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DEPARTMENT OF MECHANICAL AND MANUFACTURING ENGINEERING

DESIGN AND VALIDATION OF A GSM ENABLED ELECTRICITY PREPAID METER

BY

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DECLARATION AND CERTIFICATION

This MSc. work is my original work and has not been presented for a degree award in this or any other university.

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DEDICATION

I dedicate this work to my dear wife, Domitila Wanjiku, for her loving and unconditional support throughout the entire period of my post graduate degree. Thank you and may Gods favor and blessings be with you forever.

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I would like to acknowledge those who have played a critical role in the development of this work. First and foremost, I am grateful to God for making this possible and seeing me through every step of the way.

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Special thanks to my schoolmate, Kim, who has given his moral and intellectual support throughout this project. Finally, I would like to thank all my family and friends who have encouraged me to see this project to fruition. May the Almighty bless you all abundantly.

ABSTRACT

This report details the working of a conventional Customer Interface Unit (CIU) for Kenya Power pre-paid meters. We study the functionality of the meters and pay particular attention to the recharge system that involves buying of tokens from Kenya Power (The vendor) and crediting the same to the customer's account. The monetary value of the tokens is predetermined by the customers metering tariff, as issued by the vendor, and is quantified as 'Units' where 1KWh = 1 Unit. The process of purchasing the tokens involves a transaction through various mobile money avenues, such as Mpesa, Airtel Money, Equitel, amongst others. When a customer makes a payment to Kenya Power, an SMS is sent to their mobile phone containing a set of numbers which represent the value of units purchased. The customer is expected to input these numbers into the CIU for their electricity account to be credited with the said units. Therefore, after purchase, there must be some form of human operation in order for the recharge process to be complete. This recharge process defines the research problem and, in this report, the method currently used by Kenya Power to issue the customer units is studied in detail and an alternative method which makes the pre-paid method more efficient and faster by automating the recharge process is designed and validated. This improvement has several advantages such as simplifying the recharge process and introducing the ability to remotely recharge the electricity accounts. The method used in achieving this solution was by introducing GSM capabilities in the prepaid metering system and the outcomes of the research were noted and the proof of concept was documented. The outcomes of the research proved that the addition of a GSM module to replace the keypad in the CIU would improve the efficiency by eliminating the need to key in the token numbers in the process of recharging the customers accounts. Also, by addition of the GSM capabilities, the prepaid metering system removed the inconvenience of having to manually enter the tokens into a CIU that is, at times, at a distance especially in country homes. The GSM enabled prepaid metering system was a success and formed a basis of future study and further improvements.

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ABREVIATIONS

Item	Description
ADC	Analog to Digital Converter
CAD	Computer Aided Design
CIU	Customer Interface Unit
DC	Direct Current
EEPROM	Electrically Erasable Programmable Read Only Memory
GSM	Global System for Mobile Communication
I/O	Input Output Peripherals
KPLC	Kenya Power and Lighting Company
LED	Light Emitting Diode
MCU	Measurement Control Unit
PC	Personal Computer
RF	Radio Frequency
SMS	Short Message Service

CHAPTER 1: INTRODUCTION

1.1 Background

Conventionally, electricity bills in Kenya were paid through a post-paid metering system where monthly bills were sent to the consumers via mailboxes, email and other forms of communication. The bills were issued on a monthly basis and detailed the amount of electricity consumed, the metering tariff subscribed and the expected date of payment. In case of default of payment, disconnection of power was done by personnel from Kenya Power after a grace period expired. Today, electricity billing is primarily done through pre-paid metering which offers a wide range of advantages to both the customer and the vendor. This research aims to study the currently deployed prepaid method and propose ways of improving it.

Traditionally, post-paid metering involved monthly billing after consumption of power. As would be the case, this method had various shortcomings which necessitated the invention of pre-paid meters. Some of the key challenges were brought about by the very principles upon which the method of payment was based. Payment after consumption literally means that the vendor would be extending some form of credit to the consumers. This translated to delayed payments and had a negative impact on the vendor’s cash flow statements. Secondly, for the payment defaulters to be disconnected from the grid, the vendor had to send out a team of technicians to carry out the exercise which meant increased costs of operations for the vendor. Further to that, this payment system was heavily reliant on the integrity of the said technicians sent out to disconnect power as there was no absolute way of confirming the power cuts save for secondary site visits by another member of staff.

With the aim of mitigating these and other hindrances to the efficient distribution and billing of power, the pre-paid system was implemented in Kenya in the year 2009 as a pilot project in Nairobi [1]. By and large, the system turned out to be a success story in Nairobi which saw its implementation spread out to other populous towns such as Mombasa, Kisumu and Kiambu. However, the pre-paid system faced a number of challenges at the inception period such as faulty gadgets and lack of sufficient information and how-to-use guidelines. Over time, these challenges have been addressed and the system provides both the customer and the vendor tremendous benefits over its predecessor, the post-paid system.

For the vendor, tracking and monitoring of power is now possible via the use of the pre-paid meters which have smart metering capabilities. This means that the power vendor has a better understanding of the consumption pattern throughout the whole distribution network further equipping them with the ability to plan any load adjustment schedules in a more efficient manner. As a standard, the pre-paid meters are also equipped with a tamper switch which can detect any kind of unwarranted interference to the meter and disconnect the power supply [2]. This in turn means that the vendor has better control of the power distribution network as they control and stop any illegal connections which would amount to theft and pilferage of power. Additionally, the pre-paid meter has a load switch which automatically disconnects the load circuit once the customers' units run out or expire which reduces the operational costs for the vendor by eliminating the need of field technicians. Finally, and of utmost importance, is the principle upon which pre-paid metering is based. In reality, pre-payment implies that the customer pays for what they intend to use thereby giving the vendor a large pool of unutilized funds which allows for better cash flow projections. This is in sharp contrast to the previous post-paid system which extended credit to the users and left the vendor chasing multiple bad debts [1].

For the customers, the pre-paid metering system has brought a lot of relief in terms of accurate meter reading. Previously, customers complained of inaccurate bills and in some cases, electricity bills were not delivered. With the pre-paid metering system, the customers are also able to track their daily consumption of power as displayed on the Customer Interface Unit which is installed in their houses.

1.2 Problem Statement

This research proposes to explore a possibility of remote top up of customer's units via the use of GSM (Global System for Mobile Communication) technologies. Currently, the pre -paid system requires the customer to input the tokens into the Customer Interface Unit (CIU) by use of an inbuilt keypad. The possibility a CIU without a keypad presents a number of advantages such as reduction in the physical size of the CIU hence saving on production costs. Such a design will also make it possible to have remote top ups thereby making the recharge process a lot easier, simpler and efficient as compared to the current set up. Additionally, a remote top up would make it possible for a customer to recharge their accounts of upcountry homes without involving the workers of those residences. This might save the customer some money as such a transaction is prone to pilferage by dishonest staff.

The outcome of implementing this proposed solution is a CIU that is smaller in physical size and loaded with GSM capabilities by use of a sim card. This sim card will make it possible for the CIU to receive the tokens directly from the vendor and continue with the process of transmitting the same to the Measurement Control Unit (MCU) via the already enabled radio frequencies (RF). Not only does this save the end user's time, it also eliminates some challenges currently faced such as accidental deletion of a token SMS (Short Message Service) from the vendor.

In reality, the current design of the CIU limits such a capability by requiring human intervention at the process of loading the units to the device. The current design is also bulky and that translates to additional cost in the manufacture process and in shipping costs. These challenges will be a thing of the past in the proposed design. In addition to the above, adoption of this solution would prove beneficial to manufacturers who will gain a competitive edge over their peers because this design would translate to savings at the fabrication stage and subsequent reduction in overall size of the CIU and directly reduce the green gas emissions associated with the manufacturing process. The effect of this proposed design will be tremendous especially when rolled out in bulk or at a national level. It boils down to a win-win situation for both the manufacturers and end users.

For the purposes of this research, we will look at using GSM technologies as a potential solution and document our findings.

1.3 Justification

Through this pre-paid metering technology, a lot of the billing processes have been simplified and this research goes a step further in adding to this simplification process. The current set up of the pre-paid system involves a meter (Measurement Control Unit) which is installed at the meter board in line with the incoming mains power line. The primary purpose of this unit is to measure and record the amount of power that is consumed by the household or end user. It is here that the smart metering functionalities are realized. The MCU is linked with the Customer Interface Unit (CIU) which is installed in the houses via Radio Frequency at a range of 100m radius and whose primary purpose is to display the measurements taken by the MCU [1].

The MCU is designed with measurement and control features that assist in proper measurement of electricity consumption and control of the same. For purposes of billing, the MCU is designed with a load switch that interrupts the load supply once the credit balance is used up or expired and the load switch is only restored once the customer's account has been topped up. After a top up, the MCU continually tracks the consumption and updates the decrements in units and displays the balance on the CIU. The continuous tracking of the units' balance is fully independent of the CIU and will continue even when communication between the two devices is compromised. In addition to a tamper switch that detects unwanted interferences, the MCU also has a programmable side to it. It is programmed such that the load is disconnected once the set limit is exceeded and reconnects when the load falls below the limit. Figure 1.1 shows the Measurement Control Unit

Figure 1.1: Measurement Control Unit [3]

Primarily, the function of the CIU is to display the status of the customer’s account. By so doing, the CIU displays the balance of the units and gives low credit warnings either by playing a sound or by flashing a light, typically a red or green light. The CIU also displays the status of the incoming power supply to notify the customer in case of a mains failure. From the same device, the customer is able to input the purchased tokens via an in-built keypad and receive an update of token acceptance or rejection. It is at this point that our research takes place where we seek automate the token input process. Figure 1.2 shows the Customer Interface Unit.

Figure 1.2: Customer Interface Unit [3]

1.3.1 Existing technologies used outside Kenya

The approach used in other countries such as the UK is slightly different from that found in Kenya. This is especially so because of the payment methods used in both countries are different. In Kenya, we make use of mobile payment methods thereby quickening the process of payment whereas in other countries (the UK for this instance) they make use of dedicated recharge shops or outlets where the customer visits to purchase the units [3]. The pre-paid system found there makes use of an additional EEPROM that is detachable and resembles a flash disk. This device holds the information regarding the customer's credit balance and units consumed. Once the credit balance has gone down to zero, the device is unplugged and taken to one of the dedicated shops where it can be recharged with the purchased units. Thereafter, the customer plugs the device back into their MCU for the system to continue functioning.

1.4 Research Objectives

The research objectives of this report are focused around pre-paid metering and the recharge process of tokens. The process of recharging the tokens is done by keying in the numbers on the inbuilt keypad on the CIU and this research seeks to automate this process by substituting the keypad with a GSM module.

1.4.1 Main objectives

The main objective of this research is to design and validate a system which, on top of the current pre-paid system, bypasses the inbuilt keypad of the Customer Interface Unit in the process of topping up units.

1.4.2 Specific Objectives

The specific objectives of the research are as follows.

i. Analyse the requirements of the new prepaid metering system
ii. Design the components of the new system
iii. Implement and validate the design

1.5 Research Questions

A series of questions arise when we look at the problem statement.

i. How do we analyse the requirements of the new system?
ii. How do we design the components of the new system?
iii. Can the new system be successfully implemented and validated?

1.6 Scope of the study

The scope of this research is centred on the existing pre-paid metering system with the aim of bypassing the keypad when recharging tokens in the Customer Interface Unit. This will be achieved by introducing GSM capabilities to the CIU which will make it possible to reload the tokens by SMS.

The GSM module will be attached to the CIU and activated over a mobile network. This will enable the end user to send the tokens they receive from Kenya Power from their mobile phone to the CIU.

1.7 Organization of the report

This report is organized in five chapters where the second chapter discusses the literature review. Here, previous works and related developments in the field of pre-paid metering have been explored and notable developments acknowledged. The third chapter details the methods and tools used to achieve the desired results of this research such as the key components and their working principles. Chapter 4 details the results of the laboratory experiments and discusses some of the challenges faced as well as the solutions found. Finally, chapter 5 being the final chapter looks at the conclusions drawn and recommendations made during this research process.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Metering of electricity involves continuous and instantaneous measurement of system volts (V) and currents (A). The computation of these two parameters gives the energy consumed in VA or in kilowatt hours (kWh) [2].

Pre-paid metering has been used in a number of sectors to streamline the process of payment. In Kenya, the most common pre-paid meters are found in the electricity and water sectors with the telecommunication sector being a late entrant. Electricity pre-payment, as the term suggests, involves a customer paying for power before consumption and when the customer's credit runs out, then the services are cut off; typically, by use of a relay in the MCU. The pre-paid metering system was first used in Kenya in the year 2009 and owing to its huge success in solving the electricity industry's billing problems, the system was deployed nationwide [1].

2.2 Types of energy meters

Energy meters are of two types.

i. Electromechanical meters
ii. Electronic meters

Electromechanical meters were used in the recent past and are commonly associated with post-paid metering. The meters are comprised of two electromagnets and an aluminium disc positioned in between them and properly anchored for a circular rotation. The electromagnets are each connected to a coil; one is connected to the load and is the current coil and the other is connected the supply voltage. As the name suggests, their designed is premised on interaction of the two magnetic fluxes that introduce a rotational torque to the measuring disc. Each rotation of the disc is proportional to the load current and is recorded by a rotational counter. The higher the load current, the faster the speed of rotation and the number of revolutions, as displayed by the counter, represent the amount of energy consumed [2].

Figure 2.1 shows an electromechanical meter.

Figure 2.1: Electromechanical meter [3]

Electronic meters are a more recent introduction to the energy sector and are less bulky as compared to electromechanical meters. They comprise of current and voltage analog sensors whose work is to detect the amount of energy consumed. This information is then relayed to Analog to Digital Converters (ADCs) for digitization. The digital signals are then fed into a microcontroller which in turn computes and communicates to an inbuilt display unit the amount of energy consumed. Figure 2.3 shows a modern electronic meter.

Figure 2.2: Electronic meter [3]

2.3 General Overview of prepaid metering

The prepaid metering system involves a set of devices called the MCU and the CIU for measurement and display system parameters respectively. These two devices communicate via Radio frequencies of pre-determined ranges. The meters are integrated into the consumer's meter board either in line with the service conductors for loads below 200A or connected through current transformers for loads above 200A. The process of pre-paid metering involves the MCU, CIU, EEPROM (Electrically, Erasable Programmable, Read-only Memory), microcontrollers and a relay. Figure 2.3 shows their configuration.

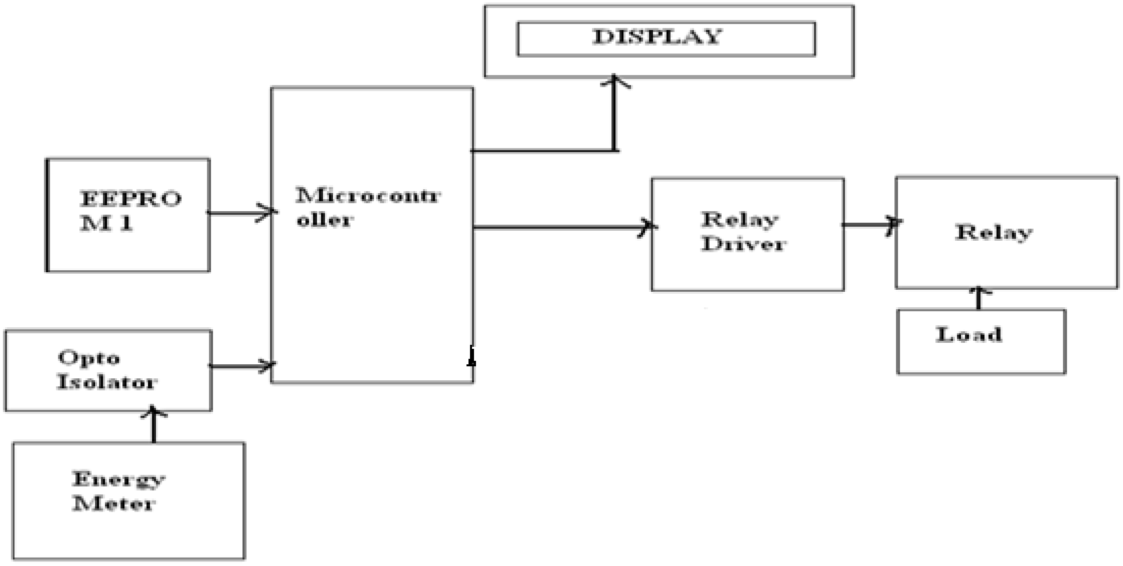

Figure 2.3: Pre-Paid metering configuration [3]

From the above configuration, the MCU is comprised of the energy meter, EEPROM, microcontroller, relay driver and the relay. In this arrangement, the function of the energy meter is to measure and communicate the amount of energy consumed to the microcontroller. It does this by sending signals of pulses the microcontroller. For each pulse, the microcontroller will communicate to the EEPROM to increase the amount of energy consumed by one unit and decrease the balance by the equivalent amount of one unit. (Usually predetermined by the user's tariff). In this case, the EEPROM serves only as a read only memory to record the amount of energy consumed (in units) and the corresponding credit balance. When the balance in the EEPROM goes down to zero, the microcontroller sends a signal to the relay driver to turn off the relay. This in turn disconnects the load supply to the consumer's facility. The gradual reduction of the customer's credit balance and the corresponding increment of their energy consumption is displayed by the CIU, depicted as the 'display' unit in Figure 2.3.

To fully appreciated the previous works done that lead up to the invention of pre-paid metering, a general overview of its components is necessary. The MCU which houses the energy meter carries a number of technologies as discussed in the following sections.

2.3.1 Components of prepaid metering

2.3.1.1 Opto Isolator

This is a key item in communication between the microcontroller and the energy meter. As defined, the Opto-Isolator or Optical-Isolator is a device that uses light (in our case LED) to transfer electrical signals between two isolated circuits. Its main advantage is that it prevents the recipient circuit from receiving high voltages that are present in the donor circuit as is the case between the energy meter and the microcontroller. In the prepaid metering setup, the energy meter gives electrical signals (pulses) to the opto-isolator which comprises of an LED and an opto-transistor. The LED glows for every electrical signal that is received from the energy meter. It is these light emissions that relay information to the microcontroller, via the opto-transistor, to perform the necessary increments and decrements in the EEPROM. Figure 2.4 shows an Opto Isolator

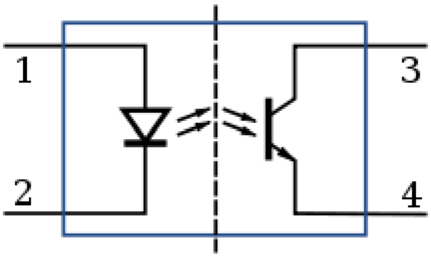

Figure 2.4: Opto-Isolator showing and LED on the left circuit, a dielectric barrier in the middle and a phototransistor on the right circuit [3]

2.3.1.2 EEPROM (Electronically, Erasable, Programmable, Read-only memory)

This is a type of memory used in computer chips that has certain unique and distinguishable attributes from other type of memories. This type of memory is suitable for the pre-paid metering setup especially because of its classification as a non-volatile memory. Such is a memory that stores information even after power to the device has been discontinued either intentionally or otherwise. In the pre-paid metering setup, the customer's credit balance is stored in this device. The other type of memory that contrasts to this is called a volatile memory which requires a constant supply of power to store data. Another aspect of the EEPROM that makes it suitable for pre-paid metering is that the memory chip does not need to be unplugged for it to be erased. In fact, the EEPROM in the pre-paid setup uses electric signals to erase the contents stored. The aspect of non-volatility ensures that customers credit balances are not lost in case of a power cut to the mains voltage line.

2.3.1.3 Microcontroller

By definition, a microcontroller is a small computer that is integrated in a single circuit and is dedicated to perform one task and execute one preset application [4]. Microcontrollers consist of three primary components, i.e., a memory, a processor and I/O (Input Output peripherals). The simplicity in their design means that they are suitable for an environment with limited computing functions such as those found in embedded software applications. The prepaid metering setup is one example of a system using an embedded application whose functions are limited to I/O (Input Output functions) and a user interface.

2.3.1.4 Relay and Relay driver

Relays are switches that are designed to open and close either electrically or electromagnetically. They control one electrical circuit by opening and closing the contacts of another circuit. Typically, there are two types of relays.

a) Electromechanical Relays
b) Solid State Relays (Electronic Relays)

Electromechanical relays make use of an electromagnet to control the contacts of another circuit. When the circuit controlling the electromagnet is turned on, a current runs through the coil around the magnet introducing a polarity. This polarity attracts the movable armature downwards thereby closing the contacts in the secondary circuit.

Electronic relays (Solid state relays) on the other hand make use of an input circuit, a control circuit and an output circuit. The input circuit is designed to go on when a voltage is applied on the input terminals. Usually, the input circuit can have a base voltage above which the circuit comes on and the circuit will be de deactivated when the applied voltage drops below the base voltage. In this case, the control circuit functions as the relay factor between the input and output circuits and determines when to activate or deactivate the output circuit depending on the pre-set voltages. This is the same function as that of the electromagnet in the electromechanical set up. The output circuit then controls the load contacts by switching them on and off.

Figure 2.5 shows an electromagnetic relay.

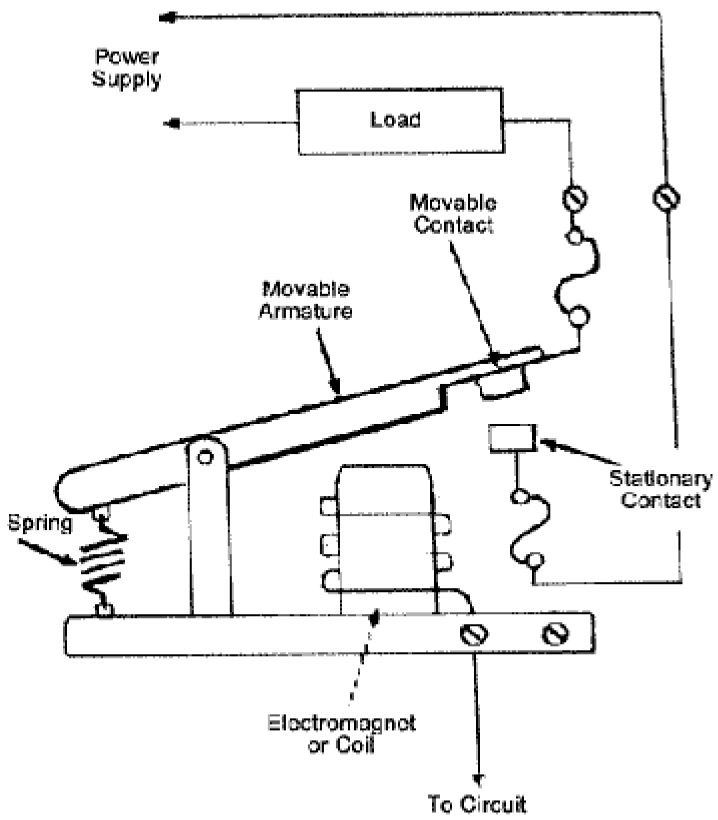

Figure 2.5: Electromechanical Relay [3]

In the pre-paid metering setup, solid state relays are used in the MCU to allow for disconnection of the load switch once the customers balance falls to zero. This happens when the microcontroller unit reads the balance in the EEPROM and finds a value of zero, then it sends a signal to the solid-state relay to disconnect the load switch. Figure 2.6 shows a Solid-State Relay.

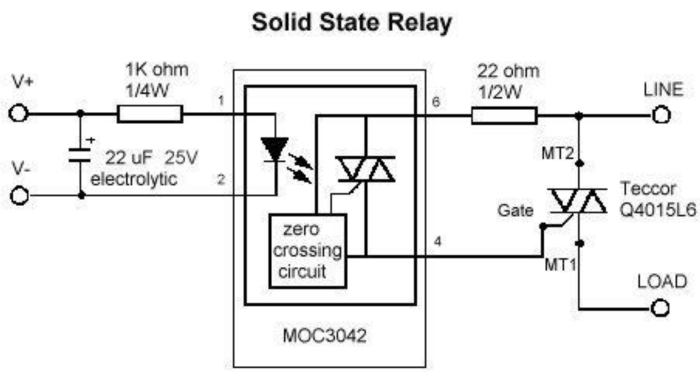

Figure 2.6: Solid State Relay [3]

2.4 Related research works

In other parts of the world, the pre-paid metering solution involves three major components namely an electricity dispenser, a vending station and a system master station [5]. In this case, the electricity dispenser is the Measurement Control Unit which tracks the usage of power and disconnects whenever the prepayment runs out. The vending station is a third party operated shop that provides and facilitates the purchase of the tokens from the power distributors such as Kenya Power and Lighting Company. The vending stations are all interlinked with their command center being the system master station. This is where all the information regarding the customer accounts is stored and processed [5].

Some of the related research works are seen in India where the researchers have continuously improved on the pre-paid metering system. In the early stages of prepaid metering, the meters made use of cards with a magnetic swipe functionality. Customers were able to purchase tokens at designated vending stations and the tokes were loaded into their magnetic swipe cards. The customers would then swipe their cards in the meters at home and the units purchased would be transferred into their meter accounts. This method provided for information flow in one direction where the meters would receive information from the vending station only. Continuous improvement from the researchers presented an improvement opportunity where a smart memory chip was added to the magnetic swipe cards. The information stored in this memory chip would include details of the customer and their rate of power usage. At the vending stations, it was possible to relay this information back to the vendors thus allowing for a two-way flow of information between the customer and the power vendors [5]. Further improvements of the prepaid metering got us to where we currently find ourselves. To make the process simpler, the magnetic cards were replaced with coded messages that come as a string of numbers. To validate these messages, the user is expected to key in the string of numbers on the keypad provided in the customer interface unit.

2.5 Research Gaps

There is need to introduce a simpler method of loading units into the Customer Interface Unit so as to solve some of the simple inefficiencies that are currently being witnessed. For example, when loading a mobile phone with airtime, we in Kenya have options of buying scratch cards or using mobile money solutions. In case of the latter, the airtime is loaded automatically into the user's phone without any physical entry of the tokens or airtime digits. This is the same line of thought that introduces the research gap in our pre-paid metering case.

It is evident that the system currently in use in Kenya is further advanced as compared to that in the other parts of the world. The fundamental difference between Kenya and the rest of the world is brought about by the method with which the tokens are purchased, In Kenya, we make use of mobile money which eliminates the need for vending stations whereas in other countries, the vending stations are the vital link between the consumers and the system master stations. It is this advantage that Kenya has that also presents a further improvement opportunity which this research addresses. The research gap is the need to bypass the keypad as a method of loading tokens into a prepaid metering system.

CHAPTER 3: METHODOLOGY

3.1 Introduction

In this chapter, the methods and tools used to realize this solution have been outlined and discussed in detail.

3.2 Analysis of the requirements

With the research objectives in mind, an analysis was done to establish the system components that would achieve the desired outcome. To do so, a questionnaire was given to a number of classmates and colleagues containing the following questions.

i. Are you currently facing any challenges with the current pre-paid metering set up?
ii. Do you find the current method of topping up units/tokens inconvenient?
iii. Would the ability to load tokens remotely make the process easier or more efficient?

The answers to these questions pointed to a glaring gap in the pre-paid meter that can be addressed by adding a communication module that would input the tokens instead of the manual entry that is currently done. To achieve this communication, a GSM module presented the best solution as it was readily available and easily configurable.

However, to achieve the integration between the CIU and the GSM module, there was need for a common link between the two devices which was obtained by means of a breadboard. In addition to this, the communication between the GSM module and the CIU would need to be facilitated and that would be done by means of a microcontroller [13]. The Arduino UNO Mega was found to be most useful for this purpose and was therefore added to the list of requirements.

Finally, the code of communication between these devices would be required and AT commands was chosen since both the GSM Module and the Arduino would accept instructions sent via these Commands [6].

3.3 Design and conceptualization

The components as established in the system analysis and their functionalities are discussed next.

i. A Keypad (existing Kenya power prepaid CIU)
ii. An open-source microcontroller (Arduino UNO R3)
iii. A GSM module (GSM SIM 900)
iv. A breadboard
v. Light Emitting diodes / Display Screen

vi. Program code in AT commands

The set-up of these devices will be used in showing proof of concept such that, a text message sent to the GSM module will be interpreted and executed. The configuration of these devices is shown and elaborated in Figure 3.1

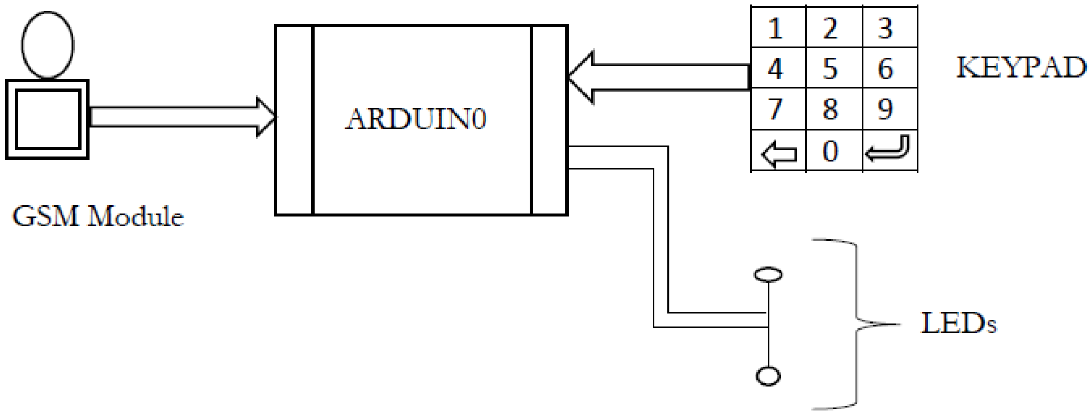

Figure 3.1: Laboratory configuration of the pre-paid set-up

In the above configuration, the Arduino serves as the microcontroller unit and is responsible for all computations and execution commands. It is loaded with a code written in AT commands and with the necessary instructions [6]. To demonstrate the conventional method of topping up units, a keypad is connected to the microcontroller in parallel with the GSM module whose aim is to replace the keypad. In this arrangement, both the keypad and the GSM module can be used. After the customer tokens have been input in the keypad, the microcontroller will issue a logic one or logic zero to show acceptance or rejection of the same respectively. Consequently, this action will be displayed by the use of an LED. In case of acceptance, the green LED will light up and incase of rejection, the red LED will light up.

3.3.1 The Keypad

The keypad typically comprises of numerical digits running through from 0 to 9, a delete button and a return/enter button. These are used to enter the token numbers as received from the vendor and serve as the contact point between the vendor and the customer's account. It is at this point that this report will introduce a different route of entering these digits.

3.3.2 The GSM Module

The GSM module usually holds a SIM card which receives the information sent via text messages. In our case, the token messages are sent via text and will be received by the GSM SIM 900 which is our module of choice primarily because it allows us to send and receive SMS and is easily integrated to the Arduino [6]. This device will make use of with AT commands to facilitate its functionality.

3.3.3 The Arduino

This is the open-source microcontroller that is loaded with the codes necessary for our set up to function [13][14]. It is connected to the keypad, the LED indicators and the GSM module through a set of cables commonly referred to as header wires [14]. The code to be loaded into the microcontroller will be written in form of AT commands and will be detailed in this report.

3.3.4 Program Code

In order for the set-up to function, the microcontroller and GSM modules will require a software that enable them. This software will be written as AT commands and the write up of this software will also form part of this report [6].

3.4 Data Collection

The process of data collection will involve testing and validating of our system on the sample Kenya Power pre-paid meters. Once the proof of concept has been actualized in a laboratory environment, we will connect the system to a sample pre-paid meter and verify the complete process of loading of tokens. It is at this stage that we will determine the viability of the concept and also uncover ways to further improve the idea of remote top ups.

3.5 Conclusion

Having completed the analysis of the system requirements, the components were procured and the laboratory set up process begun at the FabLab located in the University of Nairobi, Kabete campus.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter looks at the findings of the research and documents the results obtained during the laboratory experiments and set up. Further to that, this chapter also documents the challenges faced and discusses the solutions found therein.

4.2 Overview

The design setup and compilation are key steps in achieving the functionalities and execution of our research. With the components of the system ready and compiled, they will be connected to an actual pre-paid meter to test the system. However, before such a connection is done, the proposed system will have gone through a series of tests involving output logic one and zero (I/0) tests. This kind of test will confirm that the first stage of the prepaid metering set up which involves sending an SMS to the CIU is functioning fully. The second stage which involves relaying of the SMS to the MCU will be tested via the LED where a green light will represent acceptance of the token and a red light will represent rejection of the tokens. Also, the Arduino will be connected to a monitor and this will display the rejection or acceptance of the tokens.

This step is crucial in ensuring reliability of the system as a whole and helps in noting possible improvements on the system. It is at this stage that all the unforeseen errors will be noted, documented and corrected. Thereafter, the corrections will be done to ensure that the system functions as required and re-testing will be undertaken to confirm the same.

4.3 Implementation of the design

With the items listed in Table 4.2 in place, the compilation of the devices was done to check for functionality for each device. To start with, a sample meter board meter was put together comprising of the prepaid meter, an electrical switch, a socket and a light bulb. This meter board set up was then connected to a power source and verification of the functionality of the system was done. Thereafter, using the pre-paid token generation system, tokens were input to the CIU and the system was verified as functional. In this set up, the MCU accepted the tokens and this could be seen as reflected in the CIU as the updated tokens were shown on the display. Figure 4.1 shows the sample meter board set-up before any additions were made and represents the conventional KPLC meter board.

Figure 4.1: Sample meter board

The relevance and purpose of the fixtures in Figure 4.1 are discussed in the following sections.

4.3.1 The power outlets – Socket and Light bulb

After the sample meter board was set up, it was necessary to add a socket to the set up to give us a means of drawing power and thereby depleting the tokens at a fast rate. This was made possible by connecting a device, in this case, an iron box which drew power at a faster rate as compared to the light bulb [8]. In so doing, turning on the iron box made it possible to deplete the tokens in a period short enough that could be accommodated during the experimental stage. Further to this, the number of tokens purchased and loaded into the CIU were also kept at a low amount of five units. This made it possible for us to reach the Zero amount and watch the MCU disconnect the power. A visual representation of the power being interrupted as a direct result of low tokens was seen when the light bulb went off.

4.3.2 Customer Interface Unit redesign

The Customer Interface Unit (CIU) is a critical device in the integration and functionality of this design.[9] It is here that the internal keypad was connected in parallel to a GSM module that can be used to input the tokens as given by the Vendor (in this case the token generating system).

To begin with, the CIU was dismantled and its internal wiring and schematics were analyzed with an aim of establishing the best point where the GSM module would be attached. To achieve this, the connections as embedded on the logic board had to be exposed and the insulation on them scrapped off. This was achieved through use of a sand paper attached to a Brummel.

Figure 4.2 shows the exposed connections on the logic board where the connections were attached.

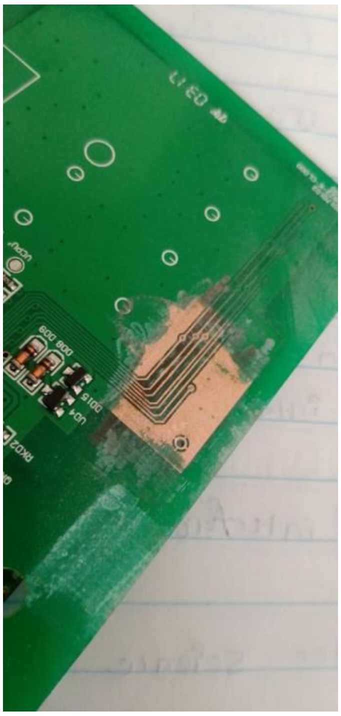

Figure 4.2: Exposed logic board connections

With the connections exposed, extra caution was taken to avoid any form of short circuiting that would lead to damage of the CIU or incorrect results afterwards. Further to this, continuity tests were done using a Digital Multi Meter which confirmed the integrity and completeness of wiring after the process of sand paper scrubbing.

The exposed connections were then connected to a set of nine cables. Two cables were connected to the power source in the circuit and the other seven cables were connected to the rows and columns in the keypad. Figure 4.3 shows the keypad wiring diagram.

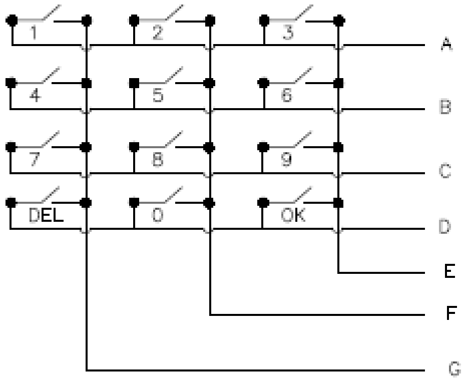

Figure 4. 3 Keypad wiring diagram

Figure 4.4 shows the connections of the cables as done on the logic board.

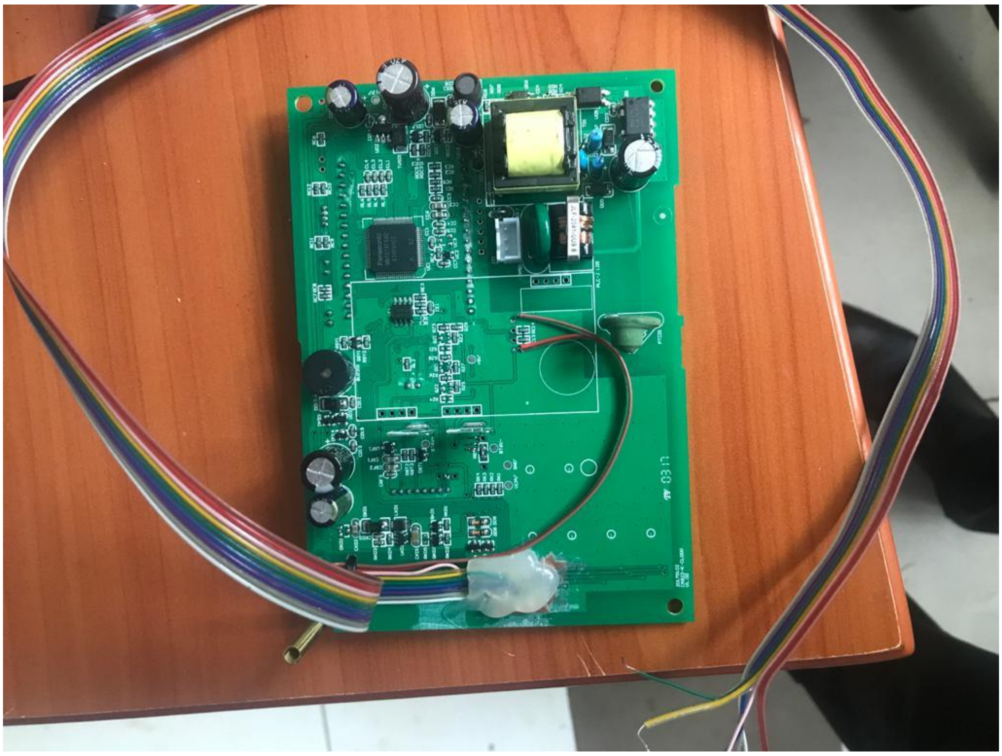

Figure 4.4. Keypad Connections

The nine cables were then connected to a breadboard which facilitated the connection to the external keypad for testing.

Figure 4.5 shows the connection of the CIU to the external keypad.

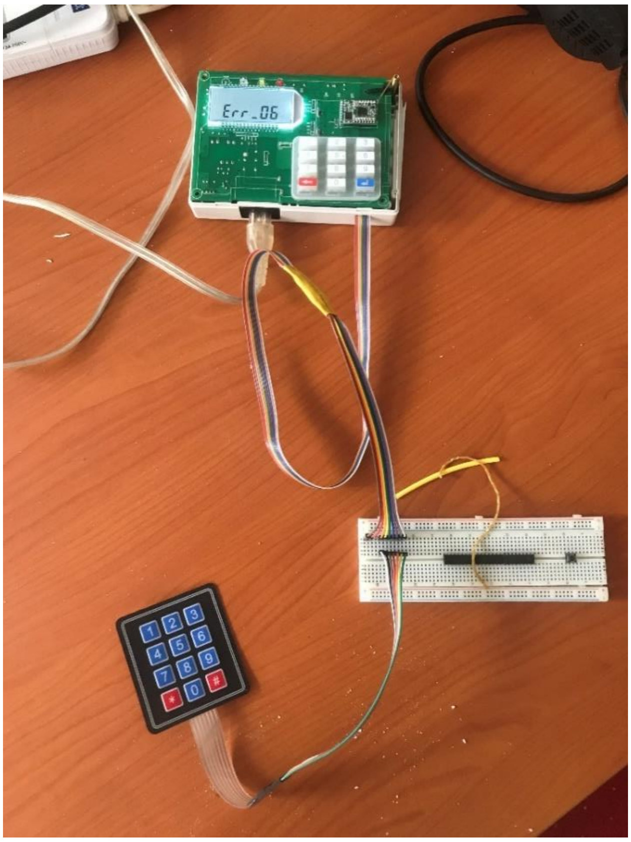

Figure 4.5 External Keypad Connections to the CIU

The external keypad was then tested to prove functionality of the set up and was found to be working well with the exception of the middle column. The video in the hyperlink shows the testing process of the external keypad.

https://drive.google.com/file/d/1cIOMMm9UaGLrC6X6aYxD2nxcCv8AnDik/view?usp=sharing

The fault as seen in the middle column where the keys 2, 5, 8 and 0 were not working was caused by an improper termination of the header wires. This was rectified and the test redone. Thereafter, the next step was to connect the CIU to the GSM module and test for its functionality.

4.3.3 Arduino and CIU connections

Having proven the functionality of the external keypad and the CIU, the next step in validation of this design was to connect the GSM module to the CIU. This led to preparation of a simple code that would facilitate transmission of data from the GSM module to the CIU. The initial aim was to be able to read a text message from the sim 900 and transmit it to the CIU. This code was written in the form of AT commands and is detailed in Figure 4.6 [6].

Receive SMS test

```
#include <SoftwareSerial.h>


//Create software serial object to communicate with SIM800L
SoftwareSerial mySerial(8, 9); //SIM800L Tx & Rx is connected to Arduino #3 & #2

void setup()
{
  //Begin serial communication with Arduino and Arduino IDE (Serial Monitor)
  Serial.begin(9600);

  //Begin serial communication with Arduino and SIM800L
  mySerial.begin(9600);

  Serial.println("Initializing...");
  delay(1000);


  mySerial.println("AT"); //Once the handshake test is successful, it will back to OK
  updateSerial();

  mySerial.println("AT+CMGF=1"); // Configuring TEXT mode
  updateSerial();
  mySerial.println("AT+CNMI=1,2,0,0,0"); // Decides how newly arrived SMS messages
should be handled
  updateSerial();
}

void loop()
{
  updateSerial();
}

void updateSerial()
{
  while (Serial.available())
  {
    mySerial.write(Serial.read());//Forward what Serial received to Software Serial Port,...
allows sending commands to SIM800L?
  }
  while(mySerial.available())
  {
    Serial.write(mySerial.read());//Forward what Software Serial received to Serial Port
  }

}
```

Figure 4.6 AT Commands

To run this code, the Arduino (connected to a PC) and GSM module were connected via a breadboard [14][16]. This set up was thereafter connected to a power source at 5V which was the rated input voltage of the Arduino. After the connection was done and testing of the code begun, it was noted that the GSM nodule was having a challenge accessing Safaricom Network. (A Safaricom sim card was in use). To solve this, an antenna with the following specifications was added to the set up [14][16].

> ‘’2.2"/57mm long antenna with 2dBi of gain and 50Ω impedance. Works with 850/900/1800/1900/2100 wireless receiver/transmitter such as any Cellular or GSM/GPRS device.’’

The setup was as shown in Figure 4.7

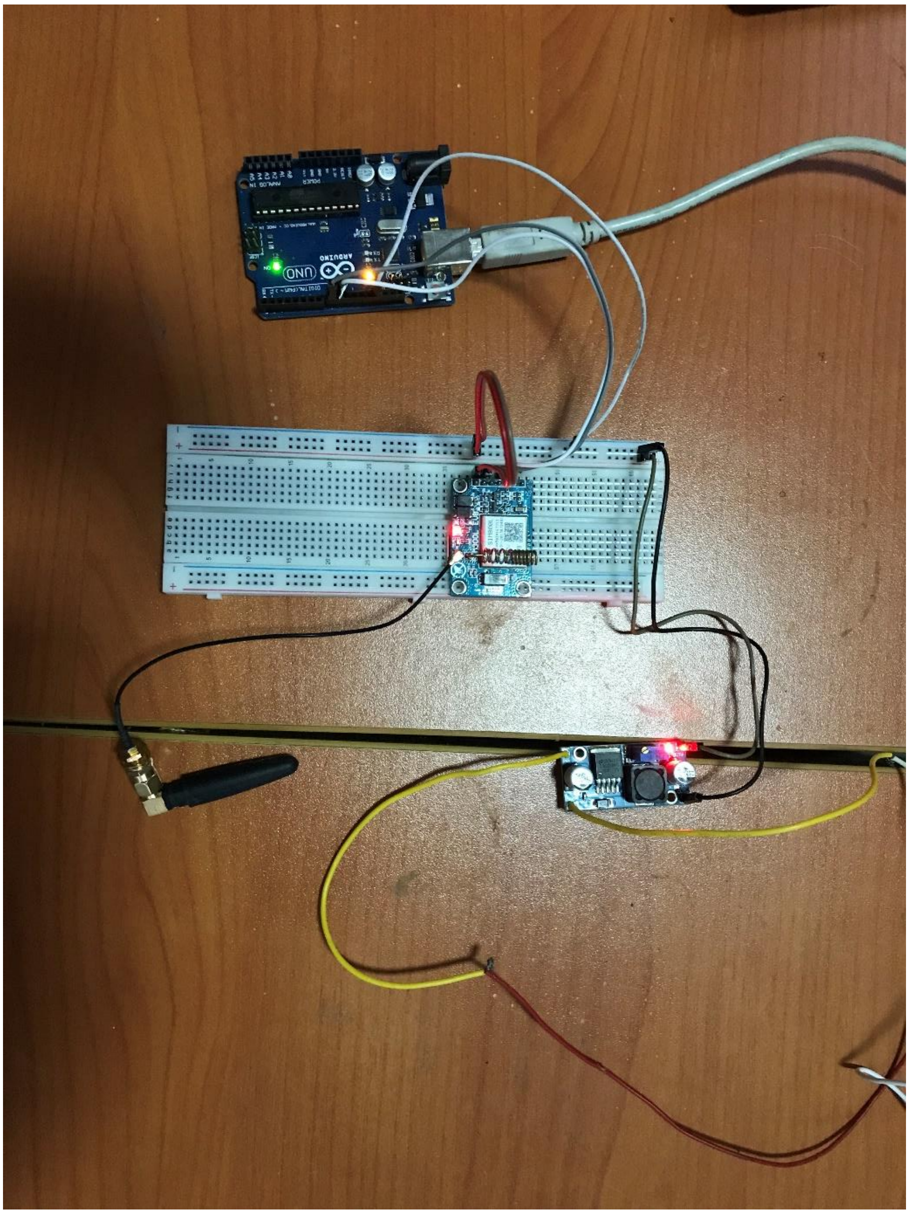

Figure 4.7: GSM Sim 900 Connections with antenna

With this antenna in place, the GSM module was able to pick up signals from the mobile network provider even when indoors. However, another challenge that came up as a result of this addition to the design was to do with the current being drawn by the GSM Module. It was observed that when the sim card was connecting to the network, the current would increase to upwards of 1.2Amps. This would prove to be a challenge because the power supply in place was rated 5V/1A. Therefore, a power source of 12V was connected in series with a DC – DC converter with the aim of providing the required voltage of 5V and currents above 1.2Amps [7][8].

Figure 4.8 shows the set up with a 12V power source

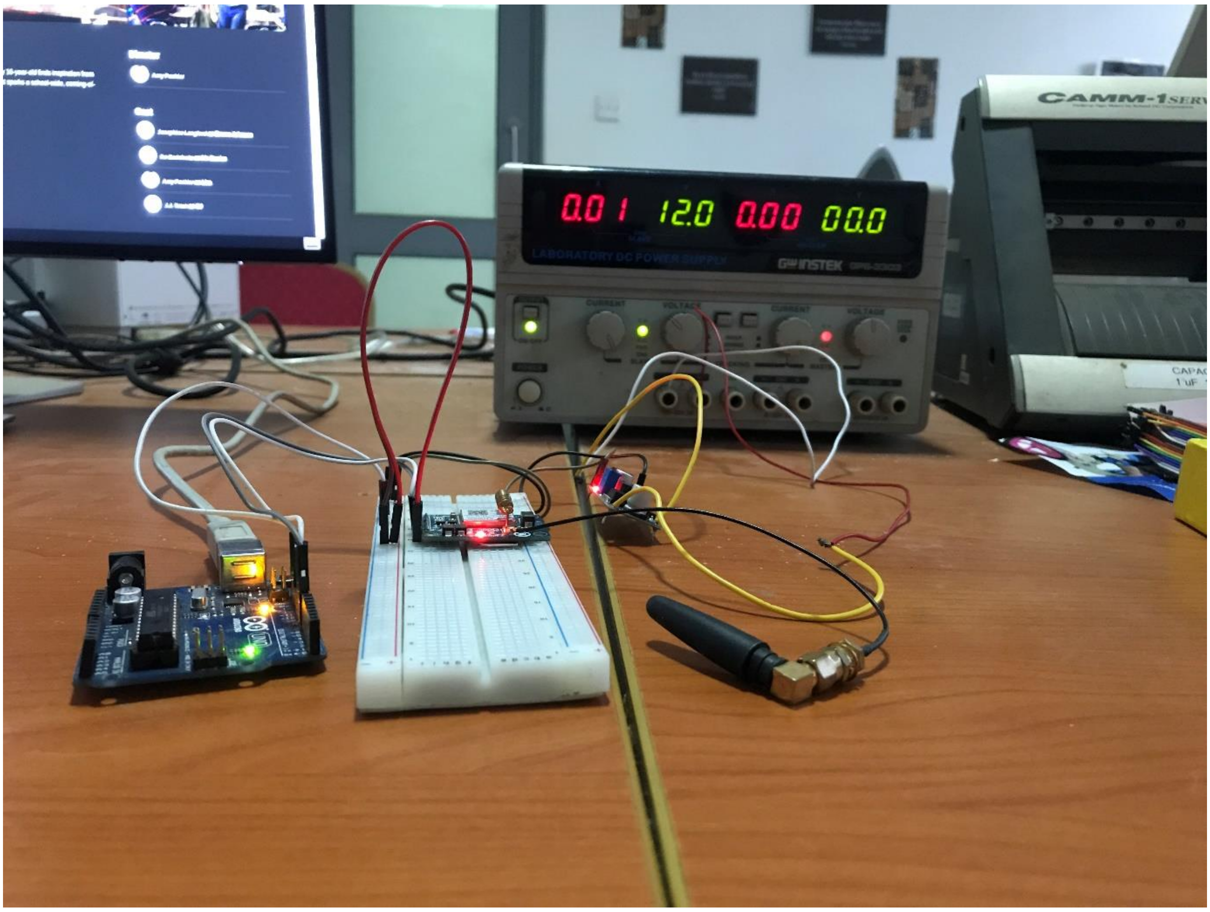

Figure 4.8: GSM Sim 900 Connections with antenna and 12V power source

From the above set up, the Arduino is connected to a PC where the program code was run and serves as its power source also. Through a couple of header wires, the Arduino is then connected to the GSM module with a SIM card in it via a breadboard. It is at this point also that the GSM is powered at 5V through the DC-to-DC converter.

To test the program code, a text message was sent to the sim card installed in the GSM module and this was read on the monitor of the PC. At this point, the first step in actualizing this new prepaid set up was proved to be working correctly and as expected. Here, it was observed on the monitor that the text message sent to the SIM card was displayed. This meant that the GSM module as connected was receiving both the network from the Mobile network provider and also was able to receive the information sent. Further tests were carried out where a phone call was made to the SIM card. To verify that the system was correctly configured, the monitor on the PC displayed ‘Ring’ as an indicator that the sim card was currently receiving a call.

Figure 4.9 shows the monitor displaying the text ‘Ring’ as an indicator of an incoming call to the GSM module and a received test message ‘123567890’

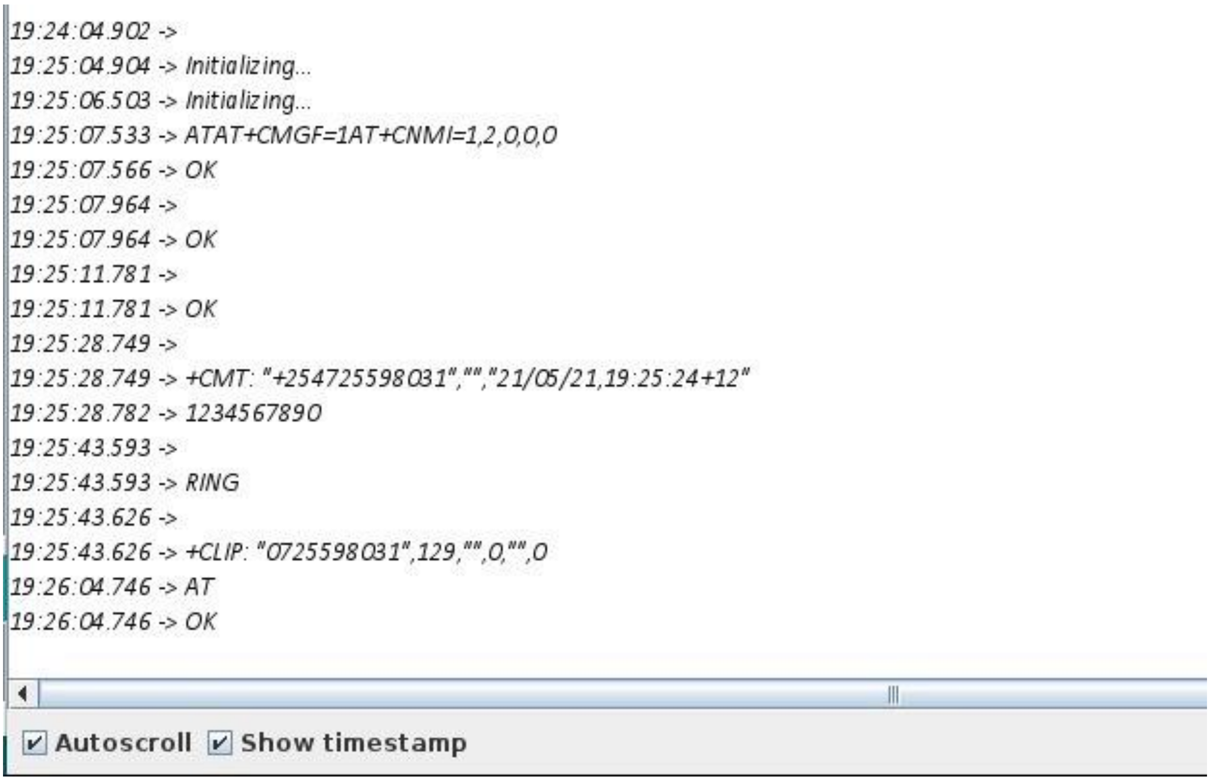

Figure 4.9: Display monitor showing an incoming text and call to the GSM module

4.3.4 Connections of the GSM Module, CIU and Arduino

The connection of the GSM module to the CIU was successfully completed via the Arduino and this meant that the set up was ready for the next step of design validation and testing. At this stage, a recurring challenge arose which was the repeated disconnection of the header wires used throughout the set up. To resolve this issue, the circuit diagram as connected was drawn using Eagle CAD software.

4.4 Validation of the design

The laboratory prepaid set up was put together including all the components necessary for full functionality of the system and tested. For practicality, the breadboard used was machine etched on a circuit board using as per Figure 4.10.

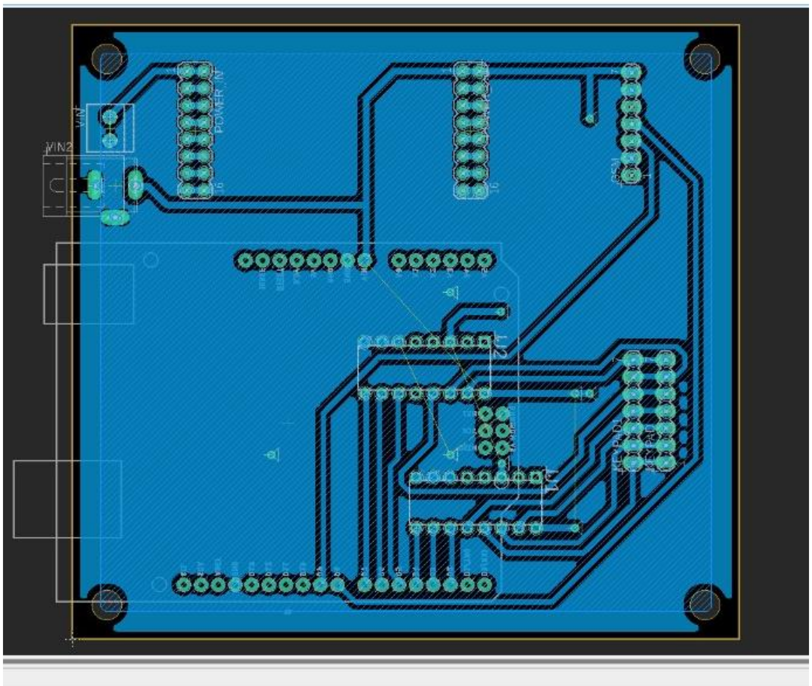

Figure 4.10: Circuit board diagram

As breadboard presented a challenge of loose cables and header wires getting disconnected while conducting the experiment, the above circuit was machine etched to provide a more reliable circuit board. Figure 4.11 shows the machine etched circuit board.

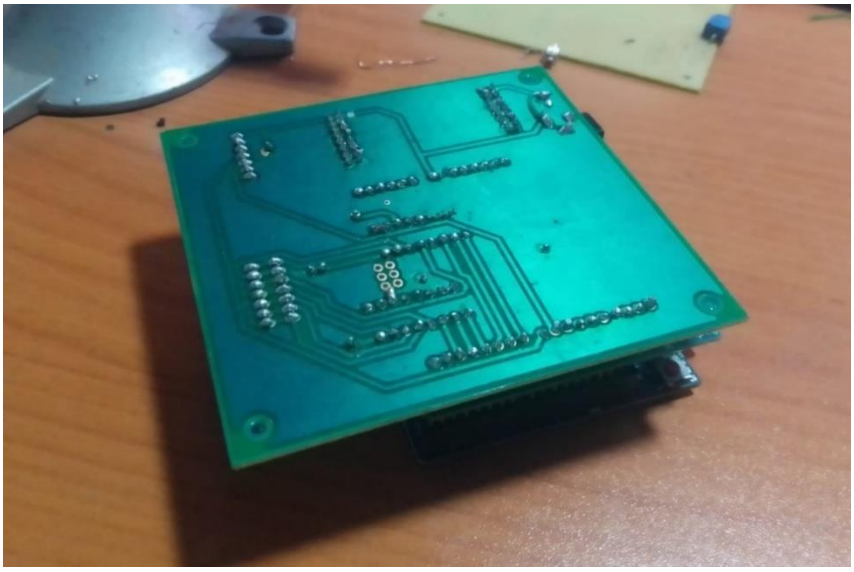

Figure 4.11: Machine etched circuit board

With the machine etched circuit board in place, connections to the GSM module and Arduino were done as per Figure 4.12.

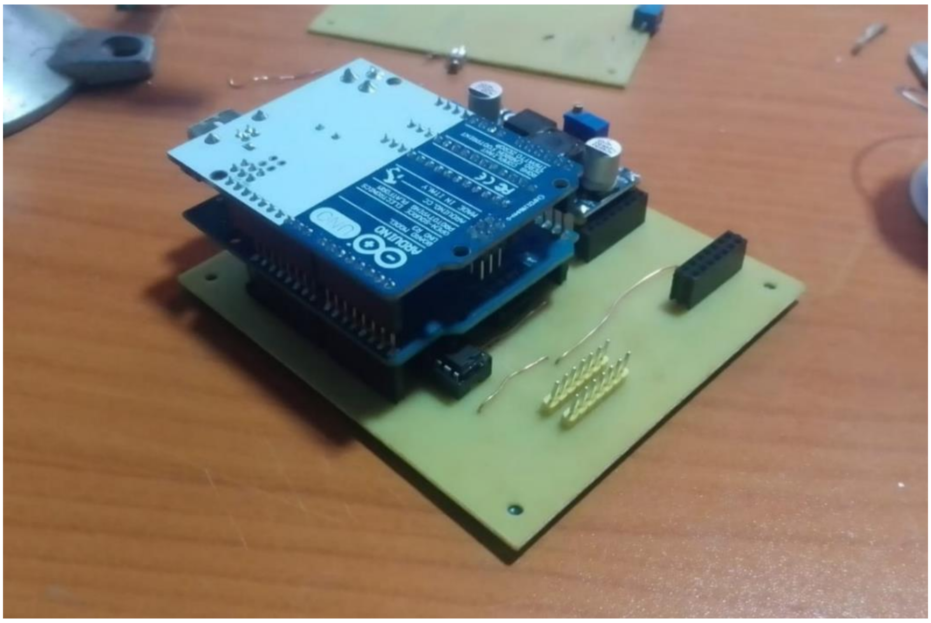

Figure 4.12: GSM module, Arduino and Machine etched circuit board system connections

After these connections were put in place, an SMS was sent to the GSM module to test the functionality of the machine etched circuit board. The board was successfully tested and proved to be working as desired. With this step completed, the CIU was added to the connections and another test was done to verify that the SMS sent to the system would be received and decoded on the CIU. The connections were as seen in Figure 4.13.

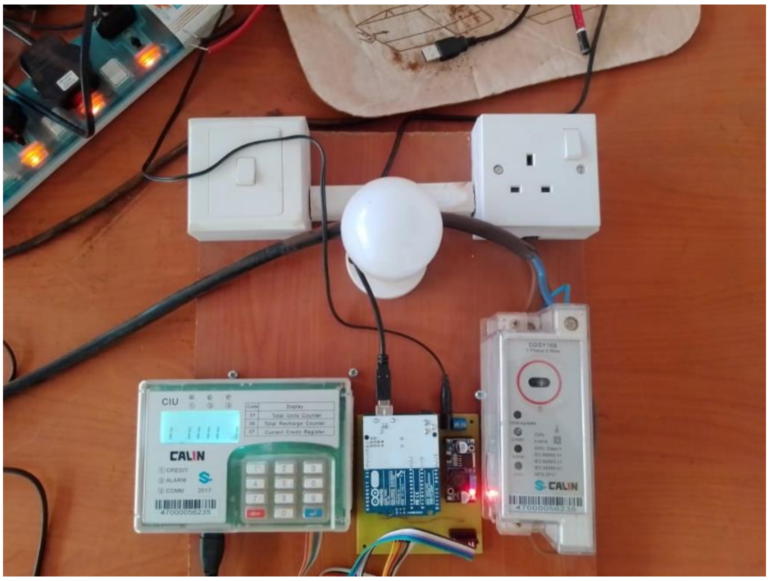

Figure 4.13: Complete prepaid metering system connections

After completion of the circuitry, a text message was sent to the system to test the functionality. The video in the hyperlink shows how it was received by the GSM and forwarded to the CIU.

https://drive.google.com/file/d/1cF6qw637XShew1rqw-Jn1V41pDhD3jgY/view?usp=sharing

In this video, it was noted that the time taken for the GSM module to receive and send out the tokens to the CIU was 22 seconds beginning from minute 0:45 of the video to minute 1:08. In comparison to the time taken by manual entry, the notable improvement was noticed by elimination of the time taken to walk or travel to the location of the CIU to facilitate the manual entry.

4.5 Summary of findings

The prepaid metering system has been of great benefit to both the consumers of electricity and the vendor. These benefits have been outlined in this report and to further the gains of prepaid metering, this report proposed a new introduction in the functionality of the system. This proposed addition was taken through a series of tests in the laboratory and proven to be of benefit to the entire electricity industry.

In the literature review section found in chapter 2, various existing technologies that are used in the world were reviewed with the aim of understanding the premise of this research and experiment. Prepaid metering has been found to have several advantages and a new improvement to this would go a long way in making our contribution to the engineering fraternity and to our country, Kenya, where the system is predominantly used.

A step-by-step analysis of the set up was done with the aim of bringing to light existing gaps in the current system of prepaid metering and in specific the process of loading or topping up tokens. The methodology in chapter 3 outlined the ways in which the proof of concept can be achieved and with this, the various methods of validating the new system were conceptualized and the findings recorded.

4.6 Conclusion

This chapter has documented the results and findings throughout the whole laboratory process and from the laboratory set up and experiments, the proposed addition of GSM capabilities to the electricity prepaid metering system was been proven to be feasible and valuable to the existing model. To add onto the benefits of this modeal

CHAPTER 5: CONCLUSSION AND RECOMMENDATIONS

5.1 Introduction

This chapter gives the conclusions drawn from the experiments carried out during the entire laboratory set up vis a vis the research questions outlined in chapter 1. Additionally, this chapter also proposes the probable recommendations that can be used in furthering the research as outlined in this report.

5.2 Conclusions

The research objectives as outlined in chapter 1 were aimed at finding an alternative method of topping up units by automating the process. This was done by adding a GSM module to the existing prepaid metering set up and in particular, the CIU.

This research and experiment had three specific objectives. The first specific objective was fulfilled by conducting literature review in chapter 2. Here the various existing technologies used in metering were examined and the main factors that make prepaid metering suitable to our Kenyan consumers were outlined.

The second specific objective of this experiment was to design the components of a new prepaid metering system that would incorporate the GSM capabilities and improve on the existing technologies. This was achieved in chapter 3 where an in-depth analysis of the system requirements was done. The new system was successfully designed and documented with a detailed explanation of the roles played by various components.

The third and final specific objective was to implement and validate the design as conceptualised. This was done and recorded in chapter 4 where the results and discussions of the findings were noted and documented.

The foregoing analysis and documentation of this experiment not only demonstrated the proof of concept but also showed that this report fulfilled all the research objectives as outlined in chapter one. In specific, the first research question was “How do we analyse the requirements of the new system?” To achieve this, we started by looking at the desired outcome and working backwards to create a table of the system requirements. These were recorded and documented in the appendix of this report under the sections of workplan and budget. The second research question was “How do we design the components of the new system?” This was achieved by examining the working of the different components and with the information found in the literature review, a new and innovative means of creating the new system was done and documented in chapter three under the methodology section. The third research question was "Can the new system be successfully implemented and validated?" To achieve this, the implementation and validation of this experiment was done by simulating the proposed system in a laboratory set up. The details of this laboratory set up were recorded in chapter three where the methods used are discussed. Further to that, the validation of this experiment was documented in chapter 4 where the findings, challenges and outcomes of the design implementation are discussed in sufficient detail.

5.3 Recommendations

The recommendations drawn from this research are broken down into two and in line with the research objectives.

1. This report has proven that the proposed improvements using GSM technologies can be achieved and recommends the implementation of this work using advanced machinery to achieve precise and refined devices ready for use in the broader engineering profession.
2. Adoption of the findings in this study is recommended with appropriate improvements.

5.4 Limitations of Study

The challenges faced while implementing and validating this experiment presented the greatest limitations to this research. Lack of access to refined fabrication equipment meant that the set-up and connection of the circuit board was bulky and subject to loose connections. Further studies can be done in this area to establish a more efficient way of integrating the GSM module into the circuit board.

5.5 Contribution of this research

The contribution that this research makes to the existing electricity prepaid metering technologies cannot be overstated. This research report has documented the ways in which the electricity prepaid meter can be improved upon by use of GSM technologies which not only makes it easier to top up customer units but also has benefits to the system vendors and product manufacturers by reduction of the overall footprint of the CIU. This report shows ways in which the addition of the GSM module makes the overall system of electricity prepaid metering more efficient and user friendly. Finally, the availability of mobile network coverage in most of the areas in the country makes the GSM system a very reliable means of product improvement.

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APPENDIX I

Student Reference Letter

UNIVERSITY OF NAIROBI

Department of Mechanical and Manufacturing Engineering

Telegrams: "Varsity" Nairobi
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Telephone: 254 020 318262
Extn: 28383
Email: dept-mmengineering@uonbi.ac.ke

P.O. Box 30197
GPO 00100
Nairobi
KENYA

4th February 2020

TO WHOM IT MAY CONCERN

Dear Sir/Madam

RE: **ANTHONY MWAURA NDUNGU – F56/83427/2015**

The above named is a student at the University of Nairobi, Department of Mechanical & Manufacturing Engineering pursuing a Master of Science degree in Energy Management.

He has completed part 1 of his studies comprising of course work and Examinations and is now undertaking a research project in part 2 of the course titled
"Design of an automated customer interface unit for Kenya Power Prepaid Meters"

In light of this, we request that you assist him, where possible, to acquire a sample pre-paid meter complete with the full functionality of topping up units via tokens purchased from KPLC for demonstration purposes of the additional capabilities that his project seeks to address.

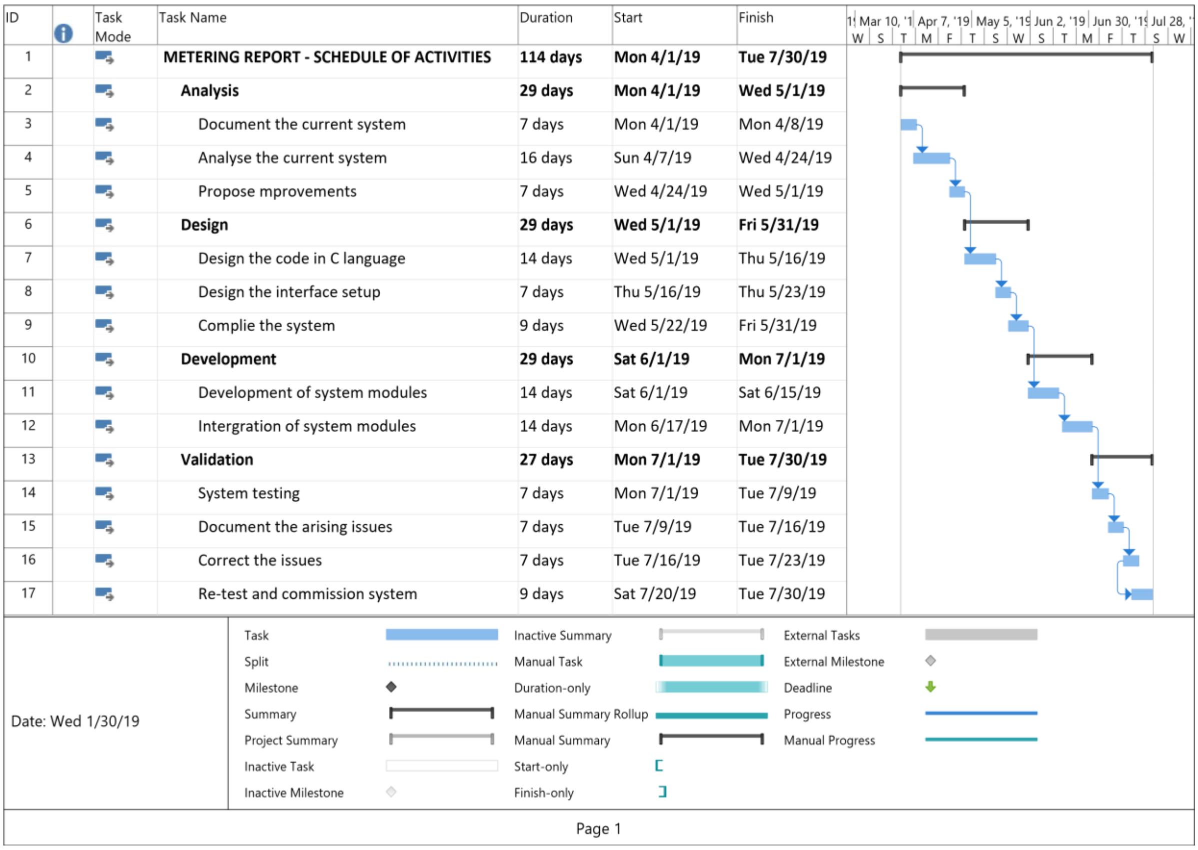
Any assistance accorded to him will be highly appreciated.

CHAIRMAN
DEPARTMENT OF MECHANICAL & MANUFACTURING ENGINEERING
UNIVERSITY OF NAIROBI
P.O. Box 30197 – 00100, NAIROBI
Email: dept-mmengineering@uonbi.ac.ke

Dr. Thomas Ochuku Mbuya,
Chairman,
Dept. of Mechanical & Manufacturing Engineering.

Work Plan

The Gantt chart shows the activities that will be undertaken and the correlating time durations. This will greatly assist with proper planning and time allocation as well give a tool for monitoring and assessment of the whole process.



ID	Task Mode	Task Name	Duration	Start	Finish
1		**METERING REPORT - SCHEDULE OF ACTIVITIES**	**114 days**	**Mon 4/1/19**	**Tue 7/30/19**
2		**Analysis**	**29 days**	**Mon 4/1/19**	**Wed 5/1/19**
3		Document the current system	7 days	Mon 4/1/19	Mon 4/8/19
4		Analyse the current system	16 days	Sun 4/7/19	Wed 4/24/19
5		Propose mprovements	7 days	Wed 4/24/19	Wed 5/1/19
6		**Design**	**29 days**	**Wed 5/1/19**	**Fri 5/31/19**
7		Design the code in C language	14 days	Wed 5/1/19	Thu 5/16/19
8		Design the interface setup	7 days	Thu 5/16/19	Thu 5/23/19
9		Complie the system	9 days	Wed 5/22/19	Fri 5/31/19
10		**Development**	**29 days**	**Sat 6/1/19**	**Mon 7/1/19**
11		Development of system modules	14 days	Sat 6/1/19	Sat 6/15/19
12		Intergration of system modules	14 days	Mon 6/17/19	Mon 7/1/19
13		**Validation**	**27 days**	**Mon 7/1/19**	**Tue 7/30/19**
14		System testing	7 days	Mon 7/1/19	Tue 7/9/19
15		Document the arising issues	7 days	Tue 7/9/19	Tue 7/16/19
16		Correct the issues	7 days	Tue 7/16/19	Tue 7/23/19
17		Re-test and commission system	9 days	Sat 7/20/19	Tue 7/30/19

Date: Wed 1/30/19

Task, Split, Milestone, Summary, Project Summary, Inactive Task, Inactive Milestone, Inactive Summary, Manual Task, Duration-only, Manual Summary Rollup, Manual Summary, Start-only, Finish-only, External Tasks, External Milestone, Deadline, Progress, Manual Progress

Page 1

Budget

The proposed solution involves purchase of selected pre-fabricated items that are key to seeing this project to fruition. The list of these items is seen in Table A.1 complete with the pricing schedule as found in the Kenyan market.

Table A.1: Itemized schedule of requirements

ITEM	DESCRIPTION	PRICE (KShs)
1	Arduino IDE	2,500.00
2	GSM SIM 900 module	4,500.00
3	Reference module	1,000.00
4	Breadboard	1,000.00
5	Light Emitting Diodes	3,500.00
6	Keypad	2,500.00
7	Electricity Pre-paid meter	5,000.00
	TOTAL	**20,000.00**

With the total cost of this project being Kenya Shillings Twenty thousand (20,000/=), it is feasible for the whole process of research and implementation to be undertaken and seen to completion without any unforeseen budgetary delays.

Questionnaire forms

RESEARCH REPORT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN ENERGY MANAGEMENT

QUESTIONNAIRE

The purpose of this questionnaire is to collect information and users' feedback regarding the use of electricity prepaid meters in Kenyan households.

Research Objectives

The research objectives of this research are focused around electricity pre-paid metering and the recharge process of tokens. The process of recharging the tokens is done by keying in the numbers on the inbuilt keypad on the customer interface unit (CIU) and this research seeks to automate this process by substituting the keypad with a GSM module.

Kindly respond to the questions that follow.

i. Are you currently facing any challenges with the current pre-paid metering set up?

   Yes   No

ii. Do you find the current method of topping up units/tokens inconvenient?

   Yes   No

iii. Would the ability to load tokens remotely make the process easier or more efficient?

   Yes   No

Name: ....

Phone Number ....

RESEARCH REPORT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE

OF

MASTER OF SCIENCE IN ENERGY MANAGEMENT

QUESTIONNAIRE

The purpose of this questionnaire is to collect information and users' feedback regarding the use of electricity prepaid meters in Kenyan households.

Research Objectives

The research objectives of this research are focused around electricity pre-paid metering and the recharge process of tokens. The process of recharging the tokens is done by keying in the numbers on the inbuilt keypad on the customer interface unit (CIU) and this research seeks to automate this process by substituting the keypad with a GSM module.

Kindly respond to the questions that follow.

i. Are you currently facing any challenges with the current pre-paid metering set up?

   Yes ✓   No

ii. Do you find the current method of topping up units/tokens inconvenient?

   Yes ✓   No

iii. Would the ability to load tokens remotely make the process easier or more efficient?

   Yes ✓   No

Name: ....E. Mutoni........................

Phone Number ....0721869492........................

RESEARCH REPORT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE

OF

MASTER OF SCIENCE IN ENERGY MANAGEMENT

QUESTIONNAIRE

The purpose of this questionnaire is to collect information and users' feedback regarding the use of electricity prepaid meters in Kenyan households.

Research Objectives

The research objectives of this research are focused around electricity pre-paid metering and the recharge process of tokens. The process of recharging the tokens is done by keying in the numbers on the inbuilt keypad on the customer interface unit (CIU) and this research seeks to automate this process by substituting the keypad with a GSM module.

Kindly respond to the questions that follow.

i. Are you currently facing any challenges with the current pre-paid metering set up?

   Yes No ✓

ii. Do you find the current method of topping up units/tokens inconvenient?

   Yes ✓ No

iii. Would the ability to load tokens remotely make the process easier or more efficient?

   Yes ✓ No

Name: Stephen Macharia

Phone Number 0720933457