Development of an Internet Enabled Smart Energy Meter

Akingbade Kayodde, F
Electrical and electronics engineering, Federal University of Technology, Akure
P.M.B 704, Ilesha-Akure Expressway, Akure-Ondo state Nigeria

Abstract –
Energy measurement has always been a critical aspect of power engineering. This is so because issues like accurate and transparent billing, energy management, cost of power transmission and distribution which all form the bedrock of the socio-economic and environmental factors involved in power engineering are based on it. Therefore, the more efficient the system responsible for measuring and analyzing power usage is, the better the decisions that can be made concerning costing, billing and distribution. A major trend in recent times that seeks to address this issue is the smart meter. The smart meter is becoming increasingly popular because it is a more sophisticated, easy-to-use and cost effective means of energy measurement. This paper deals with the design and implementation of a smart meter that has wireless internet capabilities which enables a remote control of components and digitizes the data acquisition process. The overall set up was tested for optimum efficiency and performance. A satisfactory outcome in terms of ease and accuracy was eventually obtained.

Keywords: *Smart Meter, Energy Measurement and Management.*

I. INTRODUCTION

The management of the ever-increasing demand for energy in today's environment is an issue with profound economic, environmental, and social impact (Das, 2009). Over 70% of total grid electricity consumption is used in various homes, therefore significant attention has been paid to `smart grid initiatives focused on reducing or optimizing the energy consumption of buildings.

In recent years, the Smart Energy metering system has evolved to be the solution for future electrical energy system where blackouts will be nullified, while being energy efficient, environmental and customer-friendly (Ipakchi and Albuyeh, 2009). A Smart energy meter being developed today will improve the reliability of the current energy system. The Smart Grid system consists of a great number of subsystems; some of the core systems are the Advanced Metering Infrastructure (AMI), intelligent electronic device (IED), Phasor measurement units (PMU). The growth of Smart Grid technology in both industry and academic circles calls for written standards and specifications, but only little effort has been made.

A change in the traditional Smart energy meter to the AMI network entails lots of technologies. One important technology is the smart meter, which is an electronic gadget connected to houses to obtain customers' usage data, and then sends the data to the utility provider for billing documentation (Kim et al, 2010).. The feature of measuring power consumption in real time scenario is a vital aspect that gives benefits for governments, industries, and the smart meter users (McDaniel and McLaughlin, 2009). The governments will have relevance from this functionality by being able to predict energy usage; therefore nullifying blackouts. Secondly, industries will have elaborate information concerning consumer energy usage through the use of Time-Of-Use (TOU) system. Typically, using a TOU system entails measuring the smart meter hourly consumption of electrical energy in a house, and then sends the record to a dedicated database of a utility provider via two-way communications. Therefore, industries with current data are able to accurately manage actual energy consumption for regions. In fact, the smart meter facilitates new applications such as Smart Home (Ipakchi and Albuyeh, 2009). This opens the benefit for applications to increase or decrease the price of bills, to manage energy consumption, and to control devices at residences. The smart meters have several advantages that make consumers' lives more convenient. For example, as shown in Figure.1, smart meters will provide a clear feedback to consumers, via tracking the spending of energy for each electrical device, such as air conditioners and dishwashers, encouraging consumers to turn off unnecessary devices during peak time with the purpose of reducing cost (McDaniel and McLaughlin, 2009).

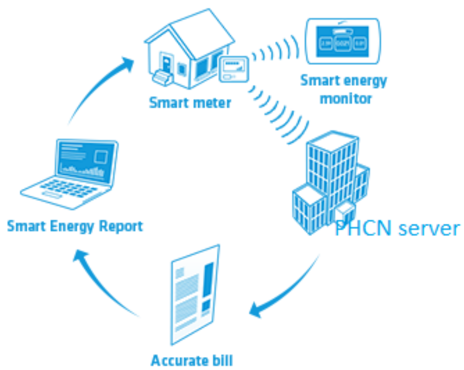


Figure 1.1: Schematic Drawing of A Typical Smart Meter System (Mora Et Al., 2009)

Moreover, while the AMI provides reliability and efficiency for the energy system, it also creates many challenges, in particular security and privacy concerns. For instance, the smart meter, as a part of AMI, collects consumers' energy consumption every hour and then instantly transmits the data to the service provider, including the individual usage for each electrical device as well as the total usage. Unlike the current energy system that collectively records the general monthly usage of all devices; the way the smart meter records and reports the electrical usage could present a record of specific consumer behaviour in the home. In addition, it can be recognized when the consumer retires in the evening and arises in the morning by observing the usage of lights. Hence, knowledge of patterns of behaviour could be an opportunity for an invasion of privacy (McDaniel and McLaughlin, 2009; Molina-Markham et al., 2010; Quinn, 2009).

Molina-Markham et al (2009) and Quinn (2009) demonstrated the risks that are associated with extracting energy consumption from the smart meter, and then applying some kind of analysis such as off-the-shelf statistical methods, one-sample t-test analysis and correlational analysis to determine the lifestyle of the consumer. As a result, once the energy consumption is known, collection of information about the consumer can easily be produced. In summary, the smart meters have detailed information about consumers; therefore, an adversary can distinguish consumer activity and behaviour at home by analysing the usage that is stored in the smart meter, which creates a critical privacy issue. Therefore, it is essential to ensure that only authorized persons can observe the data.

Utility billing is not unavoidable worldwide as post-paid smart energy meter is concerned. In this billing system a utility worker goes to utility users to take the meter reading and document manually. These readings will be brought to the utility administrative office for onward documentation. The prepaid billing procedure is applied in accordance to the billing regulations and rules. Finally after all proper documentation, the utility employee goes to every door to issue the billing slips of their respective consumption rate to utility users (Das, 2009; Cao, 2006). Load consumption can be provided by Energy meter companies to the smart meter users so that proper load management can be observed and also control their consumption rate effectively (Al-Mutairi, et al., 2013). Smart meters are employed in Automatic Meter Reading (AMR) techniques to improve meter reading accuracy. Power Line Communication (PLC) can also be employed to obtain meter readings but there will be some inadequacies in reading as a result of noise and interference along transmission line. Information obtained from metering can be sent through wireless interfaces like Bluetooth, ZigBee and Wi-Fi but their range has some limitations hence effective solution has not been provided yet (Sadiq, 2012). Meanwhile for distant remote scenario, GSM communication system will be more effective. Automatic billing system is part of the most reliable ways to conquer the shortcomings of conventional billing system; since conventional method of prepaid billing has lots of setbacks, such as: wastage in resources and time wastage. In automatic billing system there is no more need for manual meter reading and issuance of billing receipts.

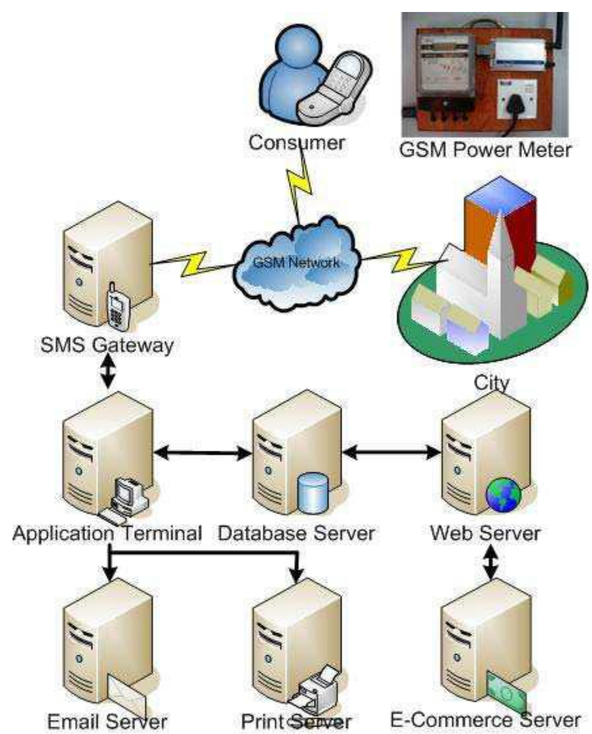


Figure 1.2: Overview of the Smart Energy Meter

The complete system architecture of the system is shown in the Figure 1.2. The overall architecture of the smart meter consists of a smart energy meter (SEM) at the consumer end and printer server, email server, remote SMS active Gateway, active database server, and e-commerce server installed and residing at a remote distributed location where the system is working in connection with a dedicated GPRS network to get the meters readings using a wireless messaging service over a GPRS. The SEM (Smart Energy Meter) is a single Phase digital system which utilizes the GSM network to send the power usage reading back to the energy provider wirelessly once in a day through the internet. The consumer can as well have remote access to the latest meter reading of the meter in form of SMS alert, in email alert when the demand is made by the consumers. A SIM card with the dedicated service is required for the GSM to receive wireless network service and send back data to the utility provider. The customer details can be retrieved and tracked from the database server using the SIM card number for billing scheme. The figure 1.2 shows the system architecture in the service provider‘s end. The total unit consumed is computed, tariffs are included and sent to the consumers in form of email alert, SMS alert, and hardcopy of bill to the address of the user at the end. The utility providers also have remote access control over consumers' meters, the load from a far end with the use of a GPRS if the smart meter users refuse to pay their bills on time. This SEM hardware unit has a 4x4 matrix keypad interfaced , a 20x4 LCD , with the help of an ATMEL micro-controller that will process and display the smart meter readings. Smart Energy meter is a broad facets in utility distribution commences with the so called Smart Energy meter (Ekhund and Brown, 2009; Mora et al., 2009). Smart Energy Meter system is however more or less remote based with the capacity to work on wireless platform and may become the gateway for development of new technology for optimum working performance (Williams et al., 1992).

II. LITERATURE REVIEW

A. *Smart Meter*

Smart Meter is an electronic device that records consumption of electric energy in intervals of an hour or less and communicates that information at least daily back to the utility for monitoring and billing. It is an environmental friendly energy meter that is used for measuring the electrical energy in terms of KWh (Kilowatt - hours). It also affords a direct benefit to the consumers who want to save money on their electricity bill (Quinn, 2009). They belong to a division of Advanced Meter Infrastructure and are responsible for sending meter readings automatically to the energy supplier. Some simple pictures of smart meters are shown in figure 2.1.

Figure 2.1: Pictorial View of Typical Smart Energy Meters (Bohli et al., 2010)

Accurate meter readings will be provided with the inclusion of firm benefits from the Smart Meter. They record the consumption on the basis of hourly or less than hourly intervals. A Smart Meter has non-volatile data storage, remote connects or disconnects capability, tamper detection and two-way communication facilities. They perform remote reporting of the collected data to the central meter. This central meter monitors the functionality of the Smart Meter. From an operational perspective, use of Smart Metering allows an improved management and control over the electricity grid (Popa et al., 2010). Some of the benefits of Smart Meters are: Low operational cost, Time savings to the consumers and utility companies in reporting the meter reading back to the energy providers almost instantaneously, Online electricity bill payment is enabled, Power consumption can be greatly reduced during the high peaks with an intimation policy, Automatic termination of appliances not in use. (Bhowmik and Paul, 2011).

A Smart Meter senses the total power consumption at the residents. Meter readings give a broader understanding to the energy utilities so that overall energy usage customs of consumers can be altered.

1) Power Consumption

The total amount of electrical power utilized in an individual household is referred as power consumption. The consumption of power is an important aspect of electricity supply. Consumers should be aware of preserving energy for future use. With daily usage of electricity, the energy patterns have been slowly varying. According to Yang (2009) this variation of consumption patterns can be caused by weather conditions or unnecessary utilization of power by inhabitants such as increase of appliances in respective households and careless attitude in utilization. As the power supplied by energy companies is vast, most consumers are neglecting energy savings. The importance of careful consumption is a declining mind-set in energy utilities. Energy utilities should play a major role in advancing the Smart Meter technology and should make consumers participate in reducing energy consequences by creating awareness about the impact of their current level of consumption.

2) *Traditional Electricity Meters and its Types*

The electrical devices that can detect and display energy in the form of readings are termed electricity meters. Traditional meters have been in use since the late 19th century (Qiu and Deconinck, 2010). They exchange data between electronic devices in a computerized environment for both electricity production and distribution. In most of the traditional electricity meter, aluminum discs are used to find the usage of power (Qiu and Deconinck, 2011). Today's electricity meter is digitally operated but still has some limitations.

Some of the limitations and demerits faced by the traditional electricity meter are: Meters are unreliable in nature as consumer has to anticipate for the monthly electricity bill, the process of measurement is supported by a specific mechanical structure and hence they are called electromechanical meters. Aside this, in order to perform meter readings, a great number of inspectors have to be employed, payment processing is expensive and time consuming, new type of tariffs on hourly basis cannot be introduced with the corresponding meters for encouraging the consumer ,development of meter software applications and supportive network infrastructure is complicated (Qiu and Deconinck, 2011).

Besides the above mentioned limitations, there are also several other elements creating a huge gap between the consumer and distributor because of installation of traditional meters. Meters are of distinct types. Even though timely development of electricity meters helps the consumer to gain knowledge with respect to electricity consumption, statistics of the consumption couldn‘t be changed.

3) *Smart Grid*

Smart Grid is the modern development in electricity grid. Recent electrical grids are becoming weak with respect to the electrical load variation of appliances inside the home. The increase in population is also the indication of electrical grids becoming more fragile. The higher the population, the more load on the grid. Improving the efficiency of grid by remotely controlling and increasing reliability, measuring the consumptions in a communication that is supported by delivering data (real-time) to consumers, supplier and vice versa is termed as Smart Grid (Blaser, 2005). A breakdown of the Smart Grid can be observed in Figure 2.2. Automated sensors are used in Smart Grids. These sensors are responsible in sending back the measured data to utilities and have the capability to relocate power failures and avoid heating of power lines. It employs the feature of self-healing operation. Literally, the concept of Smart Meter is originated from the idea of Smart Grid. A carbon emission reduction of 5% is expected by 2030, annually by its installations and it can show a greater impact on environmental changes (Blaser, 2005). For a sustainable development and establishment of new grid infrastructure, Smart Grids are recommended for many countries.

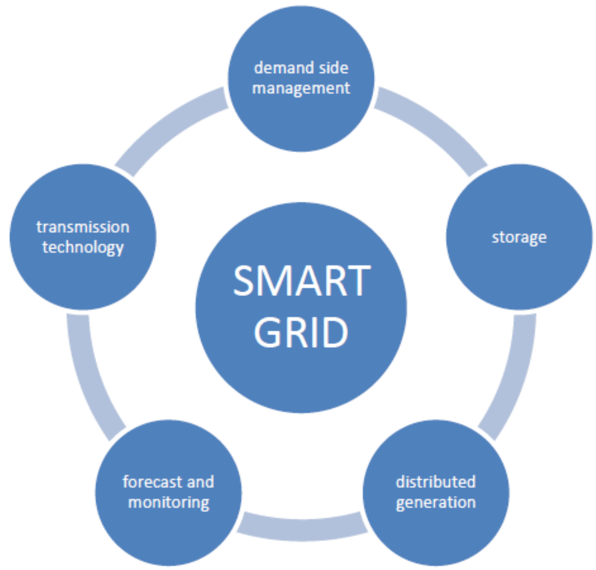


Figure 2.2: Smart Grid (Aroge, 2014)

B. *Related Works*

Several studies approached the problem of designing a smart energy meter. Numerous amount of research focused on using GSM based meters. In Tan et al (2007), a GSM energy meter database was developed that provides information to the costumer. Sodiq (2012) designed a power meter based on GSM network, with the main communication way being GPRS and SMS as secondary. In Blaser (2005), a Zigbee-GSM based automatic meter reading system was developed; the meters were equipped with Zigbee that sends the data to a data collector device which uses GSM to communicate with the central computer. In addition, Yang (2009) developed a Zigbee based smart meter that collects the data and acquire outage event data. Furthermore, research on other communication technologies for designing smart meters have been done (Li et al, 2009).In this work, a complete system from smart meter to data management system was developed. The smart meter developed is Zigbee-based using the Arduino microcontroller. Like other GSM approaches, there is no need for external wiring as all data are transferred wirelessly. The data is provided to the user through the website, SMS and mobile application.

C. *The Smart Meter Architecture*

A smart meter consists of three major modules, as shown in Figure. 2.3.

1. Micro-controller; 8, 16, or 32-bit microcontrollers (MCUs), such as the Cortex CPU M series and Cirrus Logic's CS7401xx series, which have limited RAM or flash memory Current or voltage sensors module ACS712 that measures the consumption of energy.
2. Current/voltage sensors module ACS712 measuresenergy consumption.
3. The communicating modules, either wire or wireless or both.

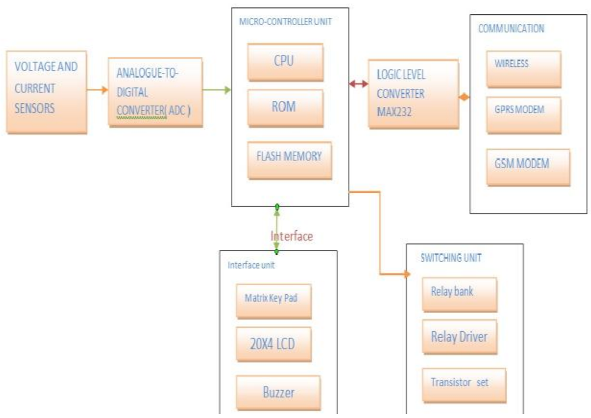


Figure 2.3: The Smart Meter Architecture

However, the GPRS wireless communication is widely used and we employed TCP/IP communication protocol. It may have an additional option of the LCD display that shows the consumption (Khalifa et al., 2010). This study considers the current hardware limitations of the smart meter. In fact, adding new hardware or modifying an existing smart meter with the purpose of improving security would be very costly for two reasons. Therefore, recalling these devices and re-installing them will be costly. Secondly, the price of smart meters will increase due to the powerful processors necessary to improve the computing power and program memory. Briefly, the new proposed scheme will protect privacy without the need of adding new hardware that provides high computing and memory.

D. *Smart Meter Security*

AMI is an important element in the Smart Grid; therefore some effort has been made to review security and related issues (Boyer and McBride, 2009). In fact, the open Smart Grid Users Group published a security specification and Security Implementation Guide (Brown et al, 2009) for the AMI; nevertheless, the AMI still has security concerns. It has been shown that smart meters have a high risk of being compromised in view of the fact that all devices are installed in insecure neighbourhoods. As a result, an adversary can easily launch a physical attack. Furthermore, a compromised single device might lead to the compromise of others. Another study shows that the AMI presents a threat with data transfer because the smart meter is a low-end device. In fact, it has shown a number of successful attacks to compromise the low-end via the JTAG interface (Johnny et al., 2010; Hartung et al., 2005).

1) *Wireless Network Security*

Most smart meters are deployed using a wireless network over other choices because it is self-organizing and low-cost. A number of AMI implementations utilize mesh network among wireless devices that offer self-adapting, multi-path, and multi-hop communications between the AMI devices. Examples of a wireless mesh network standard include ISA 100.11a, Wireless HART, and ZigBee, all of which have been widely implemented. However, all of these standards need more time to improve security, yet there are already vulnerabilities such as denial-of-service attack on IEEE 802.14.4. In fact, the AMI wireless technology is insecure, despite the vendors‟ claim simply because the vendors were under the initial pressure of marketing, and paid little attention to the issue of security (Kalogri et al., 2010).

In summary, an adversary can compromise a smart meter by using various tools such as Killer Bee (Johnny et al., 2010), which will break consumer privacy. Until now, the security specifications and security implementation guidelines do not succeed in protecting security and privacy. As a result, there is a need to improve the security defensive in order to protect the privacy which the present study is attempting to achieve.

2) *Smart Meter Security Requirements and Constraints*

The smart energy meter as a part of AMI has specific characteristics that make it difficult to secure; however, any attempt at solutions to secure it without considering these characteristics will be unsuccessful. As this study attempts to protect consumer privacy; this section will review these requirements. Cleveland (2008) analyses the privacy issue in the smart meter and recommends that there should be security techniques which can prevent unauthorized access to discover the consumption of energy either on the smart meter or on the communication channel.

Firstly, a great number of consumers will purchase a smart meter, so the cost is quite important.

Adding memory or a processor to secure the smart meter will increase the price. As a result, the security technique that attempts to secure the smart meter should not need to increase the price by adding hardware, e.g. for encryption/decryption. Furthermore, the smart meters are placed in insecure locations, so they can be easily accessed. As a result, a physical detection such as wall or glass cannot secure the smart meter, so there is need for other techniques.

Secondly, the majority of communications between the elements in the AMI are based on low bandwidth, such as ZigBee and Wi-Fi. Therefore, a security approach requiring a high bandwidth to secure the AMI (such as sending a large certificate), will be impracticable. Moreover, a number of the AMI elements will communicate via the public telecommunications services, so that perhaps eliminates the security approaches that could be implemented. In fact, the new scheme does not require adding new hardware for protecting privacy. Moreover, it will consider the weakness of physical detection, so it will protect the device even when physical protection fails, such as if the glass is broken. Also, the new scheme will be based on low-rate transition, and it does not require transfer a large data for security.

3) Smart Meter Privacy

The smart meter privacy is the ability to obtain the consumption of energy data either on stored memory or on the communication channel. Since the smart meter has valuable information about consumers that could be used to explore the consumers‟ lifestyle, this section will review a number of proposed schemes that aim to protect privacy in smart meters. Efthymiou et al (2009) review the issue of privacy in the Smart Grid; specifically, during the transmission of data from the smart meter to the utility every few minutes. Typically, the data can identify the lifestyle of the consumer since the smart meter data can easily link to householder location by observing the sender of data. Consequently an adversary is able to analyse the data frequently. In order to prevent the issue, Efthymiou et al, (2009) suggests applying anonymity of smart metering data. The smart meter sends data anonymously; in other words, without associating the data with the real identity of the smart meter that refers to the identity of the householder, instead uses an anonymous identity. The utility collects the data from the smart meter with an anonymous identity and then authenticates the data via an escrow service. As only the escrow service is aware of the two identities of the smart meter, the service must be a trusted party between the consumer and the utility provider.

E. Smart Meter Communication

Smart meter is an advanced energy meter that measures the energy consumption of a consumer and provides added information to the utility by using a two-way communication scheme (Das, 2009). Consumers are better informed in their consumption of their energy, so they can make better decisions when they are using the energy. Suppliers on the other hand won't need the old fashioned way of manually reading the energy consumed as they would get this information automatically.

The system that utilizes one-way communications to collect the data is referred to as automated meter reading (AMR) system. While the system that utilizes two-way communications with the ability to control and monitor the meters is referred to as advanced metering infrastructure (AMI) system. The combination of automatic reading and two-way communication are the reason why the meter is called "smart" and they are also the difference between the traditional energy meter and the smart meter. The idea of AMR technology is to do the meter reading automatically and accurately. The benefit of AMR is reducing the meter cost to the supplier and billing the customers with actual meter readings. In addition, AMR will increase the accuracy of the readings and it can allow frequent readings.

Smart meters are able to send the readings over communication lines and recognize their addresses and to activate/deactivate internal modules. To have that capability, AMR requires a specific infrastructure which would make it bidirectional. Such an infrastructure is called AMI. The communication medium in an AMI system must ensure the communication between the smart meters and the central computer at the service provider. The AMI network has the ability to register meter points, communicate into the customer premises, service connecting and disconnecting and other capabilities (D. hart, 2008). The communication structure can be wired like Power Line Communication (PLC) or wireless like Global System Mobile (GSM) and WIMAX. The chosen way must take into account the distances between the devices and the existing infrastructure (Benerett & Highfill, 2008). GSM is a digital mobile telephony system that digitizes and compresses data before sending it. The main advantage of the GSM is its widespread use throughout the world and the use of subscriber identity module (SIM) cards to send short message service (SMS) messages. Another new technology that smart meters are using is the ZigBee communication. ZigBee is a low-cost, low-power, wireless mesh networking standard. It is best suited for local coverage such as Home Area Networks (HANs). ZigBee is a key technology for the smart grid considering its automated controllability of appliances, ability to control devices, and lower installation and upgrade cost. ZigBee can offer meter-to-meter communication and remote monitoring ability of whole home conditions (Blaser, 2005).

Smart meter is an important component of the smart grid. Detailed load flow can be provided by such meters to the distributers so they can manage the grid effectively. Other features like recording the power quality, detecting any unauthorized access to the meter and storage capability will all help and improve the grid. Smart grid is a type of electrical grid that intelligently responds to the behaviour and performance of all electric power components in order to deliver electricity services efficiently. The smart grid delivers electricity from suppliers to the consumers by using digital technologies to save energy, reduce cost and increase reliability of the system (Popa, 2011). The needs for smart metering projects are essential for the success of a complete smart grid.

F. Electricity Billing System

1) Energy Measurement

A simple energy meter measures electricity consumption of an end-user. The most common type is a kilowatt hour (kWh) meter. When used in electricity retailing, the utilities record the values measured by these meters to generate an invoice for the electricity. They may also record other variables including the time when the electricity was used. Modern electricity meters operate by continuously measuring the instantaneous voltage (volts) and current (amperes) and finding the product of these to give instantaneous electrical power (watts) which is then integrated against time to give energy used (joules, kWh etc.)

2) Demand Side Management and Load Control

Demand side management is the concept which describes techniques used to monitor and control efficient use of electric energy at the consumer side (Nthontho, 2012).The main objective is to reduce the energy demands of consumers. Electricity demand is growing faster than most utility companies' generation infrastructure capacity can handle. One of the ways of achieving demand side management is by utilizing appliance controller devices. An appliance controller device is a device installed within the premises of a customer. The function of the device is to regulate electricity use by controlling consumption of electric appliances of the customer.

III. METHODOLOGY

A. System Design Overview

The design has two sections-the hard ware, and the software section. The modular approach was employed in the hard ware section of this work. The modular approach involves breaking down the overall design into functional block diagrams, with each block in the diagram representing a section of the circuit that does a specific function. Figure 3.1 gives the summarized block diagram. The functional block diagram also shows interconnection between each block. The Smart Meter is powered by 5v DC power supply; there are sets of relays for switching ON/OFF loads from the Smart Meter for energy consumption control. The data acquisition unit employs a multi-channel analogue-to-Digital converter(ADC0808 LCN) which will be taking analogue data from voltage and current sensor, ACS-712 module and modifying them into digital form and passes the modified data to controller unit via its data bus. The ADC is an asynchronous IC that requires some form of negative edge triggered clock pulses generated by the micro-controller and some form of sampling frequency generated by an RC circuitry.

The system has a 20x4 LCD (Liquid Crystal Display) which can display maximum of 80 characters, the LCD was interfaced with the controller port that displays the instantaneous working voltage, Real time power consumption and Instantaneous energy usage.

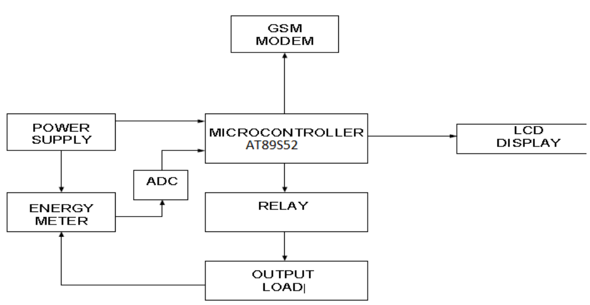
The GPRS/GSM module has a UART (Universal Asynchronous Receiver/Transmitter) interfaced with the micro-controller through an RS232-TTL converter which is a MAX-232 driver for logic level translation. The GSM/GPRS was used to facilitate wireless communication/link between the Smart meter , the utility company server and the customers/users using some sets of AT-command protocols. The system setup has output socket where loads like Electric cooker, Fridge, lamps, heater, TV etc. can be connected to. Whenever a particular load is connected to the output socket there will be a voltagedrop which will be sensed by the ACS-712 sensor. The ACS-712 sensor modifies and calibrates the voltage drop, hence sending the data to an ADC for digital conversion. After conversion, the output is passed on to the Micro-controller (MCU) for onward data processing.

The extended memory unit is an EEPROM (AT24C512) which has 512 KB of flash memory. Data is read and written using I2C protocol which as implementation is carried out ted in the micro-controller firmware. There is always a decrease in energy in the meter as a result of loads being connected to it which is being updated and stored in the extended memory.

The keypad is a 4x4 matrix keypad which is used to top-up the smart meter by keying in the voucher code. The Matrix keypad has sets of 4 rows and 4 columns arrangement which are connected to the micro-controller port. Whenever any key is pressed it means a row and a column have been connected and the micro-controller detects and uses the key press to carry out action. The Smart Meter can be top-up by entering the Voucher codes from the Matrix keypad which will be sent through a TCP/IP node to the utility company server via a GPRS for authorisation and energy unit purchase. The server runs a database which houses details of all vouchers, smart meter ID number; customer's details. The server will then send a response (Energy unit or unauthenticated/invalid voucher) through a TCP/IP node via the Internet to the requester. Switching unit employs sets of 12v/10A relays and relay driver (ULN2003) which contains 7 pairs of Darlington transistors. ULN2003 is an integrated chip which will be connected to sets of relays and the also to the micro-controller I/O ports. Each device will be controlled by a relay; the micro-controller handles all necessary control action.

Architecturally, the circuit diagram shown below has 2 MCUs i.e. MCU1 and MCU2. One MCU alone cannot handle the full functionalities of the Smart Meter owing to its limited number of IOs, so 2 MCUs were used to handle the entire Smart Meter logic and operation. MCU1 is interfaced to the 4x4 matrix keypad and also the Buzzer, while MCU2 is connected to the GPRS module via MAX-232 driver, connected to the 8-channel ADC module(ADC080-LCN) ,connected to 4x20 LCD screen ,relay driver (ULN2003) base terminals(the input terminals).While the relay driver collector lines(output lines) are connected to sets of relays. Then the relays NO (Normally Open) terminals were connected to the various loads, while its NC (Normally Close) terminals were connected to 240V AC line. However, both MCUs must work synchronously; hence, they were interfaced through their UART/serial link for data sharing and communication.

Figure 3.1: Simple Block Diagram of a Smart Energy Meter



B. System Architecture

The Smart Energy Meter has various functional components;

- the Wireless messaging module (which is the communication section- it employs the use of SIM900 GRPS module that uses TCP/IP datagram protocol for its wireless communication),
- Current/Voltage sensor (ACS 712 sensor- this module senses the amount of current and voltage drop across the loads),
- DAM (Data Acquisition module - which is an ADC0808-LCN with an 8-channels analogue input module),
- the Micro-controller unit(An Atmel MCU was employed that has 256 Bytes of RAM, 8kB of Flash memory),
- Logic level converter- This unit uses MAX 232 driver thatconverts RS232 logic standard from the SIM900 module to TTL logic standard of the MCU and vice-versa for compatibility of logic level for feasible data communication ,
- Interface unit (this section has a 20x4 LCD display, 4x4 Matrix Key Pad. This unit act has input where the Smart Meter users can top-up the meter and also retrieve the meter GPRS network settings/port number/IP address and switching unit, which has some sets of relay driver (ULN2003) which in turn contains 7-pairs of Darlington transistors.

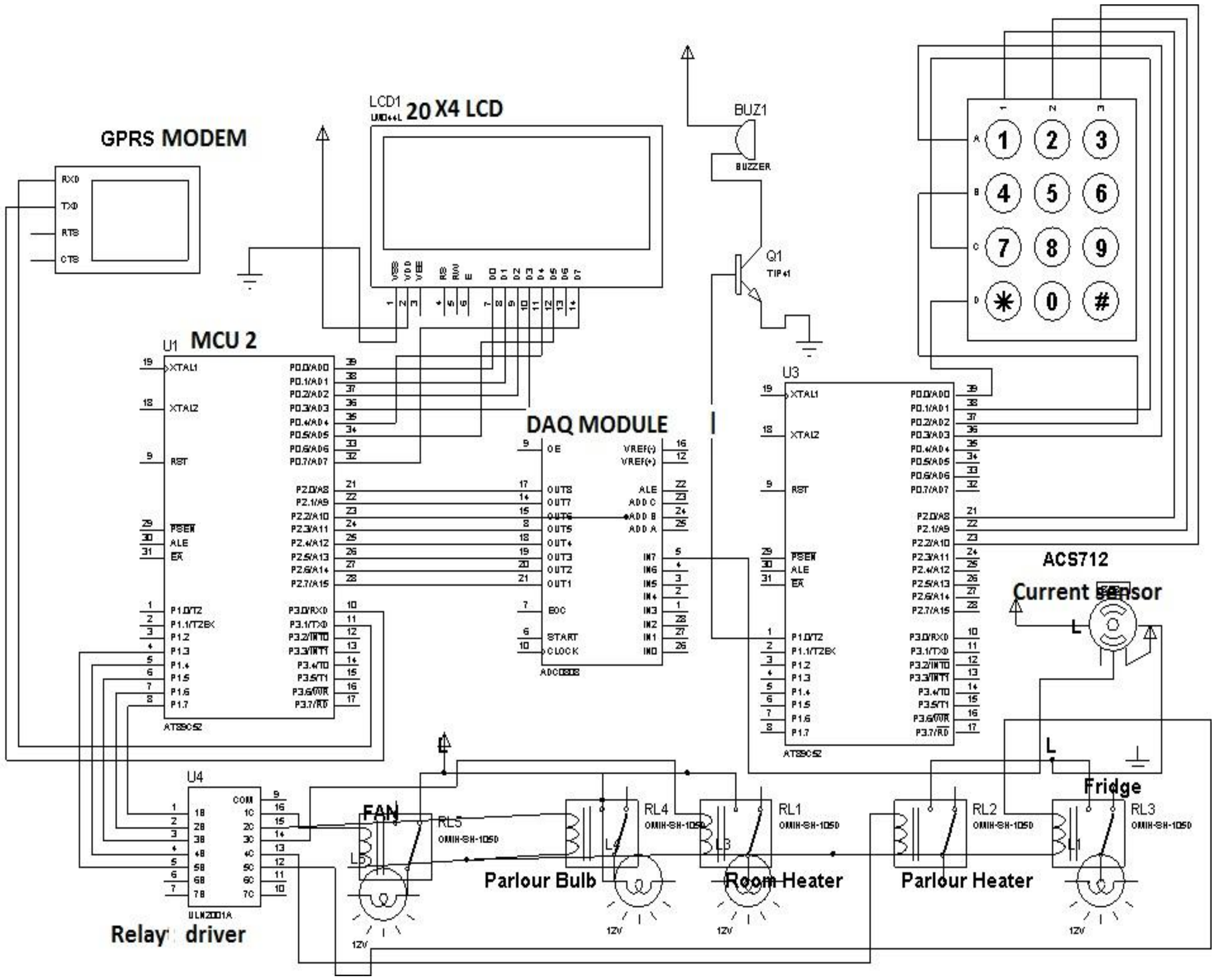


Figure 3.2: Detailed Circuit Diagram of the Smart Meter

C. Software Implementation

This section deals with software development, validation, result evaluation and the software design algorithm for the Smart Energy Meter. This aspect of the work is where most of all the abstractions surrounding the working operation of the Smart Meter were implemented. Since the work entails different modules, different software abstractions were employed.

1) The Smart Meter Server Side Development

The server side application runs on Windows XP OS (Operating System); it coordinates all the smart meter billing services. The server side runs various functional services like: SMS gateway service, database service, and Email services.The Server communicates to customer/client request via SMS and TCP/IP data socket. The SMS and the TCP/IP data socket application was developed using JAVA. The JAVA graphical programming language was chosen as a preferred programming language for the development of the Smart Meter Server side development.

Being a graphical programming language, pre-built drag and drop objects (program codes) can be readily picked and used for the development of the controller, it has lots of advance programming components to develop robust software application. Any application abstraction can easily be implemented using JAVA, it is software with the flexibility of a powerful programming language but without the complexities of traditional development environment, with JAVA, measurement data can easily be visualized, it can be easily learned, it can be used to create a user friendly user interface, JAVA has extensive acquisition, analysis and presentation capabilities in a single environment, it provides seamless connectivity with measurement hardware allowing virtually any measurement instrument to be quickly configured and used with it.

2) *Mobile GUI Development*

A Graphical user interface takes advantage of the computers graphics capabilities to make the computer easier to use. It presents the information and actions available to the user through graphical icons and visual indicators. It offers a consistent visual language to represent information stored in computers which makes it easier for people with little computer skills to work with and use computer software. Here the graphical interface has been so well defined so as to free the users from learning complex command languages. Thereby making it easier to access and operate the software. The Graphical User Interface (GUI) of the mobile phone was developed and deployed using J2ME (Java 2 Micro-Edition). J2ME is an application framework that is used to develop application in any device with Java Runtime Engine (JVM) [174]. This mobile GUI helps customers to have access to their meters and also to top-up their meters remotely from their mobile devices. Similarly, this GUI also permits users to control the meter usage in their houses from any location. The wireless data communication was achieved using mobile phone Data socket abstraction where IP datagrams was be sent across the network via TCP/IP data socket. The Mobile application code will be written using Netbeans IDE 6.8.

The J2ME application of the mobile GUI was tested using Java 2 ME SDK 3.0 Emulator manager as shown in the figure 3.3.

Figure 3.3: Screenshot of the MOBILE Emulator

The Emulator was used for testing the J2ME application during the development stage before the actual deployment of bytecote into the live MIDP device/actual mobile hand held device. The wireless messaging abstraction of the mobile phone was explored using TCP socket connection, a class found in the Java.net API found in the Java JDK (Java Development Toolkits). The mobile phone forms a client in the server-client scenario. The socket connection class has methods used to open the client socket which uses port number and IP address to get connection, which in turn returns two communication streams, output stream and the input stream for sending IP datagrams and receiving IP datagrams via its TCP socket respectively. For a successful TCP connection with any remote TCP server, the remote server IP address and its port number must be the same as inputted from the mobile .With the mobile GUI, Smart meter users can top-up his/her Smart Meter remotely. The GUI makes it much easier to access the Smart Meter remotely as far the mobile internet connection is perfect.

3) *The Micro-Controller Firmware Development*

The Micro-controller firmware is a low level programming language. This aspect has to do with development and deployment of a machine specific low level application into a micro-controller flash memory for program execution. The Smart meter integration has 2 units of AT89S52 MCUs and one extra AT89S52 MCU for the IVRS hardware design. The IVRS hardware MCU was programmed using embedded C language, while the 2 other MCUs for the Smart Meter was programmed using A51 Assembly language. The firmware was developed and coded using MIDE-51 environment which is highly integrated.

After the MCU firmware development, testing and code evaluation, deployment of the HEX files into the controller program memory was done. This application deployment was done using TopWin7.0 using a USB interface connected to the laptop/PC where the program HEX files are stored. The figure 3.4 shows the look of a universal TopWin programmer.

Figure 3.4: Picture of a Universal TOPWin programmer

IV. ANALYSIS OF RESULT

The evaluation of the smart meter was done. Importantly, a database was built with Microsoft Access software for registering customers and their meter records for effective simulation of the meter usage where a unique security access code was generated for each user after successful registration. The designed smart meter is shown in Figure 4.1

Figure 4.1: Completely Built Smart Energy Meter

A. *System Operations as a Customer*

The program flow chart is given in figure 4.1. Usage of the smart energy meter by the customer requires authorisation where customers log on to the utility company servers via a mobile phone using the utility company's IP address. Subsequently, the consumer may perform all system operations of the smart energy meter.

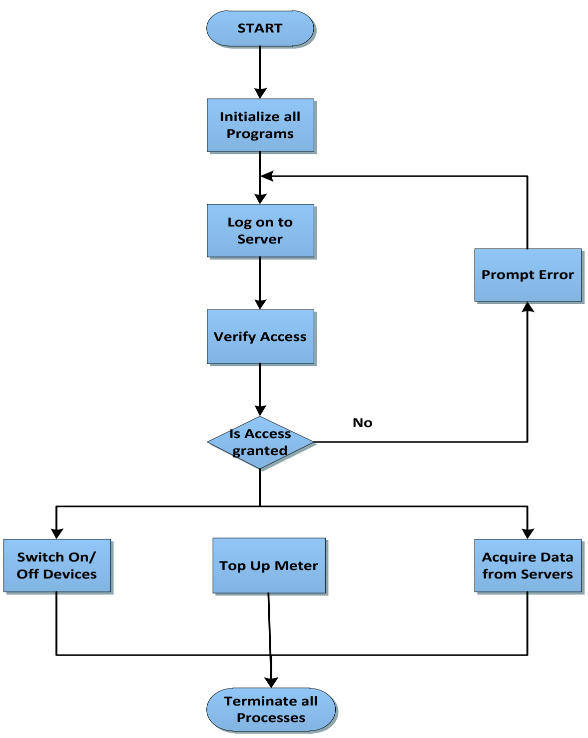


Figure 4.1: Program Control Flowchart.

1) *Monitoring and Notification System*

The designed smart energy meter monitors load usage, supply voltage and unit level. With the aid of a mobile phone, customers can request information about load usage and supply voltage from the smart meter. In cases of low unit, the smart mete displays an 'Insufficient Unit' on the LCD display as indicated in figure 4.2.

Figure 4.2: Insufficient Unit Notification on the Meter's LCD

In addition, when the unit level is low, the top-up functionality of the smart meter is invoked causing the smart energy meter to sends an SMS to the user notifying the consumer that the system's unit is low and it requires recharge. Figure 4.3, shows the notification sent by the smart energy meter to the user.

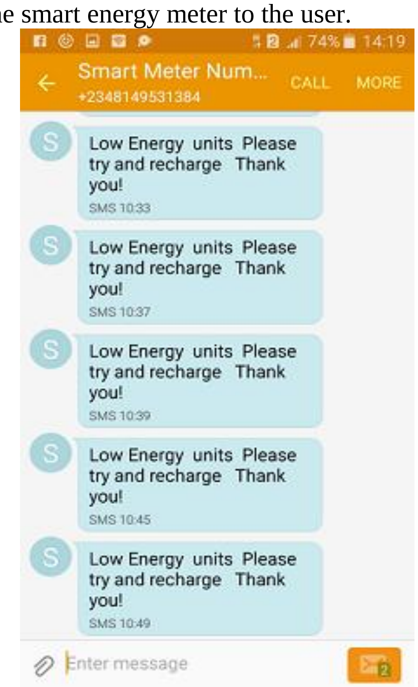


Figure 4.3: SMS Notification from Smart Energy Meter

2) *Unit Top-up*

On receiving a low-unit notification from the smart energy meter, the customer can top-up the unit of the smart meter using the mobile application. The top-up process requires the meter serial number and the recharge pin. Using the mobile application, the customer inputs the meter serial number and the voucher pin corresponding to a particular unit level; afterwards, the user clicks the recharge button and awaits a response from the smart energy meter.

B. System Operations as a Utility Company

All of the activities of the utility company are performed remotely (without coming in contact with the smart meter); in this case, a laptop was adopted as the remote station for the operations of the utility company. The designed software for the activities of the utility company was installed on the laptop. Importantly, an internet connection is required to perform the operations of the utility company.

1) Customer Management

Using the software, the utility company can register, verify and delete smart meter users. The GUI for the registration process requires the surname, first name, smart meter ID; on successful registration, a unique security access code is created for smart meter users. Table 4.1 shows the customer information used to register the customer with the utility company.

Table 4.1: Customer Details

Required Information	Customer Details
Surname	UMOH
First Name	IME
Data of Birth	04/04/1990
Phone Number	07030800704
Meter Serial ID	234567 (unique, 6 digit)
City	Akure

Using the GUI for customer registration, the customer details is typed in and the "Register Customer" button is clicked (see figure 4.4).

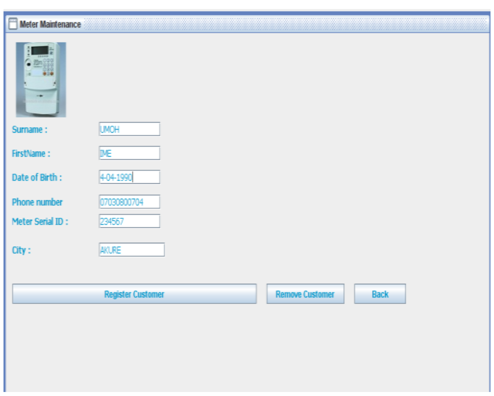


Figure 4.4: Interface for Registering Customers

2) Voucher Management

The software interface also allows for the utility company to create and delete vouchers for topping up the units of smart energy meters.

Table 4.2: Voucher Pins

Energy Unit (KW)	Voucher Pin
200	777890
400	223421
600	876544
800	908214
1000	554673

To achieve this, the user types in the energy (in KWs) for the voucher, and a 6-digit voucher pin and then clicks on register voucher. Using the interface, the voucher pins in table 4.2 are created (see figure 4.5)

Figure 4.5: Interface for Registering Voucher Pins

3) Remote Meter Top-Up

Using the software interface, the utility company can also top-up the smart energy meter of customers remotely. As shown in figure 4.6, the remote meter top-up requires the meter serial ID of the customer, and the voucher pin. In this case, the meter serial ID for the registered customer (234567) and the Voucher pin for 1000 KW (554673) was used. Subsequently, the user clicks the recharge button and the smart energy meter recharged.

Figure 4.6: Remote Meter Top-Up

4) Monitoring Customers' Load Usage

The software interface also allows for the utility company to monitor the energy consumption of customers remotely. To achieve this, the IP address of the meter is typed in, and the 'View Meter Readings' button is clicked; an interface showing the energy usage of the customer after entering the meter IP address. The IP address of the meter is dynamic (always changing); though, for this activity, the IP address used is 194.184.42.55 (see figure 4.7).

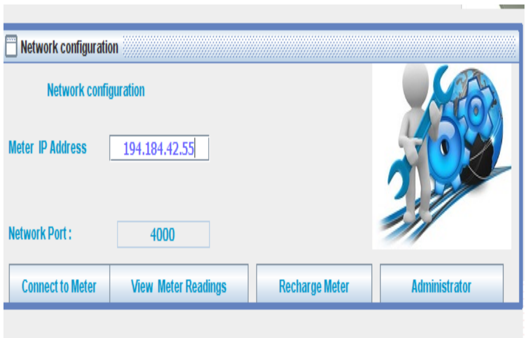


Figure 4.7: Interface to View Meter Readings

After clicking the 'View Meter Readings' button, the smart meter readings are displayed (see figure 4.8)

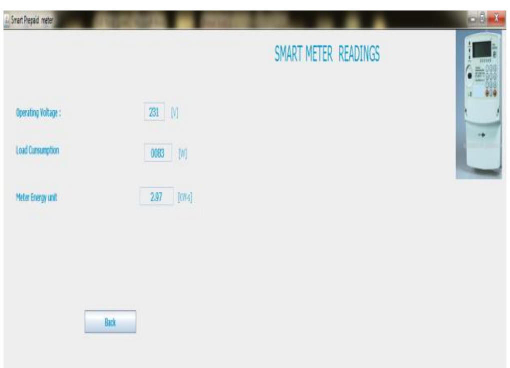


Figure 4.8: Smart Meter Readings

V. CONCLUSION AND RECOMMENDATION

The Smart Meter has the potential to change and improve the energy billing and management system in Nigeria. An improved energy billing system has the viability to help energy distribution companies to reduce costs, increase profits, and improve metering, billing accuracy and efficiency, as well as contributes to energy in a sustainable way. In addition, the process of reading the energy consumption is facilitated by the LCD display that is simpler than that of the analogue meters because it reduces human errors while noting down the meter reading. The smart meter can be topped up remotely and within the meter itself.

Improvement of the designed smart meter can be done in three major areas:

- The encryption can be improved by taking advantage of a unique feature of Rabin cryptosystem where fast encryption can be performed in a smart meter and computationally intensive decryption in utility equipment to broaden data security.
- A compatible Mobile platform could be designed that will work on varieties of hand held devices like Blackberry platform, iOS phone, Android platform, CDC devices, QT devices, PDA.
- Lastly, ARM-Cortex controller should be used because it has inbuilt TCP interface, CAN interface , inbuilt ADC , inbuilt I2C interface and lots of useful interfaces so that the external SIM900 GPRS used in this project shouldn't have been used.

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