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Development Of A Cost Effective Realtime Monitoring System For Lt Distribution

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Abstract: *Low tension distribution systems, integral components of the electrical power grid, face persistent challenges, including overloading, technical losses, and delayed fault detection. Traditional passive networks struggle to meet the demands of modern energy consumption, compounded by the rise of distributed generation. Additionally, the prevalence of energy theft further undermines the efficiency and reliability of these systems. This paper addresses these challenges through the development of a cost-effective real-time monitoring system. By strategically placing sensor nodes within the distribution network, we aim to collect precise data on three-phase voltages, currents, and neutral currents. The incorporation of GPS transceivers ensures accurate location data and time synchronization. Utilizing LoRa technology for data transmission, our solution seamlessly integrates with existing infrastructure, providing real-time monitoring and control capabilities. This transformation is crucial for addressing grid challenges such as delayed fault de- tection and restoration. Furthermore, this work incorporates advanced metering ICs to enhance event detection, tackling the pervasive problem of energy theft. The proposed system offers a comprehensive solution by actively managing the distribution network, optimizing efficiency, and safeguarding against challenges unique to low tension distribution grids. Its cost-effective design allows for easy installation onto existing infrastructure, minimizing financial implications for utilities.*

Keywords: *Real-Time Monitoring Sensor Nodes LoRaTechnology, Advanced Metering IC Low Tension Distribution System*

1. INTRODUCTION

The imperative for real-time monitoring of low tension transmission lines has reached unprecedented significance against the backdrop of a dynamically evolving power distribution landscape. In the current scenario, the power grid operates amidst surging demands for electricity, driven by factors such as urbanization, technological advancements, and shifting consumer patterns. This escalating demand places an immense strain on the existing infrastructure, elevating the risk of inefficiencies, disruptions, and, notably, concerns of energy theft. The contemporary power grid, while robust in many aspects, faces challenges in swiftly adapting to dynamic conditions and proactively addressing evolving threats, including faults and illicit energy consumption.

The existing power distribution infrastructure operates in an environment where the energy landscape is undergoing a transformation. With the increased adoption of renewable energy sources, decentralized energy generation, and a growing reliance on smart technologies, the demands on low tension transmission lines have become more intricate and demanding. The grid now contends with fluctuations in power generation, bidirectional energy flow, and the need for real-time adjustments to maintain stability. Additionally, the geographical expansion of urban areas and the integration of electric vehicles further compound the challenges faced by the grid. In light of these complexities, the need for real-time monitoring becomes not just a necessity but a strategic imperative[1,2,3].

Several research papers have been published on the topic of real-time monitoring of low tension transmission lines. A system that uses electrical components that includes a relay, a thermistor and a transformer to detect have been used to isolate faults that occour in transmission lines. The system is compact, reliable, and can be easily integrated into existing power systems to improve their stability and reliability [4]. Phasor measurement units (PMUs) are also in research papers used to detect and classify faults in the transmission line [5-8]. It is also reported that PMU data can be erroneous and there may be lose of data on the way to the control room. Therefore, some techniques that deal with data corruption issues are proposed in [6-12]. PLC and webservers are also used for automated electrical load monitoring. [13, 14, 15]. IoT technology is used to monitor transmission lines in real-time. The system is capable of detecting faults such as overvoltage, undervoltage, and overcurrent in real-time. [16]. Power spectral density index, Neural networks, k-Nearest Neighbor, SVM and other artificial intelligence techniques have also been used for fault detection and identification of transmission lines [17-21]. The paper concludes that the resultant performance shows sensitivity to noises.

Recognizing these challenges, this work strives to be a transformative force in the landscape of power distribution monitoring. At its core, the Atmel ATM90E36 energy meter IC is chosen for its ability to precisely measure a spectrum of power parameters, providing granular insights into voltage, current, power factor, and energy consumption. This IC serves as the foundational component, enabling the identification of anomalies and potential faults in the system. The STM32 MCU, renowned for its computational prowess, orchestrates the integration of diverse data streams, executing advanced algorithms for real-time fault detection and response coordination. In parallel, the Neo 6M GPS module enriches the system by providing spatial context. It not only aids in pinpointing fault locations but also contributes to a compre- hensive understanding of the grid's geographical intricacies. Simultaneously, the high- precision RTC module ensures accurate timestamping of events, facilitating chronological analysis of data. However, the complexity of the contemporary power grid extends beyond fault detection to encompass the critical concern of energy theft.

Energy theft poses a dual challenge to the grid by causing revenue losses for utility providers and compromising the overall stability and reliability of the system. The clan- destine nature of this illicit activity demands a sophisticated monitoring system capable of differentiating between legitimate energy consumption and anomalous activities indicative of theft. The work also addresses this multifaceted challenge by incorporating advanced features explicitly designed to combat energy theft. The comprehensive approach involves not only detecting abnormal consumption patterns but also strategically mapping areas prone to theft with the Neo 6M GPS module and ensuring precise time stamping of events for forensic analysis with the high-precision RTC module.

2. METHOD

The proposed real-time monitoring system for the LT distribution system is a comprehensive solution composed of two primary components: the sensor node and the base node.

2.1 Sensor node

The block diagram for the proposed sensor node is given in Fig 1. The sensor node is positioned strategically on LT distribution poles. It serves as the cornerstone of the proposed real-time monitoring system. At its core, it incorporates a set of volt age and current sensors designed for monitoring of 3-phase voltage and currents, including the neutral current. These sensors lay the foundation for capturing real-time electrical characteristics, essential for comprehensive insights into the LT distribution system. Data acquired from these sensors undergoes thorough processing through the ATM90E36, an application-specific 3-phase energy monitoring IC from ATMEL semi- conductor. Renowned for its robust features such as RMS measurements, THD monitoring, and precise event identification, the ATM90E36 forms the backbone of accurate and comprehensive data analysis within the sensor node. The data from the ASIC is processed by STM32F103C MCU from STMicroelectronics.This high speed MCU offers a substantial amount of RAM and ROM and serves as the central processing hub. Time synchronization is a critical element addressed through the integration of the DS3231 Real-Time Clock (RTC) from MAXIM, offering precision in timekeeping. In addition to this, the NEO 6M GPS module[22] provides not only accurate time but also a PPS sync signal, enhancing the temporal accuracy of the system.

The sensor node is also equipped with an external 4MB SPI flash memory which serves as a repository for logging events and storing unsent data, preserving critical information for future analysis and system diagnostics.Facilitating seamless communication is a wireless transceiver employing LoRa technology [23] on the 865 to 868MHz frequency. This transceiver enables data transmission between the sensor node and the base node, ensuring timely responses and system re- liability. A 3W flyback-type Switched Mode Power Supply (SMPS) incorporating the TNY288PG IC from Power Integrations is used for ensuring sufficient power supply throughout the system. This SMPS ensures low standby power, crucial for low-power application, and charges a 3.2V LiFePO4 cell, providing sustained power to all sensor node components.

The power supply system gains resilience through the integration of a three-phase half-controlled rectifier, ensuring uninterrupted power supply even under conditions where two phases are unavailable. Surge protection is added through the inclusion of a Metal Oxide Varistor (MOV) with a series resistor [24], fortifying the power supply architecture.

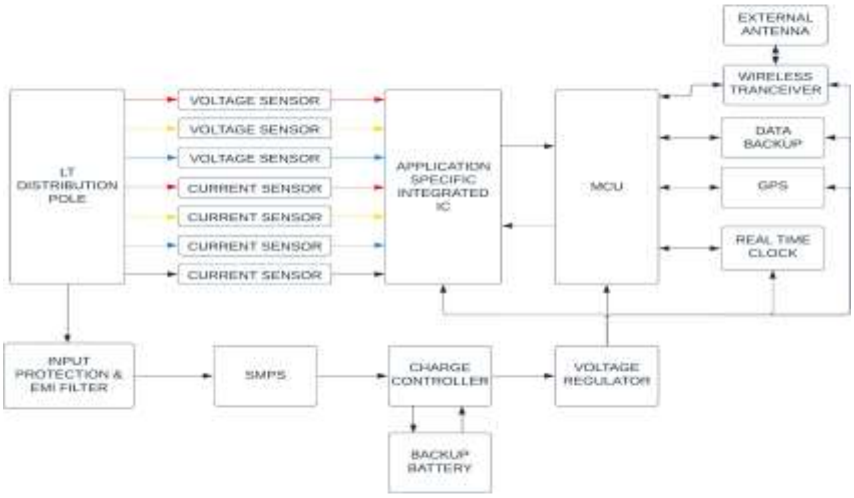

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Fig.1 Block diagram of sensor node

2.2 Base node

The base node plays a crucial role in the system architecture. The block diagram for the same is show in Fig.2.

The gateway acts as a link between sensor nodes and the broader network. It efficiently receives data from sensor nodes and connects to the internet, using a WiFi module for data transmission to the cloud server.

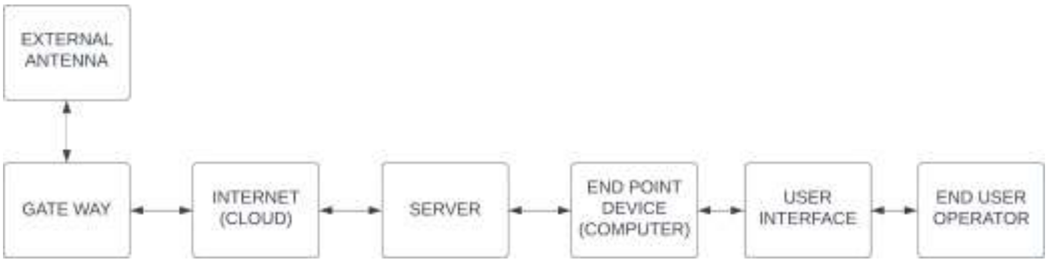

Fig. 2 Block diagram of base node

The cloud server is a central hub, receiving, storing, and managing the data. It makes the information accessible to pro- cessing systems and endpoint devices for analysis. The endpoint device, typically a computer at a nearby substation, communicates with the cloud server to retrieve and interpret the data. Specially designed software hosted on the computer visualizes the information, providing insights for operators and generating graphical representations and event notifications.

The user interface provides visual representation for data analysis. It allows end operators to interact with and interpret information from sensor nodes. The user interface allows the operators to make informed decisions that are based on real-time data, give event notifications, and analytical insights obtained from the LT distribution system. The methodology for the proposed real-time monitoring and fault detection system revolves around the integration of key hardware components and a robust communication infrastructure. At the heart of the system lies the Atmel ATM90E36 energy meter IC, dedicated to acquiring and processing vital power parameters such as voltage, current, and power factor. The STM32 microcontroller unit (MCU) serves as the central control unit, orchestrating data integration, executing fault detection algorithms, and commu nicating with the energy meter IC via SPI for seamless data exchange.

In addition to these components, the system incorporates a Neo 6M GPS module to provide accurate location data, enhancing spatial awareness for fault localization and strategic maintenance planning. A high-precision Real-Time Clock (RTC) module ensures accurate timestamping of events, contributing to chronological analysis and temporal correlation of data.

Communication plays a important role in the system's efficacy. The data acquired by the energy meter IC is transmitted to the STM32 MCU through SPI, facilitating real- time data processing and decision-making. Subsequently, the data is transmitted via LoRa (Long Range) communication, offering low-power, long-range capabilities ideal for remote monitoring applications. LoRa technology ensures efficient and reliable transmission of data from the local system to LoRa gateways.

Upon reaching the LoRa gateways, the data is then forwarded to the cloud for cen tralized storage, analysis, and further processing. This cloud-based architecture enables scalable and accessible data management, providing stakeholders with real-time insights into the performance and health of the low tension transmission lines. The integration of SPI, LoRa, and cloud communication forms a robust data transmission pipeline, ensuring the timely and secure transfer of information from the field to the centralized cloud infrastructure.

3. RESULTS AND DISCUSSION (10 PT)

The testing phase of the system involves verifying the functionality, performance, and reliability of both the sensor node and the gateway. The testing procedures aim to ensure that the system operates as intended and can effectively collect, process, and transmit data from the field to the client application.

3.1. Grid simulation setup

For testing and hosting the sensor node, a small isolated grid setup is created using auto transformers and isolation transformers. The schematic diagram of the testing setup is shown in Fig.3.

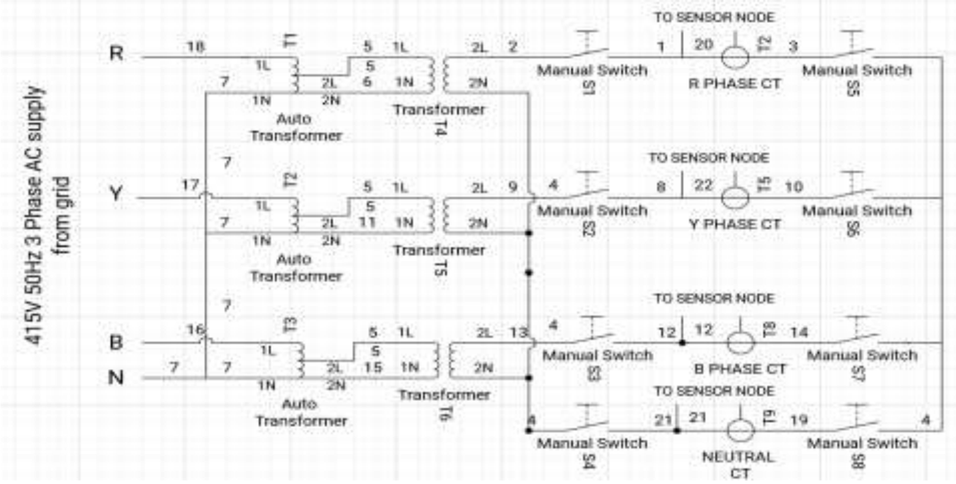

Fig.3 Schematic diagram of testing circuit

The switches S5,S6,S7 and S8 is used for simulating various line fault conditions like LG, LL, LLG and LLL faults[25,26] as shown in Table.1.

Table 1 Fault conditions and corresponding state of switches

Fault condition	S1	S2	S3	S4	S5	S6	S7	S8
Phase R open	Open	Closed	Closed	Closed	Open	Open	Open	Open
Phase Y open	Closed	Open	Closed	Closed	Open	Open	Open	Open
Phase B open	Closed	Closed	Open	Closed	Open	Open	Open	Open
Neutral open	Closed	Closed	Closed	Open	Open	Open	Open	Open
Phase R to Ground	Closed	Closed	Closed	Closed	Closed	Open	Open	Closed
Phase Y to Ground	Closed	Closed	Closed	Closed	Open	Closed	Open	Closed
Phase B to Ground	Closed	Closed	Closed	Closed	Open	Open	Closed	Closed
Phase R and Y	Closed	Closed	Closed	Closed	Closed	Open	Closed	Open
Phase R and B	Closed	Closed	Closed	Closed	Closed	Closed	Open	Open
Phase Y and B	Closed	Closed	Closed	Closed	Open	Closed	Closed	Open
Phase R and Y to Ground	Closed	Closed	Closed	Closed	Closed	Open	Closed	Closed
Phase R and B to Ground	Closed	Closed	Closed	Closed	Closed	Open	Closed	Closed
Phase Y and B to Ground	Closed	Closed	Closed	Closed	Open	Closed	Closed	Closed
Phase R, Y and B	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Open

The simulated grid setup is realised in hardware and is connected with a three phase load in our laboratory as shown in Fig.4.

Fig. 4 Hardware realisation of test circuit

3.2 Test results

Upon power-up, the sensor node undergoes initialization, which includes acquiring a GPS fix for latitude, longitude, and time synchronization. The real-time data like phase voltages, current, phase angles,power factor is send every second and the harmonics data of the three phase currents and voltages are send every 15 seconds and the energy measurement data is send every 30 seconds. From the gateway the sensor data is then send to the client app running on our test PC via WiFi using UDP (User Data Gram) protocol. Fig.5 shows the maps monitor page with the LT pole sensor which shows the location of our electrical lab.

Fig. 5 Maps monitor page with test data

To the simulated grid a three phase resistive load of 3 kW is connected to simulate the distribution system during its nominal condition. The device overview page for the sensor node is as shown in Fig.6

Fig.6 Device overview page with test data

By clicking on the voltage gauges, the variation of voltage with respect to time can be seen. During the test the voltage is varied and the change in voltage is accurately tracked by sensor node which can be seen from the graph. In the final portion of the graph it can be seen that the voltage falls rapidly to 0V, this represents phase loss condition on the respective phases which is simulated by opening the switches from S1 to S4 in the simulated grid. The Phase voltage analysis page with test data is as shown in Fig.7

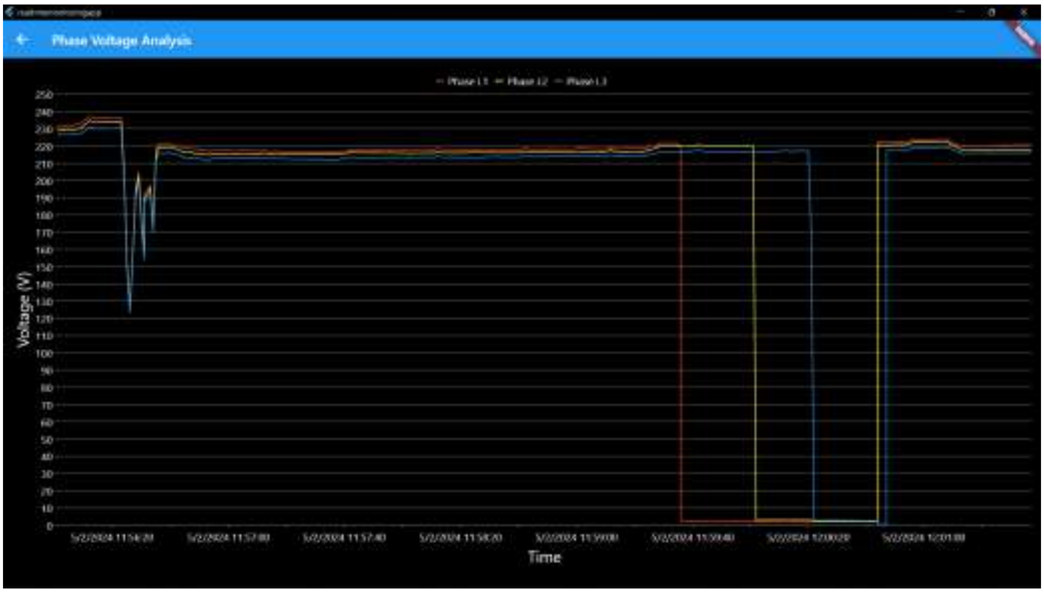

Fig. 7 Phase voltage analysis page with test data
The dynamic variations in current can be observed by clicking the current gauges.

4. CONCLUSION

The real-time monitoring system designed for Low-Tension (LT) distribution systems represents a groundbreaking advancement in the realm of electrical and electronics engineering. This innovative system not only addresses persistent challenges such as over- loading, technical losses, and delayed fault detection but also offers a proactive and comprehensive solution to enhance the efficiency and reliability of power distribution networks. By strategically placing the sensor nodes within the distribution network, the system enables the collection of precise data on three-phase voltages and currents thereby, facilitating proactive monitoring of LT distribution lines. The system cost is reduced significantly by employing LoRa technology for communication
This real-time monitoring system brings many benefits. It's affordable and easy to set up on current infrastructure, helping utilities save money while improving how they operate. By actively controlling the distribution network and making it run better, the system helps solve problems that are specific to low-voltage distribution grids. It also helps build a stronger and more reliable electrical power grid.

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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