AN AUTOMATED ENERGY METER READING SYSTEM USING GSM TECHNOLOGY

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Abstract: The measurement of the energy consumed by residential and commercial buildings by utility provider is important in billing, control and monitoring of the usage of energy. Traditional metering techniques used for the measurement of energy are not convenient and is prone to different forms of irregularities. These irregularities include inaccuracies in billing due to human error, energy theft, loss of revenue due to corruption and so on. This research study proposed the design and construction of a microcontroller based electric energy metering system using the Global System for Mobile communication (GSM) network. This system provides solution to the irregularities posed by the traditional metering technique by allowing the utility provider have access to remote monitoring capabilities, full control over consumer load, and remote power disconnection in the case of energy theft. Proteus simulation software was used to model the system hardware and the software was obtained by using embedded C programming and visual basic. It was observed that the system could remotely take accurate energy readings, provided full control over consumer loads and execute remote disconnection in case of energy theft. The system provides high performance and high accuracy in power monitoring and power management.

Keywords: GSM, Automatic Energy metering, Load Control, Energy Theft.

INTRODUCTION

Energy meters are electronic instruments used to measure the amount of electric energy used by consumers in a circuit within a residence areas, industry or business at any given time. They are often calibrated in the unit of electric energy, kilowatt-hour (kWh). Equation 1 shows the mathematical expression for the product of the power consumed and the period of consumption while Equation 2 and 3 expresses the relationship between power, energy and time.

$$P = I * V \quad (1)$$

$$E = I * V * t \quad (2)$$

$$E = P * t \quad (3)$$

Where; E= Energy in kilowatt-hour, P= Power consumed in kilowatts, t= time in hours. The major challenge encountered in the existing metering system is the energy theft which reduces the efficiency of electricity transmission in the world. Since meters are positioned within the electricity infrastructure at a key location or node in the network, distributors, retailers and customers intersect with all potentially having a claim to own the meter (Heather, 2017). In Nigeria, this major factor has both technical and commercial losses in the power sector with about 75% loss. However, large percentage ranging between 50-60% of these losses is attributed to energy theft (Obadote, 2009). This theft could be in form of unpaid bill or illegal connections in the electrical power system (Nizar and Zhao, 2006). Researchers have made continuous effort to reduce these technical and non-technical losses, hence advancing into the development of Electric energy meters in the last decade (Hasbullah, 2012). The conventional electromechanical meters are being replaced by new electronic meters to improve accuracy in meter reading. The electronic meters are also being improved and communication technologies have been incorporated into them to make them smarter (NARUC, 2007) which resulted into the Automatic metering system.

Automatic metering system is a technology that gathers data from metering devices and sends it to a master station for billing purposes. These metering devices could be used for energy gas or water metering devices. The data from these devices are obtained remotely without the need to physically access the metering device (Hasbullah, 2012). Features of Smart Metering Systems include: Time-based Pricing, Providing consumption data for consumer and utility, net metering, Failure and outage notification, Energy theft detection etc. (Ramyar et al., 2014).

Different communication technologies could be through wired or wireless technologies (Adekunle, 2012). The wired technology includes the use of Power line carrier, coaxial cables, pilot cables, etc. for data transmission from the consumer end to the utility station while the wireless technology includes the use of Global System for Mobile Communication (GSM) technology, WIFI, etc.

GSM network is characterized by digital voice communications and support of low-rate data services (Le-Bodic, 2005). However, due to its high speed and high transmission range, GSM technology is suitable for automatic metering system applications (Dhok and Deshmukh, 2014).

The motivation of this study is based on the fact that Nigeria still has challenges at automating completely our energy systems, therefore there is a need in developing an intelligent energy metering system which will compact existing energy metering limitations such as: Inaccuracies in generating billing information due to corruption or human error, difficulty in accessing home energy meters, high level of theft resulting in loss of revenues, inaccuracies in meter reading activities and also difficulties in preventing unwanted use of energy and controlling peak time load. Therefore, a more automatic and accurate metering system is required to successfully and accurately read a metering system, transmit the energy readings to a utility station through a suitable communication infrastructure. In addition, developing a real-time monitoring system for generating billing information with a security feature for theft detection and remote disconnection of meters is hereby proposed (Prachi, 2014). This study aims at designing an automatic energy metering system with the capacity to transmit energy meter readings from meters to a utility provider and remotely disconnecting power in case of energy theft.

The rest of the paper is organized as follows. The literature review and related work is presented in section 2. Section 3 presents the methodology for the study while section 4 gave a detailed discussion on the system implementation and result obtained. The study is finally concluded with recommendation for future research work in section 5.

REVIEW OF EXISTING WORK

This section reviews some related works on Automatic Energy Metering (AEM) system and divides them into categories like: Radio Frequency-based AEMs, ZigBee-based AEMs, ZigBee-GSM based AEMs and Bluetooth-based AEMs.

Radio Frequency-Based Automatic Metering System

RF based automatic metering system was the most common types of metering systems some of which include the handheld, mobile and fixed network (Chu and Hogg, 2000; Prachi, 2014). Despite the advantages of using RF technology such as reduced meter reading time however, Ali et al., (2012) highlighted the inherent limitations to the RF based automatic metering system which include: reduced range of radio signals, susceptibility to interferences from weather conditions, difficulty in receiving from some specific areas shielded by structures (e.g. mountains). EPRI (2010) states that RF exposure may be hazardous to consumers therefore; this technology is not suitable for meter reading.

ZigBee-Based Automatic Metering System

Shang-Wen, 2009; Joongwong, 2007; Knauth et al., 2008) presented an AMR that utilized ZigBee technology to build up home area networks of connected metering devices. Although, Knauth et al. (2008) reduces manpower requirement but it still requires the consumers to deliberately take pictures of the energy meter in their premises. It also requires ZigBee networks to be installed at different locations in the country due to its short range (<10m) and a low data speed. Hence, requires different ZigBee networks to be deployed across a specific geographical region (Dhok and Deshmukh, 2014). However, the use of GSM based AMRS can counter the limitations posed by the ZigBee based AMRS since GSM provides large range and high data speed as compared to ZigBee technology. The shortcomings of this study include: the great intervention of consumers to take pictures of meter reading before it can be monitored remotely and it is capital intensive to build a ZigBee network rather than using the existing networks.

ZigBee-GSM Based Automatic Metering System

(Quan-Xi, 2010; Primicanta et al., 2010) presented a GSM and ZigBee based Automatic Meter Reading System. The system proved to correctly take electric energy reading of large power consumers while (Arun and Naidu, 2012; Dongre and Rathkanthiwar, 2014) adopted a GSM technology using the SIM300 GSM modem. It utilizes power saving techniques of current consumption as low as 2.5mA. The strength of the work reduces the cost of using only ZigBee network by using GSM technology with the ZigBee modules. This therefore reduced cost in meter reading and provides efficient services to their consumers. Limitations include slow communication process for many users since ZigBee transfers information at low data rate as compared to GSM technology which can make the communication process slow for many users

Bluetooth-Based Automatic Metering System

However, like the ZigBee technology, distance is a major setback in the Bluetooth based Automatic Metering System (Newbury and Miller, 2002) because Bluetooth technology can only work effectively in close range and sends data at a very low speed.

GPRS-based Automatic Metering System

Kumar et al. (2013) developed a GPRS based Automatic Metering System using the advancement in the mobile communication technology to reform electricity market. This technology measures the energy reading from a meter regularly. The data obtained are sent to the utility centre through SMS. However, GPRS based AMRS in this paper was mainly for monitoring purposes and generation of the appropriate billing information at the required period. It has no system set up to detect energy theft and has no remote disconnection capability.

GSM-Wed Services based Automatic Metering System

Xiaoliang et al. (2010) designed a GPRS and web based automatic metering system. The system utilizes the internet and GSM modules to monitor electricity consumption. The strength of the work is the ability to obtain real time data from energy meters and its supports for wide coverage area communication and easy maintenance. The system is however, capital intensive due to the cost of managing and maintaining a web services.

Automatic Metering System Based on WIMAX Technology

Ahmed et al. (2011) developed a WIMAX technology based Automatic Metering System. The system was divided into four units and the strength include: high performance, high data rate and high coverage area. The WIMAX technology provides AMRS process with good efficiency and reliability, however it is complex to implement and capital intensive.

Power Line Carrier-Based Automatic Metering System

Poonamborle et al. (2013) developed a PLC-based automatic metering system which allows data from energy meter to be sent over existing electric power lines. The strength of the system is the usage of limited cables for communication since it allows the use of existing electric power cables. Therefore, controlling, monitoring, and transfer of consumers energy data is made possible via existing power lines. The major disadvantage of PLC technology is signal interference and the inability to transmit data on high voltage side of a power system (Cogency, 2014).

However, our proposed system was designed to mitigate the following limitations as identified by existing literatures:

(1) Reduces management, maintenance, and start-up cost significantly.
(2) Incorporating energy theft detection system through remote disconnection.
(3) Effective data transfer speed with better coverage when compared with Bluetooth and ZigBee technology.
(4) Reduces design complexity and easy to deploy when compared with the microprocessor based AMS.

MATERIALS AND DESIGN

This section describes the detailed system, the modelling, simulations and every other detail required for the successful design and construction of the proposed system.

The Automated Energy Metering System using GSM Technology (AEMS_GSM)

This section presents a simple and detailed overview of the design of the automated metering system using GSM technology. This section is divided into four major subsections which are:

(1) Metering Circuits;
(2) Power supply;
(3) The Communication section;
(4) PIC Micro-controller.

Figure 1 depicts the functional block diagram of the Automatic Metering System using GSM (AEMS_GSM). The diagram shows how the different sections of the metering system are connected for full functionality.

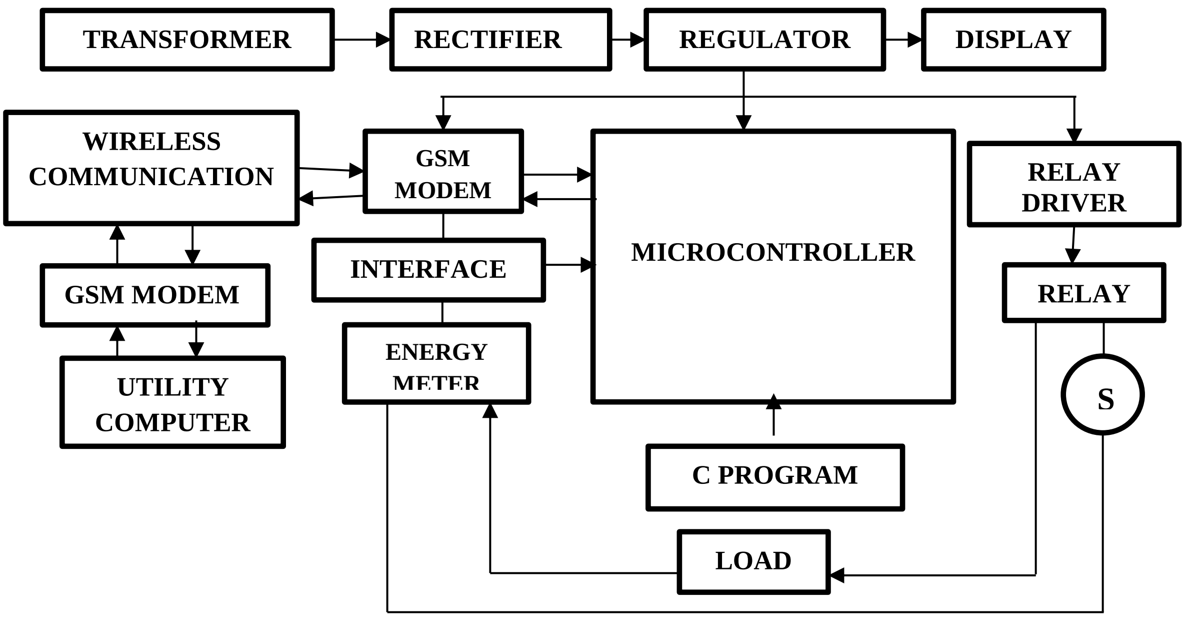

Figure 1: Functional block diagram of the AEMS_G

Metering Circuits

This phase consists of voltage and current sensing circuits which is used to sense the voltage and current consumed by the load. For this research study, the sensing circuits are used to reduce the cost of constructing an energy meter. The potential transformers and the current transformers are both used to sense voltage and current reading in the load. The Analysis of the voltage and the Current sensing circuits for this study is listed described below.

Voltage Sensing Circuits: For this research study, a step-down transformer was used to step down 240VAC supply from the mains to 12VAC. Therefore, turning the ratio of the transformer used to 20:1. Equation 4 depicts the Transformer ratio while equation 5 gave a mathematical expression for calculating voltage divider circuit.

Analysis of The Voltage Sensing Circuit:

Transformer ratio of potential transformer used,

$240/12 = 20/1$ (4)

Using the voltage divider circuit,

$V\_(OUT) = (V\_IN \times R\_2)/(R\_1 + R\_2)$ (5)

$V_{IN} = 12$V, R_1 = 10K, R_2 = 1K

$V\_(OUT) = (12 \times 10^3)/(10^4 + 10^3)$ =1.0909V

To protect the microcontroller from high voltage, the maximum amount of voltage that would be sensed by the ADC port of the controller is 1.09099V. The values read by the ADC port of the microcontroller is multiplied by as scaling factor to obtain the actual voltage value read by the potential transformer.

Current Sensing Circuits: The measurement of alternating electric current is done by using a current transformer which was used to observe the flow of current by reporting the accurate current usage and phase angle to the microcontroller. The current sensing circuit was designed in such a way that it connects to the microcontroller at the output and in series to the load at the input.

Analysis of the Current Sensing Circuit: Current transformer is rated 1V/Amp, therefore, at 5A current for standard current transformer, 5V is induced at the secondary winding.

Using the voltage divider circuit,

$V\_(OUT)=(V\_IN \times R\_2)/(R\_4+ R\_5)$ (6)

V_IN= 5V, R_4 = 100K, R_5 = 10K

$V\_(OUT)=(5\times10^4)/(10^5+10^4)$= 0.4545V (7)

Design of the Power Supply Unit

For this study, the power unit supplies 5VDC to the PIC microcontroller, GSM module and the LCD. The mains voltage 240VAC is supplied to the transformer which steps it down to 12VAC. AC voltage output is converted to pulsating DC voltage by the bridge diode. Capacitor C2 is used to filter the pulsating output of the bridge rectifier. The 7805-voltage regulator is used to maintain a constant output voltage of 5V. The input voltage of the regulator should not exceed 35V as stated in the device datasheet. From Equation 5, the condition is met since $V_{L(DC)}$ = 9.913V. Capacitors C1 and C3 are decoupling capacitors used to prevent electromagnetic interference from interfering with the supply to the microcontroller. Typical values of 100µF and 100nF is used. The LED acts as an indicator lamp to show that the power supply is functioning. The resistor R1 acts as a current limiting resistor for the LED to reduce the current passing through the LED.

Communication Section

The communication section of the study is responsible for bi-directional communication between the meter and the remote PC. It sends and receives information such as disconnection signal and meter readings from the PC and the energy meter, respectively. The main device that is responsible for communication between the meter and the PC is the GSM modem which sends and receives data through radio waves over a wireless network.

The GSM modem at the PC side is made up of a P16F873A microcontroller and a USB to TTL converter. The converter retrieves data from the PC and sends it to the microcontroller. The microcontroller then processes this data and sends it to the GSM modem which sends the data to the energy meter. The converter also accepts data from the GSM modem and sends it to the converter which processes the data and sends it to the PC.

Microcontroller Section

The microcontroller section is responsible for computing power calculations and displaying the value obtained on the LCD. The controller is also used to automate the meter reading process by interfacing a GSM modem. The GSM modem is responsible for communications between the energy meter and the remote PC. The PIC microcontroller used in the development of this work is the PIC18F452 which is a 40-pin high performance microcontroller. Table 1 shows the algorithm for the automatic energy metering system using GSM.

IMPLEMENTATION AND TESTING

This section discusses the implementation and the testing phase involved in this study. The implementation phase entails purchasing the required hardware and the different softwares. However, in the testing phase, different parts of the project were tested using various methods to ensure they perform as required; a load is also used to test the functionality and accuracy of the energy meter.

Implementation

The implementation of this system is divided into two (2) main categories:

(1) Hardware implementation
(2) Software implementation

Hardware Implementation

This subsection phase of this study entails the following:

(1) Bread boarding of components
(2) Mounting and soldering of components
(3) Packaging

Bread Boarding of Components: Prior to the construction of the project, the various components used for the project were bread boarded to ensure that all the components are functioning properly.

It was also done to ensure that the circuit diagram designed for the project is correct without necessarily soldering the components on the Vero board permanently.

Mounting and Soldering of Components: After the bread boarding stage, the components were mounted appropriately and soldered on a Vero board to ensure permanent connection between the components. This was properly done to avoid bridging, short circuit or open circuit problems.

Packaging: After the mounting and soldering of various components, the project was packaged within a plastic case with the LCD projecting from the top of the casing.

Table 1: The Algorithm for Automatic Energy Metering System using GSM

ALGORITHM FOR THE AUTOMATIC ENERGY METERING SYSTEM USING GSM (AEMS_GSM)

Input: {system clock Timer (C), LCD, Microcontroller unit (MCU), GSM modem;
Load ADC production calibration constant, Load gain calibration constant;
Energy reading on utility PC (ERUP), Energy reading on the consumer meter (RCM)};

Output: {Meter Tampering Signal (MTS), Billing Information};
Initialize Clock Timer C = 0;

Process:

Step 1: $\forall$ Timer ϵ {Load ADC calibration, Load gain calibration constant};
Step 2: Count Pulse C to obtain energy usage;
Step2: Calculate the basic parameters for energy usage:
- i. $V_{r.m.s}$ and $I_{r.m.s}$
- ii. Apparent power
- iii. Active power and Energy Time using Equation 1, 2 and 3.
- iv. Power factor demand
- v. Frequency from timer count

Step 3: Display reading on LCD;
Step 4: Enable GSM modem application to:
- i. Obtain data from modem
- ii. Display energy reading on utility PC;

Step 5: Check for meter tampering signal;
Step 6: if (ERUP != RCM) {
Step 7: Do these:
- i. Send meter tampering signal
- ii. Send disconnect signal to MCU
- iii. MCU activate relay unit
- iv. Alert delegate to start investigation

Step 8: }
Step 9: Else if (ERUP==RCM) {
Step 10: Do these:
- i. Generate billing information based on amount of energy consumed
- ii. Send billing information to consumer

Step 11: }
Step 12: Stop

Software Implementation
This subsection entails the coding of the PIC18F452 microcontroller using MikroC and the GUI on the personal computer using Visual basic. After compiling the program for the microcontroller, it was converted into a .hex file which was then loaded into the microcontroller using a PIC programmer.

Testing
In this section, different tests were carried out to monitor and verify the operations and performance of the metering system. The key tests used in this research study include:

1) Unit Testing
2) Integration Testing
3) System Testing

Unit Testing
The metering system consists of different units which were coupled together to obtain the whole system. Tests on units independent of one another were carried out such as the resistance and capacitance values before circuit connections. The transformer was tested to ensure that it provides the necessary voltage levels when it is connected to the mains. The diodes, transistors, capacitors and resistors were also tested to ensure that they were functioning properly.

Power Supply Unit Testing: The power supply unit consists of the step-down transformer, the bridge diode, capacitors and voltage regulator. The tests were carried out at different outputs of these components to ensure that the required wave form and AC or DC voltage levels are obtained.

Communication Unit Testing: The communication unit consists of transistors, the GSM module, potentiometer and the PC. All tests were carried out at various outputs to ensure that the required results are obtained.

Integration Testing
To evaluate the interaction between separate modules of the project, the integration testing was carried out. This was important because the project involves the integration of several components to obtain a complete system. The test was about connecting the power supply unit, the microcontroller, metering section and the communication section together.

Table 2: Various voltage flow

S/N	Outputs/Inputs	Expected values (V)	Practical values (V)
1	Output at Power Supply Unit	5.0	5.01
2	Output at Current sensing unit	0.45	0.5
3	Output at Voltage sensing unit	1.09	1.3
4	Output at step down transformer	12.0	13.05
5	Input at GSM modem	4.2	4.0

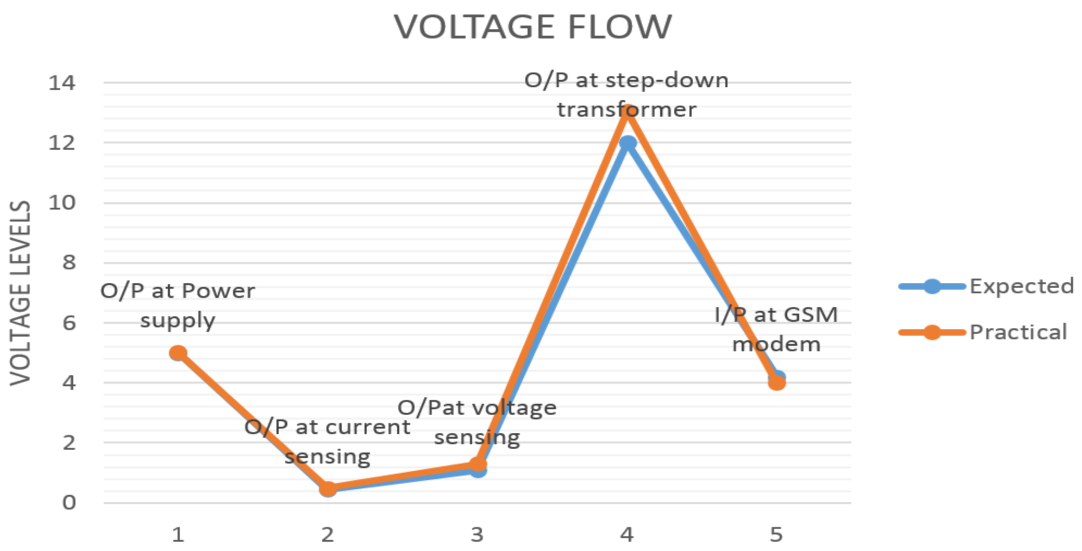

Figure 2: Graphical representation of voltage flow

Table 2 depicts the various voltage flows obtained at different outputs of the study where the maximum, the voltage entering the ADC port is 0.4545V. The expected values obtained during the system design and the practical values obtained during the implementation of the project are also compared. Figure 2 shows the graphical representation of the voltage flow at different outputs and inputs in this project. From Figure 2, the practical values obtained in this study was very close to the expected values.

System Testing

System testing was done to test the complete metering system. This involves the complete operation of the system based on the interaction between the different modules. It involves obtaining the meter readings from the test loads and sending the required data to the personal computer. The test load also disconnects from the power source automatically once the preset energy limit has been exceeded.

CONCLUSION

An Automatic metering system using GSM technology (AMS_GSM) was designed, implemented and tested. This system gives a revolutionary advancement in the innovation of energy metering which considers the concept of a two-way wireless communication technique and accurate measurement of electric energy used by a consumer load. The testing shows the accuracy of the practical testing values to the expected testing values hence, energy meter could have better accuracy reading and energy calculations. Therefore, this study also contributes to the development of smart grids to make the delivery of electric energy reliable and properly accounted for. Challenges encountered during the implementation are the difficulty in analyzing and calculating the necessary values and results required for this study.

Future research can be carried out by using smart energy metering IC such as ADE7166 or ADE7169 to interface directly to an LCD thereby eliminating the use of a microcontroller which can be difficult to program and incorporating method like inspection and comparison energy theft detection instead of bypass detection used in this research study.

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