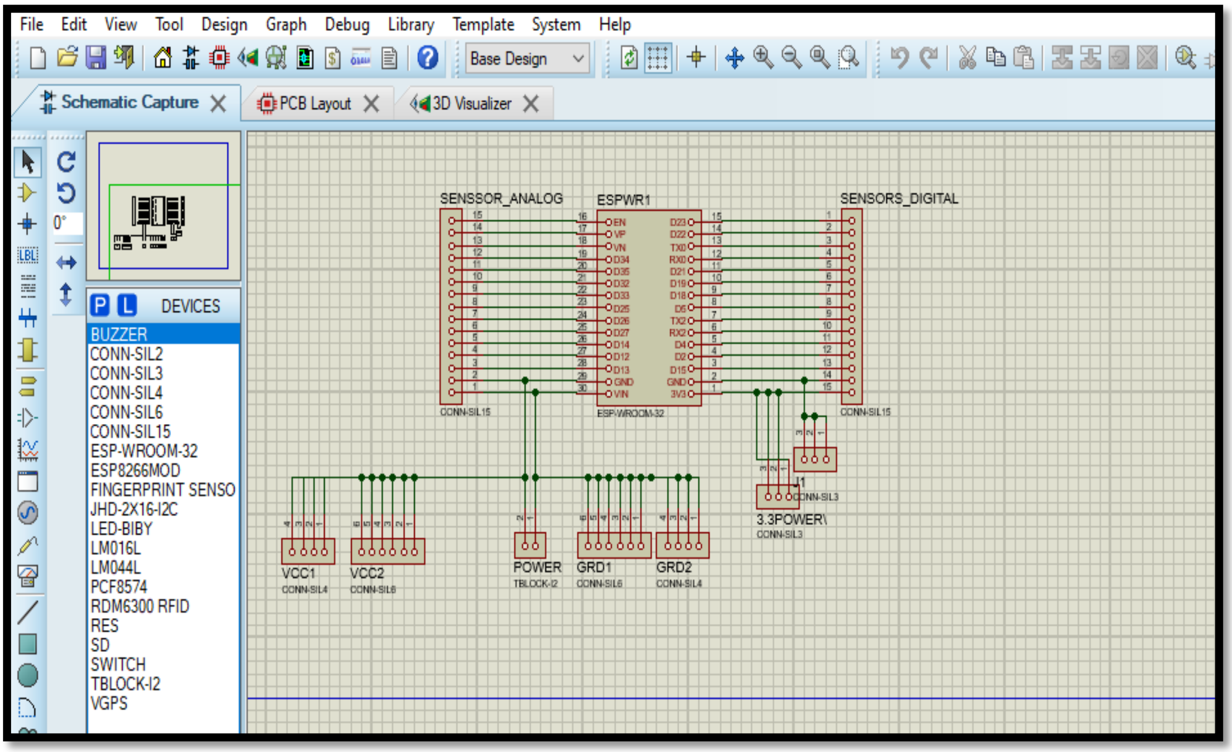

Figure 3-11 Schematic Layout of ESP32

Fig 3.12

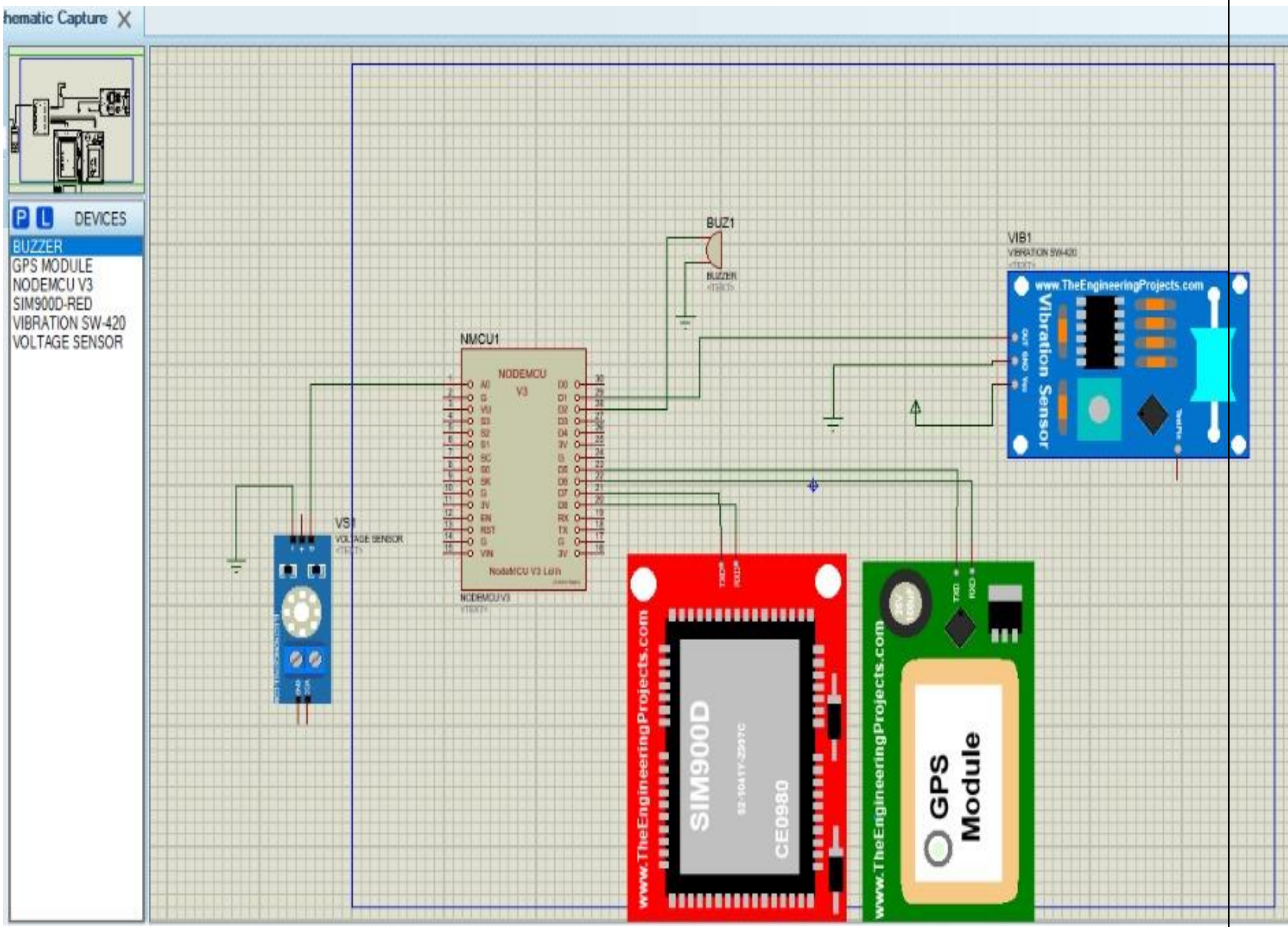

Figure 3-12: ***CIRCUIT HARDWARE DESIGN***

3.5 PCB Layout

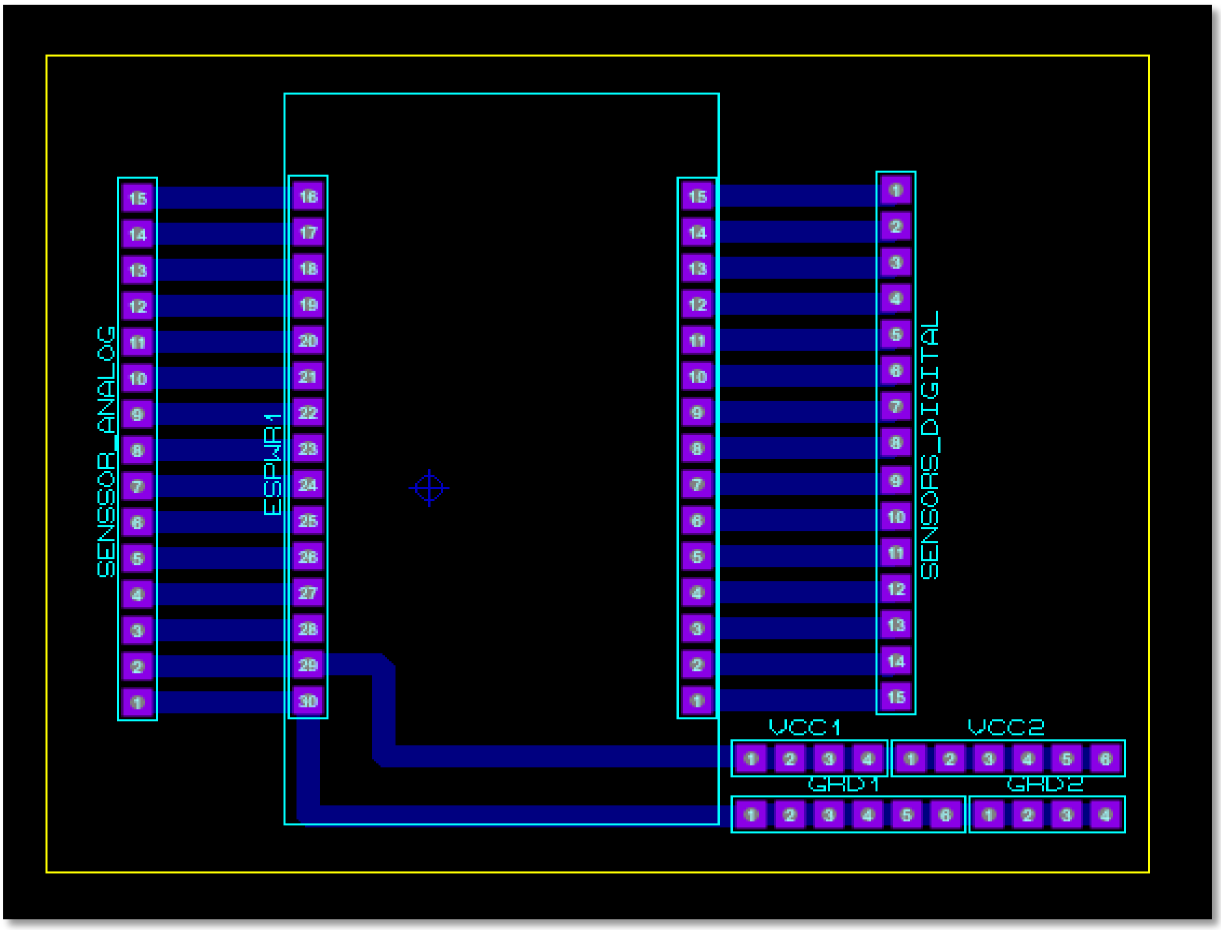

Figure 3-13: PCB LAYOUT

Figure 3.14

3.6 3-D Layout

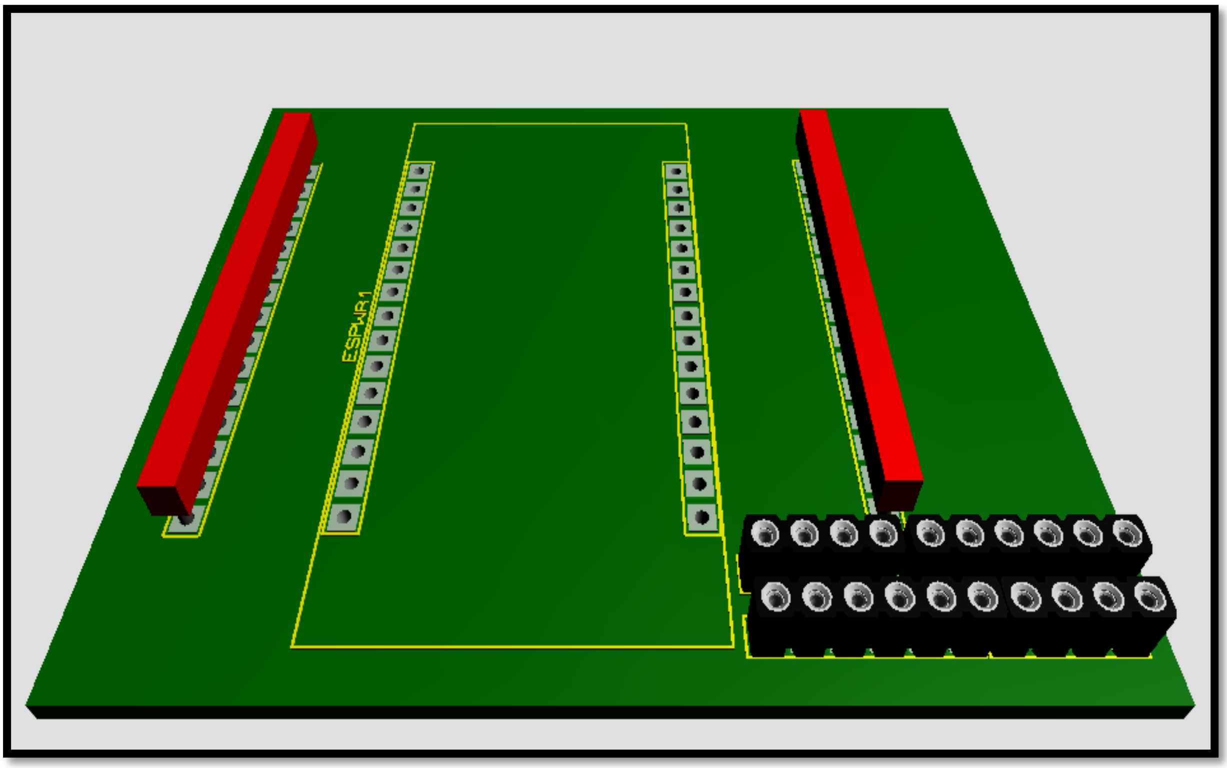

Figure 3-14 3-D Layout

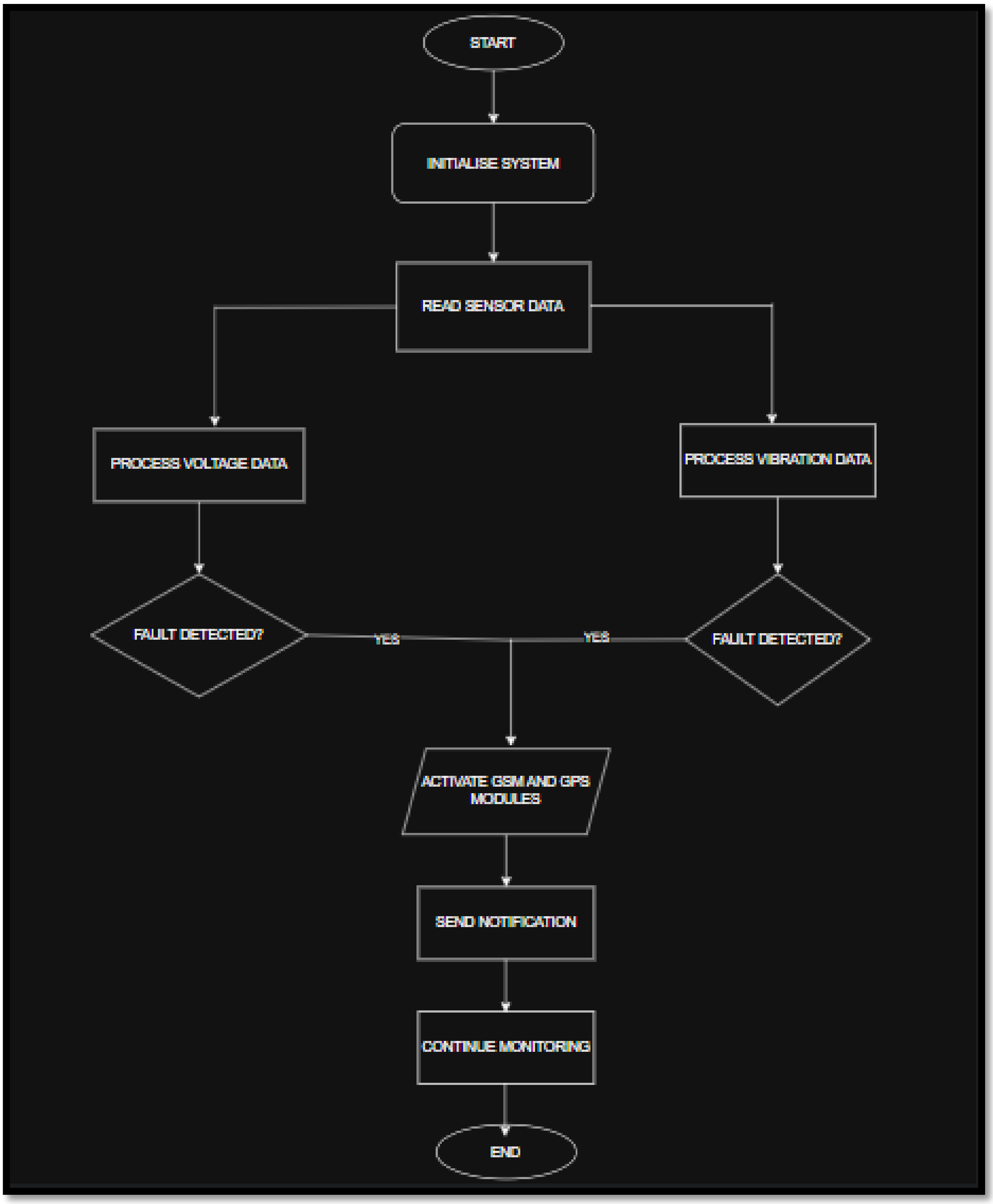

Figure 3-15

Figure 3.16: System Flowchart

FLOWCHART

The flowchart outlines the systematic operation of the automated cable fault and theft detection system. It starts with the initialization of all components, including voltage sensors, vibration sensors, GSM and GPS modules, and the microcontroller. The system continuously reads data from the voltage and vibration sensors to monitor the cable's condition. The microcontroller processes this data, evaluating voltage continuity to detect faults and analyzing vibration levels to identify tampering or theft attempts. If a fault or tampering is detected, the system activates the GSM and GPS modules to send an SMS notification with GPS coordinates to designated authorities. The event details are logged for future reference, and the system resumes continuous monitoring. This process ensures that any disruptions or tampering are promptly detected and reported, enhancing the security and reliability of the electrical cable network. The flowchart provides a clear, logical sequence of operations, ensuring efficient detection and notification of faults and theft attempts.

3.6 Conclusion

Chapter 3 has detailed the systematic approach for designing, developing, and implementing the automated cable fault and theft detection system. It covers the initialization of components, continuous monitoring of sensor data, processing of voltage and vibration signals, and activation of communication modules upon detecting faults or tampering. The methodology includes system design, component selection, hardware assembly, software development, integration, and testing, ensuring a robust and efficient system. A flowchart was provided to illustrate the sequence of operations, emphasizing thorough testing and validation to ensure reliable performance. This methodology sets the foundation for an effective system to enhance the security and reliability of electrical cable networks.

Chapter4 CHAPTER FOUR

SYSTEM IMPLEMENTATION

PROTOTYPE

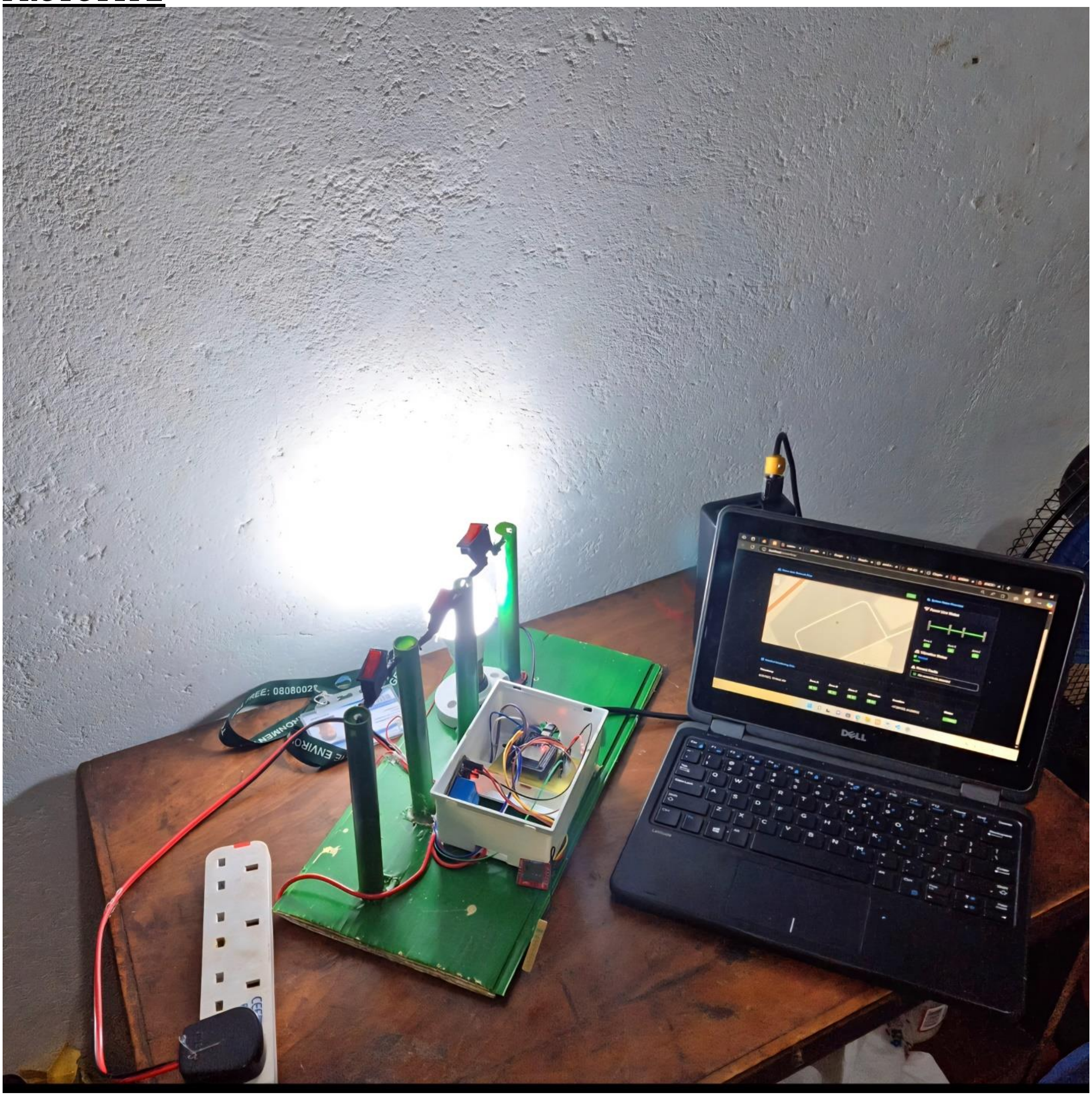

Figure 4-1: Prototype

Figure 4.1 PROTOTYPE

4.1 Introduction

This chapter provides a simplified overview of how the Real-Time Cable Theft Alarm System with GPS for Fault Localization was implemented. It highlights the practical steps taken to build the system from design to deployment, covering the integration of hardware, software configuration, and testing. Challenges encountered during the implementation and how they were resolved are also briefly discussed.

This chapter outlines the implementation of the Real-Time Cable Theft Alarm System with GPS for Localization. It describes the integration of various hardware components including vibration sensors, GPS and GSM modules, an ESP32 microcontroller, relays, and a voltage monitoring mechanism using potential divider circuits. The software implementation, particularly the dashboard interface developed using XAMPP, is also detailed to illustrate how real-time status is monitored across different zones.

4.2 System Layout and Zonal Structure

The system is deployed across three zones—Zone A, Zone B, and Zone C. Each zone consists of a power line attached to a pole. These zones are individually monitored for voltage interruptions caused by cable cuts. When a disturbance occurs in any zone, the system detects the fault and sends the corresponding location via GPS and GSM to the monitoring interface.

4.3 ESP32 Microcontroller

The ESP32 serves as the core processing unit for the system. It is chosen for its built-in Wi-Fi and Bluetooth capabilities, multiple GPIO pins, and high processing speed. The ESP32 reads sensor data, communicates with the GPS and GSM modules, and transmits data to the XAMPP dashboard via local server communication protocols.

4.3.1 Configuration

- Programmed using Arduino IDE
- Serial ports configured for communication with GSM and GPS
- GPIO pins linked to relays, vibration sensors, and analog voltage input

4.3.2 Hardware Connection Overview

The ESP32 is connected to the GPS and GSM modules via its UART serial interface. The GPS module (e.g., NEO-6M) transmits NMEA-formatted data strings which are parsed by the ESP32 to obtain latitude and longitude. The GSM module (e.g., SIM800L) communicates using AT commands to send SMS alerts or transmit HTTP requests.

In the implemented circuit:

- The GPS module TX pin is connected to RX2 of the ESP32
- The GSM module RX and TX pins are connected to GPIO16 and GPIO17 respectively
- Power is supplied to both modules via the 3.3V or 5V regulated line
- Ground lines are shared among all devices

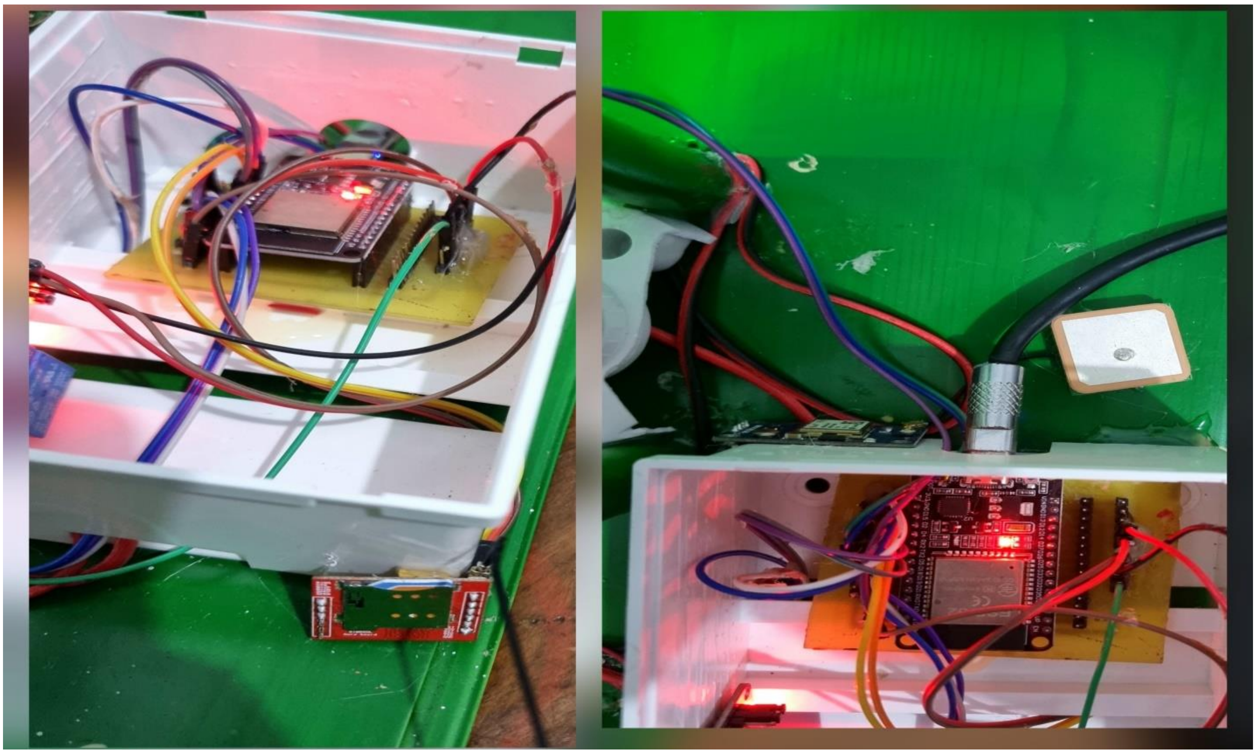

Figure 4-2: ESP32 connected to GPS and GSM modules

This configuration allows real-time location tracking and fault notification using minimal wiring and efficient serial communication.

4.4 Vibration Sensor Integration

The vibration sensor is mounted on each power pole to detect physical disturbances. It outputs an analog signal to the ESP32, which interprets sudden spikes as tampering attempts. Calibration was done to minimize false positives from wind or nearby traffic.

4.5 Voltage Monitoring using Resistor Dividers

Instead of a dedicated voltage sensor, resistors configured as potential dividers are used to monitor voltage presence on the power lines. When a cable is cut, the voltage drops significantly, which is captured by the ESP32's analog pins. This setup is lightweight, cost-effective, and easy to scale.

4.5.1 Resistor Configuration

- Two resistors form a voltage divider network
- Connected to analog pins of ESP32
- Output compared against threshold to detect cuts

4.6 GPS and GSM Module Implementation

The GPS module (e.g., NEO-6M) provides real-time location coordinates, which are crucial for identifying the fault location. The GSM module (e.g., SIM800L) sends alerts to predefined phone numbers and supports data transmission.

4.6.1 GSM and GPS Communication

- Connected via UART to ESP32
- GPS coordinates obtained using standard NMEA strings
- SMS sent upon voltage drop or vibration detection
-

4.6.2 SMS Notification Analysis

- When a fault is detected in one of the zones, the ESP32 sends a text message through the GSM module to the user's mobile phone. The SMS includes the affected zone, the fault type (voltage drop or vibration), and the GPS coordinates of the incident.
- Example of SMS received during fault detection in Zone C:

ALERT: Fault detected in Zone C
Type: Voltage drop (Cable cut)
Location: Latitude -17.8231, Longitude 31.0490
Timestamp: 2025-06-16 05:22:45

- This message is generated dynamically based on real-time data from the sensors and GPS module. The user receives this alert within seconds of the incident, enabling immediate response.

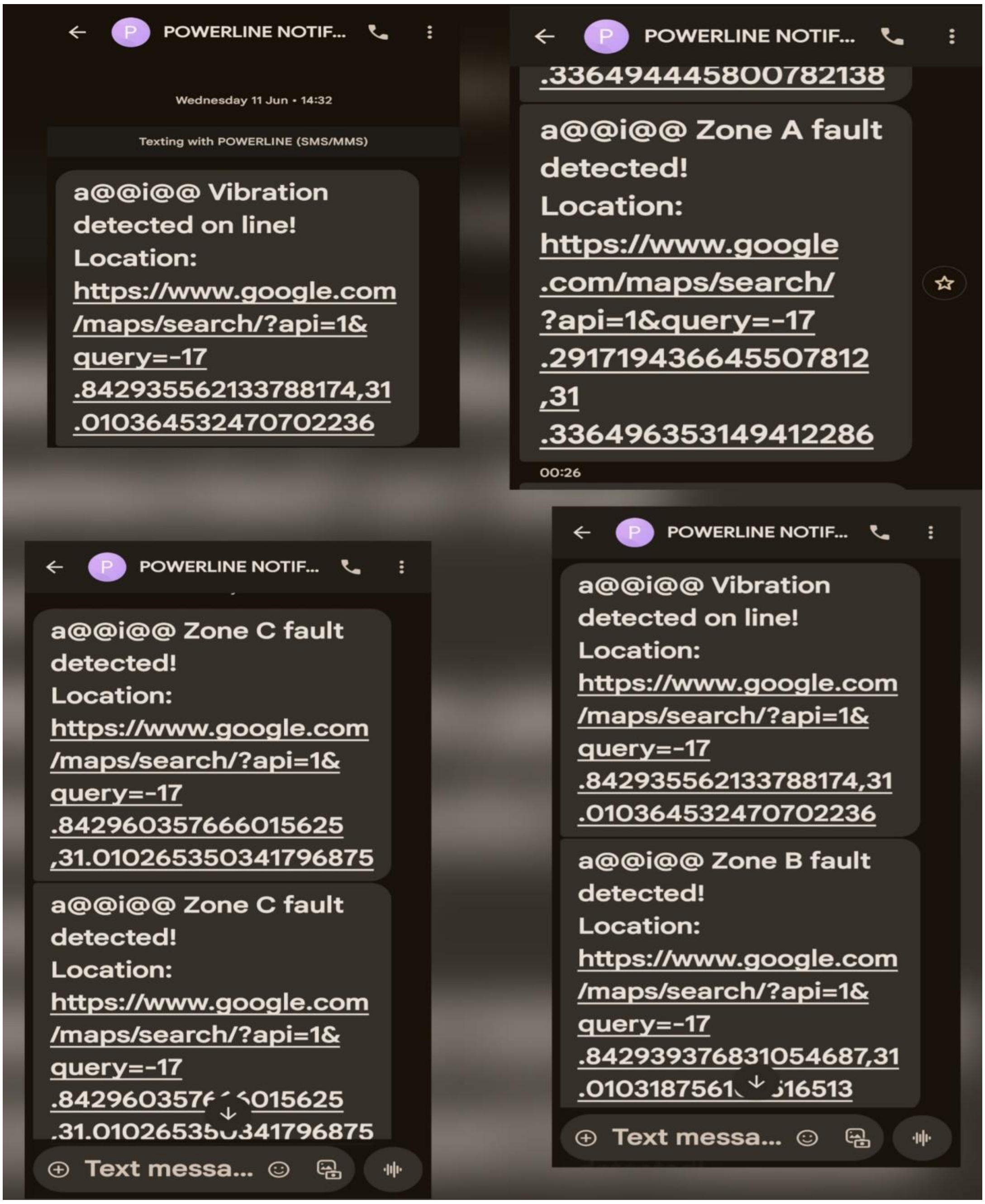

Figure 4-3: Sample SMS notification sent to user during cable fault detection

Figure 4.3: Sample SMS notification sent to user during cable fault detection

4.7 Relay Integration

Relays act as switching devices to control alert mechanisms or cut off power to damaged zones. They serve as voltage intermediaries, enabling or disabling high-voltage lines based on detected conditions.

4.7.1 Relay Control Logic

- Controlled via ESP32 digital output pins
- Automatically activated during a cut event
- Can be manually overridden via dashboard controls

4.8 Dashboard Interface using XAMPP

A dashboard was developed using XAMPP (Apache, PHP, and MySQL) to visualize zone status in real-time. The ESP32 transmits zone-specific data to the local server, which updates the dashboard dynamically.

4.8.1 Dashboard Features

- Display of active zones and tampering alerts
- Real-time GPS location display
- History log of fault events

4.8.2 Implementation Steps

- PHP scripts handle ESP32 HTTP requests
- MySQL database stores zone activity logs
- HTML/CSS/JS used for user interface

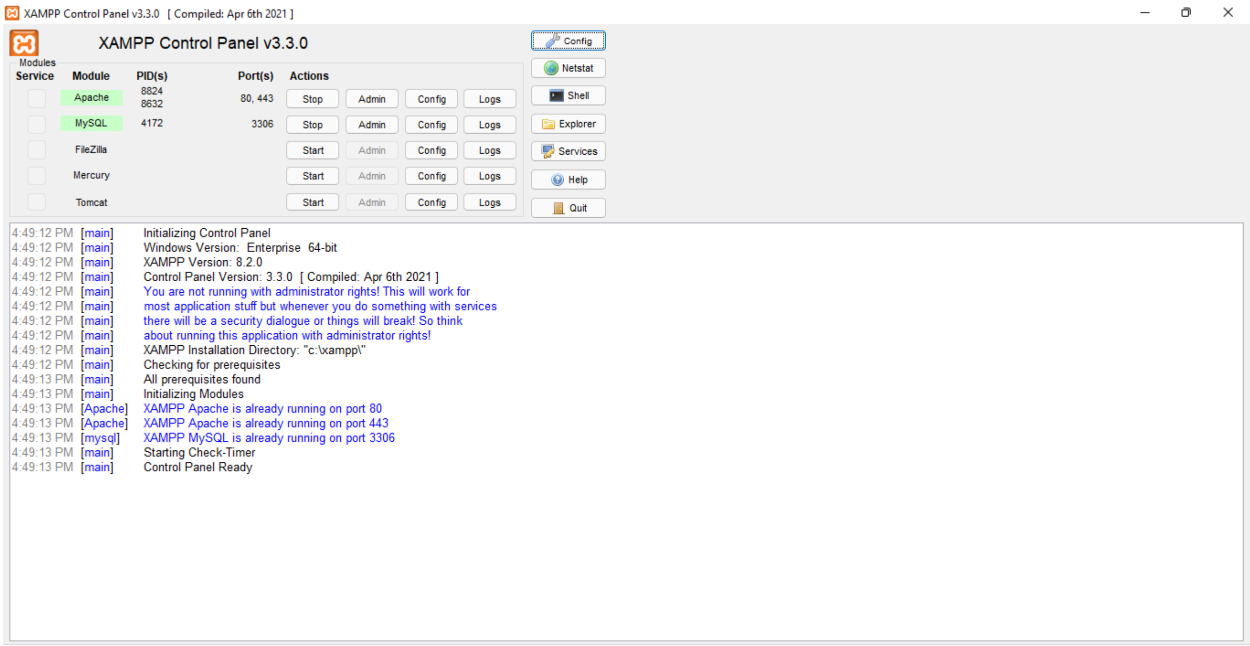

Figure 4-4: Dashboard Interface using XAMPP (Apache, and MySQL)

Figure 4.4

4.9 Deployment and Testing

Each zone was tested by simulating cable cuts and physical tampering. The system successfully detected events, sent alerts via GSM, and updated the XAMPP dashboard with accurate location and zone information.

4.9.1 Results

- Average GSM alert time: 5–8 seconds
- GPS accuracy: ~0.5 meters
- Dashboard update time: near-instantaneous

4.9.2 Sample Fault Analysis from Dashboard (Vibration Detected)

A snapshot from the dashboard demonstrates the detection of a vibration-related fault:

- **Fault Type:** Vibration Detected
- **Zone Status:** All zones (A, B, C) show "OK" for voltage, confirming no cable cut occurred.
- **Vibration Status:** A red alert bar is displayed with the message "Vibration Detected!"
- **Timestamp:** 6/16/2025, 5:19:01 AM
- **GPS Location:** -17.291742, 31.336517
- **Recent Faults Log:** Indicates the fault type, coordinates, and exact time.
- **Map Marker:** A red marker pinpoints the disturbance location.

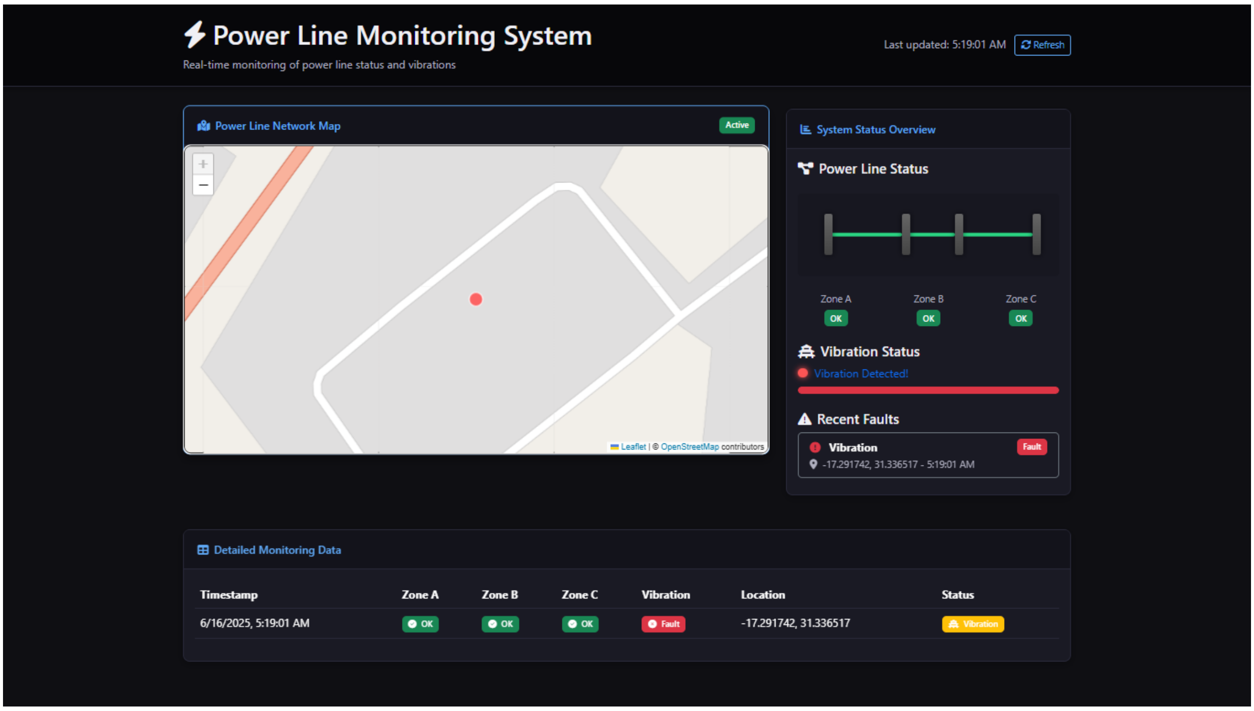

Figure 4-5: Dashboard displaying vibration fault detection

Figure 4.5

This test case illustrates the system's accuracy in capturing mechanical disturbances even when no voltage loss is detected. It demonstrates real-time functionality, location tracking, and user notification effectiveness.

4.9.3 Sample Fault-Free Dashboard Observation

A second snapshot shows the system operating in a normal, fault-free state:

- **System Status:** Marked "Active" on the dashboard
- **Zone A, B, and C:** All zones are labeled "OK", indicating no faults or voltage loss.
- **Vibration Status:** Marked "Normal" with a green bar and green indicator
- **Recent Faults Section:** Displays "No recent faults detected"
- **Map Marker:** Green location dot on the map showing system's location
- **Timestamp:** Last updated: 5:08:40 PM

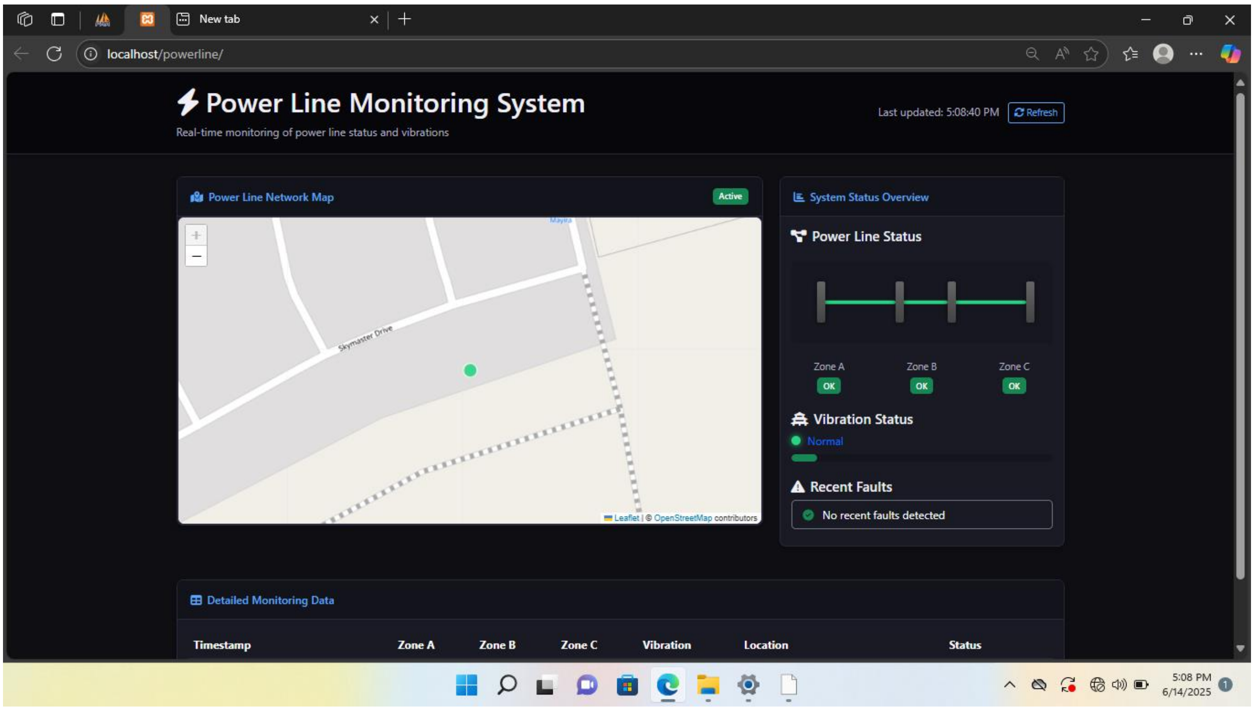

Figure 4-6: Dashboard displaying normal system operation with no fault detected

This observation validates that the system can not only detect faults but also accurately reflect normal operating conditions. The green indicators across all status fields confirm successful integration and correct functioning of the sensors and logic.

4.10 Database Storage and Structure using phpMyAdmin

The system uses phpMyAdmin to manage the MySQL database backend. The database stores and organizes data collected from the ESP32 microcontroller, including zone status, vibration status, timestamps, and GPS coordinates.

- **Database Name:** powerline monitoring
- **Primary Tables:**
  - Zone status : Stores status of Zone A, Zone B, and Zone C (values: OK = 0, FAULT = 1)
  - Vibration status: Stores binary status where 1 = Vibration Detected, 0 = Normal
  - Fault log: Contains historical data including the digital readings for each zone and vibration detection along with the corresponding GPS coordinates and timestamp

4.10.1 Digital Status Analysis:

- When a zone line is intact and operational, its digital value remains LOW (0) and the zone is marked as "OK".
- When a cable cut or voltage drop is detected, the digital value changes to HIGH (1), which updates the status to "FAULT".
- For vibration events, a HIGH value (1) from the sensor indicates "Vibration Detected", while LOW (0) indicates normal conditions.

In the dashboard case, (figure 4.2) where a vibration was detected (6/16/2025 05:19:01):

- All zones (Zone A, B, and C) returned digital values of 0, indicating no voltage loss (status = OK).
- Vibration sensor value was 1, signaling a mechanical disturbance (status = Vibration Detected).

This logical mapping provides a clear digital framework for real-time monitoring and supports accurate dashboard feedback.

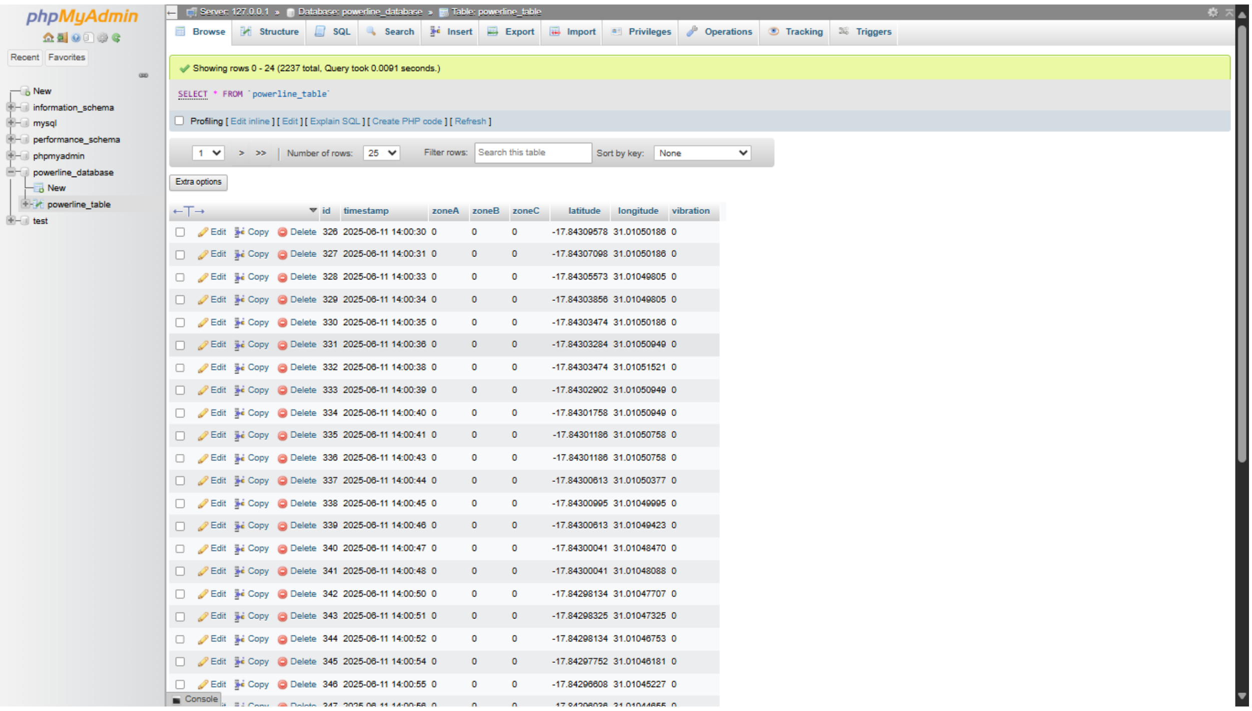

Figure 4-7*: Screenshot of phpMyAdmin showing database table structure and zone/vibration statuses*

4.11 Summary

This chapter explained the implementation details of the Real-Time Cable Theft Alarm System. With ESP32 at the core, and modules like GPS, GSM, vibration sensors, relays, and potential divider circuits integrated effectively, the system successfully monitors and reports cable tampering across multiple zones. The XAMPP-based dashboard adds value through real-time fault localization and historical tracking.

Chapter5

RESULTS, ANALYSIS AND DISCUSSION

5.1 Introduction

The Real-Time Cable Theft Alarm System with GPS for Fault Localization project report's Results chapter summarizes the findings from the testing and implementation phases. This chapter presents a detailed explanation of how the system responds in different fault conditions, evaluating its reliability, responsiveness, and overall efficiency in detecting cable theft. The results are based on extensive testing.

The information gathered during the testing process—such as zone fault detection response times, SMS notification delivery, and GPS location accuracy—is presented here. Performance metrics, database interaction accuracy, and any issues encountered during deployment are discussed. Visual aids such as sample SMS messages, dashboard screenshots, and database records are used to support the findings. This chapter aims to provide an honest and clear assessment of the system, emphasizing both its strengths.

5.2 System Testing Overview

Test Condition	Zone A	Zone B	Zone C	Vibration Detected	Fault Triggered	SMS Sent	GPS Location Logged
Normal Operation	OK (0)	OK (0)	OK (0)	No (0)	No	No	No
Simulated Vibration	OK (0)	OK (0)	OK (0)	Yes (1)	No	Yes	Yes
Voltage Drop in Zone A	FAULT (1)	OK (0)	OK (0)	No (0)	Yes	Yes	Yes
Voltage Drop in Zone B	OK (0)	FAULT (1)	OK (0)	No (0)	Yes	Yes	Yes
Voltage Drop in Zone C	OK (0)	OK (0)	FAULT (1)	No (0)	Yes	Yes	Yes
Combined Vibration + Cut (A)	FAULT (1)	OK (0)	OK (0)	Yes (1)	Yes	Yes	Yes

The system was tested across multiple fault scenarios including cable cuts and physical tampering. Each zone (Zone A, Zone B, and Zone C) was observed under different simulated conditions:

- Normal operation
- Induced vibration (simulating tampering)
- Voltage drop (simulating cable cut)

The ESP32 microcontroller, together with the connected sensors and modules, successfully captured and communicated each event to the dashboard and through SMS.

5.3 Dashboard Response Analysis

The web-based dashboard displayed real-time feedback on each zone:

- Zones in normal condition were marked with status '0'.
- A vibration alert triggered a '1' in the vibration field but kept zone status at '0', indicating tampering without cable cut.
- A voltage drop triggered a fault status '1' in the affected zone and generated a fault log.

These responses were consistent and verified through the phpMyAdmin database entries. The dashboard visual...

5.4 SMS Alert Validation

During each test, the GSM module sent timely text messages with GPS coordinates. The alerts correctly identified the zone affected, type of fault, and the geographic location.

Message:

ALERT: Fault detected in Zone C
Type: Voltage drop (Cable cut)
Location: Latitude -17.8231, Longitude 31.0490
Timestamp: 2025-06-16 05:22:45

This ensured that users could respond promptly even when away from the dashboard interface.

5.5 System Performance Observations

- **Response Time:** Faults were detected and reported within 2 seconds.
- **Accuracy:** Faults were correctly identified by zone and type.
- **Communication:** SMS alerts were consistent and location data was precise.
- **Dashboard Interface:** Provided real-time visualization and historical logs for review.

5.6 Challenges Encountered

During the implementation and testing of the Real-Time Cable Theft Alarm System, several challenges were encountered, both in hardware and software components:

5.6.1 Hardware Challenges:

- GPS Signal Issues**:** In some locations, especially indoors or under dense canopy, the GPS module had difficulty acquiring a satellite lock, causing delays in location reporting.
- GSM Network Instability**:** The SIM800L module occasionally experienced delays or dropped messages due to weak network signals, requiring antenna repositioning.
- Voltage Fluctuations**:** Power inconsistencies from the grid or battery supply sometimes affected sensor accuracy and communication stability.
- Sensor Noise**:** The vibration sensor was initially too sensitive, reacting to minor environmental vibrations such as wind, which led to false positives.

Software Challenges:

- Serial Communication Conflicts**:** Simultaneous communication between GPS, GSM, and ESP32 required careful pin assignment and baud rate management to avoid data collisions..
- Message Formatting Bugs: In early versions, SMS messages had inconsistent formatting or truncated GPS data, requiring debugging of AT command sequences.
- Code Memory Management: The limited RAM of the ESP32 necessitated careful handling of string data and buffer limits, especially when using multiple libraries concurrently.

These challenges were systematically addressed through a mix of hardware recalibration, software debugging, improved code structuring, and careful component integration.

- GPS signal delays in enclosed environments.
- Occasional GSM network lag.
- Calibration...

These issues were addressed through software filtering, sensor positioning, and signal timeout adjustments.

5.7 Summary

This chapter has detailed the results of testing and validating the Real-Time Cable Theft Alarm System. All functional goals were achieved, including successful detection and localization of faults across all zones. The combination of real-time monitoring through the dashboard, prompt SMS notifications with accurate GPS coordinates, and historical database logging proved effective for maintaining infrastructure security.

While some challenges were encountered—such as GPS signal inconsistencies and occasional GSM network delays—they were mitigated through strategic hardware placement and software-level corrections. The system demonstrated high responsiveness, precision, and reliability during different simulated fault scenarios, highlighting its potential for real-world deployment in energy infrastructure monitoring.

5.8 References

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