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Final Year Project:

Design and Implementation of an Arduino-Based GSM Prepaid Electricity Meter with Automated Billing

Research Project submitted in partial fulfillment of the requirement for The award of Advanced Diploma in Electronics and Telecommunication Technology.

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Done by:

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September, 2024

DECLARATION

I, MULUMBA BAKILONGO NICOLAS, hereby declare that the above is my work and has not, either in part or in whole, been presented to any University or High Learning Institution for the award of a degree or any other academic award. No part of this research can be reproduced without the consent of the author.

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Date: ___________________________

CERTIFICATION

I hereby certify that the research work for this project has been carried out under my supervision. I have gone through the final submission, and hereby approve it to be submitted in accordance with the requirements of ULK Polytechnic Institute.

Supervisor name: Eng. Annuarita GATESI

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APPROVAL SHEET

This research project entitled "**Design and Implementation of an Arduino-Based GSM Prepaid Electricity Meter with Automated Billing"** prepared and submitted by MULUMBA BAKILONGO NICOLAS in partial fulfillment of the requirement for award of advanced diploma (A1) in Electronics and Telecommunications Technology has been examined and approved by the panel on oral examination.

Name and Sig. of Chairperson: ___________________________

Date of Comprehensive Examination: _____________________

DEDICATION

Above all, may the grace of God and his guidance be a source of strength and inspiration in my study.
My dear family, especially my parents, whose support, encouragement, and sacrifices have built the cornerstone of my education.
To my friends and colleagues for the inspiring and supporting atmosphere and help at every step of the preparation of my project.
To all my teachers and mentors, who in the light of knowledge, guided me in the completion of this work.
And to those who did believe, who gave me that push to keep going a deep-felt thank you.

Thank you all, my strengths.

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I would like to express my deepest gratitude to my family and friends who, in the very difficult moments of this project, supported me, understood and motivated me. Their confidence in me allowed me to continue even in the most difficult times.

I am deeply indebted to the cooperation and participation of all those who provided me with valuable data and feedback for this research study. Without their willingness to participate, this research study would not have seen the light of day.

Thank you for all your support and contributions.

ABSTRACT

The project involves the design and implementation of an Arduino-based integrated GSM prepaid electricity meter along with automated billing. The purpose of this project was to analyze the conventional modes of postpaid electricity billing along with their drawbacks, and overcoming this issue by providing a more accurate and reliable prepaid electricity billing meter.

With the proposed project, the consumed electricity was confirmed to continuously be sensed in real time to develop automatic updates on the billing by using the GSM channel.

Achievements of this project include real-time monitoring, accurate billing through sensor calibration, and automated alerts via SMS for low balance notifications. The system enhances consumer awareness and simplifies energy management by providing automated, transparent updates on electricity consumption.

Experiments were conducted to test the accuracy of the sensors, balance tracking, and power control. Calibration of the voltage and current sensors confirmed precise energy readings, while tests on the relay and SMS alerts demonstrated the reliability of balance deductions and automated notifications.

In conclusion, this project successfully demonstrates a functional, efficient, and reliable solution for prepaid electricity metering. The system offers substantial improvements over traditional postpaid methods, benefiting both consumers and utility providers by promoting transparency and efficient energy management.

Key words: Arduino, GSM, Prepaid Electricity Meter, Automated Billing, Real-Time Monitoring, Energy Management, Voltage Measurement, Current Measurement, SMS Notifications and Smart Metering.

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AC – Alternating Current

ADC – Analog to Digital Converter

DC – Direct Current

EEPROM – Electrically Erasable Programmable Read-Only Memory

GSM – Global System for Mobile Communications

I2C – Inter-Integrated Circuit

IDE – Integrated Development Environment

LCD – Liquid Crystal Display

PCB – Printed Circuit Board

RTC – Real-Time Clock

SMS – Short Message Service

Tx – Transmit

Rx – Receive

VCC – Voltage Common Collector

Wi-Fi – Wireless Fidelity

CHAPTER 1: GENERAL INTRODUCTION

1.0 Introduction

This is a visionary design where advanced technologies in solution design and consumption control would be integrated to help control electricity consumption but also automate billing processes; But more importantly, it has the potential to significantly increase security concerns related to unauthorized access and tampering issues. It is specifically aimed at real-time usage monitoring using GSM technology and Arduino microcontrollers, where it might be possible to automate billing along. Going through all these features, we can easily say that this new energy metering system is more efficient and reliable than conventional electricity management systems.

This is an imperative for operational efficiency and fairness of consumption in terms of electricity resources; it will find its place in the global effort to achieve sustainable energy management with regard to efficient use of resources and operational transparency in electricity distribution.

1.1. Background of the Study

Electricity is, therefore, the backbone of modern industrialization, life at home, and the dispensation of numerous other crucial services (Garcia, L., 2018). Other than that, traditional electricity management systems often face a host of challenges which basically compromise their effectiveness and efficiency; a big challenge, for instance, that postpaid billing systems represent by causing errors and delays that later lead to billing disputes and consumers' reaction with dissatisfaction, hence financial losses for utility companies (Rahman & Kumar, S., 2017).

Unauthorized access to electricity utility not only results in huge financial loss but also destabilizes and reduces the efficiency of electrical power s (Ishola, B. & Adewale, T., 2021). The features and old capabilities of traditional energy meters have not effectively met such challenges.

Promising solutions devised through technological advancement could have overcome problems like those being faced above. Inclusion of Global System for Mobile Communications technology with a microcontroller-based system like Arduino brought forth an important function. GSM would make real-time communication and data transmission possible, while Arduino availed an easily programmed flexible low-cost platform on which would be created smart devices (Johnson, 2016).

Under this framework, consumers may pay and buy electricity in advance before using it through the various providers by use of payment terminals or mobile platforms. It allows consumers to monitor and control electricity use as it is being consumed so to avoid cases of high unexpected bills. Further, the prepaid meters would help utility service providers avoid the risks of losing out on revenue and ensure that the payments are timely (Nwankwo, O. & Uchenna, K., 2020).

It's based on the project of designing a GSM prepaid electricity meter embedded with Arduino, among other characteristics within it like an automated billing. The innovation brought into the designed system gives real-time information about energy use and an automated billing system. The systems present in conventional meters were ineffective, and therefore, there exists a need for improvement toward effective efficiency and security in electricity management. But with the aid of innovative technologies, it is the project that intends to improve basically the ways by which electricity is monitored, billed, and consumed; hence, such modification has become a win-win situation for both suppliers and consumers.

1.2 Statement of the Problem

Even though electricity plays a vital role in running daily life and much of economic activity, the traditional system of electricity billing faces numerous problems: from error-laden bills to delays in the processing of payments. Traditional postpaid billing invariably gives rise to disputes between utilities and consumers and, in turn, leads to financial losses and customer dissatisfaction. One of the major lacks in the currently laid infrastructure is a function of real-time monitoring instant billing system which would manage the electricity properly. Both these deficits call for a solution to address it; it should be one that gives utility providers access to correct, real-time data of electricity use, automating billing processes to the optimum The research project is, therefore, aimed at structuring a sustainable solution to such problems by applying a base of GSM-based prepaid electricity metering and Arduino technology. It will ensure accuracy in the billing system and timely payment for both, affect greater effectivity, and efficiency of electricity management

1.3 Research Objectives

These have been categorized into main objectives and specific objectives:

1.3.1. Main objective:

To design and implement Arduino-based GSM prepaid electricity metering with automated billing

1.3.2. Specific objectives:

i. To design a prepaid energy meter based on GSM for the measurement of electricity, mainly incorporating the aspects of accurate measurement of electricity units supplied to monitors and managers.
ii. To enable real-time monitoring of the meter: It provides a record of how much energy has been consumed to the very last penny to both the consumer and utility service provider, leaving no room for discrepancies at the time of billing
iii. To provide consumers with the channels to monitor their energy consumption in real time; it keeps them informed to make a decision toward the optimization of the use of energy for lesser cost

1.4 Research Questions

In line with these specific objectives, the following research questions are formulated for the project:

i. How can an Arduino-based GSM-encoded prepaid energy meter be designed in a way that can accurately measure electricity units for monitoring and management purposes?
ii. How can real-time monitoring capabilities be implemented to provide accurate and update information on energy consumption to both consumers and utility Providers alike?
iii. To what extent can energy data help consumers optimize their electricity usage and reduce costs?

1.5 Scope of study

The proposed project focused on the design and implementation of a GSM based prepaid electricity meter implemented using Arduino, specifically at Goma Town in Democratic Republic of Congo. Factors considered in research include energy consumption patterns, billing accuracy and consumer feedback.

1.6. Significance of the Study

This study sought to solve these perennial challenges associated with the electricity management and billing system in SNEL in Goma, Democratic Republic of the Congo. The general object of the study was to assist SNEL, situated in Goma, Democratic Republic of Congo, in designing and implementing an Arduino-built, GSM-based prepaid electricity metering and billing system that automatically provides billing. This is likely to improve operational efficiency for utility providers such as SNEL, reduce loss from incorrect billing, and enhance service delivery.

The results obtained from this study were expected to add value to general knowledge by demonstrating that GSM technology can be integrated along with Arduino-based systems in prepaid electricity meter readers, and its implementation can be more efficient.

1.7 Organization of the Study

This research work has therefore been segmented into 5 chapters so as to systematically address the research objectives and explore the design and implementation of a GSM-based prepaid electricity meter as well as an automated billing system using Arduino as follows.

Chapter 1**:** General Introduction

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

Chapter 2: Literature Review

A critical examination of previous studies, theoretical approaches, and existing concepts related to prepaid electricity meters, GSM technology, and embedded systems using Arduino. It highlights gaps identified in current solutions.

Chapter 3**:** Research Methodology

Describes the research design, methods, and procedures used in developing and implementing the prepaid electricity meter. It includes a detailed description of the components, testing procedures, and calibration methods.

Chapter 4**:** System Design Analysis and Implementation

Presents the detailed design, including system architecture, flowcharts, block diagrams, circuit diagrams, and implementation steps. The performance evaluation and testing results of the prepaid electricity meter system are also discussed.

Chapter 5**:** Conclusion and Recommendation

This chapter summarizes the research findings, provides conclusions on the project outcomes, and offers recommendations for future work and system improvements.

CHAPTER 2: LITERATURE REVIEW

2.0 Introduction

This chapter provided general information and important backgrounds of the study. This was a critical examination of previous studies and theoretical approaches associated with the subject of the study. More specifically, this research begins by presenting the general discussion of the ideas, opinions and existing concepts of different authors and academics in the field of prepaid electricity metering and GSM technology. This was also presented in the conceptual framework overview that underlies this study, as well as a more critical review of the concept, theory, models and approaches to intelligent measurement and energy management. This section also shows the empirical studies relevant to the research issue, its findings and the gaps that this study aims to filled. This has established a good review of the literature to understand the current literature on what is understood on this subject and to identify contributions to which this work would add value in the field.

2.1 Overview of GSM Technology on Energy Meter

GSM is a set of mobile communications standards and protocols governing second-generation or 2G networks.

Figure 1. GSM SIM900 (Abbas, 2018)

An energy meter is a device that measures the amount of electric energy consumed by a residence, a business, or an electrically powered device over a time interval.

Integrating GSM technology in energy metering systems which resulted in one of the most important breakthroughs in the field of energy management.

This GSM technology benefits from a reliable and robust platform for real-time data transmission and remote monitoring applications (Purohit, A & Tiwari, K, 2017). Thus, in the next discussion section, it must examine the characteristics and advantages that this technology brings to an energy meter, as well as its impact on contemporary energy management practice.

It is in this respect that GSM technology establishes the basis for easy real-time transmission of any amount of energy consumed from the consumer meter from the consumer to the relevant utility provider. This effectively handles a much more accurate invoice generation process, as captured data can be used in automatic invoice generation based on actual consumption and not mere estimates at a given time. Automated billing can avoid office errors and disputes between consumers and utilities, resulting in transparency and therefore effective billing.

Apart from this, the introduction of the use of GSM technology in meters will facilitate the diagnosis of electricity theft cases. Traditional energy meters are still subject to tampering and unauthorized use, hence a great loss of revenue for utility providers. Whenever such counters are activated by GSM, this may indicate such contradictions and quick verification. This feature protects revenues and is extremely important for the overall stability and reliability of the power system as a whole.

The other essential benefit of GSM-based electricity metering will be to ensure that the exact amount of electricity consumed is relayed to the consumer in real time. In this way, a consumer will stand in a very good position to monitor the amount of electricity he consumes, thus using energy consciously and efficiently. With the warning of updating usage patterns, the consumer can premeditate the measures they had taken earlier to reduce electricity consumption and, consequently, their bill above the dollar (Kalyani, R & Shinde, M, 2016).

In addition, GSM technology supports scaling and flexibility of energy management solutions. Large regional areas may be covered by the availability of GSM networks, and advanced counting solutions will be able to implement both in urban and rural areas. The flexibility of GSM technology ensures that the distribution of this utility will be applied to a wider range of customers in case there is an infrastructure change challenge.

The application of GSM technology in energy meters is therefore extremely useful in terms of accuracy, efficiency and safety associated with consumer empowerment. Basically, the development of GSM-based energy meter tilts towards more practical and efficient energy management systems taking into account real-time data transmission, automatic billing, and customer participation, among other measures.

2.2 Arduino in Embedded Systems

Arduino has probably become one of the most ingenious and flexible platforms, achieving a real turning point in the very concept of an embedded system (Jadhav, S & Rajput, R, 2019).

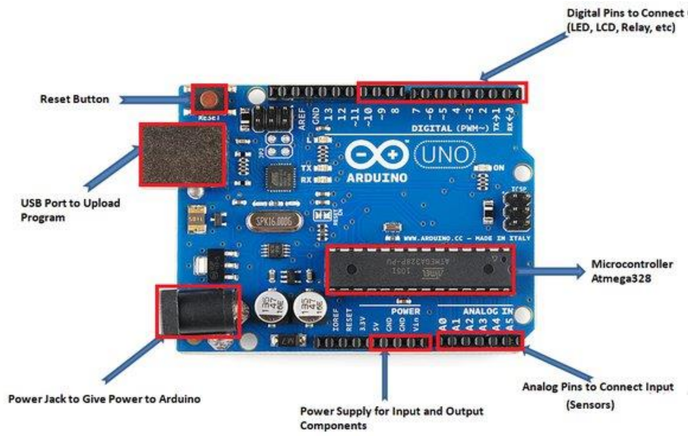

Figure 2. Arduino UNO (· Osaghae, 2020)

With this open-source electronics prototyping platform, flexible hardware, and easy-to-use software, hobbyists, educators, and professionals have been in dire need of a device. To the general description of what Arduino is in relation to the context of the embedded system, its characteristics, its application examples and its influence on contemporary technological solutions, the following is devoted.

Arduino is a great platform for interactive electronic parts. Basic hardware functions include a microcontroller, input/output pins, and a standard development environment. At its core, the microcontroller dominates the board as the "brains" that reads inputs, whether it's light from a sensor or the placement of a finger on a button, then converts them into an output, which can consist of a motor or LED lights (Jadhav & Rajput, 2019). This will make Arduino ideal for developing a wide range of applications, from ordinary devices for everyday use to complex systems for industrial use.

One of the main advantages of the Arduino is its ease of use. The Arduino IDE is user-friendly. It's pretty easy to code in a much better supported version of C++ and then just upload it to the board. It is this simplicity that has reduced embedded development costs and allowed someone with minimal technical experience to develop a working prototype. A large community and library of shared code and tutorials take any user's learning and development experience to the next level.

When it comes to energy management and smart metering solutions, Arduino steals the show by designing and developing advanced metering solutions. Arduino boards can interface with a variety of available sensors and communication modules to form a highly efficient smart energy meter, capable of measuring power consumption with a high degree of accuracy, supporting wireless transmission usage data and automate billing. For example, the integration of Arduino with GSM modules will provide an opportunity for development of prepaid energy meters to transmit real-time usage to utility providers, thereby improving billing and operations efficiency.

Suffice it to say that Arduino's flexibility reaches advanced levels to include a long list of supported devices and modules. This will have to be done to provide tailor-made solutions to certain specific needs. For example, Arduino in an energy meter reading system is able to interface with current and voltage sensors to control electricity consumption, use GSM modules to transmit data and have LCD screens that reflect real-time user feedback on consumption. In this modular approach, designs are likely to be more elastic and adaptable as they change over time and changing needs.

Additionally, its price makes the Arduino very attractive for developing countries or other resource-limited settings. For the price paid for Arduino boards and parts, one can be very confident that advanced energy management systems can be created and deployed on a fraction of traditional, mostly proprietary systems. Such a capacity for democratization strengthens innovation, providing access to intelligent solutions to a greater number of people and therefore sustainable development and improvement in quality of life.

At its core, Arduino is simply deep, flexible, and affordable: a truly deep embedded systems platform. Its application to energy management systems is one of the ways in which Open Source can place innovation and efficiency at the heart of critical infrastructure. With Arduino, a developer can create complex and reliable solutions at an affordable cost to help solve contemporary energy consumption and management problems.

2.3 Specification

2.3.1 Arduino

Arduinos are open-source systems of microcontrollers with the ability for the user to operate hardware and software to accomplish an immense variety of tasks. There are several models of Arduino boards, like Arduino Uno, Arduino Mega, Arduino Nano, but their usual way of working remains the same for all.

Figure 3. Arduino Uno (Osaghae, 2020)

2.3.2 ZMPT101B voltage Sensor

The ZMPT101B is a high-precision voltage sensor capable of converting an AC voltage signal into an Arduino-readable analog signal that will be proportional. An integrated operational amplifier is used in it, thus providing conditioning of the signal to measure the voltage correctly. Very suitable for energy monitoring systems.

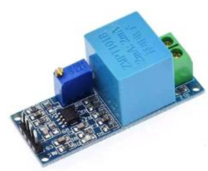

Figure 4. Voltage Sensor zmpt101b (· Purohit, A. & Tiwari, K, 2017)

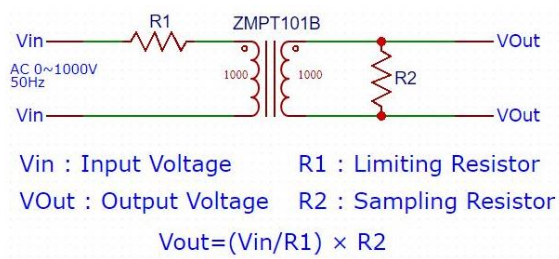

Figure 5. Voltage sensor schematic Diagram

2.3.3 Current Transformer SCT013 30A

The SCT013 is a non-invasive current transformer based on the operation of clipping the alternating current around a conductor. Such a module provides an analog voltage output proportional to the current entering the conductor. It is this kind of analog output which Arduino reads for further processing; hence, it finds a perfect application in energy measurement.

Figure 6. Current Transformer (Jadhav & Rajput, 2019)

2.3.4 SIM900 GSM module

This shield enables interfacing with a SIM900 GSM module that can, in turn, be used for sending and receiving text messages over the cellular network, even calling and receiving calls, and further connect to the Internet. In the system here, it is in communication with the Arduino via serial communication for remote control or SMS monitoring (Kalyani & Shinde, 2016).

Figure 7. GSM SIM900

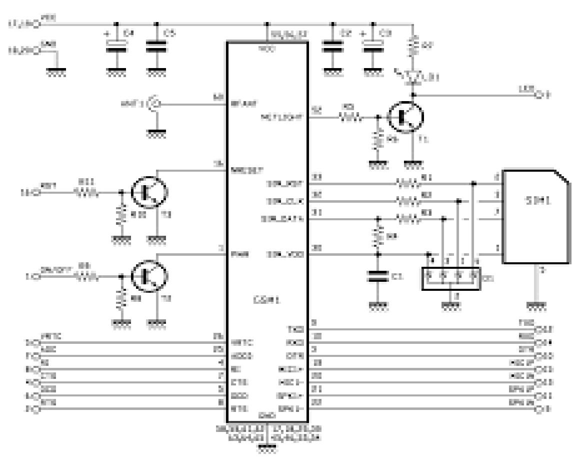

Figure 8. GSM SIM900 Circuit Diagram

2.3.5 I2C LCD screen

The I2C LCD is used for displaying characters and is responsible for the communication between the Arduino through the I2C protocol. This can be supplied with just two wires, SCL and SDA, thus not wasting too many I/O pins. Real time data encompassed in this system, which is displayed on the screen, includes current, voltage, power, and balance.

Figure 9. Liquid Crystal Display I2C (Abioluwajumi, L & Osaghae, F. S. O, 2020)

2.3.6 DS3231 RTC (real-time clock)

The DS3231 is a very accurate real-time clock module that maintains time and date even though the system is powered off. It has a battery onboard and uses an I2C interface with Arduino to program in schedules or events with high-precision timestamps.

Figure 10. Real Time Clock (Osaghae, 2020)

2.3.7 Relay module

It behaves like an electromechanical switch that may drive a high-powered device-like lamp or motor-with a low-powered control signal from Arduino. If a controlling signal is given out from Arduino, it will close its switch and current will flow through the device connected to it, hence turning it on or off.

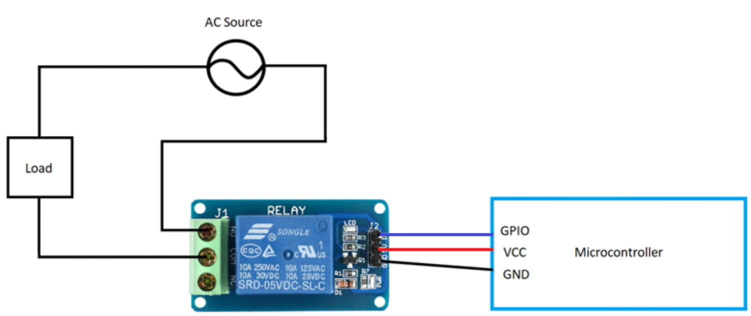

Figure 11. Single 5V Relay module connection

2.3.8 Additional components

Lamp: It shows if the system is on or off; hence, it is alive when the system is on or in action.
PCB: For providing the system with a more fixed structure for mounting and connection of other components in the circuit.

Jumper wires: These are wires normally used in prototyping; they are used in establishing connectivity amongst various components.

2.4 Automatic Billing Systems

One of the key elements of any modern utility and service sector is automatic billing systems, as they significantly improve the efficiency and accuracy of all billing-related processes. Such systems are intended for the production, distribution and management of invoices with minimum human engagement, thereby simplifying the monitoring of these steps and reducing probable operating costs and errors through sophisticated technologies. Additionally, the operating principles, technologies and benefits of such automatic billing systems are explained here, especially in the context of energy management.

Such a system would involve synergies in technologies related to data collection, processing and communication to accomplish the enormous billing tasks without manual intervention. In an energy management context, these are typically smart meters that can record electricity consumption in real time and then generate the information for the utility provider's billing system (Abbas, E. I., 2018).

Doing it this way would automatically collect data to ensure that billings reflect actual consumption and not estimates, making the billing process more accurate and fair.

On the other hand, the use of automated billing system technology involves smart meters with integrated communication modules like GSM, Wi-Fi or Zigbee. These meters are installed to record power consumption and the data is sent to a central server at predefined periodic intervals. The server processes this data to later apply rates during automatic invoice generation. This in turn reduces the incidence of billing errors while enabling a very fast billing cycle, ensuring timely payments and increased cash flow for the utility provider.

Automatic meter reading systems enable a higher level of customer satisfaction and transparency. Additionally, they grant real-time access to customers through online portals or mobile applications, allowing them to track their consumption habits and effectively manage their energy consumption. Customers receive billing status notification, payment due notifications, and even anomaly alerts for thermal usage that can escape unexpected high bills and reduce less responsible energy consumption.

Additionally, this integration can pave the way for sophisticated energy management by integrating AMI with automatic billing systems. One pricing method, dynamic pricing, involves fluctuating electricity rates based on demand or supply conditions. This would encourage consumers to shift their electricity consumption to a period when electricity demand is low, thereby facilitating efficient use of energy resources and reducing pressure on the electricity grid.

One of the most important operational benefits is that they minimize much of the administrative work for utility companies. The three successive steps of manual meter reading, data entry and invoice generation are time-consuming processes, prone to errors and delays. Automating them not only improves the accuracy of these tasks, but also frees up resources that can be redirected to other areas critical to running the business efficiently, like maintenance and customer service.

Additionally, electricity theft detection and prevention is improving through automation of the billing system. Such a system continuously monitors the usage pattern and easily identifies unauthorized usage through anomaly detection. The system thus protects income to ensure the security and reliability of energy supplies.

In summary, automatic billing systems are central to the development of improved energy management over time. Some of the key benefits of these include improving Dal in terms of billing accuracy, customer satisfaction, operational efficiency and theft detection. As part of the overall smart grid infrastructure, these systems are becoming very important to revolutionize electricity management and meet the challenges of a complex and rapidly changing energy landscape (Kalyani & Shinde, 2016).

2.5 Theoretical positions

Theoretical positions that inform this work on the design and implementation of a GSM-based prepaid electricity meter, with automated billing using Arduino technology, lie in communication theory, control systems and behavioral economics.

Communication Theory: This is the backbone of the project and is essentially an application of GSM technology, which essentially falls within the broad field of communication theory. Global System for Mobile Communications, aka GSM, refers to a standard designed to describe protocols used in the second generation of digital cellular networks. The theory highlights how data is routed through wireless networks to ensure an efficient and reliable way, which is essential for real-time data communication between the smart meter and the utility provider. This smooth flow of data resulting in accurate bills prepared on time based on actual power consumption has the characteristics of reducing disputes and increasing customer satisfaction.

Control Systems Theory: This theory is an integral part of understanding the regulation and automation features of the prepaid energy meter. Fundamentally, control theory relies on algorithms and feedback in automated systems with the goal of achieving and maintaining a desired outcome. In this regard, the Arduino microcontroller acts as a control unit in processing sensor data to measure energy consumption and modulates the operation of the meter. He will ensure the correct reading of meters and billing; on the other hand, it would trigger alerts in case of tampering or abnormal use, thus improving security and reliability.

Behavioral economics: This perspective becomes very relevant when considering the effect of prepaid meters on the consumer. So behavioral economics theories aimed at inducing more conscious use and therefore energy savings when real-time information on energy consumption is provided to the consumer, can serve as a guide. By allowing consumers to pay for their electricity in advance and closely monitor their consumption, it helps them become more responsible in their energy consumption and manage the household budget effectively.

Theories on Diffusion of Innovation and Technology Acceptance Model Technology adoption models are based on explaining how new technologies, such as GSM-based prepaid energy meter, are adopted by the users. Theories provide insight into the factors that influence the acceptance and use of new technologies; for example, perceived ease of use and perceived usefulness, among others, and the readiness of a population on the side of potential users. These, if understood, can be of great help in creating user-friendly interfaces and also in the successful implementation of a system.

This study integrates these theoretical perspectives by attempting to present a more holistic understanding of the technical and behavioral dynamics involved in the adoption and operation of a GSM-based prepaid electricity meter. The approach would therefore address not only the technological challenge of the system, but also its socio-economic impact that it could present on the targeted consumer base, thus proposing a holistic solution to the problems presented in conventional energy management systems (Jadhav & Rajput, 2019).

2.6 Related Studies

Many studies have been carried out on different prepaid metering systems to address two major shortcomings of traditional postpaid billing systems.

This section presents some of the past research efforts with their findings relevant to the present research, focusing on the methodologies used, key results acquired, and gaps observed.

Abioluwajumi Lucky & Osaghae F. S. O, (2020), in their research, entitled as "An Assessment of the Privatization of the Power Sector in Nigeria: A Study of Benin Electricity Distribution Company (BEDC)" During this research, these systems reduced the occurrence of bill disputes and improved utility revenue collection performance. The methodology adopted in the study was quantitative, with questionnaires administered to consumers and utility providers. The results are expected to have limitations to mass adoption, such as high initial setup costs and human resistance to change. GSM Technology in Energy Management: Many potentials have been exploited by different research studies on the capabilities of GSM technology to improve communication and data transmission capabilities within energy management systems.

Eyad I. Abbas et al, (2018), in their research "Design and Implementation Prepaid Energy Meter Supported by RFID and GSM Technologies": The following work highlights the design for a radio-frequency identification and Global System for Mobile Communication-based prepaid energy meter. The proposed system shall provide the facility to the users of topping up their energy balance through cards using RFID, while the GSM module shall be provided for remote communication to utility providers. Consumption data goes to the supplier in real time, warnings are raised for low balances. This system ensures automated billing and increases the users' transparency in managing energy consumption.

Kalyani and Shinde, (2016), on remote monitoring and control of energy meters applied GSM technology. For billing purposes, a prototype system using GSM modules was developed to send consumption data to a central server for processing. This proved the possibility of real-time data communication, reduced manual intervention and increased accuracy of the billing system. However, it also highlighted the presence of robust network infrastructure to ensure reliable data transmission. Arduino based smart meters: Some research studies have focused on the application of Arduino microcontrollers in smart meters.

Jadhav and Rajput, (2019), In their research, they designed and tested an Arduino-based prepaid energy meter. Several features have been included, such as real-time electricity consumption monitoring and automated billing. The researchers said the Arduino platform presents both cost-effective and flexible solutions for smart meter development. The study also highlighted the need for better and more user-friendly user interfaces, in order to get consumers to interact with the system more easily. The reported limitations mainly concern security aspects, which must be strengthened to prevent tampering and unauthorized access.

Problems in traditional electricity management**:**

Purohit and Tiwari, (2017), aimed to address the inherent flaws in conventional electricity management systems, which were responsible for problems such as inaccurate billing, delays in payment processing, etc. electricity theft problems. Some technological developments that help overcome these challenges are reviewed by the authors: smart grids and advanced metering infrastructures. The authors concluded that modern communication technologies, particularly GSM, hold enormous potential for integration with smart meters to improve the efficiency and reliability of electricity management. Regulatory support and consumer awareness have also been identified as key drivers of adoption of these technologies.

2.7 Chapter Conclusion

In the light of that view, Chapter 2 therefore posits that an integration of GSM and Arduino in prepaid electricity meters' advances energy management through real-time monitoring, correct billing, and prevention of electricity theft. GSM ensures reliable communication, while Arduino offers a flexible, cost-effective platform for their practical implementation. Application Security and Network Infrastructure challenges, yet both the technologies were thought to hold high potential to help improve the accuracy of customer billing along with providing a means of control to customers over their electricity consumption. These results constitute the backbone of web-based prepaid metering and this makes the solution efficient and user-friendly.

CHAPTER 3: RESEARCH METHODOLOGY

3.0 Introduction

The methodology for designing and implementing an Arduino-based GSM prepaid electricity metering system with automated billing is what this chapter details. It revisits the details of the research design, and makes up components of the system to be used and how it is to be developed. This approach stipulates how to ensure the system hits the target: accurate monitoring of energy and user-friendly billing by conceptually structuring the project down to implementation.

3.1 Research Design

The design to be adopted for this project is experimental in nature; it involves the development and testing of an Arduino-based GSM prepaid electricity meter. The objectives are to come up with a functional prototype that will be capable of successfully measuring the usage of electricity and supporting automatic billing.

There have been a number of major phases through which the design process has gone:

- Requirements Analysis: The phase shall involve the identification of components and functionalities to be required for the system, taking into consideration the needs of electricity consumers and set objectives of this study.
- Component Selection and Integration: Hardware and software components was being properly selected, such as Arduino and a GSM module with sensors, and then integrated into one cohesive system.
- System Prototyping**:** According to the specification of the design, the system prototype was assembled step by step.

➢ The Arduino is loaded with the operating program for reading input from the voltage sensor, ZMPT101B, and current transformer, SCT013. This would provide the ability to make real-time measurements of the power consumed.

➢ Integration of Sensors: Voltage sensor and current transformer integration to the Arduino. The two sensors produce continuous input signals to the Arduino microcontrollers for processing data continuously

➢ Relay Configuration: The 5V relay has been connected in order to control the system load-for example, socket or lamp-according to the prepaid balance. When credit gets exhausted, power will be cut by the relay. I2C LCD display has been connected with Arduino and the code has been written such that consumption, balance, and the status of a system is displayed on it in real time.

- Integrating the GSM Module: This will integrate the SIM900 GSM module, which has the capability to send and receive SMS notifications communicating with the users their remaining balance, low credit warnings, and system top-ups.
- Real Time Clock: The DS3231 module was added for tracking time. This is important in exact billing based on time intervals of energy consumption.
- System Testing: Once the system was assembled, the whole system was tested for its accuracy. The energy consumption data is compared with that of the industry standard meters for accurate measurement, and SMS functionality is checked to see that communication between the system and users is proper.

3.2 Choice of research instruments

Arduino Uno: Arduino Uno is a major microcontroller that reads sensor inputs, processes power consumption data, and controls the GSM module for communication to the users.

The Voltage Sensor ZMPT101B module measures the voltage in the electrical system, sending current data to Arduino for real-time updates.

SCT013 30A Current Transformer: SCT013 is one of the sensors contributing in measuring current passing through the system so that it could calculate the consumption in kWh from the system.

Relay 5V: This is used for the control of an electrical connection for the ON/OFF status with the balance available to the user. It cuts off power when it gets exhausted (Kalyani & Shinde, 2016).

I2C LCD Display: The LCD display represents real-time information on Power Consumption, prepaid balance, and also the status of the system itself to the user.

The SIM900 GSM Module will allow the system to send and receive a short message service from the user. In essence, this means provisions for inquiries by users in regard to their balance, notifications, and even recharging of their account from a distance.

DS3231 RTC: The DS3231 module provides real time tracking of electricity consumption for correct billing with respect to time intervals.

Socket and lamp: Both socket and lamp represent the system load. In these devices, the power is controlled by the relay depending on the available prepaid credit.

3.2.1 Instruments validity and reliability

Before integrating the various components comprising the system, each component was initially tested for functionality and in providing the actual reading. The system has also been calibrated using industry standard energy meters so as to ensure the voltage and current reading accuracy against metering.

Internal Consistency: Each component has been tried a number of times in order to ensure repetition of consistent reading.

Reliability test-retest: The entire system has passed through various scenarios as one of the ways to validate the accuracy of energy reading against the performance continuance of the billing technical system.

3.3 Chapter Conclusion

This chapter presents the methodological application in designing and implementing an Arduino-based GSM prepaid electricity metering system. Selection of hardware components, techniques of data collection, and methods of analyses have been performed in such a way that the design of the system for accurate energy monitoring will also be user-friendly in terms of pre-paid billing. The subsequent chapter presents the design of the system, implementation, and performance evaluation.

CHAPTER 4: SYSTEM DESIGN ANALYSIS AND IMPLEMENTATION

4.0 Introduction

This chapter gives the detailed design and implementation of an Arduino-based automated billing GSM prepaid electricity meter. The proposed system was designed such that it will be able to track the power consumption in real-time, send SMS automatically, and also turn electrical appliances on and off remotely. In this proposed design, several sensors, a relay, a GSM module, and an LCD screen were integrated around an Arduino Uno as the base controller. These are comprised of the design and implementation phases: calculations, system specifications, component descriptions, cost estimation, and coding logic.

4.2 System design

This is an Arduino Uno system-based solution operating on input from voltage and current sensors that drive the switching relay, in turn communicating with the user via a GSM module, while displaying the information on the LCD display.

4.1.1 Design Calculation

E = Energy consumed (kWh)

P = Power in Watts

V = Voltage from the sensor (ZMPT101B)

I = Current from the sensor (SCT013)

Power Calculation:

$$\mathrm{P} = \mathrm{V} \times \mathrm{I}$$

Energy Consumption

$$\mathrm{E} = \mathrm{P} \times \mathrm{t}$$

Balance Update:

$$\text{New Balance} = \text{Old Balance} - \frac{\mathrm{P} \times \mathrm{t}}{3600}$$

Recharge Calculation:

$$\text{Recharge Balance(kWh)} = \frac{\text{Recharge amount (kWh)}}{200} \qquad \text{(200 RWF = 1 kWh)}$$

These calculations manage the energy consumption, power deduction, and recharge for the prepaid electricity system.

4.2.2 Flow chart organization

The flowchart depicts the logical flow in the control of the operations within the system, which includes monitoring power consumption, sending alerts via SMS, controlling the relay, and updating the LCD screen.

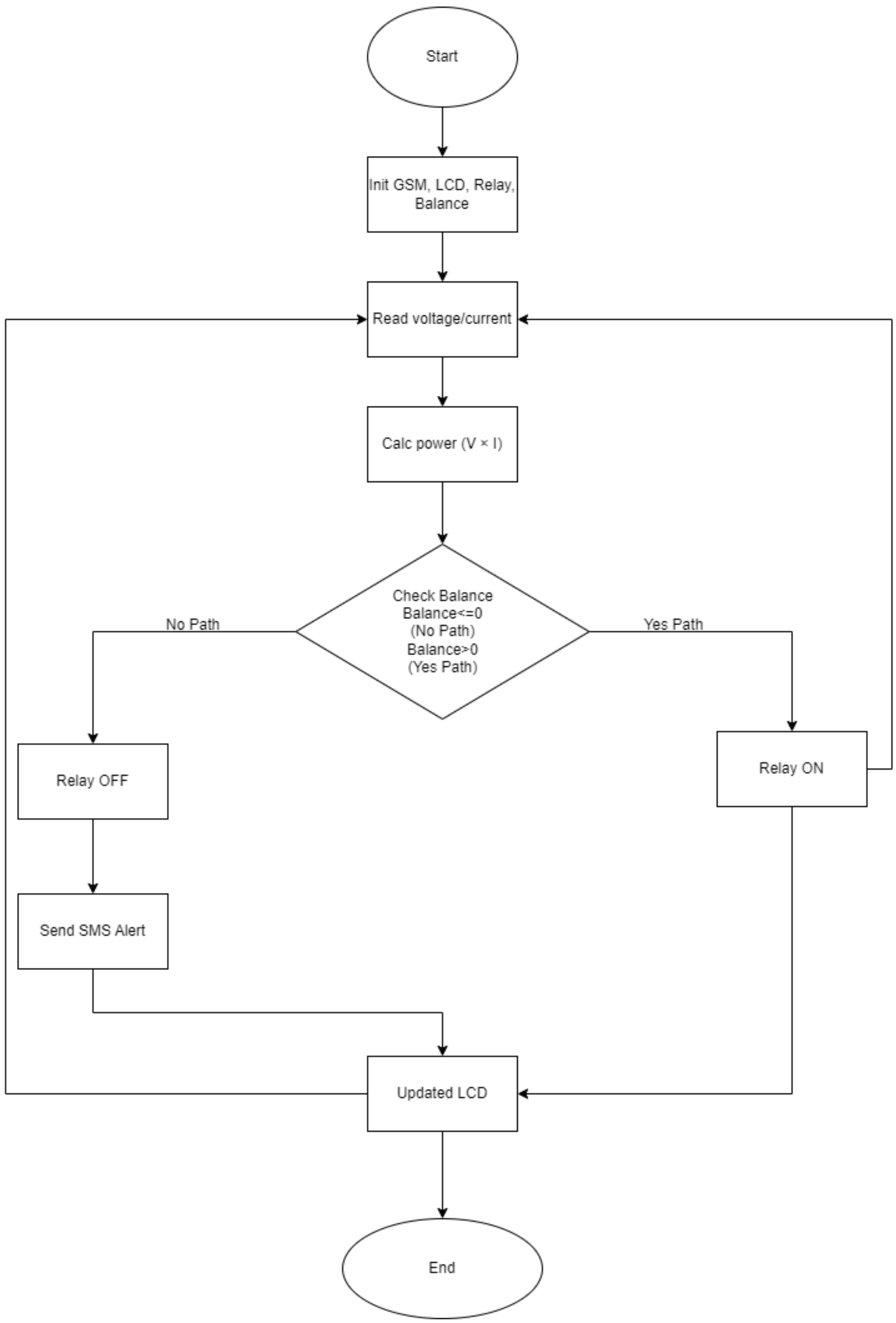

Figure 12. Flowchart of Prepaid Electricity Meter System

4.2.2 Block diagram

The block diagram for the prepaid electricity meter system below identifies the components used: Arduino Uno, GSM module, current transformer SCT013, voltage sensor ZMPT101B, relay, RTC and LCD display.

Voltage Sensor (ZMPT101B): Measures the voltage.

Current Transformer (SCT013): Measures the current.

Relay Module: Controls the power supply.

Arduino Uno: Processes data and controls the entire system.

GSM Module: Sends billing information and system alerts via SMS.

LCD Display: Displays real-time consumption and remaining balance.

RTC Module: Tracks time for accurate billing.

Socket and Lamp: Represent the load controlled by the relay based on available credit.

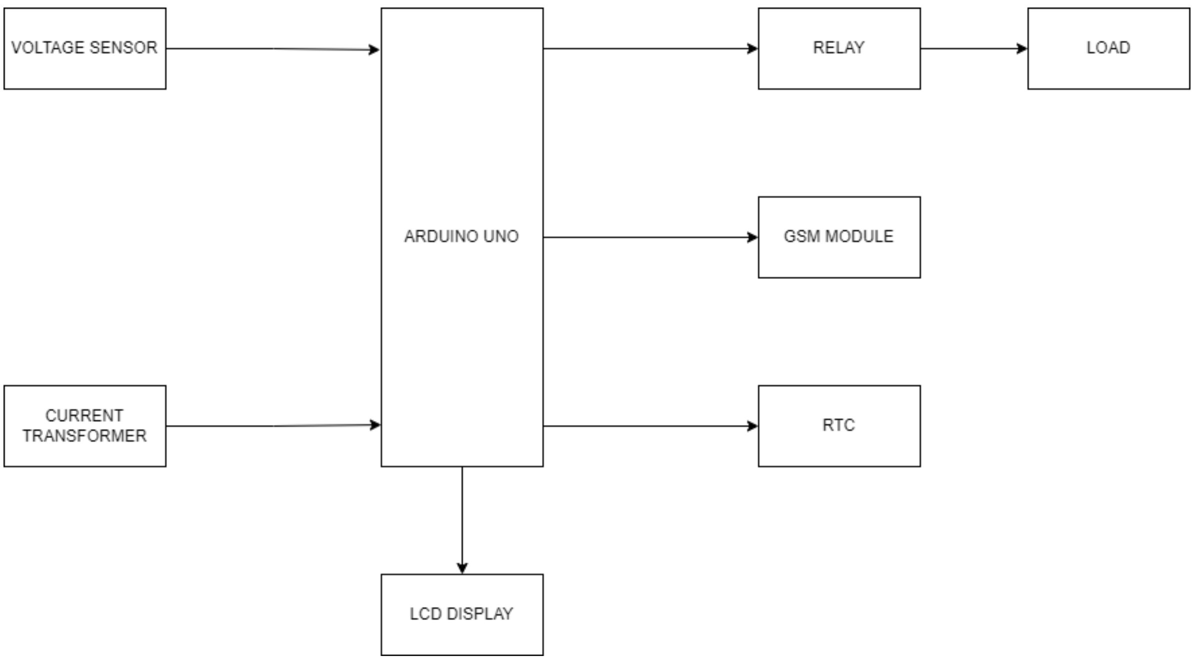

Figure 13.The block diagram of the prepaid electricity meter system

4.2.3 Circuit Diagram

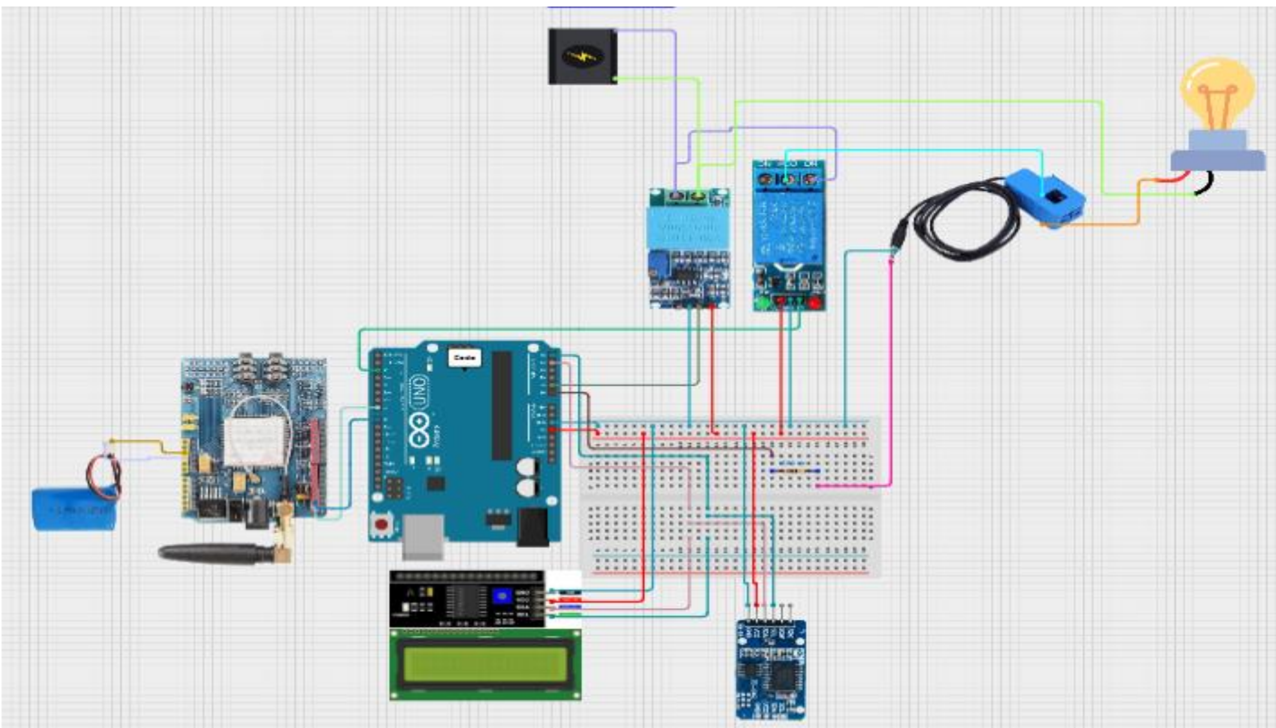

Figure 14. Circuit Diagram

4.3 Implementation

After assembling the system, its working principles are as follows:

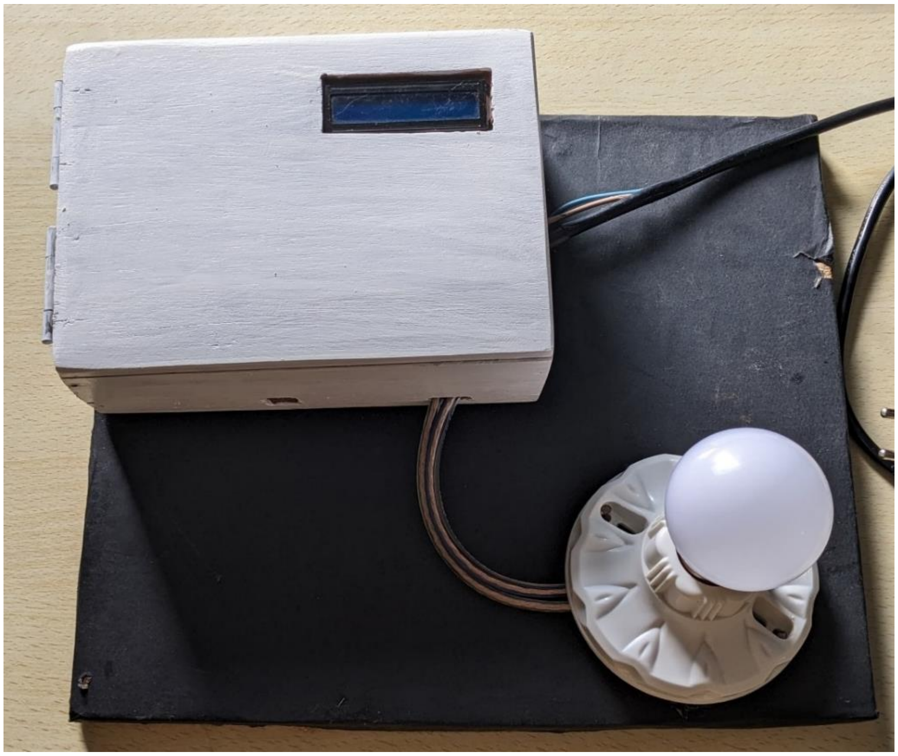

Figure 15. Project photo

The following picture depicts the assembled project with the generated results.

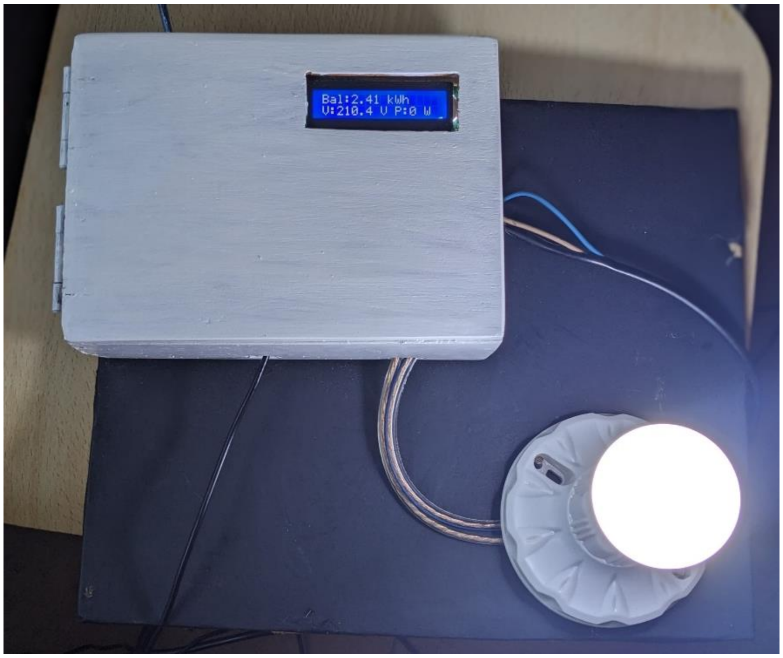

Figure 16. Project Result

After assembling the system, its working principles are as follows:

Power Monitoring: Voltage and current sensors measure real-time consumption, sending data to the Arduino for calculation of power using $P = V \times I$.

Real-Time Display: The I2C LCD displays voltage, current, and remaining prepaid balance, updating continuously.

Automated Billing: The system deducts energy consumption from the prepaid balance. SMS alerts are sent via the GSM module when the balance is low.

Relay Control: The relay cuts off power when the balance is exhausted and restores it when recharged.

GSM Communication: The GSM module enables remote balance queries, top-ups, and sends notifications to the user.

Time-Based Billing: The RTC module ensures accurate billing based on time intervals of energy usage.

Testing: The system undergoes calibration and testing to ensure accurate readings, proper relay control, and reliable SMS alerts.

When the system is operating:

Power Monitoring: The voltage sensor (ZMPT101B) and current transformer (SCT013) continuously monitor the voltage and current passing through the load. The Arduino uses these inputs to calculate the power consumption in real-time.

Real-Time Updates: The current power consumption, remaining prepaid balance, and system status are displayed on the I2C LCD screen. These values are updated continuously.

Billing and Balance Deduction: As electricity is consumed, the system automatically deducts the corresponding amount from the prepaid balance. If the balance drops below certain thresholds (e.g., 10%, 5%), the system sends SMS alerts to notify the user.

Relay Control for Power Supply: The relay module controls the power to the load. If the prepaid balance is exhausted, the relay cuts off the power supply, preventing further usage. Once the user recharges their balance, the relay restores the power.

Remote Monitoring and Recharge: The GSM module enables remote communication with the user. The system sends SMS notifications about balance status, and users can remotely recharge their balance or check system status via SMS commands.

Time-Based Billing: The RTC module tracks time to ensure energy consumption is accurately billed in kWh, ensuring that users are charged only for the electricity used during specific time intervals.

In summary, the system works transparently, constantly monitoring energy consumption, billing in real time, alerting users when their balance is low, and automatically managing power supply based on prepaid balance.

4.4 Conclusion

The chapter designed and presented an Arduino-based prepaid electricity meter that was able to monitor the power consumption in real time, process SMS alerts to turn off the power right when exactly the scale runs out of power. In this regard, the use of detailed design calculations together with system integration results in the system meeting all requirements concerning an automated electricity meter.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.0 Introduction

This chapter summarizes the development of a prepaid electricity meter using the integration of GSM communication, Arduino Uno, and sensors. The project was undertaken with an overview of developing automated electrical billing and monitoring systems that would show real time and real usage to its clients and service providers. Indeed, this system through advanced technologies provides better transparency and limits energy wastage and hence simplifies the billing process. This chapter, therefore, proceeds to present conclusions of the project, and recommendations based on improvements and further research.

5.1 Conclusion

This project successfully designed and implemented an Arduino-based GSM prepaid electricity meter with automated billing. The system meets its objectives by providing real-time monitoring of electricity consumption, automated balance deductions, and SMS notifications when the balance reaches critical levels.

Throughout the implementation, three prototypes were developed and tested:

Prototype 1 focused on sensor calibration.

Prototype 2 integrated the GSM module for SMS alerts.

Prototype 3 tested the full system under normal load conditions.

In conclusion, the system achieved its goals of accurate energy tracking, automated billing, and efficient user notifications. It enhances energy management for consumers and ensures transparency for utility providers, addressing the original objectives and research questions effectively.

5.2. Recommendations

To ensure scalability by having **the system developer** integrate a centralized server system to manage multiple units (e.g., for apartment complexes or large buildings) and collect data from multiple meters, providing a unified interface for monitoring and billing.

To implement remote power control by having **the hardware and software engineers** incorporate a more advanced SIM800 or SIM900 GSM module, allowing users to control power remotely via SMS or mobile app, enabling them to turn on/off appliances or the entire system from any location.

To integrate with payment systems by having **the software development team** connect the system with mobile payment platforms such as M-Pesa, PayPal, or local banking apps, allowing users to recharge their prepaid accounts directly through the mobile app and streamlining the payment process.

To develop a cross-platform mobile app by having **the app development team** use frameworks like Flutter or React Native to create an app (for both Android and iOS) that enables real-time monitoring, alerts, and balance recharging, providing users with real-time notifications, balance updates, and control over power usage.

To upgrade GSM communication by having **the system developers** use SIM808 or SIM800 for more reliable communication with enhanced network connectivity for SMS and GPRS services.

To incorporate advanced energy analytics by having **the data analytics team** develop a dashboard using software like Google Firebase or Power BI, providing users with detailed reports on consumption trends, peak usage times, and suggestions for energy optimization.

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APPENDICES

Appendice A: Software Implementation code

The system is programmed using the Arduino IDE in C++. Key libraries used include:

- SoftwareSerial.h: For communication with the GSM module.
- LiquidCrystal_I2C.h: To control the LCD display.
- EmonLib.h: For energy monitoring.
- RTClib.h: To manage the RTC.

The code continuously monitors power consumption, controls the relay based on the balance, and handles SMS communication for recharging and status updates.

Appendice B: Arduino Code for Prepaid Electricity Meter System

```
#include <SoftwareSerial.h>
#include <EEPROM.h>
#include <Wire.h>
#include <LiquidCrystal_I2C.h>

// Pin definitions
const int relay_pin = 2;
const int voltagePin = A1;
const int currentPin = A0;  // SCT013 output

// Pin declarations for A4 and A5 (I2C communication)
const int SDA_pin = A4; // SDA for I2C communication
const int SCL_pin = A5; // SCL for I2C communication

// Calibration constants
const double voltageCalibration = 220.0 / 1054.0;  // Voltage scaling for 250V
const float currentCalibration = 30.0 / 1023.0;    // Current scaling for 30A (ADC range is 0-1023)
const float currentCalibrationFactor = 111.1;  // Calibration factor in amps per volt
```

```
// Global variables
double voltage = 0;  // Voltage in volts
double current = 0;  // Current in amps
double power = 0;  // Power in watts
double power_kW = 0;  // Power in kilowatts
double balance = 0;  // Balance in kWh (kilowatt-hours)
const int costPerKW = 200;  // Cost per kWh in RWF (200 RWF = 1 kWh)
const int balanceAddress = 0; // EEPROM address for balance

// LCD display
LiquidCrystal_I2C lcd(0x27, 16, 2);

// GSM module
SoftwareSerial SIM900(7, 8);
String incomingData = "";

// Thresholds for alerts
const double threshold50 = 0.5;  // 50%
const double threshold30 = 0.3;  // 30%
const double threshold10 = 0.1;  // 10%
const double threshold5 = 0.05;  // 5%

// Variables to track if an alert has been sent
bool alert50Sent = false;
bool alert30Sent = false;
bool alert10Sent = false;
bool alert5Sent = false;

// Function to read and average current
float readCurrent() {
  float total = 0.0;
```

```
  // Take multiple readings and average them for better accuracy
  for (int i = 0; i < 10; i++) {
    total += analogRead(currentPin);
    delay(10); // Short delay between readings
  }

  float averageReading = total / 10;
  float voltage = averageReading * (5.0 / 1023.0); // Convert to voltage (assuming 5V reference)
  float current = voltage * currentCalibrationFactor; // Convert to current using the calibration
factor

  return current;
}

void setup() {
  Serial.begin(115200);
  SIM900.begin(19200);
  pinMode(relay_pin, OUTPUT);
  digitalWrite(relay_pin, HIGH);  // Start with relay off

  SIM900.print("AT+CMGF=1\r");  // Set SMS mode to text
  delay(100);
  SIM900.print("AT+CNMI=2,2,0,0,0\r");  // Show SMS on serial out
  delay(100);

  lcd.init();
  lcd.backlight();

  // Initialize balance to 0 kWh
  EEPROM.get(balanceAddress, balance);
```

```
  if (balance != 0) {
    balance = 0;  // Reset balance to 0 kWh if EEPROM contains any non-zero value
    EEPROM.put(balanceAddress, balance);  // Save reset balance to EEPROM
  }

  // Ensure the relay is off initially
  digitalWrite(relay_pin, HIGH);
  send_message("System initialized. Balance is 0 kWh. Please recharge to turn on the power.");
  update_lcd();  // Update LCD display with the initial balance
}

void loop() {
  // Read voltage and current
  voltage = analogRead(voltagePin) * voltageCalibration;  // Convert raw reading to actual voltage
  current = readCurrent();  // Get the current from SCT013-030 sensor

  // Calculate power in watts and kilowatts
  power = voltage * current;
  power_kW = power / 1000.0;

  // Print and display readings
  Serial.print("Voltage: "); Serial.print(voltage); Serial.println(" V");
  Serial.print("Current: "); Serial.print(current); Serial.println(" A");
  Serial.print("Power: "); Serial.print(power); Serial.println(" W");
  Serial.print("Power (kW): "); Serial.print(power_kW); Serial.println(" kW");
  Serial.print("Balance: "); Serial.print(balance); Serial.println(" kWh");

  // Update balance based on power consumption if relay is on
  if (digitalRead(relay_pin) == LOW) {
    balance -= power * (1.0 / 3600.0);  // Deduct power consumed (W) per second in kWh
    if (balance <= 0) {
```

```
      balance = 0;
      digitalWrite(relay_pin, HIGH);  // Turn off the power
      send_message("Balance depleted. Power is turned OFF.");
    }
    EEPROM.put(balanceAddress, balance);  // Save updated balance to EEPROM

    // Check for balance thresholds and send alerts
    check_balance_thresholds();
  }

  update_lcd();  // Update LCD display with the current balance, voltage, and power

  receive_message();
  process_commands();  // Process incoming commands

  delay(1000);  // Delay between readings
}

void receive_message() {
  if (SIM900.available() > 0) {
    incomingData = SIM900.readString();
    Serial.print(incomingData);
    delay(10);
  }
}

void send_message(String message) {
  SIM900.println("AT+CMGF=1");  // Set GSM module to text mode
  delay(100);
  SIM900.println("AT+CMGS=\"+250790008098\"");  // Replace with your mobile number
  delay(100);
```

```
  SIM900.println(message);  // The SMS text you want to send
  delay(100);
  SIM900.println((char)26);  // ASCII code of CTRL+Z
  delay(100);
}

void process_commands() {
  if (incomingData.indexOf("Turn_on") >= 0) {
    if (balance > 0) {
      digitalWrite(relay_pin, LOW);  // Turn on the power
      send_message("Power is turned ON");
    } else {
      send_message("No balance available. Please recharge to turn on the power.");
    }
  } else if (incomingData.indexOf("Turn_off") >= 0) {
    digitalWrite(relay_pin, HIGH);  // Turn off the power
    send_message("Power is turned OFF");
  } else if (incomingData.indexOf("Recharge_") >= 0) {
    int rechargeAmount = extract_recharge_amount(incomingData);
    double rechargeKW = rechargeAmount / (double)costPerKW;  // Convert RWF to kWh
    balance += rechargeKW;
    EEPROM.put(balanceAddress, balance);  // Save updated balance to EEPROM
    send_message("Recharge successful. Current balance: " + String(balance, 2) + " kWh");

    // Automatically turn on the power if balance is sufficient and it was off
    if (balance > 0 && digitalRead(relay_pin) == HIGH) {
      digitalWrite(relay_pin, LOW);  // Turn on the power
      send_message("Power is automatically turned ON after recharge.");
    }

    update_lcd();  // Update LCD display with the new balance
```

```
  } else if (incomingData.indexOf("Status") >= 0) {
    String status = (digitalRead(relay_pin) == LOW) ? "Power ON" : "Power OFF";
    String statusMessage = "Status Report:\nVoltage: " + String(voltage) + " V\n" +
                           "Power: " + String(power, 0) + " W\n" +
                           "Balance: " + String(balance, 2) + " kWh\n" +
                           "Power Status: " + status;
    send_message(statusMessage);
  }
  incomingData = "";  // Clear the incoming data after processing
}

unsigned int extract_recharge_amount(String message) {
  int startIdx = message.indexOf("Recharge_") + 9;
  String amountStr = message.substring(startIdx);
  return amountStr.toInt();  // Convert the extracted amount to an integer
}

void update_lcd() {
  lcd.setCursor(0, 0);
  lcd.print("Bal:");
  lcd.print(balance, 2);  // Display balance with 2 decimal places
  lcd.print(" kWh");  // Indicating kilowatt-hours (kWh)

  lcd.setCursor(0, 1);
  lcd.print("V:");
  lcd.print(voltage, 1);  // Display voltage with 1 decimal place
  lcd.print(" V ");
  lcd.print("P:");
  lcd.print(power, 0);  // Display power in watts with no decimal places
  lcd.print(" W ");
}
```

```
void check_balance_thresholds() {
  if (balance <= threshold5 && !alert5Sent) {
    // Calculate remaining time in seconds
    double remainingTime = (balance / power) * 3600;  // Time remaining in seconds
    send_message("Warning: Balance is at 5%. Estimated time remaining: " +
String(remainingTime, 0) + " seconds.");
    alert5Sent = true;
  }
  else if (balance <= threshold10 && !alert10Sent) {
    send_message("Warning: Balance is at 10%.");
    alert10Sent = true;
  }
  else if (balance <= threshold30 && !alert30Sent) {
    send_message("Warning: Balance is at 30%.");
    alert30Sent = true;
  }
  else if (balance <= threshold50 && !alert50Sent) {
    send_message("Warning: Balance is at 50%.");
    alert50Sent = true;
  }
}
```

Appendices C: Cost estimation

Following is the cost of some components used as per following table:

components	Quantity	Unit Cost	Total Cost
Arduino Uno	1	15000 FRW	15000 FRW
Voltage Sensor	1	11000 FRW	11000 FRW
Current Transformer	1	11500 FRW	11500 FRW
GSM Module SIM900	1	22000 FRW	22000 FRW
LCD I2C Display	1	8000 FRW	8000 FRW
5V Relay Module (1 channel)	1	2500 FRW	2500 FRW
Lamp	1	1500 FRW	1500 FRW
PCB Board	1	2700 FRW	2700 FRW
Jumper Wires	50	100 FRW	5000 FRW
12V adaptor	1	5000 FRW	5000 FRW
Real Time Clock Module	1	5400 FRW	5400 FRW
Socket	1	500 FRW	500 FRW
Total	-	-	90100 FRW