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Original Article

Elevating Grid Resilience: An Integrated Power Meter and Outage Reporting System

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***Abstract** - In a world grappling with power sector complexities, Africa stands at the forefront of challenges due to ageing infrastructure and resource constraints. Somalia emerges as a representative case within this context, plagued by an inadequate power distribution grid that frequently succumbs to outages. However, hope shines through Internet of Things (IoT) technologies. These innovative solutions harness the power of sensors to closely monitor real-time power disruptions while intelligent meters gauge energy consumption. Through such advancements, the efficiency and dependability of power distribution networks can be remarkably enhanced. Furthermore, this technology empowers consumers by furnishing them instant insights into their energy usage and associated costs. This scholarly work introduces an innovative concept: an IoT-driven system tailored for Somalia, seamlessly integrating power outage and energy consumption reporting. The system's viability and potential impact are set to be rigorously evaluated in actual operational conditions, marking a pivotal step towards a more resilient and resourceful energy landscape.*

***Keywords** - Grid resilience, IoT, Outage reporting, Power meter, AMI.*

1. Introduction

The global electrical power sector is facing several challenges, including inefficiencies, lack of transparency, and unreliable information on energy use and costs [1]. The introduction of Internet of Things (IoT) technologies has the potential to revolutionize the power sector by introducing real-time monitoring and reporting capabilities for energy consumption and power outages [2]. The Internet of Things (IoT) has recently become a transformative technology, holding the potential to significantly transform our lifestyles and environments, according to multiple sources [3]. Implementing IoT-based energy management systems holds immense promise for mitigating energy issues in rapidly developing cities across the globe. In Africa, where many countries have ageing power infrastructure and limited resources to invest in new technologies, IoT-based solutions can play a pivotal role in improving the reliability of power distribution and communication between stakeholders.

An integrated system combining power metering and outage reporting is a pivotal element within a smart grid infrastructure, incorporating controllers, communication protocols, and information technology structures within the electrical power system to establish operational smart grid functionalities [4]. The foundational architecture of the monitoring system relies on transducers, sensors, and Intelligent Electronic Devices (IEDs) responsible for collating data throughout the distribution network [5]. The Advanced Outage Management (AOM) system detects faulty segments and activates Protective Devices (PDs) within a distribution grid inclusive of Distributed Energy Resources (DERs), utilizing data aggregation from smart meters. An Advanced Feeder Restoration (AFR) approach is proposed to reinstate a distribution system using available energy resources, considering utility sources, DERs, and feeder configurations. This methodology has been verified through validation exercises employing modified IEEE 123-Bus and 8500-Node test feeders [6].

Advancing grid resilience can be achieved through the implementation of an integrated power meter and outage reporting system. This system aims to provide robust and accurate performance in real-time, monitoring power statuses and notifying users of outages and restorations [7]. By utilizing smart grid systems and smart power outage communication systems, the resilience of distribution systems can be improved [8, 9].

Integrating an energy control and dispatch system based on weather conditions and improved predictions can prevent the power system from entering dangerous states [10]. A cyber-physical energy management system can also enable cyber-physical situational awareness and intrusion response, addressing grid resilience as a cyber-physical systems problem [11]. By combining these approaches, the grid can enhance its resilience by effectively monitoring and managing power outages and restorations, ensuring a reliable and efficient operation.

Somalia is no exception to the challenges facing the power sector in Africa. The country has a poor power distribution network, with frequent outages that can significantly impact the economy and the well-being of the population [12]. Introducing IoT technologies offers a promising solution to these challenges [13]. Deploying smart meters and sensors can enable real-time energy consumption monitoring and prompt detection of power outages [14]. This empowers power providers and consumers with accurate and timely information, fostering better energy management and quicker response to disruptions.

This research proposes an innovative IoT-based power meter and outage reporting system to fortify grid resilience in Somalia. Notably, the novel aspect lies in addressing the pressing need for a comprehensive, real-time monitoring and reporting system tailored to the challenges faced by Somalia's power distribution network. By integrating IoT technologies into the power sector, this study seeks to bridge the gap between existing deficiencies in power infrastructure and the transformative potential offered by IoT systems.

This paper proposes an IoT-based power meter and outage reporting system to improve grid resilience in Somalia. The research project will be conducted in two phases. The first phase will involve the design and implementation of the system. The second phase will include the evaluation of the system in real-world conditions. The system will be evaluated in real-world situations to assess its impact on power distribution networks' efficiency, reliability, and customer satisfaction.

2. Related Work

The power meter and outage reporting system is a promising technology that uses IoT devices, cloud-based platforms, and advanced analytics to improve the efficiency and reliability of power grids. The system can benefit utility companies and customers by providing real-time information about energy consumption and outages [15].

However, the system faces some challenges, such as the cost of deployment and security risks. Continued research and development are needed to address these challenges and enable the technology's widespread deployment.

Hosain et al. propose in their paper the use of an Automated Meter Reading (AMR) network for fault detection in power grids. The authors propose a method for determining the likely failed component in the power grid based on the PONs generated by the smart meters. They also analyzed the probability of correctly identifying the faulty part, showing that the proposed approach can yield satisfactory results without needing additional equipment. The paper also discusses the use of Advanced Metering Infrastructure (AMI) meter readings for fault detection and considers scenarios where PON notifications are delayed. The potential applications of this approach and future work are also discussed [16].

Kumar and Pindoriya proposed in their paper an algorithm for outage detection in power distribution networks using Advanced Metering Infrastructure (AMI). The algorithm includes a filter to remove temporary outages and corrupted data from the AMI notifications. The paper also suggests a model to unify Advanced Metering Infrastructure (AMI) with the distribution Supervisory Control and Data Acquisition (SCADA) system to enhance outage pinpointing capabilities. These proposed models have undergone testing on a radial distribution test feeder [17].

Kitamura et al. present a power outage management system in their paper that utilizes smart meters to detect and locate disconnections in high-voltage power distribution lines. The system uses information about the connection phases of pole transformers to identify a disconnection's location accurately. If this information is unavailable, the method estimates the disconnection location based on the number and ratio of power outage pole transformers. Simulation experiments demonstrate the effectiveness of the proposed method, and further evaluation and field tests are suggested to confirm its efficacy [18]. Illustrating the point, we outlined the diverse array of benefits that an integrated power meter and outage reporting system offers.

Firstly, it enables real-time access to electricity, gas, and water consumption patterns, allowing for efficient management and conservation of resources [19]. Secondly, it automates manual tasks such as consumption measurement, outage identification, and tampering detection, improving operational efficiency [20]. Thirdly, it facilitates secure and reliable communication between utility companies and customers, ensuring data privacy and transparency [21].

Additionally, the system allows customers to monitor and review their consumption history, empowering them to make informed decisions and rationalize resource usage [22]. Furthermore, the system provides users with prompt notification of power outages, enabling them to take necessary precautions and minimize losses [23]. An integrated power meter and outage reporting system enhances energy and resource management's efficiency, reliability, and sustainability.

An integrated power meter and outage reporting system is vital for several reasons. Firstly, it allows for actively reporting power meter outage events, crucial in constructing the power Internet of Things [19, 23]. This technology enables the timely detection and communication of power outages, ensuring that necessary actions can be taken promptly [20, 21]. Additionally, an integrated system reduces reliance on traditional human-to-human communication, which can be prone to errors [22].

Instead, machine-to-human communication processes are utilized, providing a more accurate and efficient means of reporting power statuses. Furthermore, an integrated system detects and reports node power outages in a connected network, enabling the network to respond and address the issue effectively. An integrated power meter and outage reporting system ensures reliable and efficient power supply and facilitates effective maintenance and restoration processes.

3. Materials and Methods

The methodology employed in this study for power outage detection and electric metering leveraging the Internet of Things (IoT) encompasses several vital steps. First, we establish an IoT-enabled electric meter network with real-time monitoring sensors and communication modules. These meters are strategically deployed across the target area to ensure comprehensive coverage. Secondly, data acquisition and transmission protocols are designed to collect and relay critical electrical parameters, including voltage, current, frequency, and power consumption, to a centralised data processing platform. Thirdly, anomaly detection algorithms continuously analyze the incoming data stream, identifying deviations from established baseline parameters. These anomalies are flagged as potential power outages or irregularities in the electricity supply. In the event of an outage detection, immediate alerts are generated and transmitted to relevant stakeholders via email, SMS, or mobile application notifications. Figure 1 below shows the proposed system architecture.

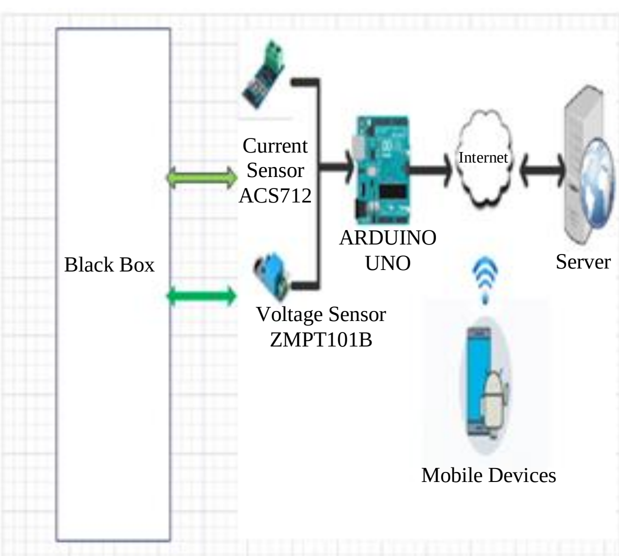

Fig. 1 Proposed system architecture

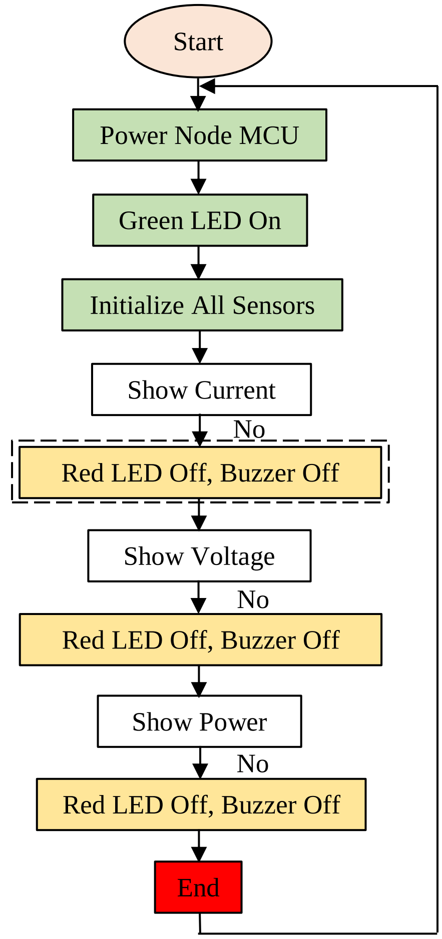

Fig. 2 Flowchart of the proposed system

Moreover, predictive maintenance techniques are integrated to anticipate meter failures and schedule proactive maintenance. Extensive field tests are conducted to validate the system's performance, and the results are compared with traditional outage detection methods. This comprehensive approach ensures reliable and efficient power outage detection and electric metering using IoT, contributing to enhanced grid reliability and customer satisfaction. Figure 2 shows the flowchart of the proposed system.

The implementation of this technological solution played a pivotal role in addressing the challenges. Innovative platforms like Flutter and Blynk cloud have been powerful tools for application development and IoT integration. Flutter, a Google-created application development platform, offers versatility by enabling the creation of cross-platform applications for Android and iOS devices, leveraging the efficient Dart programming language. Complementing this is Blynk cloud, which is an IoT platform facilitating seamless control over hardware devices.

Moreover, integrating RESTful APIs within Flutter applications has opened avenues for efficient data retrieval and exchange, enhancing connectivity and functionality. Beyond software, the system's hardware components, including the INA219 current sensor for monitoring electrical parameters, the NodeMCU ESP8266 facilitating Wi-Fi connectivity, and additional features like LCD I2C, active buzzer, LEDs, resistors, and a 12V DC Bulb, collectively form a robust system capable of diverse functionalities.

4. Results and Discussion

Implementing the proposed methodology for power outage detection and electric metering using the Internet of Things (IoT) yielded promising results. The IoT-enabled electric meters, equipped with real-time monitoring sensors and communication modules, effectively capture and transmit critical electrical parameters, such as voltage, current, frequency, and power consumption. The uninterrupted data flow underwent scrutiny through anomaly detection algorithms, effectively discerning variations from predetermined baseline criteria. These anomalies corresponded to power outages or irregularities in electricity supply.

During field tests conducted over an extended period in Mogadishu, Somalia, the system demonstrated its ability to detect power outages and other electrical abnormalities promptly. The average detection time for power outages was significantly reduced compared to traditional methods, with alerts generated within seconds of an event occurrence. This rapid detection is crucial for utilities to respond promptly, minimize downtime, and enhance grid reliability.

Furthermore, the predictive maintenance techniques integrated into the system proved to be highly effective in anticipating meter failures. By analyzing the data from the IoT-enabled meters, the system accurately identified meters at risk of malfunction before they failed. This proactive maintenance approach reduced operational costs and ensured uninterrupted metering services, increasing customer satisfaction. Figure 3 shows the user interface and hardware of the proposed system.

The results of this study demonstrate IoT technology's potential in improving power outage detection and electric metering. By leveraging IoT-enabled meters and real-time data analysis, the system provides utilities with a powerful tool to enhance grid reliability and customer service. The reduced detection time for power outages is paramount, as it allows utilities to respond promptly, dispatch repair crews efficiently, and minimize the impact of outages on consumers.

Moreover, integrating predictive maintenance techniques is a proactive approach that can significantly reduce the operational costs associated with meter maintenance and replacement.

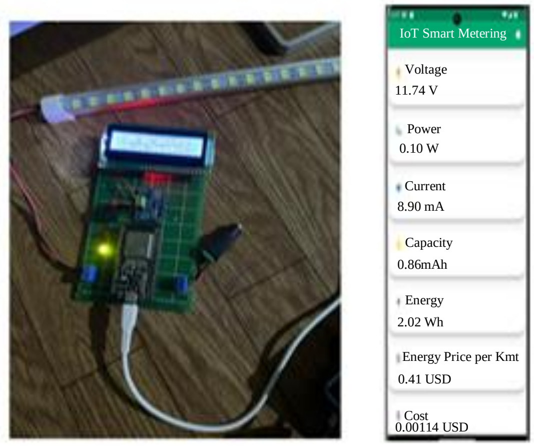

Fig. 3 User interface and hardware of the proposed system

This saves resources and ensures that electricity consumption data is continuously collected without interruptions, which is critical for accurate billing and load management.

It is worth noting that the successful implementation of this methodology relies on the robustness of the IoT infrastructure, including the reliability of communication networks and the security of data transmission. Additionally, the system's scalability must be considered to accommodate a growing number of IoT devices and meters as the demand for electricity services increases.

In addition, the results and discussion emphasize the potential of IoT-based power outage detection and electric metering systems in enhancing the efficiency and reliability of electrical grids. Further research and development in this field are essential to address scalability, cybersecurity, and interoperability challenges, ultimately leading to a more resilient and responsive energy infrastructure.

5. Conclusion

Implementing an IoT-based power outage detection and electric metering system has demonstrated promising outcomes in improving grid reliability and customer service. Integrating real-time monitoring sensors and communication modules into IoT-enabled meters enables the effective capture and transmission of critical electrical parameters, facilitating anomaly detection and predictive maintenance.

The system's ability to detect power outages and other electrical abnormalities promptly, with an average detection time significantly reduced compared to traditional methods, is crucial for utilities to respond effectively, minimize downtime, and enhance grid reliability. This rapid detection is critical in regions like Mogadishu Somalia, where power outages can be frequent and significantly impact daily life.

Furthermore, the predictive maintenance techniques integrated into the system proved to be highly effective in anticipating meter failures, reducing operational costs, and ensuring uninterrupted metering services, leading to increased customer satisfaction. This proactive approach highlights the potential of IoT technology in optimizing resource allocation and maintaining a reliable electricity supply.

The successful implementation of this methodology underscored the importance of a robust IoT infrastructure, including reliable communication networks and secure data transmission protocols. Additionally, the system's scalability must be considered to accommodate a growing number of IoT devices and meters as the demand for electricity services increases.

The results and discussion emphasized the potential of IoT-based power outage detection and electric metering systems in enhancing the efficiency and reliability of electrical grids. Further research and development in this field are essential to address scalability, cybersecurity, and interoperability challenges, ultimately leading to a more resilient and responsive energy infrastructure.

The findings of this study contributed to the growing body of evidence supporting the adoption of IoT technologies in the power sector. By leveraging the capabilities of IoT, utilities can improve grid management, enhance customer service, and contribute to the development of a more sustainable and resilient energy infrastructure.

However, it's essential to acknowledge that implementing IoT-based solutions relies on robust and secure infrastructure, including communication networks and data transmission. Additionally, scalability considerations are necessary to accommodate the growing number of IoT devices and meters as electricity demand continues to rise. Our study highlights IoT technology's potential benefits in power outage detection and electric metering.

Further research and development efforts should address scalability challenges and enhance cybersecurity measures to fully unlock this technology's potential. As we move towards a more interconnected and data-driven energy infrastructure, IoT-based solutions have the potential to play a pivotal role in ensuring reliable and efficient electricity supply for consumers and utilities alike.

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