Design and Implementation of Low-Cost SMS Based Monitoring System of Distribution Transformers

Mohamed Ahmed Eltayeb Ahmed Elmustafa Hayati
National Load Dispatch center
Sudanese Electricity Transmission Company
Khartoum, Sudan
moh.hayaty@gmail.com

Sherief F. Babiker
Electrical and Electronics Engineering Dept
University of Khartoum
Khartoum, Sudan
shariefbabikir@gmail.com

Abstract—Gathering information from distribution transformers is very important in order to monitor and control the entire electric distribution grid efficiently and reliably. It acts as a decision support system to assist the grid operation engineers with information helps to estimate the load, fix problems and identify the week points in the grid. The objective of this paper is to build a system to acquire the remote electrical signals from distribution transformers such as voltage, current, power and temperature; then send these values to a monitoring node via Short Message Service, SMS, along with exact date and time of measuring. At the monitoring node, software is built to receive the information, save into databases and also display the data on a screen for use by the operation engineers. Tests conducted on the system have shown that the monitoring node continues to receive periodic status data. Observed Intermittent delay is attributed to the congestion in the Global System for Mobile Communications, GSM network.

Keywords—SMS; PIC 18f4550; Distribution transformer; RTU; Monitoring node;

I. Introduction

In power systems, a distribution transformer is an electrical device that provides the final voltage transformation in the electric power distribution side, stepping down the voltage used in the distribution lines to the level used by the customers. Operation of distribution transformer under rated condition guarantees their long life. However, their life is significantly reduced if they are subjected to overloading, resulting in unexpected failures and loss of supply to a large number of customers thus effecting system reliability [1]. Overloading of distribution transformer and Insufficient cooling are the main reasons of failure in distribution transformers.

Gathering information from distribution transformers such as voltage, current and temperature is very important in order to monitor and sometimes control the entire distribution network efficiently and reliably. It helps the operating engineers with the monitoring of the electric distribution grid

which is definitely increase the life time of the transformer and maintain the stability of grid.

Global System for Mobile Communications (GSM) is a wireless communication technology; most popular today for transmitting data anywhere in the world through short messages service (SMS). When using GSM networks, proposed system will act as an embedded system which can monitor and control transformers through SMS using service available on most digital mobile phones and modems that allows sending and receiving of short messages. GSM technology provides an easy way to transmit data from distribution transformers to the main control centre with less cost and proper way.

II. System design

This paper is divided into two parts. First of all, the remote terminal unit (RTU) is designed using PIC18f4550 microcontroller to collect data from sensors nearby the transformer and sending data to monitoring node via SMS messages. Secondly, at the monitoring node, there is software built to receive data from the RTU and display it for the use of operating engineers.

A. Remote Terminal Unit

All functions of data acquisition, processing and transmission are usually performed by a single unit called the Remote Terminal Unit (RTU). As the name implies, a remote terminal device, RTU, is an Intelligent Electronic Device (IED) that can be installed in a remote location, and acts as a termination point for field contacts [2]. RTU is built around PIC18F4550 and it is designed to send the data of distribution transformer to the monitoring node every one hour via SMS and also to response to the monitoring node requests. Therefore, The RTU acquires temperature, voltage and current from sensors every fifteen seconds and calculates the power (in

kilowatt). Then the RTU adds the value of power in KW to the previous once. After sixty minutes, the RTU divides the summation by number of measurements to calculate the power in kWh and sends it with ambient temperature and actual voltage and current to monitoring node along with date and time of measurements. Also there is LCD at RTU side to show date, time temperature and voltage. The RTU design is consist of two parts; these are the hardware design and software design.

1) Hardware design

The hardware design is consist of the PIC18f4550 surrounded with sensoners circuits and power supply. Fig. 1, below shows the hardware design of the RTU.
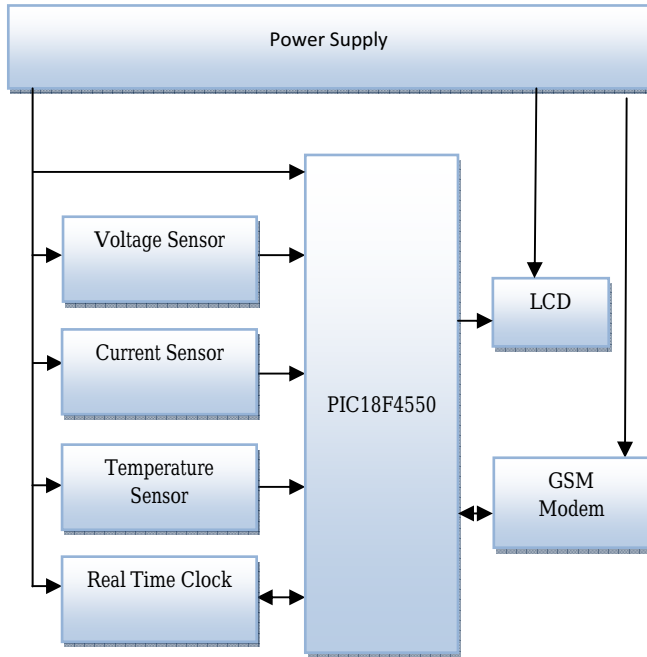

Fig. 1. RTU Block Diagram

a) The Temperature Measuring Circuit:

The LM35 integrated circuit sensor is used to measure ambient temperature with an electrical output proportional to the temperature (in ℃). The sensor has a sensitivity of 10mV / ℃. PIC18f4550 MCU's ADC gives the value between 0-1023 for input voltage of 0 to 5V. So if the reading is 0 then input is 0v, if reading is 1023 then input is 5v.

b) The Voltage Measuring Circui:

The mains voltage across the load (low voltage side of 11kV/415V transformer) is divided by a factor 253 (115 % of rated voltage 220V) and shifted to a DC level of 2.5 V. This shifting enables to measure positive and negative voltages. Fig. 2, shows the voltage measuring circuit. Resistor R1 and R3 (which are equal 62.51 KΩ, 4.7 KΩ respectively) by

default produces a 2V AC signal when the line voltage reaches 115% of nominal voltage as shown in "(1),".
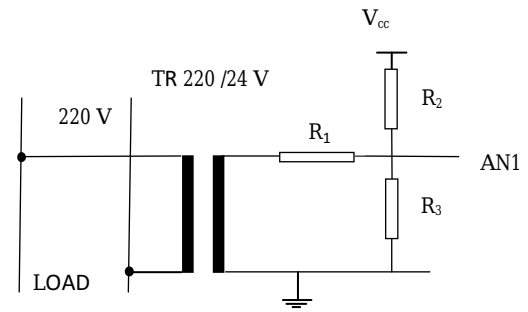

Fig. 2. Voltage Measuring Circuit

$$V_{Max} = 1.15 \ V_{Rated} \ (N_2 \ / \ N_1) \ R_3 \ / \ (R_3 + R_1) \qquad (1)$$

The 253V limit is there to leave 15% margin for over-voltages. The DC bias ladder R2, R3 (both are 4.7K Ω) positions the AC signal halfway up the analog to digital converter (ADC) voltage reference to enable measuring positive and negative voltages as shown in "(2),".

$$V_{DC} = V_{CC} \ R_2 \ / \ (R_2 + R_3) \qquad (2)$$

Then the sumation of two voltages is fed to an ADC input (AN1, AN2, and AN3 for phase 1, 2, 3 respectively) of the PIC18f4550.

c) The Current Measuring Circuit:

Current transformer (CT) is used to reduce the magnitude of current. The CT is typically described by its current ratio from primary to secondary. A 1000:5 CT would provide an output current of 5 amperes when 1000 amperes are passing through its primary winding. Most common secondary current ratings are 5 amperes or 1 ampere. In this project the CT with output 5 Ampere has been preferred. There are numbers of dedicated current IC's exist which translate the current sensed into a voltage directly appropriate for the analog input of the PIC18f4550. The one is used here is ACS712, 5 Ampere. The microcontroller uses the supply voltage (+5V) as reference for ADC conversion. The digitized sensor output is processed through software to convert it to the actual current value. According to datasheet of ACS712, 5 A the sensitivity is 185mV/A. The ACS712 produces an output of 2.5V for 0A current through the current sensor. Fig. 3, below shows ACS712 IC with basic connections.

Fig. 3. Current Measuring Circuit
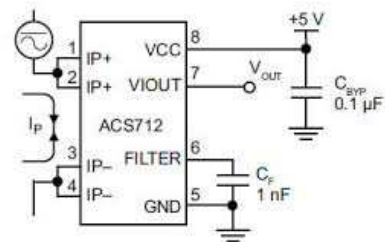
$$V_{Constant} = 253\ V_{dd}\ /\ 1024 \qquad (3)$$

$$I_{Constant} = 5.404\ V_{dd}\ /\ 1024 \qquad (4)$$

Where V_{dd} = 5V.

d) Re

The DS1307 serial real-time clock (RTC) is a low-power, full binary-coded decimal (BCD) clock/calendar plus 56 bytes of NV SRAM. Address and data are transferred serially through an I2C, bidirectional bus. The clock/calendar provides seconds, minutes, hours, day, date, month, and year information. The end of the month date is automatically adjusted for months with fewer than 31 days, including corrections for leap year. The clock operates in either the 24-hour or 12-hour format with AM/PM indicator. The DS1307 has a built-in power-sense circuit that detects power failures and automatically switches to the backup supply. Timekeeping operation continues while the part operates from the backup supply [3]. Fig. 4, shows DS1307 IC and its connections.
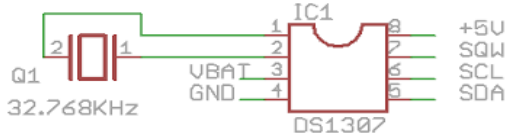

Fig. 4. Pin Diagram of DS1307

2) Software design

The RTU code is written in C language using Mikro C environment. The software is responsible for managing the PIC microcontroller and the devices connected to it. The measured signals come from the sensors went through several stages before been sent to the monitoring node. Firstly, analog signals are manipulating to meet the requirements for further processing. Secondly, the RMS values of voltage and current are calculated from real samples, and then the kWh is calculated and sent with other data along with time and date to monitoring node. The flow chart shown in fig. 4, represents the actual code running inside the RTU.

3) Principles of working

a) Sampling:

For analog inputs (current and voltage) 100 samples are measured, one every 400 microseconds, and stored inside two arrays $V_{in}[100]$ and $I_{in}[100]$ for voltage and current respectively. This is equal to total measuring time of 40 milliseconds, which is 2 full 50Hz cycles.

b) Calculation:

For the voltage and current the samples taken are scaled to actual volts and amperes and 2.5V offset has to be subtracted (Value = nominal 511, the middle of the ADC range), and multiplied with a constant value to get the correct volt and current values out of the samples.

The multiplication factor for voltage and current will be 253.0 and 5.404 respectively.
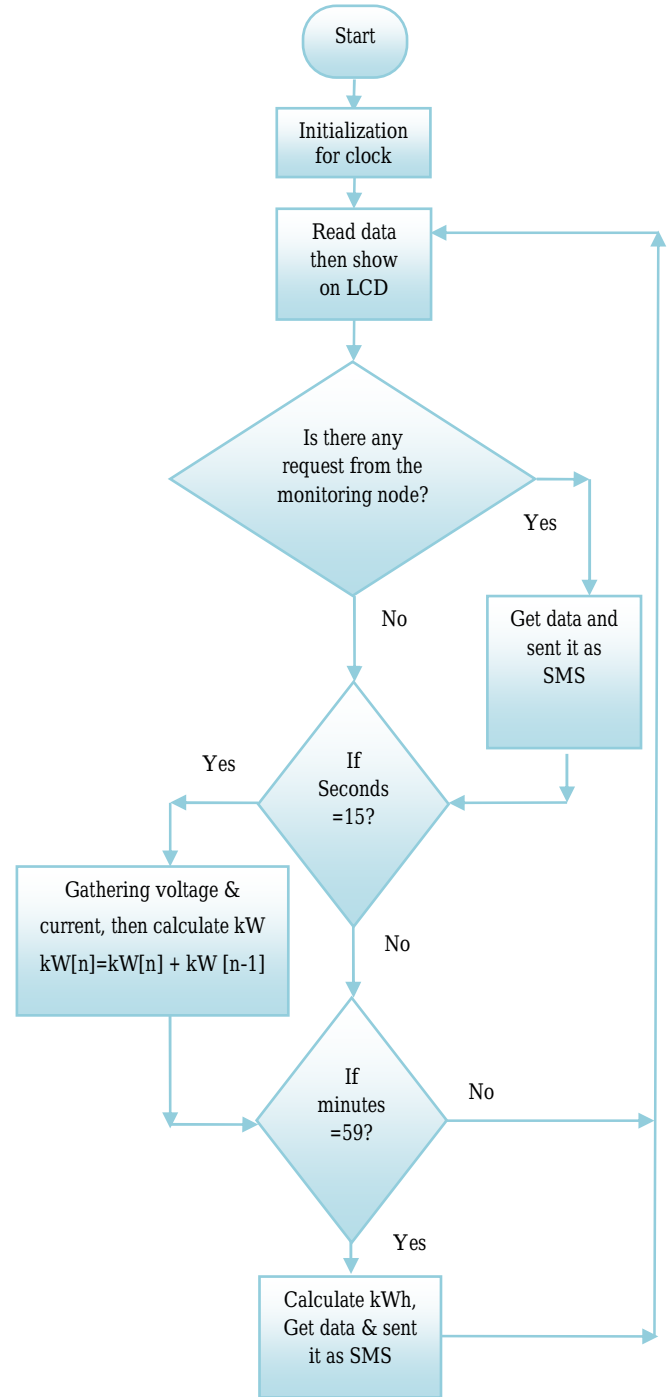

Fig. 5. RTU code flow chart

Equation (5) and Equation (6) show how the real voltage and current were calculated by subtracting the offset values which were added by the voltage and current measuring circuits.

$$V_{real} = V_{constant} \times (V_{in} - V_{offset}) \qquad (5)$$

$$I_{real} = I_{constant} \times (I_{in} - I_{offset}) \qquad (6)$$

Wherein V_{in} and I_{in} represent the ADC values corresponding to input voltage and current respectively. V_{offset} and I_{offset} represent the middle value of ADC range which is equal to 511 or 2.5 V. Then to calculate the RMS values of voltage, current and power, the formulas are

$$V_{rms}(V) = \sqrt{\left(\sum_{i=0}^{100} V_{real}[n] * V_{real}[n]\right)/100} \qquad (7)$$

$$I_{rms}(A) = \sqrt{\left(\sum_{i=0}^{100} I_{real}[n] * I_{real}[n]\right)/100} \qquad (8)$$

$$P_{rms}(watt) = \sqrt{\left(\sum_{n=0}^{100} V_{real}[n] * I_{real}[n]\right)/100} \qquad (9)$$

The symbol n represents the sample number.

To calculate the energy in kWh since there are 240 measurements of $P_{rms}(watt)$ every hour, the formula is

$$P_{rms}(kWh) = \left(\sum_{n=0}^{240} P_{rms}[n]\right)/(240 * 1000) \qquad (10)$$

The symbol n represents measurement number.

B. Monitoring Node

This part presents the design of monitoring node system including wireless modem and software that organize all the data coming from RTUs, saves it into database and displays it into screen for the use of the operators.

1) Wireless Modem

Modems which use a mobile telephone system (GSM, GPRS or UMTS etc.), are known as mobile broadband modems (sometimes also called wireless modems). USB wireless modems use a USB port on the laptop instead of a PC card or Express Card slot. Most of GSM wireless modems come with an integrated SIM cardholder and some models are also provided with a micro SD memory [4]. In this paper the wireless modem has used with RTU as well as the monitoring node. wireless modem is connected with simulated RTU

circuit using RS232 cable and virtual serial port software to act as a GSM module. Also Monitoring node used wireless modem to send and receive SMS from RTUs. Fig. 6, shows the wirless modem connected to PC.

Fig. 6. Wireless Modem

2) Main Program design

The main objective of program at monitoring node is to assist the operator engineer to communicate with a system easily and efficiently through the use of symbols. Therefore the program is built using Microsoft visual basic 2012 which runs on windows operating system; it requires the ".Net" version 4.0 being installed. The software is responsible for acquiring data anytime, receiving data from remote units, identifying the sender RTU, showing data on the system and also saving it into database. The database in this system called transformers database and it built using Microsoft access. There are four tables inside the database in this system.

- Login table
- Incoming data table.
- Engineers table.
- Stations table (Transformers table).

a) Login table:

It contains all the usernames and passwords for the users in the system. Every time the operator logs in, the system check whether the password and user name are in this table or not. Also whenever the administrator add new user, the new user's name and password are saved on this table.

b) Incoming data table:

It contains the imported signals (voltage, Current, Power, temperature, date and time) from the RTUs.

c) Engineers table:

System uses this table to send SMS alarm message to engineers listed on this table whenever some events occur, for example, if the administrator needs to send message to station's engineer, when the station's temperature level exceeded particular limit, at this time system will use the table to identify the engineer phone number and to any station he belongs.

d) Stations table (or transformers table):

It contains the all stations names and their unique addresses (the address is a SIM card number). System uses this table to add/remove stations (transformers) also when new message received, to figure out if this message comes from listed station or not, by comparing the addresses inside this table with the address inside the message and if they match, system shows the data to operator, otherwise system will discard the message.

3) Monitoring Node Operations
a) User access and authentication subsystem:
User authentication system handles the process of allowing users to access the system and it deals with login table. Also administrator also uses this subsystem to add or delete users.

b) Communication:
This part is responsible for establishing a connection with the communication media (USB wireless modem). Therefore, a port should be chosen in which the modem is connected. Then the baud rate, data bits, stop bit and other parameters of serial communication should be defined. The connection can then be established.

c) Database manipulations:
Addition, removal and updating of records are very important operations for system administrator in order to face the changes of RTUs. This part is responsible for query database to show its data, insert new RTU, delete or remove stations, update station name or address and add new user or changing the password or user name.

d) Receiving data from RTUs:
This is the main part of the monitoring node. It handles the received data, filters it and saves to the database. The idea behind this is: the system always listening and waiting for SMS messages come from the stations and when new message comes, the system will match the station name with station names listed in station database, and if it matches the system will filter and save data to the database inside the incoming data table.

e) Other features:
There are other features of monitoring node system such as interrogate data from particular RTU anytime, show data in graphs, display the status of RTUs and saving important events in a log file for more security.

III. TESTS & RESULTS

A. RTU Tests
In this part, USB wireless modem and RTU circuit which is built with Proteus ISIS software are connected together using virtual serial port software on the same computer. Then by using mobile phone few SMS messages were sent from/to the RTU to test the validity of the RTU system. All circuit components of the RTU are tested one by one and work well.

Fig. 7, shows the RTU system simulated with Proteus ISIS software.

B. Monitoring Node Test
The software at the monitoring node designed using Visual
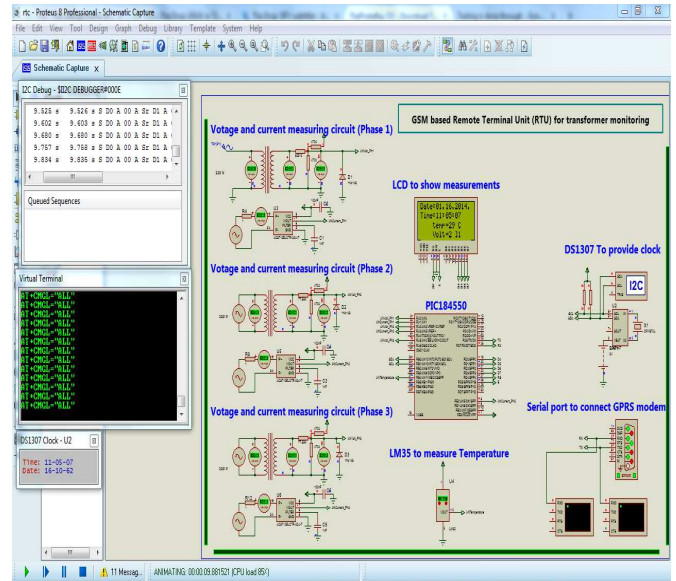
basic 2012 connected to modem through USB port.

Testing is done through two stages. Firstly, the modem was connected to a computer and tested using Microsoft hyper terminal software to check the ability of modem to send and receive SMS messages using AT commands. Secondly, the modem and the monitoring node software were connected together via the USB port and few SMS messages were sent form mobile phone to the system to test the system.

1) Modem Test
SMS is sent / received from a computer using a USB wireless modem. For sending / receiving SMS messages, a valid SIM card was used for the modem, which is then connected to a computer. There are certain AT commands that can be used through HyperTerminal software to send and receive SMS messages. Fig. 8, shows the commands sent from hyper terminal to show the messages stored inside the wireless

Fig. 7. RTU system simulated with Proteus ISIS software
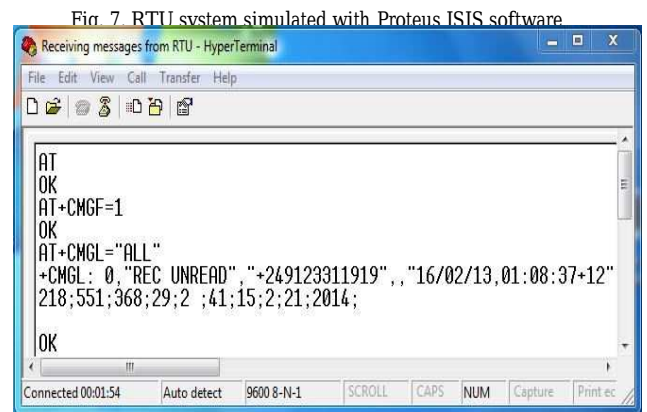
modem.

2) Graphical User Interface Software Test
In this part, the GUI software is connected to wireless modem via USB port. Then few SMS messages were send and receive to check the response of the system. The format of the messages came from RTUs are following this format "Voltage; Current; Power; Temperature; hours ; minutes ;seconds; month; day; year". All other GUI functions were tested one by one. Fig. 9, shows the GUI software at monitoring node.
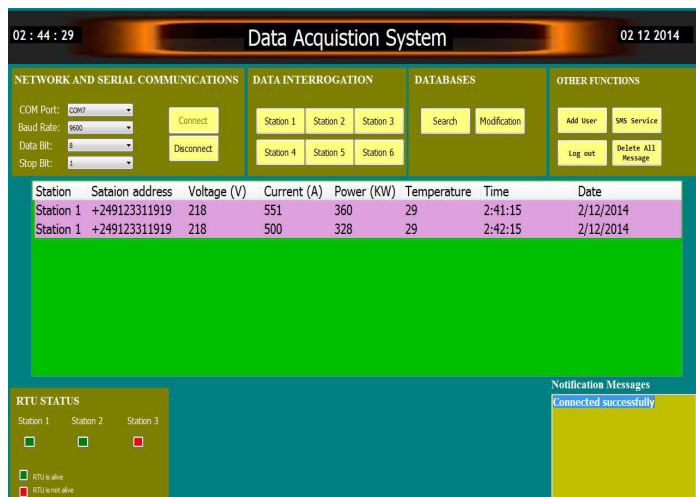

Fig. 9. Monitoring node software

3) Results
This paper is accomplished by designing a hardware circuit and a software program. The design of the desired circuit and the controlling program were carried out through a set of procedures. Firstly data acquisition device called RTU is connected to distribution transformer in order to measure signals. Secondly these measured signals went through several stages before sending it, those stages are

- Signal conditioning by manipulating an analog signal in such a way to meet the requirements of the next stage for further processing.

- Calculate the RMS values for current and voltage from real samples and then calculate the power factor and power in kWh.

Finally, data was sent to the monitoring node via SMS messages. The remote monitoring node received the data and saved it into database. The sensors and circuit were used in the RTU gave suitable output voltage related to input signals (Voltage, temperature or current). The serial port was used to transfer data serially to the wireless modem according to the specified modes. The RTU successfully continuously sent SMS message every hour and whenever the monitoring node request data any time. However, the use of SMS however, shows some delay at certain time, due to the unavailability and traffic busy of the GSM network. But this is not a big deal since this system is not a real time system and also the date and time of measuring of all measurements were recorded at RTU side. At the monitoring node, all subsystems work well and system successfully sent and received SMS messages.

IV. CONCLUSION

This paper has suggested and implemented a method to remotely monitor a group of distribution transformers. The suggested method was accomplished by designing an interface circuit and a software program. System is designed based on a PIC 18F4550 microcontroller which acts as a data acquisition processing and transmission system. The RTU system was periodically sent the data and whenever a request is received from monitoring node. At monitoring node side, software is built based on Visual Basic 2012 to receive data, save it into a database and allows the user to easily monitor and acquire data from RTU side.

REFERENCES

[1] Ansuman Sharma, Rajesh Behura; "GSM based Distribution Transformer Monitoring System", May 2013.

[2] A. Adejumobi, I.G. Adebayo and A.J. Olanipekun.; "Development of Microcontroller-based Electric Power Distribution Automation System", Journal of Innovative Research in Engineering and Sciences, Vol. 2, Issue 1, pp.10-28, March 2011.

[3] DS1307 64 x 8, Serial, I^{2}C Real-Time Clock, Maxim Integrated Products Inc., California, 2008.

[4] (2016, Jan 2). Modem-Mobile BroadbandModems [Online]. Available: http://www.liquisearch.com/modem/mobile_broadband_modems