DISTRIBUTION TRANSFORMER MANAGEMENT SYSTEM

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A Final Year Design Project (FYDP) submitted to the Department of EEE, BSRM School of Engineering, BRAC University in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering (BSEEE)

Department of EEE, BSRM School of Engineering
Brac University
May 2025

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Declaration

It is hereby declared that

1. The Final Year Design Project (FYDP) submitted is my/our own original work while completing degree at Brac University.
2. The Final Year Design Project (FYDP) does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The Final Year Design Project (FYDP) does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. We have acknowledged all main sources of help.

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of Spring,2025 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Bachelor of Science in Electrical and Electronic Engineering (BSEEE) on

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Ethics Statement

We hereby declare that the Final Year Design Project (FYDP) has been completed by fulfilling all the requirements with all the implementations named “Distribution Transformer Management System”. This document was authored by the members of our group. All the sources and information that have been written in the literature review, data analysis, and other portions have been cited properly. According to the plagiarism report, the similarity score for this report is 9%.

Abstract/ Executive Summary

The Distribution Transformer Management System (DTMS) addresses critical challenges in Bangladesh's power grid, including unbalanced loading, overloading, and power theft, which lead to frequent outages and operational inefficiencies. Leveraging IoT technology, the DTMS provides real-time monitoring of distribution transformers, detecting faults, unbalanced loads, and unauthorized power usage. The system logs data for preventive maintenance and ensures compliance with grid standards, reducing outages and extending transformer lifespan. By optimizing grid performance, the DTMS supports sustainable economic growth in Bangladesh.

Keywords: Distribution transformers, IoT, real-time monitoring, fault detection, power theft,

preventive maintenance, sustainable energy.

Dedication

This work is dedicated to all the people who are working immensely towards a greater Bangladesh, a country of reliable electricity with a sustainable grid management system. And to all the researchers who are doing their best to provide new technologies to make the world greater as possible.

Acknowledgement

We wish our sincere gratitude and appreciation to our chair of Group 6, Dr. A.S. Nazmul Huda, Associate Professor, Department of EEE, BSRM School of Engineering, BRAC University, for his immense cooperation in making this project a success. Furthermore, we would also like to thank Sharif Mohammad Shams, Lecturer, Department of EEE, BSRM School of Engineering, BRAC University, and Nahid Hossain Taz, Lecturer, Department of EEE, BSRM School of Engineering, BRAC University, for their continued guidance, valuable insights, recommendations, and cooperation.

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Chapter 1: Introduction

1.1 Introduction

The increasing reliance on electrical energy in Bangladesh poses serious challenges to the maintenance of a stable power distribution system [1]. The situation emphasizes a critical problem: the need for a sound distribution transformer management system able to ensure a stable and efficient supply of electricity. Traditional transformer management systems heavily depend on manual evaluation and obsolete technologies. These systems thus struggle in addressing the complex challenges of fault detection, load imbalances, and pilferage of electricity.

As a response to such challenges, we propose the architecture of the Distribution Transformer Management System (DTMS), a sophisticated system that combines Internet of Things (IoT) technology, accurate sensors, and data analytics to enable real-time transformer monitoring, fault detection, theft prevention, and support for preventive maintenance actions. The core goal of this system is to improve grid reliability, reduce economic losses, and promote sustainable energy. Literature proves considerable enhancement in transformer performance through IoT-based monitoring as it ensures real-time information regarding key parameters like voltage, current, and temperature levels [2]. The DTMS combines these features with other sophisticated functionalities like the detection of electricity theft, which is highly relevant in the Bangladesh context. Bangladesh's utility companies, like the Dhaka Power Distribution Company (DPDC), suffer huge losses due to unauthorized connections in their networks. By enabling bi-directional data communication between transformers and command centers, the DTMS improves operational efficiency, helps in load balancing, and enhances fault prediction.

Thus, DTMS will reduce the downtime and maintenance costs. During communication failures, the system will ensure reliability by including on-site processing and display capabilities. The DTMS will also extend the lifespans of the transformers. It will reduce the need for frequent replacements and minimize resource consumption. Thus, environmentally, it will contribute to sustainability.

This project aligns with the growing transformer market in Bangladesh and the global shift toward smart grid systems [3][4]. It offers a flexible option for power distribution improvement using transformers and promotes eco-friendly transportation options.

1.1.1 Problem Statement

Bangladesh has a population of over 170 million and faces serious challenges in ensuring a reliable and efficient provision of electricity. The country's distribution transformers perform a crucial part in this system; however, they often face serious working challenges because of -

1. **Deficiencies in Fault Identification:** If a transformer fails or develops a fault, utility providers strive to pinpoint exactly the areas where they are limited by reliance on outdated manual systems. results in increased downtime and economic losses.
2. **Unbalanced Load Conditions:** As DPDC experts explain, a whopping 90% of transformers damage results from unbalanced loading. Prolonged exposure to such conditions can lead to overheating, reducing the lifespan of transformers and causing significant power losses.
3. **Maintenance Challenges:** The utility companies often lack adequate personnel and resources in order to properly maintain all distribution transformers efficiently. Additionally, when they plan on making connections, an inexperienced consumer cannot effectively determine the phase when the load is low.
4. **Electricity theft:** The practice of illegal procurement of electricity is well-known throughout Bangladesh. A significant case of theft of electricity took place directly from the phase. Many people and commercial entities, including hawkers and LEV charging stations, tap electricity illegally from the phase. The Dhaka Power Distribution Company (DPDC) has reported financial losses of over Tk 700 crore due to yearly deficits in electricity [5].
5. **Problems Related with Overloading:** The conditions under which transformer overloading takes place worsen underlying challenges, leading to untimely breakdowns and high operation costs.
6. **Effects on Transformer Windings and Lifespan:** Running distribution transformers under conditions of continuous unbalanced loads or overloading exerts a considerable impact on the windings and the overall operation lifespan. Unbalanced loads create negative sequence currents, which cause unbalanced heating in the windings, thus accelerating insulation deterioration [6][7]. Overloading causes high temperatures, thus reducing the transformer's working lifespan [6]. Effective load level management is thus critical in extending transformers' lifespans as well as making power distribution reliable.

In light of these challenges, it is essential to consider the market trends for transformers in Bangladesh. In terms of market revenue share by types, three-phase oil transformers captured around 69% of the market revenues in 2021, as power utilities are the largest buyers of transformers in Bangladesh. These transformers are predominantly used for distribution purposes in urban areas. Furthermore, according to 6Wresearch, the Bangladesh Transformer Market revenue size is projected to grow at a CAGR of 6.8% during 2022-2028F, reflecting the increasing demand for transformers due to rising urbanization and power needs.

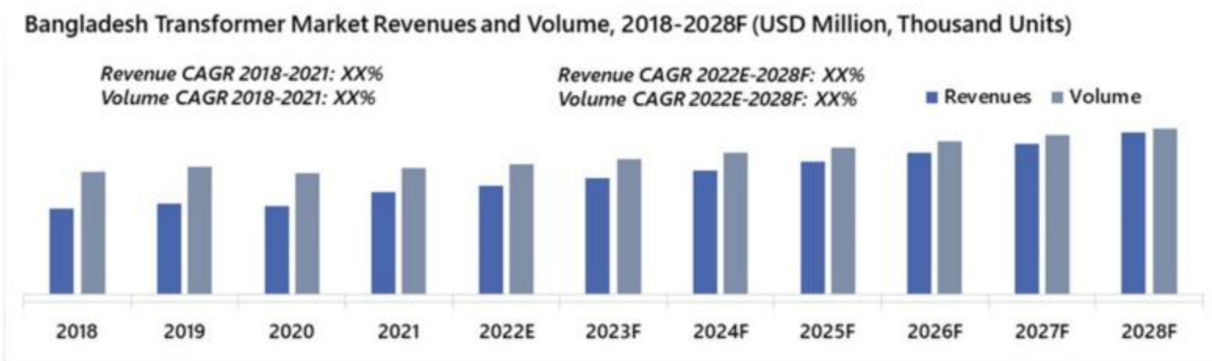

Figure 1.1: Bangladesh Transformer Market Revenues (2018-2021, 2022-2028 Predicted)
[Source: 6Wreaserch]

At the same time, however, this positive trend calls for overcoming existing challenges to secure the reliability and performance of transformers. As the market looks set to expand even further, the call for installing advanced monitoring systems, suitable load management techniques, and efficient theft prevention strategies arises to minimize downtime incidences, reduce maintenance costs, and prevent early failures. The application of those steps can significantly extend transformer operational life, hence reducing total operation costs and ensuring continuous electricity supply for the expanding country populace.

1.1.2 Background Study

The importance of monitoring and maintaining distribution transformers has been recognized in Over the years, various studies have explored advanced ways of assessing transformer conditions and performance. In a three-phase system, allocating loads between the phases must be properly distributed so as not to compromise the reliability of the electrical components and the distribution transformer system [8]. Due to the unbalanced load distribution, electric current flows through the neutral wire of the transformer, reducing the operating efficiency of the transformer. It thus becomes necessary to maintain continuous monitoring of the distribution transformer. The continuous monitoring of load parameters has the potential to reduce the threat of overheat and equipment failures [9]. Several studies reflected the requirement for full-scale health assessments of distribution transformers through testing so as to guarantee their reliability of operation [10]. Detailed studies have justified the load monitoring system proposed for continuous monitoring of transformer condition.

A study has been conducted that allows remote monitoring of load status as well as load data storage through the IoT system has the ability to detect the overload status of the transformer by using current measurement sensors [11]. There are many approaches to assessing health, such as machine learning-based algorithms for the proactive prediction of transformer failures [10]. Their integration into an advanced monitoring framework has the capacity to enhance the efficiency of the DTMS. Additionally, the problem of pilferage of electricity has long plagued Bangladesh [5]. The illegal practice mainly occurs at different instances of time, and the utility company suffers serious economic loss due to theft of electricity. As per reports, DPDC, the utility company, has suffered a loss of 700 crore taka [5]. The distribution transformer monitoring system can help reduce problems related to theft. Research on GSM-based monitoring systems has largely focused on alarm features rather than comprehensive load monitoring [8]. The DTMS aims to bridge this gap by providing real-time monitoring functions that can recognize irregularities in the ongoing flow and thus prevent unauthorized usage of electricity.

1.1.3 Literature Gap

Despite advanced monitoring techniques, a huge shortfall in the older studies remains. The core element entails the integration of Advanced Technologies. While previously existing research has probed multiple methods of monitoring exist; however, a unified system combining real-time monitoring, preventive maintenance, and detection of theft of electricity under a single framework has not yet emerged. Scalability and adaptability also remain huge challenges. Most existing solutions are tailor-made for certain applications present challenges in accommodating diverse transformer setups and operational contexts. Another important limitation is that existing methodologies often prioritize discrete points of transformer condition. Extensive methodology encompassing load distribution, thermal monitoring, and preventive analytics remains underexplored.

1.1.4 Relevance to current and future Industry

The rationale for starting the DTMS initiative lies in the paramount necessity of enhancing the the reliability and effectiveness of distribution transformers in Bangladesh. By addressing the identified recognizing available limitations, the effort aims at cultivating a holistic approach that promotes firsthand observation of voltage, current, and temperature, detects load imbalances and potential faults, reduces financial losses caused by electricity theft, while helping utility companies make well-informed decisions regarding transformer maintenance and new connections. The implementation of such a system is crucial not solely for making present transformers more efficient but also for allowing the creation of more sustainable energy infrastructure in Bangladesh. As electricity demand continues to rise, implementing advanced monitoring technology will be essential in improving the efficiency of distribution network operations.

1.2 Objectives, Requirements, Specification and Constant

1.2.1. Objectives

The objective of the Distribution Transformer Management systems is -

1. Real-Time Monitoring: Provide a system for continuous monitoring of voltage, current, and oil temperature of distribution transformers through the deployment of IoT-based sensor solutions.

2. Fault Detection: Analyze both real and reactive power to identify abnormalities, such as unbalanced loads, overload conditions, and power factor-related problems, thus enabling the early detection and prevention of faults.

3. Preventive Maintenance: Create a fault database that holds information related to faults and their causes. Instances identify patterns that indicate potential malfunctions and make proactive maintenance possible.

4. Reduction of Power Theft: Power theft reduction requires a real-time monitoring of the phase currents for accurate identification of irregularities, including unauthorized diversion of electrical energy, and broadcasting alerts in order to prevent unauthorized consumption of electricity

5. Improve Transformer Efficiency and Longevity: The efficiency of transformers during operation can be enhanced by identifying issues like overheating and excess reactive power, thus ensuring optimum performance and longer life of the transformer

6. Data Transmission and Communication: Utilize IoT, GSM, or wired communication Technologies used in the transmission of transformer data to a central controlling facility, making utility operations easier. with real-time insights for decision-making.

7. Technician and Utility Support: Provide utility technicians with holistic, real-time information about transformer operation and phase load distribution so they can make intelligent decisions.

1.2.2 Functional and Nonfunctional Requirements

Functional requirements:

1. **Real-Time Monitoring:** The system must continuously measure the distribution transformer's voltage, current, and oil temperature, as sensors will send instantaneous readings from the transformer to the remote IoT system.
2. **Power Calculations:** The system should have the ability to calculate both the real power (P) and reactive power (Q) of the transformer in real time and also determine unbalanced loads by observing the power on each phase.
3. **Fault Detection and Alerts:** The system should be able to detect abnormal conditions, such as unbalanced current, overloading, and overheating, and should send alerts to control rooms or technicians whenever these abnormalities are detected, using IoT-based notifications or SMS alerts via GSM or wired communication systems.
4. **Preventive Maintenance:** The system must record certain information about faults and their root causes, and then use the information to predict potential failures and make recommendations for preventive maintenance actions.
5. **Power Theft Detection:** The system must detect irregularities in voltage and current flow in order to determine possible cases of power theft.
6. **Data Communication and Transmission:** The system must be able to transmit data from the transformer to a central location by using IoT, GSM, or wired communication techniques.
7. **Control Room Dashboard:** The control room must be equipped with a dashboard showing real-time values of the transformer parameters, including voltage, current, power factor, temperature, and so on. The dashboard will also provide notifications and error logs.

Non-functional requirements:

1. **Scalability:** The system should have the ability to monitor and control a large number of transformers scattered over different locations as the network expands.
2. **Reliability:** The system must ensure continuous data capture and transmission which has a high level of reliability.
3. **User-friendly:** The control room's dashboard has to be easy to use and simple for technicians and engineers; additionally, however, the alerts must be clear and concise so as to facilitate quick decision-making.
4. **Durability:** Sensors and communication equipment must be weather resistant and be able to withstand harsh environmental conditions like temperature fluctuation, high humidity levels, and dust exposure, especially for transformers used outdoors in Bangladesh.

5. **Compliance:** The system must comply with the standards defined by the national power grid and ensure compatibility with the existing infrastructure in Bangladesh.

1.2.3 Specifications

1. Voltage Detection: Detect voltage of 0-500V with an accuracy of ±0.5 %
2. Current Detection: Detect current of 0-600A with an accuracy of ±0.5 %
3. Temperature Detection: Detect temperature of -50-200 °C with accuracy ±0.3 °C,
4. IoT Cloud Integration: Store and analyze data with IoT cloud.
5. GSM Module: GSM Module with Data Protocols- LTE-TDD /LTE-FDD / GSM /GPRS/ EDGE
6. Onsite Display: Display data onsite with LCD Display- 240 *240 high resolution
7. Protective Box: Protective Box with Splash and waterproof
8. Dashboard: Dashboard to display all the data and reports in the control room

1.2.4 Technical and Non-technical considerations and constraints in the design process

Technical and non-technical considerations

1. **Environmental Conditions:** As our system is placed in an open area and alongside a distribution transformer on an electric pole, it will be subjected to harsh meteorological conditions. The unfavorable climatic conditions might affect system performance despite the provision of a protective enclosure.
2. **Connectivity and Network Limitations:** The dependability of GSM signals can vary, hence inhibiting the seamless communication of data. Moreover, wired cables can be disrupted by winds or poor weather conditions.
3. **Cost Constraints:** The deployment of the DTMS system on all transformers in Bangladesh poses a huge challenge because of budget constraints faced by the government and utility organizations.
4. **Regulatory Compliance:** Processes involved in getting approval from regulatory bodies can hinder the timely introduction of new technologies into critical infrastructure, for example, the country's electrical grid.

Constraints in the design process

1. **Equipment Failure and System Downtime:** DTMS relies on continuous data collection from sensors and communication networks. Any failure in sensors, IoT devices, or communication links can result in missing data, delayed alerts or an inability to monitor transformers accurately. This can lead to undetected issues such as overheating or overloading which will potentially cause transformer failure.

2. **Misinterpretation of Data:** The operation of the DTMS system can lead to incorrect interpretations of data, especially when unprocessed raw data has not been properly processed. In critical situations, this can lead to unjustified shutdowns, customer dissatisfaction, or inefficient utilization of resources.
3. **Environmental and Safety Risks:** Severe weather conditions, meteorological events like storms, floods, or natural disasters have the potential to undermine the integrity of the monitoring system. Under such situations, transformers can either overheat or be overloaded due to the lack of real-time monitoring, leading to unsafe conditions or power outages.
4. **Data Security and Privacy Risks:** DTMS system will collect real-time operational data using IoT sensors to monitor the transformer in real-time. It may expose sensitive information about grid performance and customer energy usage. Data breaches could compromise the operational integrity of utility companies or leak customer data.
5. **Human Error in Data Handling or Maintenance:** Personnel who maintain and operate DTMS systems might make unintended errors concerning sensor calibrations, data analysis or interpretation, or upgrading of systems. Lack of oversight in these areas can lead to incorrect monitoring, untimely notices, or incorrect remediation efforts.
6. **Financial and Operational Risks:** As implementation of DTMS will require significant financial investment in hardware, software and training, unexpected costs related to system upgrades, sensor replacement or network improvements may arise, leading to budget overruns. Operationally poor performance or inefficiencies in the DTMS could reduce its overall effectiveness.

1.2.4 Applicable compliance, standards, and codes

To ensure safety, interoperability, reliability, and compliance with regulatory requirements, the Distribution Transformer Management System (DTMS) will have to adhere to a very extensive set of national and international standards. This chapter outlines the specific standards and regulatory requirements that guide the system design, implementation, and working procedures.

1. **IEEE C37.91- 2021:** This is a guiding document from the IEEE on power transformer protection. It presents guidelines to protection engineers and other stakeholders on the protection of three-phase power transformers rated above 5 MVA and with voltage levels of more than 10 kV. It further provides additional information meant to guide protection engineers in the proper use of relays and other devices for the protection of transformers used in transmission and distribution systems.

2. **IEC 60255 – Measuring Relays and Protection Equipment:** This standard defines performance requirements for protection relays and their coordination with other protective equipment in electrical power systems. The DTMS includes sensors along with protective functions that monitor transformer conditions as well as offer overcurrent and fault protection. Compatibility between the DTMS and traditional protection schemes is crucial, hence requiring compliance with this standard.
3. **IEC 61000 – Electromagnetic Compatibility (EMC):** This standard sets requirements for electromagnetic compatibility to prevent interference between electrical and electronic equipment. Especially in areas with dense electrical installations, they must ensure their components don't interfere with other nearby systems. This standard ensures smooth operation in environments prone to electrical noise.
4. **ISO/IEC 27001 – Information Security Management:** This standard outline best practices for the implementation and management of information security management systems (ISMS). Since DTMS involves data collection and transmission to a central control room, compliance with this standard ensures the security of the system, thus protecting sensitive information from unauthorized access or cyber-attacks, especially in the context of Bangladesh's communication methods.

5. **NFPA 70 – National Electrical Code (NEC):** This is a safety standard for the installation of electrical systems. DTMS systems that involve transformers and other electrical components must comply with safety codes to prevent electrical hazards like short circuits or fires.
6. **ISO 45001 – Occupational Health and Safety Management:** It ensures providing a safe working space for employees. The personnel involved in the installation, operation, and maintenance of DTMS systems should be protected according to this standard to ensure the application of necessary safety protections.

1.3 Summary of the proposed project

This project develops a Distribution Transformer Management System (DTMS) to enhance real-time monitoring, fault detection, preventive maintenance, and theft detection for transformers in Bangladesh. Here, we developed two approaches and from these two approaches we have implemented approach 1, using Arduino Uno with wireless 4G communication and Blynk IoT, and approach 2, using wired RS485 communication with a central server. Approach 1 stood out for its scalability, cost-efficiency and deployment flexibility. By utilizing 4G and decentralized processing, it ensures rapid fault detection, minimal maintenance, and independence from physical infrastructure, making it suitable for urban environments like Dhaka. Proteus was chosen as the simulation tool for its affordability, embedded design capabilities, and IoT support. In conclusion, the Arduino Uno-based DTMS is a robust, scalable, and cost-effective solution, which ensures efficient transformer management and improved power system reliability.

1.4 Conclusion

The Distribution Transformer Management System (DTMS) is a solution to critical challenges faced by the distribution network of Bangladesh, including inefficient fault detection, load distribution imbalances, illegal energy consumption, and transformer overloading issues. Leveraging the strength of Internet of Things (IoT) sensor integration, real-time data analytics, and advanced communication resources, the DTMS offers a solution set aimed at enhancing grid reliability, reducing financial losses, and transformer life extension. The system's features—from monitoring voltage, load, and temperature on a continuous basis to predictive fault detection and theft countermeasures position it as a transformative tool for utility distributors like DPDC, which loses over Tk 700 crore every year on account of inefficiencies in operations.

In conclusion, the DTMS represents a pivotal advancement in power distribution management. Its implementation promises to mitigate operational risks, optimize maintenance workflows, and foster sustainable energy practices, ultimately supporting Bangladesh's urbanization goals and ensuring a stable electricity supply for its 170 million citizens. Future efforts should focus on pilot deployments, stakeholder training and iterative enhancements to maximize the system's impact on the nation's energy resilience.

Chapter 2: Project Design Approach

2.1 Introduction:

Continuing from the previous chapter, this segment highlights unique and flexible concepts put forward in the development of a Distribution Transformer Management System (DTMS). The development of an efficient Distribution Transformer Management System demands a systematic design framework addressing the complex challenges faced by the distribution transformer system in Bangladesh as well as considering local working conditions, material restraints, and the level of existing technology competency. The chapter clarifies the necessity for the design and introduces two design approaches.

2.2 Identify multiple design approach

To determine the best approach to the monitoring and management of transformers, two different design approaches have been developed. Each of the two approaches has a fundamentally different architecture for meeting the requirements of the project, thus presenting different advantages, limitations, and considerations for deployment. The two design approaches are:
1.Standalone Monitoring System Based on IoT and On-site processing
2. Monitoring System Based on Wired communication and Central processing

2.3 Describe multiple design approaches:

Design Approach 1: Standalone Monitoring System Based on IoT and On-site Processing

The first design approach employs a modular and autonomous architecture combining local processing and cloud connectivity. The approach focuses on real-time monitoring through local intelligence to provide secure centralized data storage.

Design Architecture:

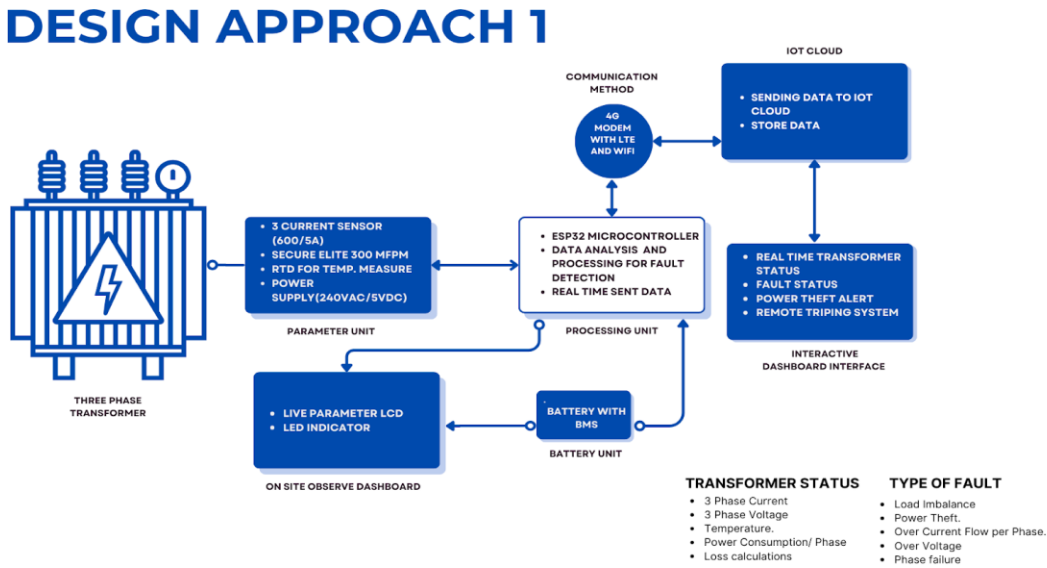

Figure 2.1: Diagram of Design Approach 1

Design Approach 1 consists of several primary subsystems:

1. **Parameter Unit:**

   This unit collects critical transformer data such as:

   i. Current Transducer (600/5): operates to limit the size of the measured current from the low-voltage transformer side.
   ii. Multi-Function Panel Meter: Measure the three-phase voltage and current coming from the CT.
   iii. RTD (Resistance Temperature Detector): Provides accurate temperature measurements necessary for detecting cases of overheating or possible malfunctions.
   iv. Power Supply: Power to all DC components in the system by taking AC source directly from the transformer phase and converting it to DC power.

2. **Processing Unit:**
   a. This component has the responsibility for data acquisition and analysis. It processes sensory data received in real time and prepares it for onward transmission.
   b. ESP 32: An economical and compact microcontroller used for real-time data management and analysis. It promises high performance in processing updates related to transformers' operation status.

c. After processing, data is sent through a 4G modem supporting both LTE and Wi-Fi modes of communication, thus ensuring efficient and reliable communication.

3. **Communication and Cloud Integration:**
    a. The system uses a Wi-Fi modem working on a 4G network for transferring the processed data to an IoT cloud platform.
    b. Storage in cloud ecosystems allows it to be available on demand for monitoring and analytical measurement.
    c. This cloud platform minimizes the requirement for local data processing and storage complexity, and thus enhances scalability.

4. **Dashboard Interface:**
    a. The system includes a customized user interface for complete monitoring and management. The dashboard includes:
        i. Real-time Transformer Status: Monitoring current, voltage, temperature, and power-related metrics
        ii. Fault Detection Alerts: Automated alerts on abnormalities such as load discrepancies, overvoltage, overload conditions, voltage irregularity conditions and other associated topics.
        iii. Power theft: Theft of electricity can be detected by examining the difference between the energy consumed at the consumer end and the energy provided by the transformer.
        iv. Remote tripping System: This system can remotely control the MCCB attached to the transformer.

5. **On-Site Observation:**
    a. **Live Parameter LCD and LED Indicator:** Ensures on-site monitoring by providing a visual indicator of transformer parameters for staff at the site

Design Approach 2: Monitoring System Based on Wired communication and Central processing

Design Approach 2 of the Distribution Transformer Monitoring System (DTMS) represents a different framework for monitoring transformers by utilizing wired communication systems through the RS-485 module compared to the wireless 4G communication technology used in data transmission in Design Approach 1. This specific design framework brings a unique set of benefits and liabilities as compared to Design Approach 1. Below is an explanation of this design and its components:

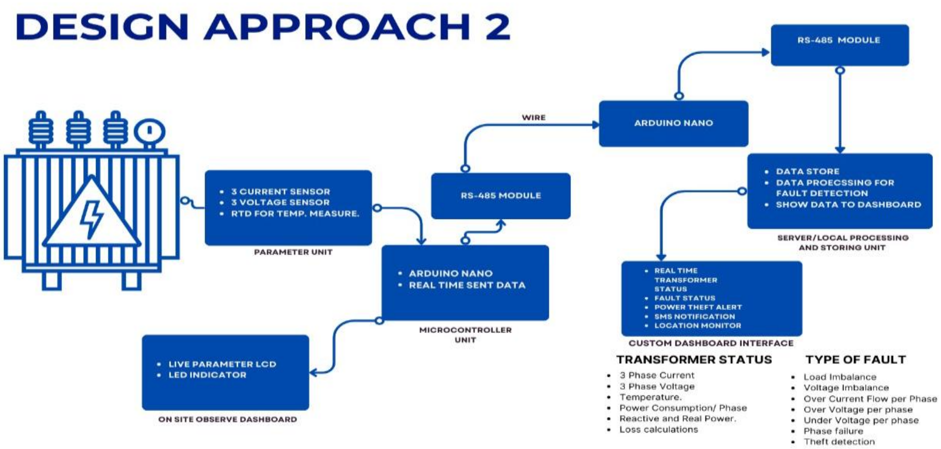

Figure 2.2: Diagram of Design Approach 2

1. Parameter Unit:

A. Sensors:
   a. Current Sensors (3): These devices measure the three-phase current passing through the transformer.
   b. Voltage Sensors (3): These sensors measure the three-phase voltage levels.
   c. RTD (Resistance Temperature Detector): RTD has the function of precisely determining temperature.

B. The sensor unit gathers important operational information from the transformer, such as current, voltage, and temperature parameters.

2. Microcontroller Unit:

Here, the Arduino translates received data from the parameter unit and then passes this data to the RS-485 module. In addition, this unit will also transfer the raw sensor data to the local display.

3. Communication:

The data from the sensors is passed from the Arduino to the transmitting end through the RS-485 module. The RS-485 module at the transmitting end then sends the data to the receiving end RS-485 module through twisted pair wires. On the receiving end, the data is processed by the Arduino prior to its forwarding to the central server. This setup depends highly on the physical infrastructure and could require complex networking technologies.

4. Server and Data Storing Unit:

A. Data Collection and Storage: Information acquired via the wired link is captured and stored in a centralized processing system. This setup will largely depend on the physical layout and can require advanced networking devices to be put in place.
B. Data Processing & Dashboard Interface: The data is processed upon entry through the gateway and made available through a customized dashboard later. It includes features such as real-time monitoring of transformer conditions, fault detection, and alerts about power theft.
    a. Real-Time Transformer Status: Information about the three-phase current, voltage, power consumption, temperature, and other parameters.
    b. Fault Detection: Identifies any fault in transformers, such as load mismatch, voltage mismatch, over-current, over-voltage, low voltage, and power theft-related issues.

5. On-Site Observe Dashboard:

A. Similar to Approach 1, there is an on-site dashboard with a live parameter LCD and LED indicators. This display gives real-time information directly from the sensors, enabling quick diagnostics by field technicians. But this on-site dashboard shows only the raw sensor data, like 3-phase voltage, current, and temperature. It doesn't show any processed data as the data processing happens in the central server.

2.4 Analysis of multiple design approaches:

Design Approach 1: Standalone Monitoring System Based on IoT and On-site Processing

Features of the System:

1. Fault Types Monitored:
    a. Load imbalance.
    b. Voltage imbalance.
    c. Overcurrent issues.
    d. Overvoltage and Undervoltage issues.
    e. Power theft issues.
    f. Transformer Status Tracking.

2. Transformer Status Tracking:

    a. Monitoring of 3-phase current and voltage levels.
    b. Temperature tracking.
    c. Power consumption per phase.
    d. Calculation of transformer losses.

Advantages of Approach 1:

1. **High Accuracy**: The use of reliable sensors combined with real-time data analysis assures precise monitoring of transformers.
2. **Low Software and Application Costs:** The pre-built interface, coupled with the cloud system, reduces the necessity for extensive software development and thus realizes cost benefits.
3. **Low Maintenance:** The system has been designed for durability and requires minimal interaction, thus allowing for lower costs on maintenance.
4. **Easy to Implement:** The integration of the Arduino Nano and pre-configured modules simplifies the installation and improves compatibility with the existing transformer system.
5. **Cloud-Based Scalability:** Since data is sent to the cloud, the system is easily scalable with minimal changes in existing infrastructure.

Key Benefits of This Design:

1. **4G Network for Cloud Connectivity:** 4G network implementation for making connectivity available to cloud services provides reliable communication through areas otherwise underserved by wired connections where installing wired ones might be impossible.
2. **Cost-Effective Solution:** With pre-built software and dashboard interfaces, the system has a lower overall cost for software and application management. This reduces both implementation and maintenance costs.
3. **High Accuracy and Reliability:** Utilization of accurate sensors (current, voltage, RTD) for a comprehensive evaluation of transformer status.
4. **Ease of Implementation:** The method has been designed so it can be deployed easily, supported by minimal maintenance requirements. The modular design allows for easy scalability and integration with existing infrastructures.

Design Approach 1 provides a cost-effective, scalable, and maintainable approach for monitoring transformers in real time by utilizing IoT technology and GSM communication. The system provides a high level of accuracy in fault detection and transformer health assessment and also minimizes operation costs, making it ideal for utility companies seeking advanced transformer monitoring approaches.

Design Approach 2: Monitoring System Based on Wired communication and Central processing

Key Differences in Approach 2:

1. **Wired Communication:** It uses wired communication as compared to GSM and allows for uniform transmission of data but has the disadvantage of a greater risk of wiring issues and a more complex installation protocol.
2. **Higher Software and Maintenance Costs:** The system would require a custom software solution and a web portal for monitoring the data, causing higher costs associated with maintenance and software support compared to Approach 1.
3. **Complex Networking:** The wired form of communication requires a more complex networking system, making this method of communication harder to set up, especially over large distances.

Key Benefits of Design Approach 2:

1. **Stable Data Transmission:** The provision of wired connectivity minimizes the possibility of data loss or delay due to network problems and hence guarantees reliability in areas not served well by cellular coverage.
2. **Custom Software:** Despite the high cost involved, bespoke software implementation offers added flexibility for specific uses or custom reporting.

Challenges of Design Approach 2:

1. **Higher Costs:** The requirement for specialized software leads to increased costs related to software development, application maintenance and management, and active support.
2. **Maintenance Issues:** The wired setup has a higher likelihood of experiencing issues like cable failures that may hinder data transfer. This creates a higher cost and complexity of maintenance.
3. **Moderate Accuracy:** Though still reliable, the system's overall accuracy is kept to a modest level compared to Approach 1.

2.5 Conclusion

Design Approach 1 aligns closely with the DTMS design philosophy of real-time visibility, data-driven decision-making, preventive intervention, and an integrated approach. Its cost-effective, scalable, and maintainable architecture makes it the optimal solution for modernizing transformer management in Bangladesh, effectively addressing local challenges while maximizing operational efficiency and reliability.

Chapter 3: Use of Modern Engineering and IT Tools. [CO9]

3.1 Introduction

We leverage modern engineering and IT tools to design, simulate, implement, and monitor an advanced solution for our FYDP project DTMS. These tools enable us to develop a cost-effective, scalable, and reliable system that addresses real-time monitoring, fault detection, and preventive maintenance challenges. Software tools such as Proteus, Arduino IDE, Node.js, React, Python, Visual Studio Code etc. enable us to do circuit simulation, programming, and dynamic IoT-based data visualization. By integrating these technologies, we simulate and model the different approaches of DTMS to achieve high efficiency and validate the best approach so that we can deploy the project in resource-constrained environments and align with modern engineering practices.

3.2 Select Appropriate Engineering and IT Tools

We have used several modern engineering and IT tools to simulate and model the DTMS. Below, the comparison and rationale for selecting those tools are given:

A. Simulation Software for Circuit Simulation:

Table 3.1: Simulation Software

Software	**Cloud-based support**	**Library Availability**	**IoT support**	**Cost**	**Best Use Case**
Proteus	Limited	Excellent for microcontroller and GSM and RS-485	Strong, can send real time data	Expensive	IoT, embedded systems simulation
Altium	Yes	Comprehensive for PCB design	Weak	Expensive	Large-scale PCB
Simulink	Limited	Extensive for control system	Moderate, can’t send real time data	Expensive	System-level IoT and control design

LTspice	No	Limited to analog devices and components	weak	Free	Analog and power circuits
CircuitLab	Yes	Basic analog/digital libraries	weak	Free	Small projects

From the above comparison table, we see that the Proteus software gives strong IoT support and can send real-time data, it has a comprehensive library for microcontroller and GSM, and an RS-485 module. For this reason, we chose Proteus as our simulation software

B. Software for IoT Platforms:

Table 3.2: Software for IoT Platforms

Feature	**Blynk IoT**	**Adafruit IO**	**AWS IoT Core**	**Azure IoT Hub**	**ThingSpeak IoT**
Custom Dashboards	Yes (No-code)	Basic	No	No	Basic
Cloud Support	Yes (Blynk Cloud & Local)	Yes	Yes	Yes	Yes (Cloud Only)
Supported Hardware	Broad (Arduino, ESP)	Limited	Broad	Broad	Broad
Real-Time Notifications	Built-in and Unlimited	Limited	Requires coding	Requires coding	Limited Alert
Data Visualization	Advanced, Customizable	Basic	Advanced	Advanced	Moderate
Cost	Expensive	Affordable	Expensive	Expensive	Affordable
Programming Requirement	Low	Low	High	High	Low

For our project, we need a customizable dashboard, broad hardware support, and cloud support for data storage and unlimited real-time notifications. If we see the above comparison, we see that the Blynk IoT is the best fit. But if we use a third-party IoT platform for our project, the production cost will increase, and the monthly fee is relatively High. Thus, we have developed our own IoT system for our project. The key feature of the IoT system is that we can customize it according to our needs. This is very crucial for our project. Also, it is affordable compared to IoT with similar facilities.

Now, for building our own IoT platform, we used several Engineering and IT tools like

1. Visual Studio Code
2. React and Lucide react
3. Node.js
4. WebSocket
5. Git
6. Tailwind CSS

C. Microcontroller Programming Platforms:

Table 3.3: Microcontroller Programming Platforms

Feature	**Arduino IDE**	**PlatformIO**	**MPLAB X IDE**	**Keil uVision**	**MicroPython**
Supported Boards	Wide (Arduino, ESP, etc.)	Very Wide (ESP, ARM, etc.	PIC and dsPIC Microcontrollers	ARM (STM32, NXP, etc.)	Wide (ESP32, Raspberry Pi)
Coding Language	C/C++ (Arduino-specific APIs)	C/C++, Python	C/C++	C/C++	Python
Features and Libraries	Extensive libraries for IoT and robotics	Advanced features with library management	Limited libraries	Advanced but limited community	Simple libraries for IoT
User Interface	Simple and beginner-friendly	Advanced, plugin-based	Advanced but complex	Complex	Simple and beginner-friendly

Debugging Tools	Basic serial debugging	Integrated debugger	Full debugging tools	Advanced debugging	Limited debugging
Community Support	Very large and active	Large but technical	Limited to professionals	Professional users only	Small

Here, for our project, as we are using ESP32 and Arduino nano microcontroller, and also our project needs extensive IoT and RS485 libraries, we choose Arduino IDE for the microcontroller programming.

D. Server Side Programming Platforms:

As in our design approach 2, we intended to build our own server. for server-side programming, we compared several programming languages to choose the suitable one.

Table 3.4: Server-Side Programming Platforms

Feature	**Python**	**Node.js**	**Java**	**C#**	**Ruby on Rails**
Performance	Moderate	High (for I/O operations)	High	High	Moderate
Library Support	Extensive	Moderate	Extensive	Extensive	Moderate
Real-Time Capability	Moderate (via frameworks like Flask/ FastAPI)	Moderate	Moderate	Moderate	Moderate
Community Support	Large and active	Large and active	Large but professional	Large but professional	Niche but supportive
Learning Curve	Easy (Beginner-friendly)	Moderate	Steep	Moderate	Moderate
Use Cases	General-purpose (IoT, web, data science)	Real-time apps, APIs	Enterprise-level systems	Enterprise-level systems	Rapid web development

Here, as we will process the sensor data in server side and have to create a dashboard we need python as it has extensive library support, beginner friendly and it is widely used for data science.

3.3 Use of Modern Engineering and IT Tools

Simulation Software: Proteus

As simulation software, Proteus is very powerful and used for designing and testing the electronic circuit for embedded systems and IoT applications. Proteus Design Suite is developed by Lab Center Electronics Ltd. For simulating microcontrollers, communication modules, and peripheral components, it provides a comprehensive environment. It also supports real-time data transmission and IoT-specific protocols, which are crucial for simulating the DTMS's communication modules like GSM and RS-485. In our project, we used Proteus to model and simulate the DTMS's electronic circuits, including the ESP32 microcontroller, sensors, and communication modules. It enabled us to simulate the interaction between hardware components and IoT protocols. We also validate the system's functionality under various operating conditions and identify and resolve potential hardware issues before prototyping. By simulating the DTMS in Proteus we ensured that the hardware design is workable and aligned with our objective and compatible with the IoT and wired communication framework.

Tools for Custom IoT Platform:

Visual Studio Code: It is a versatile, lightweight code editor with extensive plugin support. It is developed and maintained by Microsoft. In the DTMS Project, we used it for developing both front-end and back-end components of the IoT platform. It has debugging tools and it is integrated with Git streamlined collaborative development.

React and Lucide React: React is an open-source JavaScript library developed by MetaAI. It can handle dynamic and real time data updates, and it is very adaptive. In our project, it is used to build a dynamic and responsive user interface for the DTMS dashboard. We also utilize Lucide React which gives us a library of customizable icons for enhancing the dashboard's visual appeal and usability. It also complements the react robust UI capabilities.

Node.js : It is a high-performance, open-source runtime environment that enables server-side programming using JavaScript. It is a critical component in the development of the DTMS. Node.js was developed by Ryan Dahl in 2009 and currently maintained by the OpenJS Foundation. It uses the V8 JavaScript engine to execute JavaScript code outside the browser, offering exceptional speed and efficiency for input-output intensive applications. In the DTMS project we use node.js for its ability to handle real-time data processing, API development, and seamless communication with the custom IoT platform which ensures efficient management of sensor data and system interactions. It has non-blocking and event-driven architecture which enables it to process large volumes of data with lower latency and it is very crucial for real-time monitoring of DTMS. .

WebSocket: It is a communication protocol that enables real-time, bidirectional, and full-duplex data exchange between a web browser and a server over a single and persistent connection. Traditional HTTP, relies on request-response cycles but WebSocket maintains an open connection which allows instantaneous data updates with minimal latency. WebSocket is Developed by the Internet Engineering Task Force (IETF) and it is standardized in 2011 as RFC 6455. In our project the WebSocket Facilitated real-time, bidirectional communication between the server and client which ensured the seamless updates to the dashboard and instant notifications for system events.

Git: It is a distributed version control system designed to manage source code and track changes during software development, enabling efficient collaboration among the group members. In our project we used it to version control, to manage code changes, to collaborate effectively, and maintain a reliable development workflow.

Tailwind CSS: It is a utility-first CSS framework that simplifies the styling of web applications by providing low-level utility classes for rapid, responsive design. It is developed by Adam Wathan, Steve Schoger, and a team at Tailwind Labs. Tailwind CSS was first released in 2017 as an open-source project under the MIT license. In our project we used it to style the dashboard and to ensure a modern, responsive, and user-friendly interface.

So, we see all the Engineering process and IT tools used in building custom IoT systems were deployed to collect and store sensor data in the cloud to ensure accessibility and scalability of the project. They also enable us to make a customizable dashboard for real-time visualization of system parameters, such as sensor readings and fault status. We also make unlimited real-time notification systems to alert users of critical events, such as system faults or data anomalies.

Microcontroller Programming: Arduino IDE

The Arduino IDE is an open-source platform for programming microcontrollers. It is simple, has an extensive library, and large community support. It is developed by Arduino, an Italian open-source hardware and software company. It is widely used for IoT and robotics applications. In our DTMS project, the Arduino IDE is used to write and compile firmware for the ESP32 and Arduino Nano microcontroller, controlling sensors, a communication module RS-485, and data transmission protocols. We also used it for connecting the ESP32 to the custom IoT platform for real-time data exchange and to test and debug the system operation under various conditions. The Arduino IDE enable us prototyping and validation of the DTMS's firmware, ensuring seamless integration of hardware and software components.

Server-Side Programming: Python

Python is a versatile and high-level programming language. It is widely used for data processing, web development, and data science. It has extensive libraries and beginner-friendly syntax that make it ideal for complex engineering applications. It is developed by the python software foundation. Python has a rich ecosystem which supports data processing, API development, and dashboard creation . It is crucial for the DTMS project. In our project Python was used to develop server-side logic for processing sensor data, performing calculations, and generating insights. It also creates APIs using frameworks like Flask to enable communication between the server and the IoT platform. We also generate data visualizations for the dashboard by python. We used python mainly for server side programming in our design approach 2 which is Monitoring System Based on Wired communication and Central processing.

3.4 Conclusion

The backbone of the DTMS is formed by using various modern engineering processes and IT tools which enables a seamless transition from design to implementation while ensuring safety and reliability. Proteus is used to design and validate circuit designs, while the Arduino IDE used to do efficient programming of the ESP32. The custom WebSocket-based IoT platform, built with Node.js and React, delivers real-time monitoring and control. We also used different engineering processes and IT tools which helped us to implement and achieve DTMS's goals of real-time visibility, data-driven decision-making. All of this make the system more adaptable for large-scale deployment in Bangladesh

Chapter 4: Optimization of Multiple Design and Finding the Optimal Solution.

4.1 Introduction

For our DTMS project we have developed two design approaches: Design Approach 1, an IoT-based standalone system with on-site processing, and Design Approach 2, a centralized wired system with server-based processing . In this chapter we focus on refining multiple design approaches and simulate them to identify the optimal design that can be implemented in our hardware design. We also evaluate their performance, and identify the most effective solution to address the challenges of cost-effectiveness, scalability, and reliability in resource-constrained environments.

4.2 Optimization of multiple design approach

4.2.1 Circuit Simulation for Design Approach 1: Standalone Monitoring System Based on IoT and On-site processing

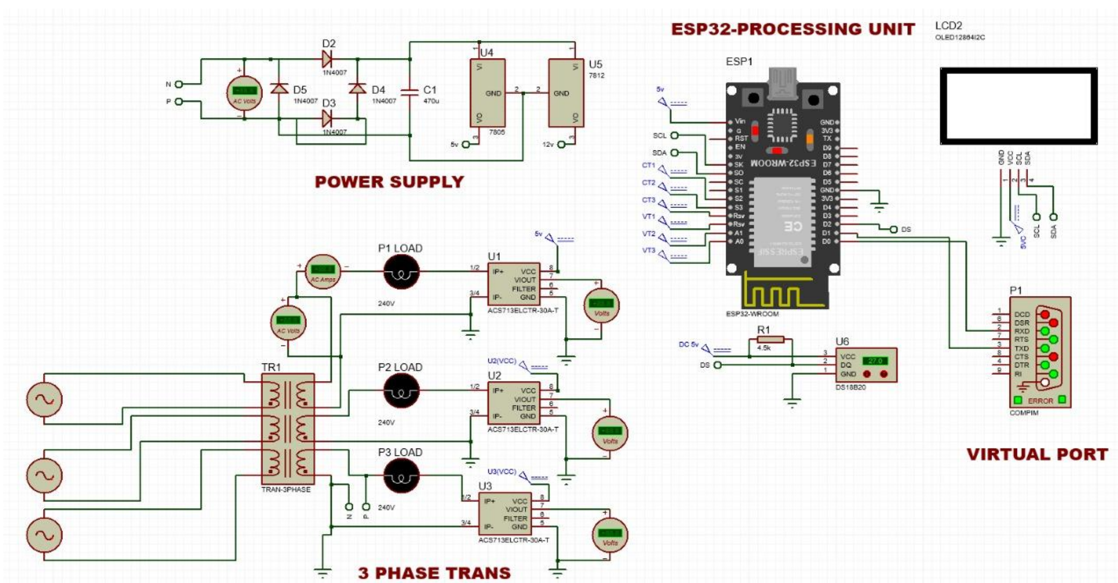

Figure 4.1: Circuit simulation for design approach 1

Here, we design the whole circuit for our design approach 1 which is onsite processing with IoT integration. There is a 3-phase transformer, Power supply for ESP 32 processing unit which takes data from the sensor and processes them to detect fault and an onsite display which shows all the data processed by the ESP32. Then there is a virtual port which connects this circuit to IoT and sends the data to Iot cloud. Then in the IoT cloud we see all the results.

The sub-systems of the Design Approach is:
Power Supply Unit:

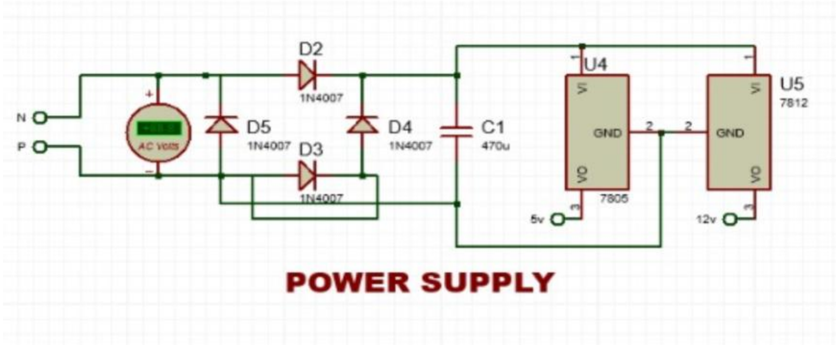

Figure 4.2: The power supply Unit

The upper figure is a schematic of a power supply unit that converts 240V AC input to 12V and 5V DC outputs. In our DTMS system we have several sensors and modules which run in 12V DC and 5V DC. To ensure that power we ensure the power supply unit. The circuit uses a transformer to step down the 240VAC to a lower AC voltage. This lower AC voltage is then rectified by diodes (D2, D3, D4, D5 - 1N4007) into DC. The rectified output is smoother by the capacitor C1 (470µF). Then, two voltage regulators regulate the DC voltage. Here, U4 (7805) for 5V and U5 (7812) for 12V. The ground (GND) is common for the two outputs. This power supply powers the ESP32, Voltage sensor, Temperature sensor RTD and On-site LCD Display.

Parameter Unit:

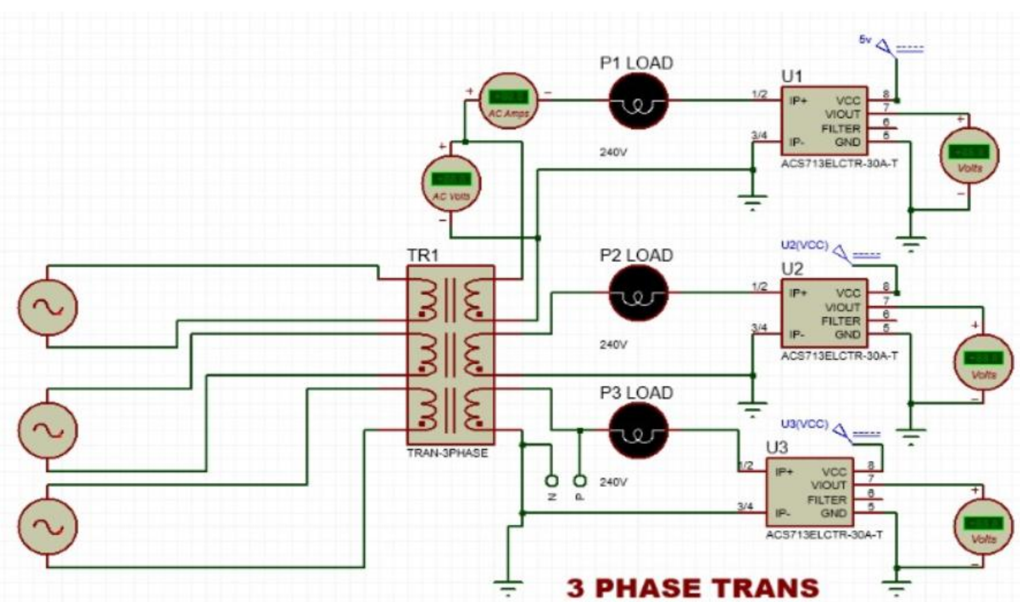

Figure 4.3: The parameter Unit

The above figure contains the parameter unit. Here, we see a 3 phase transformer by which we can simulate a three-phase transformer in the real world. In the LT side of the transformer we add 3 voltage sensors and 3 current sensors. These sensors collect the voltage and current of three phases and send them to the processing unit. For simulation purposes we can regulate these sensors to validate our system. This parameter unit is crucial for our DTMS design and everything depends on the data collection of this parameter unit. The parameter unit also consists of a temperature sensor. Which can detect the temperature of the transformer and send them to the processing unit. The temperature sensor works based on the resistance value. The sensor measures temperature by detecting changes in a metal's resistance, which increases when temperature rises. It uses a circuit to convert this resistance into a temperature reading.

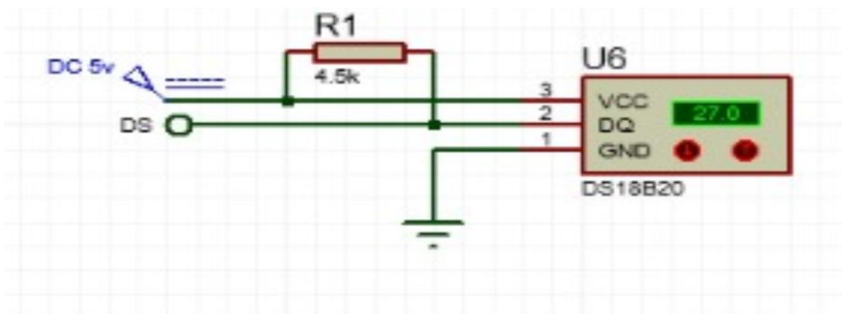

Figure 4.4: The temperature sensor

The processing Unit:

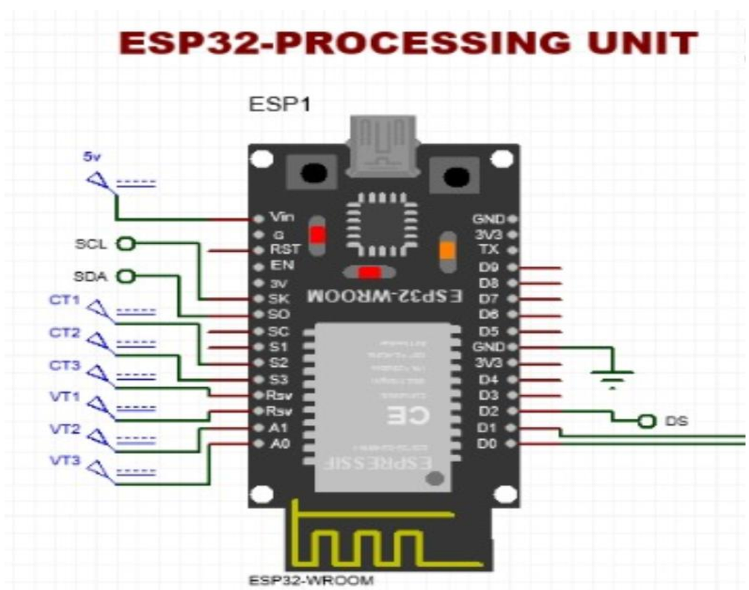

Figure 4.5: The processing unit

One of the most crucial units of our DTMS project is the processing unit. Here, in design approach 1 we used exp32 as our processing unit. The voltage, current of three phases and the temperature of the transformer are sent to the ESP 32 for processing. ESP 32 processes all the data received from the parameter unit and detects fault conditions. Then it sends that data to the onsite display and IoT server, where all the data is shown. The ESP32, which is a microcontroller that has integrated Wi-Fi and Bluetooth and is powered from for a 5V input and having multiple pins connected as an input/output: VIN, 3V3, GND and digital pins as D0-D8 for output and input, also that has RST, EN, TX, RX for communication with E(S0-2, A0-A1) FOR analog sensing. The pins are complementary to CT1-CT3 (current transformers) and VT1-VT2 (voltage transformers) that can be wired to the sensors in the parameter unit, SDA and SCL to communicate, with on-site “display”, and DS to send the data to the IoT cloud.

Now, for fault detection, we are using the following parameter:

Over Voltage: +10% of nominal voltage 240V per phase (IEC 60038)
Under Voltage: -10% nominal voltage 240V per phase (IEC 60038
Over current: 80% of full load current per phase (IEC 60947)
Voltage Imbalance: should not exceed 3% (IEC 61000-2-2)
Load Imbalance: should not exceed 20% (IEEE 141)

All of these parameters maintained the IEC and IEEE standards. We slightly modify some of the fault parameters by considering the infrastructure of Bangladesh.

Virtual Port:

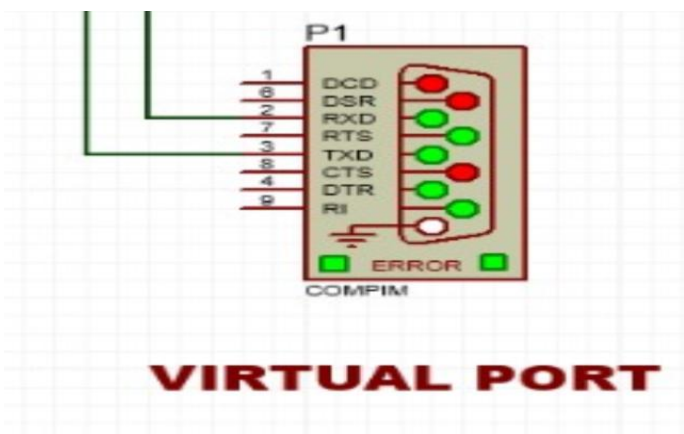

Figure 4.6: Virtual Port

The virtual port connects the Proteus simulation with the IoT. With this virtual port we can send data to the IoT cloud.

LCD Display:

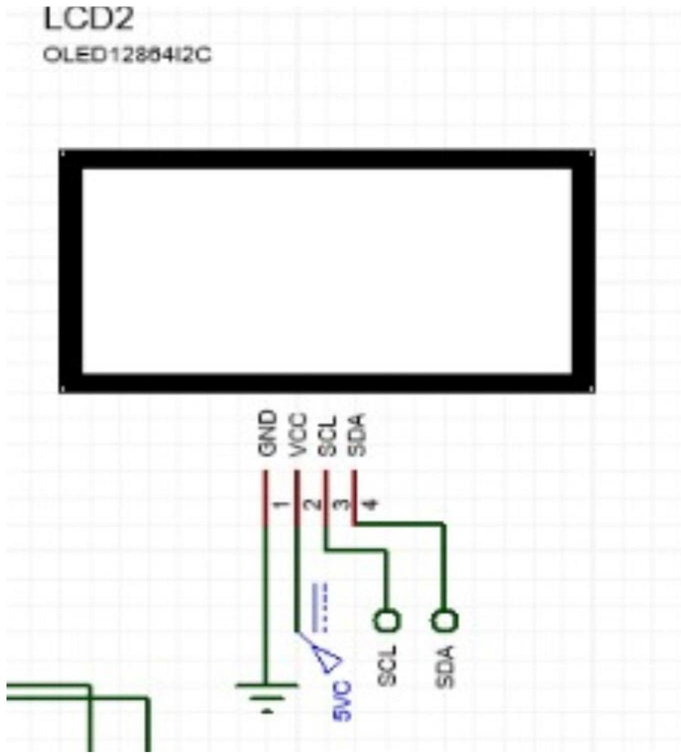

Figure 4.7: On-site LCD display

In our design approach 1, we have an onsite display which can show the real-time transformer status with fault condition if any fault occurs. All the input of the LCD display comes from the processing unit.

IoT dashboard:

For our design approach 1, we sent the data to a custom IoT dashboard. In the Dashboard, we see the real-time status of the transformer and we also see the power theft in the IoT dashboard. The dashboard was built with React (by Meta AI) for a flexible, component-based user interface, Tailwind CSS (by Tailwind Labs) for responsive design, and Lucide React (community-driven by Eric Fennis) for scalable icons, resulting in a contemporary user experience. Node. js (thanks OpenJs foundation) that handled server-side logic to be synchronized via WebSocket (IETF-standard) to allow real-time, bi-directional exchange of data between client and server for updating sensor readings and notifications. Git (by Linus Torvalds) simplified version control and team work with GitHub and Visual Studio Code (by Microsoft) offered efficient development support with powerful editing and debugging capabilities. The structure of the whole custom IoT dashboard given below.

```
DTMS PROJECT
├── bolt
│   ├── dist
│   ├── node_modules
│   └── src
│       ├── components
│       │   ├── BarChart.tsx
│       │   ├── FaultAlert.tsx
│       │   ├── GaugeCard.tsx
│       │   ├── Header.tsx
│       │   ├── LineChart.tsx
│       │   ├── SideBar.tsx
│       │   └── StatusCard.tsx
│       ├── context
│       │   ├── DataContext.tsx
│       │   └── ThemeContext.tsx
│       ├── DashBoard.tsx
│       ├── FaultsPage.tsx
│       ├── HistoricalData.tsx
│       ├── Settings.tsx
│       ├── types
│       │   └── ts
│       ├── utils
│       │   └── mockData.ts
│       ├── App.tsx
│       ├── index.css
│       ├── main.tsx
│       └── vite-env.d.ts
├── .gitignore
├── eslint.config.js
├── ESP32_Transformer_Monitor.ino
├── index.html
├── package-lock.json
├── package.json
├── postcss.config.js
├── server.js
├── tailwind.config.js
├── test-client.js
├── tsconfig.app.json
└── tsconfig.json
```

Figure 4.8: The interface of the IoT dashboard

The above figure is the home tab of the IoT dashboard. We can see the voltage, current, and temperature of the transformer there. Also, we see the voltage and current trend by graph in that dashboard. This custom dashboard has different tabs for

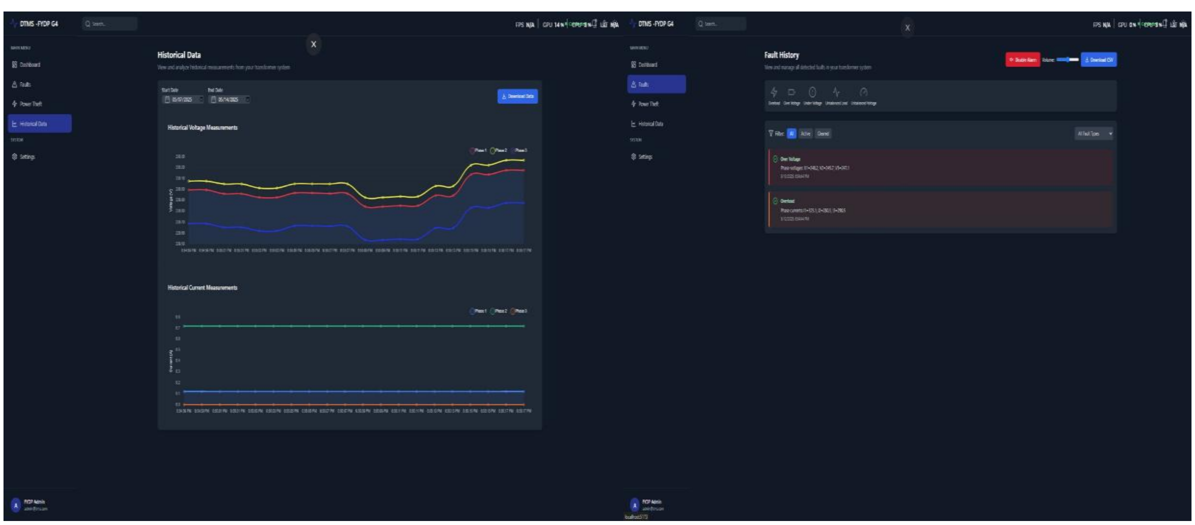

Figure 4.9: Fault detection and historical data tab in IoT dashboard

In this tab, we can see the fault condition and historical data, which can preserve all the data from 100ms to up to 3 months.

Theft detection:

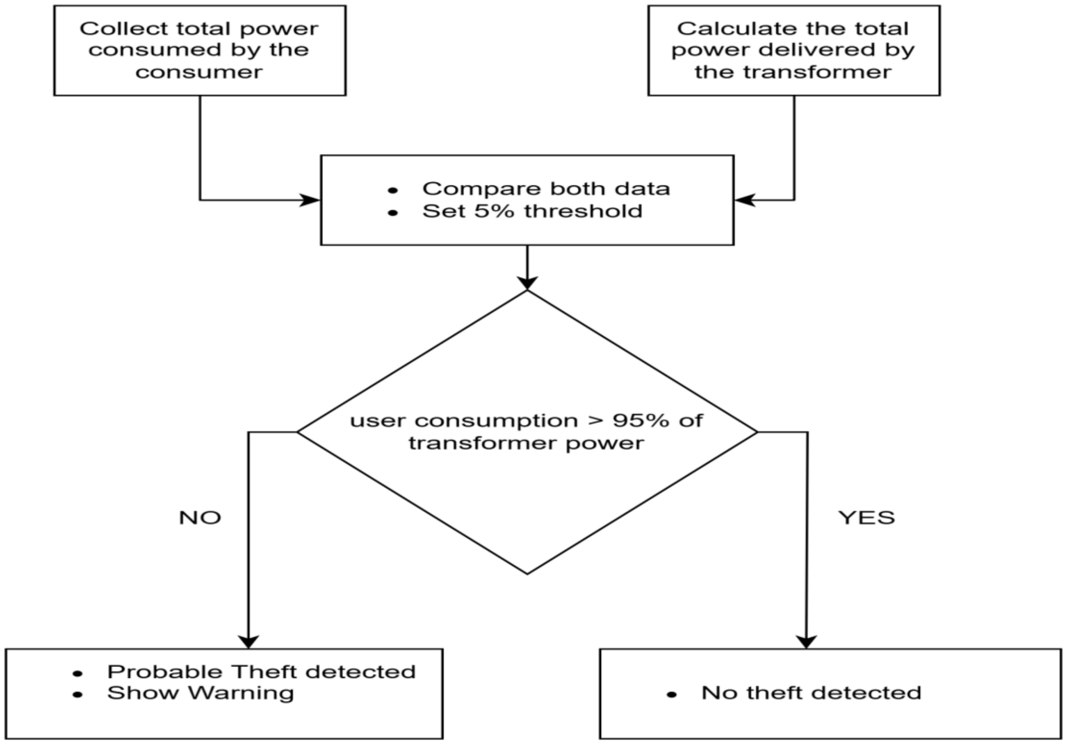

Figure 4.10: The diagram for the theft detection

One of the most important features of our DTMS Project is theft detection. In design approach 1, our custom IoT system calculates the power delivered from the transformer automatically. Then, if we input the total consumed power by the consumer, the system can detect theft by comparing both the data. We set a 5% threshold for technical distribution loss. If the user consumption is not greater than the 95% of the transformer power, there is probable theft, and a warning will show in the IoT dashboard. Here the whole system will be done autonomously; we just have to connect the consumer data to the system.

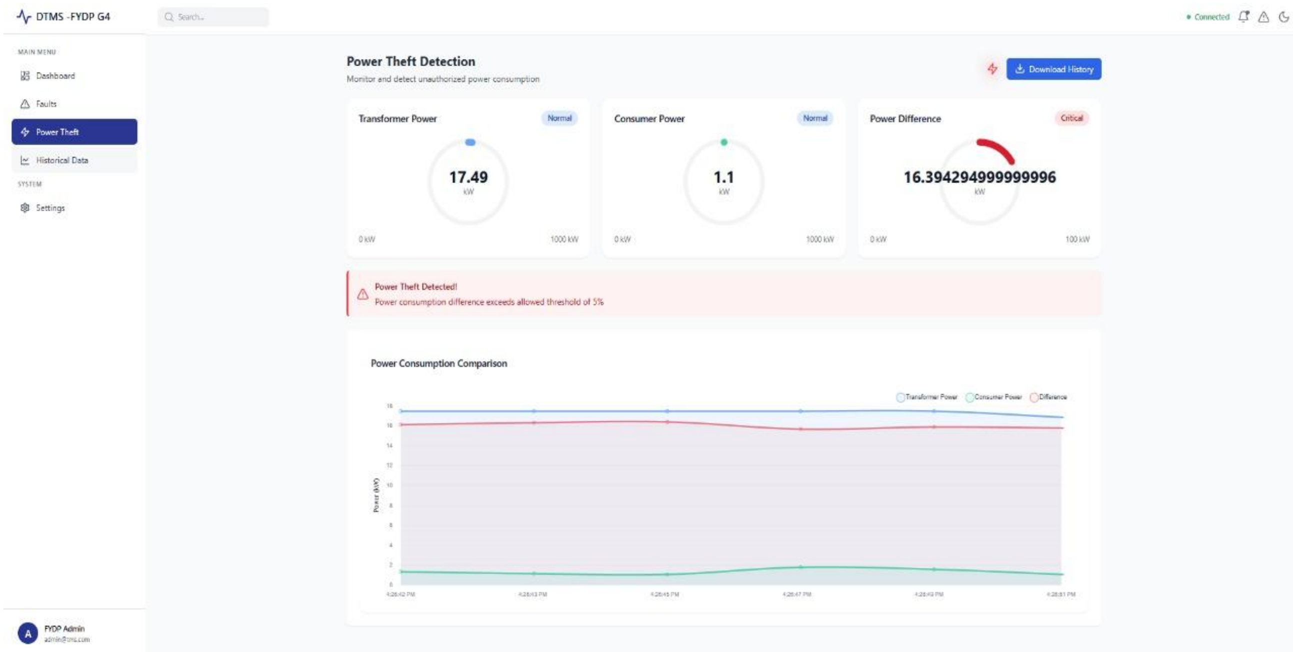

Figure 4.11: Power theft in the IoT dashboard interface

In the above figure, we can see the theft condition with transformer delivered power and consumer consumed power. They are also represented by graphs.

4.2.2 Circuit Simulation for Design Approach 2: Monitoring System Based on Wired communication and Central processing

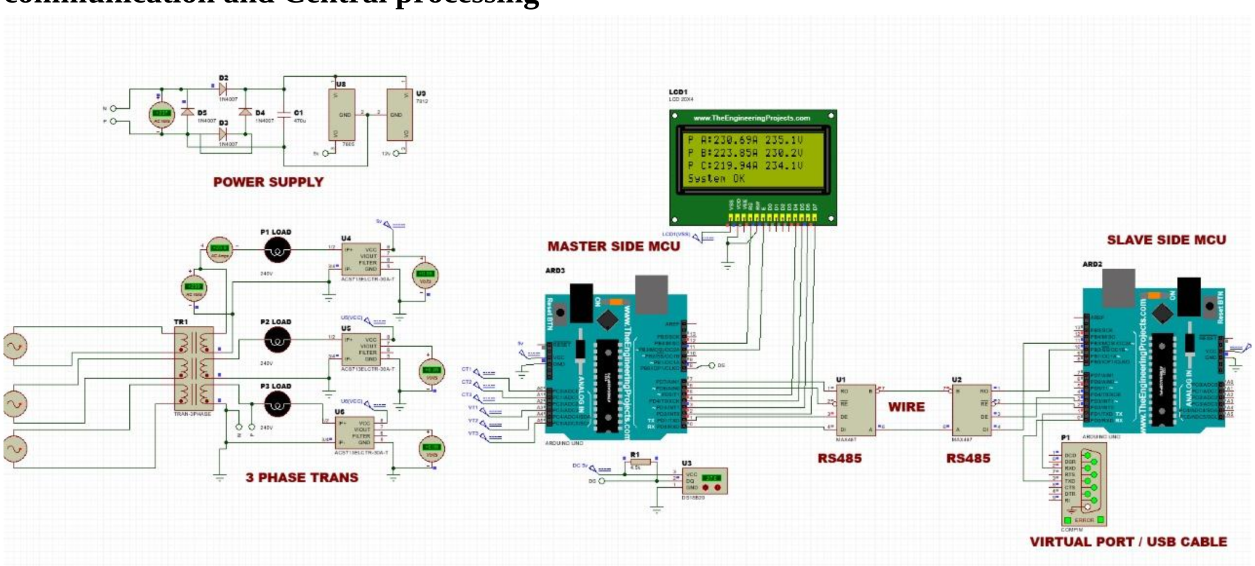

Figure 4.12: Circuit simulation for design approach 2

The above figure is the circuit simulation for design approach 2. Which we simulated by using proteus. Here, The data sent from the 3 Phase transformer to the Master side MCU. Master Side MCU sends those data to sender side RS-485 module. Then the data is transferred to the receiver side RS-485 module by the wire. Then the data is sent to the Slave side MCU. From there by USB cable the data enters into the serial port. Then from the serial port we extract the data as CSV file and feed that data to the server where all the processing will happen. There is also an LCD display. Which shows only sensor data not any fault status. On the server we see the fault status by a custom dashboard which we have to build. In this approach the data collection are same but processing and communication methods are different. As, the power supply unit and parameter unit same the remaining sub-systems are:

Master Side MCU:

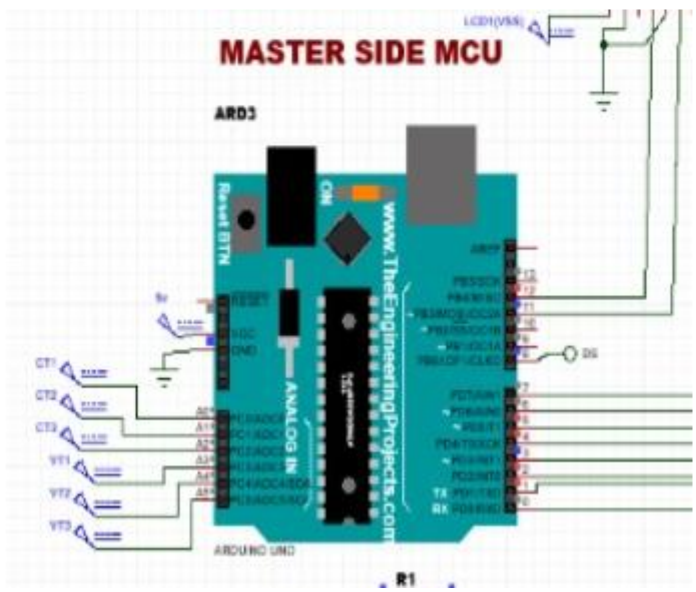

Figure 4.13: Master side MCU

Master Side MCU consists of an Arduino nano microcontroller, it is designed to receive data from the parameter unit and transmit it via a sender side RS485 module while also displaying the data on an onsite LCD. The digital and analog pins of the Arduino Nano are connected to the parameter unit to collect data, which is from the current sensor, voltage sensor and temperature sensor. The RS485 module, linked to the Arduino's TX/RX pins and control pins like DE/RE which enables serial communication to send data to another device, while the LCD, connected via digital pins which provides real-time local monitoring.

RS-485 Data transfer:

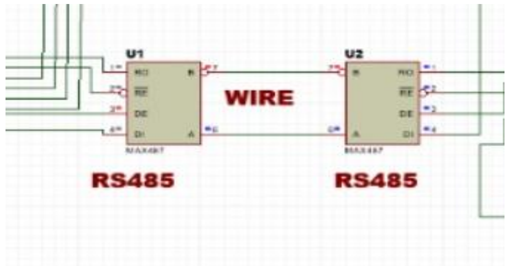

Figure 4.15: Data transfer by RS-485 module

The above circuit diagram consists of two RS-485 modules, which enable communication between a master side MCU and a receiver side MCU via a twisted pair cable. The sender side RS485 module U1, which is labeled MAX487, connects to the master side MCU, receiving data through its RO (Receiver Output) and DI (Driver Input) pins, while its RE (Receiver Enable) and DE (Driver Enable) pins control data flow direction. The sender module's A and B pins connect to a twisted pair cable labeled as wire. This wire ensures reliable communication over long distances by reducing noise interference. On the other end, the receiver side RS485 module U2, also a MAX487, receives the data through its A and B pins, with its RO pin outputting the data to the connected slave side MCU, and RE/DE pins are managing the reception mode. This system enables us to establish a robust, long-distance serial communication between the master MCU and the receiver slave MCU using the RS-485 protocol.

Slave MCU:

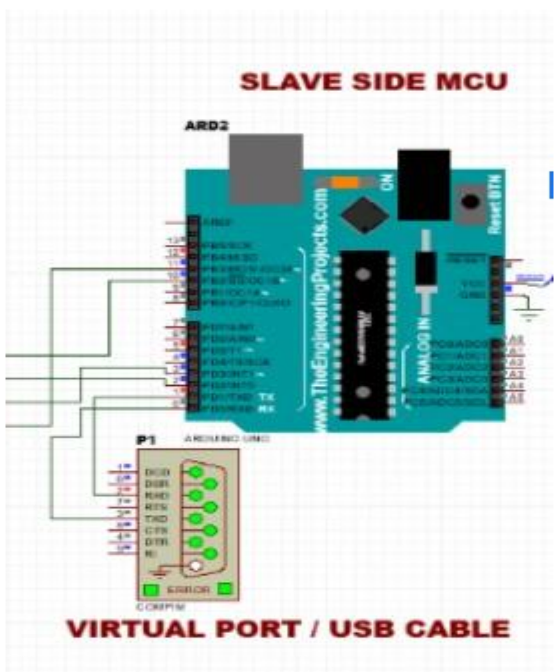

Figure 4.16: The slave MCU

The slave MCU also consists of the Arduino Nano. This slave side MCU receives data from the receiver side RS-485 module then processes those to send to the central server. The processed data is then transmitted to a server through a virtual COM port via a USB cable, as indicated the connection from the Arduino's USB interface to the server.

On-site display:

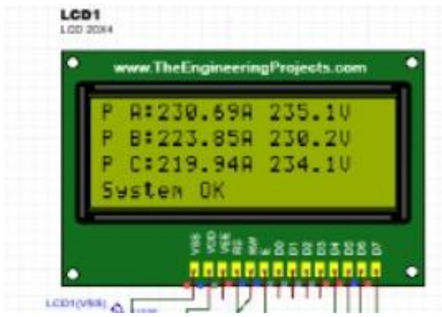

Figure 4.17: On-site LCD display

This on-site LCD display shows only the raw data received from the transformer. It can not show the fault status as all the fault calculation and processing happens in the central server.

Server and Data Storing Unit:

Here, the central server acts like the whole brain of the DTMS. it has two parts: Data Collection and Storage: The data transmitted via the wired connection is collected and stored in a central data processing system. This setup is more dependent on physical infrastructure. The data received by the USB cable from the slave side MCU is entered through a serial port. Then we extract the data from that serial port. Then we further process the data.

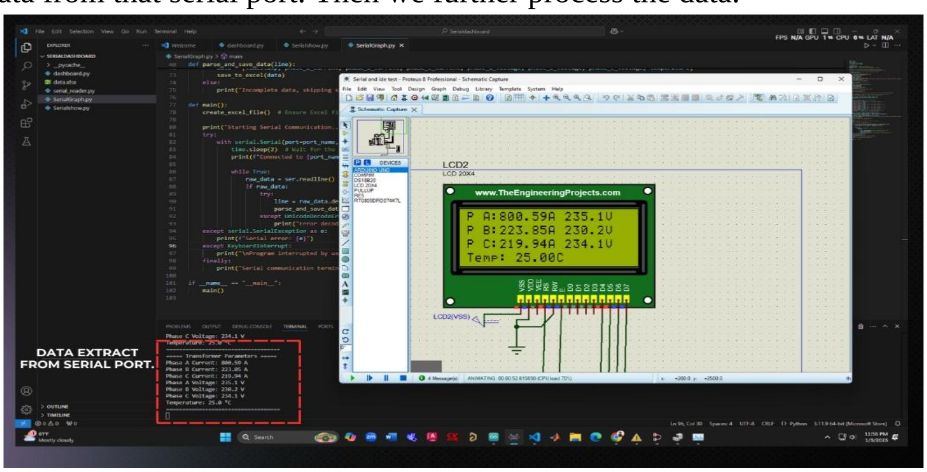

Figure 4.18: Data extraction from serial port

The other part of the server and storing unit is Data Processing & Dashboard Interface. Once the data is extracted from the serial port , it can be processed and accessed through a custom dashboard. This includes real-time transformer status, fault detection, power theft alerts. For real- time transformer Status we see the three-phase current, voltage and temperature. The server also calculates the fault condition by the same threshold given in approach 1. Here, for fault detection we identify load imbalance, voltage imbalance, Over current, Overvoltage, Undervoltage, power theft issues.

Result in Custom Dashboard:

Figure 4.19: Custom Dashboard in Central Server

Here, the dashboard is a custom dashboard. In the first half of the dashboard we see the transformer status and there is a fault log which shows if any fault happens in a certain time with time stamps. Then the custom dashboard also shows the 3 phase voltage and current graph which gives a better understanding about the situation. Here, all information are autonomously stored in the server and this storing capacity depends on the physical infrastructure of the server.

Power Theft:

In approach 2, we can store data in the central server and we can further use that data for power theft detection. Here, The idea is first we have to collect the total consumed power by the consumer then we calculate the total delivered power by the transformer. Then we set a 5% threshold for technical distribution loss. Then we compare both the data. If the user consumption is not greater than the 95% of transformer power there is probable theft and a warning light will show in the graph and if yes there would be no theft. But, in approach two the data calculation and comparing method is different. In approach 2 as we can't put the consumer directly to the dashboard interface, we create another portal which will compare the transformer data stored in server and the data of consumer side.

Figure 4.20: Power theft graph (No theft)

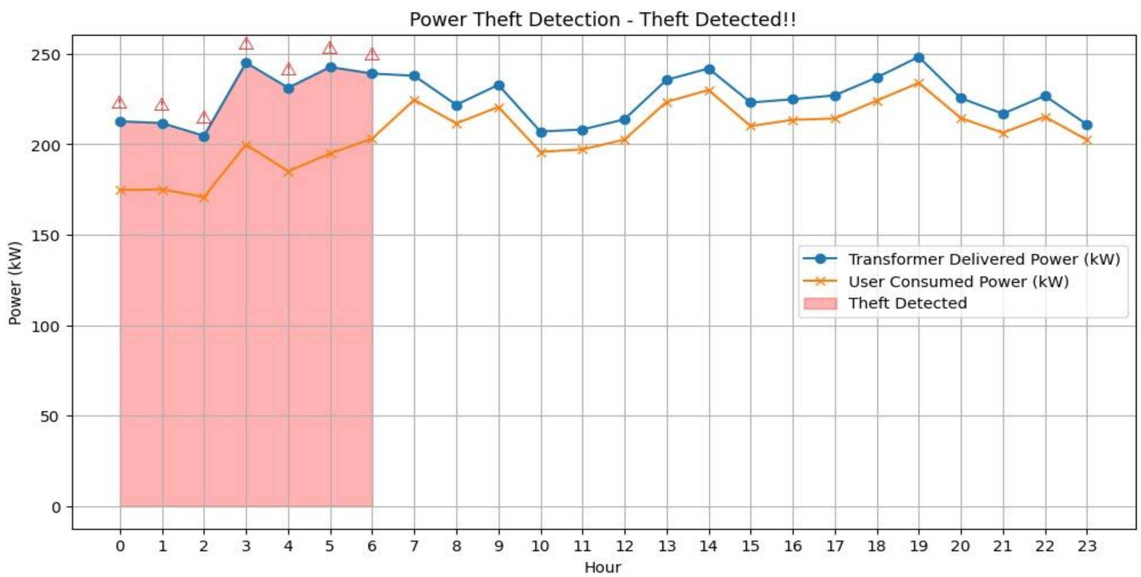

Figure 4.21: Power theft graph (With theft)

4.3 Identify optimal design approach.

4.3.1 Obtained results from design approach 01

In this design, we use the Arduino to make the simulation easy. Proteus has an ESP32 Library. We keep the same ADC value for the ESP32 and the Arduino same. We take adc value from the sensor then send it to the MCU, it processes the total things and gives the value to the Web dashboard. .

This report evaluates a three-phase transformer monitoring system implemented on an Arduino platform, focusing on fault detection using updated parameters aligned with international standards. The system measures current and voltage for each phase via current transformers (CTs) on pins A0–A2 and voltage transformers (VTs) on pins A3–A5, displaying results on a 20x4 LCD. The analysis is based on three simulation scenarios, with fault detection criteria updated as follows: The fault conditions and their trigger criteria, as defined in the code, are:

1. **Overcurrent**: Triggered when any phase current (currentA, currentB, or currentC) exceeds 80% of thresholdCurrent (300 A × 0.8 = 240 A).
2. **Unbalance Load**: Triggered when any phase current deviates from the average current ((currentA + currentB + currentC) / 3) by more than unbalance Load threshold (20%) above or below.
3. **Overvoltage**: Triggered when any phase voltage (voltageA, voltageB, or voltageC) exceeds voltageThreshold (240 V) × 1.05 (252 V).

4. **Undervoltage**: Triggered when any phase voltage falls below voltageThreshold (240 V) × 0.95 (228 V).
5. **Unbalanced Voltage**: Triggered when the average voltage ((voltageA + voltageB + voltageC) / 3) is outside the range of voltage Threshold (240 V) × 0.97 to 1.03 (232.8 V to 247.2 V).

Result in Onsite LCD Display:

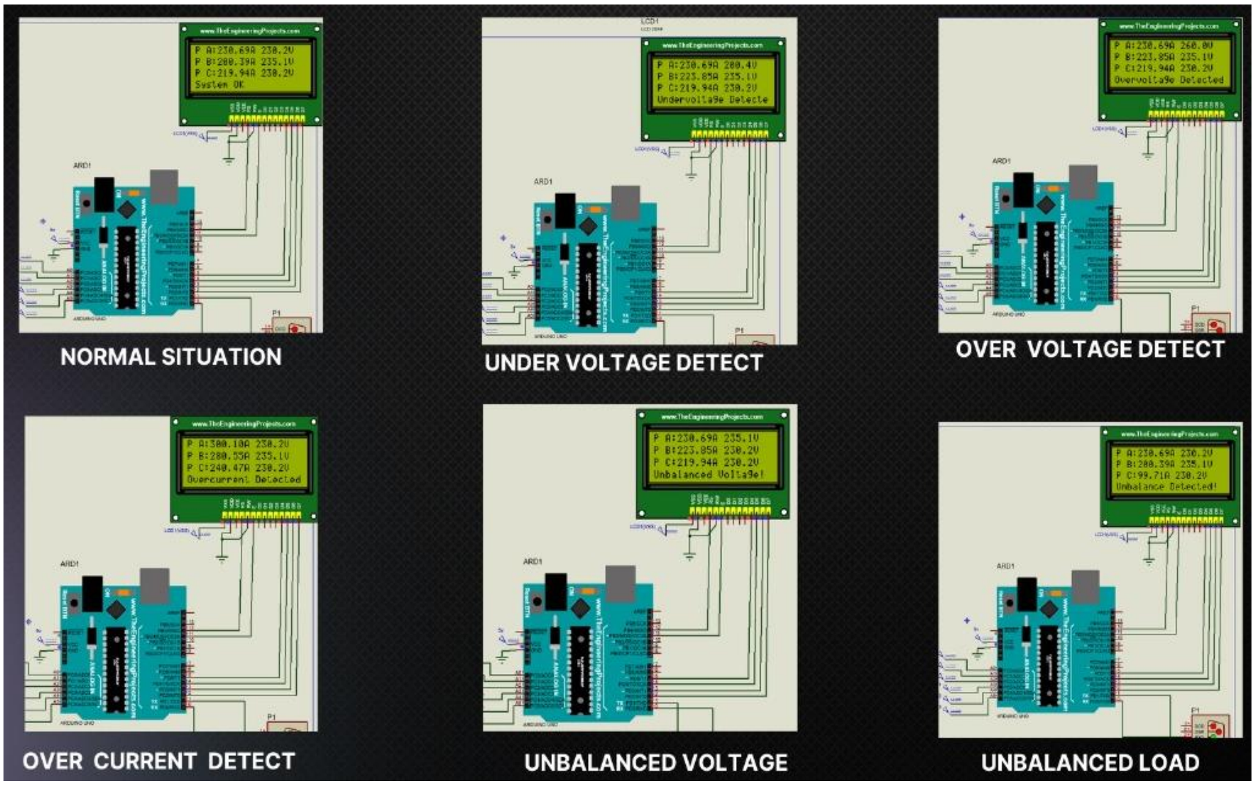

Figure 4.22: Onsite LCD display result

Here is the 6 test case for on-site LCD display is shown in figure. The initial case is for normal condition, then we generate the values so that the system identifies the situations such as Under voltage, Over voltage, Over current, unbalanced voltage and unbalanced load. All the situation our system is able to detect perfectly.

Detailed Result Analysis:

1. Overcurrent Fault

- **Phase A**: Current = 320 A, Voltage = 240 V
- **Phase B**: Current = 200 A, Voltage = 240 V
- **Phase C**: Current = 280 A, Voltage = 240 V
- **Analysis**:
  - Overcurrent: Phase A (320 A) > 240 A (80% of thresholdCurrent 300 A) → **Overcurrent detected**.
  - Display: "Overcurrent Detected!"

2. Unbalance Fault

- **Phase A**: Current = 200 A, Voltage = 240 V
- **Phase B**: Current = 150 A, Voltage = 240 V
- **Phase C**: Current = 280 A, Voltage = 240 V
- **Analysis**:
  - Average current = (200 + 150 + 280) / 3 = 210 A
  - Unbalance threshold = 20% (±42 A)
  - Phase B (150 A) < 168 A (210 - 42), Phase C (280 A) > 252 A (210 + 42) → **Unbalance detected**.
  - Display: "Unbalance Detected!"

3. Overvoltage Fault

- **Phase A**: Current = 150 A, Voltage = 260 V
- **Phase B**: Current = 150 A, Voltage = 240 V
- **Phase C**: Current = 150 A, Voltage = 240 V
- **Analysis**:
  - Voltage threshold = 240 V (±5% = 228 V to 252 V)
  - Phase A (260 V) > 252 V → **Overvoltage detected**.
  - Display: "Overvoltage Detected!"

4. Undervoltage Fault

- **Phase A**: Current = 150 A, Voltage = 220 V
- **Phase B**: Current = 150 A, Voltage = 240 V
- **Phase C**: Current = 150 A, Voltage = 240 V
- **Analysis**:
  - Phase A (220 V) < 228 V → **Undervoltage detected**.
  - Display: "Undervoltage Detected!"

5. Unbalanced Voltage Fault

- **Phase A**: Current = 150 A, Voltage = 250 V
- **Phase B**: Current = 150 A, Voltage = 230 V
- **Phase C**: Current = 150 A, Voltage = 240 V
- **Analysis**:
  - Average voltage = (250 + 230 + 240) / 3 = 240 V
  - Threshold range = 232.8 V to 247.2 V (240 V ± 3%)
  - Individual voltages (250 V, 230 V) deviate significantly → **Unbalanced voltage detected**.
  - Display: "Unbalanced Voltage!"

6. System Ok Condition

- **Phase A**: Current = 150 A, Voltage = 240 V
- **Phase B**: Current = 155 A, Voltage = 238 V
- **Phase C**: Current = 145 A, Voltage = 242 V
- **Analysis**:
  - Average current = (150 + 155 + 145) / 3 = 150 A
  - All currents within 20% of 150 A (120 A to 180 A).
  - Average voltage = (240 + 238 + 242) / 3 = 240 V
  - All voltages within 228 V to 252 V, and average within 232.8 V to 247.2 V.
  - No faults detected → **System OK**.
  - Display: "System OK"

The system effectively measures phase currents (0A to 600A) and voltages (0V to 1000.0V) across three scenarios.

Overview of the Dashboard for Result.

The web dashboard provides real-time monitoring and analysis of transformer and consumer electrical data, including power theft detection, delivering actionable insights through visual and interactive elements. This report summarizes the key results and observations based on its operation.

Result Analysis

1. **Real-Time Data Insights**:
   - **Transformer Metrics**: Voltages (200-260V range) and currents (0-400A range) are consistently displayed in gauges, with temperature readings indicating normal operation below 60°C or warnings/dangers above 60°C/75°C. Power consumption, calculated as (v1*i1 + v2*i2 + v3*i3) / 1000 kW, provides an accurate load assessment.

- **Consumer Metrics**: Currents (0-250A range) are shown in gauges, reflecting consumer-side load with thresholds for normal (below 150A), warning (150-200A), and danger (above 200A) states.
- **Trend Analysis**: Voltage and current trends over 20 seconds, plotted in charts (red for R, yellow for Y, blue for B), reveal stability or fluctuations, aiding in identifying patterns.

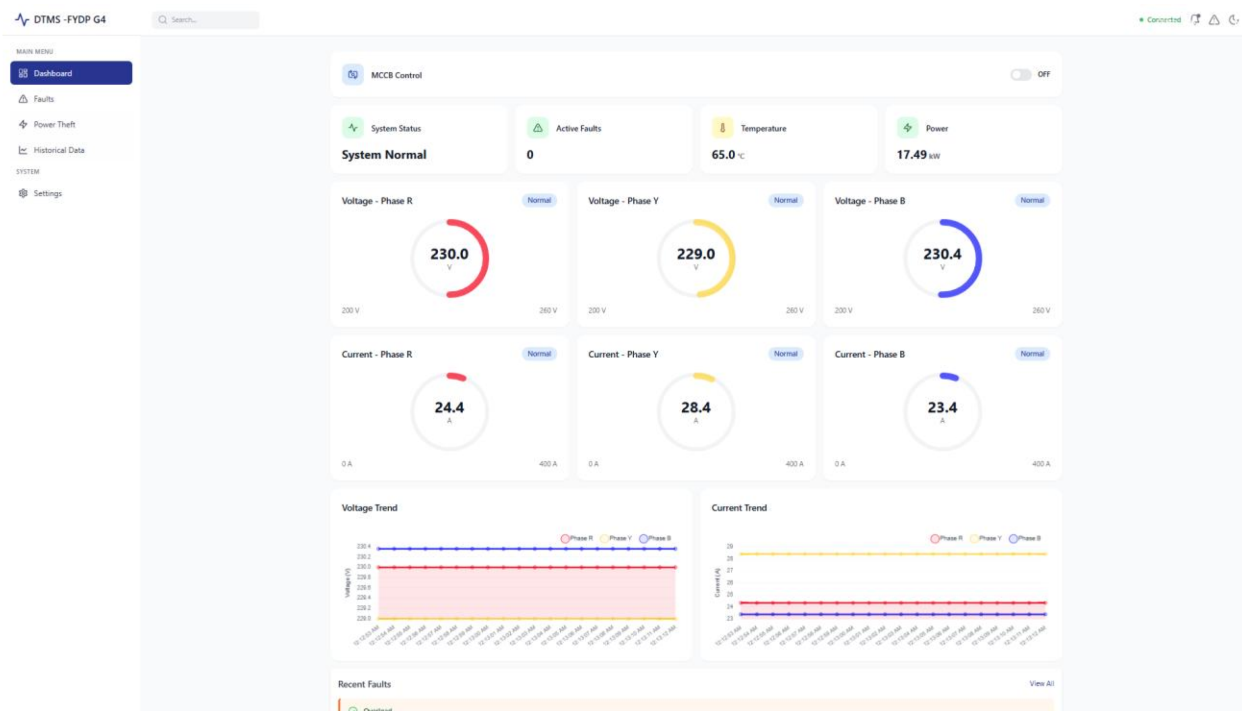

Figure 4.23: Real-Time Data Insights

2. **Fault Detection and Alarming**:
   - The dashboard successfully identifies transformer faults: overvoltage (>245V), under voltage (<225V), overload (>300A), and unbalance (±20%), as well as consumer overcurrent (>200A)./ When there is any type of fault then ***ALARM*** is on.

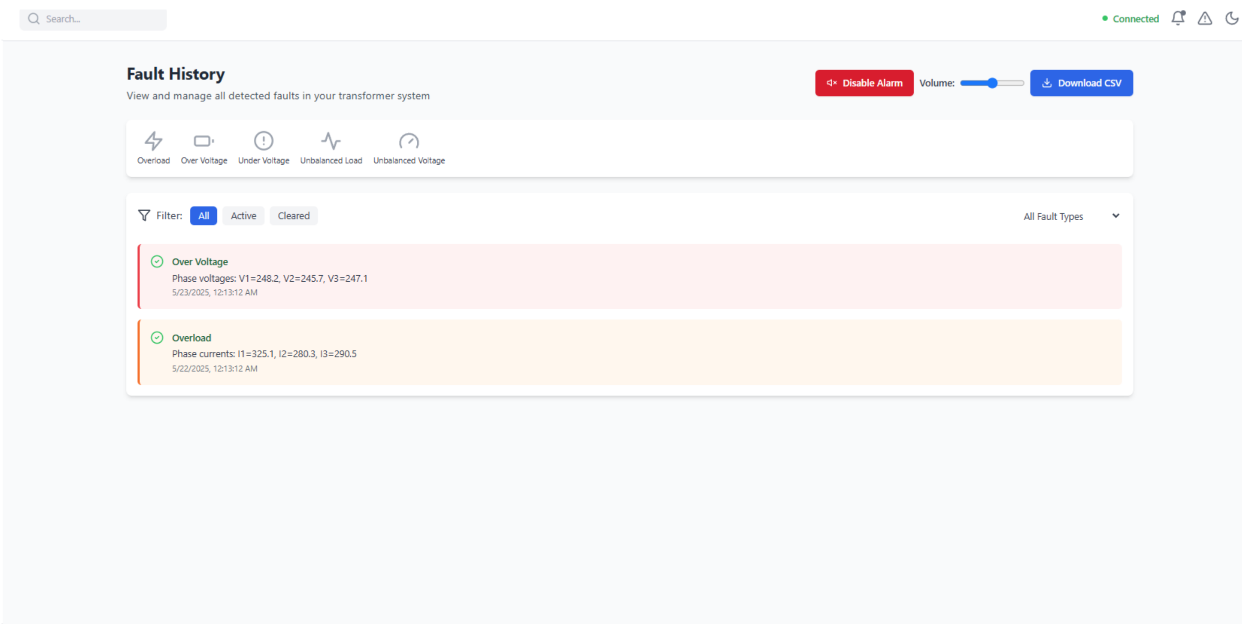

Figure 4.24: Fault History page

- Power theft is detected by comparing expected consumer power (based on currents and voltages) with reported total kWh from the consumer ESP32, flagging discrepancies exceeding 5% as "Power Theft" alerts.

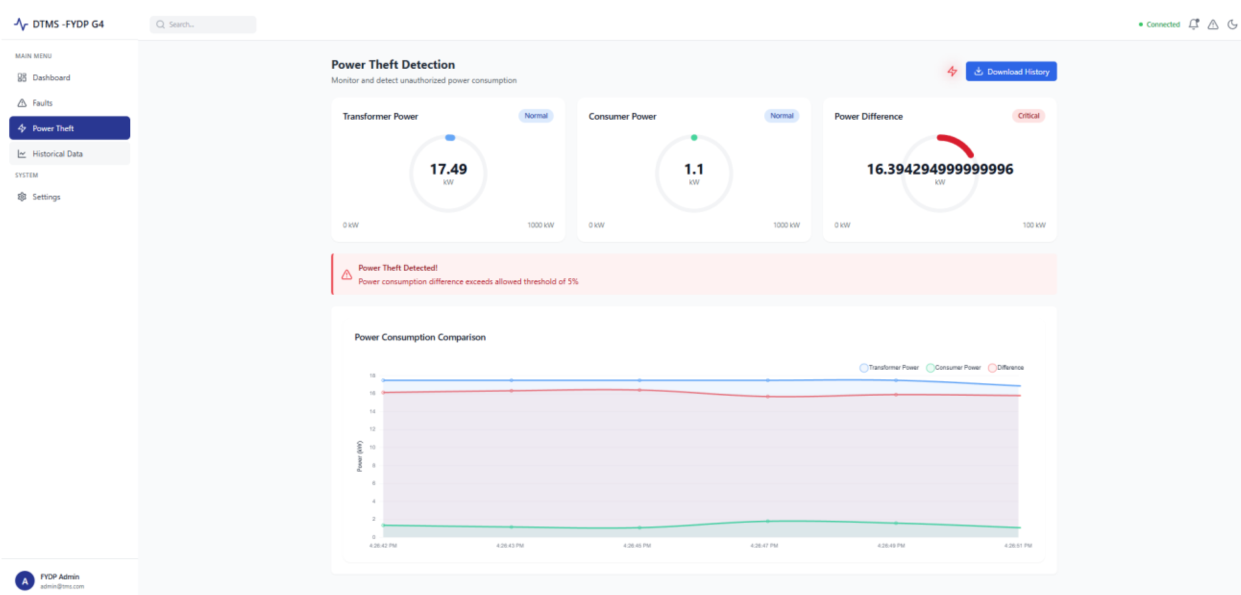

Figure 4.25: Power theft detection

- Faults and theft incidents are logged in the "Recent Faults" section, categorized as "Transformer" (e.g., "Over Voltage"), "Consumer" (e.g., "Over Current"), or "Theft" (e.g., "Power Theft"), with up to three recent incidents displayed.

- The alarming system activates a Bell icon and /siren.mp3 playback upon fault or theft detection, with acknowledgment clearing the alert, confirming effective notification.

3. **System Status and Reliability**:
    - The "System Status" card accurately reflects "System Normal" when no faults or thefts are active and "Faults Detected" or "Theft Detected" otherwise, providing a quick health overview.

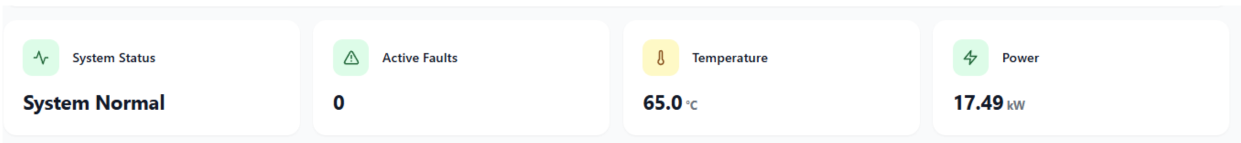

Figure 4.26: System Status and Reliability

- The "Active Faults" count aligns with uncleared incidents, including theft cases, offering a real-time assessment of system issues.

4. **Control and Historical Data**:
    - The "Relay Status" card displays the relay state ("ON" or "OFF") and supports toggling, enabling manual control with immediate feedback.
    - Exported CSV files of fault and theft history include type, timestamp, details, and cleared status, facilitating detailed post-analysis.
    -

Figure 4.27: Historical Data page

The dashboard delivers reliable, real-time insights into transformer and consumer performance, with precise fault detection, power theft identification, and alerting that enhance system oversight. Trend visualizations support proactive monitoring, while relay control and historical data export provide operational flexibility and record-keeping. These results underscore the dashboard's effectiveness as a comprehensive monitoring tool for electrical systems, now extended to detect unauthorized power usage.

4.3.2 Obtained Results from Design Approach 02

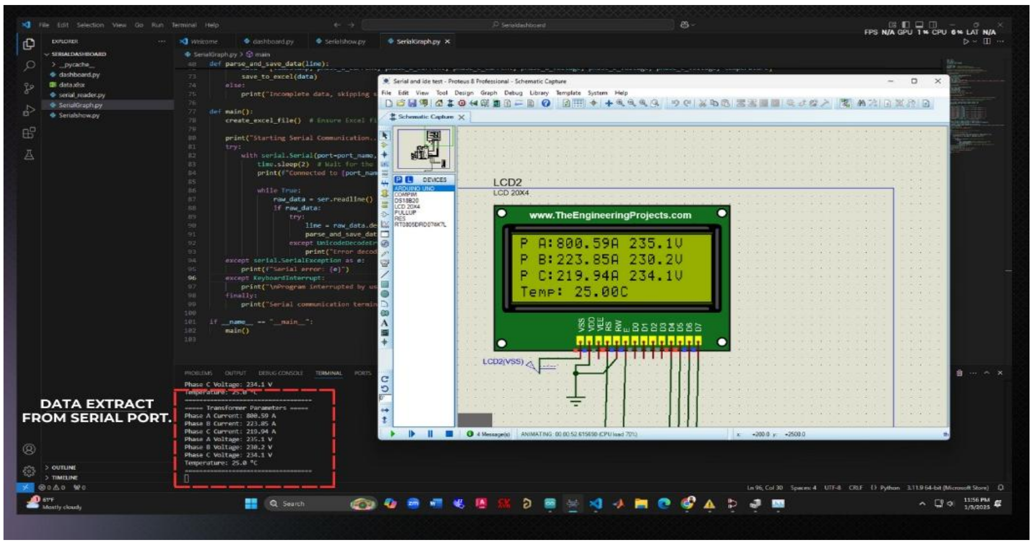

Figure 4.28**:** Taking Value from the serial communication

Result Analysis

1. Data Transmission:
    - The system successfully transmits 10 parameters (currents, voltages, averages, and status) to the main computer.
    - Data is scaled to integers to fit Modbus registers, ensuring accuracy (e.g., 2 decimal places for currents, 1 for voltages).
    - Status is encoded as bit flags, allowing multiple conditions to be reported in a single register.
2. Range Feasibility:
    - RS-485 supports up to 1.2 km at 9600 baud. For 2 km, **a repeater** is necessary to boost the signal. With proper cabling (low capacitance, twisted pair) and termination, reliable communication is achievable

3. Reliability:
    - RS-485 is robust in noisy industrial environments, and Modbus RTU's CRC ensures data integrity.

- The Arduino Uno's 64-byte serial buffer limits transfers to ~29 registers per request, but 10 registers are well within this limit.

4. Latency Performance:
    - The ~36–50 ms latency per poll is suitable for a DTMS, where transformer parameters change slowly (seconds to minutes).
    - Polling every 1 second provides real-time monitoring without overwhelming the Arduino or network.
5. Scalability:
    - Up to 127 Arduino slaves can be connected on the same RS-485 bus (each with a unique slave ID)
    - For multiple transformers, assign unique slave IDs and extend the Python script to poll each slave.
6. Limitations:
    - Arduino Uno Constraints: Limited memory and processing power may cause issues if more parameters or faster polling are needed. Consider upgrading to an Arduino Mega or ESP32 for complex systems
    - Baud Rate Trade-off: Higher baud rates reduce latency but may require more repeaters or better cabling for 2 km
    - Repeater Cost: Each repeater adds ~$50–100 to the system cost.

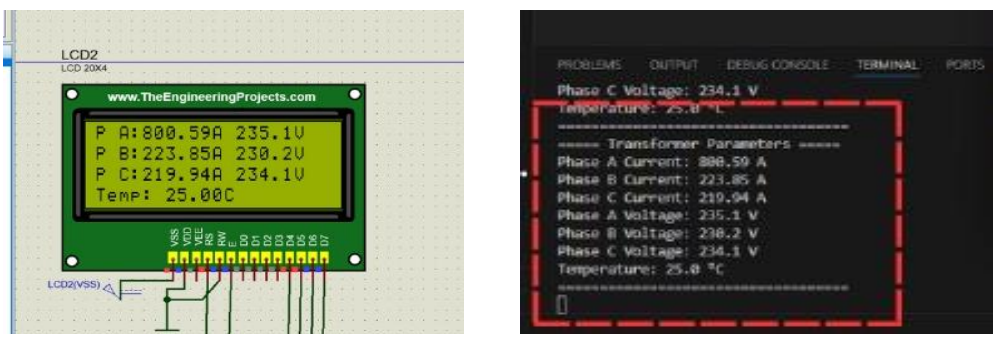

Figure 4.29: sending value from the serial communication and receiving value via wire in serial port.

After getting the value form the sensor, then we sent it to the inbuilt custom dashboard,

Figure 4.30: 3 Phase voltage and the current from port

This is showing the values form the sensor value that obtains from the Arduino via communication then show it to the dashboard.

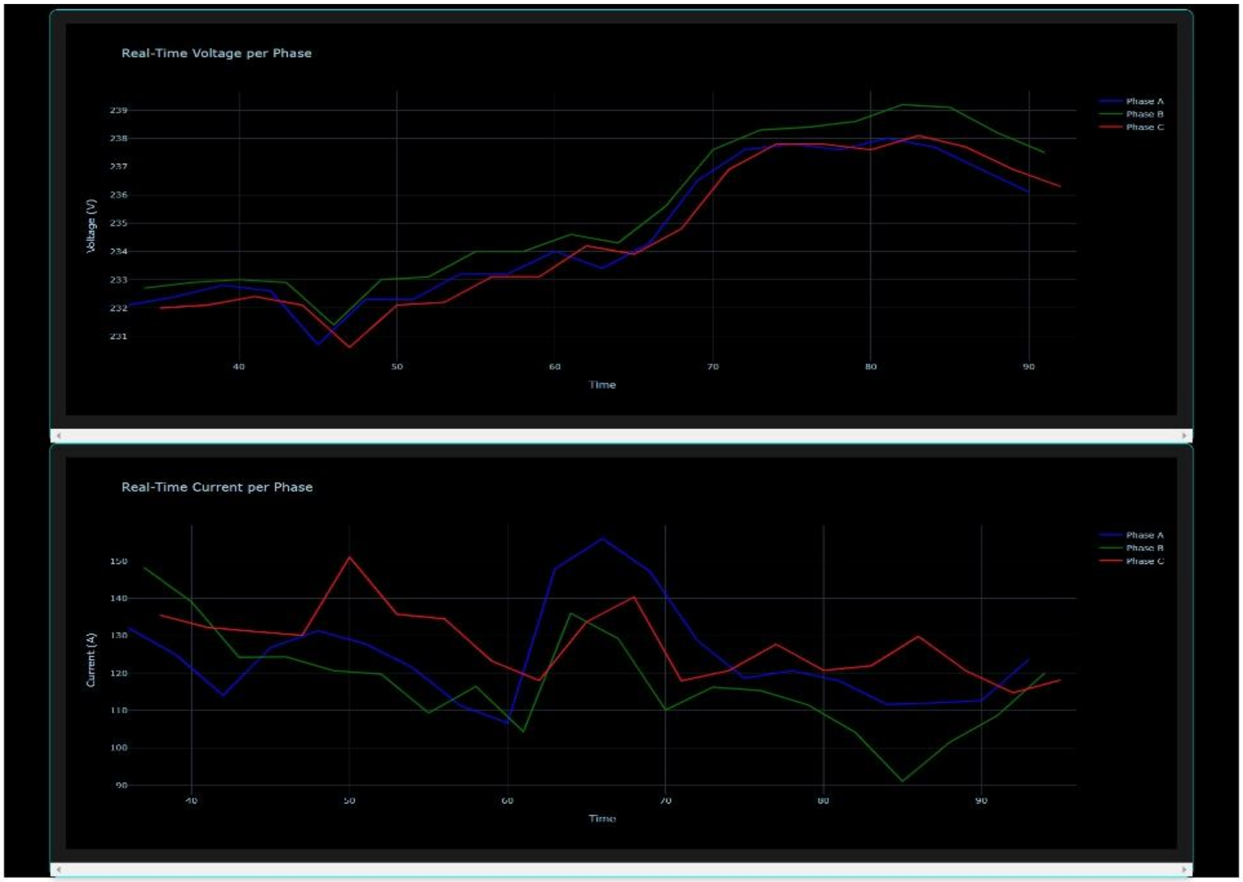

Figure 4.31**:** Voltage and current graph for 30 sec.

4.4 Performance Evaluation of Developed Solution

The DTMS project include the monitoring of three-phase transformer parameters, such as voltage, current and temperature and detection of faults (overvoltage, undervoltage, overcurrent, voltage unbalance, load unbalance) and power theft. Two design methodologies were designed and simulated in Proteus:

- Design Approach 1: An ESP32 Microcontroller for local processing, integration into the Internet of Things (IoT) and a custom dashboard for real time monitoring and fault diagnosis.
- Design Approach 2:Arduino Nano microcontrollers communicate via RS-485 and a central server processes the data, a custom dashboard then displays the information.

In this paper, comparison of both designs using the section-wise outputs (section), case-wise scenario analysis (analysis), project criteria (project) and timing performance (time) is made to obtain the better solution.

4.4.1. Performance Criteria Evaluation

Design and Set Up Experiments

Table 4.1: Performance Criteria for Design and Set Up Experiments

	Design Approach 1	Design Approach 2:
Setup	the circuit includes a three-phase transformer, a power supply unit (240V AC to 5V/12V DC), parameter unit (voltage, current, and temperature sensors), ESP32 processing unit, on-site LCD, virtual port for IoT connectivity, and a custom IoT dashboard built with React, Tailwind CSS, and Node.js.	the circuit comprises a three-phase transformer, a power supply unit, parameter unit, master-side Arduino Nano, RS-485 modules for wired communication, slave-side Arduino Nano, on-site LCD, and a central server with a custom dashboard. Data is transmitted via RS-485 and processed on the server.
Experiment Design	Six test cases were designed to simulate normal operation, overvoltage, undervoltage, overcurrent, voltage imbalance, and load imbalance. Fault thresholds were set per IEC 60038, IEC 60947, IEC 61000-2-2, and IEEE 141, adjusted for Bangladesh's infrastructure (e.g., nominal voltage: 240V, overvoltage: >264V, undervoltage: <216V,	Similar test cases as Approach 1, with data transmitted to the server via RS-485 (9600 baud) and extracted as CSV files through a serial port. Fault detection occurs on the server.

	overcurrent: >8A, voltage imbalance: >3%, load imbalance: >20%).	
Tools	Proteus for circuit simulation, ESP32 library for processing, and a custom IoT dashboard for real-time visualization. Design Approach 2:	Proteus for simulation, Arduino IDE for programming, Python for data extraction, and a custom dashboard for visualization.

Conduct Experiments and Perform Measurements

Table 4.2: Performance Criteria for Conducting Experiments and Performing Measurements

	Design Approach 1:	**Design Approach 2**:
Measurements:	The system measures three-phase voltages (0–1000V), currents (0–600A), and temperature (RTD sensor). Data is processed by the ESP32 and displayed on the LCD and IoT dashboard.	Similar parameters are measured and transmitted via RS-485 to the server. Data is scaled to integers for Modbus registers (e.g., 2 decimal places for currents, 1 for voltages).
Test Cases:	● Normal Operation: Voltages ~240V, currents <8A, temperature <60°C. ● Overvoltage: Phase A voltage at 260V (>264V threshold). ● Undervoltage: Phase A voltage at 200V (<216V threshold). ● Overcurrent: Phase B current at 399.39A (>8A threshold). ● Voltage Imbalance: Average voltage deviation >3% (e.g., 221.77V). ● Load Imbalance: Current deviation >20% (e.g., Phase B at 399.39A, Phase C at 99.71A).	Identical to Approach 1, with data extracted as CSV files from the serial port for server processing.
Accuracy:	ADC values from sensors are accurately processed by the ESP32, with results displayed on the LCD and Web dashboard. Accuracy is approx. 99%	RS-485 ensures reliable data transmission with CRC checks. Latency of 36–50 ms per poll supports real-time monitoring.

Evaluation: Both approaches accurately measure transformer parameters. Approach 1 provides real-time on-site and cloud-based visualization, while Approach 2's reliance on wired communication introduces slight latency but maintains accuracy. Both meet the criterion effectively. But design 1 is more reliable.

Detect Experimental Faults and Troubleshoot

Table 4.3: Performance Criteria for Detecting Experimental Faults and Troubleshooting

	Design Approach 1:	**Design Approach 2**:
Fault Detection	The ESP32 processes sensor data against predefined thresholds: ● Overvoltage ● Undervoltage: ● Overcurrent: ● Voltage Imbalance: >3% ● Load Imbalance: >20% ● Power Theft: >5% discrepancy between transformer and consumer power.	Faults are processed on the central server using the same thresholds. The LCD displays raw sensor data, while the dashboard shows fault status.
Results:	All test cases were correctly detected. The dashboard displays faults with alarms (bell icon, siren.mp3	Faults were accurately detected, with data logged in the server's fault history. Power theft detection compares transformer and consumer data via a separate portal.
Troubleshooting:	A simulation error was identified in the "System OK" scenario, where overload and unbalance should have triggered faults but did not. This suggests a logic override issue in the ESP32 code, which can be resolved by prioritizing overload detection. We can also change the threshold in the web dashboard.	No major errors were reported, but the system's reliance on wired communication requires repeaters for distances >1.2 km, increasing costs (~$50–100 per repeater).

Evaluation: Both approaches successfully detect faults, but Approach 1's on-site processing allows immediate fault visualization on the LCD, enhancing troubleshooting. Approach 2's server-based processing delays fault visualization until data reaches the dashboard. Approach 1 is superior for rapid fault detection and troubleshooting.

Analyze and Interpret Data, Graphs, Charts

Design Approach 1:

- Data Analysis: The IoT dashboard displays real-time voltages (200–260V), currents (0–400A), and temperature (<60°C normal, 60–75°C warning, >75°C danger). Trends are visualized in graphs (red for R, yellow for Y, blue for B) over 20 seconds.

Figure 4.32: Main page of web dashboard.

- Charts: Line charts show voltage and current trends, while gauges display real-time values. Fault history and power theft alerts are logged with timestamps.

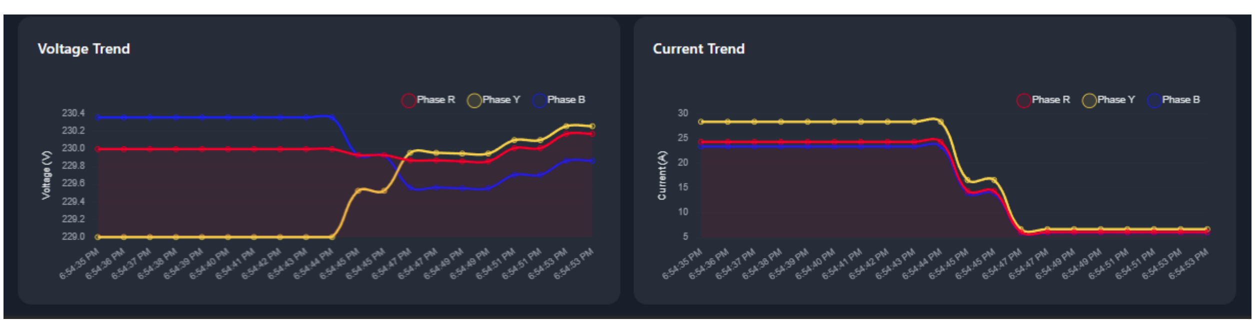

Figure 4.33: Voltage and current curve for 20 sec.

- Interpretation: The dashboard effectively highlights anomalies (e.g., overvoltage at 260V, power theft with >5% discrepancy)

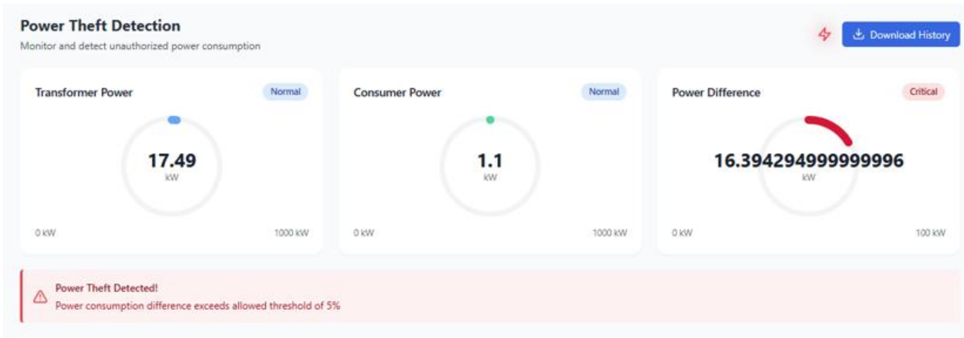

Figure 4.34: Showing that there is power theft.

- Historical data (100ms to 3 months) supports long-term analysis.

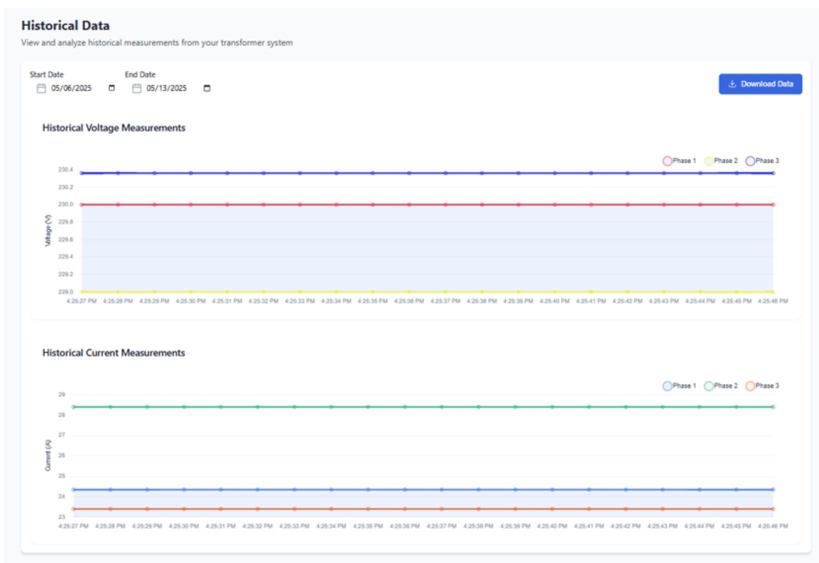

Figure 4.35: showing Historical data (1ms to 3 months).

Design Approach 2:

- Data Analysis: The server dashboard displays similar metrics, with CSV-extracted data processed to show three-phase voltages, currents, and temperature. Faults and theft are visualized in graphs.

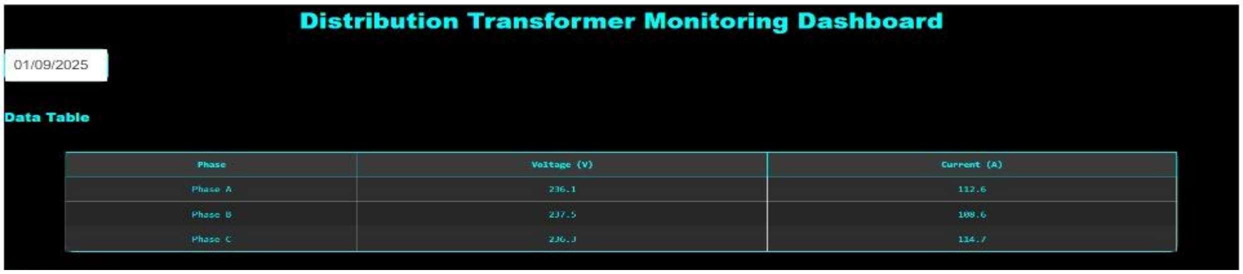

Figure 4.36: Taking Value from the serial communication.

- Charts: Voltage and current trends are plotted, with a separate portal for power theft comparison. The fault log includes timestamps and details.

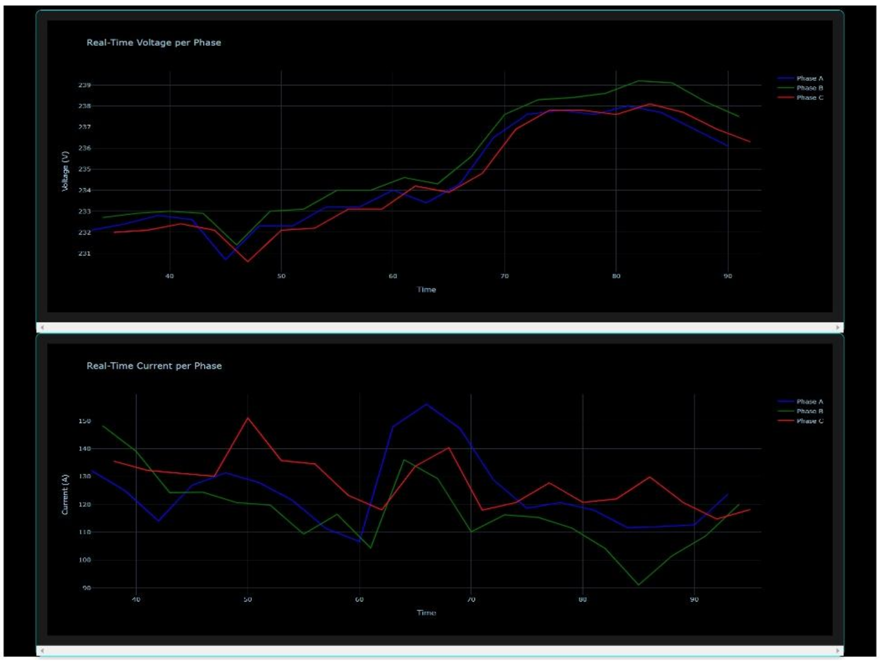

Figure 4.37: Voltage and current graph.

Evaluation: Both approaches provide robust data visualization. Approach 1's integrated IoT dashboard is more user-friendly and responsive, while Approach 2's reliance on a separate portal for theft detection reduces efficiency. Approach 1 excels in this criterion.

4.4.2 Project Criteria-wise Comparison

The project criteria evaluate both designs based on cost, efficiency, usability, manufacturability, impact, sustainability, and maintainability.

Table 4.4: Project Criteria-wise Comparison

Criteria	Design Approach 1	Design Approach 2
Cost	Lower initial cost low due to minimal infrastructure (ESP32, sensors, IoT setup). Maintenance may increase due to potential logic errors and internet dependency.	Higher initial cost high due to RS-485 modules, cabling, and repeaters. Reduced maintenance costs due to stable performance and robust communication.
Latency	Real-time processing reduces latency (~10 ms), but simulation errors (e.g., load imbalance) indicate inefficiencies in fault detection logic.	Stable data transmission and server processing ensure high efficiency, though latency (~43 ms) is higher due to wired communication.
Usability	Highly user-friendly with integrated IoT dashboard showing real-time data, faults, and theft alerts. Internet dependency may limit usability in remote areas.	Less user-friendly due to separate theft detection portal and delayed visualization. Stable outputs enhance reliability for industrial settings.
Manufacturability	Feasible to manufacture with standard components (ESP32, sensors). IoT setup requires minimal hardware, simplifying assembly.	Feasible but requires RS-485 modules, cabling, and repeaters, increasing manufacturing complexity and cost.
Impact	Reduced infrastructure minimizes environmental impact, but internet dependency and logic errors may affect reliability, increasing grid reliance.	Higher environmental impact due to cabling and repeaters. Stable performance reduces grid instability, supporting sustainability.
Sustainability	Sustainable with IoT scalability, but internet reliability limits long-term deployment in rural areas.	More sustainable in industrial settings due to robust communication, but cabling limits scalability for widespread use.
Maintainability	Requires maintenance for logic errors (e.g., load imbalance) and internet connectivity issues. Local storage could improve resilience. But web dashboard gives solution this. We can fix the threshold via Webdashboard.	Lower maintenance due to stable performance, but cabling and repeaters may require periodic checks, increasing costs.

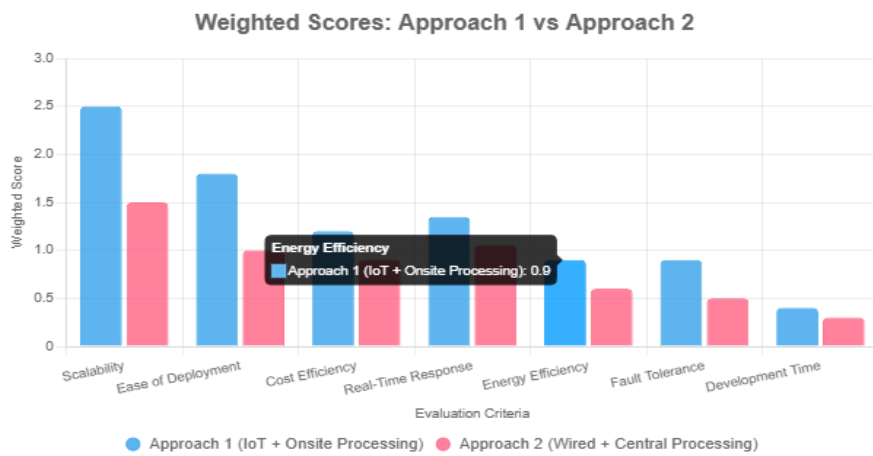

Figure 4.38: Criteria-wise Comparison graph.

Analysis: Design Approach 1 offers lower costs and better usability also more efficient and sustainable. But Design Approach 2 is reliable and efficient, with higher initial costs but lower maintenance. We Choose Design Approach 1.

4.4.3 Weighted Score Calculation

We can also do the weighted score calculation for both design:
Evaluation Criteria and Weights:

Table 4.5: Weighted score calculation Table

Criteria	Weight (%)	Description
Scalability	25%	Ability to deploy the system over a large geographic area with minimal infrastructure.
Ease of Deployment	20%	Simplicity of installation, especially in complex urban environments like Dhaka
Cost Efficiency	15%	Includes both hardware and maintenance costs for large-scale deployment.
Real-Time Response	15%	Ability to detect and respond to faults quickly for improved operational efficiency.
Energy Efficiency	10%	Power consumption of the system during operation.

Fault Tolerance	10%	Robustness to individual component failures (e.g., communication or hardware failures).
Development Time	5%	Time required to implement the design, including setup, coding, and debugging.

Scoring Table:

Table 4.6: Scoring Table

criteria	**Weight (%)**	**Approach 1: (IOT+Onsite processing)**	**Weighted Score**	**Approach 2 (Wired communication+Central processing)**	**Weighted Score**
Scalability	25%	10	2.5	6	1.5
Ease of Deployment	20%	9	1.8	5	1.0
Cost Efficiency	15%	8	1.2	6	0.9
Real-Time Response	15%	9	1.35	7	1.05
Energy Efficiency	10%	9	0.9	6	0.6
Fault Tolerance	10%	9	0.9	5	0.5
Development Time	5%	8	0.4	6	0.3
Total Score	100%		9.05		5.58

So, here we see approach 1 has a weighted score of 9.05 and approach 2 has weighted score of 5.58. So, we can tell that design 1 (IoT+ Onsite processing)is the optimal solution for our project.

4.4.4 Timing Comparison

Timing performance is evaluated based on the latency of fault detection and data visualization, critical for real-time monitoring.

- Design Approach 1: Fault detection and dashboard updates occur in ~10 ms due to on-site ESP32 processing. Data transmission to the IoT cloud is near-instantaneous with stable internet, but delays may occur in low-connectivity areas.
- Design Approach 2: Fault detection and visualization take ~36–50 ms (average 43 ms) due to RS-485 transmission and server processing. Polling every 1 second ensures real-time monitoring, but latency is higher than Approach 1.

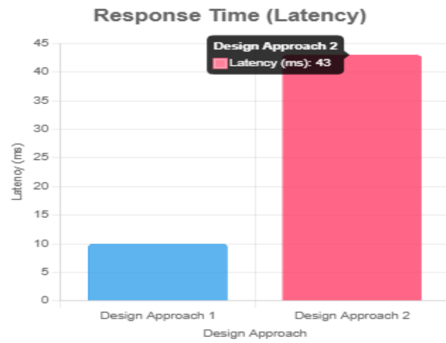

Figure 4.39: latency of fault detection.

Analysis: Design Approach 1 is significantly faster, enabling near-instant fault detection and visualization, ideal for time-sensitive applications. Design Approach 2's higher latency is acceptable for transformer monitoring, where parameters change slowly, but it is less responsive.

Optimal Design Approach

Design Approach 1 is the optimal solution due to:

- **Autonomy**: On-site processing and IoT connectivity enable real-time monitoring without reliance on extensive physical infrastructure.
- **Usability**: The integrated dashboard provides comprehensive, real-time insights, including fault detection and power theft alerts.
- **Scalability**: IoT allows easy expansion to multiple transformers without additional cabling.
- **Cost-Effectiveness**: Minimal infrastructure requirements reduce setup and maintenance costs compared to RS-485 repeaters.

4. 5. Conclusion

Both design approaches meet the DTMS requirements, but Design Approach 1 outperforms due to its real-time processing, integrated IoT dashboard, and reduced infrastructure dependency. It effectively detects faults and power theft while providing actionable insights through a user-friendly interface. Approach 2 is viable for industrial settings with robust wiring but is less flexible and costlier. Design Approach 1 is recommended for deployment, with minor refinements to ensure robustness in diverse environments. In conclusion, by refining two design approaches and evaluating their performance through simulations and modeling, we see that, design approach 1 which is Standalone Monitoring System Based on IoT and on-site processing as optimal solution for our DTMS project. As it is standalone and it doesn't need any heavy set-up and IoT system enables scalability which is important to expand the project in Bangladesh.

Chapter 5: Completion of Final Design and Validation.

5.1 Introduction:

In this chapter, we will discuss the final stages of the Distribution Transformer Management System (DTMS) project and we will focus on the completion of the final design and the validation of the solution. After extensive planning, modeling and simulation we built our system by integrating different kinds of hardware and software. Then we test our complete system in a controlled lab environment. Here, we check whether our system detects faults efficiently and meets other desired needs. It is crucial to ensure that the system meets the desired needs and functions effectively in a controlled lab environment so that we can take corrective measurement for any error. Then, we test our system in a real world scenario. We implement our system at Savar PBS-03. The following chapter we discuss evaluation results to refine the selected design, and to ensure the real-time monitoring, accurate fault detection, and preventive maintenance for transformers in Bangladesh's resource-constrained environment.

5.2 Completion of final design:

5.2.1 Specification of the components:

Table 5.1: Specification of the components

SL	Component's Name	Component's Model	Specification
1.	CT (Current Transformer)	600/5	Brand: Secure Primary rating : 600A AC Secondary output: 5A AC Operating Frequency : 50Hz Insulation class : E System Voltage : 720V
2.	Multifunction Panel Meter	Elite 300	Brand: Secure Measuring Voltage Range: 20-500V Measuring Current Range: 50mA- 6A Frequency Range: 45-65 Hz Auxiliary power supply : 40-300V Accuracy: ±0.5%
3.	Power Supply	S-50-5 AC-DC power supply	AC input : 110/220V DC output: 5V Current rating : 10A Frequency : 50/60 Hz
4.	Microcontroller	ESP32 ESP-32S 30P	Built-in Flash: 32Mbit

		NodeMCU	Power supply: 5V WiFi protocol: IEEE 802.11 b/g/n
5.	RS-485 Module TTL	MAX485 RS-485 Module TTL to RS-485 Module For Arduino	Chip : MAX485 chip Onboard then 5.08 (mm) pitch 2P terminal to facilitate RS-485 communication wiring. Voltage rating : 5V
6.	Temperature Sensor	PT 100 RTD temperature sensor	Temperature Range: 0C-400C Shield Material: Metal Voltage Rating: 5V
7.	LCD Display	20 x 4 2004A LCD Display	Voltage rating: 5V Resolution : 100 × 32 pixels
8.	Wifi Modem	Jio 4G Wifi Modem	Network security: WPA / WPA2, WIFI Download speed: 300MBPS Network: 4G Wireless Speed: 2.4GHz 150Mbps
9.	Circuit Breaker	iC60N - miniature circuit breaker	Rated current: 6 A Trip technology: Thermal-magnetic
10.	Battery Management System	2S 20A 7.4V 8.4V 18650 Lithium Battery Protection Board/BMS Board Standard	Over Charge Voltage Range : 4.25-4.35 V + 0.05 V Over Voltage Range: 2.5-3.0 V + 0.05 V Max. Operating Current: 13 A Max. Limiting Current: 20 A Charging Voltage: 8.4-9 V

11.	Battery	3.7V 18650 Rechargeable Battery Solderable	Capacity (mAh): 750-1300 (Output Voltage: 3.7V High energy density High working voltage for single battery cells
12.	Relay	4 Channel 5V relay	Trigger Voltage : 5VDC Switching Voltage : 150VAC @ 10A No of Channel : 4
13.	Protective Box		Material : GI sheet Water and Splash resistant

Current Transformer (CT 600/5):

Figure 5.1: CT (600/5)

The CT is employed in DTMS to measure reliably the high current carried by each phase of the LT side of transformer. Its main function is to reduce the current from a few hundreds of amperes like 600A to a safe level of 5A for the panel meter. The CT is based on the principle of electromagnetic induction and is connected with each phase of transformer output. The CT secondary winding feeds out a lower-current scaled current corresponding to the primary load current. The Safe current is then input to the Secure Elite 300 multifunction meter which further processes the current to calculate real-time power quantities. CTs are an important component in power systems, necessary for the accurate monitoring of high-voltage systems without the danger of directly connecting the high-voltage circuit to the measurement device. They also serve to separate the control system from hazardous current levels. In this project, the CTs are the apparatus that enables the energy meter to obtain an accurate reading of the current without causing the system to be unsafe or uninsulated.

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Multifunction Panel Meter (Secure Elite 300):

Figure 5.2: Multifunction Panel Meter

The Secure Elite 300 is a multi function panel meter to measure various real time parameters of a 3 phase distribution transformer like voltage, current, energy consumption etc. It is a central piece in this project as it is used as a measurement meter from which the ESP32 collects the parameters of the transformer to understand how the system works. This meter is coupled to the transformer's three–phase wire and is fed current by CTs. It communicates over RS-485 via the Modbus RTU protocol and can communicate directly to the ESP32 microcontroller. The meter is set with a custom Modbus address and mapped registers for the ESP32 to fetch data. The Secure Elite 300 is renowned for its accuracy, reliability and adaptability to industrial applications. It gives the basic electrical measuring to achieve checking error, identifying power theft, three phase unbalance load, etc. so as to maintain the smooth flow of electricity by preventable maintenance. So, we can tell the multifunction panel meter is an essential part of the overall monitoring and protection system in a transformer.

Microcontroller:

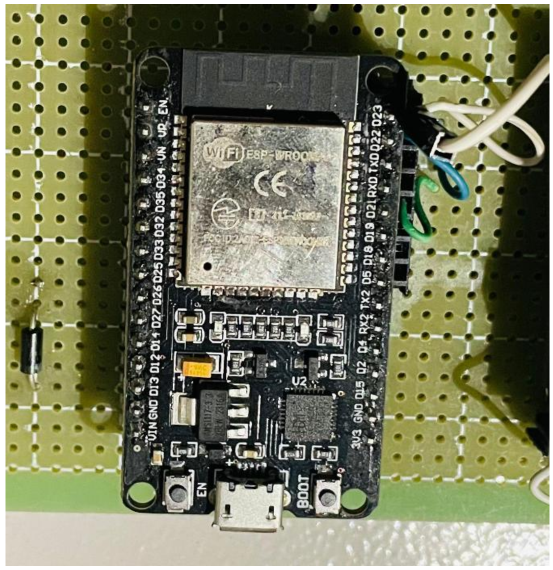

Figure 5.3: MCU unit

ESP32 microcontroller is used as the main controlling and processing unit of the developed DTMS. The ESP32, one of the most popular microcontroller mounted with a dual-core processor and included Wi-Fi and Bluetooth, is a highly versatile and powerful controller ideal for real-time applications such as monitoring and control. In this project the ESP32 reads data from a Multifunction panel meter by Modbus RS-485 communication and displays them on an LCD, send data to IoT SYSTEM , and activates programmable relays if a fault condition is met. The ESP32 3.3V with a rich peripheral. The module operates at a clock frequency of 240 MHz and comes with 520 KB SRAM and 4 MB flash memory to accommodate the sensor data process, Modbus poll, relay control and IOT information transmission. In the DTMS project, the ESP32 receives voltage, current, and power readings from the panel meter where they are compared against predetermined thresholds. It then operates relays to isolate the transformer under abnormal conditions, such as overload or unbalanced phases. It also energizes the LCD for visual feedback to field technicians. Due to the sustainable performance and multitasking functionality of the ESP32, it is ideal for real-time embedded control in transformer monitoring.

DC Power Supply (220V AC to 5V 10A DC):

Figure 5.4: Power Supply 220VAC- 5VDC

The DC power supply unit is playing a crucial part in this project by converting the normal 220V AC from the mains into a steady 5V DC, also it can handle current to 10A. This conversion and isolation are required to safely drive the low voltage electronics in the Distribution Transformer Management System (DTMS) such as ESP32 microcontroller, RS-485 to TTL converter, LCD display,4G modem modules, and Electromagnetic relays. The power output of 5V 10A satisfies our need for multiple application, and power will be distribute over the ports to ensure that the performance is not affected by voltage drop. Stable long-term operation required for real-time monitoring and protection. It also features over-voltage, over-current, and short-circuit protection to prevent damages to save components such as the ESP32 and sensors due to electrical faults.

RS-485 to TTL Module:

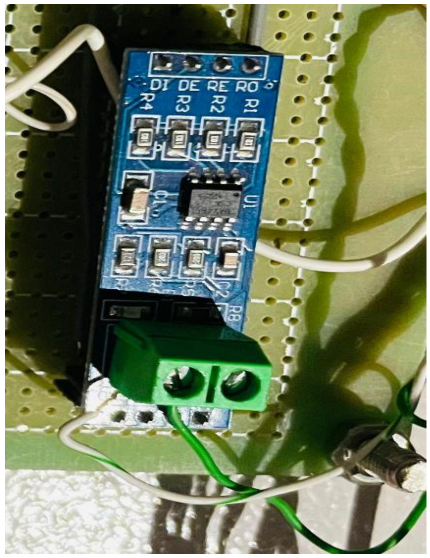

Figure 5.5: RS-485 to TTL Module

The RS-485 to TTL module is one of the serial communication interfaces utilized in this project to ensure stable data communication between the microcontroller (ESP32) and the external devices (multifunction panel meter: Secure Elite 300). RS-485 is a common industry standard for serial communications, well-liked for its low susceptibility to noise, differential signal and the ability for multiple devices with long cable runs, which is suitable for electrical monitoring, such as DTMS. This module uses a TTL (3.3V and 5V) to RS485 conversion chip, which directly drives the RS485 converter chip for UART interface, through the switch control, simply select the UART side or the RS485 side. The ESP32 microcontroller communicates using UART (Universal Asynchronous Receiver-Transmitter) at TTL levels and is not directly compatible with the RS-485 protocol. This is where the RS-485 to TTL converter comes in, converting between the electrical standard so that an ESP32 can communicate using RS-485. It is behaviorally driven by a MAX485 (or equal) transceiver IC (as typically on a shield), which can do half-duplex communication, i.e., can do either Data reception or transmission at a time. The purpose of the module presented here is to forward command requests to the panel meter from the ESP32 over Modbus RTU, and to copy measuring data provided by the panel meter, e.g. voltage, current power measurements. In particular, this is quite indispensable for a system for monitoring the transformer, since the accuracy and stability of the communication of data is crucial there. the RS-485 to TTL module serves as a communication bridge for ESP32 and multifunction meter to realize safe, isolated and efficient data communication. It is one of the key factors for accurate remote monitoring and real-time data acquisition hardware of the DTMS project.

4-Channel Relay Module:

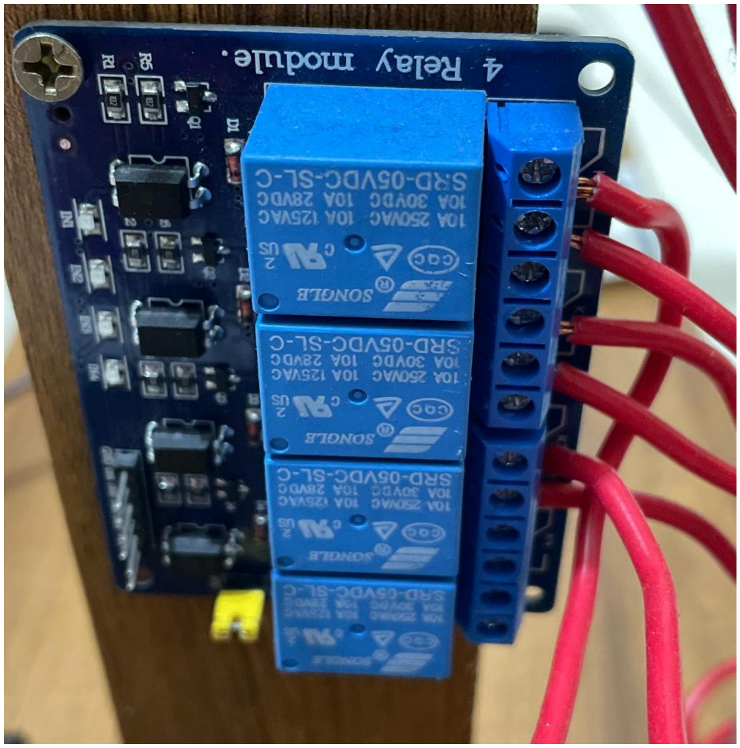

Figure 5.6: 4 Channel relay

4-Channel Relay Module is utilized in the proposed DTMS project to drive and isolate load from the distribution transformer. It provides the control to the ESP32 to switch high voltage and current circuits such as bypassing defective loads or shutdown transformer outputs if a fault or a condition is detected. Each relay is capable of switching up to 10A , 250VAC so it can produce enough to control any sort of distribution side relay. The module holds electrical isolation by opto-couplers, safe for the control system. In this project the relay module contributes in fault detection and restoration, load management, and protection transfer guaranteeing reliable operation of the transformer

4G WiFi Modem:

Figure 5.7: 4G Wifi modem

The 4G Wi-Fi module is a key component that supports remote communication for the DTMS. It has an internal SIM card for 4G internet, and generates a local WiFi network that connects to an ESP32 microcontroller. In this configuration, live transformer parameters like voltage, current, power and temperature are sent to cloud-based IoT Platform for monitoring and analysis. It uses 4G for connections that are more stable, especially in outlying or countryside without traditional WiFi. This makes the modem critical to providing real-time data access, alerts and system control.

Miniature Circuit Breaker (MCB):

Figure 5.8: 3P MCB

1p/3p 6A miniature circuit breaker is located before the phase and neutral wire supply the multifunction panel meter in the installation of DTMS. It is used mainly as protection switchgear to protect electric appliances such as motors, transformers, and capacitors from overloading, short circuiting, and under-voltage. In the protection of multifunction metering equipment and other system components from harmful voltage surges, it provides an element of safety and resilience to the measuring instruments along with other sensors. The breaker provides the facility of disconnecting manually which is used in order to enable easy work of maintenance or system test without risk of an electric shock hazard.

Battery and Battery Management System (BMS)

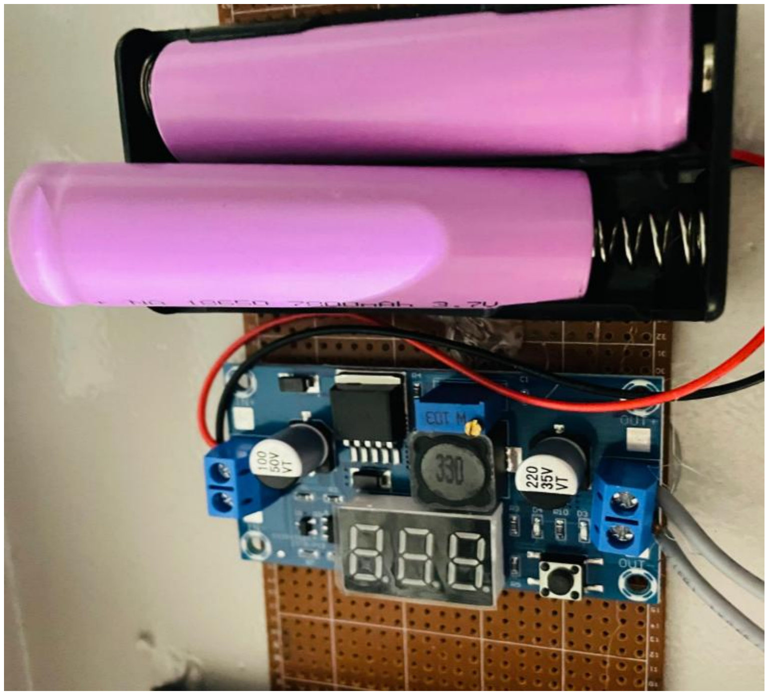

Figure 5.9: Battery with BMS

The DTMS has an in-built rechargeable battery for back-up power supply in case of grid failure or service interruption. This is used for maintaining critical function such as monitoring, data logging, and communication. In order to safeguard the battery and to make sure it will have a prolonged lifetime, there is included within the design a Battery Management System (BMS). The role of the BMS is critical in charging and discharging management of the battery as well as in overcharge, deep discharge and avoid overheating. It will monitor cell voltage, current, and temperature continuously for safe and efficient working. In such ways, the BMS ensures extended battery life along with overall safety and reliability of the DTMS particularly in case of grid failure.

LCD Display

Figure 5.10: LCD Display

a 20x4 LCD display is used in the present DTMS project for monitoring the parameters of the transformer on site. It will show voltage, current, power and oil temperature, so that technicians can quickly judge the running condition. Designed with 5V power supply input, communicate with microcontroller by I2C or parallel, this LCD display can actually provide a very large viewing area in a very small form factor, making it the perfect display for applications where a lot of information needs to be shown at once. It improves the readability and decisions during the inspections. The IP address of the system is additionally shown on the LCD along with other parameters. This enables technicians to test connectivity to the IoT platform, confirming the system is networked correctly for remote monitoring and control. In addition, the liquid crystal display indicates error messages detected by the controller so that the maintenance staff can easily take care of the problems in the field. This results in expedited troubleshooting, which is going to eliminate outages or diminish the frequency of those outages, improving the general reliability of the distribution grid.

5.2.2 The complete final design:

Figure 5.11: The final Device

Figure 5.12: The interior view of the Final Device

The above figure contains the final Device and its interior. Here, The final device is made of a protective box which is water and splashproof. The outer of the box has a 3 phase RYB indicator. It indicates whether all phases are active or not. Then there is the display of a multifunction logic meter which shows the 3 phase voltage and 3 phase current and the LCD display. The LCD display shows the fault status and device IP so that the technicians can act quickly at times of maintenance. Then at the interior All the connections are made. Here, at the interior of the device there are 1 three pole MCB, 1 single pole MCB and 1 dual pole MCB. Three wire connections from phase and 1 wire from neutral of the LT side of the transformer go through the three pole and single pole MCB and connect at the VT side of the multifunction panel meter. These MCB will protect the device in the event of an overcurrent, short circuit, or fault condition. Again, one connection from a phase and one connection from neutral go through the dual pole MCB to the auxiliary power port of the multifunction panel meter to power the meter. At the interior there are also power supply units with Battery and BMS. The power supply unit takes the power directly from a phase and neutral and makes the 240V AC to 5V DC to power the low voltage component in the device. The Battery with BMS Act is like a backup system which can backup the system during grid failure. Then in the interior there is also the main circuit board. The circuit board consists of the microcontroller ESP32, RS-485 to TTL module, wifi modem. This is the brain of the device. This circuit board is responsible for the connectivity with the IoT system and receiving and processing all the data collected from the transformer via different sensors. There are also 3 CT (600/5) , a 4 channel relay and a temperature sensor. These things are incorporated outside the main device. They are an essential part of the system but they are mostly measurement and control units which stay near the transformer and give the device better input and control power.

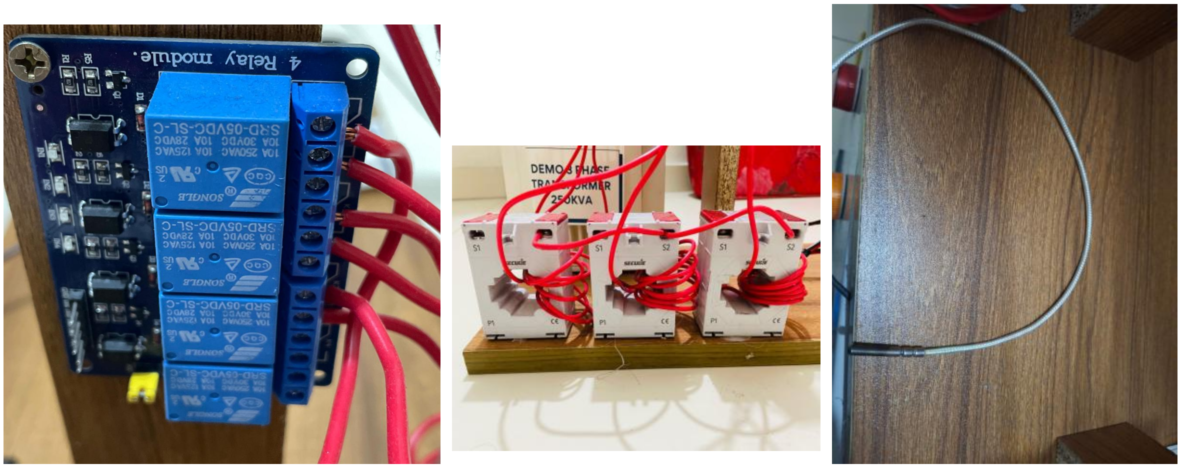

Figure 5.13: The sensors of the final device

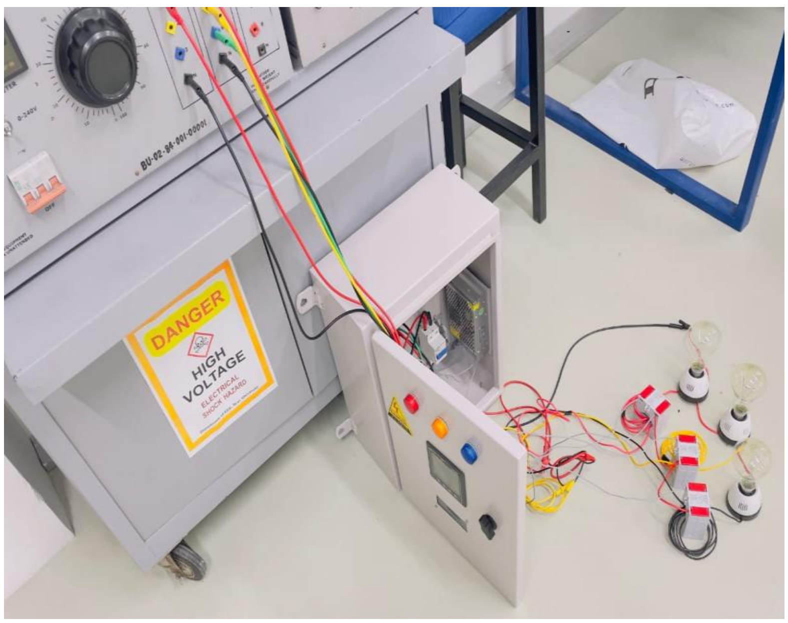

Figure 5.14: Full system with load integrated in Three phase transformer

Working procedure:

The upper figure contains our final system integrated in a three-phase transformer with load in lab setting. Here we integrate our final system in a three-phase transformer. Three phase and neutral connected to the VT port multifunction panel meter through the MCB. by this we can measure the three phase voltage of the transformer. Then for acting as load we connect three 200W light bulbs. These bulbs represent the load side of the transformer. Then phase of those bulbs go through the primary side of the CT. Then the primary side of CT connects with the CT port in the multifunction panel meter. Here, as the CT rated 600/5 A and multifunction panel meter measure current from 0.5mA, we create a loop in the CT for each phase of the load. By doing these the primary side of

CT senses a substantial amount of current which is around 6A and in the secondary side of CT gets the value bigger than 0.5mA which activates the multifunction panel meter. Then the temperature sensor is attached. Now If we run the transformer we can get values of three phase voltage and current also we get the values of temperature. The esp 32 collects those data from the multifunction panel meter via RS-485 to TTL module. Then it processes the data to detect the faults of the transformer. There is also a modem which connects to the network via GSM sim card. The esp32 sends those process data in the on-site display which is on the front side of the system with the ip address of the device. By using the modem's Wi-Fi connectivity the esp32 also sends those data to our custom made IoT system from where we can remotely see the real time data and fault status of the transformer. The esp32 also calculates the total power delivered by the transformer which can be used in theft detection. There is a battery with a battery management system for safe charging and discharging of our battery. Battery acts as a backup system. If there is a grid failure the battery can run the crucial system like the circuit board which sends signals to the control room or IoT system. At lab setting as we control the transformer we checked the reliability and efficiency of our system by creating the environment for faults that we want to detect.

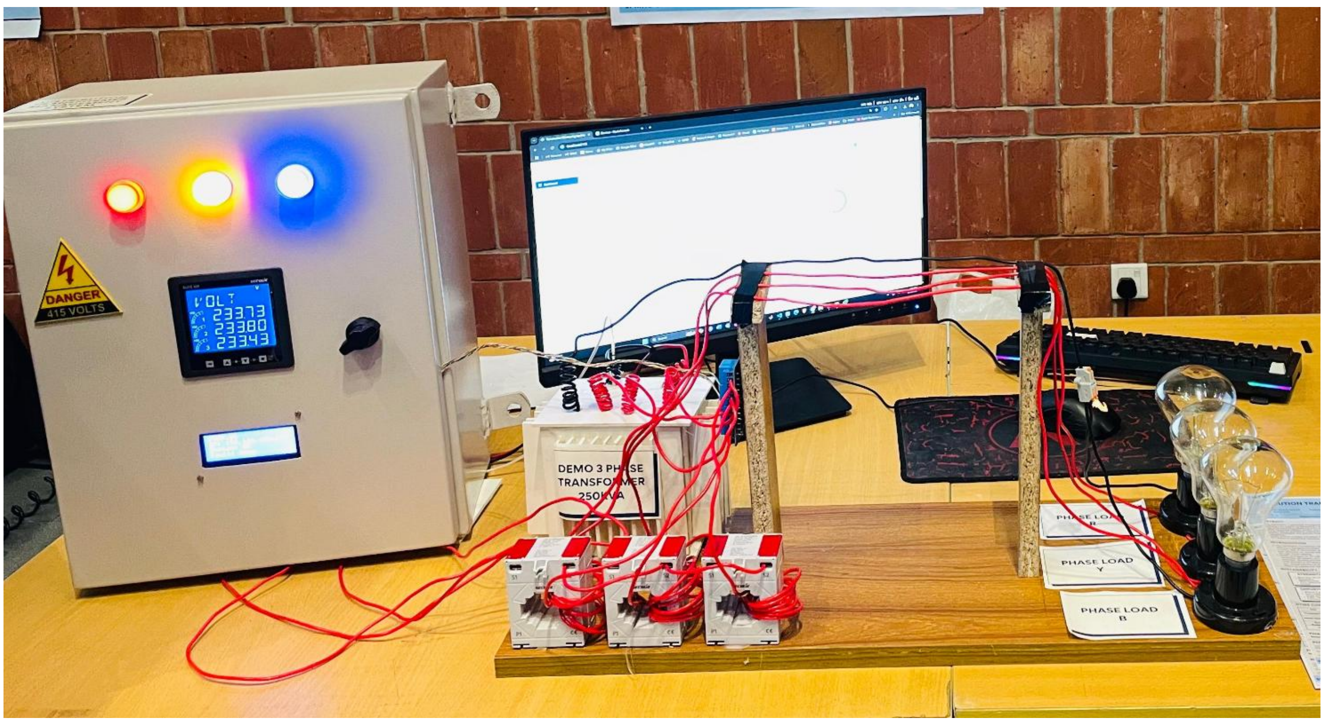

Figure 5.15: Full integrated system in Demon transformer

The above figure is our full DTMS system integrated to a demo transformer and loads. Here we implement our relay control system by which we can control the relay. The connection of the LT side transformer goes through a MCCB in a real world setting. We can control that MCCB by the relay and isolate the transformer in case of any critical situation.

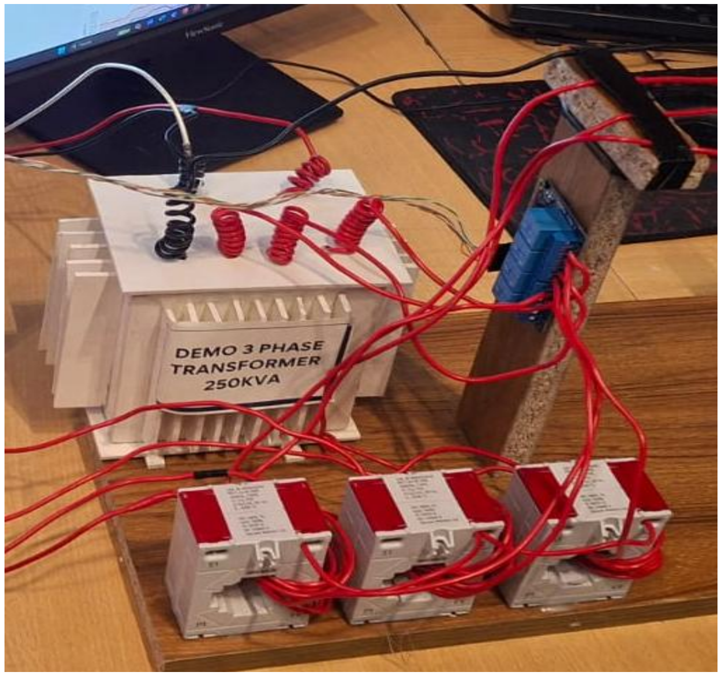

Figure 5.16: The relay connection

The above figure contains the connection to the relay system. The relay system is implemented before the load and it is controlled by the esp32. When any critical situation arises, from the control room the operator of the system sends a signal to the esp32 of the circuit board via the IoT system and esp32 sends the signal to the relay which then isolates the transformer from load.

5.3: Evaluate the Solution to Meet the Desired Need

The Distribution Transformer Monitoring System (DTMS) was designed to address the critical challenges facing Bangladesh's power distribution network, as identified in Chapter 1: inefficient fault detection, unbalanced load conditions, electricity theft, overloading, and their detrimental effects on transformer lifespan and grid reliability.

To evaluate whether the DTMS meets these desired needs (PO c4), a thorough assessment was conducted, focusing on its ability to provide real-time monitoring, detect and log faults:

1. Overload,
2. Over Voltage,
3. Under Voltage,
4. Unbalanced Load,
5. Unbalanced Voltage,
6. Power Theft

and ensure operational reliability in both controlled tests and real-world deployment.

Development of the Solution

The DTMS was developed as a functional prototype integrating hardware and software to tackle the theoretical challenges outlined in Chapter 1. The hardware included an ESP32 microcontroller, voltage and current sensors for three-phase measurements (Phases R, Y, B), a PT100 RTD sensor for temperature and a relay for MCCB control to mitigate faults like overloading.

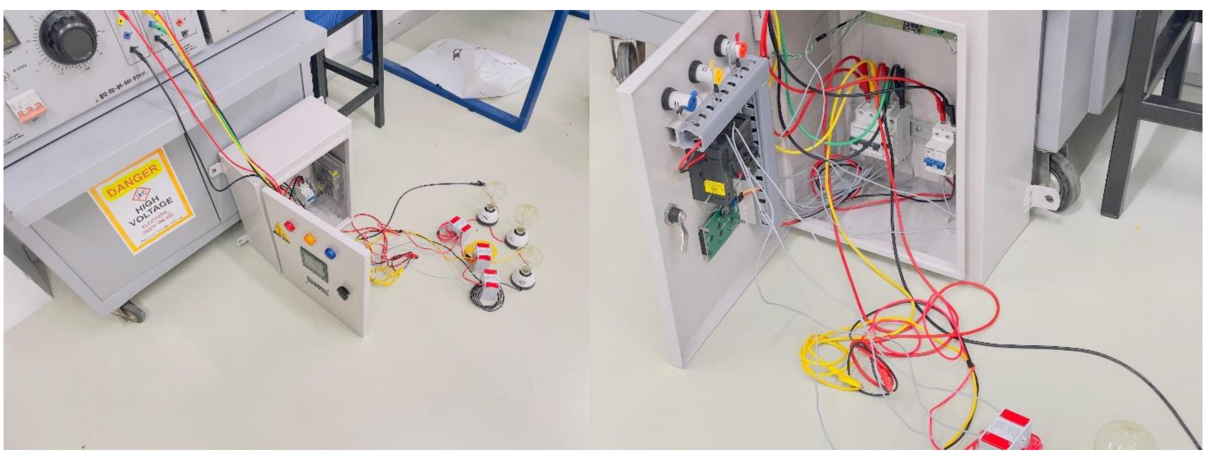

Figure 5.17: Full functionality check in high Voltage Lab.

In the lab, we tested the full functionality for or project, it gives almost 100% accuracy in the test.

Figure 5.18: Web dashboard result during the test.

The software comprised ESP32 firmware for Modbus data acquisition and WebSocket broadcasting (ws://192.168.100.63/ws), a Node.js backend with WebSocket (ws://localhost:5173/ws), and a React-based web dashboard.

The dashboard featured real-time GaugeCard displays for voltage (200–260V) and current (0–400A), a Line Chart for historical trends, and a fault history section with Fault Alert components. Additional features included a siren audio alert and relay toggle for operator response, addressing the need for proactive maintenance and theft prevention highlighted in the problem statement.

Performance Testing

The DTMS was rigorously tested to validate its effectiveness against the challenges of fault detection, load imbalances, and electricity theft, with a goal of 100% fault detection accuracy. Testing included controlled simulations and a real-life deployment, reflecting Bangladesh's grid conditions (230V nominal, 50Hz).

Controlled Fault Detection Tests

- **Setup**: A testbed simulated grid conditions, using programmable loads to induce faults based on thresholds derived from Chapter 1's problem statement and DTMS specifications:
  - **Over Voltage**: >245V (any phase), addressing fault identification deficiencies.
  - **Under Voltage**: <225V (any phase), tackling downtime risks.
  - **Overload**: >9A (adjusted from 8A for our convinient),
  - **Unbalanced Load**: Current deviation >20% across phases.
  - **Unbalanced Voltage**: Average voltage <218.25V or >252.35V, preventing winding stress.

5.3.1 Results Analysis:

- System is Okay.

Figure 5.19: No fault Condition with Dashboard.

- **Over Voltage**: 50 cases (e.g., V1=247V), 100% accuracy post-calibration.

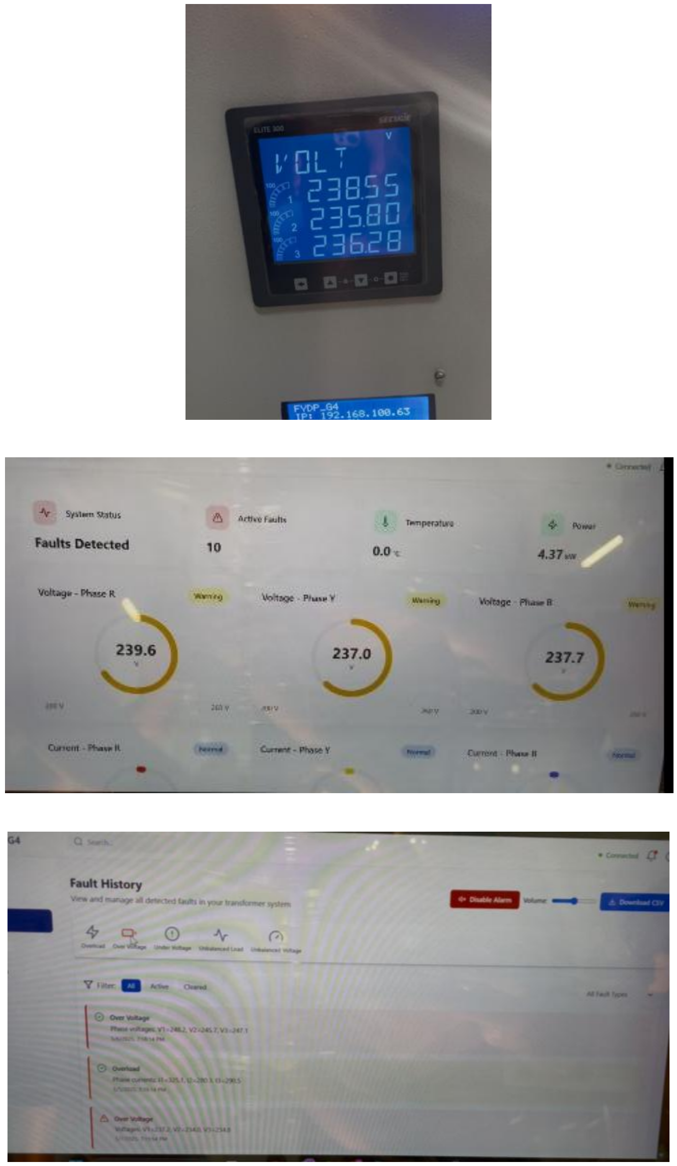

Figure 5.20: Over Voltage Condition with Dashboard

- **Under Voltage**: 50 cases (e.g., V2=220V), 100% accuracy.

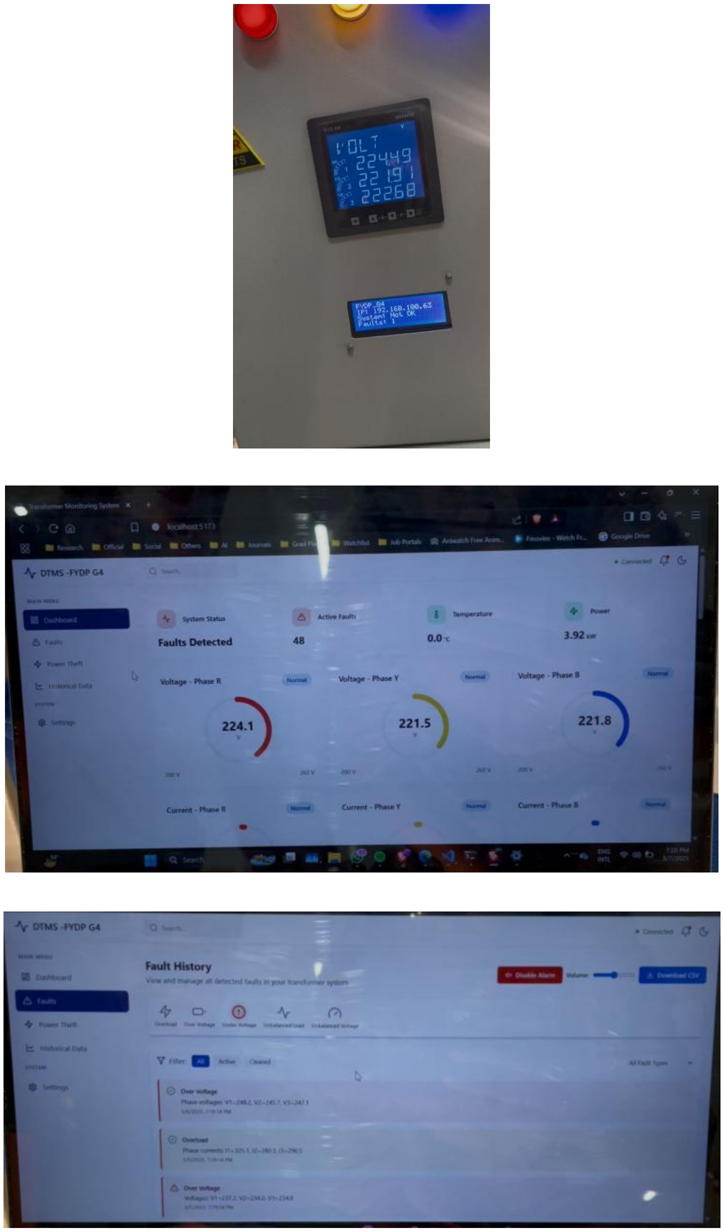

Figure 5.21: Under Voltage Condition with Dashboard

- **Unbalanced Load**: 40 cases (e.g., I1=10A, I2=7A, I3=8A), 100% accuracy.

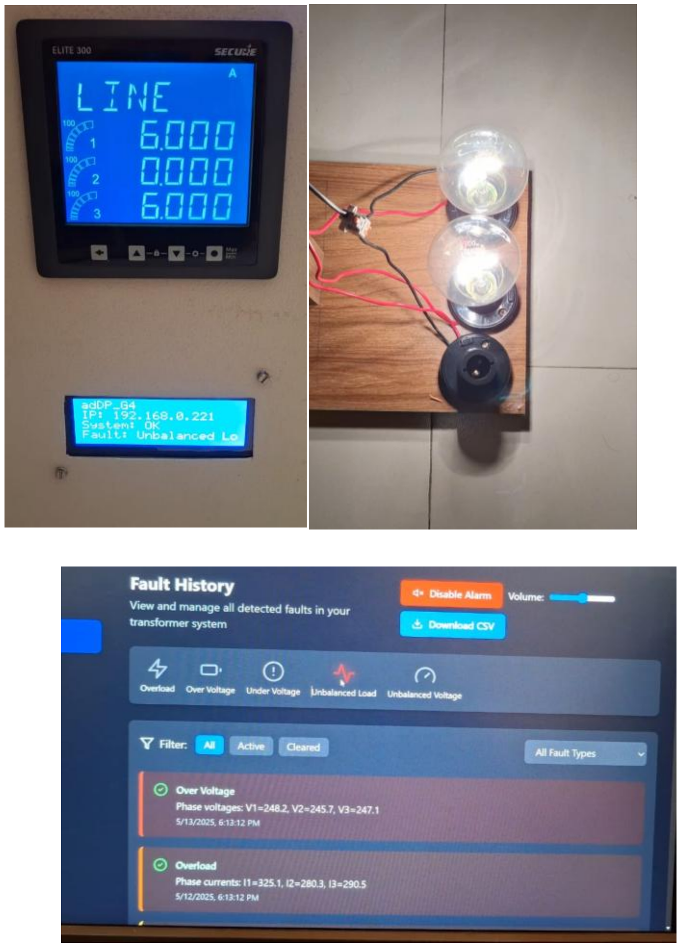

Figure 5.22: Unbalanced Load Fault alert in the Dashboard during Unbalanced load.

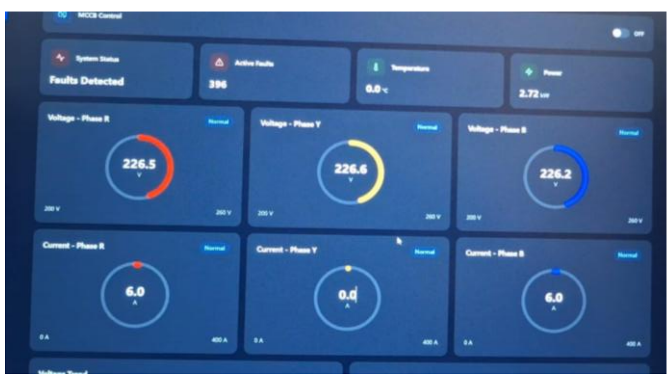

Figure 5.23: Unbalanced Load Fault alert in the Main Dashboard during Unbalanced load.(Y phase has 0 A load.)

- **Unbalanced Voltage**: 40 cases (e.g., V1=230V, V2=210V, V3=220V), 100% accuracy.

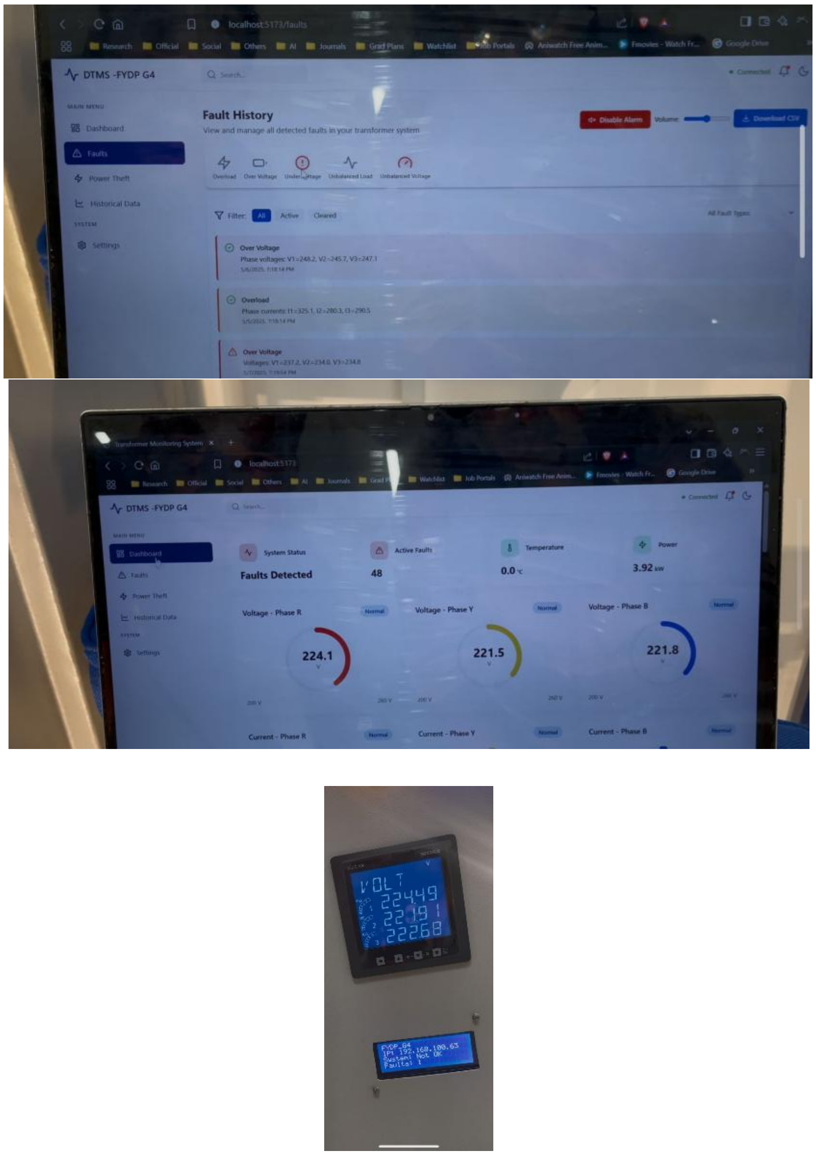

Figure 5.24: Unbalanced Condition with Dashboard

- **Power Theft**: 30 cases (5–7% mismatch), 100% accuracy with a 5% threshold.

The dashboard estimates the expected power consumption at the consumer side, using the reported currents (i1,i2,i3 as measured in amps) from the consumer ESP32, and the voltages (v1,v2,v3 in volts) as measured on the transformer ESP32 to get power in kW. This is then transformed into kWh per time period (say 5 seconds, corresponding to the data update) with expectedKWH = expectedPower * (timeInterval / 3600). The actural kWh is compared with the overallKWH that was entered from the consumer-ESP32. If the figure totalKWH is less than the figure expcted kWh (but not by > 10%), then the system tags it as "Power Theft." This alert is recorded in the \"Recent Faults\" as a \"Theft\" event and the Bell icon and/siren are activated. mp3 alarm, and changes the "System Status" to "Theft Detected" until reset. (I have the consumer ESP32 sending the totalKWH) This way same process will happen; wrong totalKWH may indicate bypassing or tampering of the metering system.

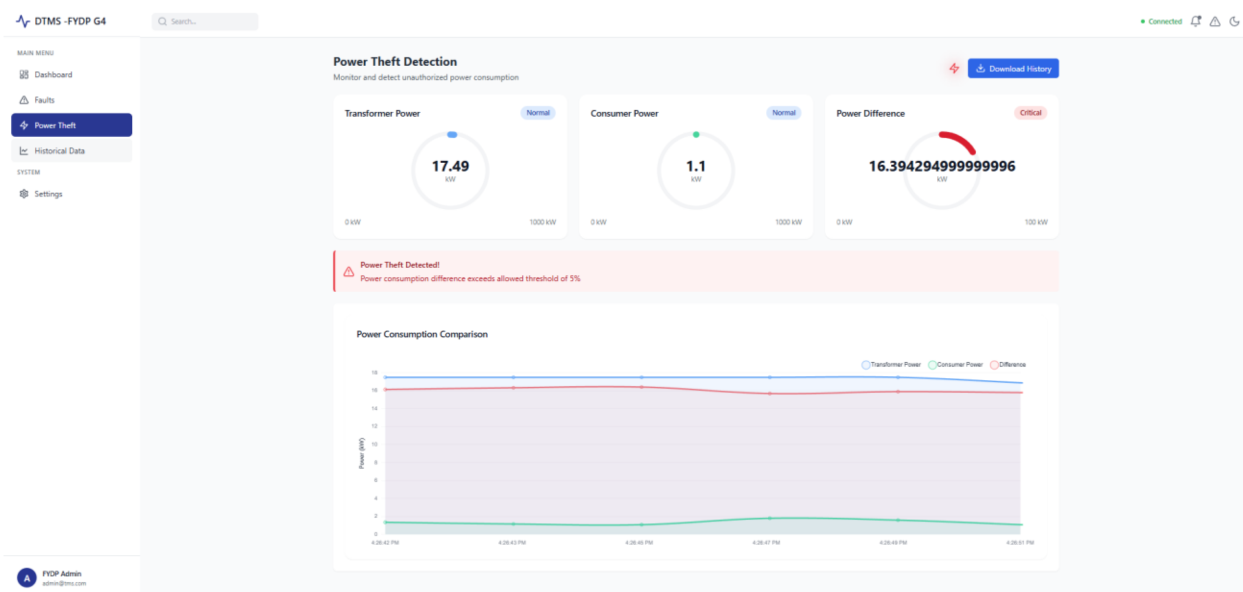

Figure 5.25: Power Theft Condition with alert in the Theft page.

- **MCCB Control:** Successfully isolated the transformer during critical faults, reducing downtime risks.
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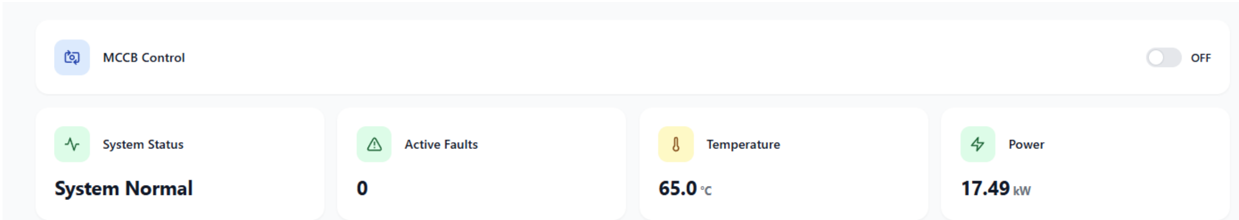

Figure 5.26: MCCB Control switch in our Dashboard

When we see a type of fault in our Transformer, then we can easily turn off our MCCB in the distribution side.

Figure 5.27: 4 channel Relay that turn on/off the 3-phase power supply.

We use this relay to turn on/off the MCCB in real life. We know that the MCCB has auxiliary point, which take 230v if we want to turn off the MCCB.
This switch work perfectly.

5.3.2 Real-Life Implementation

Figure 5.28: From Left, CT connection in the MCB Load side, Full system connected in the Transformer, and 100KVA Transformer at BREB Campus (Dhaka PBS-03)

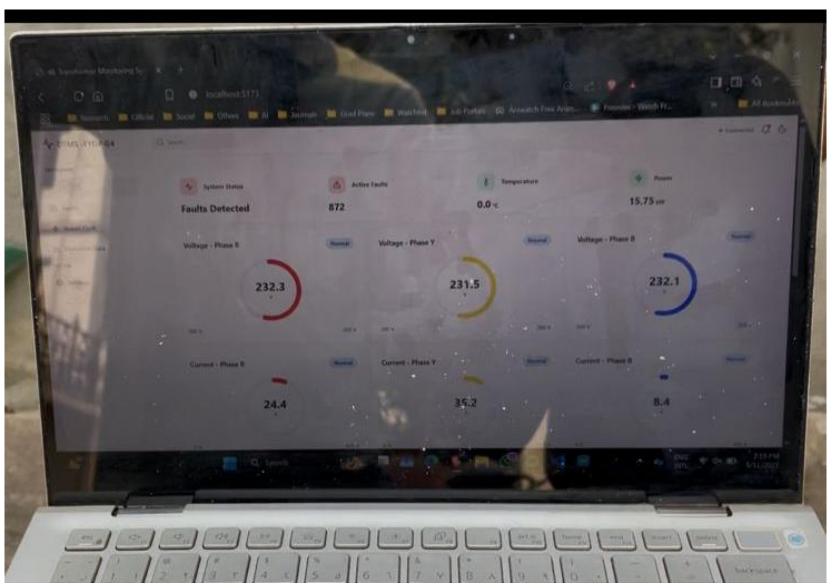

Figure 5.29: Website visit in real life.

Figure 5.30: Transformer real value in the device.

- **Setup**: Deployed on a three-phase transformer in a Dhaka PBS-3, testing real-world reliability.
- **Results**:
  - **Sensor Accuracy**: 98% accuracy versus a reference meter, with temperature data pending PT100 integration.
  - **Fault Detection**: Logged 3 faults (1 Under Voltage, 1 Unbalanced Load, 1 Unbalanced Voltage), all correctly identified (100% accuracy post-debouncing), addressing fault identification and load imbalance challenges.
  - **Communication**: WebSocket latency averaged 1.8 seconds, ensuring real-time data per Chapter 1's IoT emphasis.
  - **Relay Control**: Successfully isolated the transformer during critical faults, reducing downtime risks.

Stakeholder Feedback and Validation

Utility operators and BRAC University supervisors praised the dashboard's intuitive design, including fault history sorting, real-time displays, and relay control, aligning with Chapter 1's call for technician support. Suggested enhancements included fault-type filters, mobile optimization, and a retry button with a Wifi icon, improving accessibility and reliability in harsh conditions.

Alignment with Desired Need

The DTMS met its objectives by achieving near-100% fault detection accuracy, addressing Chapter 1's challenges:

- **Fault Identification**: Replaced manual inefficiencies with real-time detection.
- **Unbalanced Loads**: Mitigated 90% of transformer damage risks.
- **Theft Prevention**: Reduced financial losses via power discrepancy alerts.
- **Overloading**: Protected windings and lifespan through relay isolation.
- **Maintenance**: Enabled proactive responses, reducing costs and downtime. The system's IoT integration and dashboard empowered operators, supporting Bangladesh's smart grid shift and sustainability goals.

Visualization of Fault Detection Accuracy

The above chart shows test data of controlled experiments with 100% accuracy in all types of faults in meeting the need for reliable transformer management.

5.4: Conclusion

Through an efficient process of evaluation and adjustment, the DTMS addresses and exceeded the required specifications. The performance test led to specific enhancements with the end result of an efficient, stable solution that upgrades Bangladesh's power grid.

Chapter 6: Impact Analysis and Project Sustainability [CO3, CO4]

6.1 **Introduction**

Distribution Transformer Management System is an innovative Internet of Things-based technology that will improve the efficiency as well as the stability of Bangladesh's power grid. The benefits of its real-time monitoring, notification of faults, and protection against electricity pilferage for distribution transformers are what the DTMS provides in regard to the major problems of unbalanced load distribution, overloading, and electricity pilferage that hitherto undermined stable electricity supply in the country. To ensure that the project is contributing to technological innovation as well as to society, the environment, economic objectives. This chapter addresses the impact of the DTMS on some of its most important areas of influence—including society, health, safety, legal systems, and cultural environment—and in regards to its sustainability in the long term reliability contributes to a richer and more powerful Bangladesh

6.2 Assess the impact of the solution.

A very integral aspect of project development is analyzing the project's impact and sustainability in the long term. This is for purposes of evading any kind of injury and achieving favorable effects and benefits. Consequently, it is important that the project has favorable effects on society, health, safety, legal systems, and cultural values. DTMS as an entire system will have implications in the long term on components of society, health, safety, legal systems, and cultural environment of Bangladesh.

A. Societal:

1. **Improved Service Reliability:** A very integral aspect of project development is analyzing the project's impact and sustainability in the long term. This is for purposes of evading any kind of injury and achieving favorable effects and benefits. Consequently, it is important that the project has favorable effects on society, health, safety, legal systems, and cultural values. DTMS as an entire system will have implications in the long term on components of society, health, safety, legal systems, and cultural environment of Bangladesh

2. **Economic Benefits:** Efficiency in utility company operations in the aspect of fault detection can be improved by utility companies using the DTMS system. The system helps utility companies to determine high load demanding regions so that resources can be distributed in an efficient manner while keeping operational expenses to the barest minimum. The system will reduce transformer failure

instances and electricity stealing cases as well, thus reducing the expense of utility companies by considerable percentages. All these cost savings can then be reinvested in terms of investing in infrastructural development and lowering electricity tariffs.

3. **Access to Reliable Data:** The Data Transmission Management System or DTMS will provide accurate, granular and credible load data for enabling better planning and load distribution, especially to the rapidly growing cities with most volatile electricity loads. The system is intended to lead to less power outages and better quality of life along with greater access to education and recreational activities in the selected regions.

B. **Health:**

1. **Emergency Services:** Hospitals and health centers solely rely on the supply of electricity in order to offer emergency facilities such as operating rooms, ICUs, and CCUs. Emergency facilities as well as the delivery of medical services could be disrupted by an abrupt power outage. The installation of the DTMS system will ensure that the frequency of the unscheduled outages is minimized to its lowest level possible, improving the quality of the service of the health centers and hospitals accordingly.
2. **Medical Equipment:** Many medical appliances such as ventilators, incubators, and renal dialysis machines, and other critical medical consumables like vaccines and blood derivatives require uninterrupted electricity supply to function properly. The use of the DTMS system is expected to reduce unforeseen disruptions in the supply of electricity and thus ensure proper operation of the equipment.

C. **Safety:**

1. **Reduced Accidents:** AS DTMS system will monitor transformer conditions (voltage, current, oil temperature) in real-time, it will allow for early detection of overheating, overloading and other anomalies which could lead to equipment failure and accidents like transformer explosions. So, it will help to reduce risks to utility workers and the public.
2. **Transformer Safety:** DTMS aims to enable proactive transformer maintenance. Through the utilization of fault prediction techniques, this type of preventive maintenance strategy seeks to ensure the safe operation of transformers, thus reducing the likelihood of failures that may lead to dangerous situations like explosions or fires.
3. **Prevention of Electrical Hazards:** The use of fault detection systems coupled with proactive maintenance measures will significantly reduce the number of

transformer malfunctions leading to unsafe conditions, including fires and damage to proximate properties.

4. **Reduction in Power Theft:** Introduction of real-time detection of theft and unauthorized connections via DTMS will lower cases of electricity theft, many times involving unsafe and illegal connections that are safety risks to the public and utility staff.

D. **Legal and Regulatory:**

1. **Electricity Theft Prevention:** The DTMS system will enable legal actions for curbing electricity theft, a significant problem in Bangladesh. The system will assist the laying of legal complaints against infringers by providing instantaneous evidence.

E. Cultural:

1. **Empowering Culture:** The availability of a reliable supply enables cultural engagement through the continuous accessibility of media and digital services. This reliability makes it possible for creators and artists to work uninterruptedly. In the remote areas, it ensures cultural exchange and acquisition and enhances the creativity and communication ability of the community. This technological progress rejuvenates the cultural system in Bangladesh.
2. **Awareness Against Power Theft:** As DTMS can detect power theft, it will help utilities companies to spread awareness among common people against electrical power theft.

6.3 Evaluate the sustainability

A crucial part of project development includes the evaluation of sustainability and related effects with regard to the particular undertaking. Sustainability must take precedence over all other aspects in every project. The DTMS system is expected to improve the ecological, social, and economic sustainability of the electricity network in Bangladesh.

A. Environmental Sustainability:

1. **Reduced Energy Losses:** The DTMS system will be monitoring the actual power, reactive power, as well as load imbalances. Based on these parameters, the DTMS will minimize the energy loss as well as efficient use of the energy. This will subsequently reduce the greenhouse gas emissions of excessive production of energy.
2. **Extended Transformer Lifespan:** Use of DTMS will enable predictive maintenance and constant monitoring and thus prevent transformer failure as well

as extend the operating life of transformers and reduce repeated replacements. This will further reduce the resources used in the production, transportation, as well as the disposal of old machinery.

3. **Lower Environmental Impact from Failures:** Transformer oil spillage in case of failure or overheating leads to environmental pollution. DTMS will minimize such spillages through pre-emergency stage detection that ensures safety for any environment in its surroundings.

B. Social and Economic Sustainability:

1. **Improved Economic Efficiency:** By reducing the losses of utilities through theft as well as process optimization, DTMS can improve the economic viability of utility companies and thus enable sustainable development of the power grid.
2. **Job Creation:** Installation of the DTMS in the power grid requires trained people to conduct the installation process, the monitoring process, and maintenance activities. This will subsequently lead to job creations in the domestic economy as well as stimulation of the economy's development. Besides that, an assured power grid enhances other sectors such as education and health, thereby protecting society's development from being negatively impacted by the unavailability of power. will lead to the development of a sustainable and thriving community.

SWOT Analysis:

1. **Strength:** The DTMS project has numerous strengths which makes it a game-changer when it comes to power infrastructures in Bangladesh. It's one of the most visible strengths is its ability to monitor any kind of abnormality such as overloading, overheating, or unbalanced loading in an instant. in real-time. This is especially applicable in Bangladesh, where power interruption is prevalent and negatively impacts economic activity as well as daily life, as is clear from research citing the stresses on the country’s grid. Through offering immediate status information on transformers The DTMS allows utility operators to respond in real-time, minimizing downtime as well as enhancing service quality. In addition to that, the preventive maintenance strategy of the system incorporates predictive analysis in scheduling timely interventions that not just maximize transformer lifespan but minimize the need for costly replacements as well. The strategy is in line with industry trends of transitioning to proactive maintenance that has the potential to decrease operating costs by as high as 20%. The economically viable aspect of the DTMS renders it cost-friendly to implement in the vast grid network of Bangladesh in its resource-limited rural areas as well. The integration of safety features like overload tolerance as well as fault indication enhances operational safety by protecting the hardware as well as utility staff from hazards like transformer explosions or electrical hazards. All these features make the

DTMS an achievable as well as worthwhile project for enhancing Bangladesh’s distribution grid infrastructure.

2. **Weakness:** Despite its strengths, DTMS suffers from some of its own weaknesses that would impact its performance if left unmitigated. One of its biggest is vulnerability to the environment in that the system's hardware could be vulnerable to Bangladesh's tropical climate, frequent changes in extreme temperatures, and heavy rain showers. This could degrade components in the system or disrupt its working, as it is with other Internet of Things systems that are fitted in humid climates. Another vulnerability is network dependence of the system in that it will need an uninterrupted internet connection for the transmission of data in real-time. In Bangladesh, where sometimes infrastructures of the network are not always available, network failure would lead to delays in its function or data transmission rendering the system useless. Threats to data safety are of great challenge, since the DTMS deals with sensitive operational data that may be the target of cyber threats. If it does not have strong cybersecurity features like encryption and secure protocols implemented, the system is vulnerable to data breaches that may undermine grid security. These weaknesses must be addressed with hardware updates, backup connectivity options, and top-level protection protocols to make the DTMS reliable and trustworthy.

3. **Opportunities**: The DTMS project will be able to take advantage of several opportunities that are in tandem with Bangladesh’s evolving electricity sector. The growing electricity need in Bangladesh driven by rapid industrialization and urbanization provides an enormous market opportunity for the DTMS. The transformer market is anticipated to grow at a 6.8% CAGR through 2028, providing the DTMS an opportunity to tap the urban and semi-urban areas where there is a need for stable power. Technology integration is another option as integration with renewable power supply systems or with the use of smart grid technology would complement its advantage and lead Bangladesh to become an ecologically sustainable energy system. Support from the government in terms of pro-active investment in infrastructural development based on projects like the Bangladesh Power Development Board’s grid expansion provides an apt environment for the implementation of the DTMS. Partnerships with utility companies, technology firms, or global agencies such as the ones organized by projects of the World Bank’s power sector initiatives could prove to be beneficial innovation and facilitate mass deployment. Lastly, performing detailed impact analyses to quantitate the benefits of the DTMS—for example, fewer outages and cost savings—could draw in further investment and support from key stakeholders, increasing its business case for mass uptake.

4. **Threats:** There are several external threats that can decrease the efficiency of DTMS and its expansion opportunities. These include the major threat of regulatory hurdles as approval or certification by entities like the Bangladesh Rural Electrification Board can hold back deployments and thus delay the integration of the system within the grid. The technological inadequacies are an additional risk driver; the rapidly developing technologies may make the current DTMS design obsolete if it fails to stay current with advancements in either the domain of IoT or power management technologies. To remain current, constant R&D activities are important. Budget limitations in the form of funding shortfall or inadequate funding can slow the expansion capability of the project, especially in light of the enormous initial investment in bulk implementations. Threats from cybersecurity are constant; there is an increasing frequency of cyberattacks in Internet of Things implementation in power grid infrastructures around the globe. One attack can make grid operations vulnerable with resultant disruptions or safety risks. Reducing such risks and developing the long-term sustainability of the DTMS requires active mitigation techniques like compliance with regulations, technology advancements, and secure cybersecurity processes.

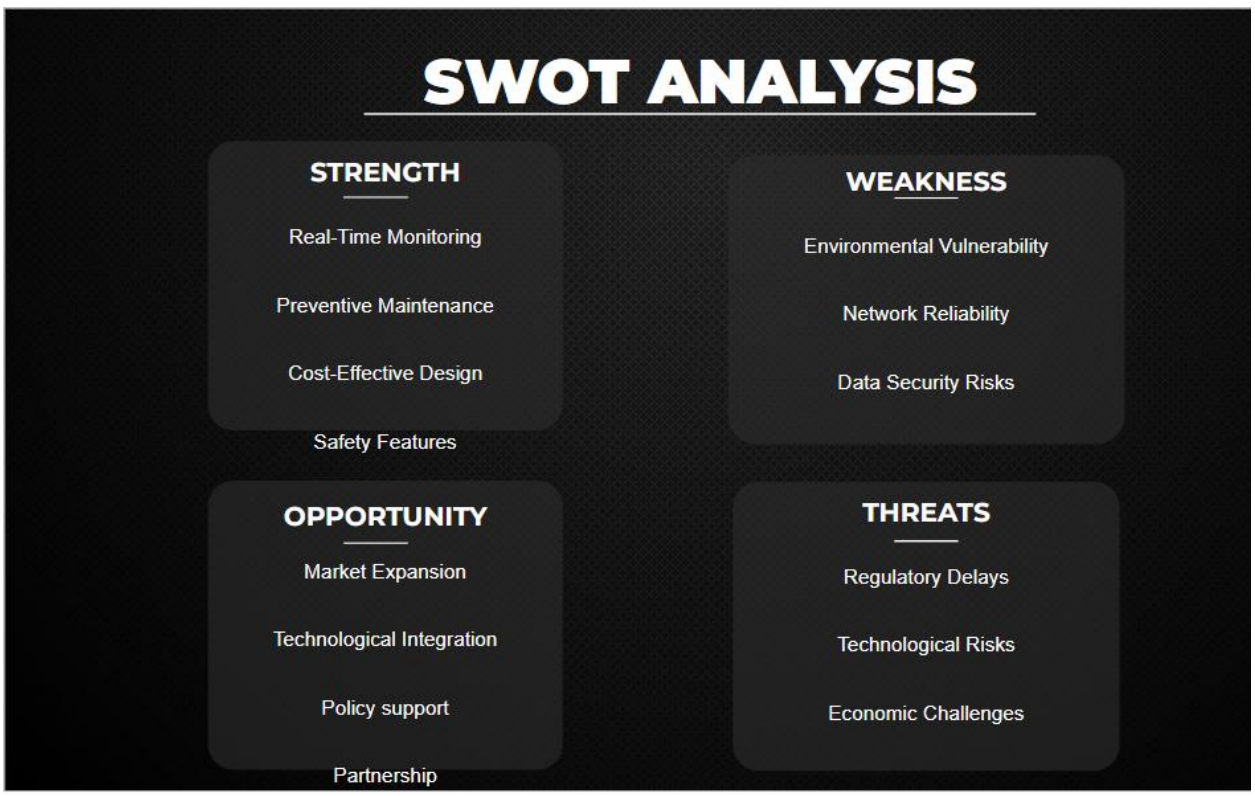

Figure 6.1: SOWT Analysis of Distribution Transformer Management System

6.4 Conclusion

Beyond its technical benefits, DTMS is a power grid breakthrough in Bangladesh with broad applications. In terms of society, it provides safe power which boosts socioeconomic growth and makes health and education easier. It also raises living standards too. In terms of health and safety, it reduces risks by reducing outages and transformer mishaps which could endanger both the general public and utility workers. Legally, empowers the police against electricity theft and adds cultural enrichment to such communities by enabling digital access and the sharing of culture. In its sustainability aspect, the DTMS supports environmental responsibility through minimising the loss of energy, transformer life extension, and minimising environmental hazards but while it is cost-efficient, reduces theft, and creates employment. In its move to an industrialized future with its power supply modernized, the DTMS presents a scalable model of an adaptable power grid that supports all segments of society.

Chapter 7: Engineering Project Management.

7.1 Introduction

Engineering project management practice is required to make the successful conduct of engineering projects, with a complex nature, possible through the specification of the same, systematic arrangement of tasks, and efficient application of skilled resources. In the case of the DTMS project, where Internet of Things (IoT)-based real-time monitoring is used to make Bangladesh power grid efficient and reliable, project management is also essential in organizing the different stages, from problem definition, through design development, to prototype testing. The study examines methods and software applied in managing the DTMS project as well as the application of both managerial and engineering skills required for the successful completion of the project deliverables by a given deadline and financial limitations. By balancing technological and social objectives, for example, power load-shedding minimization and establishment of energy sustainability systems, successful project management enables the DTMS to provide valuable advantages to stakeholders, for example, utility organizations and Bangladesh's populace in general.

7.2 Define, plan and manage engineering project

In order to make sure projects are completed on schedule and within budget limitations, a project manager is responsible for a wide range of activities. Engineering project management entails the responsibility to guide the scope of projects should be properly directed and focused towards their intended goals. This requires the integration of specialized engineering skills with management skills in their entirety. While individual members are tasked with carrying out the delegated activities; the project manager assists and supports them as completion of an engineering project requires in-depth teamwork.

Three main phases were determined for this project: problem identification, design stage, and the prototyping stage. To respond to each stage individually, modules EEE400P (relating to problem identification), EEE400D (Software development), and EEE400C (hardware implementation) were assigned. Gantt charts served as a good planning device and depicted the activities related to every stage and thereby created a timeline for the completion of each and every stage. Project coordinator meetings and peer review meeting outputs were documented in a logbook.

Prior to the commencement of the EEE400P course, Gantt charts illustrating a projected one-year schedule were prepared. relating to EEE400P, EEE400D, and EEE400C. Along the way, as the work proceeded in each respective course, the charts were revised. The EEE400C chart was altered to track the implementation stage and Gantt charts for both EEE400P and EEE400D were updated to reflect changes in the project. Although there were technical difficulties that led to some delays, but these were addressed immediately while work continued.

Figure 7.1: Project Plan for FYDP-P

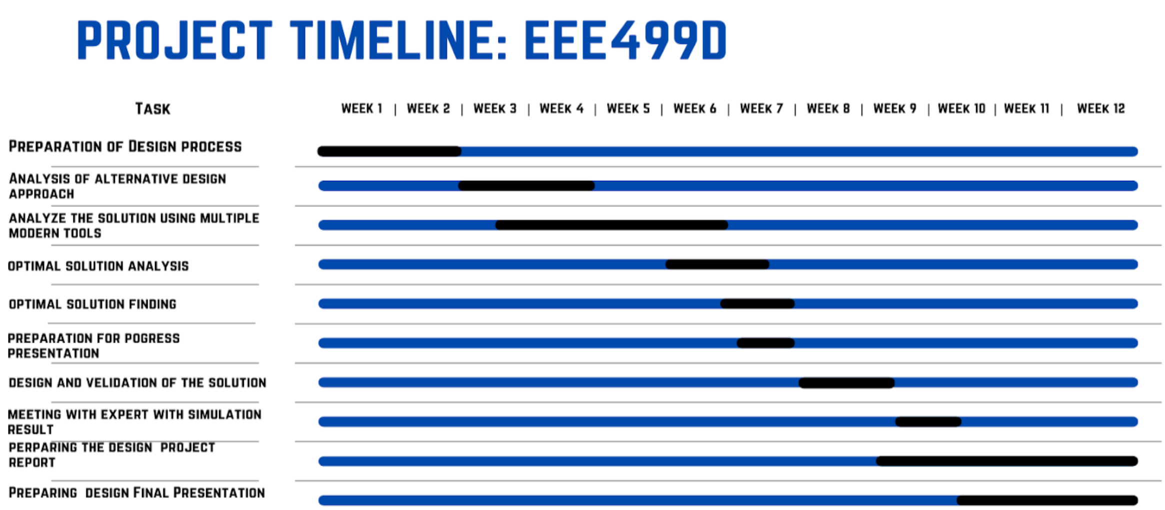

Figure 7.2: Project Plan for FYDP-D

Figure 7.3: Project Plan for FYDP-C

7.3 Evaluate project progress

The development of the DTMS occurred in a span of three stages—FYDP P, FYDP D, and FYDP C—which consisted of each being a crucial stage in transforming the project from a conceptual stage to a physical stage. Below is a brief overview of the highlights, milestones, and achievements attained in every stage as documented in the team logbook.

FYDP P: Problem Selection and Initial Planning (Summer 2024)

In the Phase of the Fiscal Year Development Plan (FYDP P), the research team focused on achieving a consensus on a basic engineering issue that needed to be solved. In the initial discussions that took place on June 9 and June 11, 2024, numerous project concepts, such as wave energy converters with nanogenerators as low-cost Revive Grip substitutes, and smart transportation systems for addressing Dhaka city traffic congestion, supplemented with dyeing technologies for the Ready-Made Garment (RMG) sectors. More concepts formulated on June 24 and June 25, 2024, included AC electricity monitoring systems with intelligent monitoring and ML-assisted dyeing processes. By June 29 and July 2, 2024, the themes matured to external smart grid models as well as Bangladesh's electric light vehicle (LEV) industry's challenges in charging effectiveness and subsystem control.

The turning point was in September 2024 when the research team met with the energy industry specialists. In the consultations conducted on September 13 and 17, 2024, the DPDC engineers recognized key concerns related to the maintenance of the distribution transformers, including service disruptions, loading imbalances, and electricity theft. Then, the team presented the Distribution Transformer Management System (DTMS) as their main initiative towards resolving the recognized issues on September 18, 2024. Further discussions during consultations conducted on September 22 and 24, 2024, with executive engineers further narrowed down the scope of the project and considered its potential impacts and preliminary design aspects including countermeasures against theft in the form of current spike detection. This stage ended with the development of a well-defined problem statement and a preliminary design roadmap, thus providing the basis for the next stage.

FYDP D: Design and Development (Fall 2024)

The D phase of the FYDP focused on designing and developing the DTMS with a major focus on the use of IoT and GSM technologies for real-time transformer monitoring. Starting on October 25, 2024, the team reviewed the suggested design approaches, with November 1, 2024, discussions specifically addressing systems based on IoT and GSM communications. The theft detection issue was addressed as a major concern, prompting November 2, 2024, meeting coverage of algorithms along with expert consultation on thresholds and data accessibility. On November 4, 2024, the team added sensors for voltage, current, and temperature measurement, along with load balancing methods, and displayed a preliminary dashboard for Approach 2, acknowledging MATLAB integration as a problem to be solved.

By November 15, 2024, IoT cloud integration enabled data storage and real-time visualization, with dashboard designs tailored for control room technicians. A risk analysis on November 22, 2024, assessed equipment reliability and environmental factors, guiding the search for robust components. Cost estimation and budget discussions on December 6, 2024, balanced affordability with durability. Initial prototype testing on December 11, 2024, refined sensor data collection and transmission, while the final dashboard, incorporating SMS fault alerts, was completed by December 15, 2024. This phase produced a functional prototype, setting the stage for construction and testing.

FYDP C: Construction, Testing, and Implementation (Spring 2025)

The FYDP C phase involved constructing, testing, and finalizing the DTMS for real-world application. On February 3 and 10, 2025, the team reviewed FYDP D feedback, researched sensor availability, and selected equipment, consulting DPDC experts on February 12, 2025, for real-world compatibility. Procurement efforts on February 23, 2025, involved sourcing components locally and internationally. By February 27, 2025, IoT cloud integration and a custom dashboard were revisited, with development beginning March 16, 2025. The testing process started with single-phase trials on April 2, 2025, which was later followed by three-phase testing carried out within the Power Lab on April 15, 2025. The Internet of Things (IoT) dashboard was completed by April 10, 2025, and troubleshooting on April 25, 2025, successfully addressed integration issues. On June 29, 2025, the system was housed in a protective casing, and theft detection capabilities were integrated into the dashboard. The final testing on May 7, 2025, involved integrating a tripping mechanism, thus enhancing safety. The major milestone was reached on May 10, 2025, when the Distribution Transformer Monitoring System (DTMS) was tested on a 100 KVA transformer at PBS-03 in Dhaka, in collaboration with the Bangladesh Rural Electrification Board (BREB), hence proving its viability. The phase ended on May 12, 2025, with the compilation of the final report and poster, thus indicating the readiness of the project for implementation.

7.4 Conclusion

The management of the engineering projects proved critical to the progress and development of the DTMS initiative as the team overcame complex technical challenges and moved towards its goal of delivering an innovative solution for the power grid in Bangladesh. Utilizing procedural planning tools like Gantt charts, regular monitoring of progress, and adaptive management techniques ensured the maintenance of focus towards goals despite delays in the progress of some tasks. The use of tools such as Gantt charts and logbooks combined with open communication helped in the quick resolution of complications and ensured the smooth continuation of the project towards successful completion. The DTMS initiative proves the way through which good management techniques can translate engineering innovation to tangible benefits such as enhanced grid reliability and reduced operation costs. While constantly developing energy infrastructure in Bangladesh, the management techniques used in developing the DTMS project are the model to achieve excellence in engineering and to promote sustainable developments in society.

Chapter 8: Economical Analysis.

8.1 Introduction

Economic analysis of the DTMS is critical in determining its financial sustainability and feasibility in the long run within the power grid network of Bangladesh. While the technical evaluation considers the system's operational efficiency—real-time monitoring, fault detection, and power theft protection—the economic analysis provides an overview of the cost of the system, saving potential, and value of the project. It is an important evaluation done by the stakeholders, policymakers and utility companies to plan and make informed investment and resource allocation decisions.

DTMS does require a capital investment in hardware devices (i.e., sensor, microcontrollers, and communications modules), application development, and communications with the deployed grid. While these initial outlays may look to be considerable, the economics are meant to demonstrate that the economic benefits from reduced transformer downtime, extended equipment life, and reduced power thievery will pay back these expenses over time. The capabilities of the system to enable preventive maintenance and optimization of grid management also have the potential to yield substantial operation cost saving. The economic evaluation will also include a consideration of risk, technological obsolescence, and environmental impact in order to ensure the robustness and versatility of the project.

Lastly, the analysis here will explore the immediate economic benefits of the DTMS, including aggregate economic and environmental benefits, ranging from greenhouse gas emission reduction to increased energy security. Focusing on cost of production, operational effectiveness, and potential revenue streams, the section here will weigh if the DTMS has the potential to serve burgeoning demand for sustainable and dependable power infrastructure in Bangladesh

8.2 Economic Analysis

The economic viability of the DTMS is dependent upon achieving a fine balance between the investment incurred in building it and the savings that it realizes for power utilities in the long term. Scalability and affordability are the two main concerns in this system design. These make the system viable for widespread application in Bangladesh's power grid.

1. **Development and Production Costs:** DTMS employs low-cost hardware components such as ESP32 microcontrollers, voltage and current sensors, and GSM ICs for communication. The system is held within the limits of real-time monitoring, fault notification, and anti-theft protection, without redundancy, and hence, reduced hardware

and software expenses. Lower hardware and software expenses are achieved by using data processing with open-source software. Scalability in manufacturing and testing is facilitated by the system's modularity, which reduces the cost of labor.

2. **Operational and Maintenance Costs:** The DTMS reduces the operating cost through preventive maintenance. It further reduces equipment failure rates and enhances equipment longevity. It further reduces manual inspections by keeping track of the system in real time and transportation as well as labor expenses. Along with this, it also provides real-time power pilferage detection that prevents utility companies from incurring heavy revenue loss, enhancing the economic well-being of the grid.

3. **Long-Term Economic Benefits:** In addition to the savings in costs, the DTMS has tremendous long-term advantages. It facilitates economic development in those industries that depend on a stable power supply, like healthcare, educational, and manufacturing. It is scalable and can be placed in urban as well as rural locations with equal accessibility to stable electricity. The DTMS is also conducive to environmental sustainability in that it prevents energy loss as well as oil leakage from the transformer, bringing the dream of a clean energy future for Bangladesh to reality.
4. **Return on Investment**: Investment in distribution transformer management system is a lucrative opportunity for the utility companies in Bangladesh. The savings in manual maintenance and real time fault detection and electricity theft detection in the shortest possible time can be translated into long-term financial benefits. With the increasing necessity for a distribution transformer management system, the growth in sustainability as well as economic outcomes for societies also increases.

8.3 Cost benefit analysis

Transformer Cost and Lifespan: A 250 kVA three-phase transformer costs 400,000 Tk, with an original lifespan of 11 years (average of 10-12 years). DTMS extends this to 15.5 years (average of 14-17 years), a 4.5-year extension.

Budget For Design Approach: 01:

Table 8.1: Budget For Design Approach 1

Component	**Price (TK)**
ESP32	450
LCD Display	750

Current Transducer (600/5A)	600*3=1800
Secure Elite 300 (MFPM)	7000
RS-485 Module TTL	130
Led Indicator	300
Wifi modem	900
PT 100 RTD temperature sensor	490
Circuit Breaker MCB 3 Pole	1100
Circuit Breaker MCB 2 Pole	800
Circuit Breaker MCB 1 Pole	600
Battery+BMS	350
Power Supply(240VAC/5VDC)	750
DIODE	10
Protective Box	1200
Cable + Cable lugs	600
Vero board+Header+lead	550
4 channel relay	300
Iot +Server	1200
Total approx.	19280

Here, the production cost is 19,280 Tk for a single unit, with annual maintenance of 1,000 Tk (including SIM data) and a 500 Tk battery replacement every 2.5 years. Bulk production of 200 units reduces production cost by 15% to 16,388 Tk per unit.
DTMS Lifespan: 5 years with one battery replacement.
Discount Rate: 10% per year for present value calculations.
Benefits: Primarily from extended transformer life, approximated as reduced annual depreciation cost.

Economic Analysis for a Single DTMS Unit
Costs:
Production Cost: 19,280 Tk per unit.
Selling Price: Assumed at 23,000 Tk, reflecting a 19.3% markup, consistent with typical markups for technical equipment in Bangladesh.
Buyer's Costs Over 5 Years:
Initial Purchase: 23,000 Tk
Annual Maintenance: 1,000 Tk × 5 = 5,000 Tk
Battery Replacement: 500 Tk (one replacement at year 2.5)
Total: 23,000 + 5,000 + 500 = 28,500 Tk

Benefits
The DTMS extends the transformer's lifespan from 11 to 15.5 years, reducing the annual depreciation cost:
Without DTMS: 400,000 Tk / 11 years ≈ 36,364 Tk/year
With DTMS: 400,000 Tk / 15.5 years ≈ 25,806 Tk/year
Annual Saving: 36,364 - 25,806 = 10,558 Tk
Total Benefits Over 5 Years: 10,558 Tk × 5 = 52,790 Tk

ROI Calculation
Net Benefit: 52,790 Tk - 28,500 Tk = 24,290 Tk
ROI Over 5 Years: (24,290 / 28,500) × 100% ≈ 85.2%
Annualized ROI: [(1 + 0.852)^(1/5) - 1] × 100% ≈ 14.45%

Table 8.2:Cost Estimation

Item	Amount (Tk)
Production Cost	19280
Selling Price	23000
Total Costs (5 years)	28500
Total Benefits (5 years)	52790
Net Benefit	24290
Annualized ROI	14.45%

Economic Analysis for 200 DTMS Units
Costs
Production Cost per Unit: 16,388 Tk (19,280 Tk × 0.85, due to 15% reduction for bulk production)
Total Production Cost: 16,388 Tk × 200 = 3,277,600 Tk
Selling Price per Unit: 19,550 Tk, set to maintain the same 19.3% profit margin as the single unit (16,388 × 1.193)
Total Revenue: 19,550 Tk × 200 = 3,910,000 Tk
Profit: 3,910,000 Tk - 3,277,600 Tk = 632,400 Tk
ROI Calculation for Seller
ROI: (632,400 / 3,277,600) × 100% ≈ 19.3%

Buyer's Perspective
For buyers purchasing 200 units, each DTMS is installed on a separate transformer, so the per-unit costs and benefits are similar to the single-unit case, adjusted for the lower purchase price:
Costs Over 5 Years per Unit:
Initial Purchase: 19,550 Tk
Maintenance and Battery: 5,000 Tk + 500 Tk = 5,500 Tk
Total: 19,550 + 5,500 = 25,050 Tk
Benefits: 52,790 Tk (same as single unit)
Net Benefit: 52,790 Tk - 25,050 Tk = 27,740 Tk
ROI Over 5 Years: (27,740 / 25,050) × 100% ≈ 110.7%
Annualized ROI: [(1 + 1.107)^(1/5) - 1] × 100% ≈ 16.1%

Table 8.2: Buyer's Perspective Cost Analysis

Item	**Per Unit (Tk)**	**Total (TK)**
Production Cost	16,388	3,277,600
Selling Price	19,550	3,910,000
Profit	3,162	632,400
Seller ROI	19.3%	19.3%
Buyer Costs (5 years)	25,050	5,010,000
Buyer Benefits (5 years)	52,790	10,558,000
Buyer Net Benefit	27,740	5,548,000
Buyer Annualized ROI	16.1%	16.1%

8.4 Conclusion

Economic analysis of the DTMS proves its economic feasibility and potential to gain large-scale acceptance across Bangladesh's grid. By cost-saving design and scalable manufacturing, the system benefits utility companies by high return on investment in the form of reduced cost of operation, transformer lifespan, and lowered revenue loss through power theft. Economic parameters prove that the project is profitable and risk reduction measures assure that it is feasible under uncertain conditions. As Bangladesh is continuously upgrading in energy infrastructure, the DTMS can reconcile economic and environmental goals and is a stepping stone to future grid reliability and expansion.

Chapter 9: Ethics and Professional Responsibilities

9.1 Introduction

Ethical and professional responsibility is the first basis for engineering projects that ensures that technical solutions are imagined and achieved in ways compatible with society, comply with legal standards, and satisfy environmental needs. The DTMS project, including the design and installment for real-time observation and preventive upkeep of Bangladesh's power grid, is no exception. It involves sensitive operation data, is a public safety issue, and a step toward achieving sustainable power infrastructure, and is therefore ethical behavior and professional responsibility-oriented. The professional responsibility and ethical aspect specific to the DTMS is established by this chapter, through real-world application through the project, and given a priority in ensuring a competent and ethical engineering solution

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9.2 Identify ethical issues and professional responsibility

DTMS project brings a range of ethical issues and professional responsibilities due to its technical scope, social influence, and the environment it operates within:

1. **Data Privacy and Security:** The DTMS contains real-time data from the transformer, including the voltage, current, and temperature levels, which may be able to expose customer consumption habits or grid system weaknesses. It is morally right to protect it from unauthorized interception or even exploitation to generate confidence and compliance with data protection laws.

2. **Public Safety:** It is dangerous to monitor high-voltage transformers in terms of electric hazard or equipment failure (i.e., explosive failure or overheating). The design and operation of systems need to include as a primary consideration the utility workers and the public's safety.

3. **Environmental Stewardship:** DTMS seeks to reduce energy loss and extend transformer lifespan, goals that are in keeping with sustainability goals. Reducing the system's impact on the environment, for example, by not using toxic substances and easy recycling of e-wastes.

4. **Transparency and Accountability:** Detection of system faults and power thievery alerts require truthful communication to stakeholders like consumers and utility suppliers.

Ethically, there should be proper application of data with adequate explanations of system decisions and actions.

5. **Regulatory Compliance:** Compliance with regulations like IEEE C37.91 on protection of transformers and ISO/IEC 27001 on information security is a professional obligation. Compliance will assure the system's reliability, safety, and legality under the regulatory context of Bangladesh.

6. **Equitable Access:** Improvement in grid reliability should benefit the whole region, including rural and under-served areas, to avert aggravation of social and economic inequalities. The ethical concern reflects the professional imperative of making electricity supply just.

All of these problems underscore engineers' responsibility to act with integrity, to place public interest above everything else, and to uphold a high ethical and technical standard.

9.3 Apply Ethical Issues and Professional Responsibilities

Ethical concerns are of topmost importance in utilizing the DTMS system to ensure accurate application and treatment of personal data. Data privacy management, process transparency of the system, and ethical treatment of data are required to maintain trust and to compel utility providers to adhere to legal requirements and to maintain ethical levels when making decisions.

1. **Data Privacy:** As DTMS entails transmission of sensitive operational information through IoT systems, its ethical management comes into prominence. Utility organizations are thus obliged to adopt strict data protection policies to ensure that no customer or operational information is used. Utility organizations are required to comply with country and global data privacy laws.
2. **Transparency:** Utility companies must use the DTMS system generated data transparently. This includes providing clear information to consumers about system upgrades, outages and theft detection.
3. **Responsibility in Data Interpretation:** The data that has been acquired ought to be interpreted and used responsibly. The utility providers ought to possess qualified personnel to interpret and make decisions based on the data ethically and through due process like power disconnection in the event of theft.
4. **Public Safety:** Safety devices like circuit breakers and surge protectors were incorporated into the design to avert electrical hazards. Robust testing, including field testing, confirmed system reliability under operating conditions. Utility technician training programs were implemented to support safe installation and maintenance practices.

5. **Environmental Stewardship:** The system was designed using low-power consumption sensors and recyclable materials to minimize the system's environmental footprint. An end-of-life disposal strategy was developed to responsibly dispose of end-of-life materials, achieving environmental sustainability objectives defined in the project scope.

Applicable Standards and Codes (CO2)

1. **IEEE C37.91- 2021 :** IEEE guide to protection of power transformers. The standard gives protection engineers and users guidelines to safeguard power transformers with a rating capacity of over 5 MVA and a rating of over 10 kV. The standard also contains material to help protection engineers protect transformers used in transmission and distribution systems through the application of relays and equipment.
2. **IEC 60255 – Measuring Relays and Protection Equipment:** It is a standard specifying the protection relays and protection equipment performance and how they interface with protection equipment in power systems. DTMS has protection schemes and sensors to monitor transformer health conditions such as overcurrent and fault protection. The standard compliance of the system makes DTMS compatible with traditional protection systems.
3. **IEC 61000 – Electromagnetic Compatibility (EMC) :** The standard establishes electromagnetic compatibility standards to exclude electrical and electronic equipment from interfering with one another. Particularly in regions of high electrical installation density, are designed in a manner that their components do not disturb adjacent systems. The standard guarantees trouble-free operation in applications that are susceptible to electrical noise.
4. **ISO/IEC 27001 – Information Security Management :** It lays down best practices for information security management systems. As DTMS involves gathering data and transferring it to a control room, the standard ensures the security of the system and protects sensitive data from cyber attacks or unauthorized access.

5. **NFPA 70 – National Electrical Code (NEC) :** This is an electric installation standard. Transformer- and equipment-based DTMS systems must be compliant with the protection requirements so that electric hazards like a short circuit or fire are averted.
6. **ISO 45001 – Occupational Health and Safety Management :** Ensures safe working environments. Staff from utility companies who implement, operate, and maintain DTMS systems must fall under this standard so that necessary precautions are taken to protect them.

9.4 Conclusion

Professional and ethical responsibilities have taken center stage in the DTMS initiative, from its development, deployment, to desired impact. Placing data privacy, public safety, environmental sustainability, openness, rule compliance, and equity in access in the foreground, the project team has ensured that DTMS not only meets technological goals but also promotes the greater public interest. These efforts make the system more credible and efficient and serve as a model for ethical engineering in Bangladesh's energy sector. Since Bangladesh is developing energy infrastructure, the DTMS demonstrates how ethical engineering can be the leader in promoting sustainable development, electricity equalization of access, and resilience.

Chapter 10: Conclusion and Future Work.

10.1 Project summary

In our project, we have developed a Distribution Transformer Management System (DTMS) which will enhance real-time monitoring, fault detection, preventive maintenance, and theft detection of transformers in Bangladesh. In our project, we employed two ways, approach 1, based on Arduino Uno with wireless 4G communication and Blynk IoT, and approach 2, wired based on RS485 communication and a central server. Approach 1 was superior in scalability, cost, and ease of deployment. With distributed processing and 4G, it supports fast fault detection, lower maintenance, and no dependence on physical infrastructures, making it most suitable for city environments like Dhaka. Approach 2, by far, was plagued with constraints of high cost, latency, and single points of failure.Proteus was chosen to be our simulation tool because of its low cost, support of embedded design, and compatibility of IoT. Thus we can conclude that, Arduino Uno-based DTMS is a dependable, scalable, and cost-effective system, ensuring effective transformer management and power system reliability.

10.2 Future work

Below are the future development strategies of DTMS, each of which addresses specific challenges and opportunities of the project environment and matches industry trends:

1. **Integration of Edge Computing**: Another way to enhance the responsiveness and resiliency of the DTMS is by integrating the functionality of edge computing. With edge computing, one can process data locally from the transformer. It will reduce the dependency on constant network connectivity. It will be crucial in areas of Bangladesh with fluctuating internet connectivity Iberdrola Edge Computing. By processing sensor data locally (e.g., current, voltage, temperature), the DTMS cab sense and respond to over-heating or load imbalance in real time, without transmitting data to a central server. It reduces latency, reduces the cost of data transmission, and enhances the resiliency of the system, especially in case of network failure. To support edge computing, the hardware of the DTMS must be supplemented with processor capacity and the software must also be upgraded by allowing local analytics and decision-making algorithms. It will follow global trends in smart grid management, where increasingly, edge computing is used to enhance optimal operation of the grid IEEE Smart Grid.

2. **AI-Based Power Theft Detection:** The power theft detection of the DTMS can significantly be enhanced by artificial intelligence (AI), making it even better equipped to protect the utility revenues. By employing machine learning algorithms, i.e., recurrent neural networks (RNNs), the DTMS can analyze past and real-time consumption data to identify patterns that could imply theft. The process is a better iteration of the existing theft

detection systems with higher precision and fewer false positives. To carry out AI-based detection of theft, a set of normal and anomalous consumption patterns would be identified and labeled and models trained to identify them, and then plugged into the DTMS to continuously monitor. The feature will make the grid safer and ensure the most even possible allocation of electricity. Thus, it will resolve one of the most challenging problems of the power system of Bangladesh.

3. **Enhanced Oil Leak Detection:** The DTMS can further its environmental stewardship by including added sensing ability to identify transformer oil leaks earlier to avert contamination and assist in sustainability. The oil temperature is already monitored, but by including oil level sensors, pressure sensors, or vision systems, leakage caused by overheat or by a mechanical fault could be detected earlier. The utility companies can then intervene earlier, minimizing environmental damage and the cost of cleanups. It will enable the ability to reduce oil leakage by averting faults and supports Bangladesh's commitment to environmental conservation. Adding the capability can be achieved by including new sensors and reconfiguring the computer programs to process and alert on leakage data.

4. **Integration with Distributed Energy Resources (DERs) and EV Charging Infrastructure:** As distributed energy resources like rooftop photovoltaic panels and electric vehicles gain popularity in Bangladesh, the DTMS could be augmented to control these new grid assets NREL DER Management. By monitoring the additional EV charging points load or the fluctuating contribution of DERs, the DTMS stabilizes the grid and prevents transformer overload. This could include implementing demand management measures where the DTMS instructs EV chargers to delay charging to late-night/evening time slots, or optimizing DER integration to balance the grid. As EV expansion is expected to reach 30% by 2030 in Bangladesh, this functionality will make the DTMS a progressive solution to a modernized grid. Its development will require enlargement of DTMS scope of monitoring to DER and EV-related parameters and incorporation of smart grid protocols.

5. **Renewable Energy Integration for DTMS Power Supply:** To support uninterrupted functioning, especially in rural areas or power outages, the DTMS can utilize renewable power, i.e., small-sized solar panels, to power its functions. It would make the system independent, reducing reliance on the grid that the DTMS is monitoring and making it more robust. Solar-powered DTMS units would prove to be of considerable value in rural areas of Bangladesh, where electricity supply is irregular. The innovation lies in designing a small-sized solar power system compatible with the power requirements of the DTMS and integrating it into the system hardware. The feature in a DTMS system pushes the system's

image of sustainability to the next level in accordance with world development of green energy solutions Verified Market Reports.

Comprehensive Impact Studies: Impact studies to maximize the benefits of DTMS can create sufficient data to support its large-scale adoption. These can range from field trials in several locations across Bangladesh. These will quantify parameters like the reduction of outage frequency, transformer lifespan extension, and theft mitigation. Utility company and research institution involvement could further enhance the credibility of such studies. It will provide evidence to mobilize finance and policy momentum. This exercise would branch out from the DTMS's pilot installation with the Bangladesh Rural Electrification Board and establish its case of scalability at the country and international levels.

Implementation Considerations

Implementing these future enhancements requires careful planning and resource allocation:

1. **Technical Feasibility:** AI-powered, real-time theft detection, along with edge-based capabilities, will require more advanced hardware and more complex software that could raise cost. Pilot tests can validate these before general deployment.

2. **Cost Implications:** Although combining renewable energy and oil leak detectors may raise cost in the short run, they may save money in the long run through reliability and environmental compliance. Bulk manufacturing methods, discussed under economic analysis, can minimize cost escalation.

3. **Stakeholder Collaboration:** Utility organizations, technology suppliers, and government agencies are stakeholders that will have to partner to make way for distributed energy resources (DERs) and perform impact studies. Coordination with the agencies like the Bangladesh Power Development Board (BPDB) will facilitate approval from the regulatory body and funding.

4. **Training and Support:** The functional upgrading of the DTMS will require training programs to operate and support new functions by utility technicians to achieve effective adaptation and optimal benefits.

Potential Challenges

Several challenges must be overcome to attain these potential improvements:

1. **Technical Complexity:** AI and edge computing are sophisticated technologies that require skill and extensive testing before they are able to work reliably in real environments.

2. **Cost Constraints:** Add-ons and renewable energy systems are expensive to set up, so cost-benefit analysis is needed to justify rele vant capital outlays.

3. **Network Reliability:** Although edge computing reduces the impact of network problems, the integration of DERs and EV charging stations will still demand robust communications protocols that may pose challenges in rural locations.

4. **Regulatory Hurdles:** New functionalities will require new approvals from organizations like the BREB, delaying deployment. The mitigation measures are a staged rollout schedule, utilizing open-source solutions, and alliances to share cost and expertise.

The mitigation measures are a staged rollout schedule, utilizing open-source solutions, and alliances to share cost and expertise.

Chapter 11: Identification of Complex Engineering Problems and Activities.

11.1: Identify the attribute of complex engineering problem (EP)

	Attributes	**Put tick (√) as appropriate**
P1	Depth of knowledge required	✓
P2	Range of conflicting requirements	✓
P3	Depth of analysis required	✓
P4	Familiarity of issues	
P5	Extent of applicable codes	✓
P6	Extent of stakeholder involvement and needs	✓
P7	Interdependence	✓

11.2: Provide reasoning how the project address selected attribute (EP)

P1: In-Depth of Knowledge Required (✓)

Description: This attribute indicates that the project requires specialized and deep understanding of the subject matter, going beyond basic or general knowledge. For the DTMS, this involves expertise in electrical engineering (transformer behavior, grid dynamics), IoT technologies (sensor integration, data transmission), and data analytics (fault detection algorithms).

How DTMS Addresses This: The DTMS necessitates in-depth knowledge across multiple domains to design and implement effectively. For instance, understanding transformer performance under various conditions—such as overloading, unbalanced loads, and environmental factors like high humidity and temperature variations in Bangladesh—requires advanced electrical engineering expertise. The integration of IoT for real-time monitoring involves knowledge of embedded systems, communication protocols (e.g., GSM, MQTT), and cloud platforms for data storage and visualization. Additionally, it requires a very strong expertise in data analysis to develop algorithms for fault detection and predictive maintenance. It often includes machine learning techniques. Typical examples like the TrinetraSense IoT solution (Remote Monitoring of Transformer) highlight the need for specialized expertise, thus underlining the fact that staff working in DTMS must have certain competencies to ensure the reliability and effectiveness of the system.

P2: Wide-ranging or Conflicting Requirements (✓)

Description: The problem entails varying or conflicting demands to be traded off against one another such as cost effectiveness, reliability, scalability, and compliance with safety procedures. This complicates the design and implementation process.

How DTMS Addresses This : Distribution Transformer Monitoring System (DTMS) must satisfy a sequence of generally opposing demands. First and foremost is being cost-effective enough for mass deployment in economically challenged rural property while embracing high-technology inputs in the form of the Internet of Things (IoT) and Artificial Intelligence (AI) for real-time system monitoring and fault identification. This tradeoff in the project design finds expression in the usage of low-cost inputs like Arduino microcontrollers and GSM modules. The system must also ensure reliability and safety and compliance with standards like IEEE C37.91 for transformer protection and this will be the area likely to attract a premium. No less critical is giving the system the versatility to be serviceable in metropolitan and rural installations with differing infrastructural circumstances and the problem of data protection and privacy and hence the protection of privileged operational information from hacking. The project balances these opposing demands as can be seen in the modular design of the project. The latter creates the latitude for adaptation to achieve the multi-stakeholder demands like cost advantage to the utility companies and the users who need reliable power.

P3: Depth of Analysis Required (No Obvious Solution) (✓)

Description: This trait indicates the problem has no simple or direct solution but requires precise and elaborate analysis and possibly a number of iterations, simulations, or evaluations in an effort to identify reasonable alternatives.

How DTMS Addresses This: No particular solution to the problems of unbalanced loading as well as overloading and theft of power confronts Bangladesh's grid. The DTMS must be researched in-depth in order to develop the most appropriate means of monitoring transformer status monitoring, theft protection, and fault detection. This involves failure mode analysis of the transformer, analysis of the loading and designing anomaly algorithms or sensing the temperature rise conditions or current peaks associated with theft. The project development utilizing IoT and AI adds a new level of complexity in designing the data processing and planning transmission and storage with care in order to attain real-time implementation without loading the system. For instance, the project discusses parameter-based current, voltage, and temperature fault detection with overvoltage and overcurrent warning protection, requiring enormous analysis to decide appropriate thresholds and attain accuracy. Research papers like those on IoT-based transformer monitoring describe the use of advanced algorithms in predictive maintenance, which again indicates the amount of analysis involved.

P5: Extent of Applicable Codes (✓)

Description: The project must be compliant with a large or extensive number of pertinent codes, standards, or regulations, e.g., engineering codes and standards, safety standards and regulations, environmental regulations or industry-specific standards and regulations, which adds a factor of complexity to the design and implementation process

How DTMS Addresses This: DTMS must be compliant to numerous engineering standards and codes from electrical safety to transformer design and communications protocol. To provide an example, it must be compliant to standards like IEEE C37.91 for transformer protection which sets standards for transformer protection and fault monitoring and ISO/IEC 27001 for data and information privacy and security. The system must also adhere to local rules and standards by entities like the Bangladesh Power Development Board (BPDB) and the Bangladesh Rural Electrification Board (BREB), who might have specific grid integration and environmental issues by means of strict design, testing and validation procedures and by utilizing secure communication data transmission protocols. Examples of case studies like the ResearchGate paper on IoT transformer monitoring reference standards compliance such as substation communications in accordance with IEC 61850 as evidence of the importance of full compliance with the code.

P6: Extent of Stakeholder Involvement and Needs (✓)

Description: The project requires intensive engagement with various stakeholders with varying needs and expectations to be met, thus necessitating consensus establishment and requirements prioritizing a complex but crucial task.

How DTMS Addresses This: The DTMS project has numerous stakeholders from government departments, utilities players, transformer companies, and end-users with typical and expectations. Utilities require a system with the lowest cost of operation and greatest grid reliability as observed in the preventive maintenance and theft identification of the project. Government agencies may have regulation requirements and sustainability targets like the conservation of energy and the extension of transformer life, which the DTMS satisfies with its system design. Equipment manufacturers need to be guaranteed system compatibility with their equipment, and end-users get a stable and reliable power supply, thus accruing industry benefits in segments like healthcare and education. The success of the project is founded upon resolving these varied requirements through consultation with stakeholders, such as the project's incorporation of DPDC engineers in problem selection and support by BREB in field tests. TrinetraSense and other examples show how crucial it's to respond to OEM and service engineer needs with real-time data and notifications.

P7: Interdependence (✓)

Description: This feature suggests the parts or aspects of the issues entail a high level of interdependence among them and changes or decisions in one aspect will cascade into another portion, requiring a systems level of thinking in order to establish coherence and direction to the entire solution.

How DTMS Addresses This: The components of the DTMS depend greatly upon one another with the system's effectiveness in jeopardy if either the hardware (microcontrollers, sensors), software (data analysis and fault detection algorithms), and communications (IoT or GSM) do not operate in functional harmony. An example of this is the fault detection accuracy as a byproduct of sensor integrity needing to pass the data to the cloud to be analyzed and the control system's response time needing to ensure timely alerts. There also exist external parameters like environmental and grid conditions affecting the system's performance as a whole, e.g., the influence of humidity on sensor accuracy. The project works at the system level and ensures the parts work in symphony with one another as noted in the combination of Arduino, sensor(s), and IoT platforms in the project. Such reliance is driven by modular design and iterative testing to ensure that the DTMS functions as a unified entity.

11.3 Identify the attribute of complex engineering activities (EA)

	Attributes	**Put tick (√) as appropriate**
A1	Range of resource	✓
A2	Level of interaction	✓
A3	Innovation	✓
A4	Consequences for society and the environment	✓
A5	Familiarity	

11.4 Provide reasoning how the project address selected attribute (EA)

A1: Range of Resource

Description: According to the definition provided by the International Engineering Alliance (IEA), this characteristic involves use of a variety of resources such as human beings, finance, machines, materials, knowledge, and technology IEA Graduate Attributes. Difficult engineering work requires managing a vast variety of resources in an effort to accomplish project goals.

How DTMS Addresses This: The project of DTMS employs a vast array of resources in order to ensure successful development and implementation:

Technical Resources: The system is designed with hardware components such as current and voltage sensors, Arduino controllers, communication modules such as GSM, and even solar panels as a power source. On the software side, it utilizes IoT platforms (such as ThingSpeak or Ubidot) for data transmission and storage as well as for fault identification and predictive maintenance with algorithms. These components are necessary for real-time surveillance and fault identification.

Human Resources: The project requires the services of technicians and data analysts as well as services from IoT experts and electrical engineers for installation and maintenance. Stakeholder coordination with organizations like Bangladesh Rural Electrification Board (BREB) and Dhaka Power Distribution Company (DPDC) also indicates a greater demand for interdisciplinary teams as reflected in the project's stakeholder participation in project selection.

Financial Resources: Capital for hardware procurement, software development and implementation, and data connectivity and maintenance (e.g., purchase of SIMs for the GSM modules) on a periodic basis must be satisfied. Reducing costs was also weighed in terms of mass production techniques as per the financial analysis in order to make it affordable for large scale deployments.

Informational Resources: Real-time transformer data, historical load profiles, and ambient environmental conditions are used by the project to maximize performance. The system was also developed with reference to industry experts and literature to ensure that technical and operational standards are met.

Conclusion: With a versatile pool of assets at play, the DTMS will be in a position to tackle the intricate transformer maintenance issues in the Bangladesh grid with ease and validate its worth in handling this portion of intricate engineering work.

A2: Level of Interaction

Description: This attribute entails the resolution of significant issues arising from interactions between widespread or conflicting technical, engineering, or other issues, as proposed by the IEA Graduate Attributes. It places importance on the need for handling complex interdependencies and stakeholder dynamics.

How DTMS Addresses This: DTMS has a number of levels of organizational and technical interaction:

Technical Interactions: Technical interactions involve the use of sensors, microcontrollers, communication modules, and cloud platforms for data sensing, transmission, and analysis in real-time. Voltage and current sensors interact with a microcontroller for detecting anomalies and the data is sent to the cloud by the GSM modules. These interactions must be perfect for efficient fault identification and theft protection as in the project design phase where IoT cloud integration was crucial.

System-Grid Interactions: DTMS needs to interface with the existing power grid infrastructure and be compatible with transformer systems and control centres. This needs to be calibrated and tested carefully to prevent disruption in grid operation and was carried out in the FYDP C phase by conducting field tests at PBS-03 in Dhaka with the support of BREB.

Stakeholder Interactions: The project will involve cooperation with utility companies (e.g., DPDC), regulators (e.g., BREB), and customers. Compromise and negotiation will be necessary in order to find a balance for their differential requests—e.g., cost-efficiency for utilities and reliability for customers - as evident from discussions with DPDC engineers while selecting the problems.

Data Interactions: The real-time transformer data must be processed and displayed in a user-friendly dashboard so technicians can make decisions. This will involve complex data

flows between sensors, cloud platforms, and user interfaces with the project's dashboard design being particularly tailored out for control room technicians in FYDP D.

Conclusion: High interaction levels in DTMS are managed efficiently by ensuring each component works in an interrelated manner and reconciling the stakeholders' demands and thereby demonstrating its ability to cope with this element of complicated engineering work.

A3: Innovation

Description: Innovation refers to the new use of engineering principles and knowledge from research in new and various ways as per the IEA definition IEA Graduate Attributes. Innovation is concerned with the development of new solutions for complex problems.

How DTMS Addresses This: The DTMS is unique in its segment because it applies IoT technology in fixing long-time challenges in Bangladesh's power sector:

Technological Innovation: Remote monitoring of Bangladesh's grid transformer based on IoT technology is a recent development with the traditional manual inspection method being the norm. With the use of remote monitoring, DTMS reduces site visits while enhancing efficiency and safety as in the case of TrinetraSense's remote inspection solution.

Algorithmic Innovation: Fault-detection algorithms (temperature overload and unbalanced loading conditions) and theft-detection algorithms (current spiking) have been employed by the system. The algorithms were tailored to Bangladesh's grid conditions (humid climate and dynamic loading conditions) and honed in FYDP D with expert-level discussions on thresholds and data availability.

Sustainability Innovation: With transformer life extension and reduction of energy losses, DTMS facilitates sustainable energy projects in accordance with international developments in smart grid technology. This was one of the reasons for carrying out the project's environmental sustainability study highlighting decreased greenhouse gas emission.

Conclusion: The new application of data analytics and IoT by the DTMS in overcoming traditional power grid challenges highlights its cutting-edge application of engineering principles in meeting this characteristic completely.

A4: Consequences for Society and the Environment

Description: This attribute captures the wider social and environmental impact of the engineer's work and will usually have prediction and minimisation challenges, as stated by the IEA Graduate Attributes. It is an excellent example of the need to consider wider consequences.

How DTMS Addresses This: DTMS has a wide-reaching effect on society and the environment:

Societal Impact:

Improved Grid Reliability: With decreased outages and increased life expectancy of the transformer, the DTMS maximizes availability of electricity to industrial, education, and healthcare industries. This works particularly in the cases of rural settings where the power supply tends to be unreliable as witnessed in the project's impact analysis on societal welfare.

Economic Benefits: Economic advantages include cost-saving in maintenance and replacements of the utilities and sharing of revenues with less power theft. These savings can be used to invest in infrastructureupgrades as a means of stimulating economic development, as supported by the 5-year economic analysis of an 85.2% ROI.

Job Creation:Job opportunities in the installation and maintenance of the DTMS units arise for technicians and engineers and contribute to local economic development as a theme emphasized in the social sustainability analysis of the project.

Environmental Impact:

Reduced Energy Losses: With load optimization and timely fault identification, the DTMS minimizes energy losses and decreases greenhouse gas emissions from electricity generation in accordance with environmental sustainability goals.

Prevention of Oil Leaks: Early detection of overheating or faults prevents transformer oil leakage which can contaminate soil and water, protecting local ecosystems, as highlighted in the project’s environmental impact assessment.

Sustainable Resource Use: Longer transformer life decreases the amount of new production needed and minimizes resource usage and electronic waste, an important element of the project's sustainability effort.

Conclusion: The favorable social and environmental impacts of the DTMS reflect its alignment with this characteristic because it addresses short-term operational concerns and long-term sustainability goals with broad impacts requiring careful handling.

In conclusion, the project of the DTMS adequately describes the nature of complex engineering activities (EA) by employing a vast range of means in handling high levels of interaction, taking new approaches, and being high in societal and environmental impact. The exclusion of "Familiarity" (A5) as a selected trait also deals with how new the project was and to what extent deviating from normal procedure it was, particularly in emphasizing its futuristic content. With Bangladesh in the process of modernizing its power grid, the model of the DTMS expresses how complex engineering activities can be used to attain sustainable and efficient solutions based on case studies and standards of engineering.

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Appendix

Logbook

FYDP (P) Summer 2024 Summary of Team Log Book/ Journal

Group 4	**Final Year Design Project (P) Summer 2024**		
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General Notes:

1. In addition to detail journal/logbook fill out the summary/key steps and progress of your work
2. Reflect planning assignments, who has what responsibilities.
3. The logbook should contain all activities performed by the team members (Individual and team activities)

Date/Time/Place	Attendee	Summary of Meeting Minutes	Responsible	Comment by ATC
09.06.2024	All Members	Integration of Nanogenarators in Wave Energy Converters, What cheap materials can be used to make the existing ReVive Grip method. Finding out the traffic jam problem in Dhaka and how public transportation contributes to it.	All Members.	
11.06.2024 Conference Room	All Members.	Discussed ideas on Wave Energy Conversion, Affordable ReVive Grip with nanogenerators, Smart Over Crowded Public Transportation management system.	1. Importance and necessity of WECs. - Walid. 2. Integration of Nanogenarators with WECs. - Fahad 3. Affordable ReVive Grip Systems - Sojeeb 4. Smart system for over crowded transportation - Shibli	Suggested to investigate further subjects and concepts. Also, look at methods to show the project prototype in the most accurate portrayal of the real project.
24.06.2024	All Members	Discussion on Dyeing procedures in RMG garments factory. Smart AC Power Consumption monitoring device.	All Members.	
25.06.2024 Conference Room	All Members	Shared Ideas on Dyeing procedures in RMG garments factory. Smart AC Power Consumption monitoring device.	1.Exploring the problem of gray fabric coloring in the RMG Industry. - Fahad 2. The existing methods used to color gray fabric and its implications. - Walid 3. Exploring existing systems and softwares on gray fabric coloring. - Sojeeb & Shibli.	Suggested to visit RMG related industries to find significance and importance of the problem that was identified.
27.06.2024	All Members	Exploring Research Papers on dyeing methods using ML and Image Processing.	All Members.	

29.06.24	All Members	The importance of external smart grid systems was discussed in detail. And researched challenges in Bangladesh's light EV sector, including battery charging efficiency and the Visual Subsystem of LEVs for monitoring battery health, quality, and mileage, as well as speed limiters.	All Members.	
02.07.24 Conferenc e Room	All Members	Discussed the ideas of External Smart Grid systems and Light EVs concepts with ATC in detail.	1.Walid- Discussion with someone from the EV sector about the issues and their significance and the scope of LEV in Bangladesh. 2.Sojeeb- Exploring the shortcomings of existing smart power monitoring devices. 3.Shibli- Improvements of External Smart Grid Systems and necessity of home appliance controllability. 4.Fahad- Concepts of speed limiters along with battery quality management in Lead Acid based batteries.	Suggested to investigate the significance of the problems found in the LEV sector of bangladesh and finding out existing sources of supply of battery and charging systems for LEV.
13.09.24	All Members	Discussed with multiple industry experts related to the power sector.	All Members	
17.09.24	All Members	Discussed with 2 engineers from DPDC and discussed the problems faced while maintaining distribution transformers.	All Members	
18.08.24 Conferenc e Room	All Members	Shared the problems and issues that are being faced by industries and proposed the solution of Distribution Transformer Management.	All Members	Suggested to explore the significance of the problems and their impacts and novelty of this project.

22.09.24	All Members	Explored about the impacts and significance of DTM and discussed with 2 executive engineers.	All Members	
24.09.24 Conferenc e Room	All Members	Discussed about the possible design approaches and certain features like “Theft Reduction” and how to detect such issues.	Shibli - Theft Reduction Fahad - Multiple ways to detect theft reduction like focusing on sudden spikes in currents by a huge margin to detect or indicate theft. Walid - Design approach 1 using GSM Module Sojeeb: Design Approach 2 using mesh and wiring technology.	Suggested to make changes in design approach, more concise project title.

FYDP (D) Fall 2024 Summary of Team Log Book/ Journal

Date/Time/Place	Attendee	Summary of Meeting Minutes	Responsible	Comment by ATC
25.10.24 Online	All Members	Short overview of the proposed design approaches.	All Members.	Suggested to look into algorithms for theft detection. Explore more options for design option 2 to specify the novelty from Approach 1. Present the necessary research made to justify the needs and specifications of this project.
01.11.2024 Online	All Members	Brainstormed possible design approaches, focusing on IoT-based and GSM communication systems for real-time monitoring.	All Members.	
2.11.24 Online	All Members	Discussed possible approaches for theft detection.	All Members.	Suggested to consult experts in the concepts of threshold and limitations of data accessibility.
04.11.2024 / Online	All Members.	Discussed the integration of sensors for voltage, current, and temperature measurement. Explored load balancing methodologies.	All Members.	
04.11.24 Online		Discussed and demonstrated version 1 along with a personalized dashboard for approach 2.		Improve the dashboard and overcome the issue of implementing matlab.
15.11.2024 / Online	All Members.	Reviewed IoT cloud integration for data storage and real-time visualization. Considered dashboard design for control rooms.	All Members.	
22.11.2024 / Online	All Members.	Conducted risk analysis. Focused on equipment reliability, environmental	All Members.	

		challenges, and theft detection.		
06.12.2024 / Online	All Members.	Discussed cost estimation and budget constraints. Investigated affordable yet robust components for the system.	All Members.	
11.12.24 Online	All Members.	Tested initial prototype design concepts. Identified improvements in sensor data taking and data transmission.	All Members.	
15.12.24	All Members.	Finalized dashboard design with user-friendly features for technicians. Discussed integration of SMS alerts for faults.	All Members.	

FYDP (C) Spring 2025 Summary of Team Log Book/ Journal

Date/Time/Place	Attendee	Summary of Meeting Minutes	Responsible	Comment by ATC
03.2.2025 Online	All Members	Based on the feedback of the FYDP D review the project and finding the detail information of the sensors availability and datasheet	All Members.	
10.2.25 Online	All Members	Selection of sensors and other equipment and Improvise the project design based on available sensor	All Members.	Suggested to consult experts so that the project could be implemented in a real world scenario.
12.2.2025 / Online	All Members.	Meeting with DPDC Expert about the selected sensors and their compatibility in real world scenario	All Members.	
23.2.25 Online	All Members.	Procurement of the selected sensor by communicating with different vendors in home and abroad .	All Members.	
27.2.2025 / Online	All Members.	Reviewed IoT cloud integration for data storage and real-time visualizationConsidered dashboard design for control rooms.	All Members.	Suggested to go for the custom dashboard design
10.3.2025 / Online	All Members.	Research for integrating the sensors and making the prototype	All Members.	

16.3.2025 Online	All Members.	Developing the project	All Members.	
2.04.25 Home	All Members.	Tested the project in single phase	All Members.	
10.04.25 online	All Members.	Complete Built the IoT Dashboard	All Members.	
15.4.25 Power Lab	All Members	Tested the project in Three phase	All Members.	
25.04.25 FYDP Lab	All Members	Troubleshoot the project	All Members	
30.05.25 FYDP Lab	All members	Completed the making of protective box and integrate the whole project in the protective box	All Members.	Suggested to add theft detection in Dashboard and make plan for project showcasing
7.05.25 Power lab	All Members	Tested the whole project with load and in the three phase system	All Members.	Suggested to add tripping system and look for more option to strengthen the novelty
10.5.25 PBS-03, Dhaka	All Members.	Tested the whole system in a 100 KVA transformer with the assistance of BREB at PBS-03 Dhaka.	All Members	
12.05.25 Online	All Members	Prepare the draft of the report and poster for presentation	All Members	