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COLLEGE OF SCIENCE AND TECHNOLOGY

AFRICAN CENTER OF EXCELLENCE IN INTERNET OF THINGS (ACEIoT)

Research Thesis Title:

"Advanced IoT-Based Smart Electricity Metering System with Automated Energy Updates and Predictive Usage Insights"

A dissertation submitted in partial fulfilment of the requirements for the award of masters of science degree in internet of things: wireless intelligent sensor network or Embedded computing system

Submitted By

UMUTONI Albertine **(Ref. No:** 222012773**)**

JULY, 2025

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UMUTONI Albertine **(Ref. No:** 222012773**)**

Supervised by:

Prof. Kayalvizhi Jayavel

Dr. Peace Bamurigire

JULY, 2025

DECLARATION

I, **Albertine UMUTONI,** a Master's student at the African Center of Excellence in Internet of Things, University of Rwanda, hereby declare that this research thesis titled "**Advanced IoT-Based Smart Electricity Metering System with Automated Energy Updates and Predictive Usage Insights**" is my original work and has not been previously submitted to any academic institution for the conferment of a degree.

Name:

Albertine UMUTONI

Ref: 222012773

Date ………01.05.2025………………….

Signature …………………………………

BONAFIDE CERTIFICATE

This is to certify that the submitted Research Thesis report represents the original work completed by **Albertine UMUTONI** (**Ref. No 222012773),** an MSc. IoT-WISNeT student at the University of Rwanda - College of Science and Technology -African Center of Excellence in Internet of Things (IoT) during the academic session 2023/2024.

This thesis has been submitted under the guidance of **Prof. Kayalvizhi Jayavel** and **Dr. Peace** Bamurigire.

Main Supervisor: **Prof. Kayalvizhi Jayavel**

Date 28/07/2025

Signature

Co-Supervisor: **Dr. Peace Bamurigire.**

Date 29/07/2025

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The Head of Masters studies and Trainings, ACEIoT

Dr. James RWIGEMA

Signature:

Date:

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ABSTRACT

The growing demand for sustainable energy management has exposed the limitations of traditional prepaid electricity metering systems, especially in developing countries like Rwanda. These systems often lack automation, real-time usage tracking, and predictive capabilities, resulting in user inconvenience, billing inefficiencies, and unexpected power outages. This research focuses on the design and development of the Smart Electricity Metering System with Automated Energy Updates and Predictive Usage Insights (SEMSAP)—an advanced solution that integrates Internet of Things (IoT) technologies along with machine learning techniques to optimize energy tracking and management.

The system architecture integrates ESP8266 microcontrollers, current and voltage sensors, a GSM module with a SIM card for SMS functionality, and wireless communication modules to enable real-time energy tracking and automated balance updates. The GSM module is specifically used to send SMS alerts to users when their remaining energy reaches a predefined threshold, such as one unit—helping them avoid unexpected service interruptions. User interaction is provided through both a web dashboard and a USSD-based interface, ensuring accessibility in areas with limited internet connectivity. A machine learning model, specifically a Random Forest Regressor, is employed to forecast monthly electricity consumption using historical transaction data, improving financial planning for consumers. The model achieved a Mean Absolute Error of 3887.87, Root Mean Squared Error of 4642.37, and an R^2 score of -0.16, indicating reliable performance for real-world applications.

Field tests in Rwanda’s Gasabo District validated the system’s ability to reduce operational bottlenecks, improve user satisfaction, and support national goals for digital transformation in the energy sector. By automating prepaid electricity updates and offering predictive insights, SEMSAP contributes a scalable, intelligent, and user-centered approach to modern energy management in emerging economies.

Keywords: IoT, Smart Metering, Energy Management, Predictive Analytics, Random Forest, SEMSAP, Rwanda.

LIST OF ACRONYMS

ACEIoT	: African Center of Excellence in Internet of Things
IoT	: Internet of Things
WISeNet	: Wireless Intelligent Sensor Network
AI	: Artificial Intelligence
GSM	: Global System for Mobile Communication
IDE	: Integrated Development Environment
LCD	: Liquid-Crystal Display
LED	: Light-Emitting Diode
Wi-Fi	: Wireless Fidelity
LED	: Light Emitting Diode
LCD	: Liquid Crystal Display
ML	: Machine Learning
EUCL	:Energy Utility Corporation Limited
REG	:Rwanda Energy Group
V	: Voltage
C	: Current
E	: Energy
ESM	: ELECTRIC smart meter
P	: Power
DC	: Direct Current
SEMAP	: Smart Electricity Metering System with Automated Energy Updates and Predictive Usage Insights
I2C	: Inter-Integrated Circuit
GSM	: Global System for Mobile Communications
ESP	: (Espressif Systems) microcontrollers
AC	: Alternating Current

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CHAP1. GENERAL INTRODUCTION

Introduction

Electricity plays a central role in driving both social and economic progress in today's worlds [1][2]. With the continuous rise in electricity consumption driven by technological advancements, industrial growth, and automation there is a growing need for energy management[3][4] . Effective energy management has become increasingly crucial in today's rapidly evolving world. A smart meter plays a vital role in energy management, functioning as an electronic device that tracks energy consumption in real time and communicates information to utility providers to support monitoring activities [5][6]. Traditional energy meters, which have been utilized for many years, mainly function to record consumption data. However, these conventional systems encounter major limitations, particularly their inability to deliver real-time insights into energy consumption, making it challenging for users to effectively manage their usage. Technological advancements have facilitated the integration of electricity meters with multiple innovations, particularly IoT technology [7]. This transformation has enabled energy meters to operate efficiently while providing real-time data monitoring and control. As IoT enables physical devices under the use of advanced microcontrollers combined with sensors, electronic components, software, was linked together by the internet performing a specific defined task, allowing them to be accessed and controlled remotely from any location [8][9].

Monitoring energy usage is one of the most impactful applications of IoT today. The growing use of smart meters has driven the development of more advanced and creative solutions in the smart grid sector, especially in the area of remote data communication technologies. The grid refers to a system made up of power generation stations and transmission lines that deliver electricity from the source to end-users. Smart meters typically track a household's overall electricity usage a few times throughout the day. However, having access to real-time energy consumption data can greatly support the creation of innovative solutions. To overcome existing challenges, Various IoT technologies have been integrated into smart energy systems, including the use of an ATMEGA328 microcontroller connected to an ESP8266 Wi-Fi module, along with a combination of sensors and actuators. This setup enables the real-time monitoring of household electricity consumption by capturing live energy measurements [10].

Incorporating machine learning into smart energy metering has significantly enhanced the capabilities of these systems. In this study, a Random Forest Regressor, a type of supervised learning algorithm, was used to analyze past electricity payment data and accurately predict future energy purchases. This predictive approach helps users manage their electricity budgets more effectively by anticipating monthly consumption. By integrating machine learning with IoT technology, smart meters can now offer real-time monitoring and personalized insights, supporting smarter energy use and improved user experience [8].

This study also aims to introduce an advanced IoT-driven smart electricity system developed for automated energy updates and predictive insights. The system is built around the ESP8266 microcontroller, which manages all operations. It features both online (dashboard-based) and offline (USSD code) methods for updating energy credits after purchase. Additionally, the system It is capable of sending SMS notifications when the energy level falls below a specified threshold. To improve user experience and forecasting, a machine learning approach—specifically utilizing a Random Forest Regressor—is incorporated to predict the next energy purchase based on historical consumption data.

By leveraging real-time monitoring, automation, and predictive insights**,** this study aims to contribute to smarter electricity management solutions that enhance consumer convenience, improve service reliability, and optimize energy consumption**.** The next section will provide a detailed background on existing electricity metering systems, discussing their limitations and the motivation for adopting an IoT-based approach to improve energy management in Rwanda.

Overview and Background

An energy meter is a vital component of the electrical system, designed to measure and display the amount of electricity consumed, primarily for billing and monitoring purposes. Conventional electricity meters have been commonly used since the late 1800s[11]. In modern power systems, certain meters are capable of enabling data communication between devices and can also contribute to the generation and distribution activities within the electric grid.

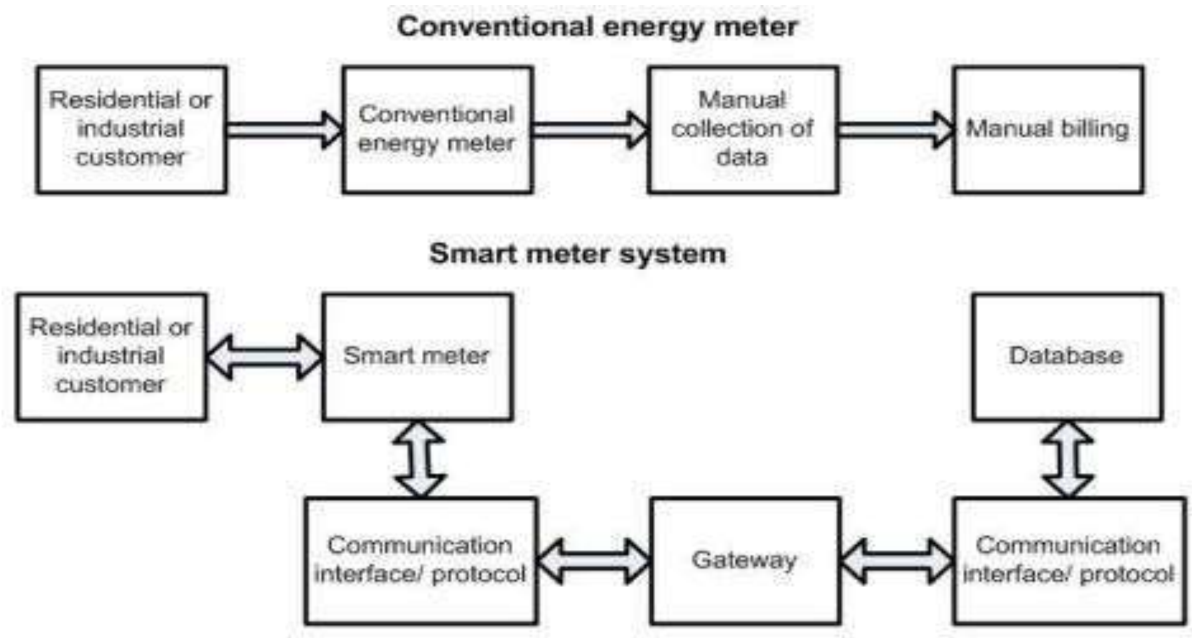

Figure 1:Architectural representation of a conventional and smart energy meter

Figure1[12] illustrates the functional differences between conventional energy meters and smart meter systems. The conventional meters, primarily used in the early stages of energy monitoring, relied on manual data collection and billing processes, which were often inefficient and prone to human error. On the other hand, smart meter systems automate data collection through real-time monitoring and communication protocols, allowing smooth integration with databases and enabling remote access. This automation makes smart meters more efficient and dependable for modern energy management compared to traditional metering method[13][14]. Although most of today's electricity meters are digital I mean smart meters but they still have a few limitations.

Smart meters have a crucial role in modern energy management by facilitating real-time monitoring of electricity consumption and transmitting usage data directly to utility providers for analysis and oversight. Smart meter deployment began globally in the early 2000s as part of broader efforts to enhance energy efficiency and grid intelligence[15]. According to a study by Allied Business Intelligence Research, it was projected that by 2021, over 1.1 billion smart meters would be deployed globally. Among these, electric smart meters (ESM) are anticipated to dominate, representing more than 70% of the total smart meters installed[16].

However, energy access and management differ significantly across different regions of the world. In developed countries, smart grids and automated metering infrastructures are widely adopted, enhancing energy efficiency and reducing operational costs Over the past few years, the deployment of smart meters in both residential and commercial environments has gained momentum across different regions. Countries like the United States and those in Europe have been implementing smart metering technologies for an extended period, while regions such as Australia and Canada have more recently initiated their deployment efforts [15]. A recent study reveals that smart meter deployments in 35 developing countries across areas such as Central and Eastern Europe, Eurasia, Latin America, the Middle East and North Africa, South Africa, and Southeast Asia resulted in more than a twofold growth in their numbers between 2012 and 2013. Additionally, Pike Research forecasts that global smart meter deployments will grow substantially, increasing from 10.3 million units in 2011 to 29.9 million units by 2017. Italy and Sweden have already achieved nationwide implementation of smart meters, while large-scale deployment efforts are currently underway in countries such as Finland and Spain. In Bangladesh while it has a large population in rural and urban areas, users were still required to manually check their electricity meter readings, which often led to inconvenience and inefficiencies in energy monitoring by 2015.

Rwanda, currently categorized as a developing nation, aims to transition toward middle-income status. In order to achieve this milestone, the government has established an ambitious goal of providing complete electricity access to all citizens by 2024 [12].

The rise of the Internet of Things (IoT) has transformed energy management by facilitating smart energy metering systems that offer real-time monitoring and automated energy updates, and predictive analytics[17]. IoT technology allows seamless integration of smart meters with digital payment platforms, ensuring that electricity balances are updated automatically upon purchase without human intervention. In addition to update the time for energy meter recharges, smart meters can provide real-time notifications to alert consumers when their remaining energy reaches a critical level, reducing the risk of sudden disconnections. Furthermore, IoT-driven predictive analytics can help users plan their electricity expenses for next month based on historical data.

Considering the current limitations of prepaid electricity metering systems, this study seeks to develop and implement an advanced IoT-driven smart electricity metering solution. The proposed system will ensure that electricity balances are updated automatically upon purchase, eliminating the need for manual code entry. Additionally, real-time notifications will be integrated to alert consumers when their remaining energy drops to one unit, allowing them to recharge in advance and avoid unexpected power outages. Furthermore, a predictive analytics model will be incorporated to estimate next month's transactions based on historical data, enabling users to plan for the upcoming month's energy consumption accordingly. By addressing these critical issues, this study aims to support the creation of a more effective, user-friendly, and intelligent electricity metering solution that aligns with modern energy management trends.

Motivation

The growing demand for efficient and sustainable energy management highlights the limitations of manual prepaid electricity metering systems, which remain prevalent in Rwanda. These Prepaid meters rely on manual token input, lack real-time tracking, and do not incorporate predictive analytics. As a result, users experience inconvenience, unexpected power outages, and difficulty budgeting for electricity expenses due to the absence of consumption forecasts. Moreover, utility companies encounter difficulties in demand forecasting and revenue management due to the lack of automated data processing**.** The integration of Internet of Things (IoT) and Machine Learning (ML) technologies into energy metering improves automation, enabling real-time energy balance updates, instant consumption notifications, and predictive insights for better customer budget planning. To address these challenges, this research proposes the "Advanced IoT-Based Smart Electricity Metering System with Automated Energy Updates and Predictive Usage Insights (SEMSAP)". This system aims to replace manual token input with automated updates, enhance user experience through real-time notifications, and improve electricity distribution efficiency by providing predictive energy consumption insights**.** This study is motivated by the need to modernize Rwanda's electricity metering infrastructure, promoting efficient energy consumption, reducing operational inefficiencies, and enhancing service reliability. Additionally, this research aligns with global advancements in smart energy solutions and Rwanda's digital transformation initiatives. It contributes to the development of a scalable, IoT-driven electricity management framework that enhances data accuracy, automation, and predictive analytics for improved decision-making.

Problem Statement

Electricity metering is essential for efficient energy management. However, in Rwanda, 99.7% of electricity meters are prepaid and rely on manual token input, leading customers to estimate monthly costs rather than understanding actual consumption in kilowatt-hours, which complicates energy budgeting[18]. Traditional prepaid meters also lack real-time usage notifications and predictive analytics, increasing the likelihood of unexpected power disruptions and reducing overall user convenience. The adoption of smart meters with real-time tracking and predictive capabilities could address these issues[19].

Although various studies have examined IoT-based smart metering systems, most existing implementations focus on remote data transmission, web-based monitoring, and real-time analytics. However, these systems do not fully automate energy balance updates and have the prediction of different type including thief detection, maintenance[20] and Enable user to manage the Electricity Expense[21]. Furthermore, there is no specialized IoT-integrated smart metering solution designed to suit Rwanda’s specific energy infrastructure and consumer needs.

To address these challenges, this research proposes the Advanced IoT-Based Smart Electricity Metering System with Automated Energy Updates and Predictive Usage Insights (SEMSAP). The system aims to eliminate manual token entry, enable real-time electricity tracking, and integrate predictive analytics to assist users in managing future energy consumption. Given Rwanda’s increasing electricity demand and the government's push toward digital transformation (Vision 2050), the lack of real-time smart metering solutions hinders effective energy management and financial planning by users.

Study Objectives

General Objective

This research seeks to assess the existing prepaid meter in Rwanda result to design, implement, an IoT-enabled smart electricity metering system in Rwanda. The system will facilitate automated energy balance updates, provide instant notifications when consumption reaches critical levels (i.e., one unit**),** and integrate predictive analytics to estimate future electricity usage, helping users optimize their energy budgeting and management.

Specific Objective

This study has the following specifics objective:

1. To evaluate the current energy metering system in order to highlight the necessity for developing an automated IoT-based energy management solution.
2. Design and build an intelligent electricity metering system based on IoT technologies, incorporating machine learning algorithms for automated energy management, real-time monitoring, and predictive analytics.
3. Implement and optimize a user-centric notification and alert system within the Advanced IoT-Based Smart Electricity Metering System (SEMSAP) to improve user engagement, real-time energy tracking, and service continuity.
4. Conduct a thorough system implementation, followed by rigorous testing and validation, to evaluate the system's accuracy, reliability, efficiency, and impact on energy consumption management.

Research questions

1. What shortcomings exist in Rwanda's current energy metering system, and how do they support the case for transitioning to an automated IoT-driven energy management approach?
2. In what ways can a smart metering solution leveraging IoT technologies be developed to enable automatic energy credit updates and deliver real-time consumption feedback?
3. How do instant alerts and real-time notifications enhance customer experience and ensure uninterrupted service in IoT-enabled smart electricity metering systems?
4. How effective, accurate, and reliable is the developed SEMSAP system in real-world energy management applications?

Study Scope

This study focuses on the development and implementation of an IoT-enabled smart electricity metering system in Gasabo District, Kigali, Rwanda [17]. The system is designed to automate energy balance updates, remove the need for manual token input, and provide instant usage notifications. By incorporating machine learning models, particularly the correlation matrix and random forest regressor, the system improves electricity consumption forecasting, allowing prepaid residential users to manage their energy usage more efficiently. Additionally, It ensures that purchased energy is automatically updated, sends alerts when the balance is low, and assists users in planning their future electricity expenses.

The system relies on Wi-Fi connectivity to facilitate real-time data transfer between the ESP8266 microcontroller and a cloud-based server, ensuring efficient communication between smart meters, backend databases, and user applications. Users can conveniently access their transaction details and energy usage insights through a dashboard (web/mobile app) or a virtual phone interface (USSD/SMS), ensuring accessibility across different platforms. Field trials were conducted in selected households to assess the system's performance, accuracy, and usability, generating valuable feedback for further enhancements and real-world deployment.

Significance of the Study

The integration of IoT-powered smart metering and machine learning-based forecasting enhances service efficiency, energy distribution, and financial sustainability for both electricity providers and consumers. By automating energy updates and utilizing predictive analytics, the system reduces manual inefficiencies, prevents unexpected outages, and optimizes grid stability, contributing to sustainable energy conservation. Through a centralized customer management system, Rwanda Energy Group (REG) and EUCL can efficiently handle meter registrations, energy distribution, and transactions, while consumers benefit from real-time balance updates, timely alerts, and future consumption predictions, ensuring better financial planning and improved satisfaction.

Beyond its impact on Rwanda's electricity sector, this study contributes to IoT-based smart metering research, energy informatics, and predictive analytics, serving as a foundation for future advancements in AI-driven energy optimization, cybersecurity, and renewable energy integration. Its findings provide a scalable model applicable to other developing nations pursuing digital transformation in energy management. By promoting efficiency, sustainability, and data-driven decision-making, this research supports global efforts in building intelligent, resilient, and eco-friendly electricity infrastructures.

Organization of the Study

This thesis is organized into six chapters as follows: Chapter 1: Introduction

This chapter provides an overview of the research background, motivation, problem statement, study objectives, scope, significance of the study, and organization of the thesis.

Chapter 2: Literature Review

The literature review discusses relevant theories, previous research, and key concepts related to IoT-based energy management systems, including predictive analytics and smart metering technologies.

Chapter 3: Research Methodology

This chapter describes the research design, methods of data collection, and the development process for the system. It also outlines the tools, technologies, and models applied in the study

Chapter 4: System Analysis and Design

This chapter focuses on the technical aspects of the study, presenting the system architecture, hardware components, software interfaces, and communication protocols used to develop the IoT-based smart metering system.

Chapter 5: Results and Analysis

The results from the system testing and pilot implementation are presented in this chapter. It includes performance evaluations, feedback from users, and a discussion of the system's effectiveness in achieving the research objectives.

Chapter 6: Conclusion and Recommendations

The final chapter summarizes the key findings of the research, highlights the contributions to knowledge, and offers recommendations for further development and potential future research.

Conclusion

To summarize, this chapter provided an overview of the research background, identified the motivation behind the study, outlined the problem statement, and presented the objectives, scope, and significance. It emphasized the pressing need for an IoT-based smart electricity metering solution to overcome the current system’s limitations. The subsequent chapters will delve deeper into existing literature, the research methodology, and the development of the proposed system.

Chapter 2. LITERATURE REVIEW

Introduction

The Internet of Things (IoT**)** has revolutionized energy management, particularly in smart electricity metering systems**,** by enabling real-time monitoring, automated energy updates, and predictive analytics[22]. These advancements have improved electricity consumption tracking, enhanced user convenience, and optimized grid performance.

This chapter reviews existing research on IoT-enabled smart metering systems**,** focusing on technological advancements, predictive analytics, implementation challenges**,** and security concerns**.** It also presents case studies from different regions and identifies gaps in current literature to justify the need for this study.

Theoretical Framework

Internet of Things

The Internet of Things (IoT) is a system of interconnected smart devices that communicate and exchange data over the internet without direct human involvement [5][23]. In smart electricity metering, IoT technology integrates sensors, microcontrollers (such as ESP8266 and ESP32), and wireless communication protocols (Wi-Fi, GSM, LoRa, MQTT) to facilitate real-time energy tracking, remote monitoring, and predictive analysis[24]. This enables users to efficiently manage electricity consumption while enhancing automation and data-driven decision-making.

Machine Learning Algorithms

Machine Learning (ML), a subset of Artificial Intelligence (AI), allows systems to process historical data, recognize patterns, and generate predictions without relying on explicitly coded instructions, as it continuously improves through data-driven learning[25]. Machine Learning has become a powerful tool[26]. In recent years, widely adopted for enhancing data analysis and decision-making processes across various fields, and complementary to traditional statistical methods and analytics tools[27].

While understanding every technical detail is not necessary for practical applications, recognizing Machine Learning's potential to transform data into actionable insights is crucial[28]. This research focuses on the predictive capabilities of ML, particularly for analyzing energy consumption trends and Predicting insight, making it an ideal solution for optimizing smart energy management systems beyond current methods."

Authentication process

The Smart Electricity Metering System incorporates a secure authentication process to protect user access during electricity purchases. Users must enter both their energy meter's Serial Number and their National ID Number, ensuring that only authorized individuals can transact[29]. This dual-factor authentication verifies the device and the user's identity, with sensitive information like the National ID encrypted using a secure hashing algorithm (e.g., SHA-256) for added protection approach enhances system security, safeguarding personal data and preventing unauthorized access, thereby ensuring that each energy purchase is secure, reliable, and personalized for each user.

Related work

This section reviews related work in smart metering technology, IoT integration, and adoption challenges while highlighting key limitations that this study seeks to address.

In literature reviewed [10], A study presents an IoT-based smart energy meter designed to monitor energy consumption at the individual device level in real time. Unlike conventional systems, it enables users to remotely track appliance-specific usage without modifying existing wiring. Developed using Arduino Uno, ESP8266, and a Hall Effect sensor, the system uploads data to Thing Speak for visualization. Tested in India, the solution proved accurate for both fixed and variable-load appliances, promoting smarter energy use.

In article [8] A study introduces a smart energy metering and power theft control system using Arduino and GSM technology, aimed at reducing energy theft in developing countries like India. The system automates energy monitoring, detects unauthorized usage, and enables remote disconnection via SMS alerts. Built around an Arduino microcontroller, GSM modem, and Solid State Relay (SSR), it accurately identifies power theft and tampering, minimizing manual intervention. The system demonstrated effectiveness in real-time monitoring and theft prevention, offering a cost-efficient solution for automated energy management.

In the [15] a study conducted in Estonia proposed a data-driven decision support system (DSS) to optimize Electric Smart Meter (ESM) operations within the IoT ecosystem. Utilizing machine learning techniques, including Bayesian networks, Naïve Bayes, Decision Tree, and Random Forest, the model accurately predicted the need for technician visits.

Article [29] Introduced a machine learning-based system to enhance the reliability and security of smart meter operations within the Industry 4.0 framework. Using the Decision Tree algorithm, the system accurately detects fake data and monitors data loss caused by internet instability. Tested on real-time industrial smart meter data, the system demonstrated effective classification of data as real or fake while mitigating environmental impacts like temperature and noise. This approach supports secure and efficient smart metering in modern industrial environments.

Another study, introduced a machine learning approach utilizing the Random Forest Regressor (RFR) to identify fault locations and estimate fault durations in power grids. The method was developed using data simulated via the Grid PACK platform on a 9-bus system, incorporating critical inputs like voltage levels, phase angles, and frequency. The model underwent testing in four key areas: identifying fault positions, forecasting durations, managing incomplete data, and adapting to real-time data streams. Across all evaluations, the RFR consistently demonstrated superior performance over other algorithms such as DNN, SVM, and KNN, particularly in terms of predictive accuracy, error reduction, and computational efficiency[30].

Understanding the limitations of past implementations was crucial, so a detailed review of previous systems was undertaken to inform the development of our improved solution. In this paper, there is an urgent need for efficient energy management due to the growing population and infrastructure strain. They propose an IoT-based smart electricity distribution system using prepaid meters, cloud analytics, and sensor-enabled modules to monitor usage, automate control, and reduce energy waste. This methodology supports real-time insights, predictive maintenance, and policy-level planning. By aligning with global best practices, the approach aims to transform residential power management and support India’s Smart Cities initiative [27].

Despite significant progress in prepaid electricity metering adoption worldwide, even in South Africa, Nigeria, Rwanda and UGANDA[31]. These prepaid meter still have some limitation including the high need for manual intervention, as users must enter a unique token received after purchasing electricity via mobile phones. This process is time-consuming and prone to errors such as delays in receiving tokens, accidental deletion, or incorrect entry.

In Rwanda, the implementation of Electricity prepaid billing system (EPBS) was managed by Electrogaz, a public utility provider. The initiative began in 1995 as a response to the challenges the company faced in billing and revenue collection from customers in the after of the 1994 genocide. With funding assistance from development partners, Electrogaz conducted a pilot program involving 500 prepaid meters in 1995, which was followed by the installation of 14,000 meters by 1996.

The adoption of prepayment meters in all government offices in 2000 marked a turning point, enhancing both public acceptance and interest in the technology. Since that decision, Electrogaz has expanded the EPBS system to serve more than 90,000 customers nationwide. The proportion of customers using EPBS increased steadily, rising from approximately 30% in 1998 to over 80% by 2008.

In Rwanda, the government aims to transition to 100% electricity access by 2024, necessitating an efficient and automated energy management system. However, current prepaid smart meters still face challenges due to the lack of real-time energy updates and insufficient notifications when energy levels are low, which can result in unexpected power cutoffs during critical activities, such as cooking or heating. This limitation prevents consumers from effectively monitoring their electricity usage and anticipating future consumption. Additionally, the absence of predictive insights makes it difficult to optimize resource allocation, potentially compromising service reliability during high-demand periods.

However, there is limited research on fully automating prepaid smart metering systems in developing nations like Rwanda. The key gaps include:

1. Current prepaid smart meters still require users to manually input tokens, creating inefficiencies and user inconvenience.
2. The manual check by users for meter levels to prevent power outages.
3. The system restricts customers' ability to plan economically, Lack of predictions inside the system prevents them from making informed financial decisions.

Conclusion

In conclusion, although there have been significant advancements in smart metering and IoT integration, challenges remain, especially in developing regions such as Rwanda. Current systems often depend on manual token entry and lack real-time energy updates and predictive features, making it difficult for users to manage their energy efficiently and plan their finances effectively. To address these issues, it is essential to develop fully automated prepaid smart meters that offer real-time monitoring, automatic notifications, and predictive insights, thereby improving energy management, resource allocation, and consistent electricity access.

Chap3. RESEARCH METHODOLOGY

Introduction

This chapter presents the research methodology utilized for the development of an IoT-enabled smart metering system. The methodology employs a structured approach that integrates both qualitative and quantitative methods to assess the shortcomings of existing prepaid systems and design predictive models for forecasting customer energy usage over a ten-year span. This study was completed in two phases. Firstly, phase one was concerned with the analysis of the existing system to inform phase two. Secondly, phase two dealt with the development of an Advanced IoT-Based Smart Metering System with Automated Energy Updates and Predictive Usage Insights. The core elements of this methodology include engaging with stakeholders, gathering data from REG/EUCL employees and customers, analyzing historical energy consumption records from customers, and applying an iterative development process. This approach ensures that the research outcomes are well-founded, addressing both conceptual and practical issues in energy management.

Research design

The research employs a sequential explanatory mixed-methods design, integrating quantitative and qualitative approaches to thoroughly address its objectives.

This study was completed in two phases:

Phase One (objective one) focuses on assessing the existing metering system. This suggests a quantitative approach, where the existing system is likely analyzed through numerical data, such as performance metrics, reliability, or efficiency. It involved administering structured questionnaires to Rwanda Energy Group/Energy Utility Corporation Limited (REG/EUCL) employees who interact with the existing prepaid electricity metering system. This approach aims to discover operational challenges, limitations, and user experiences. In addition, historical energy consumption data from customers in the Gasabo district (Kinyinya branch) was be analyzed. This analysis identified patterns and trends, forming the basis for predictive models capable of estimating annual energy usage over a ten-year period. By combining insights from customer and data-driven analysis, the research methodology ensures a comprehensive, evidence-based foundation for developing a smart metering system that addresses both technical and operational challenges in energy management. The data obtained in phase one informed phase two.

Phase Two involves the development of an Advanced IoT-Based Smart Metering System, along with features like Automated Energy Updates and Predictive Usage Insights. This would likely include both quantitative aspects such as analyzing system performance and qualitative components (for example: user feedback on system usability). The development of an automated energy updates and predictive usage insights was aligned with customers' needs and resolves real-world issues.

Study setting

The data were collected in REG/EUCL and their branches located in Gasabo district, Kigali Rwanda. Those study settings were purposefully chosen because of their particularity and expertise in energy management in Rwanda.

Study population (phase one)

The study covers 77 members of multidisciplinary team working in REG/EUCL branches located in Gasabo district. This research aimed to gather ideas from a multidisciplinary team involved in energy management.

Sample size and sampling strategy (phase one)

This study involved 77 staff working at branches of REG/EUCL operating in Gasabo district reached using total sampling strategy. In this case, researchers selected every member of the population of interest for inclusion in the study. This strategy was applied because the population size was small enough to allow for the collection of data from everyone without being resource-prohibitive.

Data collection tool (phase one)

An adapted self-administered, structured English version questionnaire was employed in the study settings to gather data from the participants. The tool consisted of three sections: The first section focused on gathering general information of the participants. The second section was dedicated to assessing the current energy system evaluation. This section comprised 10 questions, five questions were multiple choice questions and five questions are Likert scale questions. The third section was devoted to assessing the need for automated IoT-Based Smart Metering System. This section comprised 10 questions, five questions were Likert scale and other five questions were multiple choice[32] .

Sampling technique

The sampling technique employed in this research was purposive sampling. This non-probability method was chosen to deliberately select REG/EUCL staff who are actively engaged in electricity distribution, commercial services, and energy metering tasks within Gasabo District. The participants were sourced from five operational branches of REG/EUCL, comprising one branch from the Commercial Operations Department (Kinyinya) and four branches under the Distribution and Operation Department (Kacyiru, Remera, Jabana, and Kimironko). Selection criteria focused on professional responsibilities and experience, ensuring that only personnel with direct knowledge of metering systems contributed to the study.

Data Collection Tool

A structured questionnaire served as the main instrument for data collection in this study. It was specifically designed to collect comprehensive information about participants' experiences with the existing prepaid metering system. The questionnaire featured multiple-choice questions to capture factual data, Likert scale items to assess opinions and perceptions, and a few open-ended questions to gather additional qualitative insights. The structured format promoted consistency across responses and simplified the process of coding and analysis. The questionnaire was organized into key areas, including demographic details, challenges encountered with current metering systems (such as manual token entry, delays in updating energy credits, and lack of timely notifications), as well as participants' expectations for the integration of an IoT-based smart metering solution.

Validity and reliability of data collection tool

The study utilized a self-administered questionnaire to gather data from participants, focusing on general information of participants, assessing current energy system and need for automated IoT-Based Smart Metering System. In order to make sure that all topics were covered and that the tool could gather the necessary data, a few questions were also extracted from the comprehensive literature review. The tool was modified to ensure content validity and translated into Kinyarwanda by a non-research team translator. This ensured comprehensive coverage of all study variables.

Data Collection Procedure

Data collection was carried out physically at the five selected REG/EUCL branches located within Gasabo District. Questionnaires were personally distributed to targeted staff members, selected based on their roles within the organization. Prior to administering the survey, the study's objectives were clearly explained to participants, and informed consent was obtained. Respondents were allowed sufficient time to complete the questionnaires independently to encourage careful and unbiased answers. Once completed, the questionnaires were manually retrieved and subsequently entered into SPSS software for statistical analysis.

Data analysis (phase one)

The data analysis was done using IBM SPSS Statistics for Windows version 25.0 (IBM Corp, Armonk, NY, USA). It involved a quantitative approach, utilizing frequencies and percentages to outline the characteristics of the dataset. Descriptive statistics are used to summarize, organize, and present data in a meaningful way, making it easier to understand and interpret. The results from the analysis are presented in the tables

Ethical consideration

the University of Rwanda, College of Science and Technology, Wireless Sensor Intelligent Network(WISINET) program in African Center of Excellence in Internet of Things(ACEIOT) Institutional Review Board (IRB) granted approval for this study. The researcher assured the participants that their participation in the study was completely voluntary. To ensure confidentiality, the questionnaires did not include any names. The researchers informed all participants that their information would be treated as confidential and solely used for the study's purposes. Each participant signed consent forms, granting permission for the researcher to conduct the study.

Results

Table 1: SPSS Result from data collected from REG/EUCL

VARIABLES	Frequency	Percentage
Age		
18-25	4	5.2
26-35	37	48.1
36-45	22	28.6
46 and above	14	18.2
Gender		
Male	53	68.8
Female	24	31.2
What department do you work in at REG?		
Metering department	2	2.6
Maintenance department	1	1.3
Distribution and operation department	59	76.6
Commercial department	15	19.5
How many years have you worked with REG?		
Less than 1 year	1	1.3
1-3years	4	5.2
4-7years	14	18.2
More than 7years	58	75.3
What type of metering system is predominantly used in REG'S operations?		
Prepaid Smart Meters	77	100.0

How often do you encounter issues with your current energy meter as claimed in your previous feedback or complaint by customer?		
Always	58	75.3
Often	15	19.5
Sometimes	4	5.2
Innaculate meter reading		
Yes	73	94.8
No	4	5.2
Delays in updating energy purchases		
Yes	72	93.5
No	5	6.5
High maintenance costs		
Yes	22	28.6
No	55	71.4

VARIABLES	Frequency	Percentage
Power outages due to lack of notifications		
Yes	69	89.6
No	8	10.4
Difficulty in predicting energy consumption		
Yes	71	92.2
No	6	7.8
Have you experienced any challenges with the current energy top-up process(e.g:entering tokens manually),as claimed by many customers?		
Yes, frequently	68	88.3
Yes, occasionally	8	10.4
No, rarely	1	1.3

Do you know what internet of thinks means?		
Yes	16	20.8
No	61	79.2
Would an automatic energy update system(without manual top-up) to improve energy improvement?		
Yes	77	100.0
No	0	0
Does your current system allow customers to seamlessly purchase electricity remotely, ensuring timely energy updates even when they are unavailable or do customers sometimes rely on neighbors to put tokens into their meters?		
Strongly agree	57	74.0
Agree	18	23.4
Strongly disagree	2	2.6
Do you have system in place that sends notification to customers when their remaining energy is low(e.g:at 1KWH) to help them manage their consumption effectively?		
Yes	8	10.4
No	69	89.6
Would an IOT-based system that updates energy automatically,sennds SMS alerts at low-energy, and predict tannual budgeting improve energy management?		
Highly helpful	76	98.7
Moderately helpful	1	1.3
In your opinion, would automating energy updates and introducing predictive insights benefit REG in terms of cost efficiency and customer satisfaction?		
Strongly agree	71	92.2
Agree	6	7.8

VARIABLES	Frequency	Percentage
How important do you think predictive insights(e.g:annual energy usage forecasts are for budgeting planning?)		
Extremely important	65	84.4
Important	12	15.6
How much do you think automating energy updates would improve customer satisfaction?		
Significantly improve	75	97.4
Moderately improve	2	2.6
What level of improvement do you expect in the operational efficiency of REG if an IOT-based metering system is implemented?		
Significant improvement	77	100.0

Following the data collection process involving REG/EUCL staff, the collected responses were analyzed using SPSS software to ensure accurate and reliable interpretation. The analysis revealed a pressing need for the deployment of an IoT-enabled smart electricity metering system, particularly emphasizing automatic energy updates, timely notifications, and predictive analytics. Specifically, 100% of respondents confirmed that having an **a**utomatic energy update mechanism to replace manual token input is essential for enhancing operational efficiency and user convenience. Additionally, 89.6% of participants acknowledged experiencing frequent power outages due to the absence of real-time low-energy notifications, demonstrating a strong need for a system that can deliver instant SMS alerts when energy balances are critically low. Furthermore, 92.2% highlighted difficulties in forecasting their energy usage, pointing to the importance of integrating predictive insights to support better energy budgeting and consumption planning. These findings strongly justify the implementation of the proposed SEMSAP system, as it addresses the critical gaps by automating energy management, improving customer satisfaction, and optimizing REG/EUCL’s service reliability and cost-efficiency.

System development methodology

In designing the SEMSAP system, the Prototyping Model of the Software Development Life Cycle (SDLC) was adopted. This approach is well-suited for complex systems like Advanced IoT Based SEMSAP, where early feedback, iterative refinement, and user-centered development are critical to success. The prototyping model enables incremental development and validation of system components, ensuring alignment with user requirements and operational goals.

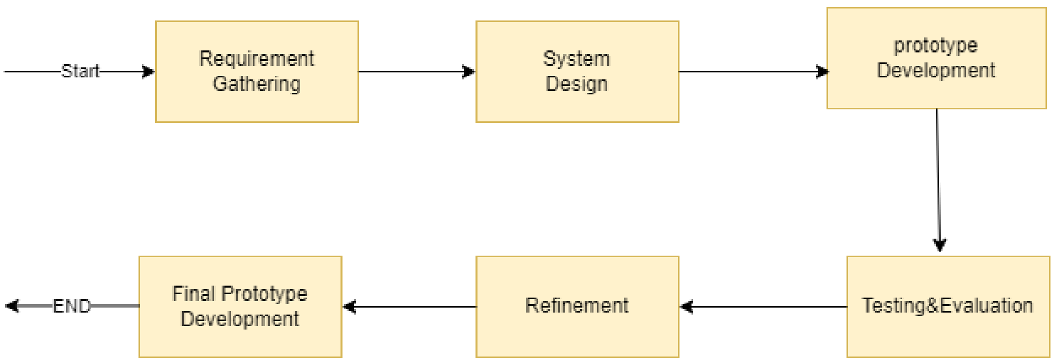

Figure 2:prototype Model

Requirements Gathering:

This stage focused on analyzing challenges in existing prepaid meters, including manual energy updates, lack of low-balance notifications, and users' inability to track their energy consumption for better planning. To address these issues, the system required real-time data collection, automated balance updates, and predictive analytics**.** Based on these needs, essential IoT components were selected**,** including voltage and current sensors for energy measurement, an ESP8266 microcontroller for data processing, a database for storing transaction records, and a Wi-Fi module for wireless data transmission**.**

System Design:

With the system requirements defined, the next step was to design the hardware and software architecture**.** The voltage and current sensors were integrated to measure real-time energy consumption, while the ESP8266 microcontroller was programmed to process sensor data and control system operations**.** The system was designed to transmit data using Wi-Fi-based communication protocols, ensuring efficient transfer of energy consumption data to a cloud database. Additionally, the software architecture was structured to handle data collection, storage, real-time analysis, balance updates, and predictive modeling**,** allowing users to monitor their energy usage effectively.

Prototype Development:
At this stage, a working model of the IoT-enabled smart metering system was built to validate core functionalities before full deployment. The hardware prototype incorporated voltage and current sensors for data acquisition, an ESP8266 microcontroller for processing, and Wi-Fi modules for real-time communication. The software prototype focused on implementing data processing algorithms, balance update mechanisms, notification triggers, and the initial integration of a machine learning model. Using historical electricity consumption data, a supervised learning algorithm was trained and embedded into the system to enable predictive analytics. This allowed the system to forecast future energy usage and display personalized insights to users. The system was tested for accuracy, responsiveness, and communication reliability, ensuring smooth integration of sensor readings, cloud storage, and predictive features before moving to the refinement phase

Testing & Evaluation:
After creating the prototype, the Testing & Evaluation phase was carried out to assess the system's performance, accuracy, and reliability before full deployment. This stage verifies that the IoT Smart Electricity Meter operates correctly in real-world environments. After purchasing electricity through either the USSD code or the administrator dashboard, the energy balance is automatically updated on the smart meter. The system is also capable of sending notifications when the energy level drops below a predefined threshold. Additionally, it utilizes machine learning to predict the user's energy consumption for the following month based on historical transaction data.

Refinement:
After creating the prototype, the Testing & Evaluation phase is carried out to assess the system's performance, accuracy, and reliability before full deployment. At this stage, different electrical loads such as laptops, smartphones, and other household or office devices were connected to evaluate the system's behavior under realistic usage conditions. The system successfully demonstrated its core functionalities, including automatic energy balance updates, low-energy notifications, and real-time status display through both the dashboard and mobile interface. All tests were performed under on-grid conditions, verifying that the smart meter operates reliably when integrated with the national electricity supply. This phase confirmed the system's ability to handle variable loads, maintain consistent communication, and provide accurate usage predictions.

Minor adjustments were made based on observed outcomes to enhance system performance and user interaction in preparation for full deployment.

Final Prototype Development:
After completing the Refinement Stage, the Final Prototype Development phase focuses on integrating all improvements, ensuring system stability, and preparing the IoT Smart Electricity Meter for real-world deployment. This stage involves finalizing hardware and software components, conducting full system validation, and ensuring user readiness.

Machine learning
This study incorporates machine learning (ML) to enhance the adaptability and decision-making capability of the smart electricity metering solution. ML is specifically applied to analyze historical energy payment data and generate predictive insights, which support more accurate and proactive budgeting by users[33]. These predictions serve to optimize energy efficiency while also improving the overall user experience within the SEMSAP system.

Dataset Description
This study utilized a synthetic dataset titled energy_usage_prediction_rwanda2.csv, crafted to replicate typical electricity usage behaviors among residential users in Rwanda. Due to restrictions on accessing real customer data imposed by the Rwanda Energy Group (REG) and Energy Utility Corporation Limited (EUCL), authentic consumption records were unavailable. As a solution, a randomly generated dataset was developed to test and validate the system's functionality under simulated but realistic conditions.

The dataset contains 70,105 records, each representing an hourly simulation of residential electricity usage.

DATASET METADATA
Table 2: Dataset Metadata

Resource Metadata	
Metadata source	Value
Data source	Locally generated synthetic dataset (not publicly available)
location	Simulated household electricity
Dataset time period	Simulated multi-year span (aggregated to 70,105 hourly records)
Time Resolution	1 hour
Number of Variable	10
Number of Record	70105

Machine learning model selection

Supervised machine learning methods were chosen for this research, as they are particularly effective for predicting continuous values based on historical patterns[34]. Among the available algorithms, the Random Forest Regressor was selected due to its robustness in regression tasks, its ability to model nonlinear relationships, and its low sensitivity to overfitting[35]. It is especially suitable for datasets with missing values or irregular trends, which are common in real-world smart energy deployments.

The model was trained using historical electricity payment data. Two key predictors were used: the customer's payment from the previous month and from two months earlier. These features allowed the model to learn usage behavior and estimate future consumption patterns.

The dataset used for model training and evaluation was a synthetic dataset labeled *energy_usage_prediction_rwanda2.csv*, sourced from Kaggle. It simulates monthly energy payment records for multiple customers over several years. Initial data exploration was conducted using head () and info () functions to understand the dataset structure and detect potential missing values. Data analysis and visualization were performed using Python libraries such as NumPy and pandas for data manipulation, and matplotlib and sea born for exploratory visualizations.

To evaluate the model's effectiveness, a time-based train-test split was applied to the simulated customer dataset. For each customer, the final six months of records were isolated for testing, while all preceding months were used for training. This approach ensured the model was validated on future-like data, closely mimicking real-world deployment where predictions are made based on past behavior without access to future values.

The following metrics were used to evaluate the model's predictive performance:

1) Mean Squared Error (MSE)

$$MSE = \frac{1}{n}\sum_{i=0}^{n}(y_i - \hat{y}_i)^2$$

[36]

Where:

- n is the total number of observations
- y_i is the actual value (ground truth) at index i
- $\hat{y}_i$ is the predicted value at index i
- $(y_i - \hat{y}_i)^2$ is the squared difference (error) between the actual and predicted values
- The summation $\sum_{i=0}^{n}$ means that the errors are calculated for all samples from index 0 up to n

Mean Squared Error (MSE) is a commonly applied metric for assessing regression models, calculated as the average of the squared differences between predicted values and actual observation[37].

The effectiveness of the system was evaluated using the Mean Squared Error (MSE), a metric that calculates the average of the squared discrepancies between actual and predicted values.

MSE calculates the size of errors without taking into account whether the errors are positive or negative.

2. Mean Absolute Error (MAE) [36]

Where:

- n is the total number of observations
- y_i is the actual (true) value at observation i
- $\hat{y}_i$ is the predicted value at observation i
- $|y_i - \hat{y}_i|$ is the **absolute error** between actual and predicted values
- The summation is from $i = 0$ to $i = n$, which includes all data points

$$MAE = \sum_{i=0}^{n} \frac{1}{n} \cdot |y_i - \hat{y}_i|$$

[36]

The model's effectiveness was further assessed using Mean Absolute Error (MAE), which quantifies the average absolute difference between actual and predicted values. This metric offers a straightforward evaluation of prediction accuracy, without considering whether the errors are positive or negative.

The Root Mean Squared Error (RMSE) serves as a standard measure for quantifying the accuracy of regression-based models. It reflects the average squared difference between predicted outcomes and actual observations. The RMSE is mathematically represented as:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\hat{y}_i - y_i)^2}$$

[36]

For the purposes of this analysis, RMSE was utilized to evaluate the predictive performance of the model.

The Random Forest Regressor was favored over other models such as Linear Regression, Support Vector Regression (SVR), and XGBoost due to its flexibility with non-linear data and ease of implementation without heavy preprocessing. While SVR and XGBoost are powerful, they require more computational resources and tuning[38], making them less ideal for lightweight deployment in real-world environments like SEMSAP. Moreover, Random Forest provides feature importance metrics, which can help inform future design and decision-making.

The prediction of the system is able to view by customer either on dashboard and via an USSD Code.

Chapter 4. SYSTEM DESIGN AND ANALYSIS

Introduction

The System Design and Analysis chapter outlines the structural framework for creating an efficient, secure, and scalable IoT-driven smart metering system that overcomes the limitations of manual token-based electricity metering**.** A well-organized design approach helps ensure the system's scalability, security, and automation by defining clear requirements, architecture, and workflows**.** By leveraging IoT sensors, cloud computing, and predictive analytics**,** the system enables real-time energy tracking, automated balance updates, and insightful user analytics, leading to improved performance and reliability.

This chapter details both functional and non-functional system requirements**,** provides an overview of the system architecture, and explains the operational workflow using diagrams and flowcharts**.** The system's core components consist of hardware (IoT sensors, microcontrollers), software (databases, mobile/web dashboards, USSD interfaces), and security protocols (authentication, encryption, and access control mechanisms)**.** Together, these elements establish the foundation for an Advance IoT BASED SMAP that enhances user convenience, supports automation, and optimizes electricity usage for both consumers and energy providers.

System Requirement

The System Requirements Specification (SRS) outlines the key parameters that the IoT-enabled smart metering system must fulfill to guarantee optimal performance, security, efficiency, and user convenience. It is divided into two main categories:

Functional requirements

The Advanced IoT-Based SMAP System is designed to provide real-time energy consumption monitoring through integrated current and voltage sensors. It automates energy balance updates and ensures seamless data transmission via a Wi-Fi module. The system incorporates machine learning (Random Forest Regressor) to predict electricity consumption for the next month, helping users for home budgeting efficiently.

To enhance user experience, the system offers an intuitive mobile and web interface for real-time tracking, along with low-balance alerts via app notifications and a buzzer. Security features, such as user authentication, protect data integrity, while recovery mechanisms ensure system reliability.

Additionally, a USSD platform allows users to purchase electricity, check balances, and access energy consumption forecasts, making the system accessible and convenient for all users.

Non-functional requirement

The Advanced IoT-Based Smart Metering System (SMAP) is built to uphold high standards of performance, reliability, security, scalability, usability, and compliance**.** It facilitates real-time energy monitoring by processing energy balance updates within one second while accommodating at least 500 concurrent users**.**

The system ensures critical operations are executed with a response time of less than two seconds**.** To enhance system reliability, it maintains 99.9% uptime**,** with an automatic recovery mechanism that restores functionality within two minutes in the event of a failure. Additionally, it includes local data storage to retain information during network disruptions, ensuring seamless synchronization once connectivity is re-established.

To enhance security, the system implements user authentication to prevent unauthorized access and uses TLS/SSL encryption to secure data transmission. Additionally, the system is designed to be scalable, allowing for the seamless integration of new users, devices, and IoT components without requiring significant modifications. To maintain optimal performance**,** it employs dynamic resource allocation**,** ensuring system stability as the user base expands.

Regarding usability and compliance**,** the system features an easy-to-navigate mobile and web interface, ensuring a smooth user experience. Additionally, a USSD platform is integrated to allow users without internet access to interact with the system. To enhance accessibility, the system supports multiple languages and provides SMS alerts for low balance notifications**,** along with a sound alert when the meter runs out of energy. These functionalities contribute to improving system efficiency, strengthening security, and enhancing the overall user experience**,** making it a reliable and effective solution for modern energy management**.**

Architectural Overview

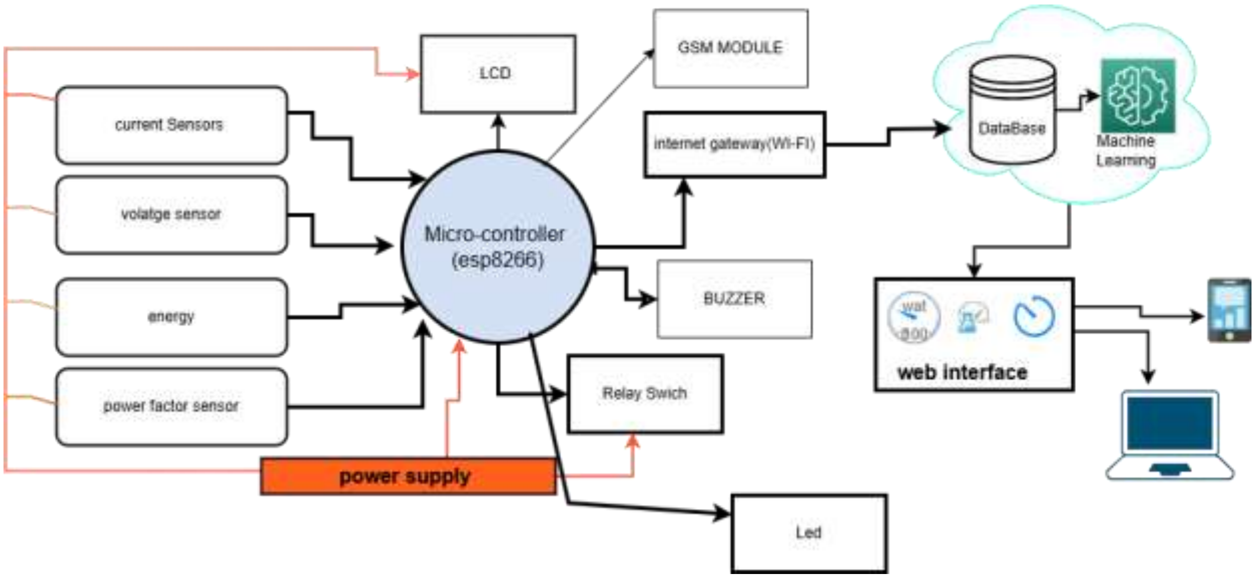

Figure 3:Architecture and Design of the System

A system architecture built around an ESP8266 microcontroller, which integrates various sensors (current, voltage, energy, and power factor) to measure energy consumption. The microcontroller processes this data and transmits it via Wi-Fi (internet gateway) to a database**,** where machine learning algorithms analyze the data for predictive insights. It includes a web interface, allowing users to monitor real-time energy usage and control power operations remotely. Additionally, LCD, LED indicators, a buzzer, and a relay switch provide local notifications and power control.

The complete system operates through a dedicated power supply, guaranteeing uninterrupted functionality.

This system utilizes two forms of electrical supply: direct current (DC) and alternating current (AC). DC is primarily responsible for powering and managing the internal circuits of energy meters, whereas AC is used to supply power to the connected loads.

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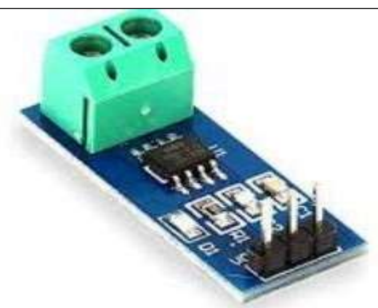
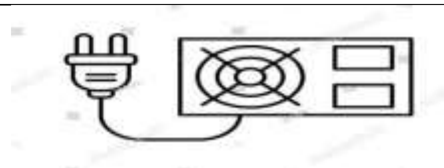
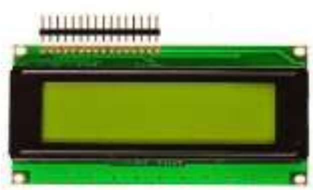
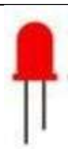
The current sensor (ACS712) has 8 pins. The VCC is associated with +5V to control the module and in this way, the GND is associated with the base of the microcontroller. And the VIOUT is connected with the microcontroller Analog Input/ Output pin.

System Components and Design

Table 3: Hardware component of my system

No	Tools or Equipment	Images	Description
1.	ESP 8266 Microcontroller		Low-power microcontroller with built-in Wi-Fi for real-time data acquisition, processing, and transmission.
2.	Current Sensor (ACS712)		current sensor detects real-time current flow and generates an analog signal that reflects the measured current, ensuring precise energy monitoring and analysis.[27]
3.	Voltage Sensor (ZMPT101B)		voltage sensor detects AC voltage levels and outputs an analog signal corresponding to the measured voltage, enabling safe and precise monitoring in electrical systems[27]

4.	Power Measurement IC (ADE7753)		a high-accuracy energy metering chip that measures active power, voltage, and current in AC systems, providing precise energy consumption data for monitoring and analysis.
5.	Power Supply Module		The power supply in the IoT system converts AC to a stable 5V DC, ensuring continuous and reliable power for the ESP8266, sensors, and other components while preventing voltage fluctuations.
6.	AC TO DC Conventor		It converts AC power to DC to supply the smart energy meter with the required operating voltage.
7.	Relay Module		Controls the power supply to connected devices based on data received, suitable for switching electrical loads
8.	LCD Display		Displays real-time data locally on the smart meter, typically using a 20x4 character LCD with an I2Cinterface[39].
9.	LED Indicators		Provides visual status indications for various states such as power on, Wi-Fi connected, and data transmission
10.	Jumper Wires		Used for prototyping the circuit during the development phase

11.	GSM MODULE	*Table 3: Hardware component of my system* 	GSM module enables real-time communication by sending SMS alerts to the users when critical conditions, such as low energy balance, are detected[40].

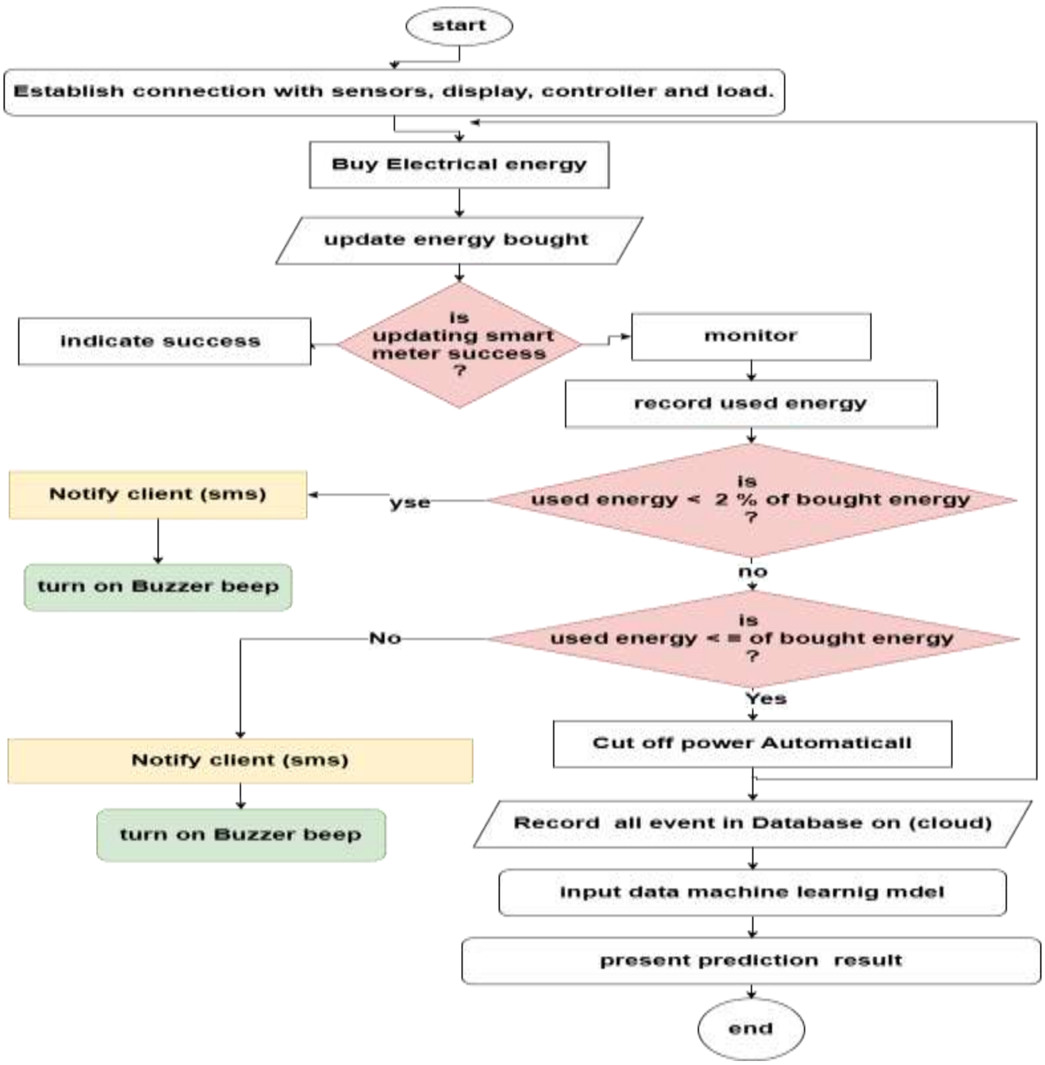


Figure 4: System flow chart

This flowchart demonstrates the operational workflow of the IoT-powered smart metering solution, which automates energy management and provides predictive analytics. The workflow starts with the activation of sensors that track energy usage and update the system following the user's electricity purchase. The system verifies that the purchased energy is properly recorded in the smart meter.

Final System Integration: Visual Feedback and Live Output

This section showcases the final implementation phase of the SEMSAP system, where all hardware and software components have been successfully combined into a fully functional unit. It provides a visual representation of the system's key features in operation, demonstrating that essential goals—such as live energy monitoring, automated notifications, usage forecasting, and remote system access—are effectively achieved. Through the use of real-time images, screenshots, and system output visuals, this section confirms the system's practical functionality, stability, and readiness for deployment in real-world energy management scenarios.

The development of the system involved two primary components: a backend database, a user interface dashboard and virtual phone interface. The backend system was developed to store a wide range of energy-related information, such as energy usage measured in kilowatt-hours (kWh), appliance-specific usage data, and forecasts for energy costs expressed in Rwandan Francs (RWF). It also keeps track of transaction details and sends system alerts, ensuring smooth functionality and effective user interaction. The frontend dashboard provides a simple and user- centered platform that allows consumers to track energy consumption, receive notifications, and access predictive analytics for planning their next month's energy budget.

The backend architecture is developed on a web-server relational database platform that effectively gathers, stores, and handles real-time energy information. Consumers are pre-registered into the system, facilitating seamless communication and transaction management.

Dashboard based SEMSAP

The Energy Meter Dashboard features two separate user roles: An Administrator Account and a Client Account. The Administrator Account grants system managers' full privileges to oversee real-time monitoring, perform meter control actions such as energy recharges and device activation or deactivation, and manage customer records. Meanwhile, the Client Account provides end-users with an easy-to-use platform to monitor their energy usage, check remaining balances, view consumption forecasts, and purchase additional energy credits. This account separation ensures secure system management while offering clients a straightforward and accessible way to manage their electricity consumption.

Key Tasks and Functional Capabilities within the Admin Interface

This image displays the login page of the Energy Meter system, where the administrator authenticates by entering the designated credentials. Here, the admin uses "admin" as the username and "0303" as the password to securely access the administrative dashboard. The login mechanism ensures that only authorized users can control and oversee system activities.

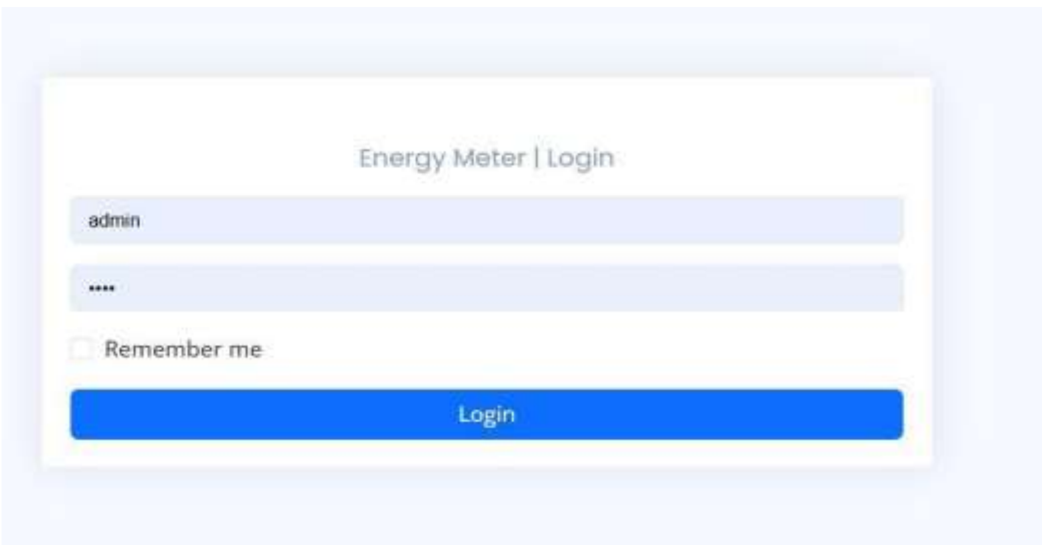


Figure 5: Administrator Login Interface for the Energy Meter System

Figure 5: Administrator Login Interface for the Energy Meter System

After login in admin account the admin will be able to perform different action in its admin account as show in the following admin page.

The image below displays the admin dashboard, which facilitates the registration of smart energy meters within the system.

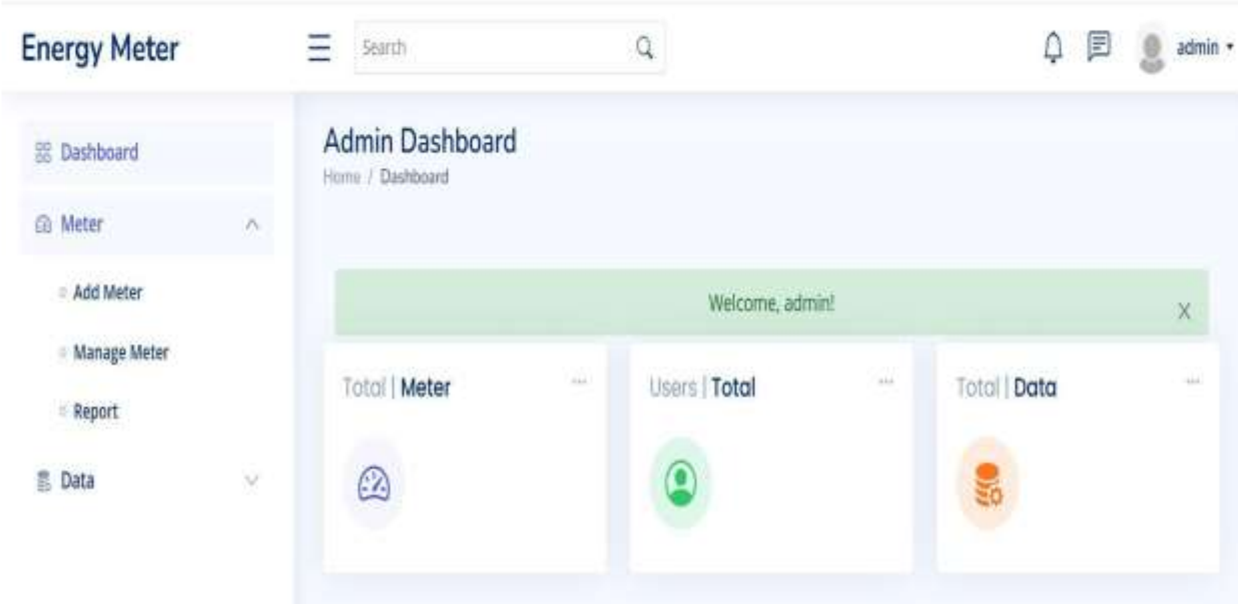


Figure 6: Administrator Dashboard Interface Showing System Overview

The dashboard below shows the Admin interface while performing the action of adding a new meter.

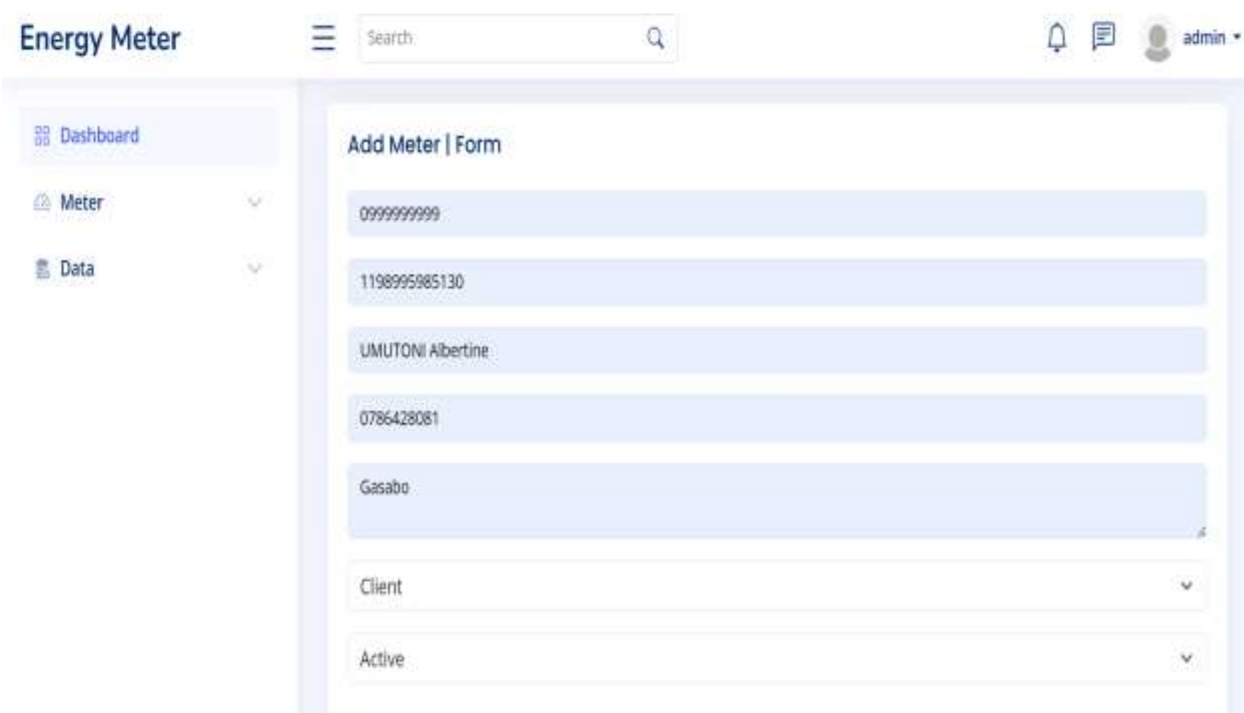


Figure 7: Admin Interface for Registering a New Smart Meter

The administrator dashboard enables adding new energy meters by entering client information, including serial number, national ID, name, phone, and address. Each meter is linked to only one customer to guarantee precise billing and energy monitoring. The system prevents duplicate meter entries to uphold database accuracy. Additionally, the admin can oversee and manage all registered meters and user records.

After completing registration, the client receives a default password that allows them to access their account.

The system below shows the notification that appears when the admin attempts to register the same meter under different customers.

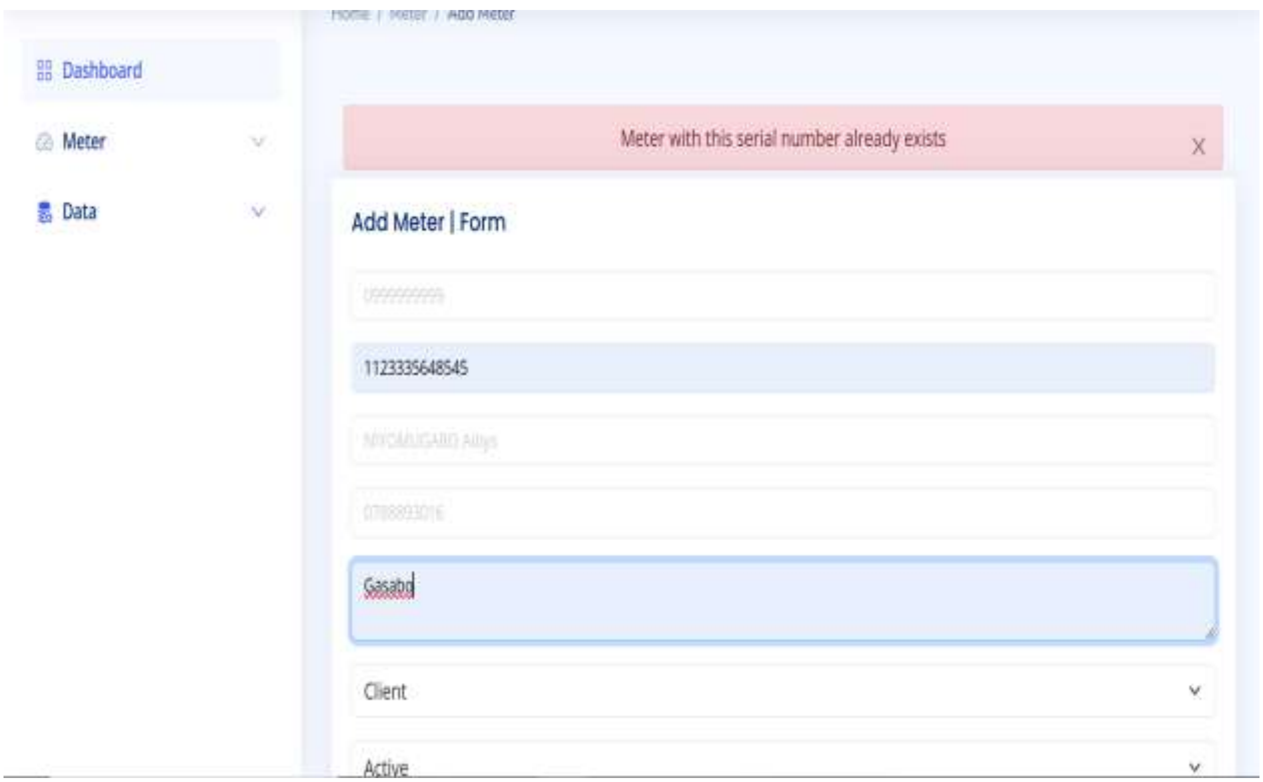


Figure 8: System Notification for Duplicate Meter Registration Attempt

The image illustrates how the system blocks the admin from assigning the same meter serial number to multiple customers. When a duplicate serial number is entered, an error message stating "Meter with this serial number already exists" is triggered. This control mechanism ensures that each meter is uniquely assigned to a single customer, maintaining data accuracy and preventing billing errors.

After a client completes the registration process, a confirmation message appears stating: "Meter added successfully!" along with the default login credentials, including the assigned username and password.

Under "Manage Energy Meters" feature enables the admin to modify or correct customer information if mistakes are found after the initial registration. Using the "Actions" dropdown, the admin can either update existing details or delete meter entries to ensure the database remains accurate. This function significantly contributes to maintaining the system's reliability and the integrity of its data.

Figure 9: Admin Interface for Managing Registered Energy Meters

In additional to this Admin dashboard allows real-time tracking of voltage, current, power output, and overall energy usage, while presenting key meter details like available balance, forecasted consumption, and days remaining. Administrators can remotely recharge energy, switch meters on or off, reset system settings, and manage customer accounts. It also features a dynamic graph that displays energy consumption patterns over time. Together, these tools support effective energy management, fast system maintenance, and enhanced service reliability.

Figure 10: Real-Time Energy Monitoring and Control Panel in the Admin Dashboard

Within the Data section, the admin can oversee live readings of voltage, current, power output, and accumulated energy consumption. The dashboard also displays important meter details, such as the available balance, last update timestamp, and estimated usage forecasts. Moreover, the admin has the ability to recharge energy, activate or deactivate the meter, and reset the system remotely to ensure effective energy control.

Client Account Functions and User Interaction Tasks

The client dashboard serves as a central hub where users can track their energy balance, monitor real-time electricity usage, and view the current status of their meter. It also allows clients to perform essential actions like buying energy, updating profile information, and adjusting account settings. This user-friendly platform simplifies service access and improves the overall customer experience.

After registration, the administrator provides the client with default login credentials, including a username and password. The client can choose to update these credentials for personal security or retain the default settings if preferred.

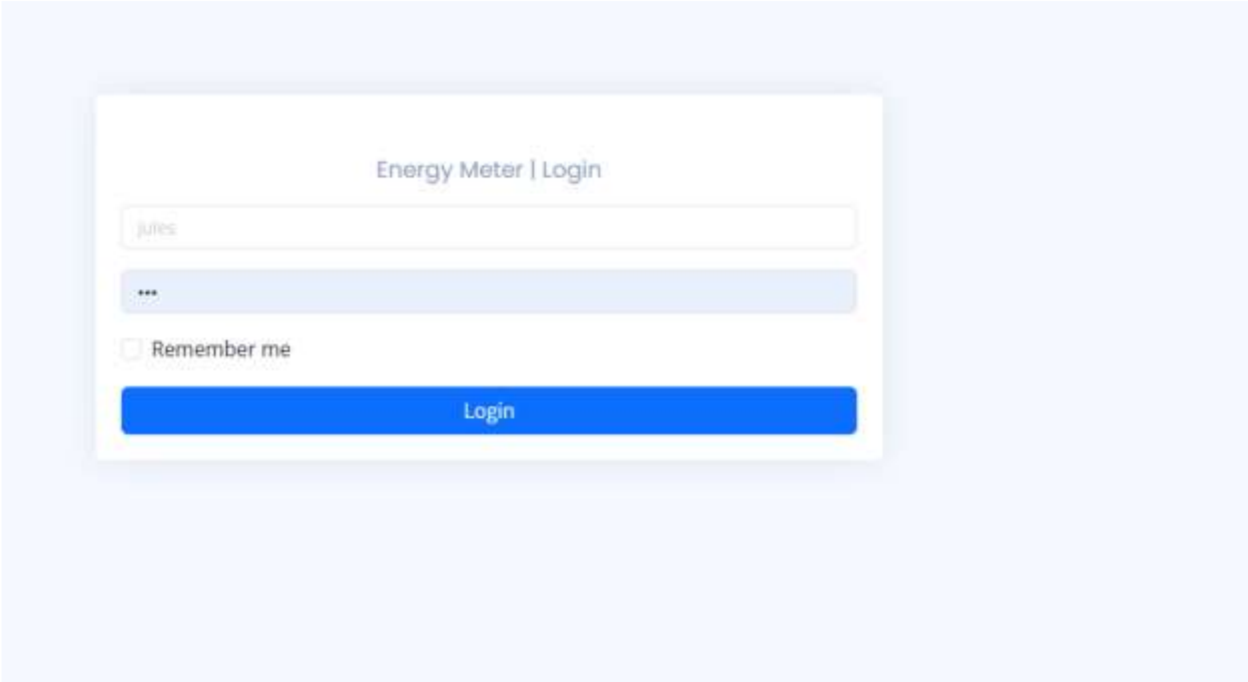


Figure 11: Client Login Interface for Energy Meter Dashboard

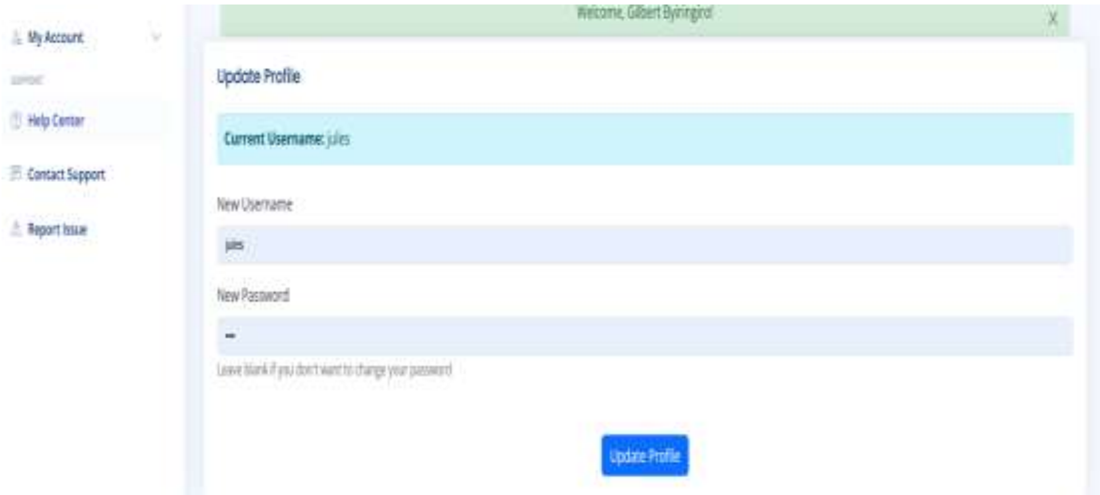


Figure 12: User Profile Panel Allowing Secure Credential Modification

The following dashboard offers an intuitive platform for users to easily monitor and manage their energy usage. It highlights essential details like the available energy balance, real-time usage, and the meter's active status. The system also allows users to quickly check power status, buy electricity, and update their account settings seamlessly from one place.

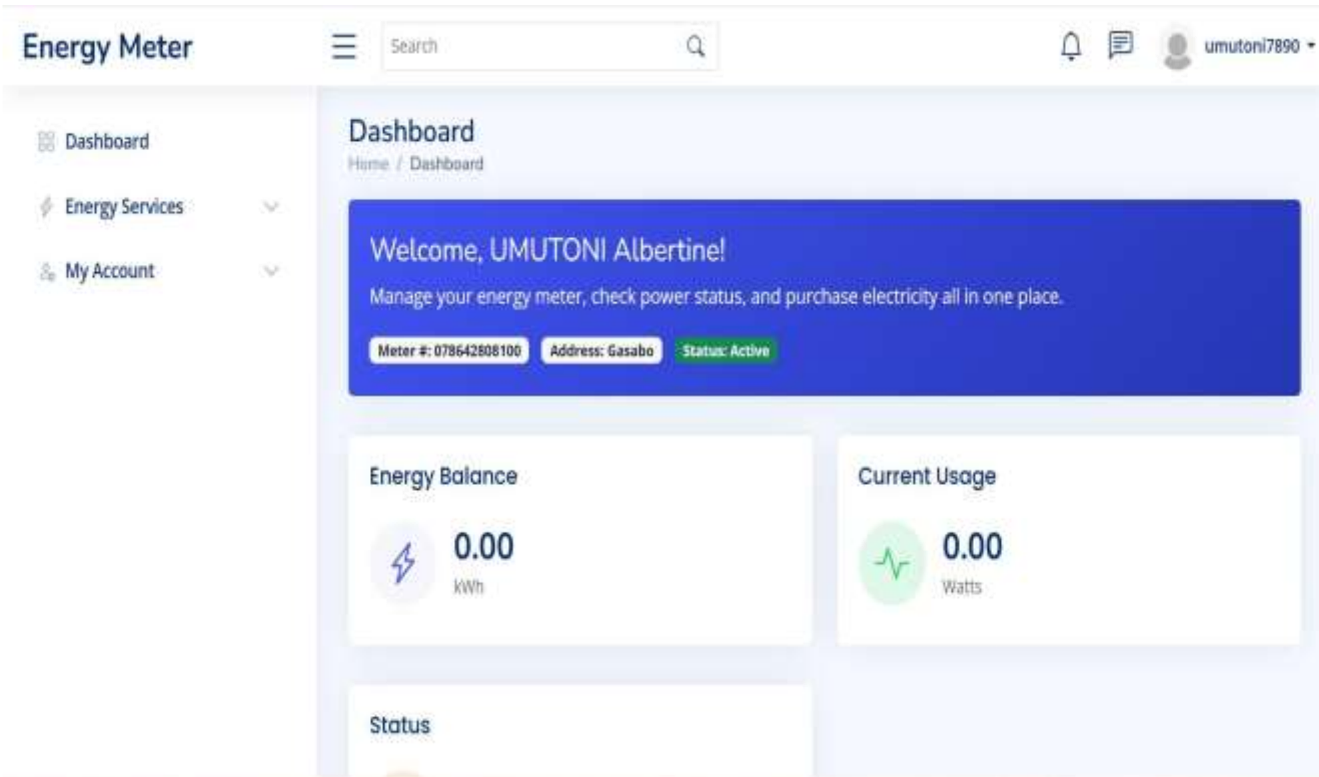


Figure 13: Energy Meter Dashboard for Real-Time Monitoring and User Interaction.

This section of the dashboard presents detailed meter information, allowing users to monitor real-time values for voltage, current, power output, and total energy consumption. It also provides a feature where users can recharge their meter by entering the desired amount of energy in kilowatt-hours and submitting it via the "Recharge" button. In addition to purchasing energy, users are given options to power on, power off, or reset their meters remotely. This setup offers a convenient and efficient way for users to manage their energy usage from a centralized interface.

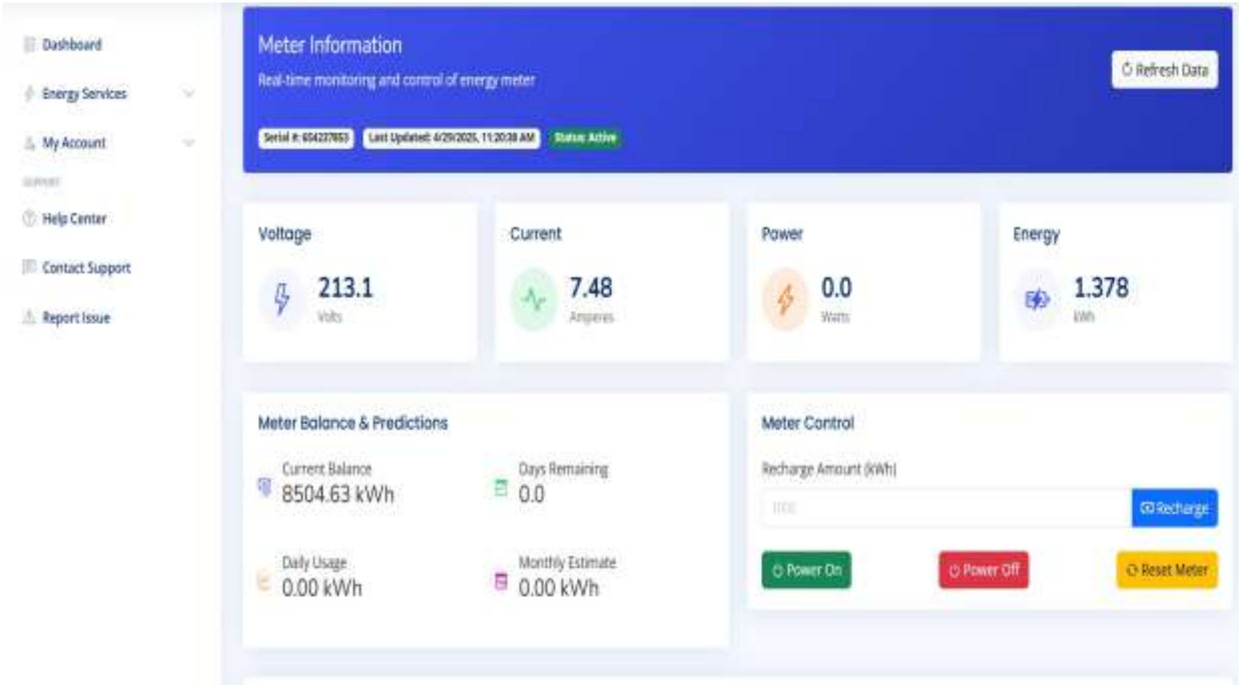


Figure 14: Live Energy Monitoring and Control Interface within the Admin Dashboard

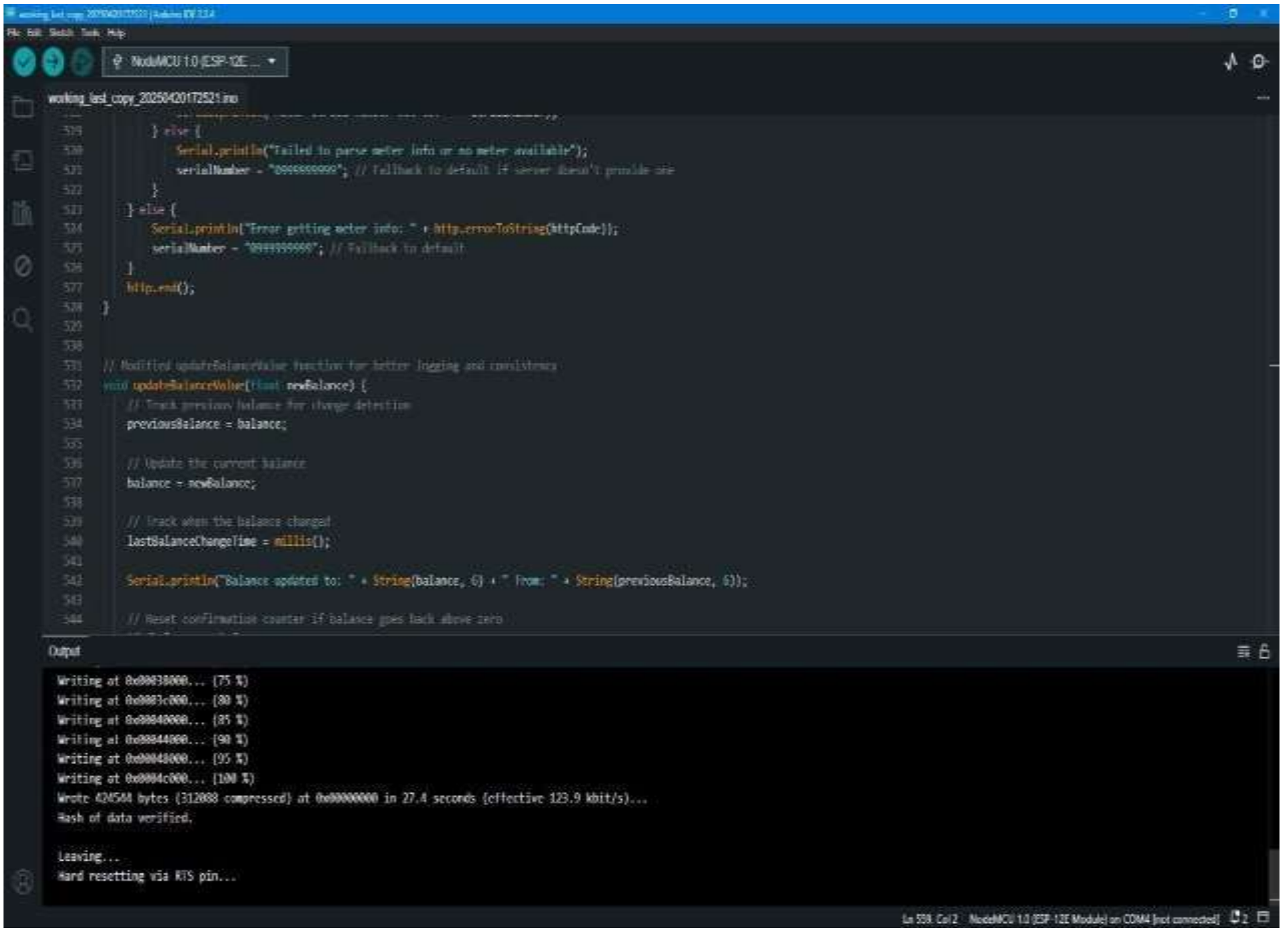
Hardware assembly of the Smart Electricity Metering System with Automated Energy Updates and Predictive Usage Insights (SEMSAP).

The hardware assembly of the SEMSAP system serves as the backbone for its real-time monitoring and automation features. It utilizes an ESP8266 microcontroller with integrated Wi-Fi and low energy consumption, alongside sensors for measuring voltage and current. A relay module manages the switching of electrical loads, while an LCD screen offers immediate feedback to users. Additional components such as buzzers, LED indicators, and a power supply unit support user notifications and stable operation. Collectively, these elements deliver a reliable and responsive smart metering solution.

The image below shows the integrated SEMSAP hardware components, assembled to automate energy updates, send alerts when the remaining energy reaches one unit, and predict the next month's energy usage.

Figure 15: Developed hardware model

The developed system is a smart energy management solution powered by a 5V supply, An AC to DC converter ensures stable power to all components. Real-time data is transmitted to the cloud via Wi-Fi, enabling remote monitoring. Additionally, machine learning algorithms are employed to analyze historical energy usage patterns and provide predictive insights, such as forecasting future consumption and estimating monthly energy transactions.



The system was programmed using Arduino IDE, where the code was developed, compiled, and uploaded onto a NodeMCU with ESP8266 microcontroller. The program performs real-time data monitoring and balance updates, including automatic error management. Arduino IDE provided a simple environment for writing, testing, and uploading the code. The upload confirmation and reset indicate that the system is ready for execution.

After the system is successfully programmed, it is deployed onto the grid, where it begins by simultaneously initializing its sensors, actuators, and microcontroller in preparation for operation. During this startup phase, the system searches for available Wi-Fi networks to establish a communication channel. Once a reliable connection is formed, it proceeds to full operation, carrying out real-time monitoring and control activities as intended.

Figure 16: System in its Initialization phase

Figure 17: Intelligent Energy Meter showing Wi-Fi connection and serial number after initialization.

USE OF USSD CODE IN ADVANCED IoT BASED SEMSAP

The use of USSD-based virtual phone simulation demonstrating how customers interact with the Smart Electricity Metering System (SEMSAP) using a predefined USSD code. This interface, developed through Africa's Talking USSD simulator, enables real-time testing of customer interactions without requiring an Internet physical mobile device. By dialing a specific code (e.g.,

*384*877645#), users can access key services such as checking balance, purchasing electricity, and next month prediction. This system ensures seamless, internet-independent communication, making it accessible to all customers. The integration of USSD technology enhances user convenience by enabling direct interaction with the system from any mobile device.

Figure 18: virtual phone

The image illustrates a USSD-based virtual phone simulation that requires users to authenticate with a predefined password before gaining access. This security mechanism ensures that only authorized individuals can interact with the system, reinforcing privacy and data security. Upon successful authentication, the interface becomes accessible, allowing users to input a USSD code to perform functions like checking balances, purchasing electricity, and checking next month transaction**.** This multi- layered security approach helps protect user interactions and prevents unauthorized access to the system.

These codes were developed using Python Flask, enabling the generation of codes required for various transactions. Africa's Talking served as the telecom provider for the virtual phone system, allowing for smooth integration of USSD codes such as *384*877645#. The platform managed the registration of the USSD code and forwarded user inputs to a Flask-based server hosted online. The server then processed these inputs and generated the corresponding responses for user interactions and transactions. The system integrates essential IoT components, such as sensors and actuators, to automatically update the Power consumption in smart meters. Buzzer alerts are triggered when the energy is fully consumed, and real-time SMS notifications ensure users are promptly informed.

A Comprehensive Guide to Performing Transactions Using USSD Codes

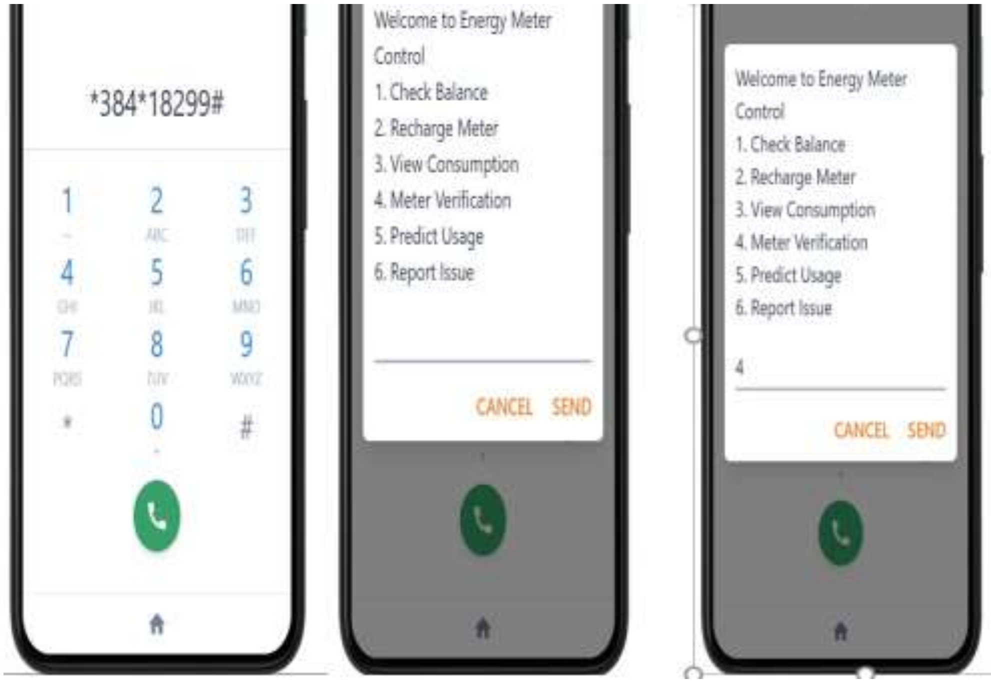
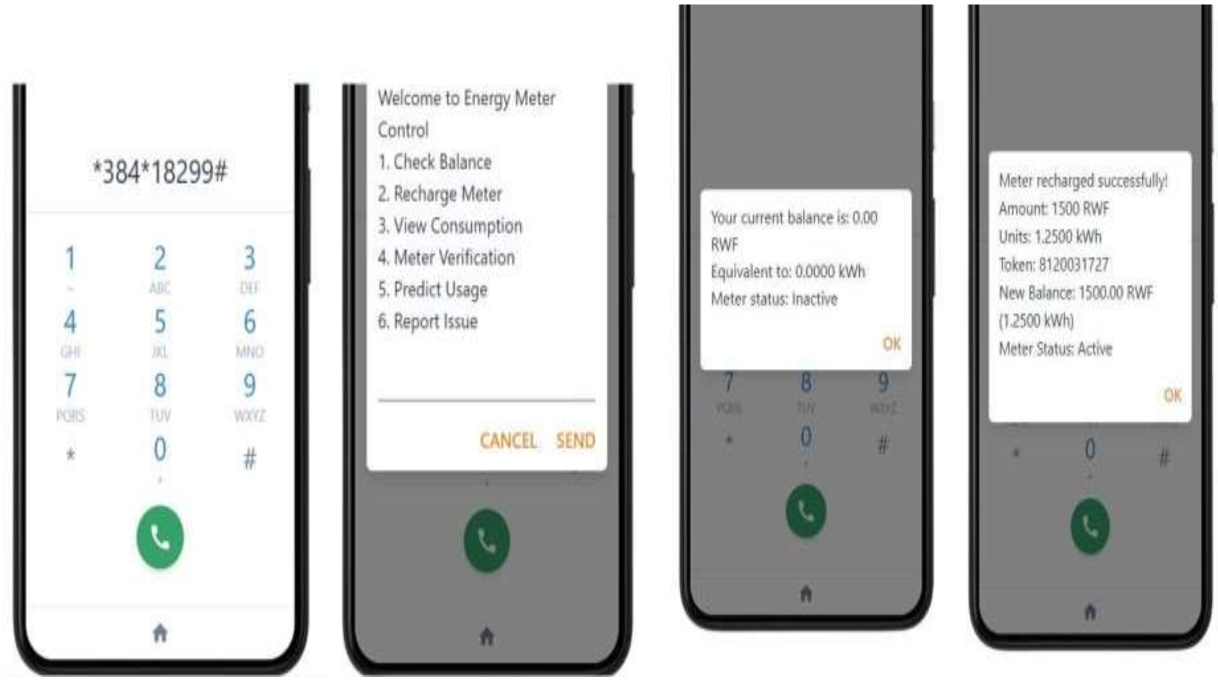


Figure 19: USSD interface for Energy Meter Control showing available service options.

To access the platform through the Africa's Talking mobile simulator, users must first enter the correct country code along with the mobile phone number they registered during the service setup. This step is necessary to accurately simulate the mobile network environment. After successful authentication, the system unlocks the USSD interface, allowing users to navigate and securely perform various operations. To begin, users must dial the USSD code *384*18299#. Before completing actions such as checking the balance, purchasing electricity, or reviewing consumption data, users must authenticate by selecting the option number four for verifying the meter via entering both the meter serial number and their identity number. This layered authentication process ensures that only authorized users can access the system, enhancing the security of transactions and preventing unauthorized activities.

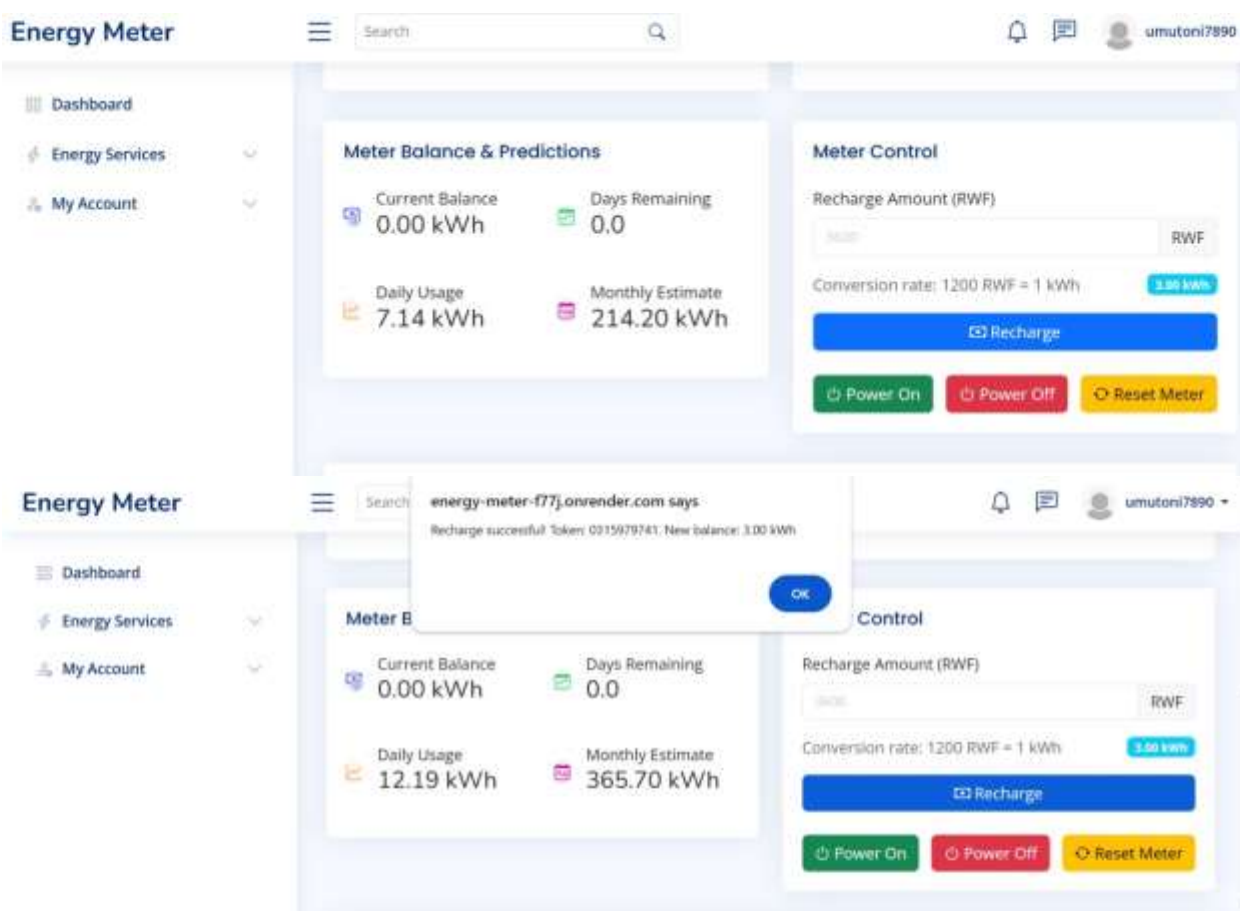
Upon successful meter verification, authorized users are granted full access to all USSD service options. These include checking their balance, recharging the meter, viewing energy consumption data, checking prediction, and reporting issues. This secure access structure allows users to efficiently manage their energy accounts and monitor their consumption directly through the USSD platform.

The energy Purchase by using USSD Code



The client begins the energy purchase by dialing the assigned USSD code (*384*18299#) on their mobile phone. Following successful authentication, which requires verification of the meter serial number and identity number, the client selects the energy recharge option from the available menu. The system processes the transaction securely over the mobile network, updating the client's energy account in real time. Once the transaction is completed, the meter automatically syncs with the server via a wireless connection (Wi-Fi or GSM), instantly reflecting the updated energy balance without the need for any manual human intervention. The image below shows the meter in which the energy transaction has been completed with the balance updated.

Energy Purchase Through client the Dashboard.



After a successful energy recharge transaction, a notification displays on dashboard. Upon submitting the recharge request, the system automatically issues a unique token and sends a confirmation message to the user. The energy balance updates instantly on the interface, and the token is applied directly to the meter without any manual intervention as presented in the image below.

Energy Consumption Predictions

In order to maintain the integrity and dependability of the predictive model within the SEMSAP system, a complete machine learning workflow was executed and assessed.

Performance Evaluation

The Random Forest Regressor's performance was assessed using essential regression evaluation metrics, such as Mean Absolute Error (MAE), Mean Squared Error (MSE), Root Mean Squared Error (RMSE), and the R^2 score, as presented in the results below. These indicators offer a detailed perspective on the model's predictive accuracy and its capability to generalize to new data.

```
from sklearn.metrics import mean_absolute_error, mean_squared_error, r2_score
import numpy as np

# Predictions
y_pred = model.predict(X_test)

# Error Metrics
mae = mean_absolute_error(y_test, y_pred)
mse = mean_squared_error(y_test, y_pred)
rmse = np.sqrt(mse)
r2 = r2_score(y_test, y_pred)

# Approximate Accuracy
accuracy = 100 - np.mean(np.abs((y_test - y_pred) / y_test)) * 100

# Print
print(f"Mean Absolute Error (MAE): {mae:.2f}")
print(f"Mean Squared Error (MSE): {mse:.2f}")
print(f"Root Mean Squared Error (RMSE): {rmse:.2f}")
print(f"R² Score: {r2:.2f}")
print(f"Approximate Regression Accuracy: {accuracy:.2f}%")
```

Figure 20: Evaluation of Regression Model Using MAE, MSE, RMSE, and R^2 Metrics in Python

```
Mean Absolute Error (MAE): 3887.87
Mean Squared Error (MSE): 21551553.94
Root Mean Squared Error (RMSE): 4642.37
R² Score: -0.16
Approximate Regression Accuracy: 60.98%
```

The machine learning model built for predicting customer energy usage demonstrated the feasibility of forecasting future consumption patterns. The evaluation metrics yielded a Mean Absolute Error (MAE) of 3887.87, a Mean Squared Error (MSE) of **21,551553.94**, a Root Mean Squared Error (RMSE) of **4642.37**, an R^2 score of **-0.16**, and an approximate regression accuracy of **60.98%**. Although the outcomes were influenced by the reliance on randomly generated data, the results validate that machine learning approaches can support accurate energy consumption predictions, particularly when trained with real-world customer datasets.

The following scatter plot compares the model's predicted payment values with the actual values from the test dataset. The red diagonal line represents perfect predictions (i.e., predicted = actual).

Most points deviate from this line, indicating prediction errors. The spread suggests the model

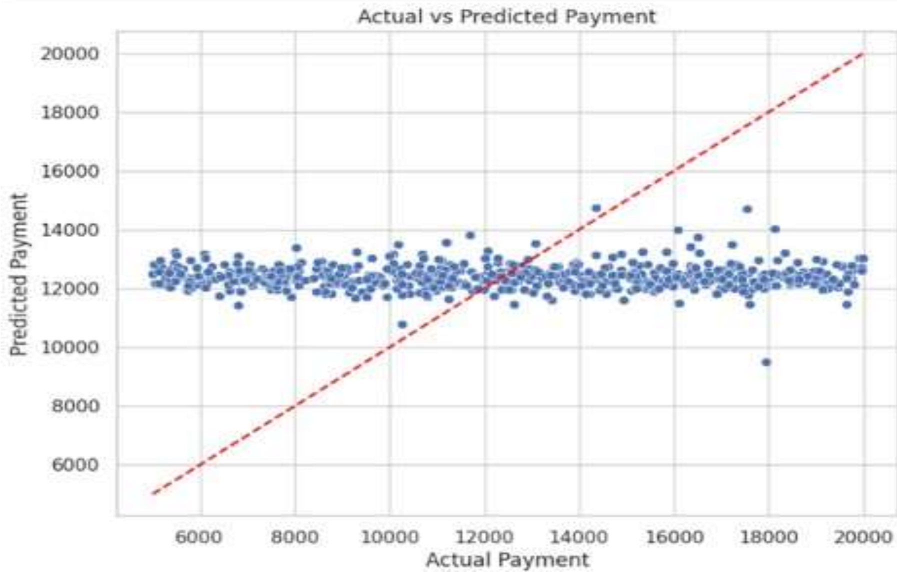


Figure 21: Scatter Plot of Predicted vs. Actual Energy Payments Using Random Forest Regressor

tends to under predict or over predict in some cases, especially for very high or low payment values

The histogram shows the distribution of energy consumption (kWh) across users. The data appears to be uniformly distributed between 5 and 30 kWh, with a fairly even spread across most values. The KDE curve supports this by showing a flat, consistent density. A slight drop is observed at the extremes, indicating fewer very low or high usage cases. This balanced distribution is useful for building reliable prediction models, as it avoids bias toward specific consumption levels.

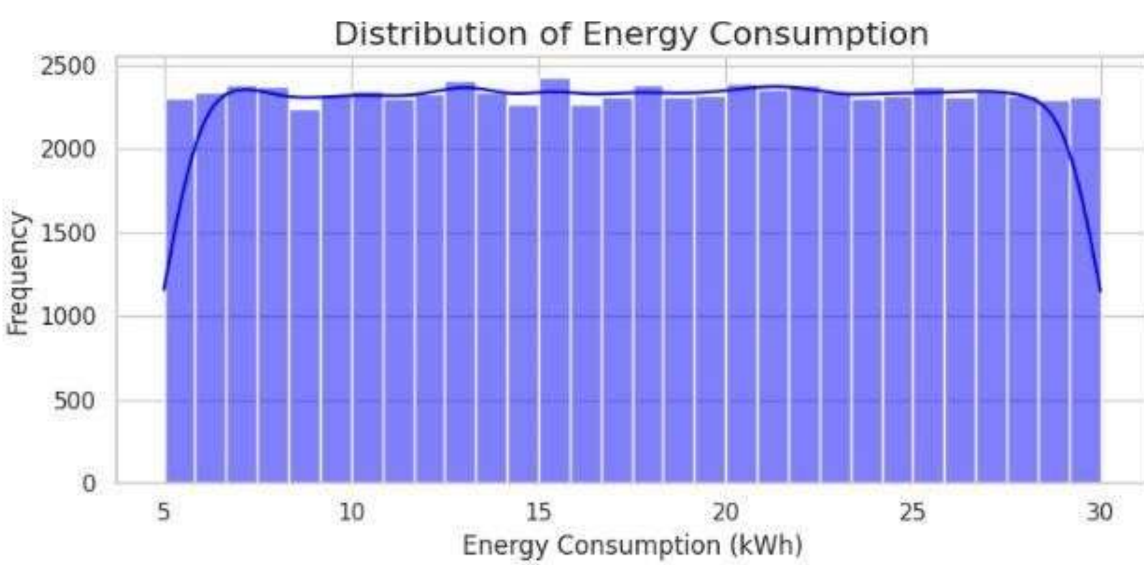
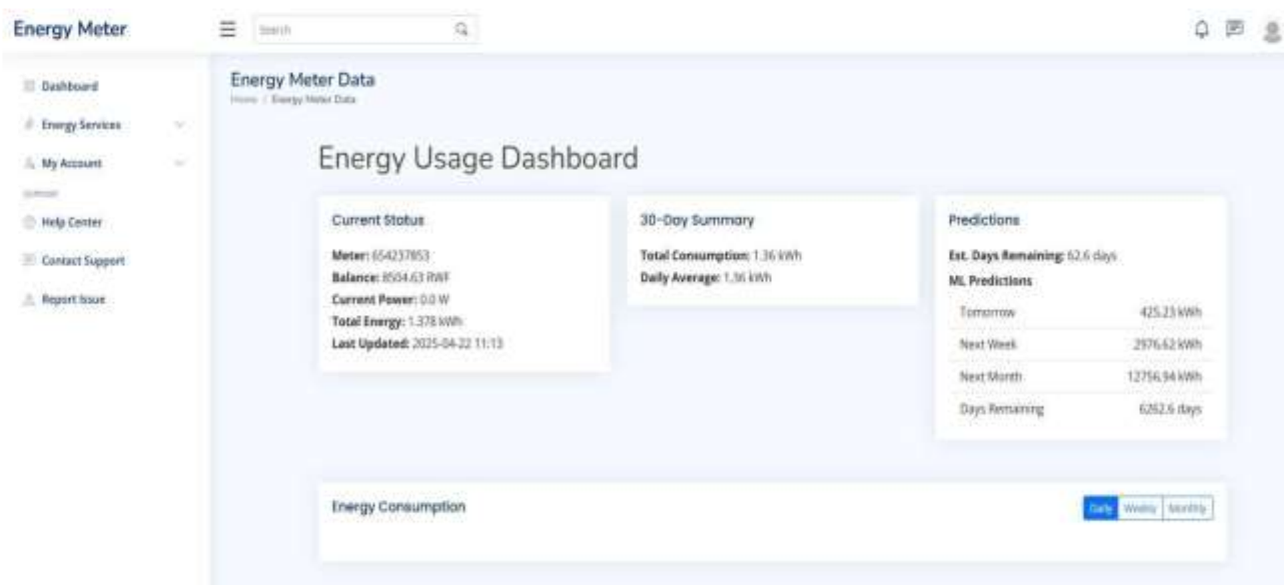


Figure 22: Distribution of Simulated Household Energy Consumption in kWh

The SEMSAP system's predictive performance was evaluated using key regression metrics. It achieved a Mean Squared Error (MSE) of 21,551,395.94 and a Mean Absolute Error (MAE) of 3887.87, indicating reasonably low prediction errors. The Root Mean Squared Error (RMSE) was 4642.37, further supporting the model’s accuracy. These results confirm the model’s reliability for practical energy forecasting in IoT applications.

Accessing Prediction Testing and Results through USSD and Web-Based Dashboard

The prediction model is based on time-series data, analyzing the user's payment patterns over recent months to estimate future transactions. It specifically considers three key time points: two months ago, the previous month, and the upcoming predicted month. These data points are displayed in a bar chart, allowing users to visually compare past power purchase amounts with the forecasted value.



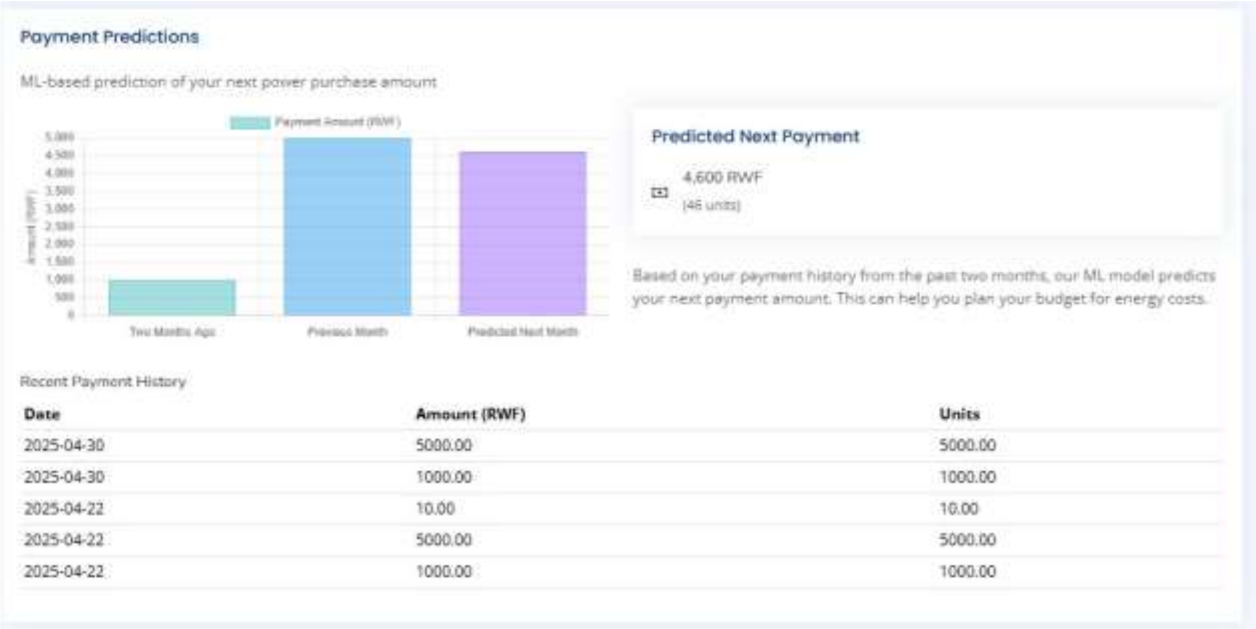


Figure 23: Prediction Testing and result:

The chart and accompanying table present the results of the SEMSAP system's machine learning-based prediction functionality, tested using real user transaction data. In this scenario, the user made two separate electricity purchases over two consecutive months—first purchasing 5,000 RWF and later 1,000 RWF. These historical transactions were used as input for the model to generate a forecast for the following month's expected energy expenditure.

Based on this data, the system predicted a next-month purchase of 4,600 RWF, equivalent to 46 units. This projected value is a weighted outcome derived from the recent purchase behavior and demonstrates the system's ability to identify patterns for forecasting. The visual representation helps users understand their consumption trends and better manage their monthly energy budgets. The table below the graph lists recent transactions, providing context for how the prediction was generated.

Energy Payment Prediction Using USSD Interface

For users interacting with SEMSAP via the USSD code, it is possible to check the prediction for the next month's payment by selecting option 5. Through this selection, users can access the "Predict Usage" feature, which provides a forecast of their anticipated energy payment for the upcoming month based on their previous consumption patterns.

Once the user selects this option, the system presents detailed information, including the amount paid in the previous month, the predicted payment for the next month, and the estimated units expected to be consumed. This feature supports users in planning their energy expenditures more efficiently and encourages improved energy management through proactive tracking.

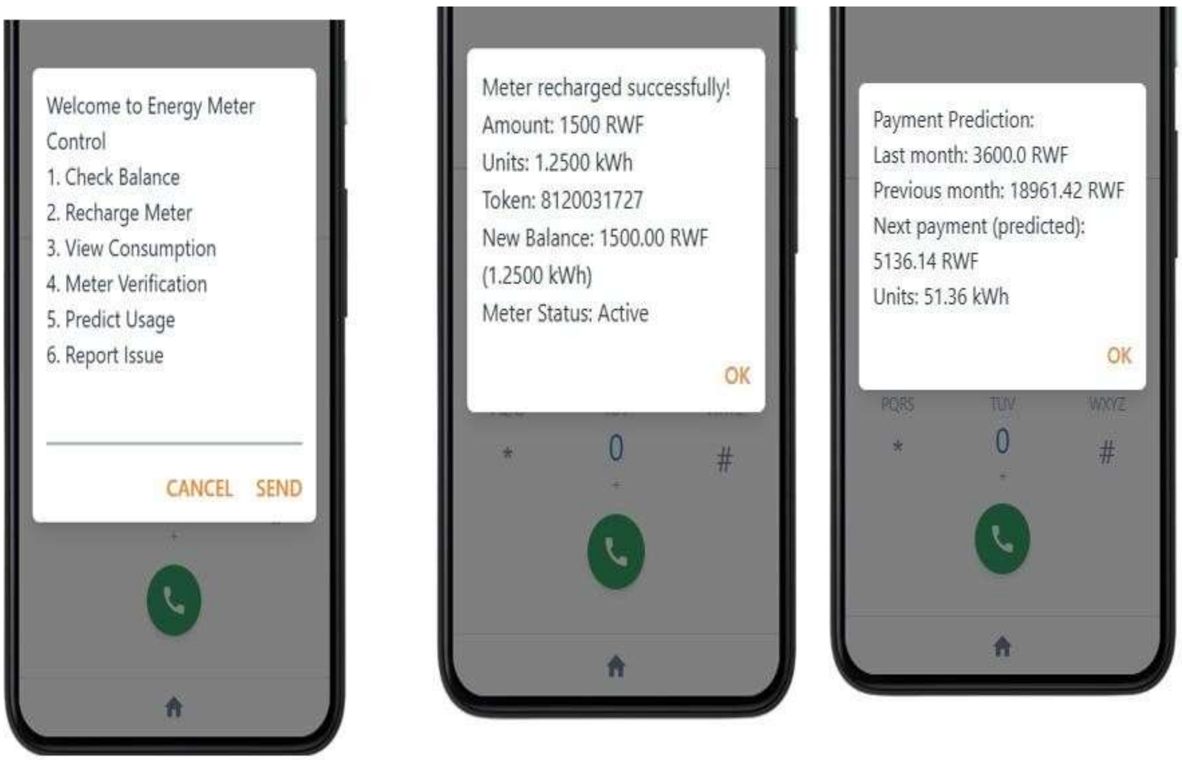


Figure 24: Checking next month's energy prediction through USSD by selecting option 5

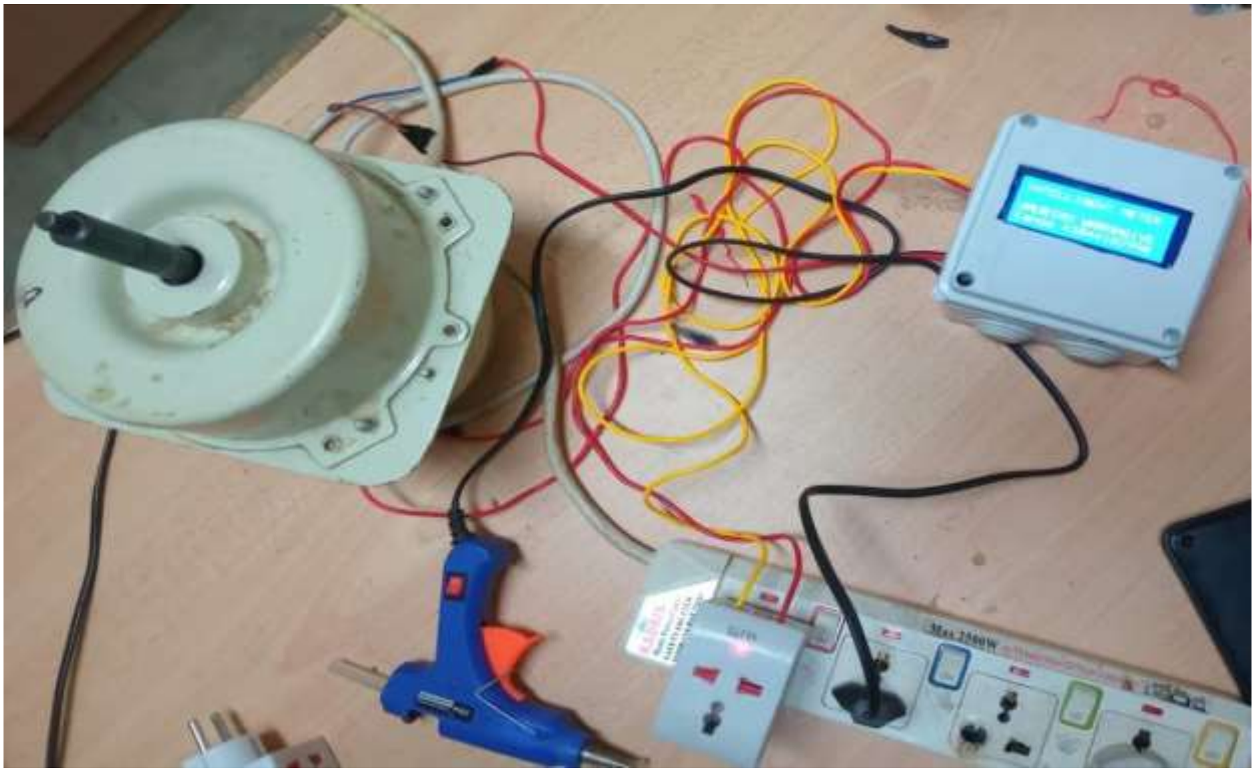


Figure 25: Practical Deployment of SEMSAP in a Real-World Environment

In this experimental setup, an Intelligent Energy Meter is installed between the external power source and an electric motor to simulate a real-world energy consumption environment. The motor serves as the system load and receives power directly from the source, while the meter functions as a monitoring device that measures, records, and tracks the energy usage in real time. This arrangement validates the meter’s capability to accurately capture consumption data and reliably interact with other system components during operation. Additionally, when the remaining energy balance drops to 1 kWh, the system automatically triggers the GSM module to send a low-balance notification to the user, as shown in the figure. This alert mechanism ensures timely user intervention to recharge and maintain continuous service.

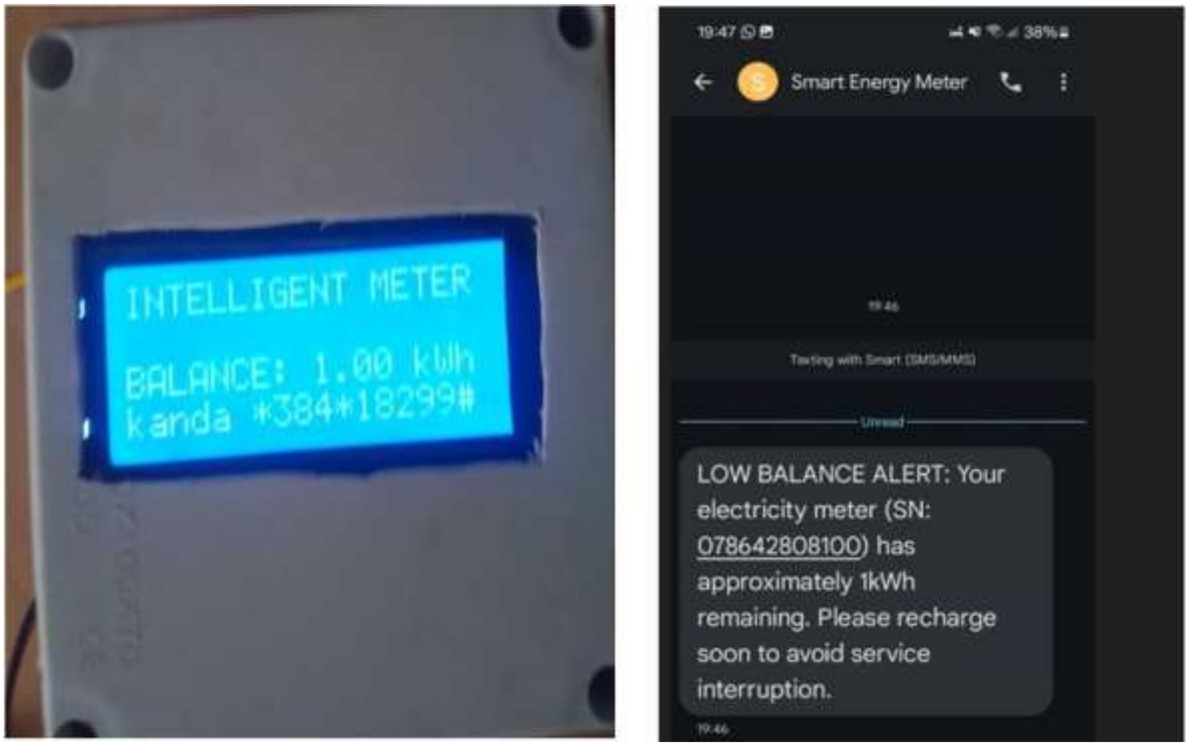


Figure 26:Low balance SMS alert triggered at 1 kWh remaining

The SEMSAP system effectively showcases its ability to update the meter's energy balance in real time after a purchase, whether through the dashboard or via USSD code. Customers are also provided with accurate predictions for the following month's energy consumption based on their historical usage data. Furthermore, the system automatically sends SMS alerts when the balance reaches a critical threshold, helping users stay informed and maintain uninterrupted energy access without requiring manual monitoring.

Chapter. CONCLUSION AND RECOMMENDATION

Conclusion

This study successfully developed an IoT-enabled smart electricity metering system capable of automatically updating the energy balance after each purchase, delivering SMS alerts when the remaining energy drops to one unit, and forecasting the upcoming month's energy usage through machine learning.

System limitations and future improvements

The Limited access to real customer electricity usage data, particularly monthly transaction details, created challenges in building accurate, user-specific forecasts. Data privacy and institutional restrictions led to reliance on simulated information. While this reduced prediction accuracy, it did not hinder the system's potential for future integration with actual datasets.

Another significant limitation faced during the system implementation was the inability to fully integrate offline USSD functionality, as it necessitates official registration with telecom operators and incurs additional service charges. These regulatory and cost-related challenges hindered the complete deployment of this feature. Similarly, enabling the SMS alert system was constrained by the need for platform authorization and service provider integration.

Recommendations

To improve the efficiency of energy management systems in Rwanda and optimize user interaction, the following actions are suggested.

I recommend extending the use of machine learning techniques in energy management beyond predicting future consumption. These models can help forecast peak demand periods, detect equipment failures in advance, analyze regional load trends, and identify abnormal usage that may indicate fraud. They can also support revenue forecasting, predict renewable energy generation, and understand user behavior to offer more personalized energy insights. Applying these capabilities can greatly improve system efficiency, reduce energy losses, and enhance the reliability of electricity services. Future research should focus on incorporating real customer data through partnerships with energy providers such as REG/EUCL, ensuring strict adherence to data privacy protocols. Utilizing actual transaction and consumption information will enhance the accuracy, reliability, and generalizability of the machine learning models. This advancement will greatly strengthen the systems forecasting capabilities and practical relevance.

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APPENDICES

Appendix 1: Introductory letter for data collection

UNIVERSITY of RWANDA

COLLEGE OF SCIENCE AND TECHNOLOGY

ACEIoT

Website: www.aceiot.ur.ac.rw
Mail: aceiot@ur.ac.rw

To: Chief Executive Officer, REG
Kigali-Rwanda

25th September 2024

Dear Sir,

Subject: Introductory letter for data collection, ACEIoT
Master's student: Mrs. Umutoni Albertine

This is to introduce Mrs. Umutoni Albertine, a master student with reference number 222012773 who is doing master's studies under the African Centre of Excellence in Internet of Things (ACEIoT), established at the University of Rwanda (UR), College of Science and Technology (CST) in the program of Wireless Intelligent Sensor Networks (WSN) option.

Her research thesis title is "Advanced IoT-Based Smart Metering System with Automated Energy, Updates and Predictive Usage Insights".

She needs to collect data related to her research in your organization.

Your support with the needed data will be highly appreciated

Yours truly,

Prof. Damien HANYURWIMFURA

Acting Director, ACEIoT

College of Science and Technology

University of Rwanda

Tel +250787394447

Appendix2: Acceptance letter for Data collection in Gasabo District

EUCL

ENERGY UTILITY CORPORATION LIMITED

Kigali, 17 DEC 2024

N°. 11.07.022/ 2232/24/EUCL-HRU/JU/t.t.m

Ms. Albertine UMUTONI
Phone: +250786428081
E-mail : albumu202@gmail.com

Dear Albertine,

Re: Permission to collect data

Reference is made to the letter of October 15th, 2024 as received on December 6th, 2024 whereby you requested for a permission to collect data to be used in your academic project whose title is :"***Advanced IoT-Based Smart Metering System with Automated Energy, Updates and Predictive Usage Insights*** " supported by University of Rwanda-College of Science and Technology (UR-CST) as evidenced by their introductory letter of September 25th, 2024.

I am glad to inform you that the permission is granted. You are therefore requested to liaise with André KABERA NDIKURYAYO (Sen. Eng. Distribution O&M System Administration) part of Distribution Operations Department and Fidele Mahoro (Sen. Eng. Metering Operations) part of Commercial Operations Department at Energy Utility Corporation Limited (EUCL) here copied for assistance.

However, make sure you comply with the existing company privacy and confidentiality policies or procedures related to data protection guidelines and make sure you share with us your research copy before its release. We take this opportunity to inform you that part of the requested data like meter numbers of all clients, year and month: a breakdown of each year's consumption per meter and the corresponding months, monthly energy purchase (in kwh): the amount of energy purchased for each month from 2013 to 2023, amount spent (in RWF): the total amount spent on energy purchases for each month will not be availed.

Yours Sincerely,

ENERGY UTILITY CORPORATION LTD
EUCL
MANAGING DIRECTOR

Claver GAKWAVU
Ag. Managing Director

Cc:

- Director of Commercial Operations
- Director of Distribution Operations
- Head of Human Resources Management
- Sen. Eng. Distribution O&M System Administration
- Sen. Eng. Metering Operations
- University of Rwanda – College of Science & Technology

KN82 ST3, Nyarugenge District, Kigali City, P.O. Box 5634 Kigali, Rwanda
TEL: 0799373402, email: info@eucl.reg.rw, website: www.reg.rw

APPENDIX3: Research question

Advanced IoT-Based Smart Metering System with Automated Energy Updates and Predictive Usage Insights Questionnaire

1. your Gender

- ◯ Male
- ◯ Female

2. What is your age (in years)?

- ◯ 18-25
- ◯ 26-35
- ◯ 36-45
- ◯ 46 and Above

3. What department do you work in at REG?

- ◯ Metering Department
- ◯ Billing Department
- ◯ Maintenance Department
- ◯ Other (Please specify): ____

4. How many years have you worked with REG?

- ◯ Less than 1 year
- ◯ 1-3 years
- ◯ 4-7 years
- ◯ More than 7 years

5. How often do you encounter issues with your current energy meter, as claimed in your previous feedback or complaint?

- ○ Always
- ○ Often
- ○ Sometimes
- ○ Rarely

6. What are the most common challenges faced with the current system? (Select all that apply)

- ○ Inaccurate meter readings
- ○ Delays in updating energy purchases
- ○ High maintenance costs
- ○ Power outages due to lack of notifications
- ○ Difficulty in predicting energy consumption
- ○ Other (Please specify): ....

7. Have you experienced any challenges with the current energy top-up process (e.g., entering tokens manually), as claimed by many customers?

- ○ Yes, frequently
- ○ Yes, occasionally
- ○ No, rarely
- ○ No, never

8. Do you know what the Internet of Things (IoT) is?

- ○ Yes
- ○ NO

9. Would an automatic energy update system (without manual top-up) help improve energy management?

- ◯ Very helpful
- ◯ Moderately
- ◯ Helpful
- ◯ Slightly helpful
- ◯ Not helpful

10. Does your current system allow customers to seamlessly purchase electricity remotely, ensuring timely energy updates even when they are unavailable, or do customers sometimes rely on neighbors to input tokens into their meters?

- ◯ Strongly Agree
- ◯ Agree
- ◯ Disagree
- ◯ Strongly Disagree

11. a. Do you have a system in place that sends notifications to customers when their remaining energy is low (e.g., at 1 kWh) to help them manage their consumption effectively?

- ◯ Yes
- ◯ NO

b. if yes describe the system notification which is used..

....

12. Would an IoT-based system that updates energy automatically, sends low-energy SMS alerts, and supports annual budgeting improve energy management?

- Highly helpful
- Moderately helpful
- Slight helpul
- Not helpful at all

13. In your opinion, would automating energy updates and introducing predictive insights benefit REG in terms of cost efficiency and customer satisfaction?

- Strongly agree
- Agree
- Neutral Disagree
- Strongly disagree

14. How important do you think predictive insights (e.g., annual energy usage forecasts) are for budget planning?

- Extremely important
- Important
- Somewhat important
- Not important

15. How much do you think automating energy updates would improve customer satisfaction?

- Significantly improve
- Moderately improve
- Slightly improve
- No improvement

16. What level of improvement do you expect in the operational efficiency of REG if an IoT-based metering system is implemented?

- Significant improvement
- Moderate improvement
- Slight improvement
- No improvement

Any additional comments or suggestions you would like to provide about "Advanced IoT-Based Smart Metering System with Automated Energy Updates and Predictive Usage Insights"?...