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Transforming the Grid: IoT-Based Monitoring Device for Enhanced Efficiency in Secondary Line Distribution Transformers

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ABSTRACT: The distribution transformer plays a crucial role in both transmission and distribution lines, serving as a vital component for power distribution across large areas. Due to the extensive requirement of distribution transformers, it becomes imperative to monitor their operational parameters to ensure their ongoing functionality. In this study, the researcher introduces a device and software solution specifically designed to monitor Electric Companies Distribution Transformer. By closely monitoring key factors such as voltage, current, apparent power, real power, reactive power, and power factor, potential issues with the distribution transformer can be identified and addressed promptly. The monitoring process utilizes real-time data, enabling the recording and analysis of daily, weekly, and monthly measurements via the Internet of Things (IoT) technology.

KEYWORDS: Internet of Things, Distribution Transformer, Monitoring, Voltage, Current, DTLMS

I. INTRODUCTION

The significance of distribution transformers in distribution lines cannot be overstated. Ensuring their efficient operation requires a monitoring system that leverages real-time data from these transformers, promptly transmitting crucial information to a central monitoring center [1]. In this research, a novel device and software have been developed to monitor Electric Companies Distribution Transformer, focusing on key factors such as voltage and current. Rather than relying on manual checks, this system, known as DTLMS (Distribution Transformer Load Monitoring System), employs the Internet of Things (IoT) to provide continuous real-time data accessible to the host through an internet connection.

The primary objective of this study is to promote sustainability and minimize potential issues related to distribution transformers by implementing a dedicated monitoring system within the transformer power grid. Notably, this initiative also seeks to enhance the safety of electrical linemen in their workplaces, reducing the risk of accidents. The benefits of smart monitoring in the secondary line of distribution transformers are substantial, as it ensures a secure and reliable operation without causing electrical disturbances. According to research by CIGRE, early detection of problems through transformer monitoring can reduce catastrophic failures by 50%, leading to a remarkable 75% decrease in repair costs and a 60% reduction in revenue loss [2]. As a result, significant cost savings amounting to 2% of the expense of a new transformer can be achieved for the operators.

Due to the continuous and often unmaintained operation of distribution transformers, they are subject to stress, making them prone to sudden failures and resulting in disruptive power outages [3]. The absence of notification systems for power interruptions within the area further complicates matters. By introducing a comprehensive monitoring system, the lifespan of distribution transformers can be extended significantly. Automatic alerts will be generated if abnormal voltage or current behavior is detected, enabling swift action by the electrical cooperative personnel to address any issues. The transition from manual to automatic monitoring is essential, as it minimizes risks associated with electrical work while allowing the cooperative to efficiently monitor voltage and current from their computers.

Ultimately, the purpose of this research is to offer comfort and compatibility to the electric cooperative and to provide consumers with reliable electricity that does not disrupt their daily lives. The study showcases the successful implementation of a monitoring system, encompassing design, system structure, and hardware, proficient in detecting voltage and current abnormalities and even identifying power interruptions in distribution transformers. This innovative approach not only helps the electric cooperative eliminate losses but also benefits consumers, ensuring a steady and dependable supply of electricity.

Concept of the study

The researcher comprehensively presented the planning, creation, and execution of the IOT Based Load Monitoring Device for Distribution Transformer Secondary Line, as depicted in Figure 1. The device was carefully designed, utilizing cutting-edge technology and rigorous testing to ensure its efficiency and accuracy. Figure 1 provides a visual representation of the step-by-step development, highlighting the researchers' dedication to delivering a sophisticated monitoring system for distribution transformers.

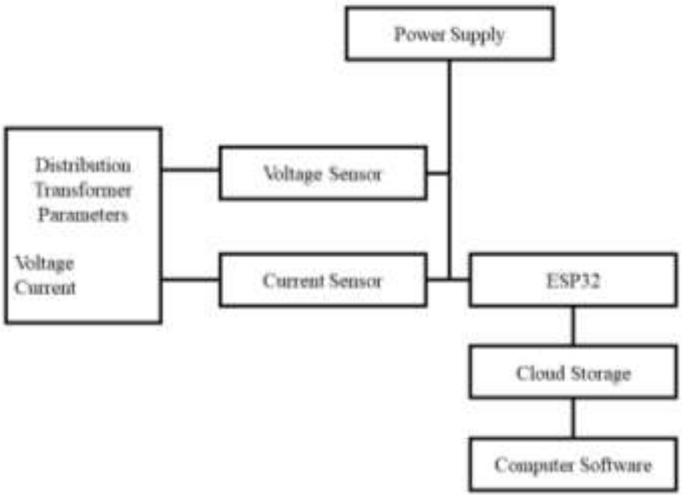

Fig 1. Conceptual of the study

Objectives

The primary aim of this study is to design and implement an IOT based load monitoring device for distribution transformers, with the goal of providing information in a convenient manner. By monitoring voltage and current behavior, Electric company can obtain vital data necessary to address specific distribution transformer issues at particular locations.

Specific Objectives:

1. Identify existing problems with Electric Companies current monitoring system for their distribution transformers.
2. Devise a device to be installed on the distribution transformer secondary line capable of measuring voltage and current and transmitting the data to cloud storage.
   2.1. Verify the functionality and accuracy of the developed device.
3. Create software for real-time monitoring, data sorting, and issuing warnings in case of voltage drops below the rated output.
   3.1. Evaluate the accuracy of the real-time monitoring software.
   3.2. Test the notification system for voltage drops and high current measurements, aiding in the identification of peak loads.
4. Implement the entire project at the Electric Cooperative.

II. METHODS

The PDCA (Plan-Do-Check-Act) process served as a vital framework for the researcher in developing a solution, effectively streamlining the project workflow. By adopting this approach, the researcher could identify potential factors that might influence the study during the planning phase. Following this, the obtained results were subjected to rigorous testing and data assessment, leading to the successful delivery of a fully functional and completed project. The model of the study is depicted in Figure 2.

Fig 2. Model of the study

Project Design

The Design and Implementation of the IOT Based Monitoring Device in the Distribution Transformer Secondary Line encompassed five distinct stages for the device's seamless operation. In the first stage, the voltage output and current flow in the secondary line of the distribution transformer were measured using dedicated voltage and current sensors, enabling precise data acquisition.

Moving to the second stage, the analog outputs from these sensors were converted into digital signals via the microcontroller GPIO pins. This was achieved by leveraging the energy monitoring library on the Arduino Ide, ensuring accurate and efficient signal conversion.

In the third stage, data obtained from the esp32 microcontroller was uploaded to a MySql host database at regular intervals of five minutes per upload, establishing a continuous data flow for further analysis and processing.

The fourth stage involved the organization and sorting of data within the host database, enhancing accessibility and facilitating streamlined data management.

Finally, in the fifth stage, the data was transmitted from the host database to the DTLMS (Distribution Transformer Load Monitoring System) software. This innovative software enabled the data to be visually represented in the form of graphs, displaying voltage and current readings at five-minute intervals, thus providing valuable insights into the performance of the distribution transformer.

To achieve these objectives, the researchers opted for the Nodemcu esp32 microcontroller, which boasted 38 pins. Notably, the microcontroller's 12-bit high-precision ADC pins proved to be an ideal feature for ensuring accurate data measurement. Additionally, a switching power supply with a 5V 2A output was employed to power all the components of the monitoring device, guaranteeing consistent and reliable functionality. Figure 3 defects the schematic diagram of the system.

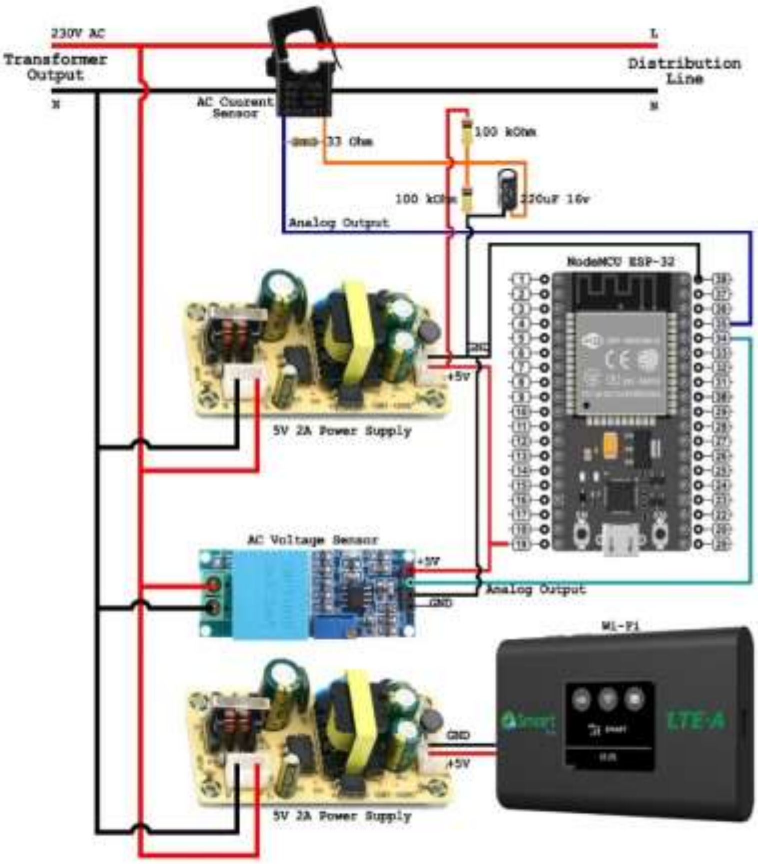

Fig 3. Schematic Diagram of the Device

As illustrated in Figure 4 below, upon system startup, the microcontroller initiates the program, commencing the data acquisition process. Subsequently, the esp32 microcontroller continuously reads the voltage and current sensor outputs and transmits the gathered data to the MySQL database at regular five-minute intervals.

During this interval, the microcontroller conducts a crucial voltage check. If the measured voltage value falls below the predefined threshold of 208V, the microcontroller promptly uploads the minimum voltage value, triggering a warning notification on the monitoring software. Conversely, if the voltage values surpass the designated threshold, the microcontroller uploads the most recent voltage and current values.

The host database stores this collected data, which is automatically sorted and made accessible through the computer software. The data is then presented in the form of graphs, facilitating visual analysis and providing valuable insights into the system's performance.

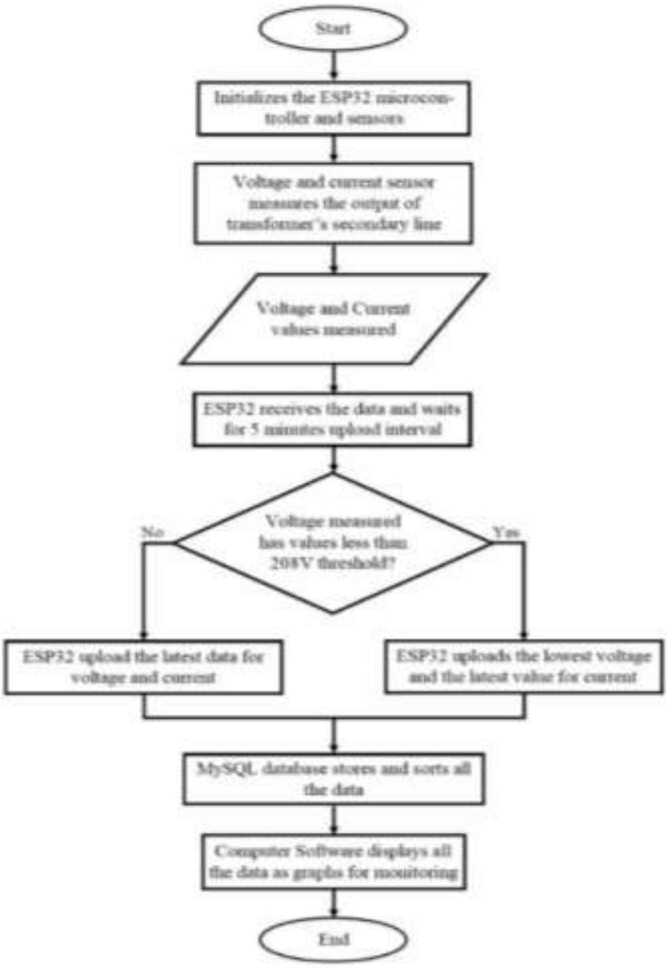

Fig 4. Flow Chart of the System

A. Plan

Project Design

In Figure 5, the initial phase of the study revolves around Investigating the Distribution Transformer. During this critical stage, the researcher meticulously examines the existing problem and diligently collects relevant data from online sources and seeks consultation from professionals, particularly those associated with Electric Companies where similar systems have been installed.

The subsequent stage is dedicated to Planning the project, encompassing several vital considerations. This entails assessing the availability of essential components, determining the budget required to procure each component and associated services, and ensuring sufficient software expertise for successful programming of both the software and ESP 32.

Once the programming aspect is effectively addressed, the researcher proceeds to Build the project. However, should any programming setbacks or challenges arise, the researcher diligently returns to the problem to identify and implement appropriate solutions.

Finally, the developed device undergoes rigorous Testing, where its accuracy and performance are thoroughly evaluated. This comprehensive testing phase aims to ensure the monitoring device's reliability and effectiveness, thereby empowering the researcher to draw meaningful and insightful conclusions from the study.

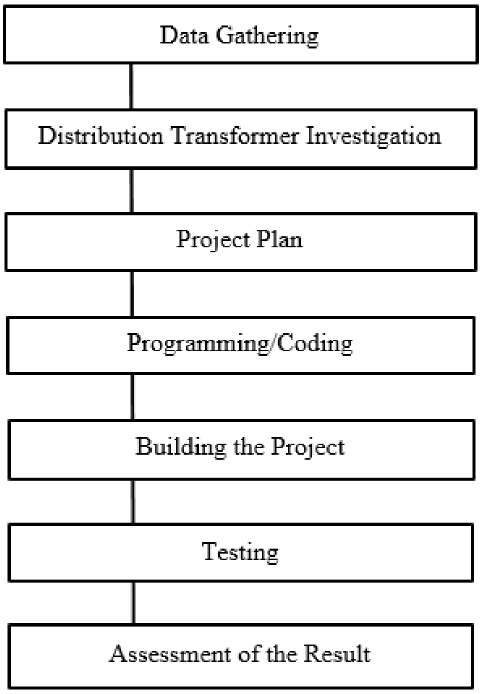

Fig 5. Project Development Flow of the Study

B. Do

Project Development

This study was undertaken at an Electric Cooperative situated in the southern part of Mindanao, Philippines, with a specific focus on their 15kVA distribution transformer. The research findings not only served as a valuable point of reference for the company's upcoming projects but also offered profound insights into monitoring devices applicable to a broader range of 10-37.5kVA distribution transformers.

Despite the device's capability to measure a wider spectrum of transformers, the Electric company deliberately chose to use a 15kVA distribution transformer for this study. This decision was based on the transformer's easy accessibility and its relevance to the company's existing infrastructure and operational context.

To assess the device's functionality and accuracy, the researcher conducted testing with Electric Cooperative equipment and tools serving as reliable references. Notably, a short-circuit test was performed on the transformer output, allowing for the measurement of current using two testing components: the variac, responsible for adjusting the input current, and the Fluke Digital Ammeter, which accurately measured the current flow. Figure 6 visually illustrates this testing process, providing a comprehensive view of the assessment procedure.

Fig 6. Actual Testing on Electric Cooperative Equipment

C. Check

Product Implementation and Testing

In this specific phase of the study, the researcher took great care in setting up the system within the designated target environment to conduct thorough tests on its functionality and accuracy. Figure 7, illustrated below, offers valuable insights into the testing process conducted during the implementation stage, providing a comprehensive view of the assessment procedures.

Moreover, Figure 8 displays the actual implementation of the transformer secondary line, presenting a practical representation of how the monitoring system was deployed and integrated into the distribution transformer setup. These visual aids offer a clear depiction of the meticulous efforts invested in both testing and the successful real-world application of the monitoring device within the distribution transformer secondary line.

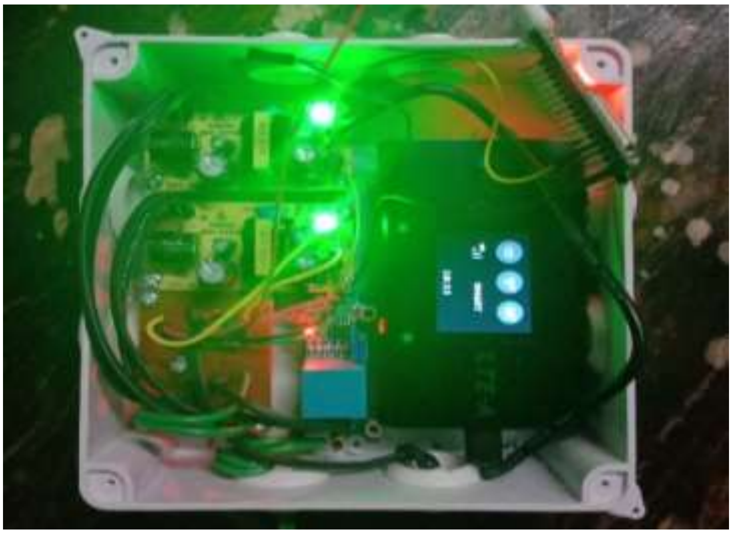

Fig 7. Testing the system during implementation

Fig 8. Product Implementation

D. Act

Project Evaluation

This study focuses on assessing the voltage and current behavior on the distribution transformer Secondary Line. By analyzing these parameters, the electric cooperative gains valuable insights into the transformer's performance, enabling them to swiftly detect any faults in the transformer's output. Consequently, prompt and effective responses can be provided to address any encountered problems with the distribution transformers.

To ensure the reliability of the monitoring process, the device used in this study must consistently function at its optimal capacity. Regular functionality is vital to obtain accurate and real-time readings of voltage and current, which are essential for making informed decisions and maintaining the efficient operation of the distribution transformer system.

Evaluate the functionality of the Device

During the testing phase, the researcher thoroughly evaluated all the interconnected components within the system. The outcomes of these evaluations are concisely presented in Table 1 below, providing valuable insights into the performance and interactions of the various system elements.

Table 3. Functionality Testing

Test	Particulars	Functionality
1	Microcontroller Testing	Functioning
2	Voltage Sensor Testing and calibration	Functioning (Tolerance ±2%)
3	Current Sensor Testing and calibration	Functioning (Tolerance ±2%)
4	Data upload to MySQL host database Testing	Functioning
5	DTMS Connection to Database Testing	Functioning
6	Accuracy Testing	Functioning

The initial interface served as a testing ground for assessing the communication between the Esp32 and the software, with a keen focus on identifying and resolving any bugs, data errors, or glitches that surfaced.

Subsequently, significant improvements were made to the software, effectively addressing and resolving all the bugs, data errors, and glitches. As a result, seamless communication between the Esp32 and the host database was achieved. Notably, the software's calendar design underwent modifications, enabling it to generate and compare data from selected date ranges with the simple action of dragging the dates to desired coverage. This enhanced functionality empowers electric cooperative personnel to interpret data accurately and efficiently.

Within the graph, the orange dots indicate voltage values above the designated threshold, while the red dots indicate low voltages falling below the 208V threshold. These visual indicators offer valuable insights into instances where the distribution transformer experiences voltage drops in its output, often attributed to transient loads. On the right side of the graph, a list of low voltage warnings is displayed alongside their corresponding time plot. This feature ensures timely awareness of any low voltage occurrences at specific intervals. The successful implementation of the DTLMS software now allows for prompt notifications whenever low voltage situations arise.

As depicted in Figure 8, the developed software for monitoring exemplifies the culmination of these improvements, providing a user-friendly and efficient tool for monitoring the distribution transformer.

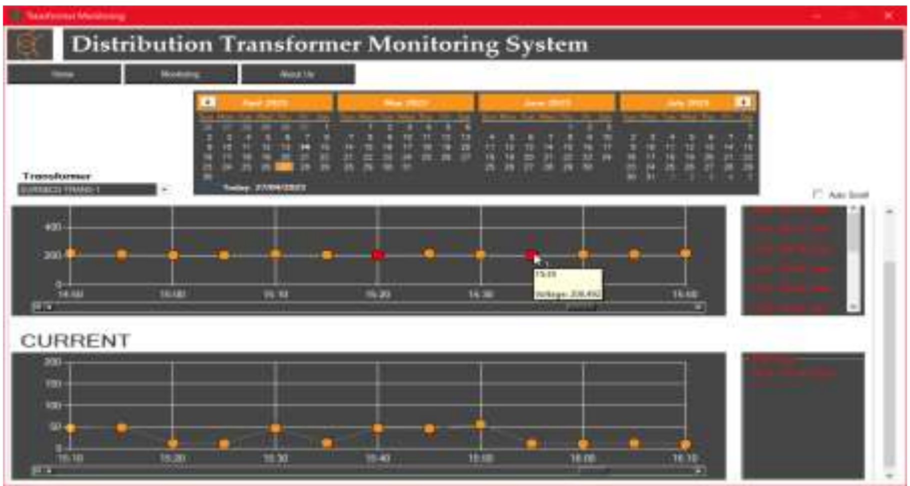

Fig 8. Develop Software for Monitoring

III. RESULTS AND DISCUSSION

During this crucial stage of the study, the researcher successfully devised a solution in alignment with the stated study objectives. This involved the comprehensive design and implementation of the monitoring system for the distribution transformer secondary line. The diligent efforts led to the creation of an efficient and effective monitoring system that catered to the specific needs outlined in the objectives.

As depicted in Figure 6, the distribution transformer monitoring system stands as a visual representation of the innovative solution developed during this phase. It showcases the intricately designed components and their seamless integration, exemplifying the researcher's dedication to delivering a robust and reliable monitoring mechanism.

This stage marked a significant milestone in the study, culminating in the successful establishment of the monitoring system capable of gathering critical data from the distribution transformer secondary line. The system's architecture and functionality were carefully engineered to enable real-time data acquisition, empowering the electric cooperative to gain valuable insights into the behavior of voltage and current in the distribution transformer.

By achieving this pivotal milestone, the researcher demonstrated the feasibility and efficiency of the proposed solution. The monitoring system showcased in Figure 6 serves as a tangible outcome of the study, laying the groundwork for enhanced monitoring capabilities and prompt detection of any potential issues in the distribution transformer secondary line. The successful implementation of this system holds great promise for the electric cooperative, promising improved operational efficiency and proactive problem-solving for their distribution transformer infrastructure.

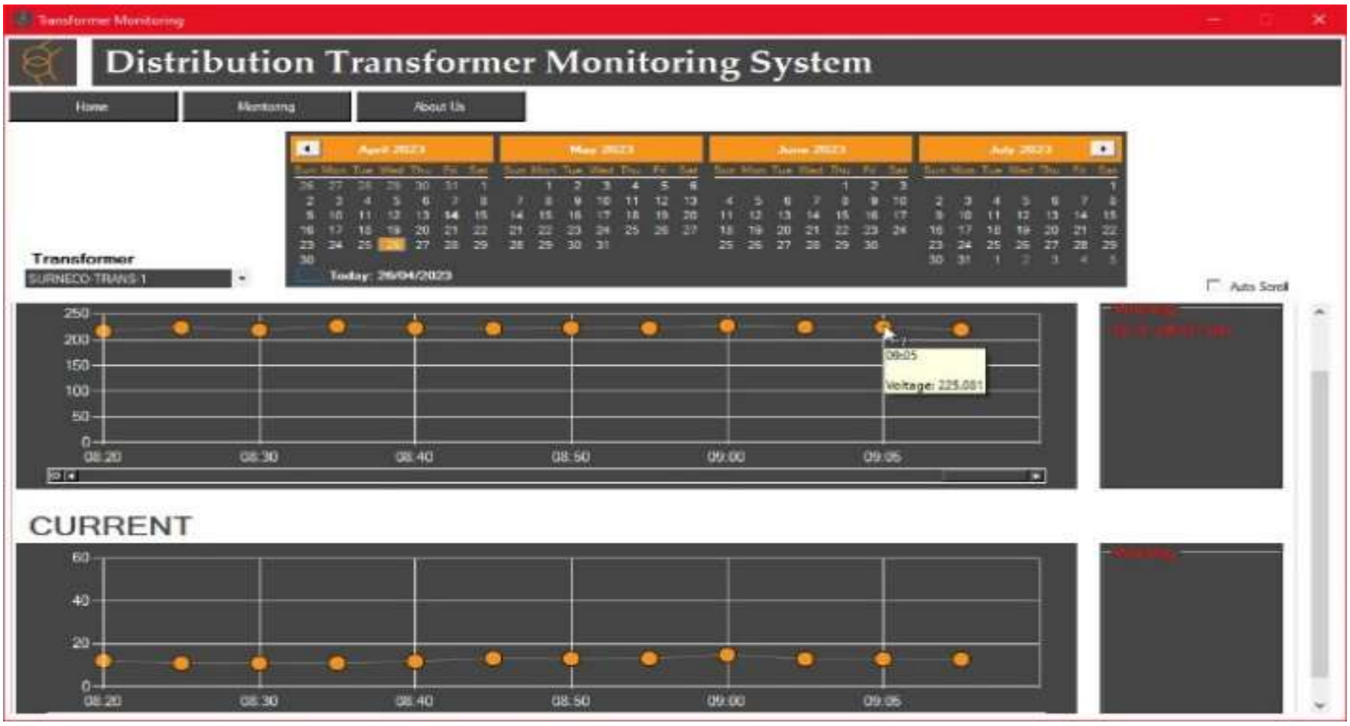

Fig 6. Software for Distribution Transformer Monitoring Systems

Regarding the hardware aspects of the system, the researcher devoted meticulous attention to developing an optimal device enclosure. This enclosure played a crucial role in safeguarding the internal components, ensuring their seamless integration and reliable functionality. The objective was to create a robust and secure environment for the monitoring device, allowing it to withstand various environmental conditions and potential hazards.

As depicted in Figure 7, the system hardware showcased the thoughtfully designed device enclosure, which encompassed all the essential components in a neat and organized manner. This deliberate arrangement guaranteed that each element was installed with precision, minimizing the risk of any internal damage or disruption to the monitoring system.

Additionally, Figure 8 provided a glimpse of the final packing of the entire hardware, exemplifying the researcher's commitment to ensuring the system's portability and ease of deployment. The compact and well-organized packaging allowed for convenient transportation and installation at the desired location within the distribution transformer secondary line.

The development of the hardware played a pivotal role in transforming the conceptualized solution into a tangible reality. The researcher's attention to detail and meticulous planning contributed to the creation of a sophisticated monitoring device, securely enclosed within a robust housing. This protective enclosure was a key factor in enhancing the system's durability and longevity, ensuring its ability to operate optimally in a range of environmental conditions.

Furthermore, the careful arrangement of the components within the enclosure facilitated easy access for maintenance and troubleshooting purposes, simplifying any potential repair procedures. The finalized packing of the hardware added to the overall efficiency of the system, making it a practical and user-friendly tool for the electric cooperative.

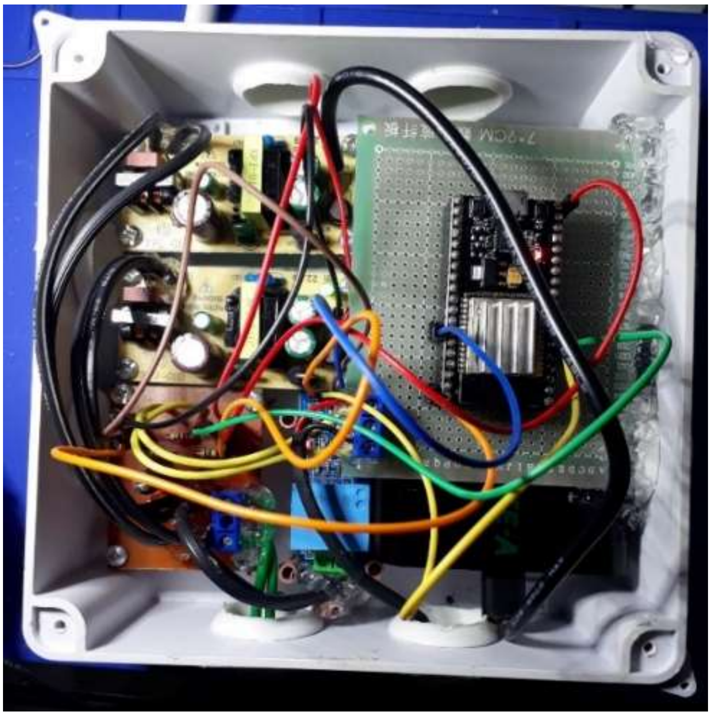

Fig 7. System Hardware

Fig 8. Packaging System Hardware

IV. CONCLUSION AND RECOMMENDATIONS

Conclusion

Based on the study's results, the researchers successfully identified the challenges faced by the Electric Cooperative in monitoring their distribution transformers through interviews. These issues encompassed manual measurements of voltage and current output, difficulty in identifying peak loads, and limited access to a modern monitoring system. To address these concerns comprehensively, the researchers developed a specialized device that significantly simplifies the electric cooperative's monitoring process, eliminating the need for manual labor.

The device efficiently measured the distribution transformer's voltage and current output at regular 5-minute intervals, as requested by the electric cooperative. Data transmission from the sensors to the DTLMS (Distribution Transformer Load Monitoring System) software was successfully established, providing accurate and stable data. The software further presented essential monitoring data through informative graphs and delivered warnings for low voltages while indicating peak loads.

Upon implementation at the Electric Cooperative, the device demonstrated full functionality, with the main microcontroller effectively carrying out the core tasks. It continuously measured the voltage and current sensor outputs, transmitting the data directly to MySQL cloud storage. The microcontroller also filtered data at 5-minute intervals, detecting transient loads, low voltages, and abnormalities in the distribution transformer's output. The successful design and implementation of the IOT based load monitoring device for the distribution transformer secondary line involved enclosing all electronic parts within a waterproof junction box, ensuring comprehensive installation of electrical and electronic components.

To ensure accuracy and functionality, several tests were conducted. The device consistently operated as intended, with the voltage and current sensors continuously measuring the transformer output. The microcontroller operated smoothly, continuously uploading data to cloud storage. The host database, utilizing MySQL, established a reliable connection with the DTLMS software, and the software itself functioned seamlessly after installation on the host computer. The electric cooperative now has easy access to real-time monitoring through the DTLMS software.

Finally, all the objectives of the study were successfully accomplished, leading to the development of an efficient and effective load monitoring device for the distribution transformer secondary line. The device's implementation has significantly enhanced the electric cooperative's monitoring capabilities, streamlining the process and empowering them with valuable real-time data for efficient management of their distribution transformers.

Recommendations

The researcher offers the following recommendations to ensure the optimal implementation of the system:

1. Enrich DTLMS Software Features: To enhance the system's monitoring capabilities, it is crucial to incorporate essential parameters such as power factor, reactive power, real power, temperature, oil level, and smoke detector data. Including these aspects in the DTLMS software will provide a comprehensive and holistic view of the distribution transformer's performance, enabling better decision-making and proactive measures to address potential issues.
2. Software Redesign for Enhanced User Experience: Consider redesigning the software interface to improve its visual appeal and user-friendliness. A well-designed and intuitive interface will enhance user experience and ensure smoother navigation through the monitoring system. Users should find it effortless to access critical information and perform necessary tasks, further optimizing the overall monitoring process.
3. Integrate Transformer Location Mapping: Redesign the software to include a map displaying the distribution transformer's physical location. This added feature will offer valuable geographical insights, enabling users to quickly pinpoint the exact transformer affected by any abnormalities. Such geospatial visualization will aid in swift response and efficient management of transformer-related issues.
4. Develop a Mobile Application: To increase accessibility and convenience, create a dedicated mobile application for users, including the host. This application will enable users to access the monitoring system seamlessly from their mobile devices, regardless of their physical location. Real-time data, alerts, and notifications can be conveniently accessed, empowering users to monitor distribution transformers remotely and respond promptly to emerging situations.

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