



ASHESI

ASHESI UNIVERSITY COLLEGE

CAPSTONE FINAL REPORT

CAPSTONE PROJECT

B.Sc. Computer Engineering

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ASHESI UNIVERSITY COLLEGE

**A SMART ENERGY MONITOR FOR COMPOUND HOUSES THAT USE ONE
SHARED METER**

CAPSTONE PROJECT

Capstone Project submitted to the Department of Engineering, Ashesi

University College in partial fulfilment of the requirements for the award of

Bachelor of Science degree in Computer Engineering.

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2019

DECLARATION

I hereby declare that this capstone is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere. Candidate's

Signature:

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Candidate's Name:

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I hereby declare that preparation and presentation of this capstone were supervised in accordance with the guidelines on supervision of capstone laid down by Ashesi University College.

Supervisor's Signature:

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Date:

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Abstract

The project proposed a method of reading individual energy consumption by tenants living in a compound house but share a single meter. The smart energy monitor was designed using ATmega8, SIM8001, PZEM004T, I2C LCD ,SCT-013-000 current sensor. The smart energy monitor solves the problem of bill sharing in compound house that share one meter. The printed circuit board was design ed using Eagle and the program for the system was programmed in the Arduino IDE in c language in Arduino syntax. The proposed method of reading energy from individual rooms using the smart energy monitor was successful. The smart energy monitor was able to read the energy consumed by two tenants on the LCD display and also sent them an SMS to inform them on the amount of energy they consumed at the end of the month.

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Chapter 1: Introduction

1.1 Introduction/ Background

A compound house was and still is in some areas of Ghana, a human habitat for extended families mostly in rural areas in Ghana. However, compound houses are used now for commercial purposes. The rooms are rented out to individuals who seek shelter in rural and urban areas. These individuals are referred to as tenants and the owner of the building as the Landlord. Compound houses are a cluster of rooms that usually take the shape of U, L or fully enclosed [1]. The rooms are generally a single room or two rooms (also known as Chamber and hall). Tenants share a general washroom, and they take turns in cleaning it [1]. The toilets are not the only facility the tenants share; they also share a public water source and in some cases an electrical meter.

A shared meter in compound houses is a common phenomenon. However, this comes with its problems. The arrears of electrical bills are accumulated and shared amongst tenants. Research during a Poverty and Social Impact assessment (PSIA) for Ghana's energy sector stated a challenge for tenants in compound houses. The challenge is keeping track of which proportion of arrears of electrical bill belongs to a tenant in a compound house[1]. The problem brings about so many uncertainties and correspondingly cause unrest between the tenants and their Landlords. Tenants find it challenging to come to a consensus on the terms of electrical bill-sharing [1]. The reason is that the amount of electricity consumed by the tenant cannot be monitored since all the tenants share one meter.

Therefore, this project aims to help eliminate the problems that arise when it comes to sharing the bill. This is going to be done by monitoring the amount of electricity each tenant consumes. This will help equitably share the accumulated arrears with ease based on the amount of power consumed by each tenant.

1.2 Problem Definition

Accumulated arrears that arise from the use of electricity by tenants in a compound house that shares a meter raises an electricity bill-sharing problem — keeping track of the consumption of each resident and what proportion of energy they use is not done. Not keeping track of the energy consumption of each resident makes it challenging to share the bills amongst them. Some tenants pay more for electricity than they consume and others pay less than they consume.

1.3 Objectives of the Project Work

- Understand the project with more research to be able to innovate and come up with an efficient and more effective solution.
- Design and build a PCB board (printed circuit board) to support the solution of reading and displaying the electricity consumption by tenants living in a compound house with a shared meter.

1.4 Expected Outcomes of the Project Work

- Research that will result in the acquisition of knowledge that will inspire an innovation that will help resolve the problem at hand in the most efficient way.
- The outcome is to design a smart energy meter that has the ability to reading the electricity usage of each tenants living in a compound house.
- Also, the output of the energy monitor should be able to solve the problem at hand to affect the lives of individuals living in compound houses with one meter, positively.

1.5 Justification/ Motivation for Project Topic

This is a problem so many Ghanaians living in compound houses with a shared meter face. However, not much attention is given to the plight of these tenants and their Landlords. The purpose of this project, therefore, seeks to provide notice to them, learn from them and offer the appropriate solution for the problems that arise when the time for sharing the electricity bills in these houses come up. This affects the revenue stream of the electricity company in Ghana. Hopefully, the project solves the issues that arise from this area as well.

1.6 Research Methodology to be used

The research methodology to be used include;

- Desk research [2]: This is research done behind a computer in the comfort of one's office or home or a conducive environment.
- In-depth Interview [3]: A personal interview with residents of compound houses that share one meter.

1.7 Materials to be used for the research

The primary materials to be used include;

- Current sensors
- Global System for Mobile Communication (GSM)
- Voltage regulators
- Micro-controllers
- Integrated circuits

1.8 Scope of Work

The focus of this project will be compound houses found in Accra, Ghana. The project lasts for two academic semesters and therefore will be SMART to focus on a particular compound house in Accra from the lot that falls into the category under study (Compound houses with shared meter).

The scope of the project will, therefore, be to design the smart energy monitor by;

- Designing the schematic for the system
- Translating the schematic design in a printed circuit board (PCB)
- Adding a GSM to send an SMS alert system for the smart energy meter
- Assemble the various components on the PCB
- Testing to ensure the system works as it should

Chapter 2: Literature Review

2.1.0 Review Paper 1 on Smart Components for a Smart Energy Meter

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2.1.1 Abstract

This paper is interested in smart devices, and one of the intelligent devices discussed is a smart energy meter. This energy meter measures the electricity consumption and the time-of-use information of the utilities and consumers. However, to build such devices, specific vital components are needed. This paper clearly outlines the elements required to develop a smart energy meter coupled with their specifications and descriptions [4].

2.1.2 Introduction

Smart devices control and coordinate other devices upon receiving signals from a coordinating device or by a user. The intelligent energy meter can measure power consumption and inform the user on a timely basis. The purpose of these smart energy devices is to facilitate a reduction and shift in overall energy consumption by averaging out the energy consumed regularly and on a timely basis. The results from the readings from the energy monitor can be recorded on a database over the internet where the user can access whatever information available. Designing these smart energy meter takes into consideration the cost, reliability, and scalability of developing one. Some of the components considered include a current transducer, a Global System for Mobile Communication (GSM), voltage regulators, a micro-controller and an energy metering integration

circuit. The parts above are what the paper discusses, the different types available, their specifications and descriptions. It ends by stating the advantages and disadvantages of smart parts [4].

2.1.3 Component Specification And Description

Unlike other papers, this paper does not have a methodology since it is not an experiment. It introduces the components directly. The first component is the **Current Transducer**. There are four different types of current transducers in this paper. They include LA 55-P Current Transducer, ACS712 current sensor, Winson WCS1500, and SCT-013-000. Current transducers convert current into proportional voltages that are needed for further processing [4].

LA55-P	ACS712	WINSON	SCT-013-000
<ul style="list-style-type: none"> • Operating range: -40°C to 85°C • Voltage range: +/- 12V and +/-15V • Nominal RMS current: 50A • Current range: 0 to 70A • Bandwidth: 200kHz 	<ul style="list-style-type: none"> • The range of current: -30A to 30A • Current flowing is a proportional equivalent of voltage • Voltage Range: +/- 30V • Bandwidth: 80kHz 	<ul style="list-style-type: none"> • Sensing range: 0 to 200A for DC (direct current) • 0 – 150 A for AC (alternating current) • Operating range: 0 to 12V • Bandwidth: 23kHz • Isolation Voltage: 4000V 	<ul style="list-style-type: none"> • Current range: 0 to 100A (AC) • Input frequency: 50Hz to 150kHz • Operating range: -25°C to 70°C

Table 2.1: Comparison of current sensors

Another component is the **GSM module**; this helps in the transmission of information.

Table 2 outlines some GSM modules that can be used for such a project [4].

SIM300	SIM 800	SIM900
<ul style="list-style-type: none"> • Operating voltage: 7V-15V AC or DC. • Current consumption 0.25A normal operation and 1 A during transmission • 3V onboard lithium battery 	<ul style="list-style-type: none"> • Quad-band: 850/900/1800/1900 MHz • Class 2/10 GPRS data connect • Operating voltage range: 3.5V to 4.4V • Operating temperature range: -40°C to 80°C 	<ul style="list-style-type: none"> • Dual band 900/1800 MHz • Connects to 12V/2A DC • Operating temperature - 20°C to about 55°C

Table 2.2: Comparison between GSM modules

The paper talks about stepping down the voltage using voltage regulators such as LM317 or a step-down transformer. The purpose of the step-down transformer is to convert high-voltage low current power to low voltage, high current power. However, the disadvantage of using a step-down transformer is a fluctuation with the design. On the other hand, LM317 has an adjustable 3-terminal positive voltage output regulator. The output voltage range is from 1.5V to about 37V. The input to an output differential voltage is about 40V at the maximum [4].

A key component in the development of a smart energy monitor is the micro-controller. This paper listed seven different types of microcontrollers that can be used. They include:

- PIC development board
- Arduino development boards
- MSP-430 Micro-controller Development board
- Renesas Development Kit

- ARM-32 bit Development Board
- Arm Cortex M Development board
- 8051 Development board

This component will act as a brain to the entire energy monitor. The various micro-controllers have their specifications that give its readers the option of choosing which micro-controller they will need to build their smart energy meter. This is dependent on how the reader wants to design and develop his/her smart energy meter.

The last but not least component is the smart power meter Integrated circuit (IC). Per the paper, the smart-power metering ICs provide an alternative to current transformers. A few smart-power metering ICs include:

- 71M6541x
- ADE77xx
- STPMxx
- MCP3909 IC

Each integrated circuit has unique features that when used will give exceptional results of how the smart-energy meter will function. Like the other components, the smart-power meter integrated circuits have a pool of options that a smart energy designer can select.

2.1.4 Advantages and Disadvantages of smart component

Advantages	Disadvantages
<ul style="list-style-type: none"> • Reduced circuitry space • Fewer shock risks are involved 	<ul style="list-style-type: none"> • Components are a bit expensive

<ul style="list-style-type: none"> • Reduced labour costs • Easier installation procedures • Highly accurate and reliable • Highly Efficient • Very much portable 	<ul style="list-style-type: none"> • Replacement of the whole element is necessary when a part is damaged • The same type of element for replacement is not available most of the time
--	--

Table 2.3: The advantages and disadvantages of smart components

[4]

2.1.5 Limitations in the paper

Individuals who seek to design and build a smart energy meter will find this paper very helpful since it outlines the major components needed to make an energy monitor successfully. It gives one the ideas of what to look for in designing an energy monitor. However, it does not explain how these components are connected. A beginner who seeks to build a smart energy meter cannot quickly identify and make sense of how the various parts work together. There was no complete sample of a smart energy meter to give the beginner an idea of how he or she can best modify it to suit his or her purpose.

2.1.6 Addressing limitations

The relation of the various components should have been specified to give clear understanding to individuals, who are amateurs, in designing and intending to build a smart energy meter. How the components interface with one another is essential for communication between the components.

A sample of an already built smart energy meter should be added to give a more vivid illustration of how the components work together in developing one. This will provide more insights to individuals who intend to build a smart energy meter.

2.1.7 Conclusion

The paper clearly defined some significant components required to build a smart energy meter. It gives the specifications and descriptions for each element. It also offers different types of each component making available different options to choose from to design a smart energy meter. The advantages and disadvantages of the smart components were listed as well.

2.2.0 Review paper two on GSM-Based Smart Energy Meter with Arduino Uno

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2.2.1 Abstract

The paper proposed a Smart Energy Meter that allows users to monitor their current power consumption using mobile phones through Short Message Services(SMS). Arduino UNO was used as the microcontroller for the project. Along with the Arduino UNO was the Global System for Mobile Communication (GSM) module and an Energy meter. The GSM connects the energy meter to the User's mobile phone while the Arduino UNO serves as the interface between the GSM and the energy meter. Other components used were the Real Time Clock (RTC) to get the real-time count and store the usage into the EEPROM. The code for the system was in C language with the

Arduino syntax. The proposed system demonstrated its capability to check the current usages and its ability to notify the user when it reaches the limit, reset the current usage successfully, only by accessing the GSM-based mobile phone[5].

2.2.2 Introduction

An electricity meter or energy meter is a device that measures the amount of electric energy consumed to residence or business. Single phase and three phases are the two types of Domestic Ordinary Power Consumers meters. Units are in Kilowatt-hours. Smart electrical energy meter technology has been investigated and developed for about ten years. For billing, the users get the information on the energy board where the energy consumed is displayed, unlike the traditional electro-mechanical watt meters whose readings are not automated. Users usually had to wait till the end of the month to pay their bill [5]. Staff from the meter board billing often visited every house to read meters and give users the electricity bill. The electronic meters were designed to replace the electro-mechanical meters from analogue to digital system [5]. The users were able to read the voltage, power, current, time and date of consumption. However, after the electronic meters, meter readings developed with the Bluetooth based technology for wireless communication it was known as the Automatic Meter Reading (AMR)[5]. However, the technology evolved from using AMR to using GSM in recent years[5].

2.2.3 Overview of the System

The system consists of two parts, the Hardware and the Software. For the hardware, the primary components include Energy meter, LCD, lamps as load, GSM module SIM900, Atmega328, Real-Time-Clock (RTC) and a light to voltage converter (TSL257). The energy meter

chosen for the project was a single-phase meter from Smart Meter Technology Sdn. Bhd. The reason for selecting this energy meter was because it has clear blinking LED indicator for a 1Wh pulse and has a direct pulse output connection that is compatible with Arduino.

The SIM900 was chosen for this project because it is a complete quadband GSM/GPRS solution in an SMT module which can be embedded in the customer applications [5]. The GSM module selected for the project also delivers GSM/GPRS 850/900/1800/1900MHz performance for voice, SMS, Data, and Fax in a small form factor and with low power consumption [5]. Other technologies that could be used besides the GSM per the paper include Bluetooth and ZigBee [5].

The microcontroller used for the project was an Arduino UNO, and the host processor is the Atmel Atmega328. ATmega328 is equipped with three main memory sections which include Flash programmable read only memory (EEPROM), Static random access memory (SRAM) and byte addressable EEPROM for data storage. The Arduino UNO is what is the 'Standard' Arduino board and readily available.

The real-time clock (RTC) used was DS1307. It is a low power, full binary-coded decimal (BCD) clock. It communicates with the Arduino over I2C connection. RTC was used to get real-time counting and storing the bill in the EEPROM. The presence of the RTC enables the ability to reset the bill at the end of every month.

The light to voltage converter (TSL 257) was used as an interface energy meter to the Arduino. It is also known as a sensor because it detects light and converts it to voltage. The system also included a Liquid crystal display(LCD) to act as an output display to show the bill, unit and GSM status on the meter. The LCD used was a 16 X 2 alphanumeric LCD which consists of 16 characters and two lines.

The software part of the project was developed in C language with the Arduino syntax in the Arduino IDE. The project used Arduino IDE to program, create, debug and upload the coding into the micro-controller. The parts that needed programming were the digital write input/output, GSM network, Real-time clock and EEPROM. To achieve success in the programming each component specified above, the various libraries were specified.

The scope of the project was that;

- The remote monitoring of the energy meter was installed at a residential house
- The sensor was placed close to the LED flash indicator of KWh energy meter, and Arduino counted the pulse as one pulse = 1 Wh when LED is blinking
- The user sets the limit of energy consumption using SMS, for example, the limit RM50
- The Arduino count the pulse continuously
- The user received SMS from the Energy Meter after the energy consumption reach the limit
- User sent "mymeter" as the command to ask the current unit of energy consumption and the price.
- The Energy Meter replied the SMS to the user which contain Unit and RM.
- The counter was reset to zero at the 1st date for every month, and the user received the last bill.
- The user also can reset by their own with sending message "reset" to the system when needed.

2.2.4 Results and Discussion

In this section of the paper, the results of the project were stated and discussed. Here the authors discussed both successes and problems faced during the implementation of the system. Two parts were combined to make up the system. The parts that were combined to make up this system were the hardware and software parts. The hardware handled the circuit for interfacing the energy meter with the Arduino and the interfacing of the GSM module to the Arduino. Each component in the hardware played a significant role in the success of the project. The reason it was successful was that the elements were carefully configured to communicate with one another seamlessly.

The software part was responsible for loading the program code into Arduino. If the user wants to check for their current bill, they send 'mymeter' to the energy meter. The energy meter responds via SMS to the user informing them about their current bill.

However, before the system worked successfully, some problems arose during the setup and testing of the system. The LCD was not working correctly; this was caused by the pulse input from the energy meter to Arduino could not connect directly from the "pulse output connection" at the meter. The problem was solved by using the TSL257 light to voltage converter as the interface between the energy meter and the Arduino. The interfacing was done using the digital write and digital read command. Another problem was that the Arduino RAM was not enough when compiling the microSD card coding, and the solution was replacing the microSD with an EEPROM for data storage.

2.2.5 Conclusion

The project proposed a new approach to monitoring the current bill using Arduino UNO as a micro-controller and GSM module as an interface with the users mobile phone. It gives the users the flexibility to monitor their power consumption from anywhere provided they have a signal on their

mobile phone. This only works for single phase residential only. The results showed that the system works successfully.

2.3.0 Review paper three on GSM Based Automatic Energy Meter Reading System with Instant Billing

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2.3.1 Abstract

The paper presents the design of a simple, low-cost wireless GSM energy meter and its associated web interface, for automating billing and managing the collected data globally. The proposed system replaces the traditional meter reading methods and enables remote access of existing energy meter by the energy provider. The readings can also be done without the staff from the electricity company visiting each house regularly. A GSM-based wireless communication module is integrated with an electronic energy meter of each entity to have remote access over the usage of electricity. The billing point is a PC with a GSM receiver at the other end; it contains the database. A friendly user interface is developed using Microsoft Visual Studio. Monthly usage of electricity and bill is messaged back to the user after processing the data.

2.3.2 Introduction

The traditional meter reading by human operators is inefficient to meet future residential development needs (cite). Therefore, the need for Automatic Meter Reading (AMR) systems, which collect meter readings electronically, have increased. Electricity utility meters are essential to help reduce the cost of utilities to customers and the cost of delivering services to the service provider. With the traditional electro-mechanical meters, the authors stressed on how inefficient the collection of meter readings is and also added that it was more problematic and costly when readings have to be collected from vast, and often scattered rural areas (cite). Therefore, to solve the problem of physically collecting meter readings, the paper proposed an electronic energy meter that will automatically sense the energy, continuously record the readings and send the information to the billing point through a GSM network. The web-based system software is used to generate the bill and send it to the customer as SMS (Short Messaging System).

2.3.3 GSM Meter – Architecture

The Automatic Meter Reading (AMR) was developed in three main parts, which include;

- A digital GSM power meter installed in every individual consumer unit
- Transmission facility (SMS gateway)
- Billing server at the side of the energy provider

This proposed system does not require human efforts to read meter and users can directly know the amount they have to pay at the end and can even pay the bill online.

2.3.4 Detailed Design

Similar to other papers on Energy meters, this project was designed in two parts, the hardware and the software. The hardware is composed of the Micro-controller (PIC16F877), Liquid crystal display (LCD 20 x 4), Energy Metering IC (MCP3905A) and GSM Modem (Fargo Maestro-20). Some essential things considered during the hardware design were the power supply to the microcontroller and other devices that need power. High voltages could destroy the microcontroller especially; therefore, the voltage that goes into the microcontroller was dropped to 5V. Another was External EEPROM memory. The EEPROM used was Atmel 24C256 for data storage for offline processes. It stores the amount of unit consumed while transferring each SMS. A Real Time Clock (RTC) was used to maintain the real time and date in offline processing. The RTC counts seconds, minutes, hours etc. The RTC used was DS1307, a low cost, easy to solder and durable.

The software design was developed in Mikroelektronika's MikroC PRO 4.15 IDE for the microcontroller. The PIC microcontroller was programmed through the In-System Programming (ISP) interface. For the graphic user interface design for e-billing, managing all received SMS readings, regularly updating the database, computing the monthly bill amount and notifying the consumer his/bill detail via SMS, Microsoft Visual Studio 2008 was used to develop the web portal.

2.3.5 Conclusion

Per the paper, the developed system is highly effective in that sense that it can eliminate the drawback of serial communication. This means that though it lacks acknowledgement of the sent SMS, that does not affect the performance of the system. Also, the system poses much less safety risk since human interaction is minimized. Last but not least, the system can be modified by using

the latest SPI metering ICs which will provide more parameters. From the paper, it made it clear that using the GSM to broadcast the billing information in the system had numerous advantages over physically reading the system by humans. Reducing the human interaction with the system increased the efficiency of the system.

2.4 Benefits from Review Papers

The above papers that have been reviewed extensively are the influencers of the project. They are what helped in knowing what components are needed when building a smart energy meter, how the components communicate with one another and most importantly gave the assurance that whatever this project is about is possible. These papers gave a better understanding of the dynamics systems like the smart energy metering system. These papers did not only help with getting the hardware components but also helped in understanding the software behind the smart energy metering system. The second paper, for example, gave ideas as to what libraries to look out for when programming the micro-controller in Arduino. Also, it discussed the successes and failure of the project giving its readers a heads up of the kind of problems to expect when working on energy metering systems. A beginner, knowing nothing about how these systems work, will find it easier to understand these systems and be able to design one by themselves.

2.5 Critique

The primary critique on these papers will be the grammar errors which can be pardoned because the content of the documents was beneficial. However, with review paper one, the components were listed and extensively discussed, but it did not explain how these components function together in the system.

Chapter 3: Design

3.1 Review of Existing Designs

Current energy monitoring devices such as the sense energy monitor, Neurio Home energy monitor, Eyedro EHEM1 TED Pro Home Electricity Monitor and Efergy Engage Hub all are designed centrally for self-contained houses and not compound dwellings [7]. The first two can detect individual devices, and the other three are not able to recognize different devices. However, the smart energy monitor project intends to design an energy monitor for compound houses that share one meter. It should be able to detect the individual electrical consumption of tenants living in the compound house. The ability to identify the individual energy consumption by residents will make electric bill sharing fair amongst them. The device should be able to display the information on an LCD and also send messages to the phones of the end users (the tenants) for alerts.

3.2 Design Objective

There are three main areas in designing the energy monitor. The areas include the power system to the microcontroller with A/D converter and D/A converter to provide intelligence and Communication on the interface, which allows the meter to interact with the rest of the grid and end user's network. The aim is to ;

- Design the circuitry of each area
- Merge them as one unit
- Print the circuitry on a board (PCB)
- Assemble all the components (i.e. The PCB and Casing)
- Write a program for the device

3.3 Design Decisions

The choice of materials for the project is essential and therefore needs critical attention. To get the appropriate components for designing the device a Pugh chart matrix is adopted. The Pugh matrix is utilized to help narrow down the vast choice of components that could be used for the project. The criteria for choosing the materials include low cost, availability and durability.

After the components are chosen, the circuitry of the selected components will be designed using a software known as Eagle. The various connections will be made based on the three areas which include the power system, the micro-controller and the communication interface. The connections will be obtained from the datasheets of the chosen components. For the power system, the right amount of voltage needs to be channelled to the Micro-controller which takes 5 V [8], and the GSM module also takes 4 V [9]. Any voltage above 5V and 4V will damage the Micro-controller and the GSM module respectively. The microcontroller needs to be able to process data that gets in at a reasonable amount of time. The communication interface, which helps the end user understand what happens within the smart energy monitor is the GSM module. The GSM module helps in sending the information via SMS to the end user's mobile phone. These three areas will be tackled one after the other and then merged as one unit. Each area plays a significant role in the design of the device. Without one, the others will not function correctly or to their full potential.

Software forms part of this project. The software project will be done the Arduino IDE in C language and Arduino syntax. The micro-controller will have to be programmed to do energy calculations, and the GSM will also have to send SMS to end users to alert them on how much energy was consumed at the end of the month. There will be a flow chart to show the programming of the system.

Another crucial decision to take proper notice of is the wiring of the compound house. There are different ways compound houses are wired. From ground research, some compound houses have their rooms wired separately and independent off one another. Others have the room wiring interconnected with one another, where a wiring system run through two or more rooms. Others wire rooms in pairs, where two rooms share one wiring connection. However, these are what was gathered from ground research by visiting compound houses and interacting with some tenants. Some compound houses have a room that is wired illegally. There are more complicated situations when it comes to wiring houses. The tenants said they do this because obtaining a meter from ECG is bureaucratic. However, the focus of this project is to design the energy monitor for compound houses that have their rooms separately wired and independent of one another but share one meter.

3.4 Assumptions

Smart energy monitors for compound houses that share one meter have complications that will have to be explored in future developments. The difficulties arise from the manner of wiring of the compound houses. Some rooms in the compound house are not wired separately, i.e. some rooms share the same wiring. Rooms that share the same wiring will make it difficult to detect the individual energy consumption of residents of the compound house. However, the scope of this project does not permit the exploration of these complex situations and therefore will have to be simplified to understand the problem better. Understanding the problem better will then form the baseline for future research into the complex spheres of the problem. Therefore, for the scope of this project, the following assumptions were made.

- Rooms in the compound house were wired separately and independent of one another.
- The electrical connection of the compound house is a single phase connection.

3.5 Pugh Matrix

A Pugh Matrix is a type of matrix diagram that allows for the comparison of several design candidates leading ultimately to which best meets a set of criteria [10]. The criteria used for the selection of the components for this project are availability, cost and durability. Availability will have to do with how easily accessible are the components are, the cost will be to check how expensive or cheap a part is concerning other candidates, and lastly, durability has to do with how long the component can last in the environment in which they will be used. The Pugh matrix was designed to select between a variety of Micro-controllers, Energy metering ICs, GSM and Current sensors. The component that best meets the criteria is what will be chosen for this project. Table 4, 5, 6 and 7 show the Pugh matrices of components that qualified for selection. However, the component will first have to meet the criteria to be selected.

Micro-controller	Criteria	Baseline	Weight	A	B
		Atmega328		Atmega8	PIC16F877
	Availability	0	5	+1	-1
	Cost	0	4	+1	-1
	Durability	0	3	-1	+1
Weighted Score		0		+6	-6

Table 3.1: Pugh matrix for Micro-controller selection

Energy Metering IC	Criteria	Baseline	Weight	A	B
		ADE7757		MCE3905	ADE7763
	Availability	0	5	+1	-1
	Cost	0	4	+1	-1
	Durability	0	3	0	0
Weighted Score		0		+9	-9

Table 3.2: Pugh matrix for Energy Metering IC selection

GSM module	Criteria	Baseline	Weight	A	B
		SIM900		SIM800L	SIM7000
	Availability	0	5	+1	-1
	Cost	0	4	+1	-1
	Durability	0	3	0	0
Weighted Score		0			

Table 3.3: Pugh matrix for GSM module selection

Current sensor	Criteria	Baseline	Weight	A	B
		SCT-013-000		WCS1500	ACS712
	Availability	0	5	-1	-1
	Cost	0	4	-1	+1
	Durability	0	3	+1	0
Weighted Score		0		-6	-1

Table 3.4: Pugh matrix for Current sensor selection

From the tables, it is observed that there is a baseline component and two alternative components (i.e. A, B). The baseline is a component chosen to be the standard, and the other components are compared to that baseline. The criteria are weighted based on which one is of the highest priority [10]. For this project, availability is of high priority followed by the cost of the component and durability is of the least priority. The baseline has a default score of zero (0) for

all criteria. When the other components best meet the criteria than the baseline, they get a plus one (+1), and when they are worse, they get a minus one (-1). In the end, the scores are multiplied by their respective weights and summed. Taking Micro-controller as an example in table 4;

Criteria	Baseline	(A) Weight x Score	(B) Weight x Score
Availability	0	5 X +1 = +5	5 X -1 = -5
	0	4 X +1 = +4	4 X -1 = -4
	0	3 X 0 = 0	3 X 0 = 0
Summation	0	+9	-9

Table 3.5: Example of how the weighted score was obtained

+9. Therefore, with this information option, A will be chosen over the other options.

With the help of the Pugh matrix, the various components were chosen for the project, Atmega8 as the micro-controller, MCE3905 as the energy metering IC, SIM800l as the GSM module and the SCT-013-000 as the current sensor. The components mentioned above best met the criteria of the Pugh matrix.

Chapter 4: Implementation

4.1 Hardware Implementation

Some components and a software (Eagle) are needed to design the Printed Circuit Board of the smart energy monitor. The components include;

- Non-intrusive/ Non-invasive Current Sensor – (SCT-013-000)
- An energy metering IC - (MCP3905)
- Micro-controller - (ATmega 8)
- I2C LCD 20x4
- GSM module - (SIM800L module)
- Voltage regulators - (LM7805, AZ1084)
- Switch mode power converter

The Non-invasive current sensor, SCT-013-000, was used to measure current from the wires [11] MCP3905 supplies current real power measurement for single-phase [12], residential energy-metering. ATmega 8 is the microcontroller responsible for the processing of the data from the MCP3905. I2C LCD displays the outputs on the screen. The GSM with some programming sends alert in the form of text messages to the tenant to inform him/her how much energy he/she has consumed at the end of the month. The switch mode power converter, LM7805 [13] and AZ1084 [14] all help in dropping down the high voltage from the mains to the various components that need relatively low voltages to operate effectively.

However, in designing the PCB, all these components need to be able to communicate properly with one another and also configured properly. The configuration is to ensure that the right voltage

and current are being supplied to the various parts of each component. Figure 4.1 shows the communication between the components;

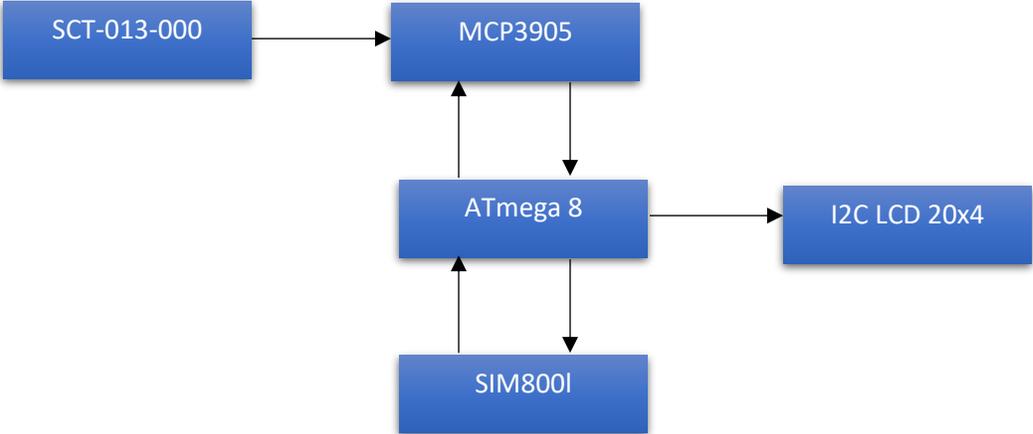


Figure 4.1: Communication between components of the smart energy monitor

Figure 4.1 influenced the schematic design of the smart energy monitor on Eagle. On Eagle the configuration for the MCP3905, ATmega 8 and SIM800I were what was displayed. The other components such as the SCT-013-000 and the I2C LCD were connected to terminal ports and pin headers respectively. The current sensor and LCD are the input and output devices respectively.

Figure 4.2 shows the eagle schematic design and PCB design of the smart energy monitor:

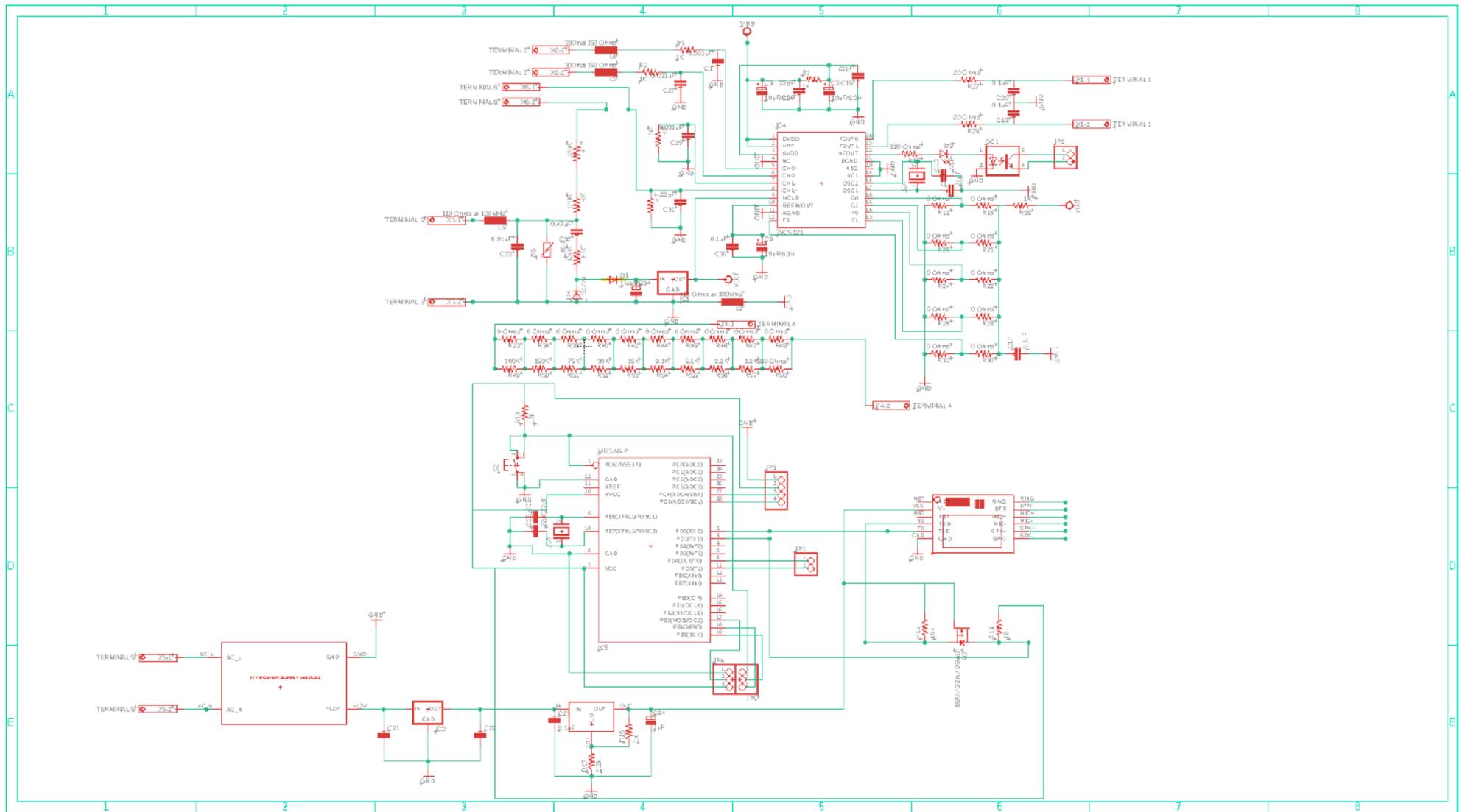


Figure 4.2: Eagle schematic design of the smart energy monitor

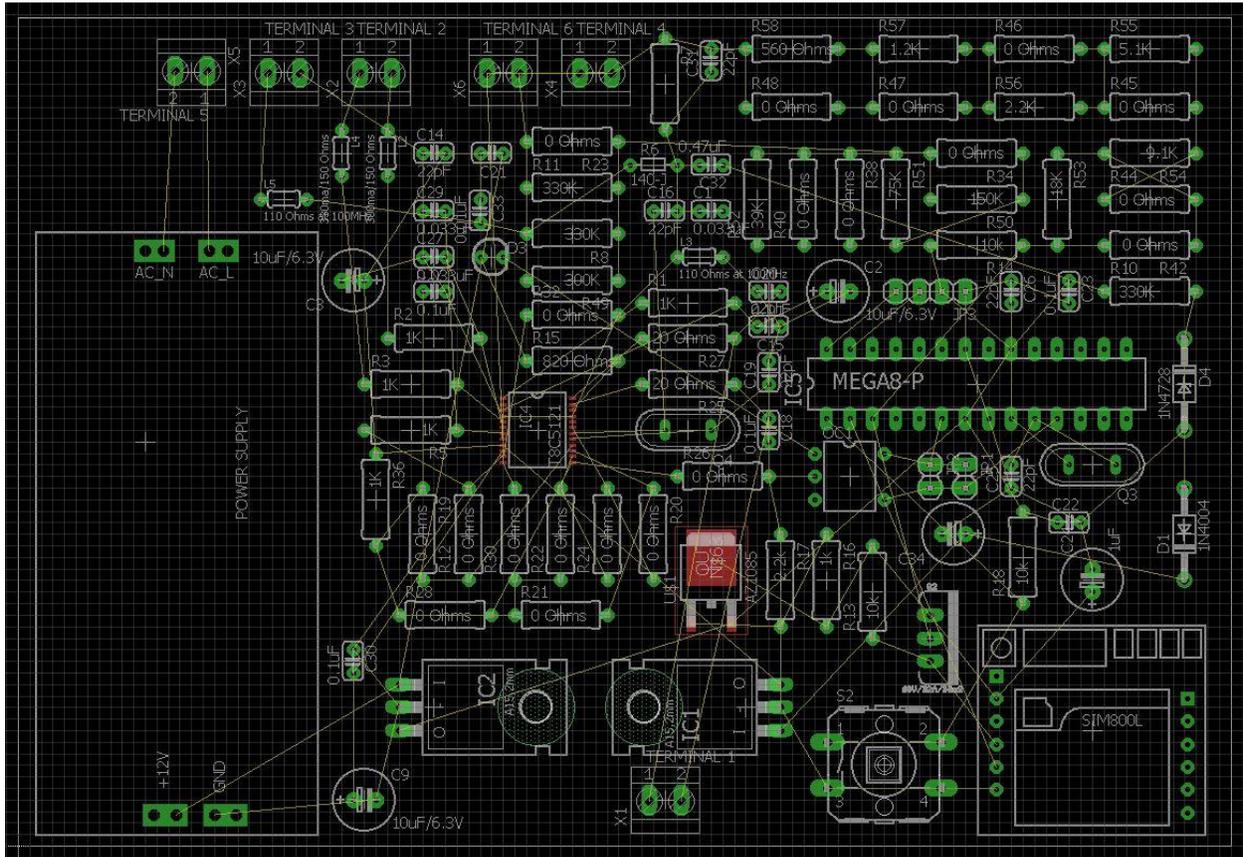


Figure 4.3: Board design of the smart energy monitor

The first eagle schematic in Figure 4.2 is translated to what is seen in Figure 4.3. The board design of the smart energy monitor is shown in figure 3. However, this schematic was revised to reduce the size of the board. The initial size of the board was 91.11mm in width and 14.60mm in length. Figure 4.4 and figure 4.5 is the second schematic and board designs respectively. The new dimension of the board is 74.60mm in width and 96.50 in length. How this was achieved was that the resistor divider calibration in figure 4.1 was removed to and replaced with calibration potentiometer. The resistor divider calibration has a series of weighted resistors, with shorting jumpers for each [15]. The resistor divider calibration needs fixed individual resistor values while with the potentiometer calibration values can be varied [16]. These resistors took up so much room

on the board in the first design as it is shown in figure 4.3. In the second design, in place of the resistors, potentiometers were adopted to help reduce the number of resistors on the board in figure 4.3, thereby, reducing the size of the board.

Another way of reducing the board was removing the switch mode power converter which drops the voltage from high voltages to +12 V. It was needed to set up down the voltage to 12V and drop the 12V down to 5V with the help voltage regulator LM7805. On the board, in figure 4.3 it is observed that the switch mode power converter takes so much space on the board. Therefore, it was removed and replaced with terminal blocks on the board. That means instead of placing the power supply on the board directly a channel has been provided to supply the power to the board. The main purpose of doing that was to reduce the size of the board.

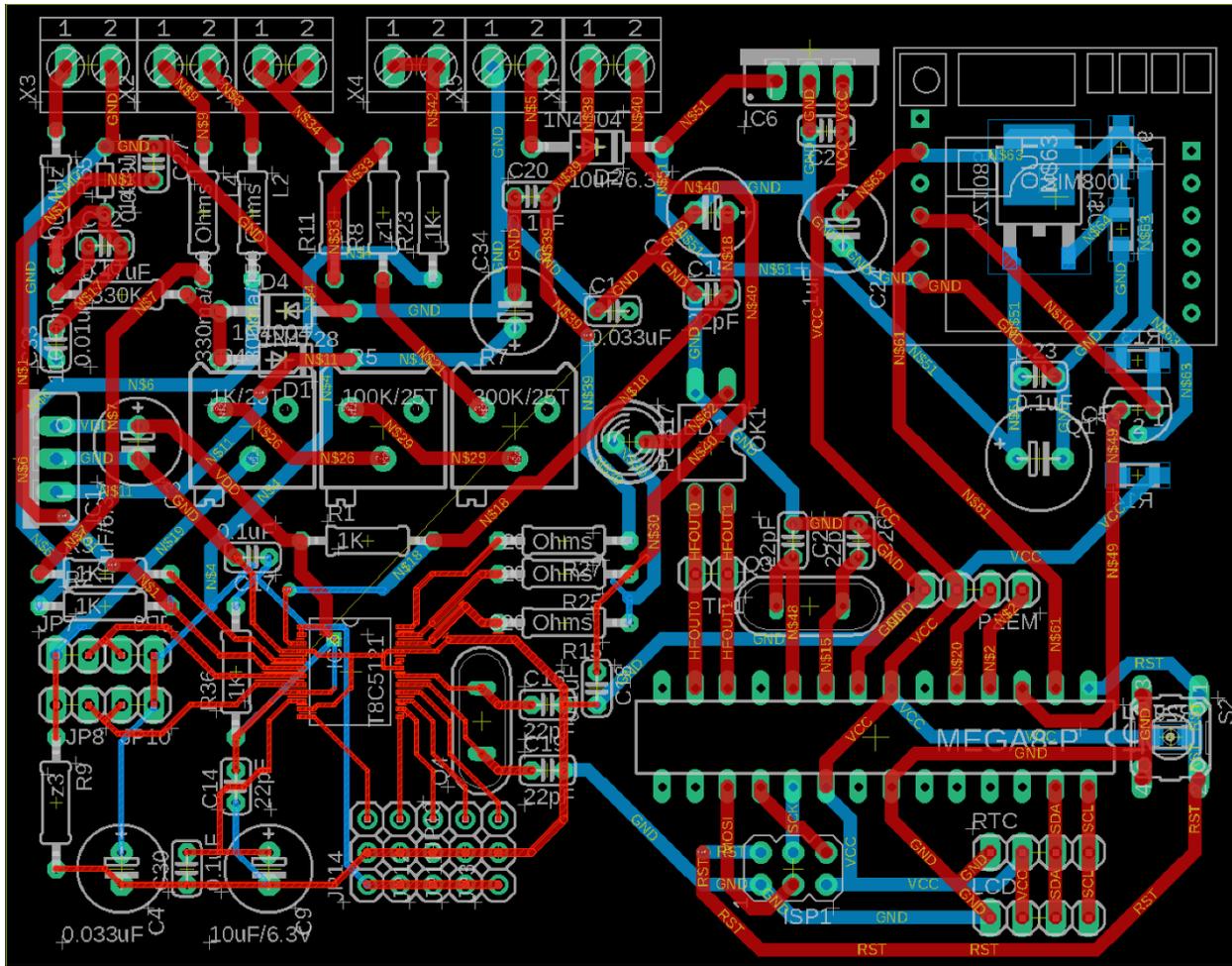


Figure 4.5: Routed board design of the revised schematic design of the smart energy monitor

For the first schematic and board design, i.e. figure 4.2 and figure 4.3 respectively, was achieved by tackling the design in three different ways. The first was to get the right connections to the MCP3905 to get it to function as it should and its communication with the micro-controller. The second was to get the link from the SIM800L module to the microcontroller and to ensure that they can communicate effectively. Ensuring that the SIM800L module and the ATmega 8 were communicating was not all about connecting the Rx of the SIM800L module to the Tx of the ATmega 8 and vice versa. Where Rx and Tx are receiver and Transmitter respectively. The communication between the two was slightly complicated. The two components need different voltages to operate. The ATmega 8 needs 5V and SIM800L module also need 4V due to this

difference in operational voltages, the 5V that goes to the ATmega 8 needs to be regulated to 4V and 2A for the SIM800L. The third and final one is the power system. In the first design from figure 2, 240V is converted to 12V by a switch mode power converter which is then later regulated to 5V by LM7805. AZ1084 is used to control the 5V to a 4V for the SIM800L to consume.

Figure 4.4 and 4.5 is a new schematic and board design. With the new design, another channel for a second current sensor was added to the design. Adding the second current sensor will allow reading from two different rooms instead of just reading one in the first design — four pin header connections to the ATmega8 for the PZEM004T. The PZEM004T gives room to add another current sensor to the system [17].

The connection made on the energy metering IC, MCP3905, was influenced by two reference design documents on MCP3905. The final connection of the MCP3905 on the smart energy monitor design was a combination of the two reference design documents. Figure 4.4 shows the new connection made on the MCP3905. The two papers are MCP3905/6 Evaluation Board User's Guide and MCP3905A/06A Energy Meter Reference Design. Figure 4.6 and 4.7 show the connections made in the documents stated above on the MCP3905 energy metering IC.

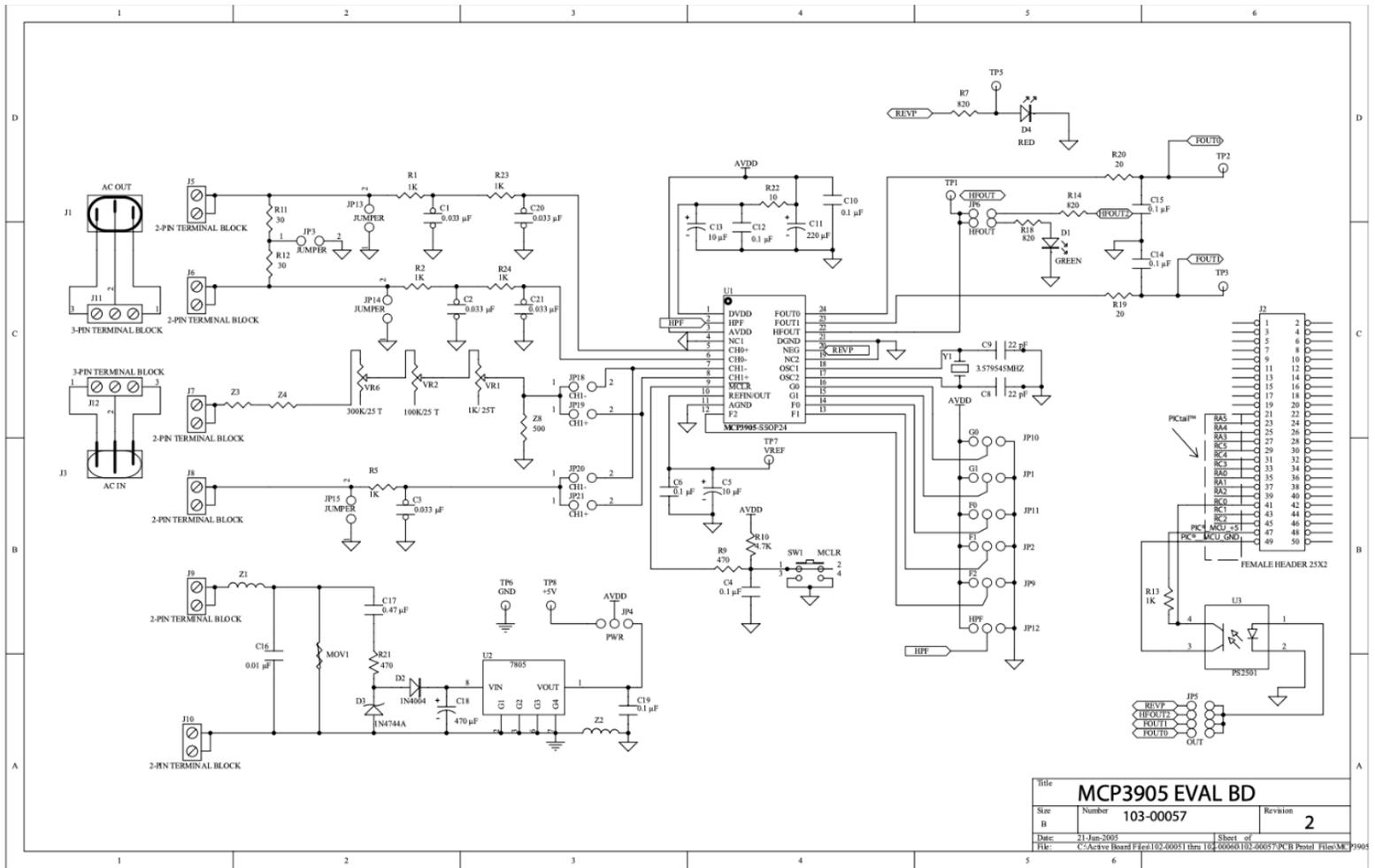


Figure 4.6: MCP3905 connections from the MCP3905/6 Evaluation Board User's Guide document

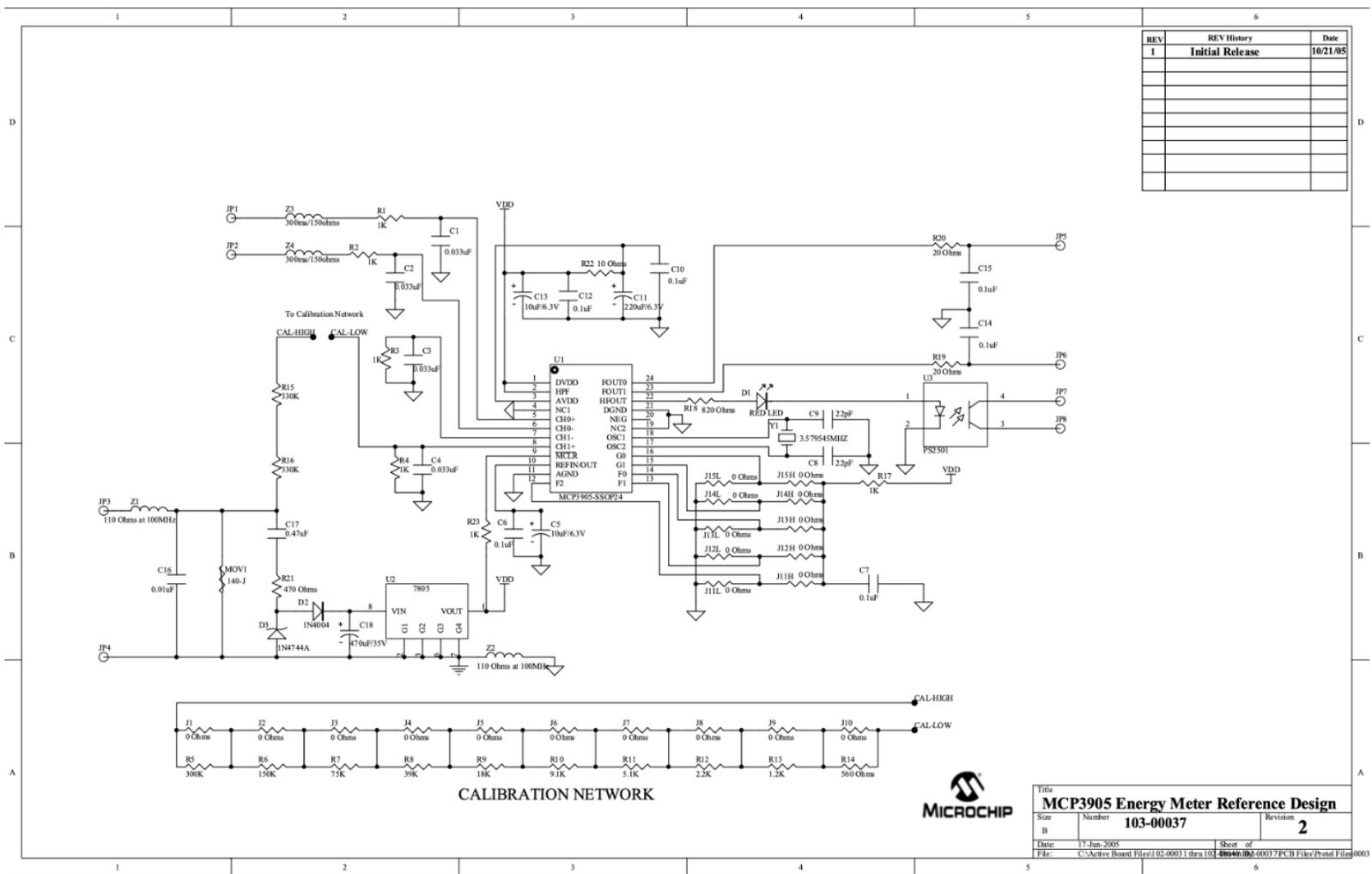


Figure 4.7: MCP3905 connection from the and MCP3905A/06A Energy Meter Reference Design document

[18]

The schematic at the top of figure 8 is the connections made on the MCP3905. It was inspired by figure 4.6 and figure 4.7. In the new schematic design shown in figure 4.8, the calibration network in figure 4.7 was replaced with the calibration network in Figure 4.6. In figure 4.7, a resistor divider calibration was used for the calibration network. This calibration network took up to much space on the board. To reduce the size of the board, a new calibration network was used from figure 4.6 which used potentiometers for the calibration network. Also, in figure 4.7 there were zero (0) ohm resistors acting jumpers. The zero ohm resistors were replaced with pin headers on the new design in figure 4.8. Using pin headers will make it easier to do connections using jumper wires.

To power the GSM module, SIM800l, which takes 4V and a peak current of 2A, the initial idea was to use a voltage divider to drop the 12V coming from the power source to 4V for the SIM800l. However, The voltage divider does not provide sufficient current for the SIM800l. Equation 1 is the calculation for the voltage divider;

$$V_{out} = V_{in} \cdot \frac{R_2}{R_1 + R_2} \dots\dots\dots$$

Equation 1

Where V_{in} = input voltage

V_{out} = output voltage

R_1 and R_2 are the resistor values. Where $R_2 = 1k$ ohm and R_1 is unknown

Expected V_{out} is 4V, and V_{in} is 12V. To find R_1 , Make R_1 the subject in equation 1.

$$R1 = \frac{(Vin - Vout)R2}{Vout}$$

.....Equation 2

Substitute the values $V_{out} = 4V$, $V_{in} = 12V$, $R2 = 1k \text{ ohm}$ into equation 2.

The results is $R1 = 2k \text{ ohms}$.

Knowing the resistor values make it possible to determine the current (I) using the equation;

$$I = \frac{Vin}{Req} \dots\dots\dots$$

Equation 3

Where V_{in} is input voltage, 'I' is current and R_{eq} is the resistance equivalence, which is the sum of the two resistors involved.(i.e. $1k \text{ ohm} + 2k \text{ ohm} = 3k \text{ ohm}$)

$$I = \frac{12V}{3k \text{ ohm}} = 0.004 \text{ A} \dots\dots\dots$$

Equation 4

The current produced as a result of the voltage divider is 0.004A, which is not sufficient for the SIM8001. The solution, therefore, was to use a voltage regulator, AZ1084 to generate the right voltage and current to the GSM module. AZ1084 stepped down the 12V input voltage to 4 V for the SIM8001.

A MOSFET, 2N7000, was used to help with the communication between the SIM8001 and the Atmega8. The Atmega8 takes 5V and SIM8001 takes 4V, therefore, connecting them directly, which is the Rx of the Atmega8 being connected to the Tx of the SIM8001 and vice versa will cause communication problems. The 5V from the Atmega8 will be fed to the SIM8001 which take a maximum voltage of 4 V. Therefore; a voltage level conversion is required to allow successful

bi-directional communication between the Atmega8 and the SIM800l [19]. How the voltage level conversion works to control the low side is that the low side device which is the SIM800l transmits a '1' (i.e. 4V), the MOSFET is off and the high side which the Atmega8 receives 5V through the pull-up resistor[19]. However, when the low side transmits '0'(i.e. 0V), the MOSFET source pin is grounded, and the MOSFET is turned on, and the high side is pulled down to 0V [19]. To control the high side, when it transmits a '0', the MOSFET substrate diode conducts a pull down on the low side, low enough to turn on the MOSFET. When the high side transmits, a '1' the MOSFET goes off because the source pin is pulled up to 4V.

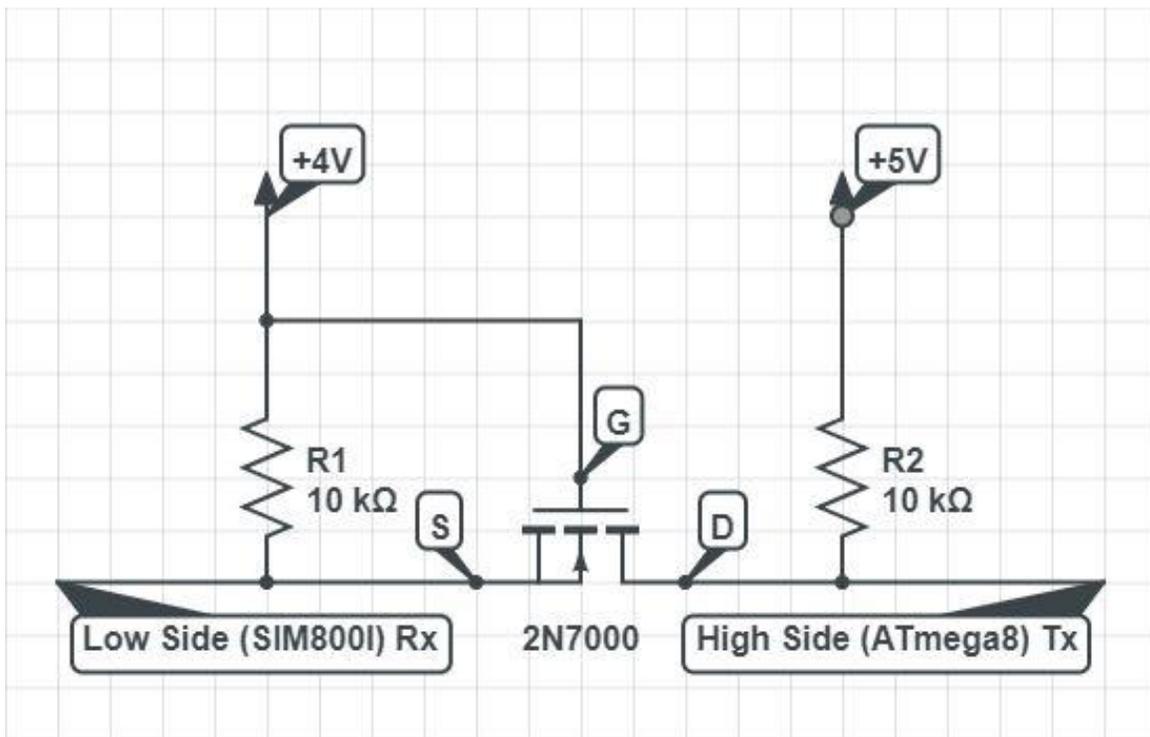


Figure 4. 9: Visual representation of how the Atmega8 and the SIM800l will communicate.

Figure 4.9 shows the connection that was done in the schematic to provide effective communication between the SIM800l and the ATmega8. The low side in figure 9 is connected to the receiving end (Rx) of the SIM800l, and the high side is connected to the transmitting end (Tx)

of the ATmega8. However, the Tx of the SIM800l can be connected directly to the Rx of the ATmega8.

4.3 Software Implementation

For the software part of the project, the procedure was listed. The process includes;

- Supply the meter with power
- Connect current sensor the desired room wire
- The current sensor feeds the energy metering IC with the information it receives
- The IC supplies the active real power measurement to the micro-controller
- Micro-controller does the energy calculations
- Sends output to the LCD
- Sends another output to the GSM
- The GSM sends the SMS to the end user as an alert

The software is responsible for the micro-controller energy calculation to the GSM sending the SMS to the end user. Therefore, the program will be written for the Atmega8 to do the energy calculations and the SIM800l to send the SMS. Figure 10 shows the flow chart for the software part of the smart energy monitor.

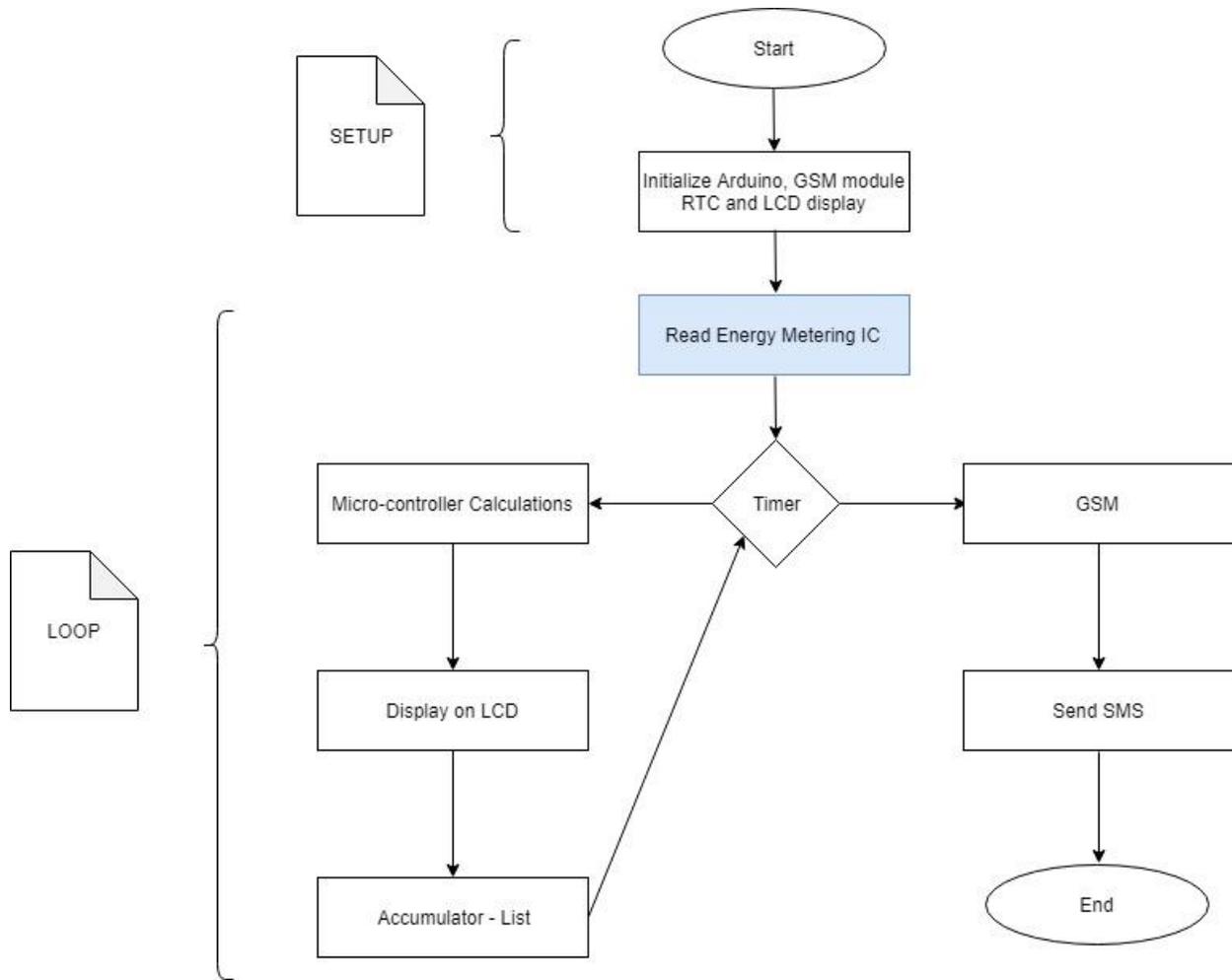


Figure 4.10: Flowchart of the for programming the system.

In the program, the components to be programmed were initialized. Components such the GSM, RTC and were initialized. The library used for this project were LiquidCrystal_I2C.h, SoftwareSerial.h. Sim8001.h, DS3231.h for the RTC, PZEM004T.h and Wire.h. The LCD was programmed to display the Room number, Voltage, Energy used and the bill at the end of the month. Figure 11 shows the snippet of the Arduino LCD code for displaying the parameters stated above.

```

lcd.setCursor(0, 0);
lcd.print("Room 1: ");
lcd.print(Roomnum1);
lcd.setCursor(0, 1);
lcd.print("voltage1: ");
lcd.print(v1);
lcd.setCursor(0, 2);
lcd.print("Power1: ");
lcd.print(p1);
lcd.setCursor(0, 3);
lcd.print("Amount: ");
lcd.print(amt1);
delay(5000);
lcd.clear();

lcd.setCursor(0, 0);
lcd.print("Room 2");
lcd.print(Roomnum2);
lcd.setCursor(0, 1);
lcd.print("voltage2 ");
lcd.print(v2);
lcd.setCursor(0, 2);
lcd.print("Power2");
lcd.print(p2);
lcd.setCursor(0, 3);
lcd.print("Amount");
lcd.print(amt2);
delay(5000);

```

Figure 4.11: Extract of the LCD display code

Also, the code for sending the SMS informing the tenants their bill for the month is shown in figure 12.

```
Sim8001.begin(); // initialize the library.
text="Room 1 your bill for this month is: " + amt1 ; //text for the message to tenant in room 1.
number="0201390586"; //number of tenant in room 1
error=Sim8001.sendSms(number,text);
text1="Room 2 your bill for this month is: "+ amt2; //text1 for the message to tenant in room 2.
number1="0265073522"; //number1 of tenant in room 2
error=Sim8001.sendSms(number1,text1);
```

Figure 4.12:Code extract for sending of SMS to tenants

The Real-time clock (DS3231) was used to keep track of real time. For every 720hrs (30 days) it is supposed to send an SMS to the tenants. The average number of days in a month is about 30 days, and when 30 days is multiplied by 24 hours, the output is 720hrs [20]. For this project, the RTC was programmed to send the SMS after every 1hr.

Chapter 5: Results

5.1 Expect Results

The results expected from the smart energy monitor design is to be able to display the electricity bill of tenants living in a compound that share one meter. It is also expected to reveal the voltage, current and power on the I2C LCD 20x4. Also, this system is supposed to be able to send the information at the end of every month to the users of the system. The SIM8001 module will be responsible for sending the message to the users or clients.

5.2 Actual results

The results expected were obtained. However, some parameters could not be displayed on the LCD because the LCD could display four parameters. It is a 20x4 LCD meaning it has 20 columns and four rows. The parameters that were shown were The room number, the voltage, the energy and the electricity bill at the end of the month. The SMS was also sent to two different people informing them about their electricity bill. The SMS was sent at the same time to the two different people acting as the tenants.

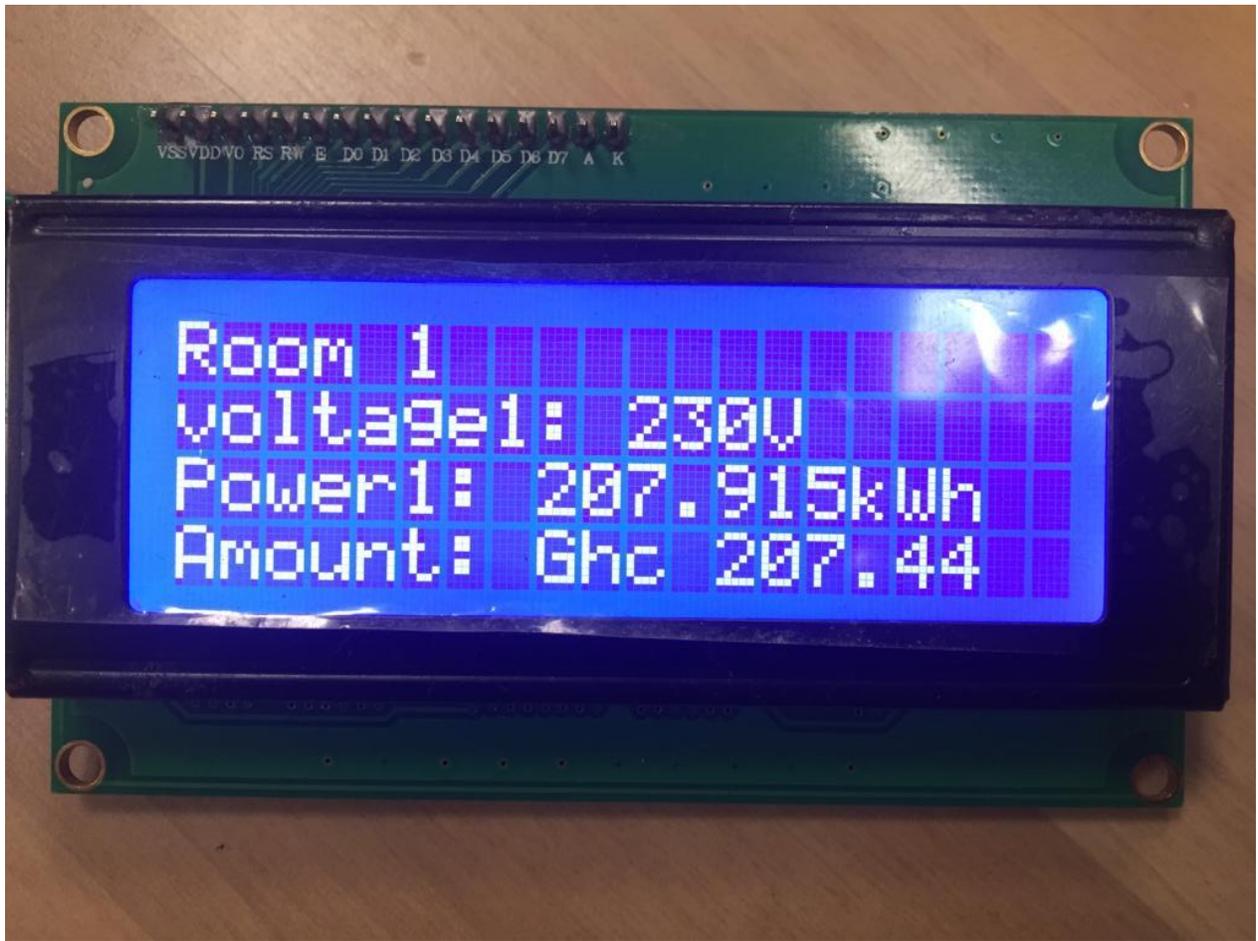


Figure 13.1: Results displaying on the LCD

The results show that the tenant in room one is using energy up to 207.915kWh and the corresponding electricity bill is Ghc 207.44. Figure 14 will show the SMS that was sent to the tenant in room one.



Figure 5.2: Showing sent SMS to the tenant in room 1

The electricity bill of tenant two was also sent via SMS and the displayed on the LCD. Figure 15 and 16 will show the LCD for room two and the SMS respectively.

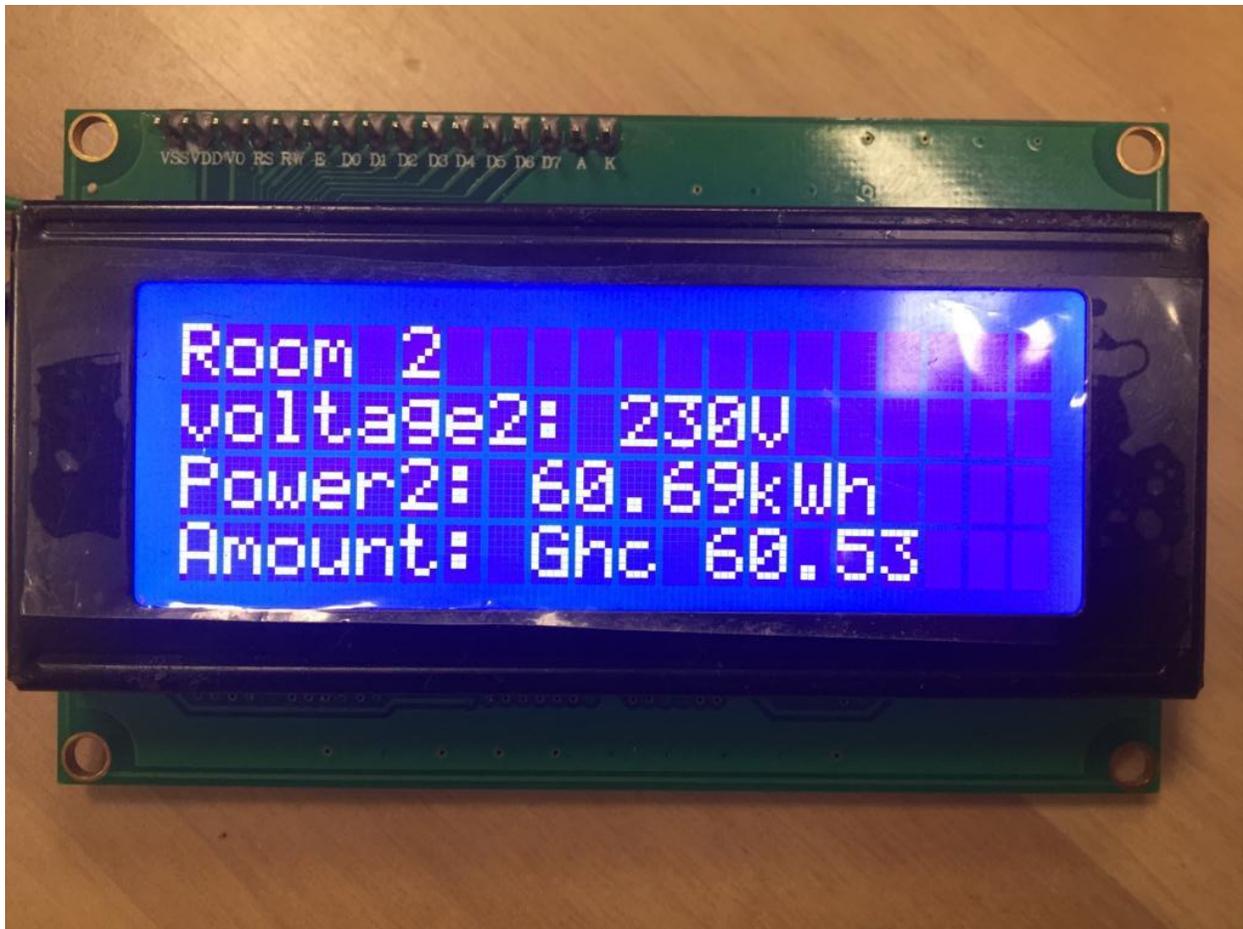


Figure 5.3: Room 2 LCD display

The energy used in room two is 60.69kWh as shown in figure 15, and its corresponding cost is Ghc 60.53. The SMS was sent to the tenant in room two, and figure 16 shows the message sent.



Figure 5.4: Showing sent SMS in room 2

The results also inform us that room one has more load than room two. The energy used in room one is 207.915kWh at the end of the month, and room two uses 60.69 kWh in a month. For this reason, it fair that tenant in room one pays more than the tenant in room two. The display of everyone's bill on the LCD and SMS will prevent unfair bill sharing among tenants leaving in a compound house but share a single meter.

Chapter 6: Conclusion

6.1 Summary

The purpose of this project to eliminate the unfair bill sharing among tenant living in a compound house but share a single meter in Ghana. To solve the problem, this paper proposed a method of obtaining the energy consumed by each tenant in the compound house using a smart energy monitor. The smart energy monitor acquires the energy consumed by each tenant and calculates the corresponding amount in Ghana Cedi and display it on the LCD of the smart energy monitor. Also, it sends an SMS to the tenant informing them about their electricity bill. The smart energy monitor was designed using components such as ATmega8, SIM800l, MCP3905 and PZEM004T, 20x 4 I2C LCD, a DS3231 (RTC) etc. for the hardware. The software was programmed in C language in Arduino syntax in the Arduino IDE. The results obtained was positive; the system works as it should, displaying the output on the LCD and sending the SMS to the tenants.

6.2 Limitation

The limitations faced while undertaking this project are listed below:

- The availability of components desired
- Unable to simulate the system to know whether it is functioning as expected
- SIM card in GSM losing connection frequently
- I2C LCD unable to display all parameters needed

Some challenges faced also include:

- Learning how to use the Eagle software for the schematic design

- Configuring the various components to ensure that they operate as they should
- Ensuring that each component had seamless communication with one another.
Components such as SIM800l and Atmega8 communication.
- Designing a flow chart for the algorithm
- Programming the micro-controller in Arduino

6.3 Future Work

The smart energy monitor was designed with the assumption that the wiring of the rooms was separated. Meaning each room's wire connections was independent of the other room. Simple house wiring is not usually the case; some places are not separately wired. Therefore, future works will have to explore how to take care of situations or scenarios where the rooms are not individually wired.

Also, more than two current sensors should be used to for the meter. In this project, only two current sensors were used for the smart energy monitor. Adding more current sensor will make it possible to read current for multiple rooms for the smart energy monitor.

Lastly, a mobile and web app should be designed for the system, instead of just merely sending an SMS. The mobile app will contain more functions such as paying the bill via mobile money. A database should be designed for the system. The back end of the mobile app and web app should contain a database to store information about the system. Also with the mobile and web app, the user should be able to access the energy consumption at any time, instead of waiting till the end of the month.

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Appendix

Picture of assembled PCB board

