UNIVERSITY of RWANDA

College of Science and Technology

ACE-ESD AFRICAN CENTER OF EXCELLENCE IN ENERGY FOR SUSTAINABLE DEVELOPMENT

DESIGN AND IMPLEMENTATION OF ARDUINO BASED BUILDING ENERGY MANAGEMENT METER WITH GSM PLATFORM

ACEESD/REE/20/13

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A dissertation submitted to the African Center of Excellence in Energy for Sustainable development

College of Science and Technology

University of Rwanda in partial fulfillment of the requirements for the degree of

MASTERS OF SCIENCE IN RENEWABLE ENERGY

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October, 2020

Declaration

I, NIYODUSENGA Jean Marie Vianney, declare that this thesis is my original work, and has not been presented for a degree in University of Rwanda or any other universities. All sources of materials used for the thesis work have been fully acknowledged.

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Date of Submission:

This thesis has been submitted for examination with my approval as a university supervisor.

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Thesis Supervisor Signature

ACKNOWLEDGEMENTS

My utmost thanks go to God for protecting me through the whole program magnificently.

The exceptional thanks goes to my supervisor, Prof. Dr. Eng. NTAGWIRUMUGARA Etienne despite of his a lot of work, he directed my work and gave me a guiding hand.

The special thanks goes to World Bank through University of Rwanda; College of Science and Technology /African Center of Excellence in Energy for Sustainable Development for the support provided that helped me to complete successfully my studies.

I cannot forget to thank the ACE-ESD teams: Director of the center, head of studies, professor lectures who helped me to boost up my knowledge.

I would like to thank my wife UWIBAMBE Valentine for her valuable encouragements and her supports she always gives to me; the blessings of God be upon her.

Finally, I wish to acknowledge and thank my parents for their uncountable supports in diverse ways in my education; God richly bless you all.

Abstract

There is high demand for electrical energy since electrical energy is very essential in both industrial and domestic events, and that has request for the introduction of diverse energy meters by various electricity companies. The need for energy at high request requires some disciplines in order to use it efficiently. One of the disciplines is building electrical energy management where house tenants exercise to use least consuming loads and switching off unnecessary load. On the side of electricity providers, energy meters were introduced to manage electricity consumed by customers. In Rwanda, families living in big and compound houses desire to have isolated energy meters from other tenants. This is because the individual's cannot monitor and control the energy consumption of each individual, and that gets miscalculation in energy bill sharing which also brings conflicts between tenants one accusing others to misuse energy. When happens to landlord to have supplementary energy meter from utility companies, having about ten or more energy meters, the former causing overcrowding of energy meters on the wall of a building which makes the wall loses its attractiveness and there is a probability of fire occurrence in the house because of the wires are not well arranged also, requesting a supplementary energy meter from Utility companies charged you more compared to the previous one. Furthermore, energy companies want enormous sum of money and labors to produce more energy meters and this can cause monetary loss to the energy companies. This has consequently called for the introduction of Arduino based building energy management with GSM platform which will improve the monitoring and satisfactory sharing of energy purchased by the household based on the amount paid by each of the users of the meter. The AT mega 2560 Microcontroller was used as per the brain of the project. The amount paid in money will be handled to the house owner or landlord. The former, using a cell phone, he or she will send an SMS via GSM. If, the received SMS is Valid it activates the Arduino mega 2560 where calculations of energy bought is done. The respective relays will activates the matching building's loads. Upon consumption, if the energy paid for is depleted, the system isolates the equivalent consumers. Arduino based building energy management with GSM platform has four relays allocated to each energy user to ensure isolation and re-energizing the user if necessary. The proposed system is able to calculate and isolate 4 houses at once. As the current energy meter doesn't have any option of controlling at least 2 consumptions, the Arduino based building energy management meter with GSM platform introduced to cover the above gap.

List of Acronyms

AC	Alternating Current
ADC	Analogue to Digital Converter
ADO	Advanced distribution operation
AMI	Advance metering infrastructure
AMR,	Adaptive Multi-Rate
ASIC,	Application-Specific Integrated Circuit
ATM	Automatic teller machine
ATO	Advanced transmission operation
AVR	Advanced Virtual RISC
BAS	Building automation system
BEMS	building energy management system
CEC,	Conference on Electronics, Communications and Control
CMU	communication unit
CO2	Carbon Dioxide
CS	Current Sensor
DC	Direct Current
EADM	*Electromechanical add-on digital meter*
EARP	Electricity Access Rollout Program
EDCL	Energy Development coperation Limited
EEI	Edison Electrical Institute
EEM	Electronic energy meter
EEPROM	electrically erasable programmable read-only memory
EMF	electromagnetic force
EMIC	energy metering integrated circuit
EMR	Energy Management Records
EMS	Energy Management System
EPROM	Erasable Programmable Ready Only Memory
ERT	Electronic Receiver Transmitter
FRW	Francs Rwanda

GDP	Gross Domestic Product
GHG	Green House Gases
GND	**Ground**
GPRS	General Packet Radio Services
GSM	Global System for Mobile Communications
HEM	Home Energy Management
HLAN	Home local area networks
HV	High Voltage
ICT	Intelligent Communication Technology
IDE	Integrated Development Environment
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
JMV	Jean Marie Vianney
KB	Kilo bite
KW	Kilo watt
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LPRF	Low Power Radio Frequency
LSC	Level Shifter Circuits
MCU	Micro-Controller Unit
MDM	Meter Data Management
MDMS	Meter Data Management System
NISR	National Institute of Statistics Rwanda
PF	Power Factor
PLC	Power Line Carrier
PS	Power Supply
PV	Photo Voltaic
PWM	Power Width Modulation
RDB	Rwanda Development Board
REG,	Rwanda Energy Group
RF	Radio frequency

RFID	Radio-frequency identification
RISC	Reduced instruction set computer
RTC	real-time clock
RWF	Rwandan Francs
SCADA,	Supervisory control and data acquisition
SEEM	static electronic energy meter
SIM	Subscriber Identity Module
SMS	short message service
SOC	system on chip
SRAM	Static random access memory
STS	standard transfer specification
WAN	wide area network
WAP	wireless application protocol

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1. Introduction

1.1.General Introduction

Most of the world's electric energy is produced in control plants from burning fossil fuels, which are constrained in accessibility and have unfavorable natural impacts [1] . Ongoing examination shows that if the utilization rate remains steady, the world hold for petroleum derivatives will keep going for as it were 50-60 years [2]. Moreover, the United Nations Sustainable Development and Paris Climate Understanding have set objectives to reduce the emanations to the environment [3], [4]. Also, the energy customers these days request more reliable and fetched successful energy, which isn't conceivable to achieve using manual framework control alternatives [5] Energy management can be performed in a small scale isolated micro grid or in a grid connected power distribution system as well as in residential building [6]. It has been an interesting research area in the past decades, to the extent that several papers have been published on different energy management options in distribution systems. The researchers have interest on the energy management subject thanks to many reasons, that include: a) loss reduction within the transmission/distribution systems by the transmission/utility firms to lower the operational prices that obliquely helps the shoppers pay fewer electricity bills; b) price reduction by directly dominant and observation the energy resources or the manageable masses, which can lead to adjusting the time of generation and consumption by completely different units and consequently scale back the generation costs; c) reducing GHG emissions that impacts the society by utility firms. Energy management in distribution systems plays a big role in system operation and management and makes the facility system operation additional economical by observation, dominant, and protective energy. It additionally helps to produce power to the shoppers of important load within the event of Associate in treatment outage within the power lines, within the primary station or throughout regular interruptions [5].

In today's world electricity has become an indispensable part of our everyday life. It is a major driving factor for advances in technology, home appliances and industry operations. The power used by the households, passes through various channels like production, transmission and distribution .However only the above stated channels are not enough to get an efficient and effective energy source. Some other factors like electricity energy management at every process are critical to a successful and sustainable energy. At production side, energy management deals with optimization and efficiency improvement of the power plant, at transmission level, energy management deals with power loss minimization and efficient carrying of energy at long distance finally at distribution level, energy management deals with effective energy sharing, optimal usage and billing process [7]. When reaches to a customer, the latter is given a meter for management and billing purposes. The given meter enables the household to recharge when electricity depletes. The meter is always the property of electricity distributing company; which is an issue for a customer who needs a modification either by taking meter from one point to another depends on uses. The provided meter is always connected to the supply and a customer's house. As the meter has only one output, there is no way a customer can manage electricity from different houses or rooms. A customer cannot share electricity equally into those houses or rooms from of one output provided with a meter. In Rwanda for example, there are some conflicts between the house owners and renters when asked to contribute to the consumed electricity monthly. Some refuse while others contribute. The contributed renters always complain about those who fail to contribute. The house owners always falls in ambiguity thinking how to solve the problem. Many researchers proposed the way a customer can manage the electricity to avoid its wastage by using smart meters.

1.2 Energy consumption impact on the environment

Energy conservation has become the main concern for scientists and researchers because of the overuse of environmental resources. A large amount of energy demand is met globally by using fossil fuels such as gas and coal and this is threatening the environment because of large greenhouse gas emission throughout the world. In [8], Kirby reported that "the world will need almost 60% more energy in 2030 than in 2002, and fossil fuels will still meet most of its needs" In fact, using fossil fuels will bring a negative impact to the environments by increasing carbon dioxide and methane; carbon dioxide emission is considered as the main cause of global warming [9] The highest percentage of greenhouse gas emissions is contributed by carbon dioxide emissions [10]. Human activities are considered as being the main source of increasing carbon dioxide emissions in modern societies. Using heaters at home, cooking, and using lights; all these activities rely on energy which makes it one of the causes of carbon dioxide emissions because power stations are run using oil and burning coal. Another cause of carbon dioxide emissions is the industrial sector fig. 1 [11]. In adding, 41% of all CO_2 emissions are produced by producing electricity in the United States [12].

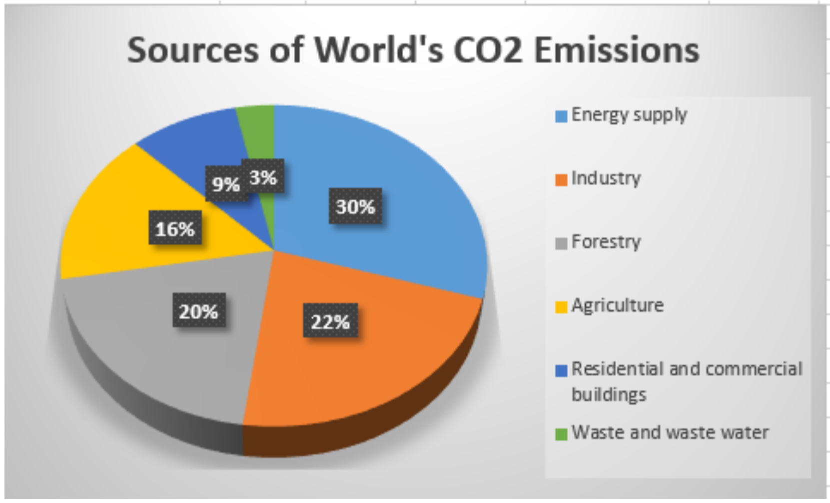

Figure 1.1 Sources of world's CO2 emissions [12]

1.3 Background of energy outline in Rwanda

1.3.1. Background

Many authors have indicated that African country is blessed by the god's energy assets, as sunlight based, biomass, hydro, and alkane gas and energy since it was referenced in [13] . Unfortunately, the vast majority of those assets remain unexploited whenever they categorically were supposed in this resources for power generation count about 1,200 MW of energy sources which are not yet been exploited. [14], [15]. This was due to the fact that wood continues to be the primary source of energy where 90% of the population use biomass for their daily life together with petroleum energy [14]. To increase the growth of the country, Rwanda has increased the productivity of electricity, however currently, only 2% of all generated energy were utilized. In opposing, energy from biomass grew up to 85% of all energy utilized. The testimony in [14] indicates that 13% of the country's most energy consumption is from petroleum. Taking account on the image of using energy, it was indicated that residential houses are the most energy consumers that count about 82%, where primarily traditional fuels like wood come on the first place.. Transportation comes on the second place with 8%, the industry with 6% and last is the public services that count about (4%) [16].

1.3.2. Electricity in Rwanda

1.3.2.1. Power production standings in Rwanda

From the report published in July 2018 in [14] the current Rwanda energy capacity stands at 218 MW where 221.5 Mw are produced within the country and 5.5 Mw from neighboring countries. The hydropower occupies 45% of all generated capacitor, thermal generators count 27%, methane gas 14%, peat 7% and solar 6%. The figure 1.2 shows the electrical power production from 2010 to 2018 whereas the figure 1.3 shows the sources of electricity currently we have in Rwanda,

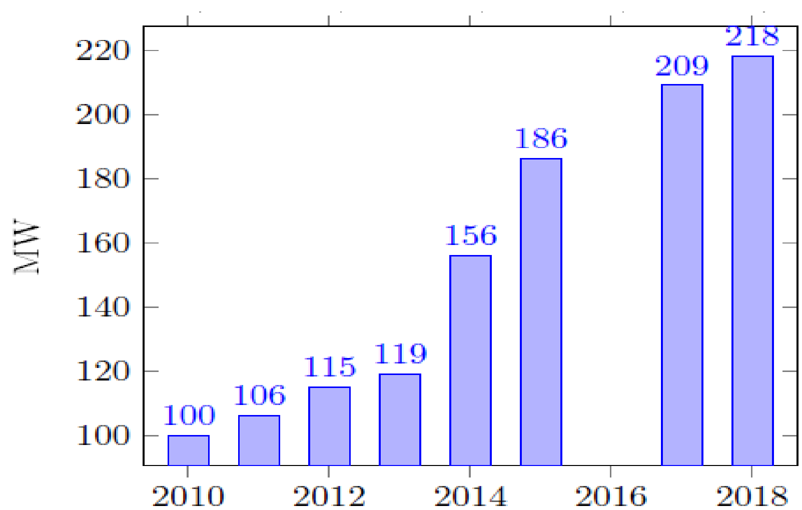

Figure 1.2 Evolution of electrical power production in Rwanda [14]

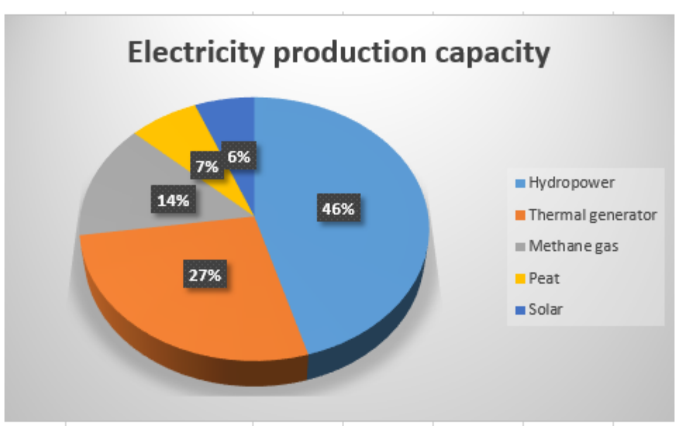

Figure 1.3 Source of electricity and their respective capacity

1.3.2.2. Transportation of electricity

As shown in [17] the unbelievable efforts has been made in installing new electrical transmission lines where only 371.4 km were constructed in 2007 increased to 744 km of high voltage transmission line in 2017. The figure 1.4 shows how electrical transmission lines were increased from 2007 to 2017.

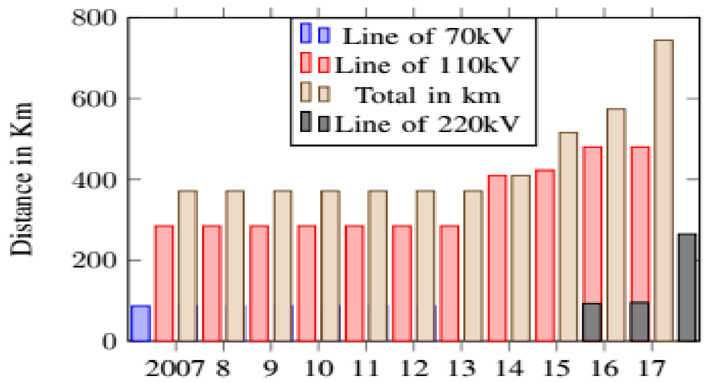

Figure 1.4 Evolution of Power Transmission Line since 2007 [17]

The connection is made of different lines that bring power from various production plants all over the nation the same as creating area interconnectivity. From 2017, Rwanda has a mixture of transmission lines where 110 kV crosses to 470.5 km while 220 kV crosses 273.5 km.

1.3.2.3. Electrical distribution network

Electrical distribution network is mainly composed by Hubs, substations and antenna. From 2010, about 16,162 km of distribution lines were built all over the country with the objective of nearing the generated capacity to the consumers. Among the built kilometers of distribution lines 5.590 km which count 35% of all distribution lines is Medium Voltage while the remaining kilometers which is 10,572 that counts 65% is low voltage transmission lines [17]. 30kV, 15kV, 17.32 kilovolt and 5.5 kilovolts lines are all Medium voltage that cross all over the country transporting electricity. Rwanda is planning to have access to electricity for all Rwandans by 2024 where 1016 Mw will have been generated. The customers are connected to low voltage of 400 V three phase system and 220 V single phase system. Actually, low voltage lines occupy 10, 575 km and the access is 34% of Rwanda residential households [17]. The figure 1.5 shows the image of electrical distribution in Rwanda.

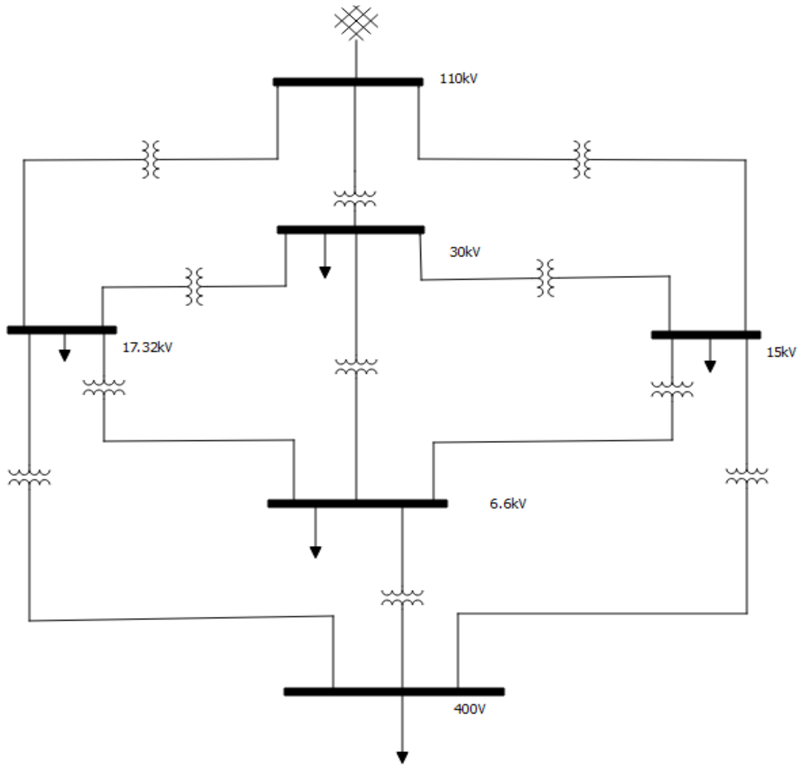

Figure 1.5: Distribution lines disposition in Rwanda [17].

1.3.2.4. Industries, households and public electricity connection status

The figure 1.6 shows the tremendous growth of electricity connectivity in Rwanda [17]. From 2006, the connectivity has been increased by 18% leaving from 77,881 to 1.384.958 connections by 2018. This achieved by the help of both On Grid and off grid [17]. On grid electricity consumption is split into households with 51% used as lighting, industrial sector that counts 42% purposively used for induction motor driving. The last is public sector that counts only 7% mainly used for street lighting, main halls and different arenas as shown from the figure 1.7 Off-grid energy access is another source which cannot be forgotten. The electricity from Off grid is mainly called solar. The access to the energy from solar still lack customers because is new technology and even is very expensive. In Rwanda, only 300,000 families were connected by the end of June 2018.which means that the growth has been made from 0 to 11% [14].

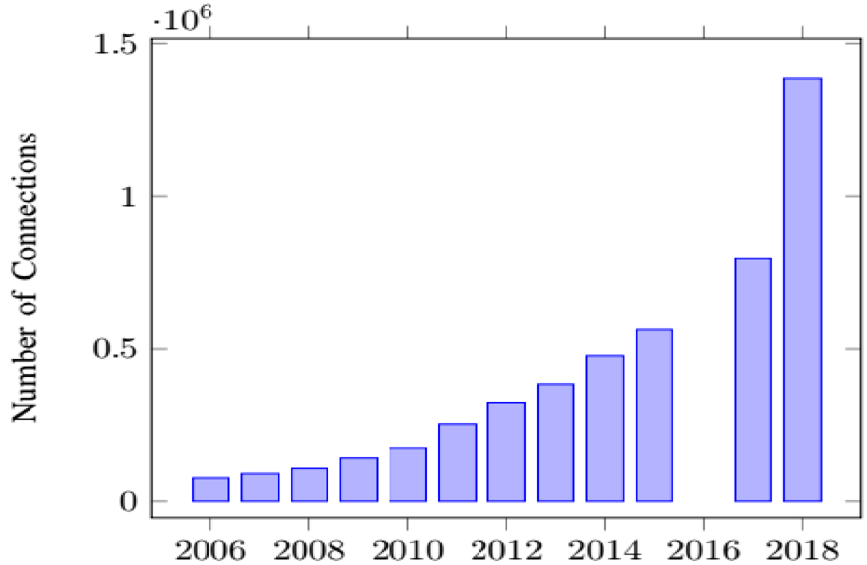

Figure 1.6: Growing of number of connections from 2006 to 2018 [14]

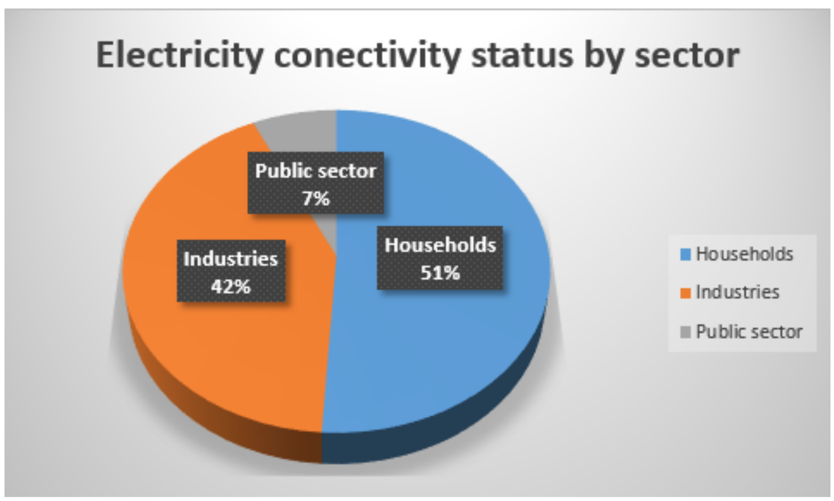

Figure 1.7 On grid electricity status by sector

1.3.2.5.Energy wastage in Rwanda transmission network

In Rwanda, losses in transmission and distribution was stand at 22% in June 2017. The losses are higher compared to international admissible allowable losses which are between 6% and 8%. 17% are due practical losses whereas 5% are due to commercial losses. If compare losses in energy, 128 GWh has been lost. Financially, 6% of losses would bring an income of $28 million [14].

1.4. Energy demand

Energy demand is one of the main problems which have become a global issue. Rye (2009) stated that energy will be of one of the top ten problems facing people in the next five decades [18]. In [19] the author predicted the increase in the energy demand between 2010 and 2040, globally, would be 30 he also stated that the large demand for energy comes from residential and industrial sectors and specifically in electricity. Electricity is considered to be the quicker energy source that is increased annually among developed countries owing to growth in population and rise in industrial sectors [20]. In [21] he stated that "Electricity demand growth is strongest in developing countries, where demand will climb by over 4% per year over the projection period, more than tripling by 2030". In general, most of the countries will face an increase in the population throughout 2040 and this rise will differ from one country to another. The main growth is expected to happen in India and China. In [19], the author indicated that "every region will see a net increase in households through 2040, but growth will be particularly strong in Africa, China, India and Latin America". This growth will result in more requirements for energy specifically in two sectors: residential and commercial.

The continuous growth in the number of households will play an essential role in increasing energy demand. In 2006, the largest power consumers of Rwanda energy were households, consuming 51 percent distributed between petrol and electricity [22].

However, the demand for energy in Rwanda has been abnormal compared to other countries of East Africa Community in the last few years [22]. The energy demand in [22] indicates that the annual energy consumption by 2050 will turn around to 10,450 GWh compared 380 GWh in 2012 [22].

Figure1. 6 below details the information about the total annual electricity generation, consumption, import and export and peak demand in Rwanda from 2001 to 2013

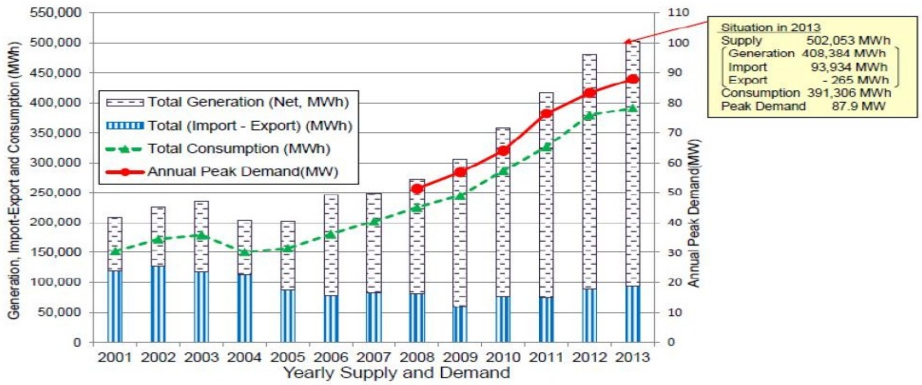

Figure 1.8 Electricity production, consumption and peak demand in Rwanda [23]

1.4.1. Power demand examination

This examination of the power utilization is accomplished subsequent to gathering the force interest into two areas which are the private and non-private where private area is isolated into family units while the non-private area involves together the horticultural, the modern, and the administration areas. To assess the force interest in future, the force utilization per house in base year and the extended populace by and large with the GDP are the elements that are required.

The normal force utilization per an electric family unit for the base year (2012) is assessed utilizing the Eq.(1)where EAv speaks to the normal yearly power utilization of an electric family (in kWh), Pi is the appraised intensity of apparatus in a house i (in kW), ni is the normal number of machine i per family unit, hi is the use season of machine i (hour/day), and 365 is the quantity of days in a year. The information utilized in Eq. (1) were recovered from the Fourth Population and Lodging Census, and from the Economic Data Collection and Demand Forecast [24].

$$E_{Av} = 365 \times \sum_{i=1}^{n} P_i \times n_i \times h_i \times p_{e,i} \qquad (1)$$

As it is the approach of the Government to accomplish the maintainable advancement objectives, this examination accepted 100% zap to imply that all family units would be associated with the public matrix in 2050. Along these lines, it is just needed to extend the quantity of families that would be there in 2050 and it is assessed dependent on the populace development. To gauge the populace towards 2050, approaches utilized in three existing projection situations for the 2015–2050 periods by the National Institute of Statistics Rwanda (NISR) are received. To assess the development of the force utilization by the non-private area, the previous power utilization and the GDP of this area are picked and afterward the relapse technique for customary least squarest is received to decide their relationship utilizing the Eq.2

$$y = ax + b \tag{2}$$

Where y speaks to the non-private area's energy utilization and x the area's GDP. The slant a and intercept b are resolved utilizing Eq.3 and Eq.4

$$a = \frac{n\times \sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2} \tag{3}$$

$$b = \frac{n\times \sum_{i=1}^{n} {x_i}^2 - \sum_{i=1}^{n} y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} x_i y_i}{\sum_{i=1}^{n} {x_i}^2 - (\sum_{i=1}^{n} x_i)^2} \tag{4}$$

Where xi is the absolute GDP for year i while yi is the force devoured by the non-private area in creating the complete GDP for year i. For the future force interest of this area, three situations for power utilization were created with the assistance of various GDP development rates however for this investigation just the medium situation is thought of. As appeared by the reproduction results, it is assessed that by 2050, the absolute yearly force utilization pivots to 6,745 GWh for the extremely low situation, 8,210 GWh for the presumable situation, and 10,450 GWh for the high situation, contrasted with 380 GWh in 2012.

1.4.2. Electricity price

Correct pricing of energy is important in providing appropriate signals to consumers to encourage efficient and productive use of energy and to ensure that energy suppliers can operate on a sustainable basis, including making investments to expand access to modern energy for the bulk of the population [25]**.** Rwanda energy regulation authority set the price for energy consumption. To facilitate the low income people, the price is minimum compared to high income people. The table below summarizes the prices of energy per kWh refer to the category.

Table 1.1 Electricity price in Rwanda. [26]

Customer	**Consumption Block**	**Tariff VAT Exclusive-FRW/kWh**
Residential customers	≤15 kWh per month	89
	]15-50] kWh per month	212
	> 50 kWh per month	249
Non Residential customers	≤ 100 kWh per month	227
	> 100 kWh per month	255
Telecom towers	All	201
Hotels	All	157
Health Facilities	All	186
Broadcasters	All	192
Small industries ≤ 22,000 kWh/year	All	134
Medium industries]22,000-660,000] kWh/ year	All	103
> 660,000 kWh/year	All	94
Commercial centers	All	179

1.4.3. Energy management smart meters

The replacement of traditional meters by smart meters is an unstoppable process all over the world. This is a hard duty of the utilities but also a great opportunity for the energy traders, distributors and users, too. It is difficult to reach the energy consciousness of the public institutions and the households because of the lack of special energy management knowledge. Also the rare energy data feed-back does not allow the control of consumption. The intelligent meters enable the development of a remote-energy management system that helps the energy user decrease the energy costs and also the amount of the used energy [27]**.** Smart energy meter used in the project will enable users to control and plan for plug in electrical appliances and manage electricity differently from other houses tenancy.

1.5. Problem statement

Rwanda is a country that tries to near electricity to each Rwandan by 2024 (Mininfra). As many people get electricity at their homes, they do many activities that bring money. Among those activities include building many houses for rent.

As they construct many single houses or house in stories, they will need many smart meters depend on number of houses located in a compound. Various individual premises like homes, hostels and other institutions involves more than one sub-users which crops up numerous problems in billing and monitoring of power usage of co-house mates. This has therefore made some of these environments less user friendly for many individuals who share energy meters with others. Some of these problems are consequently elaborated hereunder;

1.5.1. Problems in energy bills sharing by occupants in a house.

People find it challenging in how to share bills among users of energy meters in a house or areas. Different techniques and methods have been adopted in the sharing of bills. Some go through the process of checking each user's appliance and compute the bill base on how their power is rated and the devices or equipment used. This brings questions since it becomes difficult in checking whether the appliance was used or not. Others adopt a strategy of sharing on percentage base. Individuals identified with more gadgets are therefore given more bills.

1.5.2. Difficulty in monitoring power usage of tenants.

The day-to-day usage of the energy by individual sub-consumers in a premises is difficult to be tracked by co-tenants and this sometimes can create a room for secrete usage of loads whose usage cannot be monitored and billed. The visual way of inspecting individual electrical loads for sharing of bills is one way adopted for decades ago but because some individuals are not honest the real consumption exceeds the documented one since other loads are used without being captured on the shared data. To diversify the usage of energy in various premises among sub-users is therefore a great field of interest to the electrical engineer and other technicians as a whole.

1.5.3. Cost of providing extra energy meters

Applications for extra energy meters at the utility company by individual consumers has an aspect of demerits since it calls for extra order of new energy meter and attracts extra change on installations and other operations like documentary and control. As a governmental agency the ministry of energy is therefore a sector that requires not to contribute much into financial loss to the state. This has therefore been captured as one of the principal key point to our problems statement in this piece of work.

1.5.4. Threat to environmental beauty

The last but not the smallest, all engineering products are expected to provide a high level of good-looking. This serves as a primary key to customer satisfaction in terms of sales and services. In reference to the local situations concerning the provision of multiple meters for separate consumers, the beauty of walls are affected since a number of metes are installed at the same point on the wall..

1.6. Objectives

1.6.1. Main objectives

The main objective of this research is to find a solution to the above listed problems. The research work will help eradicate the problems associated with the usage of multiple meters in households and other premises by introduction of **Arduino based building energy management meter with GSM platform** which will act as energy manager as well**.** It shall involve the introduction of an electronic security system that may monitor and control the consumption of individual's sub-users. This piece of work is therefore required to be able to isolate a user from the mains if he/she does not meet the right validation of the embedded system. As the consumer uses the power, the microcontroller reduces the power allocated to the consumer till his or her power gets finished.

1.6.2. Specific objectives

- ✓ To design a system that helps to share electricity unequally within apartment or different houses.

- ✓ Design a system that enables cell phone to recharge electricity when one user ends up his or her share remotely.
- ✓ The price of energy meter will be reduced at 75% compared to the existing meter.
- ✓ Reduce conflict between landlords and house renters.

1.7. Scope of the study

1.7.1. Intended users

The system will be used by anyone who possesses residential or commercial buildings. This is a countdown meter where the consumption is monitored every two seconds and deducts the consumed amount from the pre-purchased maximum usable amount if the pre-purchased energy balance reaches at zero, the user is out of power and the meter cut the power from the house until the landlord recharges it again.it is a user centered platform where a landlord has full privilege to manage all other users. The system isn't intended to replace the current master energy meter (cash power) but act as a slave supplementary energy meter to satisfy co-housing responsible energy sharing needs. The following are the pre-featured specifications:

- ✓ Manage and controls only four houses at time.
- ✓ Recharging is only made by landlord who sends a recharging sms containing a valid set of codes to the meter by the use of cell phone.
- ✓ Specific land load phone number should be pre-recorded into a system.

1.7.2. System limits

This work is restricted to solving problems such as monitoring energy usage, control switching and providing security to houses based on energy consumption. Besides, the work concentrates on a central switch which monitors and control power usage by individuals. The following are the system ratings:

- ✓ A Single phase distribution lines
- ✓ Maximum voltage rate: 250v
- ✓ Minimum voltage rate: 180v
- ✓ Operating voltage rate: 200-230v
- ✓ Fusing rate: 30A per port
- ✓ Maximum tolerable temperature: < 80 ^{0}C

- ✓ Operating frequency: 50- 60 Hz
- ✓

1.8. Expected outcome

The expected outcome from the project is a prototype that will have 4 out puts of power programmed so that to enable a landlord to recharge electricity refers to the ability of house renters.

1.9. Significance of the study

- ✓ It will unify the people because the conflicts will be the story.
- ✓ It will provide job ; during installation, job will be provided
- ✓ It will provide taxes to country when goes to the market

1.10. Methods Used

The methods used to achieve this work is through both hardware and software implementation at desired stages in the design process. I also considered the management of energy used in building. The work employs the prototyping method of project design to complete it. It also calls for the programming of a microcontroller based embedded system that monitors the usage of power and also provide a set of control commands for isolation when the entitled power is completely consumed. The general architecture of the setup consists of two main parts to be interacted for the full functionality. The system is mounted between the main utility energy meter and the loads of the individual consumers. The system monitors all individual loads connected through the utility energy meter, and upon reading the power consumption at all instances, the consumption can be quantified to take further decisions. The idea is of the project is shown in figure below

The Arduino based building energy management smart meter with GSM has 4 ports of connection to the occupants of the household. It acts as an interface between the household wiring or users lines and the energy meter. It controls and takes care of the power exchange between the energy meter, utility and energy consumption in the household devices.

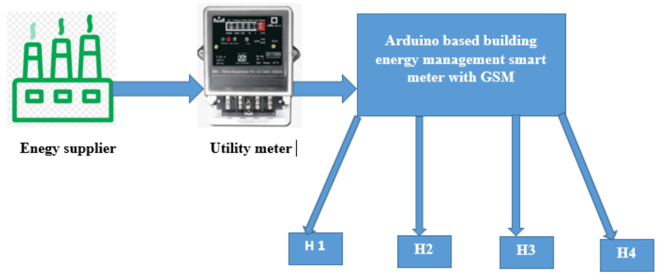

Figure 1.9. Block diagram showing the idea of the project

1.11. Thesis Organization

The thesis is organized as follow:

Chapter one talks on introduction, background of the study, problem statement, objectives, significance of the study, scope of the study and methods used to achieve the objectives.

Chapter two talks about energy management in buildings, technical evolution of electricity meters and their types, related works and summary of the reviewed related work to identify the gap.

Chapter three talks about methodologies used to come up with a prototype, those methodologies we can say primary data collection, secondary data collection, tools used and experimental method used.

Chapter four talks about design and implantation procedures: DC power supply design, current sensing and GSM, Arduino mega selection criteria.

Chapter five talks about result and discussions: current energy meter vs Arduino based building energy management meter with GSM platform are discussed in this chapter. Results from simulation also are presented.

Chapter six talks about conclusion and recommendation.

2. LITERATURE REVIEW

2.3. INTRODUCTION

Buildings are important contributors to energy consumption accounting for around one-third of energy consumed in cities, where large public buildings are the dominant energy consumers [28]. Consequently, building energy management system (BEMS) are often outlined as a system with combination of each intelligent and inexperienced building technology. Previous literature has already bestowed a group of technical options of a BEMS. Building energy management is initially to reduce loss of energy in buildings in developed countries. Currently unremarkably spoken 'improving the energy potency of buildings', rational use of energy, improves energy potency in making certain the conditions of building comfort. Building energy management specifically refers to that In the building planning, design, construction (reconstruction and expansion), the process of transformation and using, doing implementation of energy efficiency standards, using energy-saving technology, technique, equipment, materials and products, improving the performance of thermal insulation and heating, air conditioning refrigeration and heating system efficiency, strengthening the operation and management of energy systems, using renewable energy, In ensuring the quality of the indoor thermal environment, reducing energy consumption of heat, air conditioning and heating, lighting, hot water supply [29] To achieve the energy management goals, microcontroller collects all information regarding energy consumption and inform the house tenancy the status of energy used via SMS using GSM. Each house is implemented as a task in a priority list based on predefined user instructions. Each task can be either interruptible or non-interruptible according to the nature of the appliance that it represents. The task execution is automatically done based on whether a tenant used power or not. The microcontroller transmits the commands and receives acknowledgements to and from the appliances in the house wirelessly.

2.2. Energy management in Building

2.2.1. Evolution of building energy management techniques

Literature defines the evolution of HEMS from 1979 to 2017 as follows. The operation of energy management system was 1st supported a microchip [30]; its performance is improved, significantly with the arrival of PCs within the Eighties. In 1982, associate degree improvement algorithmic program for energy management was developed to cut back electricity price by reducing demand and usage time [31]. A study [32] developed a computerized energy management system that considers operational size, geographical location, and numerous levels of energy management, like the entire variety of applications and therefore the basic, advanced, and total energy management. A previous study [33] conjointly developed a HEM system for residential application employing a home automation communication network. Technologies, such as radio frequency, video technology, and ultrasonic sensors, were applied to track customers and locate missing objects [34]. Associate degree energy controller system was put in to manage the energy input/output of twenty residences in Japan by employing an entranceway for every home [35]. This entranceway provides customers with energy usage data and controls A/C and lights.. Network architecture and power line communication have also been used for an energy management controller using home computers to control and monitor appliances [36]. The appliances connected to the home network are controlled by a compact appliance control interface, which is installed between home appliances and a network adapter. Furthermore, an intelligent algorithm based on game theory was integrated into the energy management scheme [37]. This algorithmic program was developed to trace the activity of one indweller and find the standing of varied occupants among an equivalent surroundings. Results showed that the algorithm can improve the comfort levels of occupants and reduce energy consumption. In 2006, the Whirlpool Corporation Company filed a patent that describes a HEM controller that manages the energy consumption of appliances [38]. This creation delivers associate degree energy management system that may receive plans of on and off-peak time segments. Associate degree economical HEMS exploitation infrared remote (IR) controls was developed to manage the lighting and power sockets during an area [39]. Even so, the performance of IR management is restricted as a result of it cannot cowl the whole distances between shops and a central controller. Advancement in HEMS began in 2012, when an intelligent HEMS with DR was developed to reduce energy consumption and electricity cost [40]. During this work, four home appliances, namely, A/C, tank, electrical vehicle, and dress drier, were controlled on the premise of priorities and luxury levels. A sensible HEM controller supported event-driven binary linear improvement was designed to supply optimum voltage management during a dominion [41]. Alternative works used advanced improvement algorithms for HEM programing and thought of the provision of adequately sized storage system, renewable resources, and electricity worth to cut back the entire energy prices in homes [42]. In addition, a score role supported intelligent HEM algorithmic program was developed to manage elect home appliances throughout a DR event by considering high-to low power, utility signal, and therefore the level of predetermined comfort [42]. Another add Turkey bestowed a completely unique HEMS algorithmic program for a sensible home with renewable energy resources [43]. The developed mechanism during this work uses multirate tariff, battery state of charge level, shops through ZigBee, and renewable energy sources to schedule home appliances and scale back worth tariffs. Renewable energy sources lead to reduced electricity prices and energy demands. An adaptable smart HEMS was proposed to schedule home appliances by accounting for the relationship between the energy usage pattern and energy capacity of the network [44]. The system conjointly considers numerous dynamic variables that embrace atmospheric condition, electricity tariff worth, time of the day, and appliance standing.

Several studies have thought-about the implementation of good HEMS exploitation period energy management approach to schedule home appliances. The DR tool permits appliances to contribute in period energy management by adopting battery charging and PV system [45]. A fuzzy controller is utilized to determine the charging/discharging power of the battery, and rolling optimization is used to schedule energy consumption during off-peak periods. In a previous work [46], a HEMS system was implemented by managing household energy without affecting customer's preference settings. Associate degree intelligent energy management system, that uses associate degree intelligent search table supported formal logic and neural network, was conjointly developed [47]. External sensors, environmental conditions, battery storage, prices, and client behavior were elect as input to the system. The associative neural network was wont to confirm the optimum energy potency, that helps minimize energy consumption. A framework for HEMS was developed exploitation a man-made bee colony because the improvement algorithmic program to enhance the system by programing home appliances at a low-cost amount [48]. Associate degree economical core algorithmic program for HEMS that controls A/Cs and water heaters therefore on scale back the entire energy consumption of appliances is additionally bestowed in another study [49]

Several corporations have designed intelligent HEMS to manage energy consumption. For instance, General electrical Co. designed a system that controls home appliances exploitation smartphones. The system offers a robust support to customers by dominant and observance devices with a smartphone app [50]. Moreover, Honda America has enforced a computer code and hardware system that controls, monitors, and optimizes electrical generation and appliance usage reception [51]. This home automation system uses solar PV and batteries to store energy that can be used during peak hours.

2.3. Technical evolution of electricity meter

The primary obvious of power meter was presented in 1870, and the gadget was made of a gas meter but not vigorous, and it needed exact metering. Thomas Alva Edison created the primary coordinate current (DC) meter, which was recorded as ampere-hour meter within the 1881. The gadget was sent into Modern York City as watt hour meter. Reechniewoki and Meylan (1886) , as detailed by [52], builts watt-hour meter for measuring DC and AC (substitute current) circuit 1886. Amid this period, AC was built for private and mechanical purposes, whereas DC was outlined as electrochemical meter known as reason Meter whose particular application electrolytic cell for summing-up the chemical utilization [53]. Within the 1889, Elihu Thompson created a measuring meter that permitted both AC and DC to work together. Essentially, Oliver B. Shallenberger built a watt-hour meter, an overhauled form of an ampere-hour meter. In spite of these innovations, meters energy utilization request is reported for private utilize in Kwh and for mechanical utilize in Kvar and Kva. In any case, as it were two fundamental sorts of meter innovation are manufactured and made accessible within the market, which are

the acceptance electromechanical meter and the electronic meter [52]. The electronic meter has digital meter, upgraded mechanical meter, remote read meters, and pre-pay. Besides, [52] clarified that utilities and fabricating companies came along
side the thought of planning different energy meters to fulfill customers' needs. In [54] the author said that smart meter possesses numerous functions to accomplish the end-user loads, and to reduce the electricity bill along with the energy conservation.

2.4. Traditional meters for electricity

[55] Described the traditional electrical meter as a device where reading done manually. During operation, the meter readers carried out a monthly collection of energy data to deter data accumulation. This type meter has an aluminium disc plate that displayed the basic operation process. There are four types of meter classified under the traditional meters, such meters as single-phase induction meter, DC watt hour meter, motor meter, and electrolytic meter [55].

2.4.1. Single-phase induction meter

In the process of selecting a suitable energy current for households, AC was selected over DC because it was discovered that DC is none changing current, which makes it difficult to be considered [52]. Afterwards, it was problematic to measure the available AC energy in the current supply to the households. This problem led to the development of an energy meter to address the problem [56]. In view of this, the rotating field in the AC meter is generated alternating ampere-hour meter. However, the meter lacked voltage element that accounts for the power factor in the system. This disapproves the suitability of the meter for commercial and household uses. The induction meter, as presented in Figure 8, replaced the alternating ampere-meter. This device is a metallic-like rotating disc controlled by two magnetic fields in phase against each other, which was fixed on a wood plate [56].

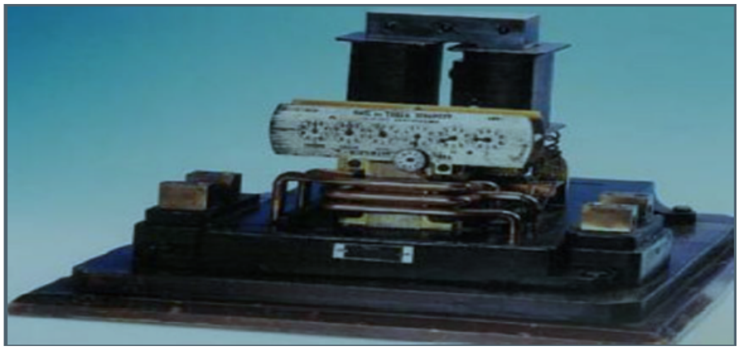

Figure 2.1 Induction meter [56]

2.4.2. DC watt hour meter

This model meter is usually used for significant current circuit wherever the temperature constant is at its peak. Also, for indication functions, a separate time switch is employed.

2.4.3. Motor meter

This is a meter developed with **the employment** of motor.. This meter has a load with a driving torque and braking torque. The driving torque is directly proportional to the load, while the braking torque helps to control the speed of the rotor in the system. This happens only when the torque is in the same state. Elihu Thompson, an American inventor, who came into limelight 1853-1937 developed an iron-less motor as a meter [52]. The meter has the stator and rotor parts. Both the stator and rotor is energised either by voltage or current via a Commutator [56]. This process propagates a driving force which is proportional to the product of the energised voltage and current. There is also an aluminium disc which is attached to the rotor, and a permanent magnet acts upon this disc to initiate counting through the help of the generated torque [57]. Although, this approach is specific for DC only. In that case, commutator poses a great disadvantage in achieving an accurate result.

2.4.4. Electrolytic meter

Between 1841-1931, Thomas Alva Edison was the first to develop an electrolytic meter for distribution systems designed for DC [58]. The electrolytic cell has a coiled copper placed at the beginning of every billing period [56]. The meter operates in a way that electric current is allowed to pass through the electrolyte with a quantity of copper deposited at the end of the billing process [59]. Furthermore, the copper is coiled with different amount of electricity consumed. The meter is measured in cubic feet, and the disadvantage of using this meter is load congestions between the utility and consumers [56]. The operational illustration of the meter is demonstrated in Figure 9.

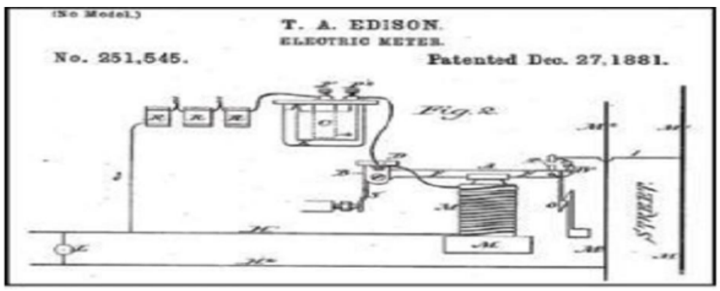

Figure 2.2 Edison electrolyte meter [56]

2.5. Electromechanical energy meter operational principles

Electromechanical meter is based on Ferrari's principle [60]. In 1885, Galileo Ferrari discovered that when a solid disc is introduced within a magnetic field, then the disc rotates in proportional to the flow of the electrical energy in the coils as generated by AC phase Sharma & Mohan Saini & [61]. This operation is based on the principle of electromechanical energy meters. Whenever the **coil** rotates **within the magnetic flux**, a counter is initiated to **notice the amount** of revolutions per disc [62].Figure 10 below [3] shows a clear picture of the electromechanical induction meter.

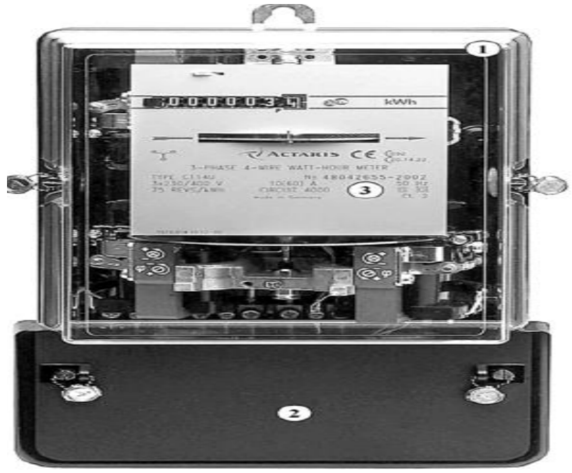

Figure 2.3 Electromechanical energy meter external part [62]

Electromechanical induction meter comprises of 10 components as numerically indicated in the Figure 10 and Figure 11 below.

- Base meter compartment
- Terminal connection and cover
- Display board
- Stator
- Voltage circuit
- Current circuit
- Rotor disk
- Magnetic brake rotor
- Pivot and spindle connected to the register
- Calibration elements

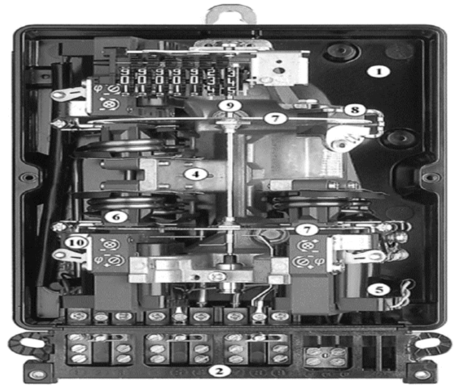

Figure 2.4 electromechanical energy meter internal build-up [52])

The energy meter is designed in association with four salient systems, which are:

- Driving system - it has two electromagnets.
- Moving system - it is composed of an aluminium disc.
- Breaking system - a permanent magnet is attached as a breaking device.
- Registering system - both gear train and counter make up this system [54].

Measurement composition for energy meters is basically composed of the two circuits highlighted below.

1. Voltage circuit.
2. Current circuit.

The voltage circuit: - this circuit **is created of** a coil connected to **the most offer** circuit. Current reference is **existent** through current flowing **at intervals this.**

The voltage coil receives the voltage reference from the line, while the current reference is acquired from the current flowing within the current coil [54]. Hence, this makes the meter performs similarly to the induction engine [52]. During this process, the voltage across the voltage coil generates an electromagnetic field proportional to the amount of voltage supplied and the current that flows through the meter. The aluminium disc is positioned on the rigid axis. The **magnetic attraction** exerted on the disc generates **associate degree** eddy current to power or rotate the **metallic element** disc [63]. The operation includes rotation of the pivot and the spindle, which power the gears in proportion to energy consumption. The speediness of the disc is recorded by the counter. The register display is composed of sub counters, with corresponding number of digits.

More so, an opposite force is produced by the magnetic brake rotor to control the speed of the disc in relation to the used energy. The base of the meter and its compartment are glued or screwed together. The connection terminal concealments are normally sealed to avoid illegal connections and for the safety purposes. As part of the safety procedures, an identification tag with necessary information is attached to the meter to guide the users or operators about the installation of the meter [52]. The information simply contains the drawing, identity and features needed to comprehend before the installation is executed. Also, other significant processes indicated an alternating flux generated through the current coil proportional to the load phase. On the other hand, the voltage coil conveys the current proportional to the voltage supplied. The flux **isn't** in **section** with the **equipped** voltage, and thereby lag by 900 with **the provision** voltage [52].

2.6. Electronic energy meter (EEM)

In electromechanical meter, energy consumption can be interpreted and documented but existing accumulated information barrier between the consumers and the utility company frustrated and rendered the process ineffective [64]. **Due to** this **impact**, EMR technology was developed **to unravel the matter** for **each** parties [65].This development eradicates the meter reading challenges associated with collection of energy consumption data.

This digital technology is designed to capture and document parameters attributed to the electricity consumption rate, such parameters as power quality, apparent power, reactive power, active power; and other parameters like power factor, frequency, phase voltage, and phase current [54]. The device has a display unit known as the LCD or light emitter display (LED), together with the radio frequency (RF) purposely for data transfer as shown in Figure 12. Although, this picture is only displaying a replica of the EEM. This receiver is a handheld device or radio base network installed in a mobile car for the collection and transfer of energy consumption data, through a wireless means such as ZigBee [64].

Figure 2.5 The electronic energy meter [65])

2.6.1. Electronic energy meter (EEM) operating principle

This form of energy meter has no moving or driving parts compare to the conventional energy meter counterpart. it is preferred to the conventional type because of its ability to operate automatically [66]. The device operates based on the application of electronic receiver transmitter (ERT), which is known as static electronic energy meter (SEEM) [52]. Therefore, this operation is made possible with the installation of application specified integrated circuit (ASIC). This is a built application primarily in embedded system used for the development of EEM [67]. ASIC is mostly installed in other devices such as digital camera, washing machines, automobiles, air conditions, and many other appliances. As part of the components, EEM contains voltage and current transformers that operate as the sensors and analogue circuits [68]. The data received or collected from both transformers are referred to as voltage and current measurements [69]. These measurements are mathematically generated within the analogue digital converter (ADC) existing in the ASIC, and therefore convert the digitalized data generated into average values (mean values).

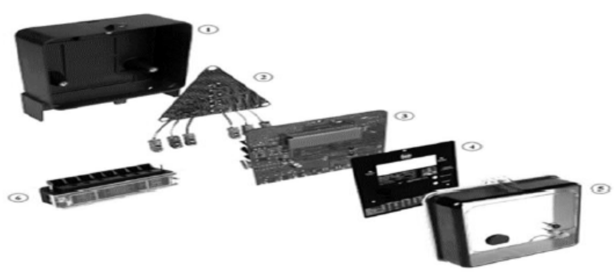

Figure 2.6 the explosive display of electronic energy meter (EEM) components [52]

Average value (mean value) is the measuring unit power [70]. The resulted output is displayed on LED. These pulses equivalent to the average kilo watt hour (Kwh/unit) . **During this** case, ASICs generate pulses **starting from** 800 pulse/Kwh to 3600 pulse/Kwh. Most of the EEMs installed by the Kerala State Electricity Board (KSEB) have pulses ranging from 3200 pulse/Kwh, which drives the stepper motor that indicates on LED through the rotation of digitals embossed wheels. The most common ASIC company deal in the manufacturing of analogy device where ADE7757 and ADE7755 are largely used in the design and implementation of EEMs. The energy meter can be classified into two phases, which are single and polyphase. The explosive display of the components that constituted the electronic energy meter is presented in the Figure 2.6 above.

The explosive display of the components is numerically indicated as follows:

1. Base compartment.
2. Acquisition and measurement board.
3. Computational circuit board.
4. Display board.
5. Main concealment.
6. Terminal connectors and cover.

However, EEMs can also be likened to electromechanical add-on digital meters (EADMs)

2.7. Electromechanical add-on digital meter (EADM)

EADM **is meant** with **the mixing** of electronic add-on module with **mechanical device** mechanism **within** the meter box (see Figure 2.7). The integration of these two processes generate vital information for both consumers and utility company. The production cost of the device is affordable, and commonly found in India. Further study shows that the electronic add-on module was designed particularly to sense the black or red strip existing on the rotation disc, by engaging an infrared (IR) sensor that converts the energy consumption into digital meter readings. The IR **sensing element** IC **can be** OPB706A and LM324 comparator, designed to count **the amount** of turns **created** by the rotor subject to **the number** of energy consumption rate captured by the meter, and displayed through the **alphanumeric display** unit [71].

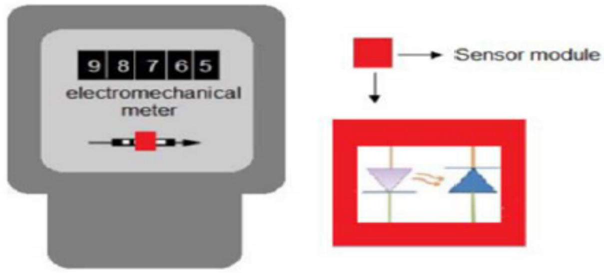

Figure 2.7 electromechanical add-on module [71])

2.8. Types of electronic meters

The electronic meter comes in various forms which are categorized into:

1. Traditional meter,
2. Modular meter, and
3. Pre-pay electricity meter.

2.8.1. Traditional meter

This a type of electronic meter designed with a single module and a seal that gives no room for embedded component upgrade. The seal was added as a protective measure to prevent any form of interfering. For future upgrading, the device undergoes a complete replacement of all the components irrespective of any identified outdated components (see Figure 2.8).

Figure 2.8 Traditional meter [52]

2.8.2. Modular meter

This is a form of energy meter that can be easily upgraded. The design of modular meter aids components upgrades because lifespan of components differs. Among the installed components, only communication technological module and switches are mostly replaced to reduce cost of field operations [52]. The picture of the modular meter displayed in the Figure 2.9 below.

Figure 2.9 Modular meter [52]

2.8.3. Pre-pay electricity meters

Pre-pay electricity meter is developed to relieve the customers from the debt suffered [72]. In addition, the device is perceived as a good veritable tool for low income earners because it assists them in off-setting their outrageous bills and reduces exorbitant use of electricity by consumers [63]. The device is generally adopted by many developing countries in some part of the world such as Africa, Asia, and Latin America. Thus, the process involved entails the purchase of electricity units by consumers from approved vendors or utility company and input the electricity units in the control box of the meter [73].

Concisely, if the electricity units inputted is valid then electric current is supplied into the household. Otherwise, no electric current is supplied to the households while the remaining amount of electricity unit is indicated or displayed in Kwh on the control box of the meter. The display process is demonstrated by three different light blinking stages, which varies from ≥1000 units (green light), and blinks yellow light at 500 to 50 units extending to red light, which blinks at ≤20 units.

Furthermore, it is a system that is branded as “pay-as-you-use” [74]. Compare to post-paid metering, consumers are tasked to monitor the usage of their electricity unit. In that case, the bills are attributed to monthly or periodical reading of the electricity unit from the meter. The depletion of the electricity unit suggests another payment for energy consumption at the end of use [63]. Emphasized that post-paid metering system is used by many African countries to increase revenue. But in some cases, is another means of extorting consumers through skyrocketed bills to be paid. Despite the fact that electricity is never supplied to some regions, however, they are still billed unfairly.

2.9. Classes of pre-payment systems

There are numerous pre-payment technologies employed today that user friendly to the customer. The use of pre-paid meter has aided the customer's ability to stabilize his/her credit generation, credit management, and customer management processes.

2.9.1. Coin meter

Coin meter is found to be used at the end of 19th century in the United Kingdom. Nevertheless, some utility companies around the world still adopt the use of mechanically operated meters (see Figure 2.10). It works by inserting coins in proportion to **the number** of energy **required**.. Furthermore, the coins inserted is collected by the authorised utility agents. Interestingly, similar method is used in some countries as a money collection and saving mechanism.

Figure 2.10 Coin meter [73]

Disadvantages

The disadvantages of adopting coin meter are highlighted below:

- Mechanical fault–which could encourage criminal activities,
- Inability to perform payment control and credit management, and
- Obsolete technology.

2.9.2. Token meter

Token meter is generally used around the world. It is a type of energy payment meter practically developed from the idea of payphone principle (refer to Figure 18). The energy credit is loaded on it as indicated on the meter. It is mostly measured in Kilowatt hours or monetary values. Hence, the energy credit cards could be of two basic forms, which are:

1) Customised energy meter.

2) Non customised energy meter

Figure 2.11 Token meter [73])

2.9.3. Customized energy meter-credit

The customized energy meter-credit operates by using a card writing machine to encode a specific or desired amount of energy credit on a card purchased at any pay point location.

2.9.4. Non-customized energy meter-credit

This type of energy meter-credit does not operate based on the use of a card writing machine to encode energy credit on a card, but it does operate only when the card writing machine is programmed with energy credit that will be inserted in the meter.

2.9.5. Advantages

The advantages of adopting both the customised and non-customised energy meter-credit are highlighted below:

- Access to the purchase of customised credit card at authorised dealers' shops such places as gas station, supermarket, etc.
- Emergency credit availability.
- Affordable costs despite the cost implication of procuring disposable cards.

These types of energy meter-credit systems are predominantly used in countries like South Africa, United Kingdom and Australia. There is a specific system used in generating these tokens or credits. This system is called standard transfer specification (STS) or international electrotechnical commission (IEC) and produced largely by many manufacturers of meter.

2.9.6. Smart card meter

The development of smart card meters was through the feasibility study performed on the token meters. It operates very similar to the token but particularly designed for specific type of meters (refer to Figure 2.19 below). Customers are mandated to always carry their smart card with them to avoid stress whenever there is any need of purchasing energy credit from any pay point location. After loading the energy credit on the smart card, then the card is inserted into the meter in order to load the credit on the smart card meter to discharge power and display customer's energy consumption rate per use in Kwh [52].

Figure 2.12 Smart card meter [52]

Advantages

- It prevents fraud by operating an open policy.
- It enhances ease resolve of debt management and fixed charges.
- It improves automated disconnection of non-credited meters.

Disadvantages

- Possibility of behavioral misconducts during credit purchase.
- Sometimes customer must travel far to purchase credit.
- Inability of customers to locate a neighboring authorized credit dealer.
- Lost, damaged, or stolen smart card can deter customer's right to credit purchase.

This technology is commonly used in Europe and Africa.

2.9.7. Key meter

Key meter is another type of energy meter that uses a similar method of loading digitalized energy credit to initiate energy supply into households (see Figure 2.13). This meter is designed with a chip embedded to store and transfer energy data across energy management institutions.

Figure 2.13 Key meter [52])

Disadvantages

▪ Customers can switch from one energy providers to another and allowed to retain the old key for use.

▪ Credits lost is tantamount to keys lost.

Hence, it is deployed and used in the United Kingdom and sparsely in other countries. [52]

2.9.8. Keypad meter

Keypad meter is another metering system with a set of buttons used to encrypt credit codes on the meter (see Figure 2.14), and it is perceived to be reliable more than the previously discussed energy meters. In addition, credit purchased by customer is loaded on the meter with the use of this set of buttons (keypad). The machine decodes the codes entered and actively converts them into credit for power supply generation or increment. This process is elevated with energy communication devices like low power radio frequency (LPRF) and general packet radio services (GPRS). Furthermore, STS and IEC are the open standards that define the code. In the process of purchasing credit, customer is instructed to present his/her allocated meter number to generate an allotted credit codes about the amount of energy to be purchased. Once the IT system receives the payment rate and meter number, then allotted credit codes is generated in sequence with the house meter number or credited to the customer's account. The net energy credit is converted and measured in Kwh [52].

Figure 2.14 Keypad meter [52])

2.9.9. Forms of procurement methods used in keypad meter

The forms of procurement methods used in keypad metering are sub-divided into scratch card, mobile phone, through wireless application protocol (WAP), Automatic Profile and Automatic teller Machine and others as seen in the section 2.9.9.1 through 2.9.9.8.

2.9.9.1.Scratch card

Use of scratch card is perceived as one of the methods of generating energy credits as printed on the cards. This is purchased or obtained from the authorised utility vendors such sale points as supermarkets, gas station, etc. The unique experience about this method is that the credit imprinted on the cards is not allotted yet to a specific household meter until when the codes is scratched off the card and sent to the authorised utility agent in form of text messages through the internet and/or dialling call centre for codes conversion into credit. Short Message Service (SMS) is received by customer that contain the converted credit and input into the meter to generate energy. [54]

2.9.9.2.Mobile phone

Another way of producing or acquiring energy credit is by using a mobile phone as a pre-paid payment communication technology (refer to Figure 2.15). This method requires pre-paid payment in exchange for energy credit, in which an SMS is received to confirm the change.

Figure 2.15 Payment via mobile phone (Muzafar Imad Ali Ahmed (2013))

2.9.9.3.Automatic profile

This is like WAP system wherein credits are automatically purchased periodically.

2.9.9.4. Automatic teller machine (ATM*)*

This system involves purchasing of energy credit from a designated automated cash dispensing and depositing machine, which automatically debited your bank account in exchange for energy credit purchased. The meter is loaded with exact amount of energy credit purchased in customer's correct details. This process loads energy credit on the meter automatically.

2.9.9.5. Barcodes

This is another system of purchasing energy credit. The system involves the decrypting of encrypted codes obtained through a pay point payment with the use of a mobile phone and then the payment is made at the bank or by cash (see Figure 2.16).

Figure 2.16 : Barcodes meter (Frost & Sullivan &Jean-Noël Georges (2011)

2.9.9.6.Automatic call center

This system provides the customer with the code via voice message on the phone through automatic call center.

2.9.9.7. GPRS terminals

These systems are made available at most strategic points for credit purchase purposes such places as gas stations.

2.9.9.8.Virtual private network (VPN)

This system is installed and implemented at energy credit purchase points by the utility company and authorized energy dealers to enable easy purchasing of credits.

2.9.10. Split meter

This type of meter is designed with separate boxes comprised of the meter and display unit. The design enables the meter to be placed anywhere around the household, while the display unit is installed within the household. Thus, it is referred to as "in-home-display". The common communication networks used are low power radio frequency (LPRF) and power line carrier (PLC).

2.9.11. Remotely managed meter

This type of energy meter emerged from the feasibility study carried out on the keypad meter. It is a debit meter with a communication device network called wide area network (WAN). Update on energy credits reflects automatically on the meter (see Figure 2.17). In this case, physical keypads are provided to deter communication breakdown. In this system, the prepayment and credit data are executed locally or remotely.

Figure 2.17 Remotely managed meters [52]

2.9.11.1.In locally debit meter

This meter aids the management through energy acquisition activities involving taxes or fees relating to monetary credits.

2.9.11.2. Remotely via IT system

In contrast, this meter operates through a fixed connection to the server in an online mode. Both data and credit management is executed remotely by the IT system and frequently displayed in the meter.

2.10. Advance metering infrastructure

Most utilities in the world today have utilized any of the meter discussed in this study, such meters as electromechanical, electronics, automatic meter reader, and pre-pay meter. Although, with the wider use of these meters around, they still lack the sensing and accurate measurement capabilities to fast-track much information concerning the usage of energy, quality of energy and impudence to bear multiple rates of forms. Therefore, advanced metering infrastructure system is considered better. Apart from the deficiency mentioned above, these meters were unable to yield more comprehensive and appropriate information to instruct customer on the use of energy credit or electricity, and lack of provision for excellent ways of using the energy to gain cost reduction. This could be actualised in a smart metering system with communication and data processing abilities called meter data management (MDM) system. The combination of these two processes formed a system called advance metering infrastructure (AMI). Actually, metering system is no longer a device that measures and records consumption rate of electricity, but it is nowadays seen as an entryway for control and communication amongst utility (grid), customer, and load.

Evidently, AMI system boosts customer's choice of attractive reimbursements (refer to Table 2.1) below for the tabularised functions of AMI). This idea is believed to guide the customer's on decision-making process when it comes to the prudent usage of their energy credits. In return, it will foster the utility efficiency in gathering data and delivering customer service through AMI data and asset management process. The smart grids have four major parameters which are:

- Advanced transmission operation (ATO).
- Advanced distribution operation (ADO).
- Advance metering infrastructure (AMI).
- Advanced asset management (AAM).

Figure 10 presents the diagrammatical relationship of the AMI systems.

Figure 2.18 Graphical relationship of the AMI system [56]

Table 2.1 The function of AMI

Main function	Optional function
Reads in real-time daily	Customer interaction
Takes record of consumption and data profile data	Interact via home area network (HAN)
Active, reactive, energy demand, voltage, current and others	Capacity to communicate with programmable communicating thermostat
Reads remotely	Energy management system (EMS)
Pre-payment operation	Building automation system (BAS)
Import / export of meters	In-home display (IHD)
Tamper detection	
Remote time clock stamping	Remote connection/disconnection
Communication and data Security	Load control
Quality of supply and another event recording	Pre-payment option
Plug and play devise commissioning	
Remote software firmware upgrade	

From the diagram above, it is simply illustrated that smart meter is the central component to assist in the reduction of design cost of the multi-functional capabilities with regard to its robustness.

Although, from the smallest components to the biggest components, all are seen as vital in creating and aiding data management through local transaction of information between the utility company and the customers.

The components that constitute the technological framework of AMI are highlighted below as:

▪ Smart meter.

▪ Home local area networks (HLAN).

▪ Communication infrastructure.

▪ Meter data management systems (MDMS).

2.10.1. Smart metering system

Smart metering system could be described as an energy system that executes measuring consumption of energy, data collection, data creation and energy billing activities [75]; [76]; [54]; [77]; [78]; [79]. [80] simply defines smart meters as the device built and installed around a home or business with the intention of measuring real time consumption rate of electric, gas, and water used to envisage the improvement required for the accuracy, reliability and efficiency enhancement of the outdated or/and overburden electrical, water and gas grids. [81] Categorically stated that that smart energy meter is an electrical device that tracks energy usage, and instantaneously communicate the outcome with the energy supplier.

Figure 2.19 Smart energy meter [55]

Understandably, process initiated in transferring the energy captured, recorded, and stored at the electricity distributors through wireless network takes ≤30 seconds to deliver. The author in [82] described the impact smart meter energy has in enhancing the challenges of energy efficiency through a concept called intelligent energy network. This concept comprises energy meter device and intelligent communication technology (ICT). Intelligent energy networking was pointed out as the ultimate energy device needed in achieving smart energy metering system (see Figure 20). This device makes it possible to monitor and control energy data exchange between the utility and the consumers effectively. This process is performed in two-way directionally between meters to meters with regard to the networking type imbibed. In [80] the author said that smart energy meter operates in two formats, such as AMR and AMI. AMR, as discussed early, communicates and collects data for the utility company just in one direction. In the same section, AMI was described as electronic meter that communicate between the energy provider and customers, by informing them about the data collected at a certain interval. Further description illustrates that AMI integrates two-way communication and electronic meter designed to observe and regulate the grid system [83].

The active grid **may be a versatile** and **extremely** controlled grid. The **flow chart** diagram displayed in Figure **25** illustrates **the method concerned within the** evolution of **sensible** meter [84]; [64] According to [85]. AMR is a classy system that automatically calculate billing and relays information about the consumption rate to the energy supplier. The researcher further stressed that the system could involve various techniques used as a means of communication such as GPRS, SCADA, RF, and GSM. In view of this, the researcher concluded that GSM is the most adaptive device with large quantity of users and coverage zone for data transmission. This quality enhances the chances of using the system for metering purposes. In addition, energy meters that use GSM prepare data for easy access to both energy consumers and energy suppliers.

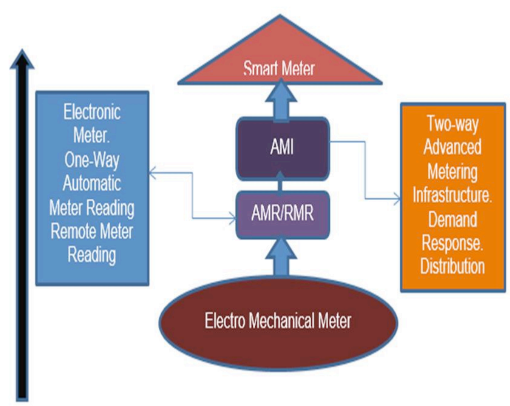

Figure 2.20 Evolution flow chat of energy metering system [64], [84]

Alternatively, AMI was developed to support the functional process of the smart meter as a two-way communication device that fosters the evolution of a smart meter. The development of AMI was mainly to enhance the data management efficiency of a smart meter. To buttress this illustration, [86] emphasized that AMI was developed to replace the AMR to function as a two-way communication and data processor.

2.10.2 Smart meter architectural structure

Smart meter design was based on the architectural understanding of two structures that determine the fundamental structure of a smart energy metering system.

2.10.1.1. Basic architecture of smart meter

In the diagram demonstrated below, the smart meter is classified into two parts which are hardware and software refer to Figure 2.21. The hardware part, as diagrammatically shown, is made up of three major units which are acquisition, data processing and data transmission units. These units represent the combination of components like voltage sensor (VS), current sensor (CS), energy metering integrated circuit (EMIC), micro-controller unit (MCU), liquid crystal display (LCD), power supply/real-time clock (PS/RTC) and communication unit (CMU) [87], [88], [54].

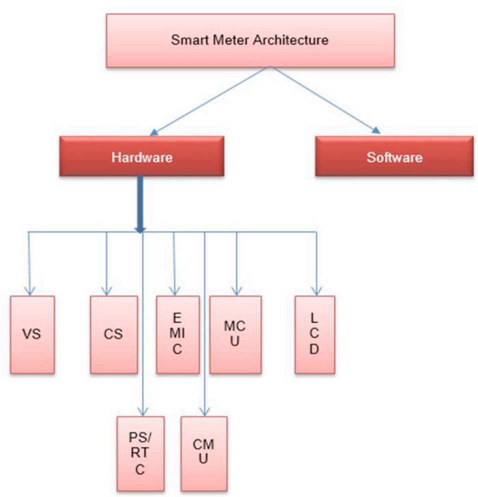

Figure 2.21 : Basic architecture of smart meter [87]

2.10.1.2. Data acquisition unit

Data acquisition, as one of the units considered in the architectural development of a smart meter, is referred to as unit where analog data is obtained, processed, and converted into a required digital input for data processing. It is advised that a careful execution of this process is required to generate a reliable result. This unit consists of VS, CS and level shifter circuits (LSC) [87]. The VS and CS functions as the facilitators of data acquisition before being transmitted to the energy metering IC for signal conditioning, while simultaneously convert analog to digital developments. This type of controller is considered to be “system on chip (SOC)”. SOC constitutes analog front end (AFE) with MCU.

More so, AFE is a section of the smart energy device that is connected to the high voltage lines [87]. This component regulates the high voltage and high current rates from the mains into smaller values that ADC and MCU can easily absorb or process [89]. In essence, MCU can be referred to as the brain of the device because it dictates and controls all processes initiated within the smart energy meter. However, the data transmission unit is responsible for transferring and receiving generated energy parameter for full notification of the billing and monitoring purposes to both the energy supplier and customers.

2.10.1.3. Data transmission unit

Under data transmission unit, data is transmitted to a centralized server with customers’ identities stored to aid easy determination of unwillingness and criminal activities exercised by the customers such as unpaid usage of electricity, electricity theft, and electricity property vandalism [76].

2.10.1.4. Communication network system for smart energy meter

Communication network system for smart energy meter are the basic existing networks which can be adapted into energy metering. It can be subdivided into cable and wireless networks as shown in figure 29 below.

According to [86], smart meter should be built to carry out some functionalities like measuring, applying, and communicating energy parameters with the intention to stimulate the efficiency use and supply of energy across to the households and industries. However, this efficiency is possible through a proper selection of communication networks and ports to manage the transmission and reception of energy data (see Figure 2.22).

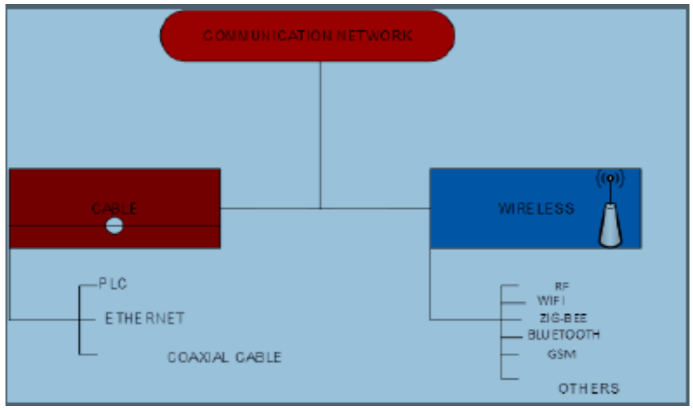

Figure 2.22 Communication network system for smart energy meter [76]

2.10.2. Hardware internal structure of a smart energy meter

Smart energy meter is composed of both the software and hardware structure. This section will force on the internal structure of the hardware the smart energy meter consists of. The section comprises of detail scrutiny of the voltage sensor, current sensor, break down and their application as discussed below:

2.10.2.1. Voltage divider for voltage sensing

Voltage divider is a modest design of voltage sensor due to its less cost in the market. The circuit connection is aimed at scaling down the AC source voltage magnitude to meet the voltage input range of the energy metering integrated circuit for appropriate measurement. The resistor R1 is connected in series with R2 , having the input voltage (Vin) across each. The output resulted voltage (Vout) is tapped from the connections in between the resistors. In this case, the voltage divider could be used for voltage references and be grounded at resistor R2 (Figure 2.23)

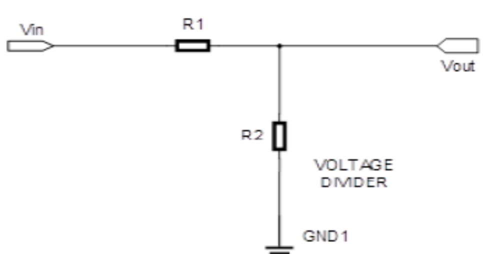

Figure 2.23 Voltage divider [80]

$$V_{out} = V_{in} \times \frac{R2}{R1+R2} \tag{5}$$

From the above diagram, Vout denotes voltage output and Vin denotes voltage Input.

Note: it is importance during selection that the resistor R1 should be greater than R2.

2.10.2.2. Current sensor unit

Current sensor is one of the units categorized under data acquisition unit. This unit is grouped into four subcategorizes, such as:

- Current transformer (see Figure 2.24),
- Hall effect sensor, and
- Shunt resistor.

According to [90], current sensor is sub-divided into two systems, such systems as aggressive and non-aggressive. In the aggressive system, current sensor is linked in series with the mains, whereas in the non-aggressive system, current sensor is not linked directly with the mains. Examples of the aggressive system are inductor with high inductance values, resistor, one axis hall-effect sensor, and solid current transformer. Also, examples of non-aggressive system are Hall Effect sensor and split-core current transformer.

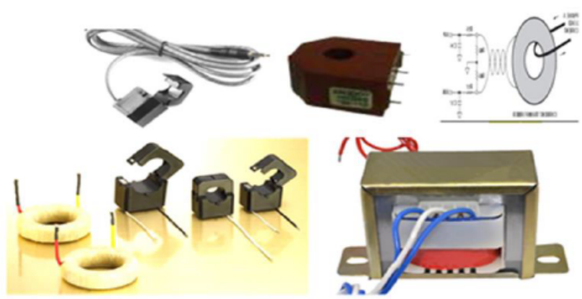

Figure 2.24 Current transformer collection [54]

The process involved in the current transformer demonstrate that primary winding aids the transformation of the AC current that flows across it. Then, a magnetic field is generated and induced on the secondary winding coil. The ratio association between the number of turns in the secondary and primary windings yields the output magnitude. Moreover, a burden resistor is connected to the secondary winding coil based on the recommended rating as specified in its datasheet. In [54] the author reported that current transformer's performance rating predicts its use. The capacity standards of current transformer used for energy metering purposes are 0.1, 0.2, 0.5 and 1. Other attributes indicate that current transformer has a nonlinear phase lower current and higher power factor. But current transformer sells at higher price more than shunt resistor.

Hall Effect sensor

Hall Effect sensor is a copper conductor with a chip. This type of sensor was used to design a low-cost smart card prepaid energy meter, wherein ACS712-30A was used as the current sensor [91] The copper conductor is positioned partly with the die. ACS712 is one of the most widely used current sensor in the energy metering system.

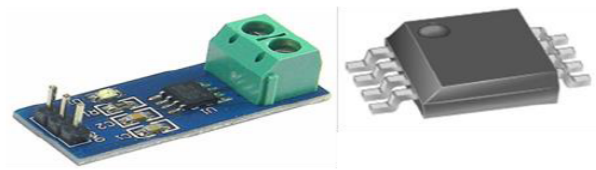

Figure 2.25 ACS712 Hall Effect sensor [92]

Moreover, when current flows through the copper conductor path, a magnetic field is generated and sensed by the hall integrated circuit (IC).

Shunt resistor

Shunt resistor is a built resistor in series that performs voltage and current measurement tasks within a smart energy meter [93]. More so, the design of shunt resistor includes the use of materials with low resistance standard that resist harsh conditions such as temperature changes, age and current. Subsequently, [54] advised that resistors within the range of 100µΩ and 500mΩ are suitable for the development of a smart energy meter. The power dissipation is directly proportional to the square of the current. This effect demonstrates a need for a smaller resistor value to reduce the amount of heat losses (refer Figure 2.26. The current fed into the microcontroller or the energy metering IC can be calculated when the resistor used is measured in ohms and the quantity generated is calculated through the application of ohms law. The voltage across the shunt resistor is proportional to the sum of current conveys through it.

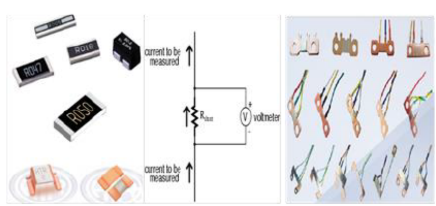

Figure 2.26 Shunt resistors

The discussions in this chapter provides detailed knowledge on the components and procedures adopted in the design and development of a smart energy meter. These components or materials were critically evaluated to suit affordable cost of purchase to enable or encourage further modification development in future.

In the subsequent chapter, analysis of the basic functionalities within the energy metering IC, signal conditioning, noise sampling, oversampling, and basic electrical parameter calculation in a sinusoidal single-phase system will be discussed.

2.11. Review of Related works

As a research work, information of different criteria has been collected from many academia of the similar field of study. The energy meter has experienced many changes in its building technology including the billing system and alert signaling system. A short-lived analysis is thus made to review into a few of thoughts on this area of study.

2.11.1. Remotely- Monitored Single Phase Smart Energy Meter via Short Message Service (SMS).

In [94] the authors aimed at design and implementation of single phase energy meter which can be supervised remotely by the use of Short-Message Service (SMS). They used some separate components or devices and a metering chip (ADE7755) to plan the energy meter. The SMS with the meter was set up with the assistance of Neoway M590 Worldwide System/Standard Versatile Communication (GSM) module. The GSM accepts commands from mobile phone for communication. The keypad was used to load up energy token and energy information received from the energy meter. They used an LCD to display the energy loaded up. They locally manufactured single layer printed circuit board on which the project was put into effect or implemented by using a Software called Diptrace Software. The Software called Proteuse was also used, 8051 improvement kit and a serial port monitor to make the simulation of the electronic circuit designs. The energy meter can measure load of minimum current of 2mA and maximum load of 40 A. The results showed that the energy meter could be used to measure an average real time power and instantaneous power that was used up or consumed when it (energy meter) was monitored and queried remotely. The variety of the Voltage was 180V-250V, and the microcontroller AT89C55WD was programmed in C language using KeiluVision compiler.

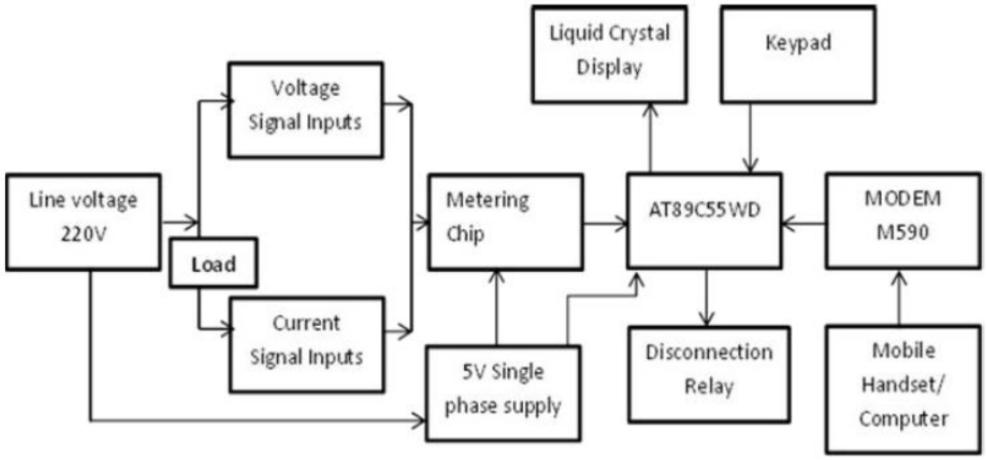

Figure 2.27 Components of the remotely metering system [94]

2.11.2. Microcontroller based wireless energy meter

In [95] author in his work, he designed a digital energy meter where he used Advanced Virtual RISC (AVR) microcontroller to transmit the data measured by wireless means to a computer. The microcontroller had an extraordinary features which were versatile in programming and to transmit data. It also has timer/counters, separate oscillator and could be used to compute the difference in phase between voltage and current. The microcontroller was used to calculate the root mean square values of the voltage V and the current I including the power factor (PF), the active or real power, the apparent power and the reactive power. All these calculated values and energy values are transmitted to a computer by wireless means through serial port. The programming language used was Microsoft visual studio C#, and he used Bluetooth serial adaptor which easily communicate with other Bluetooth devices like ipad, mobile phone, laptop e.t.c to transmit the data.

2.11.3. Prepaid electricity system based on RFID

In [96], the author focused at developing a management system which was prototype to manage prepaid electrical power meter. These scholars used wireless gateway, digital meter, microcontroller, and Radio Frequency Identification (RFID) reader to design the proposed prepaid electrical meter. The suggested prepaid meter was built in client and the server. The designed circuit is connected to a computer, where Radio Frequency Identification (RFID) reader is utilized to read the data on the credit card. The RFID uses radio waves to recognize things and people automatically. On the client part, an RFID reader and digital meter was controlled by microcontroller. The RFID reader reads the information on the ID card and this information is sent to the server to check if it is authentic and later the client receives the information. The microcontroller was used to administer the work of the system in the client.

2.12.Summary

The thorough research into other related work provides an insight of what is to be designed and its related constraints and challenges. Research was done on how utility companies can manage electricity generated to the consumers. Many researchers presented many options however no one researched about how energy meter can be shared by four tenants. The research stacked on energy meter that has one output connects to the grid and consumers entrance houses. The providing information on energy consumption to each individual sharing the same energy meter seems impossible, because the house tenants always asked contribution regardless of the time or load used. This serves as a gap to be covered by my project as each house tenant will be aware of energy consumed and the latter will plan for better management of electricity. The introduction of Arduino based building energy management smart meter with GSM platform to interface the utility energy meter and the household electrical inside building will prevent misunderstanding on energy billing sharing. The system will monitor and control individual's energy consumption depends on the load plug in. Thus with this brief study on how various technologies like the microcontroller and GSM, a massive motivation and guide lines were provided to the development of the system at hand.

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3. RESEARCH METHODOLOGY

3.1. Introduction

For this research to successfully be completed, a survey was conducted to get insights on electricity consumption by the households at their respective homes. The households are connected to the utility line through energy meter. As said by households, regardless of number of houses in one compound, they are given only one meter. When asked if they should be given the second energy meter, the utility can provide but to the cost which is higher compared to the first one. The households prefer to own only and single energy meter that brings conflict between them. As stated by many researchers in literature review above, they presented many researches on smart metering. They used different technology that can help house hold and utility to manage electricity in favor of utility because the latter needs to manage electricity by avoiding losses and theft. SMS should be given to utility when a strange happens to household side or on line transferring power to households. Even if those researchers tried to help utility, they forgot the main parts which are consumers in their homes. The surveyed households are from Gasabo district where many people share one energy meter. The results from this survey after hearing and see how they suffer from sharing one energy meter, the latter proves me to aid in the design of the hardware and software technologies which is independent from the main energy meter where each household manages electricity and pay for what he /she consumes. The landlord will have the right to manage each house located in the compound. The approach to the design and implementation of the presented work is fragmented into two main parts: the physical part or hardware and the hidden part or software. The physical part will include component acquisition, tools and building the entire circuit whiles the hidden part which will concentrate on programming of AT mega 2560 Microcontroller to respond to command and activate set of instruction.

3.2. Data collection

The present research, two types of data collection were used:

3.2.1. Primary Data

The data to be collected for the first time. The following methods of Primary Data Collection were used

3.2.1.1.Observation method

With my own observation, the visited site is principally occupied by business houses and residential houses. Many business houses I observed, shares one energy meter the same as residential houses that found in the same compound. The tenants are not satisfied with one meter shared. When look on the wall where landlord managed to buy extra energy meters; as all engineering products are expected to provide a high level of good-looking. This serves as a primary key to customer satisfaction in terms of sales and services. In reference to the local situations concerning the provision of multiple meters for separate consumers, the beauty of walls are affected since a number of metes are installed at the same point on the wall. It is the get-together of primary data by agent's own straight reflection of pertinent people, actions and situations without asking from the respondent. Observation is also a method used by the researcher to collect data. It is used to get both past and current information. This method helped me together relevant information on how people being satisfied with energy meter sharing.

The following questions were developed to help me in survey.

1. How many families do locate in the compound (Igipangu)?
2. How many electricity meters are you using?
3. Are you sharing the same electricity meter?
4. If yes,
    a. Why are you sharing the same energy meter?
    b. Are consuming the same electricity as your neighboring families?
5. How much do you pay per month as contribution?
6. What is the major electrical equipment do you use?
7. How much electricity do you consume in kWh?
8. Is there any conflict from sharing the same energy meter?
9. If yes, what are the cause of those conflicts ?
10. Is there any advantage of having your own electrical energy meter?
11. If yes, are you willing (able) to buy your own electricity meter on the utility?
12. If no, why ?
13. If there are any other alternatives of getting your own electricity meter are you willing to buy them?

14. If yes, how much could you pay them?
15. How do you wish to pay them ? (installment ? Or Pay at once)
16. If it is pay installment , how much are you willing to pay per month?

3.2.1.2.Experimental method

Based on Empirical experience, **Arduino based building energy management meter with GSM module**'s prototype was produced and experimentally test for accuracy, reliability and cost lie was conducted. The experiments showed the promising results as each house tenant is able to consume energy refer to the ability. The components and tools used for experiment are as follow:

3.2.1.2.1. Components

The main components used in the construction of this thesis project are Microcontroller (Arduino Nano), GSM module, ACS712 Hall Effect current sensor, ZMPT 101 B Voltage sensor, LCD display, switching relays and cell phone.

3.2.1.2.2. Tools

Tools used to build the circuit include the following: a working table, a clean duster, a set of screw drivers, a pair of pliers, cutters, scissors, files, sand paper, an electrical extension cable , AC/DC clamp meter , soldering iron and soldering wire, glue gun, etc.

3.3. Circuit Design of the planned model

The circuit is designed in software using PROTEUS 8 software. The circuit is split into segments such as DC power supply, AC power supply, Arduino Mega 2560, GSM module, ACS712 current sensor, keypad, Relays and simulated independently. The Arduino Nano is programmed and assembled with IDE compiler. A refined box, screws, glue, and veneer were used to house and enclose the system. The power source delivers the energy for the electrical system from the main grid. The apparatus utilizes the electrical energy provided by the source. For example, bulb, computer, etc. The liquid crystal display (LCD) shows the credit loaded up in the system. The relays are there for control apparatus which when energized with current authorizes energy to drift through the system to do the appropriate work.

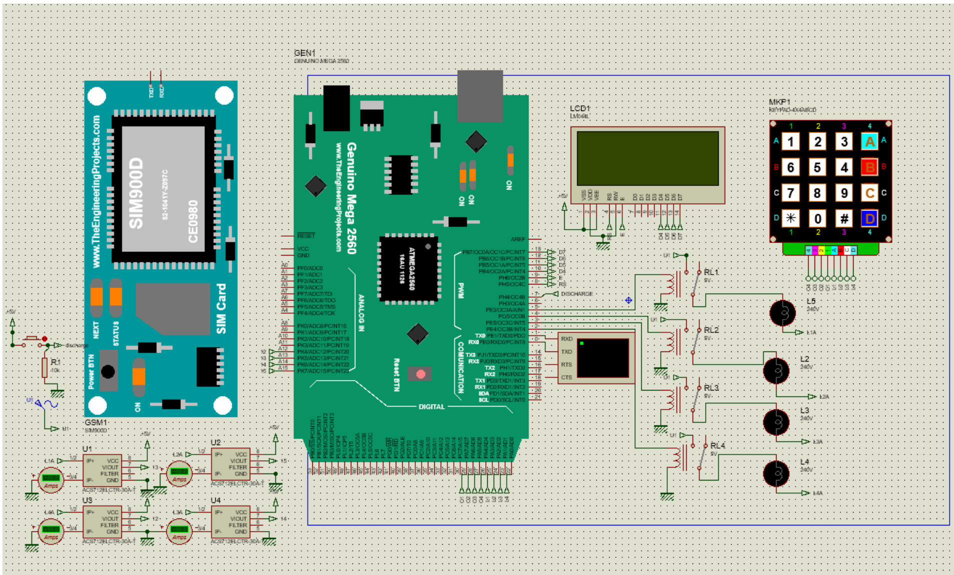

Figure 3.1. Circuit design of the proposed system

3.3.1. Secondary Data

This was used to get what other writers/researchers have written about the related matters to my topic. This includes the analysis of documents, records pertaining to the energy meter and management of energy. The researcher was used the relevant materials from libraries and different websites on the internet to find out the literature review. This means that it is a written summary of journal articles, books and other documents that describes the past and current state of information, organizes the literature into topics and documents a need for a proposed study.

4. SYSTEM DESIGN AND IMPLEMENTATION PROCEDURES

4.1. Description of the system

The system architecture of Design and implementation of Arduino based building energy management meter with GSM platform **is** shown in the Fig.4.1. The targeted purpose of the circuit is to continuously measure the amount of consumed energy and deducts it from a preset allowed usable amount to get the remaining balance and when the balance reaches at its minimum which is zero, relays are turned off to cut the power consumption. This is done through sensing of the current flow by Hall Effect current sensor (ACS 712) and measuring the applied voltage by the use of ZMPT 101B voltage sensor. The power is computed as a product of current and applied voltage. The computational calculation of energy is done by continuously monitor the time of operation and multiply it with the power to get the exact energy consumption. Recharging is done by a landlord cell phone with a specific sim card number recognized by the system. Specific set of alphanumeric and special characters are sent through the system by a cell phone and received by a GSM sim900 module and if found valid, it is decoded into an amount of energy and added to remaining balance. Decoding process is done by a complex set of mathematical protocols and instructions formatted as executable hex file and are uploaded to microcontroller by the use AVR programmer. Houses are connected to the respective relay the latter whose function is for switching on or off houses/load when necessary. This system is a low cost, continuous, simple but fast means of data acquisition at any remote locations irrespective of location and size. Although fast and simple, it can be applied to both simple home automation and also to complex industrial automation. This system also has no limited operability as the user with any GSM based mobile phone having simple messaging and calling function in any path of the world with GSM network can monitor any location. With small size and portability in mind, the choice of the LCD display and miniaturized sensor aims at eliminating the need for a PC display, while making it easier to carry the system about, for continuous monitoring. It thus ensures flexibility in real-time remote monitoring regardless of distance and location. Another interesting feature of this particular design is the reprogrammable and open source nature of the product, which makes it easier to re-specify the particular heart rate to watch out for, as well as play with the system parameters, to suit the users need better. This is necessary due to varying environmental and physical conditions. The block diagram of the proposed system is given in figure below.

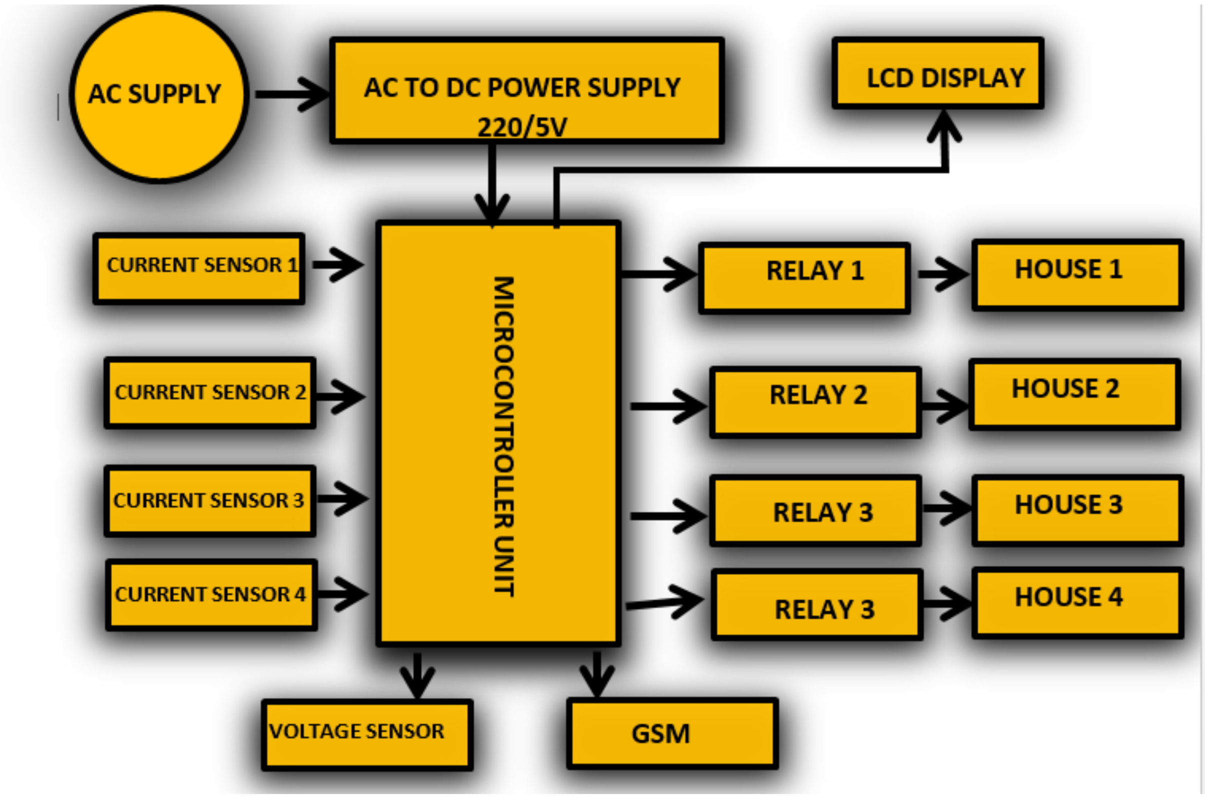

Figure 4.1 Block diagram of proposed model

4.2. Design procedures

4.2.1. Hardware design

This section defines the methods used in designing each component part of the system. Analyzing the selection of electronic components and values as used in the circuit. The circuit was designed using Proteus 8 software.

4.2.1.1.Circuit analysis

The circuit is spilt into 6 parts: AC to DC power supply, current sensing unit, relay Switching units, microcontroller unit, LCD and communication units via GSM.

4.2.1.1.1. AC to DC regulated power supply

The circuit is designed so that to gives 5V DC that used to supply LCD and Microcontroller the circuit uses Bridge rectifier, capacitor and step down transformer whose turn's ratio is 45:1

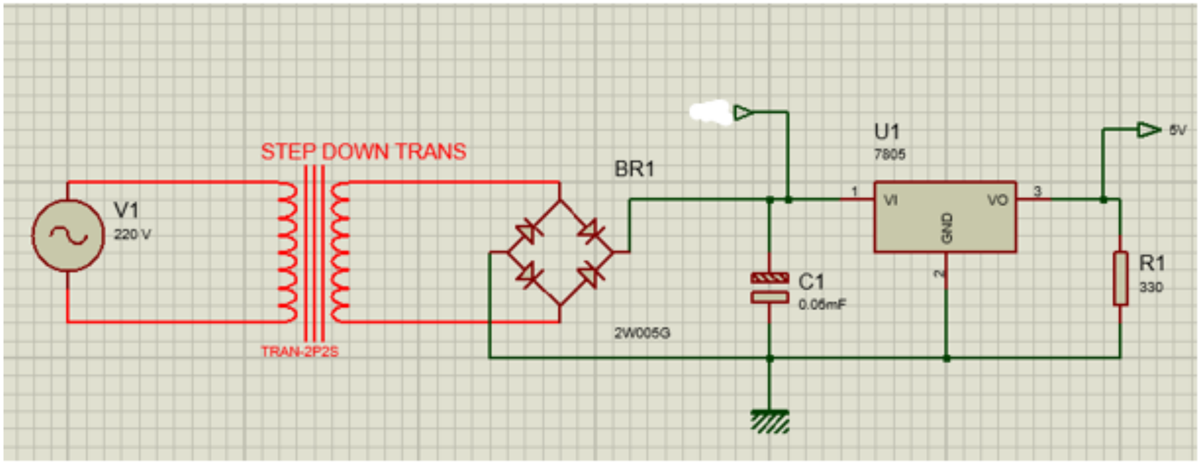

Figure 4.2 Single phase AC to DC power supply

4.2.1.1.1.1.Single phase transformer design

The single phase transformer used to design the power supply has the following parameters have been calculated and shown from the table bellow

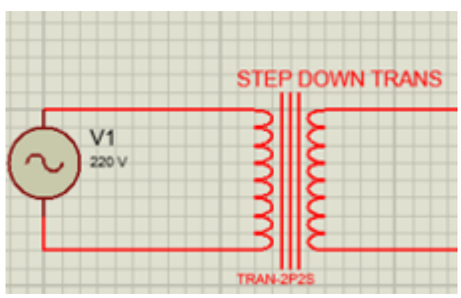

Figure 4.3 Single phase transformer design

$$\frac{V_P}{V_S} = \frac{N_P}{N_S} = \frac{I_S}{I_P}$$

$$V_P = \sqrt{2}\ \text{RMS} \quad (6)$$

$$V_{Psec} = \frac{1}{23} \times V_{Ppri}$$

$$V_{sm} = V_{pm} \times \frac{Ns}{Np} \leftrightarrow \frac{Ns}{Np} = \frac{1}{23} \quad (7)$$

Table 4.1 Transformer design parameters

S/N	Parameters	Value
1	RMS voltage (primary	220 V
2	Peak voltage (primary)	311.12 V
3	Frequency	50 Hz
4	Transformer turns ration	23:1
5	Peak secondary voltage (V_{psec})	13.5 V

Reading from table 4.1, all parameters were calculated and the transformer is able to supply both microcontroller and LCD.

4.2.1.1.1.2. BRIDGE RECTIFIER

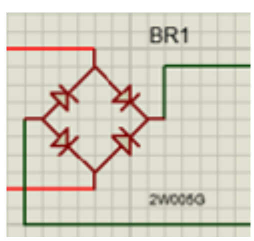

Figure 4.4 Bridge rectifier design

The diodes used for bridge rectifier are made from Silicone, the threshold voltage that makes the diode to start conducting is 0.7 V. The following formula was used to estimate the output voltage from the Bridge.

$$V_{dc\ bridge\ output} = V_{psec} - 2 \times 0.7 \quad (8)$$

Table 4.2 Bridge output voltage design parameters

S/N	Parameters	Values
1	V_{dc}bridge out put	12.1 V
2	Threshold voltage (silicone)	0.7
3	Voltage peak secondary winding of transformer	13.5 V

The output from the bridge is not a complete DC while is varying signal. The following figure shows the signal output from the bridge rectifier.

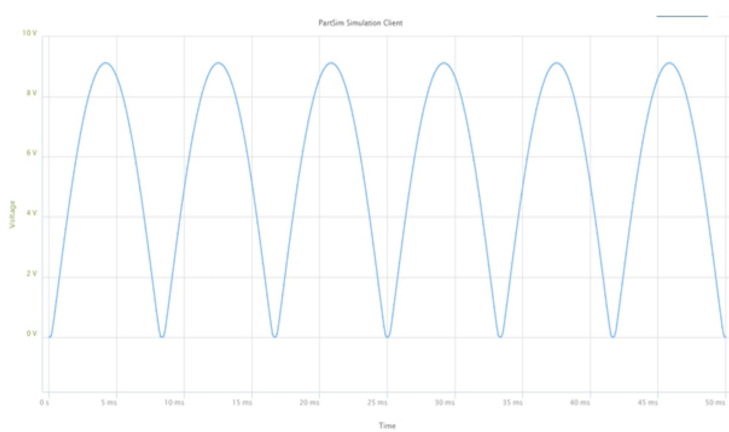

Figure 4.5 Wave form output of bridge rectifier

4.2.1.1.1.3. Filtering capacitors

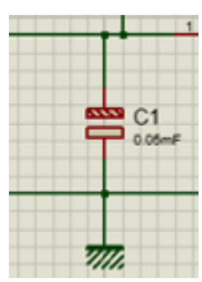

Figure 4.6 Filtering capacitor design

The filtering capacitor has a role of removing ripples output of bridge so that to remain with somehow DC signal. The formula below was used to estimate the capacitor needed.

$$V_{DC\ supplying\ the\ load} = V_{P filter\ input}\left[1 - \frac{1}{2fR_L C}\right] \quad (9)$$

All parameters for capacitor design are summarized in table

Table 4.3 Load voltage after filtering

S/N	Parameters	Values
1	$V_{P filter\ in\ put}$	11.5 V
2	$V_{DC\ supplying\ the\ load}$	5.499
3	Frequency	100 HZ
5	$Load\ resistance\ (R_L)$	22 kΩ
6	Filter capacitor (C)	0.05mf

4.2.1.1.1.4. LM7805 voltage regulator

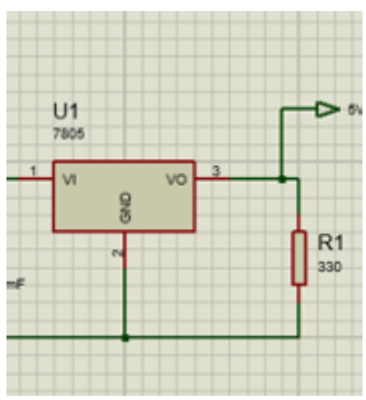

Figure 4.7 LM7805 Voltage regulator

The LM7805 Family monolithic 3-terminal positive voltage regulators employs internal current limiting, thermal shutdown and safe-area compensation, making them essentially indestructible. If adequate heat sinking is provided, they can deliver over 1.5-A output current. They are intended as fixed voltage regulators in a wide range of applications including local (on-card) regulation for elimination of noise and distribution problems associated with single-point regulation. In addition to use as fixed voltage regulators, these devices can be used with external components to obtain adjustable output voltages and currents.

Table 4.4 The output fixed parameters of LM7805 voltage regulator

Output options	**Fixed Output**
Iout (Max) (A)	1.5
Vin (Max) (V)	30
Vin (Min) (V)	7.5
Vout (Max) (V)	15
Vout (Min) (V)	5
Fixed output options (V)	5, 12, 15
Noise (uVrms)	40
Iq (Typ) (mA)	6
Thermal resistance θJA (°C/W)	24
Load capacitance (Min) (μF)	0
Accuracy (%)	3
PSRR @ 100 KHz (dB)	48
Operating temperature range (C)	0 to 125

LM7805 Pin Configuration and Functions

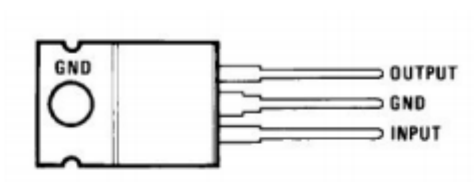

Figure 4.8 LM7805 Pin Configurations

Table 4.5 LM7805 Pin functions

PIN		*I/O*	*DESCRIPTION*
NAME	*NO.*		

INPUT	*1*	*I*	*Input voltage pin*
GND	*2*	*I/O*	*Ground pin*
OUTPUT	*3*	*O*	*Output voltage pin*

Table 4.6 LM7805 Electrical Characteristics, VO = 5 V, VI = 10 V, 0°C ≤ TJ ≤ 125°C unless otherwise specified

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
V_O	Output voltage	$T_J = 25°C$, $5 mA \le I_O \le 1 A$		4.8	5	5.2	V
		$P_D \le 15 W$, $5 mA \le I_O \le 1 A$ $7.5 V \le V_{IN} \le 20 V$		4.75		5.25	V
ΔV_O	Line regulation	$I_O = 500 mA$	$T_J = 25°C$ $7V \le V_{IN} \le 25V$		3	50	mV
			Over temperature $8V \le V_{IN} \le 20V$			50	mV
		$I_O \le 1 A$	$T_J = 25°C$ $7.5V \le V_{IN} \le 20V$			50	mV
			Over temperature $8V \le V_{IN} \le 12V$			25	mV
ΔV_O	Load regulation	$T_J = 25°C$	$5 mA \le I_O \le 1.5 A$		10	50	mV
			$250 mA \le I_O \le 750 mA$			25	mV
		Over temperature, $5 mA \le I_O \le 1 A$				50	mV
I_Q	Quiescent current	$I_O \le 1 A$	$T_J = 25°C$			8	mA
			Over temperature			8.5	mA
ΔI_Q	Quiescent current change	$0°C \le T_J \le 125°C$, $5 mA \le I_O \le 1 A$			0.5		mA
		$7 V \le V_{IN} \le 20 V$	$T_J = 25°C$, $I_O \le 1 A$			1	mA
			Over temperature, $I_O \le 500$ mA			1	mA
V_N	Output noise voltage	$T_A = 25°C$, $10 Hz \le f \le 100 kHz$			40		µV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple rejection	f = 120 Hz $8 V \le V_{IN} \le 18 V$	$T_J = 25°C$, $I_O \le 1 A$	62	80		dB
			Over temperature, $I_O \le 500$ mA	62			dB
R_O	Dropout voltage	$T_J = 25°C$, $I_O = 1 A$			2		V
	Output resistance	f = 1 kHz			8		mΩ
	Short-circuit current	$T_J = 25°C$			2.1		A
	Peak output current	$T_J = 25°C$			2.4		A
	Average TC of V_{OUT}	Over temperature, $I_O = 5 mA$			−0.6		mV/°C
V_{IN}	Input voltage required to maintain line regulation	$T_J = 25°C$, $I_O \le 1 A$		7.5			V

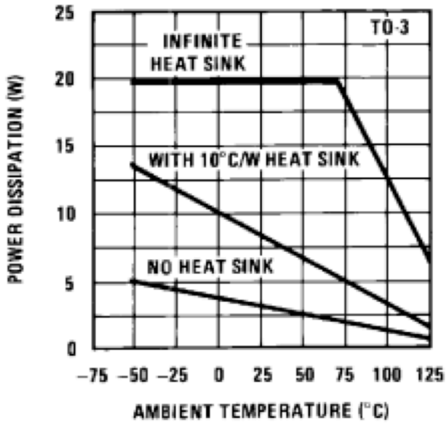

Figure 4.12 . Maximum Average Power Dissipation

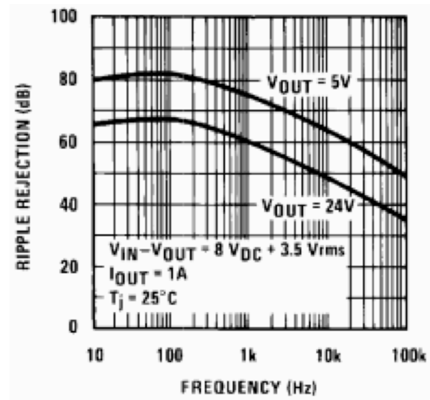

Figure 4.11 . Ripple Rejection

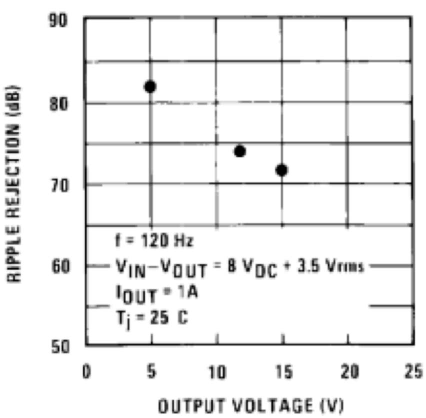

Figure 4.10 . Ripple Rejection

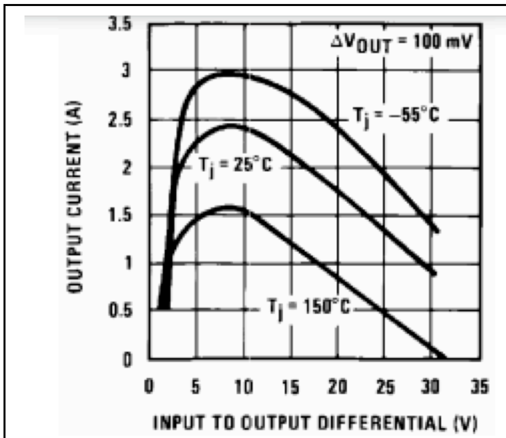

Figure 4.9 . Peak Output Current

4.2.1.1.2. Current sensing design

Sensing and controlling current flow is a fundamental requirement in a wide variety of applications including, over-current protection circuits, battery chargers, switching mode power supplies, digital watt meters, programmable current sources, etc. In this design, the ACS712-30 A current sensor is used as it provides economical and precise solutions for current sensing in industrial, automotive, commercial, and communications systems. The figure 4.13 is a block diagram of ACS712-30A

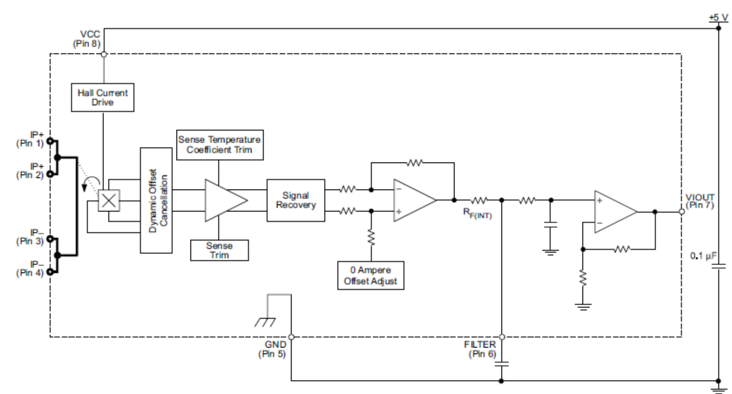

Figure 4.13   Functional block diagram of acs712-30A

4.2.1.1.2.1.Sensitivity and output of ACS712

The output of the device has positive slope when an increasing current flows through the copper conduction path. At zero current, the output voltage is half of the supply voltage

(Vcc/2). It should be noted that the ACS712 provides ratio metric output, which means the zero current output and the device sensitivity are both proportional to the supply voltage, VCC.

The microcontroller ADC uses Vcc = 5.0V as a reference for A/D conversion and the same supply voltage powers the ACS755 sensor chip. The analog output of the ACS755 is digitized through the ADC chip. When there is zero current through the current sensor, the output is Vcc/2 = 2.5V.

The curve below shows the output voltage and the current sensed of ACS7212 current sensor with 5.0V of supply

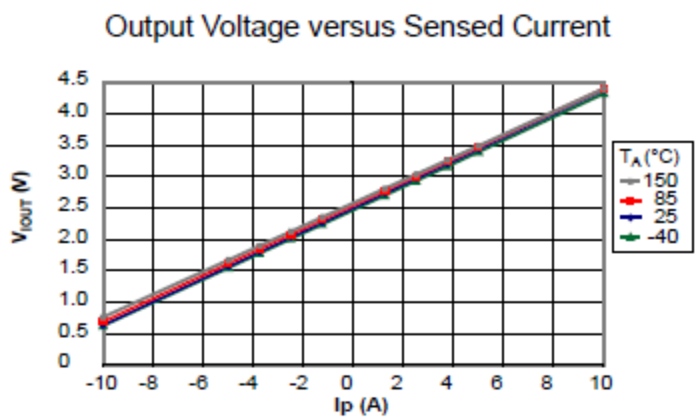

Figure 4.14 Output voltage vs sensed current of acs7512 at 5.0 v power

4.2.1.1.2.2.Supply and varying temperature

The output of the sensor modules goes to the analogue pins of ATMEGA2560 microcontroller. The microcontroller uses the supply voltage (+5V) as reference for A/D conversion. The digitized sensor output is processed through software to convert it to the actual current value. The mathematics involved in the process is described below.

ACS712- 30A current sensor

Sensitivity =66mV/A

For VCC = 5.0V and ADC Vref = VCC

The relationship between input voltages of ADC count is:

$$Count = \frac{1024}{V_{CC}} \times V_{in} \tag{10}$$

But $V_{in} = \frac{V_{cc}}{2} \times 0.066 + I$

$$Count = \frac{1024}{V_{cc}} \times \left[\frac{V_{cc}}{2} \times 0.066 + I\right]$$

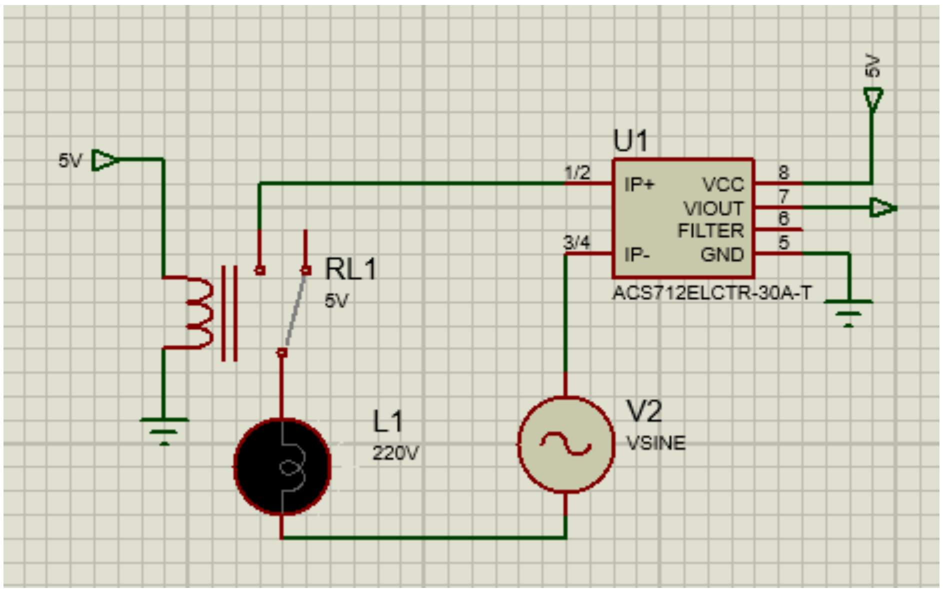

Figure 4.15 Current sensor circuitry

4.2.1.1.2.3. Relay switching

A relay is an electrically operated switch. The relay is used to control the flow of current to the load through the instructions received from Microcontroller. Many relays use an electromagnet to mechanically operate a switch, but other operating principles are also used, such as in solid state relays. Generally, relays are used where it is necessary to control a circuit by a separate low power signal, or where several circuits must be controlled by one signal.

The first relays were used in long distance telegraph circuits as amplifiers: they repeated the signal coming in from one circuit and retransmitted it on another circuit. Relays were used extensively in telephone exchanges and early computers to perform logical operations.

The relay in this circuit is primarily used to isolate the consumer load from the power grid when either units are exhausted or the generating capacity is low or when the energy meter is being tampered with.

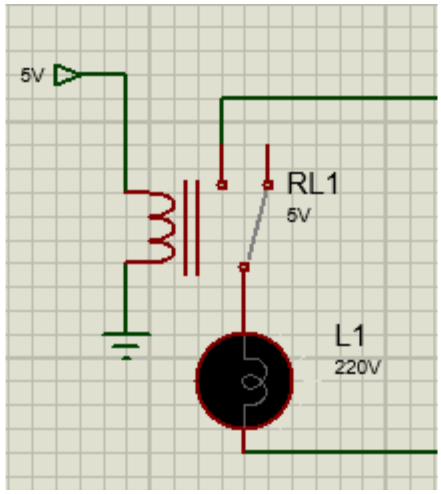

Figure 4.16 The relay circuit

4.2.1.1.2.4.The microcontroller unit

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560 according to datasheet [97]. In [98], the author used AT mega 2560 in real time monitoring and controlled power distribution system with smart meter to support smart grid For. The Arduino Mega works as brain of the entire smart meter. It gets analogue readings from current sensor and voltage sensor and calculates the consumed energy. In reference [99], CLC (Cellular Lightweight Concrete) brick making process using neural network and extreme learning method based on microcontroller and Visual Studio.Net was developed, the ATmega2560 was use as the brain of the system. The measurement of weight of bricks was made easy using AT mega 2560. In reference to [100], the author presented a distance locally controlled energy with load control using mobile billing System through GSM , the Arduino Mega 2560 was used purposively to communicate with GSM in converting SMS into readable energy. In [101], Design and Implementation of a GSM-Based Single Phase Prepayment Energy Meter with Hybrid Recharge Mode was proposed. The Atmega2560 was used to manage the unit consumption; control and monitor the activities of the meter. The GSM-based Energy Metering System developed worked satisfactorily. It is reliable and efficient for use by the supply authority and the consumers

Prepayment Energy Meter with Hybrid Recharge Mode In the proposed project, the Arduino serves as energy meter which is independent from the utility meter. The Arduino Mega 2560 used for this project is a microcontroller board based on the ATmega2560 and its pin specifications are summarized from the figure 4.17 below.

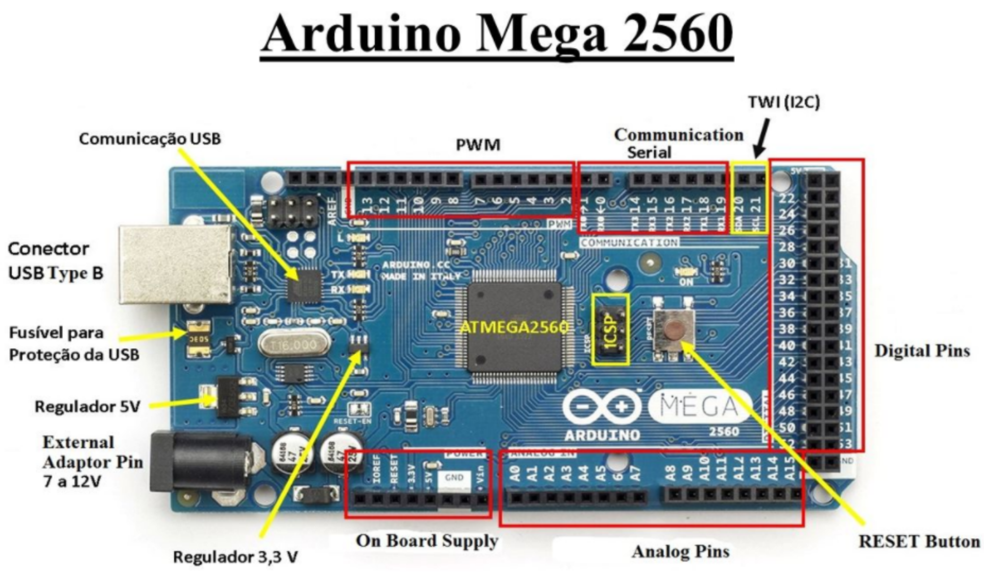

Figure 4.17 Arduino Mega 2560 pin description (adapted from internet)

The technical specification of ATmega2560

Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	54 (of which 14 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	256 KB of which 8 KB used by bootloader
SRAM	8 KB
EEPROM	4 KB

Clock Speed	16 MHz

4.2.1.1.2.5.Interfacing the GSM modem with microcontroller

Modem*s* are devices that let computers transmit information over ordinary telephone lines. Modem is an acronym for "modulator/demodulator." Modems translate a stream of information into a series of tones (modulation) at one end of the telephone line, and translate the tones back into the serial stream at the other end of the connection (demodulation). Most modems are *bidirectional*, so a data transfer can take place in both directions simultaneously. Many researchers used GSM to perform many activities. Like in to [100], the author created a prepaid energy meter; GSM was used to communicate with Arduino in electricity billing purpose. In [101] the author designed and implemented GSM-Based Single Phase Prepayment Energy Meter with Hybrid Recharge Mode; SIM900 was used to achieve the SMS recharging and communication capability. The results also show a mean time of 28.99sec in the SMS round-trip delay test for SMS recharging and 100% success rate in wireless and keypad recharging. The GSM-based Energy Metering System developed worked satisfactorily

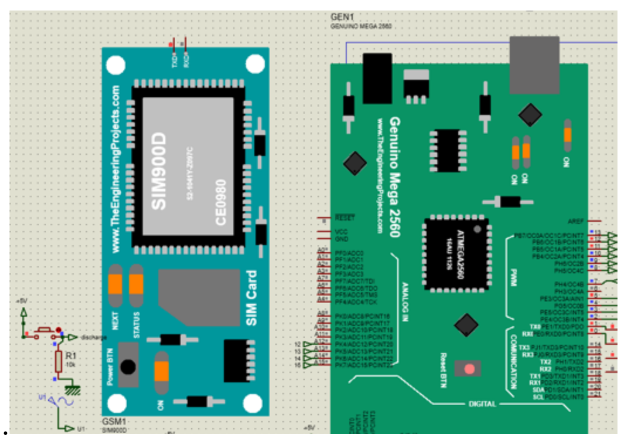

Figure 4.18 GSM SIM900 interfaced with Arduino Mega 2560

4.2.2. Software design

The building energy management is the major work of the prototype. Similarly it measures the power consumption parameters of the system and display them on the LCD monitor for the purpose of monitoring. Accordingly, the system supply to the loads is through four relays that switch off some house loads when the total contribution is depleted. This switching off of the loads is based on the program given to Arduino. When the contribution is ended up, it will require a landlord to recharge through GSM by sending an SMS via GSM.

Been an embedded system, the program was written in C# using the Integrated Development Environment (IDE). The program was compiled to the memory of the AT mega 2560 microcontroller using the compiler software. The following steps were considered during design

- Understanding the problem
- Planning the logic
- Coding the program
- Translating the program to machine language
- Testing the program
- Putting the program to production

The software is designed with reference to 4 houses to be controlled. From the figure below, when Arduino together with GSM receive power, LCD and GSM initialize and LCD starts reading energy consumed from different houses A, B, C and D and energy balance is displayed on LCD. If energy balance is greater than 0, the Arduino orders respective relays to turn on. If the balance is less or equal to 0 the Arduino also commands the respective relay to turn off. The house will get powered back once GSM receives an SMS from landlord's cell phone. If an SMS is sent, the GSM checks whether it is valid or Not. If the SMS received is valid, automatically the balance will be added to the previous one which was 0 to activate the respective relays. The balance again is displayed on LCD. If the received SMS is not valid, the LCD will display the word "please recharge". Arduino codes were programed in the IDE environment

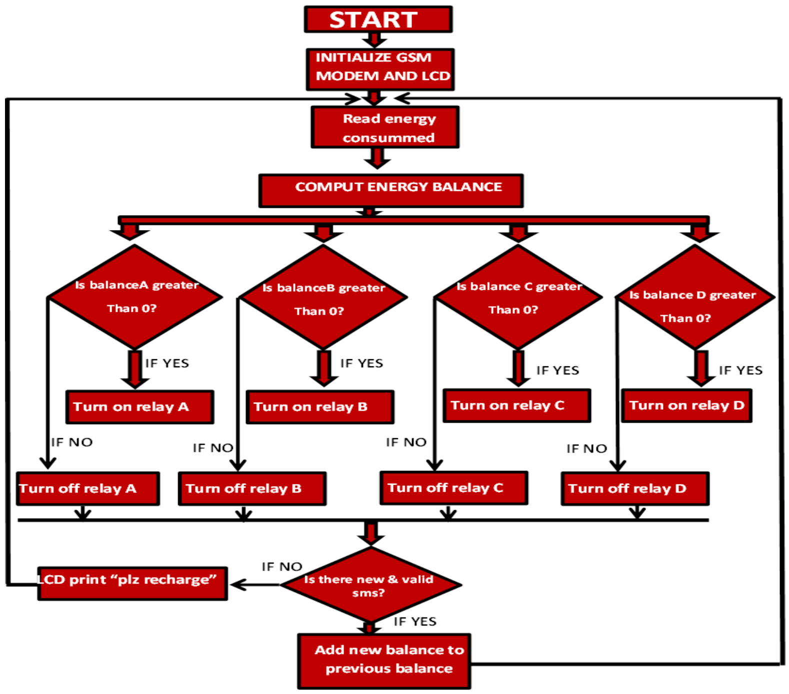

Figure 4.19 Software design flow chart of the proposed system

The codes used are screened in the figure 4.20

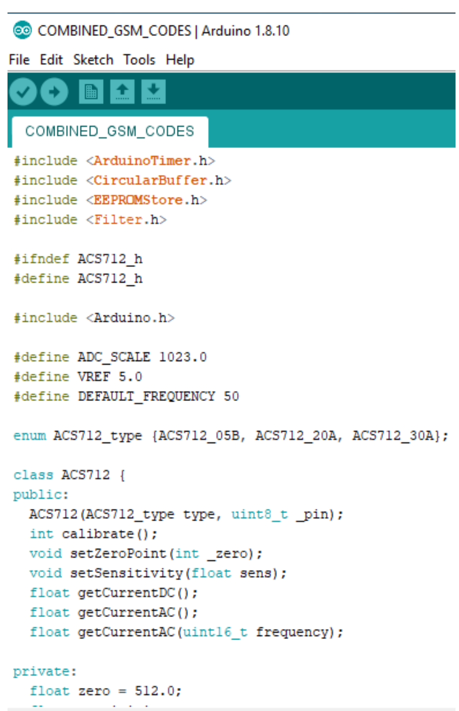

Figure 4.20 Arduino IDE

4.3. The implementation of the project

Hardware implementation was done by joining al electronic components to come up with a prototype that meets the objectives. Arduino Mega 2650, GSM module, LCD, RELAYS, current sensor were used. For implementation to be achieved, PCB (printed circuit board), soldering iron, soldering wire and casing were used.

4.3.1. Printed circuit board

PCB (Printed Circuit Board) is used to mechanically support and electrically connect electronic components using conductive pathways, tracks or signal traces fixed from copper sheets laminated onto a non-conductive board. Components are connected through the conductive material below a non-conductive board, the common conductive material used in packaged PCBs are usually copper, since copper is cheap and common. Figure below shows a typical PCB used in the project.

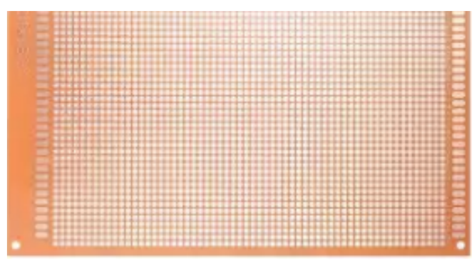

Figure 4.21 PCB layout

4.3.1.1. Fixing all components on PCB

To achieve the working prototype, all electronic components were fixed together on PCB. The figure below shows the components fixed on PCB.

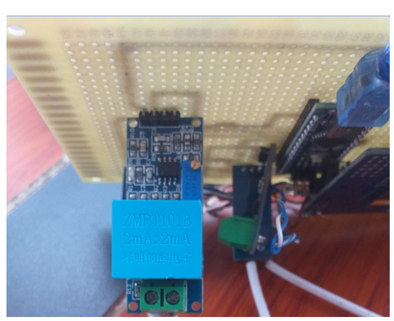

Figure 4.22 Components on fixed on LCD

5. RESULTS AND DISCUSSION

5.1. Current energy meter shared by different users without the proposed system

The current metering system without my proposed system works in such a way that if two or more users use one energy meter, individual's consumption could not be monitored by the system, consequently there is always misapprehension between the house tenants and some of the tenants feel resentful. Tenants may pay the same amount of money to buy the power with different appliances and at the end they will be isolated from the grid at the same time, and this occurs when all the existing power gets ended. In added situation the consumers may pay different amount of money and in the same way they will be isolated from the grid at the same time when all the power is used up. The next tables and graph display the nature of the consumption degree by the consumers when the proposed system is not used. The figure5.1 signifies the amount of money paid by house tenants and the corresponding power to be consumed. The energy or power consumed by individual provider was calculated according to ratios using the expression:

$$\boldsymbol{C_t = \frac{E_S}{Z} \times E_t(kWh)} \qquad (\mathbf{11})$$

Where $\mathbf{C_t}$ stands for each house tenants'allowed energy in kWh

$\mathbf{E_s}$ stands for each tenant's money in Rwf . From the tables E_s can be considered as A, B, Cor D

Z stands for the total contribution of users in Rwf. That is $Z = A + B + C + D$

E_t stands for the total energy bought in kWh to be shared by all contributors

Example: the following table shows each user' contribution in Rwf if the bought energy is 20.7 *kWh, energy allowed by each contributor can be calculated*

Table 5.1 Energy contribution by users in RWF

Users	Contribution in Rwf	Energy bought in kWh
A	500	20.7
B	1000	
C	1500	
D	2000	

$$Z = A + B + C + D = 500 + 1000 + 1500 + 2000 = 5000$$

$$\boldsymbol{C_A = \frac{500}{5000} \times 20.7\ (kWh) = 2.08\ kWh}$$

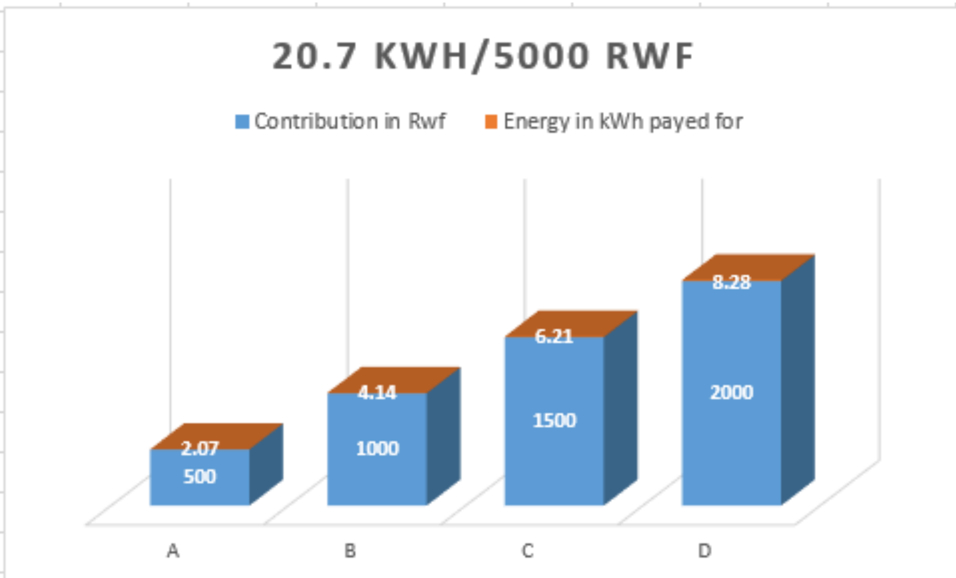

Figure 5.1 Contribution in RWF vs total energy in kWh

The figure 5.1 shows the contribution in money and the kWh corresponds to the contributed amount. Refer to the above formula, the contribution is done randomly means every family contributes regards to the pocket capabilities. After calculation, every family has the energy in kWh to be consumed. However, as they are sharing the same energy meter connected to the national grid, it not possible to manage electricity considering the energy allocated to each family. The family that contributed less consumed the same and even more compared to the family that contributed more money.

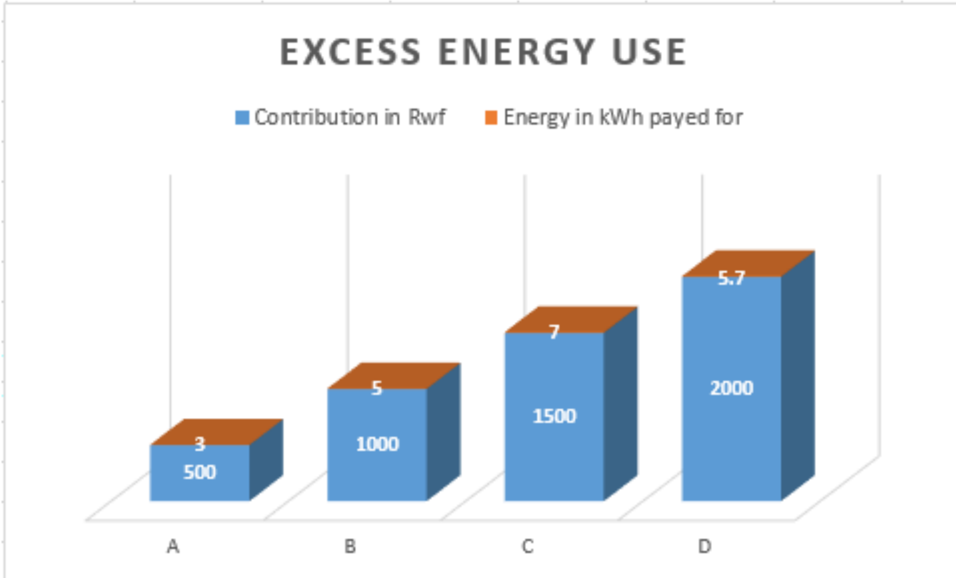

Figure 5.2 Contribution with corresponding surplus excess use of energy

The figure 5.2 shows how least contributors benefit from big contributors. This create conflicts when a big contributors end up their shares premature. Their contribution are not related to the consumption and even no one from contributor could estimate the quantity of energy used by another one. The electricity will be isolated from the grid if all energy was depleted. This was caused by the sharing the same energy meter which is not controllable.

The cheating from least contributors will be ended up with introduction of the proposed system as every contributor will consume in regards to what they contribute.

5.2. Energy management using the proposed system

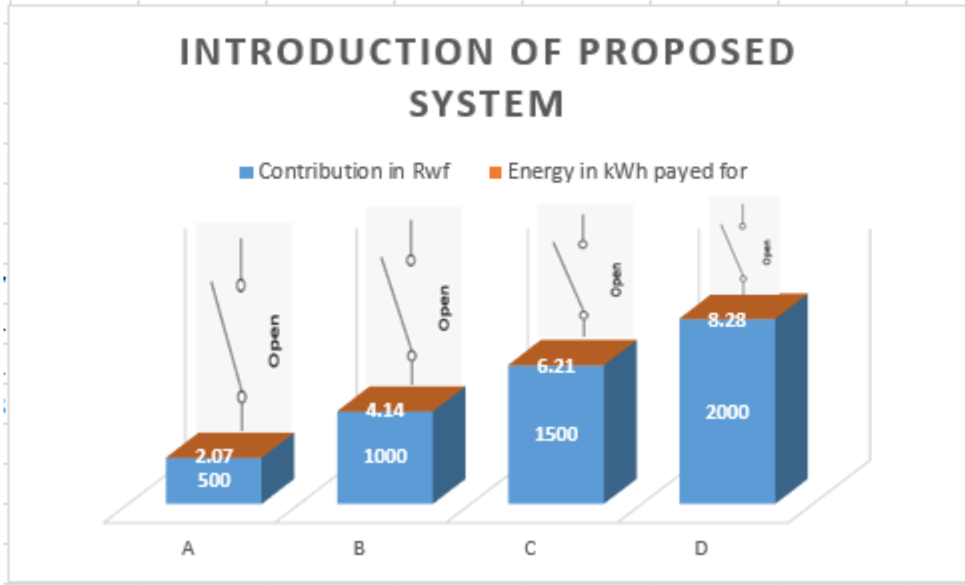

Figure 5.3 Isolation of consumers from grid if the contribution ended

As it is explained from the figure 5.2, the contributor is not able to monitor energy consumed from others sharing the same energy meter. This taken as cheating because you ended up your energy bought and continue using the share of others. The proposed system is programed with the aim of sharing energy differently based to the contribution. The sum of cash paid by each contributor is entered in to the system of Arduino that will diminish each user's energy of power based on the user's consumption rate. The system will control each contributor's consumption and isolates the user from the grid when he or she entirely consumes his or her share.

The figure 5.3 explains how the system will isolate the consumer once his or her share gets finished. The system ensures energy management as long as none will continue to use the shares of the contributors.

5.3. Simulation results

The simulation of the proposed system was done before implementation. The Proteus software was used.

During simulation, the expected results was achieved at 90 %. The project was simulated in different part to ensure the functionality of the implementation.

At the beginning when the system was off, nothing is read on LCD. When the system is ON, energy management meter is displayed on LCD as well come message. As shown by the figure below.

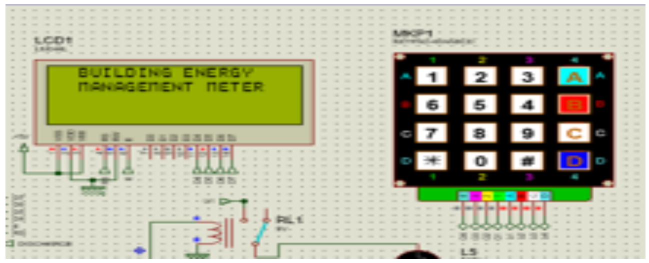

Figure 5.4 Well come note of the proposed system

5.3.1. Results when all users contribute same amount of money.

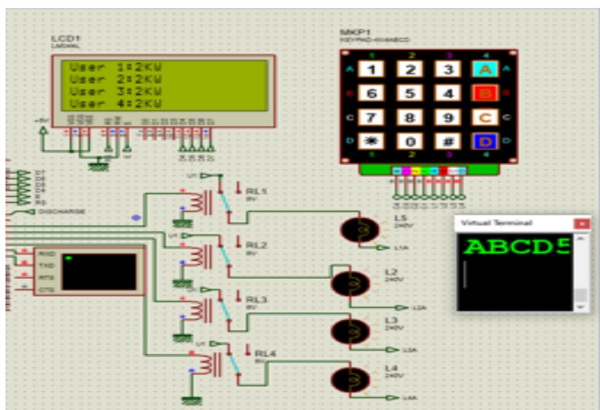

Figure 5.5 All users connected having same rated power appliances and contributing same amount of money

From the figure 5.5, all users are connected and sharing 2 kWh bought. All loads where simulated within 5 minutes. As the result, all loads were isolated at the same time from the grid. As explain from figure 5.6, the simulation shows that each user consumes his/her share without cheating from others

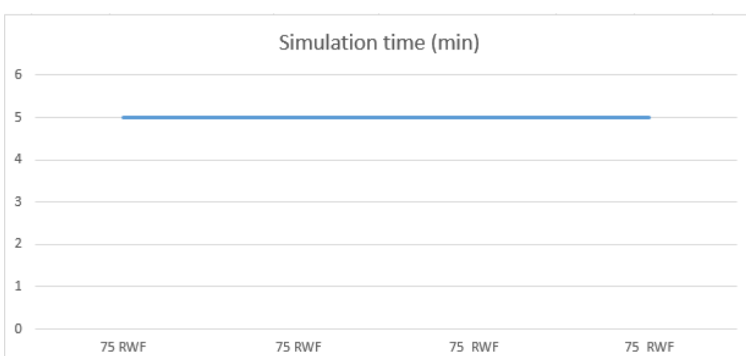

Figure 5.6 Simulation time against contribution in RWF (same contribution and same simulation time)

The current flows through each lamp is measured from ACS712 current sensor as shown from figure 5.7

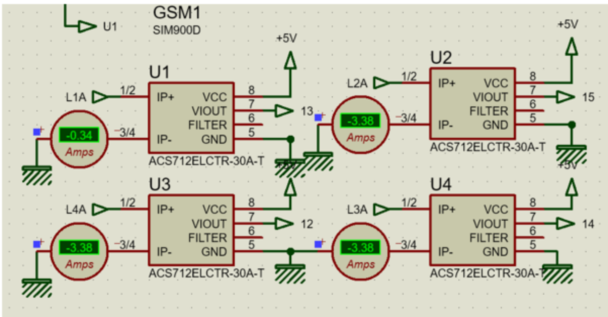

Figure 5.7 ACS sensing current flowing through each load

5.3.2. Results when all users contribute different amount of money, having same energy 2kwh.

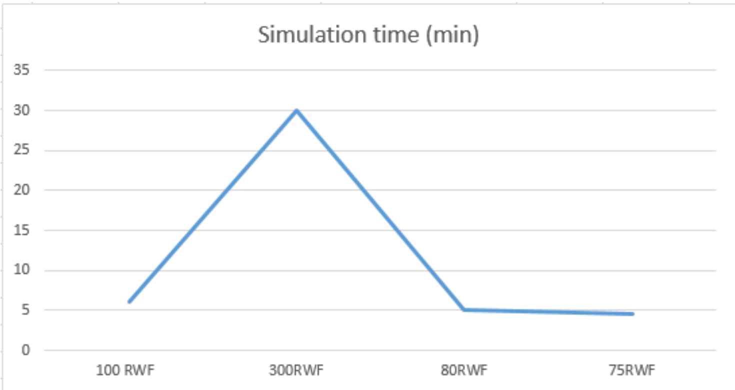

Figure 5.8 Simulation time against different contribution in RWF

From the figure 5.8, the simulation shows that the least contributor uses short time to end up his /her contribution while the more contributor uses long time to end up the contribution.

When one user ends up the contribution, the LCD displays a message of recharging again as shown from the figure below

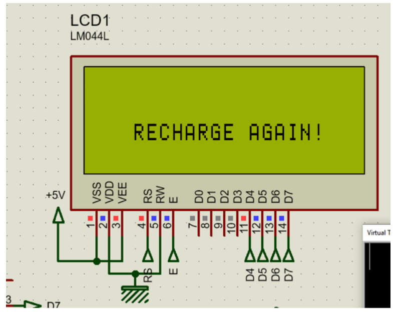

Figure 5.9 LCD displays recharge again if the contribution ends up.

5.4. Testing the prototype

After fixing all components on PCB, the codes programed for the project were transferred to the computer via serial monitor. The results found were promising because the prototype worked 85% as designed. At the beginning, the Arduino and GSM are energized. The GSM looks for nearby network available for connection. After being connected to the network, the landlord starts loading the energy into the Energy management meter. The code used to energize the house tenants using cell phone are as follow:

RH1A500, RH2B500, RH3C500, and RH4D500: The message sent by GSM meaning that house 1 is recharged by 500 RWF that corresponds to energy calculated by Arduino. For my case, for saving time; 500 RWF corresponds to 4 Wh. For normal working, 500 RWF corresponds to 2.1 kWh that corresponds to the energy given by Utility Company in Rwanda. When house 1, 2, 3 and 4 are recharged, GSM SMS back says “Recharge accepted” the figure 5.10 ;5.11 shows the screen shot of the SMS sent and received from GSM after house recharging respectively.

Figure 5.10 Recharging energy in houses via GSM SIM 900 *Figure 5.11 Message received from GSM when houses are recharged*

During testing, the results were displayed from serial monitor of the computer figure 5.12 and interpreted from the table 5.2.

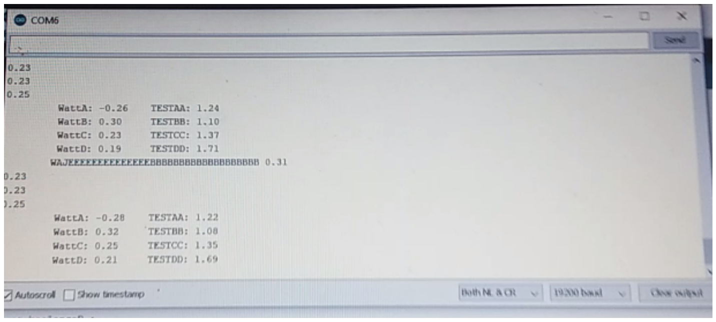

Figure 5.12 Screen shoot showing each lamp energy consumption

Table5.2 Four lamps energy consumption vs Time

Time	Lamp A (wh)	Lamp B (Wh)	Lamp C (Wh)	Lamp D(Wh)
1	2.3	3.4	2.3	4.4
2	2.2	3.3	2.2	4.3
3	2.1	3.2	2.1	4.2
4	2	3.1	2	4.1
5	1.9	3	1.9	4
6	1.8	2.9	1.8	3.9
7	1.7	2.8	1.7	3.8
8	1.6	2.7	1.6	3.7
9	1.5	2.6	1.5	3.6
10	1.4	2.5	1.4	3.5
11	1.3	2.4	1.3	3.4
12	1.2	2.3	1.2	3.3
13	1.1	2.2	1.1	3.2
14	1	2.1	1	3.1
15	0.9	2	0.9	3
16	0.8	1.9	0.8	2.9

17	0.7	1.8	0.7	2.8
18	0.6	1.7	0.6	2.7
19	0.5	1.6	0.5	2.6
20	0.4	1.5	0.4	2.5
21	0.3	1.4	0.3	2.4
22	0.2	1.3	0.2	2.3
23	0.1	1.2	0.1	2.2
24	0	1.1	0	2.1
25	2.3	1	3	2
26	2.2	0.9	2.9	1.9
27	2.1	0.8	2.8	1.8
28	2	0.7	2.7	1.7
29	1.9	0.6	2.6	1.6
30	1.8	0.5	2.5	1.5
31	1.7	0.4	2.4	1.4
32	1.6	0.3	2.3	1.3
33	1.5	0.2	2.2	1.2
34	1.4	0.1	2.1	1.1
35	1.3	0	2	1
36	1.2	1.6	1.9	0.9
37	1.1	1.5	1.8	0.8
38	1	1.4	1.7	0.7
39	0.9	1.3	1.6	0.6
40	0.8	1.2	1.5	0.5
41	0.7	1.1	1.4	0.4
42	0.6	1	1.3	0.3
43	0.5	0.9	1.2	0.2
44	0.4	0.8	1.1	0.1
45	0.3	0.7	1	0

From table 5.2, the lamps A, B, C and D consume energy refer to the amount of money payed. Lamp A and C use short time to end up the loaded units while Lamp B and D use long time to end up the loaded Units. The chart from figure 5.13 shows how lamps consuming the energy loaded.

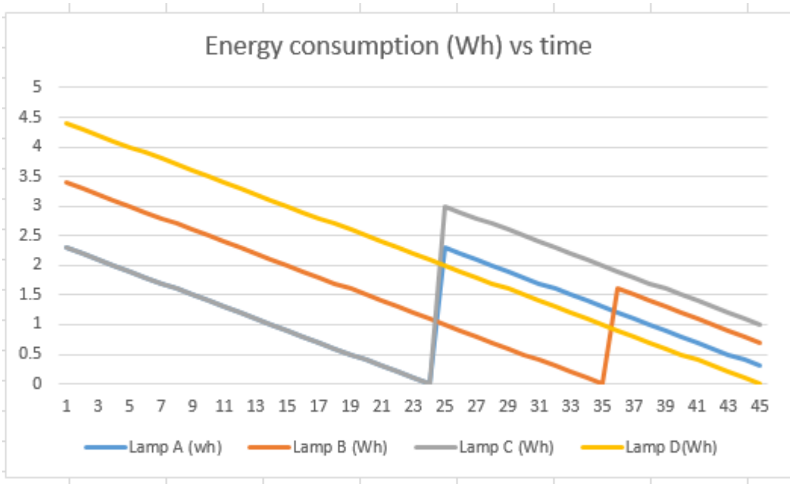

Figure 5.13 Energy consumption (Wh) vs Time

The figure 5.13 summarizes the data from table 5.2. Energy loaded into the lamps are displayed on the left side of the chart while the time is on the horizontal bottom line of the chart. For the first loading, each lamp consumes its shares. For the second loading, the lines move up and start going down. If all lamps completely deplete all energy loaded, they relays switch all lamps off.

5.5. Comparison between the current Energy meters with the proposed meter in terms of time used to consume energy loaded.

The comparison was done using different lamps of different capacity. Incandescent lamps whose rated power are: 40 W, 60W, 75W, 100W were used. Both current and implemented meter were recharged with 4Wh for each. The results found are displayed in table 5.3 and table 5.4.

Table 5.3 The energy consumption time of the current energy meter

USER	Appliance	Rated power (W)	Energy recharged (Wh)	Time of consumption (min)
A	Lamp	40	4	6
B	Lamp	60	4	4

C	Lamp	75	4	3.2
D	Lamp	100	4	2.4

Table 5.4 The energy consumption time of the proposed energy management meter

USER	Appliance	Rated power (W)	Energy recharged (Wh)	Time of consumption (min)
A	Lamp	40	4	6.23
B	Lamp	60	4	4.2
C	Lamp	75	4	3.31
D	Lamp	100	4	2.9

From table 5.12 and 5.13, the accuracy of the current energy meter is not far from the designed system. Apart from the readings, the errors can be calculated. Taking consumption time from the proposed energy management meter minus the consumption time from the current energy meter.

The average error is equal to 26%

5.6. The cost analysis of the project

Table 5.5 Implementation cost of Arduino based building energy management meter with GSM platform

S/N	ITEM	SPECIFICATION	UNIT	QTY	U.P (RWF)	T.P (RWF)
1	Arduino	AT mega 2560	piece	1	35000	35000
2	GSM Module	Sim 900	piece	1	45000	45000
3	Current sensor	ACS 712 30 A	piece	4	20000	80000
4	Voltage sensor	ZMPT101B	piece	1	18000	18000
5	Relays	10 amps	piece	4	6000	24000
6	LCD	4*16	piece	1	12000	12000

7	soldering wire	Sn-Pb, melts at 188 °C (370 °F)	roll	2	5000	10000
8	Electrical wires	1.5 msquare	meter	6	300	1800
9	Housing		piece	1	10000	10000
10	CONNECTORS		piece	1	5000	5000
TOTAL						240800

From table 5.14, the cost seems to be high compared to the existing energy meter. However, the price of the proposed system reduces the existing energy meter into four. The proposed system has 4 outputs means buying only one unit you will be able to control the energy consumption from 4 houses. It is 4 in one energy management meter. In Rwanda, supplementary energy meter with one output none individual control costs 115,000 RWF (REG). The implemented energy management meter which is controllable with four outputs cost around 250000 RWF, you can save 75 % if you use energy management meter.

5.7. Discussion

The ideation of implementing energy management meter has been accomplished with several levels of knowledges in many uses. This research work was planned based on the ability to incorporate both hardware and software technologies to design a flexible and controllable system to be used in household wiring installations. This was made possible by using a microcontroller based embedded system with other electronic circuit to stimulate a software interface to serve as a security based entity to enable the desired purpose. After implementation. The results found shows that this system may be used everywhere where many people share the same energy meter. The implemented system works at 80 % because the electronic components used are coming from where the trust is low. Sometimes GSM doesn’t connect to the network and other components present some fails caused by inaccuracy of manufacturers.

5.7.1. Social Impact

Based on the problem statements of this research work, a lot of positive impacts are reflected on the society. The problems stated above have been achieved in about 80% efficiency interface to the serial monitor of the computer, the right status of the consumption is displayed on without manually sharing of credit and calculation of load used by individuals in a household. This research work has been one of the complex systems which combine multiple schools of taught in a single unit. Using this Unit, people will be separated from conflicts presented when sharing the same energy meter. User will be independent therefore, the management of energy will be done in the collect way.

6. CONCLUSION AND RECOMMENDATION

6.1. Conclusion

Electrical energy is one of the highest entities for human life in many ways. In Rwanda the desired amount of electrical energy is distributed among individuals through energy meters. Users have cases of consumption by individuals. This research work was about the difficulties and the limitations that exist in the manual system for monitoring these systems and therefore embarked on this work to solve the problems noticed. This research work has demonstrated how to get a fully functional embedded product for monitoring the status of an electrical power usage in households and communicate the information to the user through software with minimal error conditions. This is implemented through the utilization of a dedicated electronic circuit, microcontroller and its assembly, and a graphical user interface installed at the consumer premises. The prototype was developed however some errors were presented and the objectives were achieved at 80%.

6.2. Recommendation

The presented works doesn't replace the existing energy meter. This comes to help people to manage electricity at their homes. I recommend users to use this system after being given the main meter as it is totally separate from utility energy meter. The country can invest in this project in order to help people sharing the same energy meter prevent from conflicts. Apart from having this system at their homes, I recommend user to adapt other methods using energy efficiently. Switching off lamps from unoccupied rooms, using less consuming energy appliances. Other recommendation goes to University of Rwanda/ college of science and technology; the African Center of Excellence in Energy for Sustainable development to deeply provide the means for the people working on research. I said these because without help of the center, the research could not well completed as planned.

6.3. Further Study

As show in Result section, the implemented system doesn't work 100%. It is for other researcher to deal with optimization of the codes used in the system design to achieve the complete functionality of the system. The research also should focus on looking how the errors presented by electronic components could be minimum. As planned a system with 4 outputs, the future works could develop a system with more than four outputs of power.

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APPENDIX

Software codes for the project

```
#ifndef ACS712_h
```

```
#define ACS712_h
#include <Arduino.h>
#define ADC_SCALE 1023.0
#define VREF 5.0
#define DEFAULT_FREQUENCY 50
enum ACS712_type {ACS712_05B, ACS712_20A, ACS712_30A};
class ACS712 {
public:
  ACS712(ACS712_type type, uint8_t _pin);
  int calibrate();
  void setZeroPoint(int _zero);
  void setSensitivity(float sens);
  float getCurrentDC();
  float getCurrentAC();
  float getCurrentAC(uint16_t frequency);

private:
  float zero = 512.0;
  float sensitivity;
  uint8_t pin;
};

#endif

int zero;
ACS712::ACS712(ACS712_type type, uint8_t _pin) {
  switch (type) {
    case ACS712_05B:
      sensitivity = 0.185;
      break;
    case ACS712_20A:
```

```
      sensitivity = 0.100;
      break;
    case ACS712_30A:
      sensitivity = 0.066;
      break;
    default:
      sensitivity = 0.066;
      break;
  }
  pin = _pin;
}

int ACS712::calibrate() {
  int _zero = 0;
  for (int i = 0; i < 10; i++) {
    _zero += analogRead(pin);
    delay(10);
  }
  _zero /= 10;
  zero = _zero;
  return _zero;
}

void ACS712::setZeroPoint(int _zero) {
  zero = _zero;
}

void ACS712::setSensitivity(float sens) {
  sensitivity = sens;
}
```

```
float ACS712::getCurrentDC() {
  float I = (zero - analogRead(pin)) / ADC_SCALE * VREF / sensitivity;
  return I;
}

float ACS712::getCurrentAC() {
  return getCurrentAC(DEFAULT_FREQUENCY);
}

float ACS712::getCurrentAC(uint16_t frequency) {
  uint32_t period = 1000000 / frequency;
  uint32_t t_start = micros();

  uint32_t Isum = 0, measurements_count = 0;
  int32_t Inow;

  while (micros() - t_start < period) {
    Inow = zero - analogRead(pin);
    Isum += Inow*Inow;
    measurements_count++;
  }

  float Irms = sqrt(Isum / measurements_count) / ADC_SCALE * VREF / sensitivity;
  return Irms;
}

#include <SoftwareSerial.h>

// Configure software serial port
SoftwareSerial SIM900(2, 3);
```

```
// Variable to store text message
String textMessage;
int lampState  ;
// relayC connected to pin 12
const int relayA = 10;
const int relayB = 6;
const int relayC = 8;
const int relayD = 5;
char wattA[5];
char wattB[5];
char wattC[5];
char wattD[5];
ACS712 sensorA(ACS712_30A, A4);
ACS712 sensorB(ACS712_30A, A0);
ACS712 sensorC(ACS712_30A, A1);
ACS712 sensorD(ACS712_30A, A6);
unsigned long last_time =0;
unsigned long current_time =0;
float WhA =0 ;
float WhB =0 ;
float WhC =0 ;
float WhD =0 ;


float balanceA=3  ;
float baalanceA ;
float balanceB=6  ;
float baalanceB ;
float balanceC=9;
float baalanceC ;
```

```
float balanceD=12  ;
float baalanceD ;

void setup() {

  pinMode(relayA, OUTPUT);
  pinMode(relayB, OUTPUT);
  pinMode(relayC, OUTPUT);
  pinMode(relayD, OUTPUT);

  Serial.begin(19200);
  SIM900.begin(19200);

  // Give time to your GSM shield log on to network
  delay(2000);
  Serial.print("SIM900 ready...");



  SIM900.print("AT+CMGF=1\r");
  delay(100);
  // Set module to send SMS data to serial out upon receipt
  SIM900.print("AT+CNMI=2,2,0,0,0\r");
  delay(100);

 sensorA.calibrate();
  sensorB.calibrate();
  sensorC.calibrate();
  sensorD.calibrate();
}

void loop(){
```

```
float V = 220;
  float IA = sensorA.getCurrentAC();
   float IB = sensorB.getCurrentAC();
    float IC = sensorC.getCurrentAC();
     float ID= sensorD.getCurrentAC();

  float PA = V * IA;
   float PB = V * IB;
    float PC= V * IC;
     float PD = V * ID;

  last_time = current_time;
  current_time = millis();
  WhA = WhA- PA *(( current_time -last_time) /3210000.0) ;
WhB = WhB+  PB *(( current_time -last_time) /3210000.0) ;
WhC = WhC+  PC *(( current_time -last_time) /3210000.0) ;
WhD = WhD+  PD *(( current_time -last_time) /3210000.0) ;

   dtostrf(WhA, 4, 2, wattA);
    dtostrf(WhB, 4, 2, wattB);
     dtostrf(WhC, 4, 2, wattC);
      dtostrf(WhD, 4, 2, wattD);



  if(SIM900.available()>0){
    textMessage = SIM900.readString();
    Serial.print(textMessage);
    delay(10);

  if(textMessage.indexOf("RH1A500")>=0){
```

```
    // Turn on relayC and save current state
     Serial.print("RECHARGE ACCEPTED");



  Serial.print(textMessage);
 textMessage = "";

    balanceA=  balanceA+10;



     Serial.print( balanceA);

balanceA;



String message = "RECHARGE ACCEPTED " ;
    sendSMS(message);
   // Serial.println("Lamp state resquest");
    textMessage = "";
}

if(textMessage.indexOf("RH2B500")>=0){
    // Turn on relayC and save current state
     Serial.print("RECHARGE ACCEPTED");

  Serial.print(textMessage);
 textMessage = "";
    balanceB=  balanceB+10;

  balanceB;
     Serial.print( balanceB);
```

```
String message = "RECHARGE ACCEPTED " ;
    sendSMS(message);
   // Serial.println("Lamp state resquest");
    textMessage = "";

}

if(textMessage.indexOf("RH3C500")>=0){
    // Turn on relayC and save current state
     Serial.print("RECHARGE ACCEPTED");

  Serial.print(textMessage);
 textMessage = "";
    balanceC=  balanceC+10;

  balanceC;
     Serial.print( balanceC);

String message = "RECHARGE ACCEPTED " ;
    sendSMS(message);
   // Serial.println("Lamp state resquest");
    textMessage = "";



}

if(textMessage.indexOf("RH4D500")>=0){
    // Turn on relayC and save current state
     Serial.print("RECHARGE ACCEPTED");
```

```
 Serial.print(textMessage);
textMessage = "";
  balanceD=  balanceD+10;

 balanceD;
   Serial.print( balanceD);



String message = "RECHARGE ACCEPTED " ;
  sendSMS(message);
 // Serial.println("Lamp state resquest");
  textMessage = "";
}

 }

 if(textMessage.indexOf("OFF")>=0){
  // Turn off relayC and save current state
  digitalWrite(relayC, HIGH);
  lampState = "off";
  Serial.println(textMessage);
  textMessage = "";
 }
 if(textMessage.indexOf("rr")>=0){
   lampState = "off";
  String message = "Lamp is " + lampState;
 // sendSMS(message);
  Serial.println("Lamp state resquest");
  textMessage = "";
 }
```

```
 //500:20000w,   1000:   4000w,   2,000:   8000w,   5000w:20000,   10,000:   40000w,   20,0000:
80,0000w

baalanceC=balanceC-WhC;

//baalanceC=balanceC-WhC;
baalanceA=balanceA+WhA;
  baalanceB=balanceB-WhB;

      baalanceD=balanceD-WhD;

if( baalanceA<=1.0) {
   // delay(1500);
     Serial.print( "\t RECHARGE AGAIN " );
     digitalWrite(relayA, LOW);
}else{

if( baalanceA>=1.0) {
 digitalWrite(relayA, HIGH);

}}
if( baalanceB<=1.0) {
   // delay(1500);
     Serial.print( "\t RECHARGE AGAIN" );
     digitalWrite(relayB, LOW);
}else{
if( baalanceB>=1.0) {
   Serial.print( "\tLM 317T IN CIRCUIT REGULATION " );
 digitalWrite(relayB, HIGH);
```

```
}}

if( baalanceC<=1.0) {
   //delay(1500);
    Serial.print( "\t RECHARGE AGAIN " );
    digitalWrite(relayC, LOW);
}else{
if( baalanceC>=1.0) {
 digitalWrite(relayC, HIGH);

}}

if( baalanceD<=1.0) {
  //delay(1500);
    Serial.print( "\t RECHARGE AGAIN " );
    digitalWrite(relayD, LOW);
}else{
if( baalanceD>=1.0) {
 digitalWrite(relayD, HIGH);

}}
Serial.println( IA);
Serial.println(IB);
Serial.println(IC);
Serial.println(ID);

   Serial.print( "\t WattA: " );
   Serial.print(wattA);
    Serial.print( "\t TESTAA: " );
    Serial.print( baalanceA);
```

```
  Serial.println();
    Serial.print( "\t WattB: " );
    Serial.print(wattB);
     Serial.print( "\t TESTBB: " );
     Serial.print( baalanceB);



  Serial.println();
     Serial.print( "\t WattC: " );
     Serial.print(wattC);

      Serial.print( "\t TESTCC: " );
     Serial.print( baalanceC);

  Serial.println();
      Serial.print( "\t WattD: " );
      Serial.print(wattD);

       Serial.print( "\t TESTDD: " );
     Serial.print( baalanceD);
  delay(1000);
  Serial.println();

}

// Function that sends SMS
void sendSMS(String message){
  // AT command to set SIM900 to SMS mode
  SIM900.print("AT+CMGF=1\r");
  delay(100);
  SIM900.println("AT + CMGS = \"+250788868255\"");
```

```
  delay(100);
  // Send the SMS
  SIM900.println(message);
  delay(100);

  // End AT command with a ^Z, ASCII code 26
  SIM900.println((char)26);
  delay(100);
  SIM900.println();

  delay(2000);
}
```