IJAMEC

INTERNATIONAL JOURNAL OF APPLIED METHODS IN ELECTRONICS AND COMPUTERS

www.ijamec.org

International Open Access

Volume 13
Issue 01

March, 2025

Research Article

User-Centric Design for Automated Metering Power Management Systems: A Case Study in Nigeria

Edemirukaye Ukeh Orodje [a,*], ***Apeh Simon T.*** [b], ***Edoghogho Olaye*** [c]

[a]*Department of Computer Engineering, Federal University of Petroleum Resources, P.M.B. 1221, Effurun, Delta State, Nigeria*
[b]*Department of Computer Engineering University of Benin P.M.B 1154, Benin City, Nigeria*
[c]*Department of Computer Engineering University of Benin P.M.B 1154, Benin City, Nigeria*

ARTICLE INFO

Article history:
Received 30 December 2024
Accepted 23 March 2025

Keywords:
Automation,
Innovation,
Monitoring,
Power Management,
User-Centric Design

ABSTRACT

Nigeria continues to face persistent power management challenges, with frequent outages affecting both urban and rural areas. Technical issues, such as open-circuit faults, contribute to significant losses in the low-voltage section of the power distribution system. Additionally, the lack of transparency in the current power management system fosters distrust between electricity consumers and providers. This study presents the Automated Metering Power Management System (AMPMS)—an integrated solution designed to improve energy monitoring, fault detection, and consumption planning. The system incorporates an automated digital meter, a Home Energy Planner (HEP), a web-based platform, and the "Meter Utility" mobile app to enhance energy management. The AMPMS utilizes a Hall effect current sensor, voltage sensor, Wi-Fi module, and Atmega328p microcontroller, enabling real-time fault detection, outage reporting, and load scheduling. Evaluation results demonstrate the system's effectiveness in reducing power consumption. Households using the AMPMS recorded an energy consumption of 3.02 kWh, significantly lower than the 4.442 kWh observed with conventional prepaid meters—a 31.9% reduction. Furthermore, survey data revealed that 96.3% of respondents experienced delays in resolving open-circuit faults under the existing system, underscoring the need for an automated fault detection and reporting mechanism. By integrating these components, the proposed AMPMS improves power distribution accuracy, enhances consumer control over energy usage, and reduces downtime. The system is scalable for residential, small office, and potential industrial applications in developing nations. This research provides a practical and technologically driven approach to addressing Nigeria's energy management challenges, promoting efficiency, transparency, and accountability in power distribution.

1. Introduction

The 21st century has been marked by a substantial rise in global energy demand, driven by rapid population growth, accelerated urbanization, and the continuous advancement of technology [1]. This increased demand has underscored the need for sustainable and efficient energy management solutions to meet consumption needs while addressing environmental concerns. As a result, there is a growing shift toward smart energy solutions that integrate advanced technologies, such as Building Automation Systems (BAS), which utilize long-range (LoRa) Radio Frequency (RF) technology for automated metering and monitoring of energy usage. This approach ensures accurate billing and more efficient energy management, which is essential given the global surge in electricity demand [6].

In particular, utility providers around the world are exploring the benefits of automated systems that leverage the Internet of Things (IoT) and LoRa RF technology to monitor and manage energy usage in real time [2]. Such systems offer the dual benefits of enabling more accurate billing while reducing energy wastage, as they allow for the automation of key processes, such as power distribution and load balancing.

Nigeria, the most populous nation in Africa, presents a unique case in the global energy landscape. Despite being a leading oil-producing country, Nigeria continues to struggle with ensuring consistent access to electricity for its citizens.

* Corresponding author. E-mail address: orodje.edemirukaye@fupre.edu.ng
DOI: 10.58190/ijamec.2025.115

The country's existing energy infrastructure is characterized by inefficiencies, frequent outages, and a lack of widespread metering, which complicates the effort to provide reliable power to a rapidly growing population [3]. This makes the adoption of advanced energy management technologies not only beneficial but also urgent.

The implementation of smart energy systems, such as Automated Metering and Power Management (AMPM) systems, holds promise in addressing these challenges. However, the Nigerian context introduces additional layers of complexity due to the country's diverse cultural, socio-economic, and infrastructural characteristics. Success in deploying such systems in Nigeria will require a comprehensive understanding of the local conditions and an alignment of technology with user needs [4].

One of the significant barriers to effective energy management in Nigeria is the lack of awareness among consumers regarding their electricity consumption. A study highlights that many consumers leave appliances on after power restoration, which is often driven by the anticipation of future outages [4]. This behaviour contributes to energy wastage, further exacerbating the country's power challenges. While the Nigerian government has made efforts to introduce prepaid meters to promote better energy management, accessibility to these meters remains limited, particularly in rural areas where power infrastructure is weaker [5].

Moreover, the effectiveness of smart metering systems, which rely on a consistent power supply, is undermined by the frequent outages that plague the Nigerian grid. In rural areas, where network signals may be weak or non-existent, the challenge of estimated billing persists, limiting the potential of smart meters to significantly curb power wastage. These issues highlight the importance of taking a user-centric approach to energy management in Nigeria, one that takes into account the specific socio-economic and cultural dynamics of the country's population.

User-Centric Design (UCD) is a design philosophy that has gained significant traction in the field of human-computer interaction. It emphasizes the importance of tailoring technology to the specific needs, behaviours, and expectations of its users [7]. This approach is particularly relevant in the context of deploying AMPM systems in Nigeria, where there is a wide range of socio-economic conditions and diverse energy usage patterns.

While there is a wealth of literature on the global application of smart energy management systems, there is a noticeable gap in the understanding of how these systems can be effectively implemented in socio-economically diverse regions like Nigeria. Studies on energy consumption patterns and user behaviour in Nigeria reveal specific challenges that need to be addressed in the design and implementation of AMPM systems. For instance, energy consumption in urban areas is often driven by different factors compared to rural areas, where access to reliable electricity is more limited [8].

Existing energy management systems, particularly in developing countries like Nigeria, have traditionally failed to account for these nuances, resulting in a lack of user engagement and acceptance [9]. Smart meters, while promising in their ability to provide real-time data on energy consumption, may face resistance or indifference from users if they are not aligned with the specific needs and expectations of the population [7].

As Nigeria faces ongoing energy challenges, the adoption of Automated energy solutions offers a promising path to enhancing energy efficiency, reducing waste, and providing more reliable electricity access for its citizens. Advanced energy management technologies, such as Automated Metering and Power Management (AMPM) systems, present a viable solution to these issues. By adopting a user-centric approach, utility providers can ensure that these systems are tailored to the specific needs and expectations of Nigerian consumers, thereby increasing the likelihood of widespread adoption and long-term success.

1.1. Related works

Extensive research in electricity tariff analysis has advanced the understanding and management of energy systems. Notable contributions include the development of a database analysis tool to assess tariffs, uncovering limitations in existing structures [9]. Evaluations of electricity supply systems in Nigeria and Latvia have similarly focused on enhancing efficiency and forecasting future load demands [10]. Additional efforts include designing home power management systems to promote energy conservation through real-time consumption monitoring [11].

Energy optimization strategies extend beyond tariff analysis, exploring reductions in building energy use via statistical analysis and intelligent building frameworks [12], [13]. Smart metering technologies have also been developed to improve consumer control and billing accuracy [14], alongside methods to analyze power consumption structures and optimize load management through monitoring systems [15], [16].

Advancements in fault detection and energy management have been significant. These include devices for fault detection [17], [18] and integrating data analysis with protection devices to enhance power distribution management [19]. Research into wireless smart metering systems and energy flow prediction models further emphasizes infrastructure enhancement and improved consumption forecasting [21], [22].

More recent studies highlight the integration of emerging technologies into energy systems. Research on active distribution systems underscores the importance of communication protocols and smart metering technologies. Additionally, machine learning applications have advanced energy management through data analytics and system stability. These studies emphasize the multi-faceted approach required to address challenges posed by evolving technologies and societal demands.

However, a review of the literature reveals gaps in integrating automated metering systems with personalized home energy planning and intuitive mobile applications. Many systems lack robust fault detection, continuous monitoring, and user-friendly interfaces for efficient power management. This study addresses these deficiencies through a user-centric design (UCD) approach, as detailed in Section 2.

2. Methodology

The research methodology follows an iterative workflow outlined in Figure 1. It begins with an Investigation stage, which includes a Literature Review that examines research on metering systems and user needs in Nigeria, detailed in section 3.2. Next is Data Collection, where surveys and interviews with electricity users and providers help understand their experiences and challenges, also covered in section 3.2. Then, Data Analysis is conducted using tools like SPSS and Excel to derive insights from the collected data, as described in section 3.3.

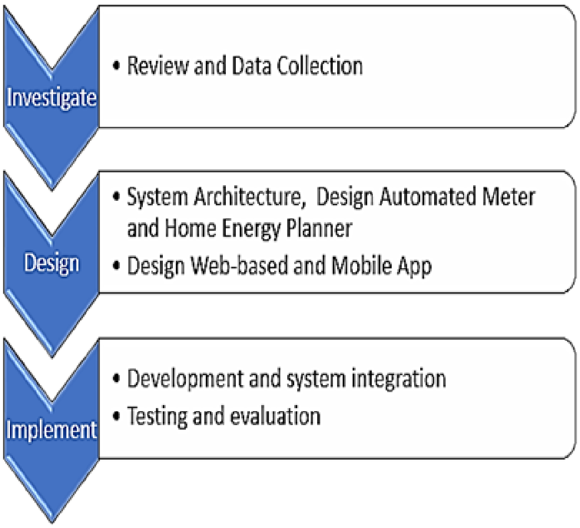

Figure 1. Research Workflow

The following step involves designing the Home Energy Planner, a software application for energy monitoring and load management, and a Mobile App for remote monitoring and data visualization, explained in section 2.4. The Implementation stage starts with Development, designing the AMPMS, Home Energy Planner, and mobile app. Then, System Integration combines system components to ensure smooth data flow. Finally, Testing evaluates system performance and functionality.

2.1. Survey and Development of Questionnaires

A set of twenty-five (25) questions were carefully developed for the questionnaires, arranged to progress from broad to specific topics, aiming to establish respondents' awareness and everyday interactions with the utility company, facilitating the identification of electricity users' issues and requirements. The survey was executed by disseminating questionnaires among the general populace, primarily targeting Evbuobanosa and Benin City and its surrounding areas in Edo State, Nigeria. To determine the representative sample size, the Cochran formula was, with considerations for a maximum variability assumption of 50% and a desired confidence level of 95% with 5% precision employed as shown in Equation 1.

$$n_o = \frac{z^2 pq}{e^2} \tag{1}$$

where $q = 1 - p$, no is the sample size, e the anticipated level of precision, z the chosen critical value of the desired confidence level, p the estimated proportion of a characteristic that is present in the population, and "q" represents the estimated proportion of the population that does not have the characteristic. The 95% confidence level with a 5% precision was also used.

Substituting $P = 0.5$, $q = 1 - 0.5$, $e = 0.05$ and $z = 1.96$ in (1) $gives$ approximate 384

Anticipating 25% return rate, four times the number of required (1,540) questionnaires distributed

2.2. Data Analysis

The survey respondents' data responses were analyzed using various applications and statistical tools. Microsoft Excel (2016) was utilized for graphical analysis and regression, while the Statistical Package for the Social Sciences (SPSS 22 version) was employed for analyzing consumer load consumption responses.

2.3. The System Architecture

The system Architecture consists of the home energy planner, base station mobile software application, and metering system (Figure 2).

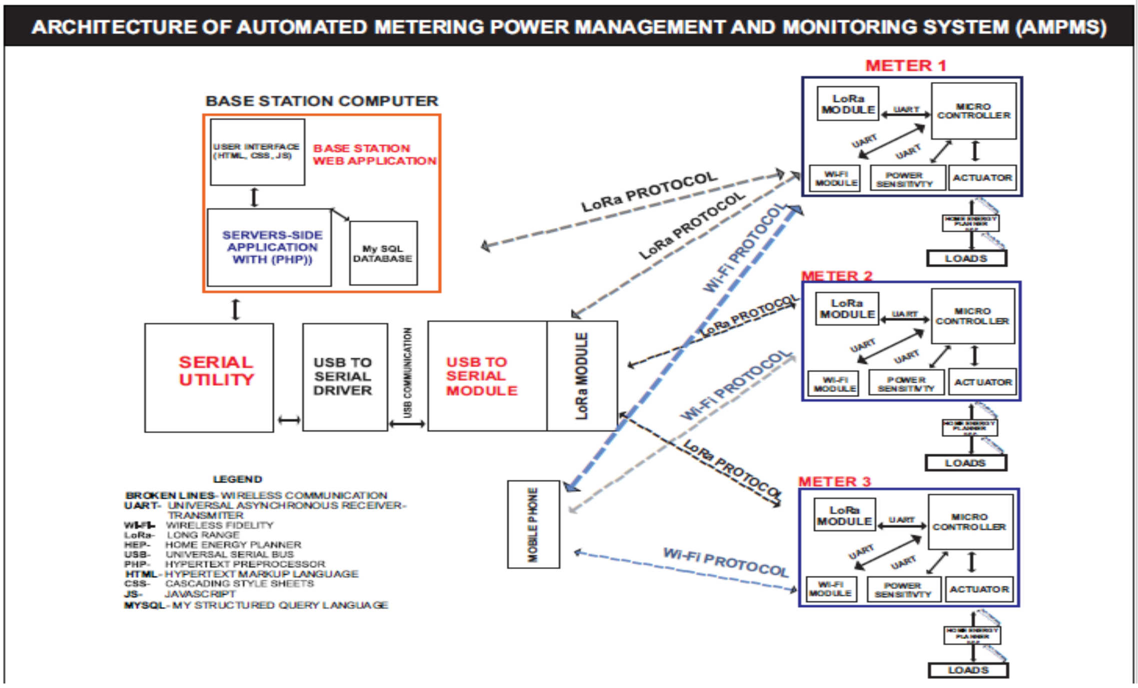

Figure 2. The Architecture of the Automated User centric System.

2.4. The Block diagram for the design of a metering system with a home energy planner

The system block diagram is shown in Figure 3.

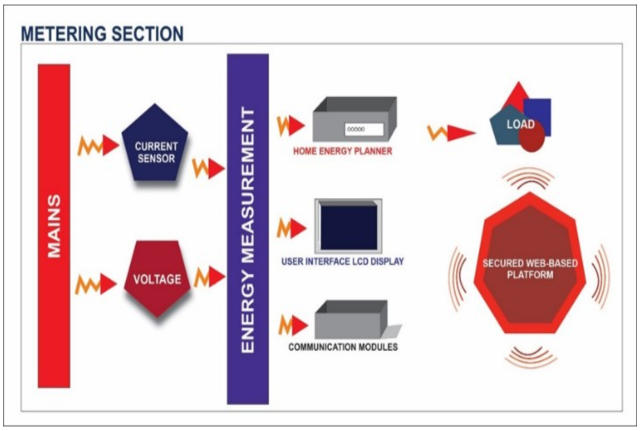

Figure 3. Block diagram of the metering system with home energy planner

The metering system in Figure 2.3 integrates sensors, an energy measurement IC, and a home energy planner to monitor and optimize household energy consumption. Data is transmitted via RF to a secure web platform for real-time monitoring, recommendations, and cost tracking. A user-friendly LCD enhances accessibility, enabling effective energy management and informed, cost-efficient decisions for sustainable consumption.

2.5. Design of the open-circuit fault detection and reporting system

A software computer program is used to design the fault detection and reporting system. The algorithm for running the program is shown in a flow chart in Figure 4.

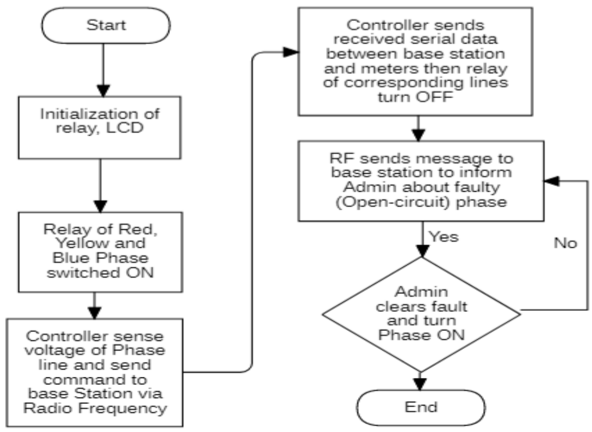

Figure 4. Flow chart of the open-circuit fault detection and reporting system.

The metering system collects voltage, current, and power data from households, sending it to the base station for efficient monitoring. This research uses a web-based system to visualize connected meters and identify open-circuit faults by detecting phase discrepancies. Sensors and RF transceivers track phase currents and voltages, enabling fault detection and automated notifications to improve system management and reliability. The monitoring base station comprises several components: a USB to UART Converter for wireless data transmission, a PC for data processing and billing, a database for storing energy data, a report section for analysis, and a billing section for generating customer invoices based on consumption.

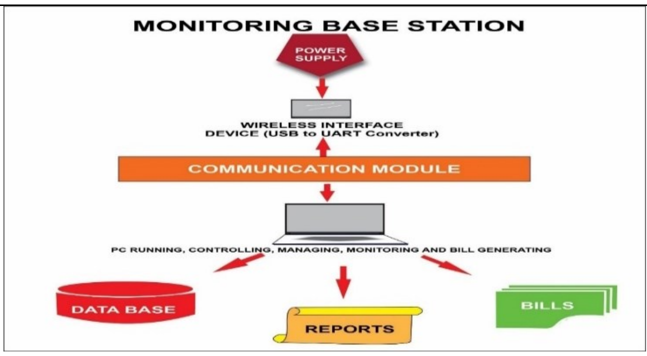

Figure 5. Block diagram of the Monitoring web-based station

2.6. The operation of the metering system with the home energy planner

The Automated Energy Meter allows consumers to monitor and control power usage via a radio network. Managed by an Atmega328p microcontroller, it uses sensors, relays, and Wi-Fi to provide real-time data and efficient energy management.

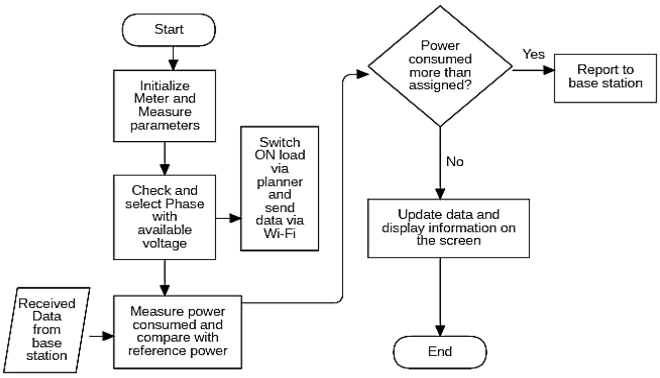

Figure 6. Flowcharts of the metering system with home energy planner.

2.7. The Design Plan of the Home Energy Planner

The Home Energy Planner (HEP) optimizes household energy usage through an ATmega328p microcontroller, RTC, relays, and Wi-Fi for remote control and efficient power management.

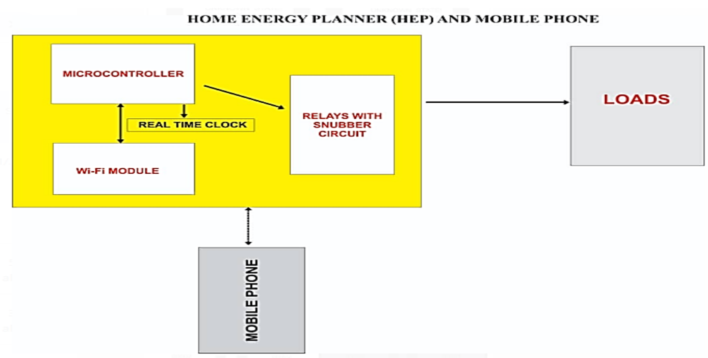

Figure 7. Design plan for the home energy planner

2.8. Design of the mobile application

The use case diagram for the design of the mobile application is shown in Figure 2.8

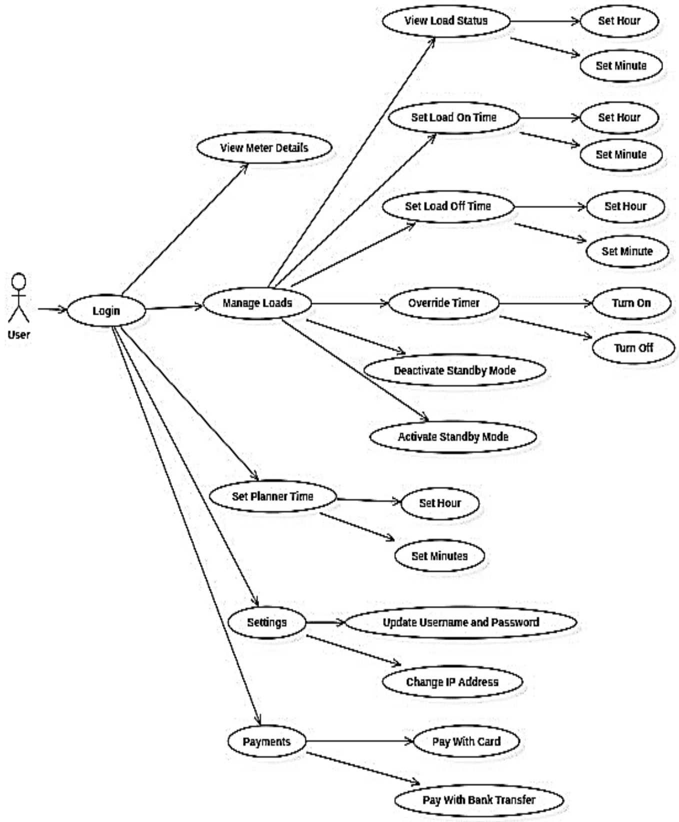

Figure 8. Use case diagram of the mobile application

Figure 8 illustrates a user-centric mobile app, enabling meter management, load control, and settings configuration for convenience.

2.9. Software Static Structure Modelling

The class diagram of the mobile application is shown in Figure 9.The class diagram of the mobile application visually represents the system's structure and interrelations among classes, showcasing their attributes, functions, and associations. Developed using Java, a prominent object-oriented programming language, the diagram outlines base classes serving as templates for others to inherit. Key classes include the device class, enabling attribute retrievals such as meter number, voltage, current, power, and frequency. Methods associated with these classes include getters and setters for meter status, as well as load time details like start and stop times, enhancing functionality and data management within the application.

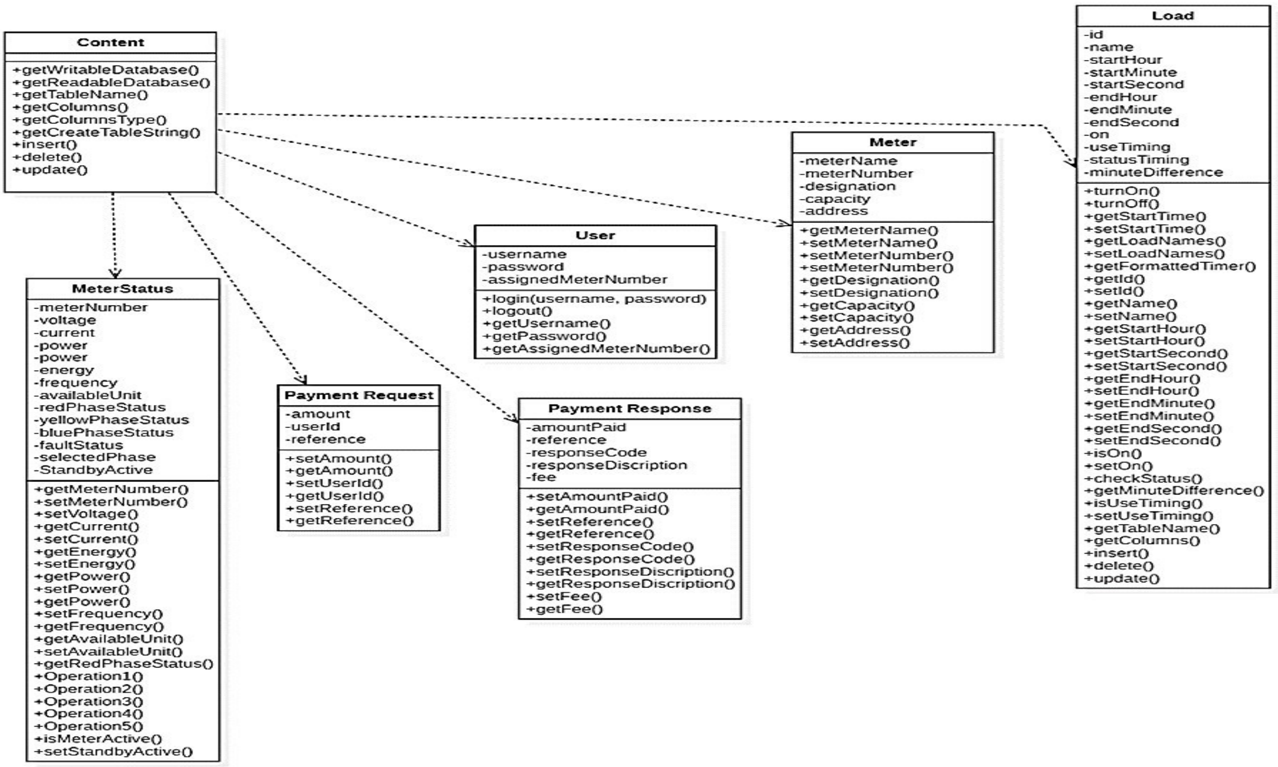

Figure 9. The Class diagram of the mobile Application.

3. The Experimental Setup, testing and overview of the system's Mobile App

The experimental laboratory was meticulously designed to support the implementation of a web-based power management and monitoring system. It featured three advanced meters, three home energy planners, a mobile application, and various electrical loads to evaluate the system's functionality and performance.

Figure 10(b) illustrates the mobile application, a cost-effective home automation tool enabling remote control of household loads, monitoring of power distribution meters, and real-time alerts for power outages.

Complementing this, the home energy planner, accessible via mobile devices over Wi-Fi, integrates seamlessly with sensors, actuators, and relays linked to the main controller. As depicted in Figure 10(c), its design incorporates energy management and control for lighting, heating, cooling, power outages, and other electrical equipment, offering a comprehensive and efficient energy utilization solution.

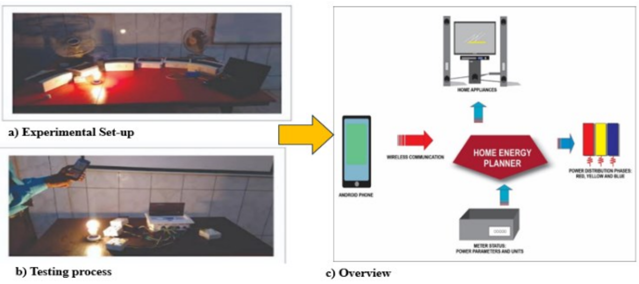

Figure 10. The Experimental Setup, testing and overview of the system

4. Results

This section contains the results of the respondents' questionnaire survey, as well as the graphical analysis of the effectiveness of the existing metering system. It also includes a comparison and findings of the entire system.

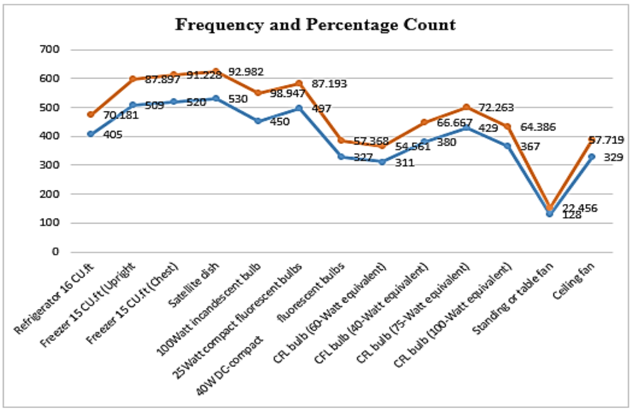

Figure 11. Frequency and Percentage count of Loads left on.

Based on the information depicted in Figure 11, a significant portion of the loads remains powered on continuously. Notably, the 15 cubic feet (Chest) freezer operates at a frequency of 520, which accounts for 92.98 percent of the observed duration. Subsequently, the 25-watt compact fluorescent light exhibits a frequency of 497, representing 87.19 percent of the total duration. In contrast, the standing fan has a frequency count of 128, which corresponds to a relatively lower percentage of 22.46.

4.1. Results for consumer's visits for service wire cut

The result for consumers who always visit the utility company in the event of service wire cut shown in Figure 12

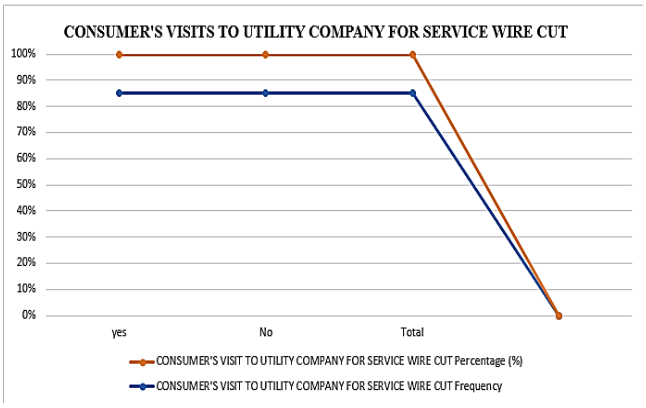

Figure 12. Consumer's visits for service wire cut

According to the data presented in Figure 12, a notable portion of individuals surveyed assert the need to visit the utility office when faced with service wire cut issues. Specifically, out of the 572 respondents, 551 individuals (equivalent to 96.3 percent) confirm that they are required to visit the utility office before receiving assistance. In contrast, a smaller percentage of 21 respondents (3.7 percent) answered negatively, indicating that they do not need to visit the office.

4.2. Results for time taken to fix service wire cut

The time taken to fix service wire cut are shown in Figure 13.

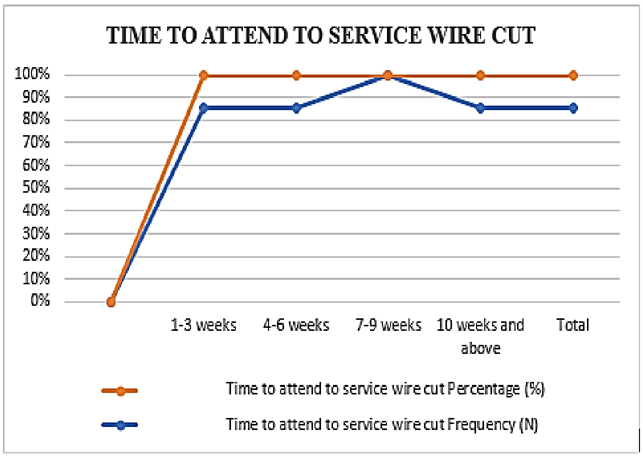

Figure 13. Time to attend to service wire or line cut

According to the data presented in Figure 13, a substantial portion of individuals interviewed express the duration it takes to address service wire cut concerns. More precisely, out of the 572 respondents, 331 individuals (equivalent to 57.9 percent) stated that it takes 10 weeks or longer to resolve the issue. Furthermore, 189 respondents (33.0 percent) report a timeframe of 7-9 weeks. In contrast, a smaller percentage of 25 respondents (4.4 percent) mention 1-3 weeks.

4.3. Screenshot showing results of Base Station and Mobile App

Figure 14 displays the homepage of the Usercentric automated metering, power management, and monitoring system. It is followed by pages for essential functions such as All meter's page, and editing meter information. Other sections include phase status, current power consumption, and security against meter tampering. Figures 11 shows Mobile App screenshots for the meters, detailing meter status, available units, energy consumption, and phase-specific power data. Figures 12 illustrate the load management features for users.

Figure 14. The homepage

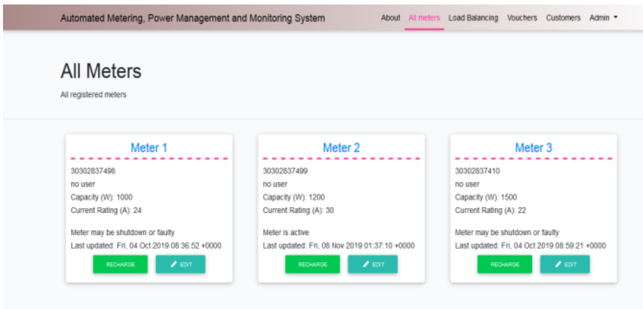

Figure 15. All meter page

The Figure 15 depicts the all-meters page for users from the wireless Automated metering based-station showing the meter status and parameter like the load capacity when one meter is active while others are inactive and the menu bar includes all meter, load balancing, vouchers, customers and administrative sections.

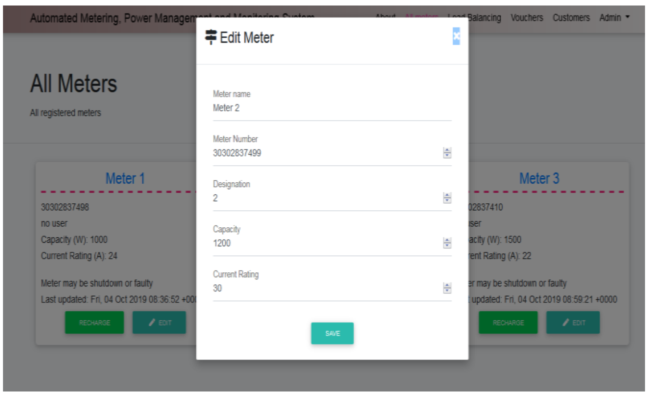

Figure 16. Edit meter page by Admin

Figure 16 illustrates the admin's "Edit Meter Information" page, where current and power capacity are assigned to a meter to enhance power management, ensure safety, optimize consumption measurement, and lower energy costs for consumers.

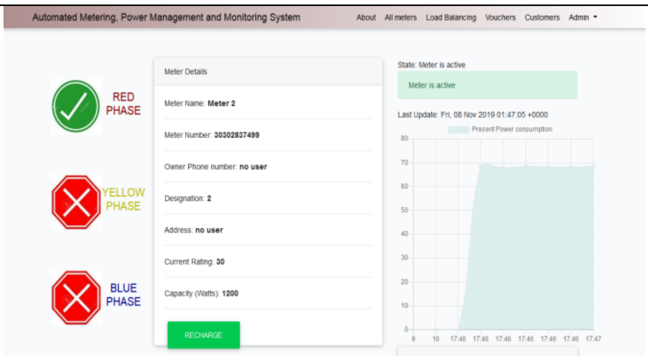

Figure 17. Phase status page when yellow and blue phase are opened (cut)

Figure 17 depicts the web-based automated fault detection and reporting system identifying open-circuit conditions in the yellow and blue phases of a three-phase service wire for users in the power distribution system.

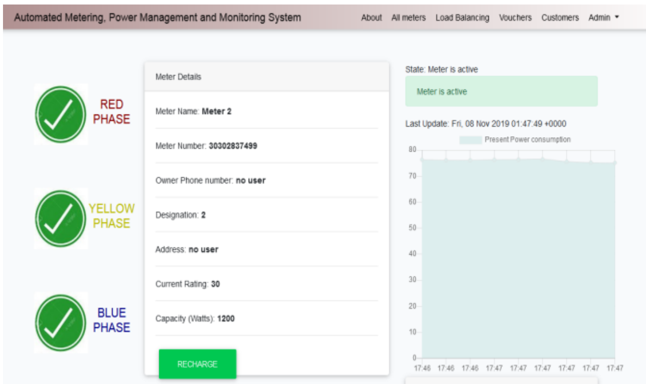

Figure 18. Phase status page after restoration of opened phases

Figure 18 shows the user's power monitoring and management interface on the web-based system after fault resolution and system restoration.

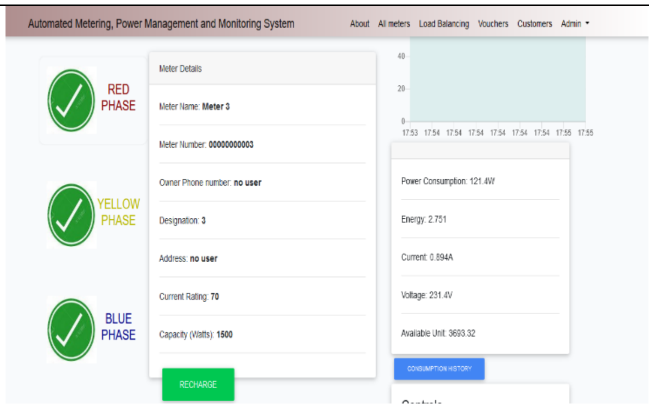

Figure 19. Monitoring users power consumption and metering parameter

Figure 19 illustrates the power monitoring page of the web-based system utilized by the utility company. This page is designed to oversee consumer power consumption and metering parameters under normal operating conditions, following the resolution of any faults and the restoration of the system.

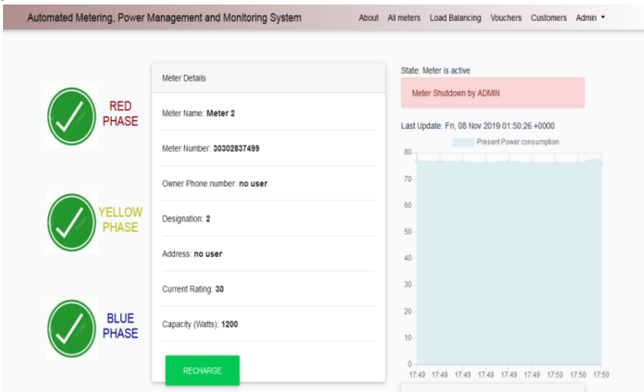

Figure 20. Control page displaying meter shut down by Admin

Figure 20 shows the feature for the system administrator to shut down the web-based system in response to unusual consumer activities, like meter tampering, bypass, overload, which could cause system instability or other risks.

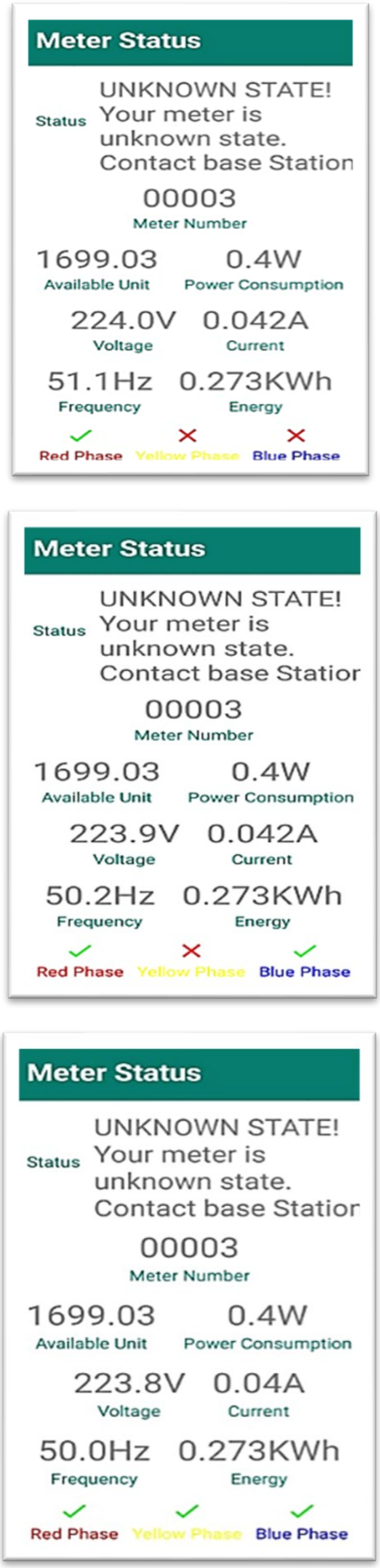

Figure 21. Information of meter on the Mobile App

Figure 21 demonstrates the efficient monitoring of open-circuit faults on the three-phase power distribution system by the mobile app. Moreover, it offers essential meter parameters. The figure shows the status of the system when two phases (yellow and blue) were opened due to a fault. However, after the fault was fixed, all phases were restored. This same scenario applies to meters one and two as well.

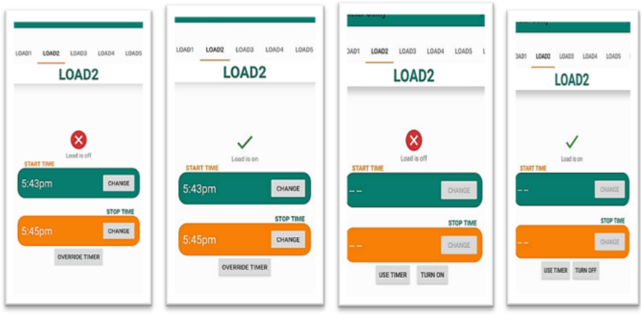

Figure 22. Mobile App's load management interface covering both the timer and override timer sections.

Figure 22 shows the load management feature of the Meter Utility Mobile App, with sections for the timer and override timer for load two when it is off. Using the timer, users can schedule load to turn on at 5:45 p.m., having been set at 5:43 p.m. The override timer allows users to switch on load along with other loads, regardless of their preset schedules. This feature gives users greater control, fostering energy efficiency and cost savings. The Mobile App can manage up to 1,024 loads, providing flexibility for growing residential needs. The same functionality applies to all loads within the app.

4.4. Results of comparison of the Energy Consumption by metering Systems

Figure 23 shows the results of the comparison of the Automated metering system and the Benin Electricity Distribution Company (BEDC) metering system in Nigeria.

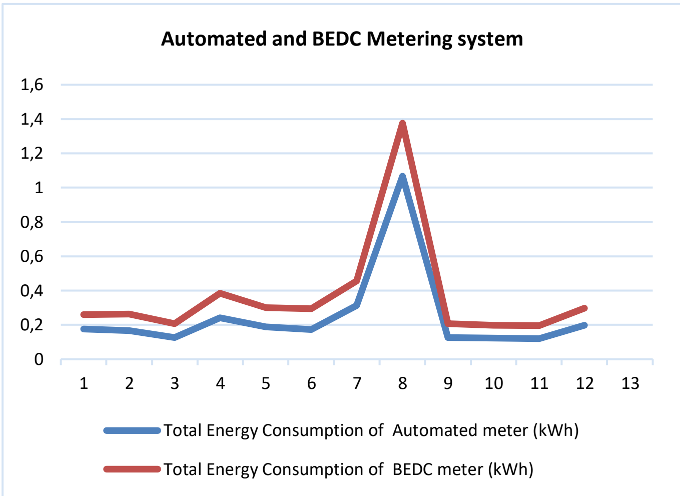

Figure 23. Results of comparison of the metering system

Figure 23 compares energy consumption over four hours, showing the Automated Metering System's efficiency (3.02 kWh) versus the BEDC meter (4.442 kWh).

5. Discussion

This study addresses energy management challenges in Nigeria by proposing an integrated system comprising an automated meter, a web-based platform, a Home Energy Planner (HEP), and the "Meter Utility" mobile app. The system enhances power distribution accuracy, incorporates automated open-circuit fault detection for three-phase lines, and provides functionalities like load control, consumption monitoring, and outage detection. Developed with an Atmega328p microcontroller, the automated meter regulates phase voltage using three-phase sensors, while the HEP and Real-Time Clock (RTC) enable efficient load scheduling.

Evaluation revealed the system's efficiency, with energy consumption reduced to 3.02 kWh compared to 4.442 kWh for existing prepaid meters. The study highlighted consumer demand for better control over electricity use and faster fault resolution, as 96.3% of respondents reported delays in addressing open-circuit faults. By integrating these components, the system offers a comprehensive solution for residential and small office energy management, with scalability for industrial applications in developing nations.

6. Conclusion

This paper presents a comprehensive evaluation of the current metering system's effectiveness in managing load consumption, addressing power management challenges, and monitoring energy usage across various prepaid meters used by diverse consumer groups. Additionally, it introduces a system for detecting and reporting open-circuit faults to enhance overall utility services. The study also proposes an automated metering system that facilitates real-time energy usage comparisons among consumers and enables efficient load monitoring through a newly developed meter utility mobile application.

The results of the study highlight significant energy savings, with the automated metering system consuming notably less energy than conventional prepaid meters during a four-hour comparison period. This underscores the advantages of automated meters over existing models in Nigeria. Furthermore, the integration of the Home Energy Planner and a mobile software application allows end-users to create personalized schedules for automatic activation and deactivation of appliances, effectively reducing unnecessary power wastage.

In Nigeria, an innovative wireless protocol has been developed to efficiently manage and monitor electricity consumption by consumers and the three-phase power distribution network during open-circuit faults. Additionally, a novel integrated system for the management, control, and monitoring of energy consumption has been designed for consumers.

Ethical Declarations

No ethical approval was required for this study, as it did not involve human participants, animal experiments, or personally identifiable data. The research focuses on the design, development, and evaluation of an automated power management system, utilizing hardware components and software tools without any direct human intervention or ethical concerns. All data used for analysis were anonymized and obtained through structured surveys, ensuring compliance with ethical research standards.

CRediT Authorship Contribution Statement

This study was conducted through the collaborative efforts of Edemirukaye Ukeh Orodje, Apeh Simon T., and Edoghogho Olaye. The conceptualization and research design were jointly developed by all authors. Methodology development and formal analysis were led by Edemirukaye Ukeh Orodje, who also managed data curation and software implementation. Apeh Simon T. contributed significantly to the writing of the original draft. All authors actively participated in the research, contributed equally to the study, and approved the final manuscript

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Funding and Acknowledgements

The authors acknowledge that this research was conducted independently, with no external funding or financial support. We appreciate any indirect support received from our academic and professional communities in facilitating this research.

Data Availability Statement

The raw data used in this study were generated and analyzed at the University of Benin, Faculty of Engineering, using a custom experimental setup developed by the authors.

References

[1] International Energy Agency (IEA). (2021). *World energy outlook 2021*. https://www.iea.org/reports/world-energy-outlook-2021

[2] Jain, M., Gupta, S., & Saini, A. (2019). LoRa RF technology for automated energy metering. *International Journal of Electrical Power and Energy Systems*, *112*, 476–483.

[3] Adaramola, M. S., Oyewola, O. M., & Fagbenle, R. O. (2020). Energy sustainability in Nigeria: Challenges and prospects. *Energy Policy*, *150*, 112-126.

[4] Ogbuanya T.C and Nuhu I.N. (2021). Effectiveness of energy conservation awareness package on energy conservation behaviors of off-campus students in Nigerian universities. *Sage Journal*, 1415-1428.

[5] Olayinka, A., & Babatunde, M. (2018). Prepaid meters and energy management in Nigeria: A critical analysis. *African Journal of Energy and Environmental Studies*, *13*(2), 57–64.

[6] Elavarasan, R. M., Pugazhendhi, R., Jamal, T., & Kumar, A. (2020). Smart energy management solutions for energy efficiency. *Renewable and Sustainable Energy Reviews*, *136*, 110564.

[7] Norman, D. A. (2013). *The design of everyday things* (Revised and expanded edition). Basic Books

[8] Adebayo, T. (2019). Energy consumption patterns in urban and rural Nigeria. *Journal of Energy and Environment*, *45*(3), 231–245.

[9] Coughlin, K.,White R., and Bolduc, C. (2006). Analysis Project: A database and Analysis platform for electricity tariffs, Energy Analysis.

[10] Odior, E. O.James K.„ and Udoh, E. (2010). An Intelligent Power Load Control/Switching System Using an Energy Meter and Relay Circuit. *International Journal of Grid and High-Performance Computing (IJGHPC)*, *8*(1), 76-84.

[11] Apeh, S. T., and Mokogwu, C. N. (2013). Development of home power management system. *Nigerian Journal of Technological Research*, *8*(2), 30-34.

[12] Georgievski, I., Degeler, V., Pagani, G. A., Nguyen, T. A., Lazovik, A., and Aiello, M. (2012). Optimizing energy costs for offices connected to the smart grid. *IEEE Transactions on Smart Grid*, *3*(4), 2273-2285.

[13] Nguyen, J., Yap, K. S., Tiong, S. K., Ahmed, S. K., and Mohamad, M. (2013). Nontechnical loss detection for metered customers in power utility using support vector machines. *IEEE Transactions on Power Delivery*, *25*(2), 1162-1171.

[14] Yutami, T. (2014). ICT technologies standards and protocols for the active distribution network. In *Smart power distribution systems* (pp. 205-230). Academic Press.

[15] Oseni, M. O. (2015). Smart metering for accurate energy consumption monitoring. *Nigerian Journal of Energy Studies*, 5(2), 45-58.

[16] Zhang, Y., Wei, J., Zhu, Y., and George-Ufot, G. (2020). Untangling the relationship between Corporate Environmental Performance and Corporate Financial Performance: The double-edged moderating effects of environmental uncertainty. *Journal of Cleaner Production*, *263*, 1-39.

[17] Fabiano, S., Khajepour, A., and Gerlich, A. (2015). Analysis of Power Consumption Structures Africa.. *The International Journal of Advanced Manufacturing Technology*, *82*, 1173-1186

[18] Massaki, S. N., Singh, B. K., and Kumar, V. (2017). A survey on secure transmission in the Internet of things: taxonomy, recent techniques, research requirements, and challenges. *Arabian Journal for Science and Engineering*, *45*, 6211-6240

[19] Sperando, L. G., and Lopez, V. I. (2018). Modeling of end-use energy consumption in the residential sector: A review of modeling techniques. *Renewable and sustainable energy reviews*, *13*(8), 1819-1835.

[20] Liu, Y., Ma, X., Shu, L., Hancke, G. P., and Abu-Mahfouz, A. M. (2020). From Industry 4.0 to Agriculture 4.0: Current status, enabling technologies, and research challenges. *IEEE Transactions on Industrial Informatics*, *17*(6), 4322-433

[21] Mukovhe, M. S., Zaki, S. A., Rijal, H. B., Hagishima, A., and Ali, M. S. M. (2023). Thermal comfort and occupant adaptive behaviour in Japanese university buildings with free running and cooling mode offices during summer. *Building and Environment*, *105*, 332-342.

[22] Seongwoo Lee, M., Murari, K., Rege, A., Cauwenberghs, G., and Thakor, N. V. (2024). VLSI potentiostat array with oversampling gain modulation for wide-range neurotransmitter sensing. *IEEE Transactions on Biomedical Circuits and Systems*, *1*(1), 63-72.