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Design and Construction of GSM-Based Smart Energy Meter

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Abstract

With advancement of technology things are becoming simpler and easier for us. Automatic systems are being preferred over manual system. The aim of this project is to design and construct a GSM based Smart Energy Meter. The meter designed can be monitored and recharged remotely via SMS. Hardware/Software Methodology was implemented in this work. Hardware implementation consists of three Key parts: The Metering unit, the micro controller and the GSM module. The Metering unit measures the energy consumption of the load and sends the data to the micro controller. The micro controller (the brain of the system) controls the operations of the meter and sends electrical parameters to both the LCD and GSM module. The GSM module establishes a communication link from the meter to the user via SMS. The Software part is responsible for the token generation and meter's querying codes which were written in C language in a Visual Studio Environment. The result obtained from this work is a GSM based Smart Energy meter that can be monitored and recharged remotely via the use of a SMS

Keywords: Energy Meter, Remote Recharging, ATMega32 Microcontroller, GSM

1. Introduction

Electricity has become the principal factor of any economy and it is the catalyst for development in any country. Electric energy is used to drive domestic, commercial and industrial loads as a key source of energy in today's world (Abdulbari et al., 2014; Jubi and John, 2013).

With the rapid demand of power in user's end (offices, school, and workplaces) throughout the world and consumers are asking for better consumer's service, high accuracy of energy measurement and healthy power supply along with timely data delivery, it has now become imperative for utility companies to devise better, non-intrusive, environmentally-safe techniques of gauging utilities consumption.

Considering the cost of power generation and transmission, it is necessary that electricity (electric energy) is monitored to ensure it is optimized and accounted for. For these reasons, energy metering system has been put in place in recent times. Metering could be defined as the process of effectively determining and monitoring power consumption (Na Wu, et al., 2013). There are two kinds of metering. They are analog and digital metering.

Energy is the total power delivered or consumed over the interval of time t may be expressed as:

$$E(t) = \int_0^t P(t)dt \qquad 1.1$$

The instrument used to measure either quantity of electricity or energy, over a period of time is known as energy meter or watt-hour meter. Energy meters are typically calibrated in billing units, the most common one being the kilowatt hour (kWh). Periodic readings of electric meters establish billing cycles and energy used during a cycle (Shomuyiwa and Ilevbare, 2013).

Analog metering consists of mainly measuring the electrical energy. This process uses mainly electromechanical meters whose mode of measurement is through a coil and rotating disc. The electromechanical meters are installed at the user's end. At the periodic intervals, meter readers/inspectors are instructed to read the unit on the meter, this reading is used to calculate the electric charges for the user. This system is ineffective because of the limited information about the power usage (usual monthly electricity bills) provided to the end users make it hard for them to adjust their energy usage to save the electricity bill. The electromechanical meters cannot display real time information of energy usage (Na Wu, et al., 2013).

Digital metering is an upgrade of the analogue metering (Shomuyiwa and Ilevbare, 2013; Satheyamoorthy, 2013; Iqbal et al., 2013). In most digital metering systems, communication is established between the meter, user and the utility company. The meters used in the process are electronic and smart meters. The electronic meter differs from the smart meter in the mode of communication. The electronic meter can only establish a simplex (one direction) communication while smart meter can establish a duplex (two directions) communication. In this system, the consumer is updated with electricity usage, cost, tariffs and other notifications sent by the utility.

The aim of this work is to design and construct a smart energy meter for remote energy measurement and monitoring unit.

This paper is organized as follows: Section 1 provide a brief introduction into energy meter. Section 2 gives a brief literature survey of related works done over time to improve metering. Section 3 provides the methodology used in this work. Section 4

Due to the advancement of technology and the demand of consumer for better power supply, Smart meter has been adopted by many. Since smart energy meters have these different

functionalities to manage the end user loads and run them in an optimal way to reduce the electricity bill as well as to conserve the energy, it's only proper to review previous works (Rodney et al., 2007).

A Bluetooth Energy Meter was invented by (Koay et.al., 2003). The interface between a Meter Reader, PC and the Energy Meter via a Bluetooth can be categorized into three main distinctive portions. The first portion consists of the interface between a PC and the Bluetooth module. The second comprises of the interface between the Bluetooth module and the microcontroller; the interfaces in the first and second portion are both using the standard RS-232 protocol. The third is about the interface between microcontroller and Energy Meter, whereby the communication link is conforming to the Serial Peripheral Interface (SPI) standard (Ekanayaka et al, 2012).

Jubi and John (2013) demonstrated the design and implementation of Prepaid Energy Meter with GSM Technology with the aim of minimizing the queue at the electricity billing counters and to restrict the usage of electricity automatically, if the bill is not paid (Koay et al., 2003). The GSM technology was used so that the consumer would receive messages about the consumption of power (in watts) and if it reaches the minimum amount, it would automatically alert the consumer to recharge. A microcontroller AT89S52 is programmed such that power supply will switch off by using relay when the unit on the energy meter is exhausted. This design will make the users can pay for the electricity before its consumption. It also brings a solution of creating awareness on unnecessary wastage of power and will tend to reduce wastage of power. The challenge in this work is that they didn't clear define how the system can be recharge remotely. Since it can send alert to the consumer about the low credit unit on the meter, it will be best if the consumer can recharge the meter on their same platform. Hence the system can be improved on by creating a means of recharging the energy meter remotely.

1. Methodology

For this project, a hardware/software co-design methodology was used to implement the GSM based Smart Energy Meter.

ATmega32 Microcontroller was programmed in C language-using AVR Studio IDE. Simulation will be done with the aid of Proteus and AVR Studio Software.

The energy meter designed used an ADE7755 metering chip, ATmega32 Microcontroller and other discrete components. The SMS communication with the meter established with the aid of SIM900 GSM module; AT-commands were being sent to the GSM module from a mobile phone for communication. Also, a 4x3-keypad was employed for loading energy tokens and obtaining energy information from the meter; the energy data will be viewed on the liquid crystal display unit. Simulation of the electronic circuit designs was carried out using Proteus software, Atmel AVR development kit and a serial port monitor via 232 RS connector.

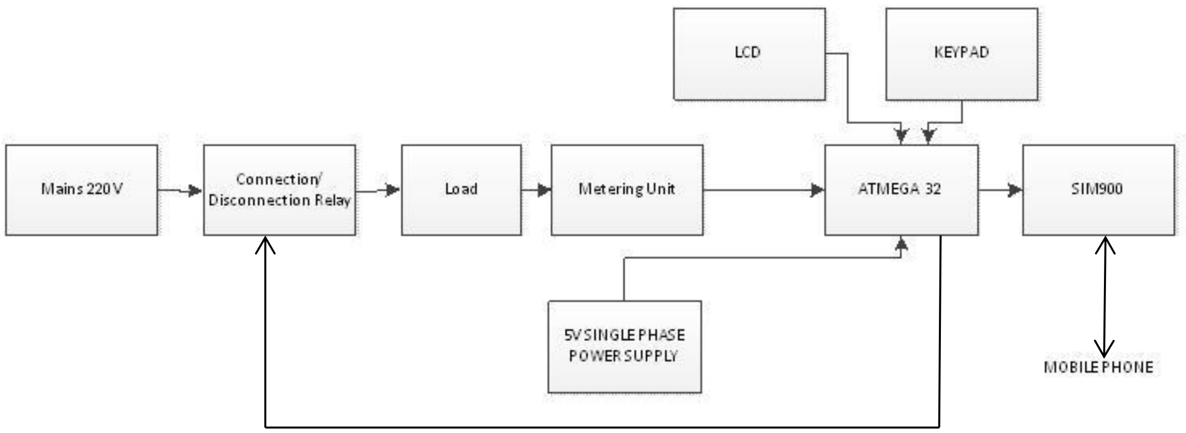

Figure 1: The block Diagram of the GSM based Smart Energy Meter.

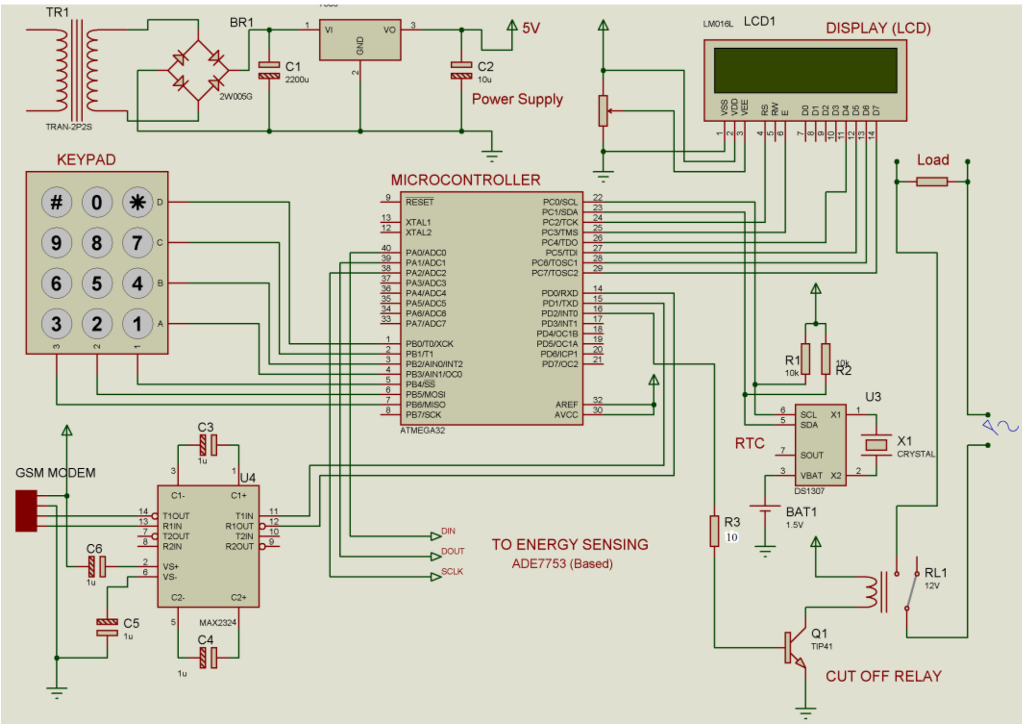

Figure 2a: Schematics Layout in Proteus Environment.

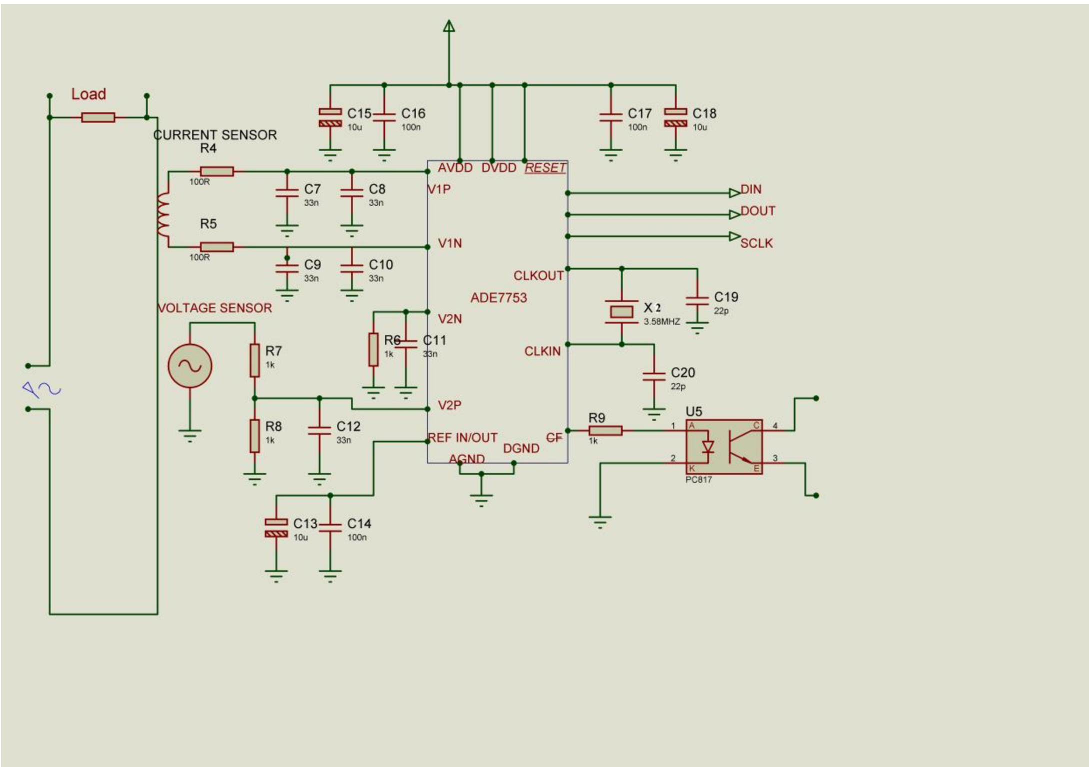

Figure 2b: Schematics Layout in Proteus Environment.

1.1 System Specifications

The system has the following specifications:

Measurement

- Single Phase 2 Wire Voltage and Power Supply
- Nominal Voltage is 220V
- Frequency is 50Hz

Current

- I_{op} = 10A, I_{max} = 60A
- Relay Disconnect Indicator

Environmental:

- Operating Range: -10^{o}C to +70^{o}C
- Storage Range: -10^{o}C to +70^{o}C

Prepayment

- Capacitive Touch Keypad
- SMS Mode Enabled

Communication Port

- 16 X 2 LCD Display
- Display Screen: 56mm(Length) X 16mm(Width)
  .

1.2 Design of the Power Supply Unit

The basic components that were used to design the power supply for the integrated circuit are:

- Step down transformer (inside AC/DC adaptor)
- Voltage regulators
- Capacitors
- Diodes

Transformer

The step down transformer steps the mains supply voltage to 12V with a current rating of 1.0A. The input voltage to the voltage regulator is the range of 7V – 35V. Hence I chose a 12-0-12 transformer, since $12\sqrt{2} = 16.97$V.

Voltage Regulator

Since a 5 V output voltage is required, an LM7805 voltage regulator IC was used with the following rating: Input voltage range 7V – 35V; Current rating I_C = 1A; Output voltage range, V_{Max} = 5.2V and V_{Min} = 4.8V.

Rectifying Circuit

Since the AC mains power supply is rectified by the AC/DC adaptor, a half wave rectifier was used for the power supply. It has the advantage of less DC saturation in both cycles of diodes conduction; higher Transformer Utilization Factor (TUF); 10A10 diodes are used as it is capable of withstanding a higher reverse voltage of 1000V.

Capacitors

Designing the values of capacitors is essentially dependent on the knowledge of ripple factor, which is given by the equation below.

$Y = \frac{1}{4\sqrt{3fRC}}$ (as the capacitor filter is used)

f = frequency of AC = 50Hz

R = Resistance calculated = V/I_C

V = Secondary voltage of transformer = $12\sqrt{2} = 16.97$V. Therefore,

R = 16.97V/1.0A = 16.97Ω, hence standard 18Ω resistor is chosen.

C = Filtering capacitance

The capacitance for filtering was determined as shown below:

$$Y = \frac{V_{ac-rms}}{V_{dc}}$$

$$V_{ac-rms} = \frac{V_r}{2\sqrt{3}}$$

$$V_{dc} = V_{Max} - \frac{V_r}{2}$$

$$V_r = V_{Max} - V_{Min}$$

$$\therefore\ V_r = 5.2 - 4.8 = 0.4V$$

$$V_{ac-rms} = 0.3464, V_{dc} = 5V, Y = 0.06928$$

Therefore, the capacitor value is found out by substituting the value of the ripple factor, Y, into equation 4.1. Thus, C

= 2314μF and the standard 2200μF was chosen.

The datasheet of 7805 prescribes to use a 0.01μF capacitor at the output side to avoid transient changes in the voltages due to changes in the voltages due to changes in load and a 0.33μF at the input side of the regulator avoid ripples if the filtering is far away from the regulator (Transistor TIP41, 2016).

Where

V_{max} = Maximum Voltage of LM7805 Voltage Regulator

V_{min} = Minimum Voltage of LM7805 Voltage Regulator

$V_{ac\text{-}rms}$ = Root mean square alternating voltage

V_{dc} = Direct Current Voltage

Y= Ripple factor

V_r = Output Voltage Range

Given the transistor parameters from its datasheet [16]

V_b=5V, V_{be}= 0.7V, I_b = 0.4A

From the expression:

$$R_3 = \frac{(Vb-Vbe)}{Ib}$$

$= \frac{(5-0.7)}{0.4}$ = 10.75Ω, but the researches chose 10Ω resistor in this design.

The values of C3-C6 are 1μF respectively which were obtained from the Max232 datasheet (Edison Electric Institute, 2011). The Value of the crystal oscillator X1 is 32.768kHz which was obtained from the RTC 1307 datasheet (Max 232 data sheet, 2016) as well as the value of the resistors R1 and R2 (10kΩ) each. The pin configuration for the microprocessor, LCD and the metering chip ADE7753 were given from the Atmel ATMEGA 32 datasheet, LCD 016M002B datasheet and ADE7753 datasheet (RTC1307, 2016; Atmel ATMEGA, 2016; LCD-016M002B, 2016). The Values of R4, R_5, R_6, R_7, R_8 and R_9 are 10kΩ, 10kΩ, 1kΩ, 1kΩ, 1kΩ, 1kΩ respectively which were obtained from the ADE7753 datasheets as well as the values of C_7, C_8, C_9, C_{10}, C_{11}, C_{12}, C_{13}, C_{14}, C_{15}, C_{16}, C_{17}, C_{18}, C_{19}, and C_{20} are 33nF, 33nF, 33nF, 33nF, 33nF, 33nF, 10μF, 100nF, 10μF, 100nF, 100nF, 10μF, 22pF, 22pF respectively. The Value of the internal crystal of the Energy sensing chip ADE7753, X2 is 3.58MHz given in the data sheet of ADE7753 (RTC1307, 2016).

1.3 Operation of the GSM based Smart Energy Meter

Energy is measured by the principle of integrating power over a period of time. The outputs of the voltage and current Sensors are fed into the metering chip (ADE7755). The metering chip converts the signals from the voltage and current sensor into their digital forms and sent them to the microcontroller. The Microcontroller (ATmega 32) acts as the primary controller. The primary controller collects information from energy meter as well as from the GSM module. The energy meter reading is compared with the information by the microcontroller. The Controller will trigger the Relay which cut off and restore power supply depending on the amount of unit in the meter. The LCD is interfaced to microcontroller using parallel port connection. The microcontroller based system, continuously records the readings. The GSM modem is serially connected with the controller which is the major communication module between user and meter. The GSM uses its own network for the transfer of information. The programming makes use of messaging features of GSM AT command. And, once the relay is triggered, the electricity supply will be cut off. The power will be supplied again only if the meter is recharged with enough credit.

GSM technology is included to send messages to the customer about the balance amount and if the amount is totally used up then will shut down the power after alerting user.

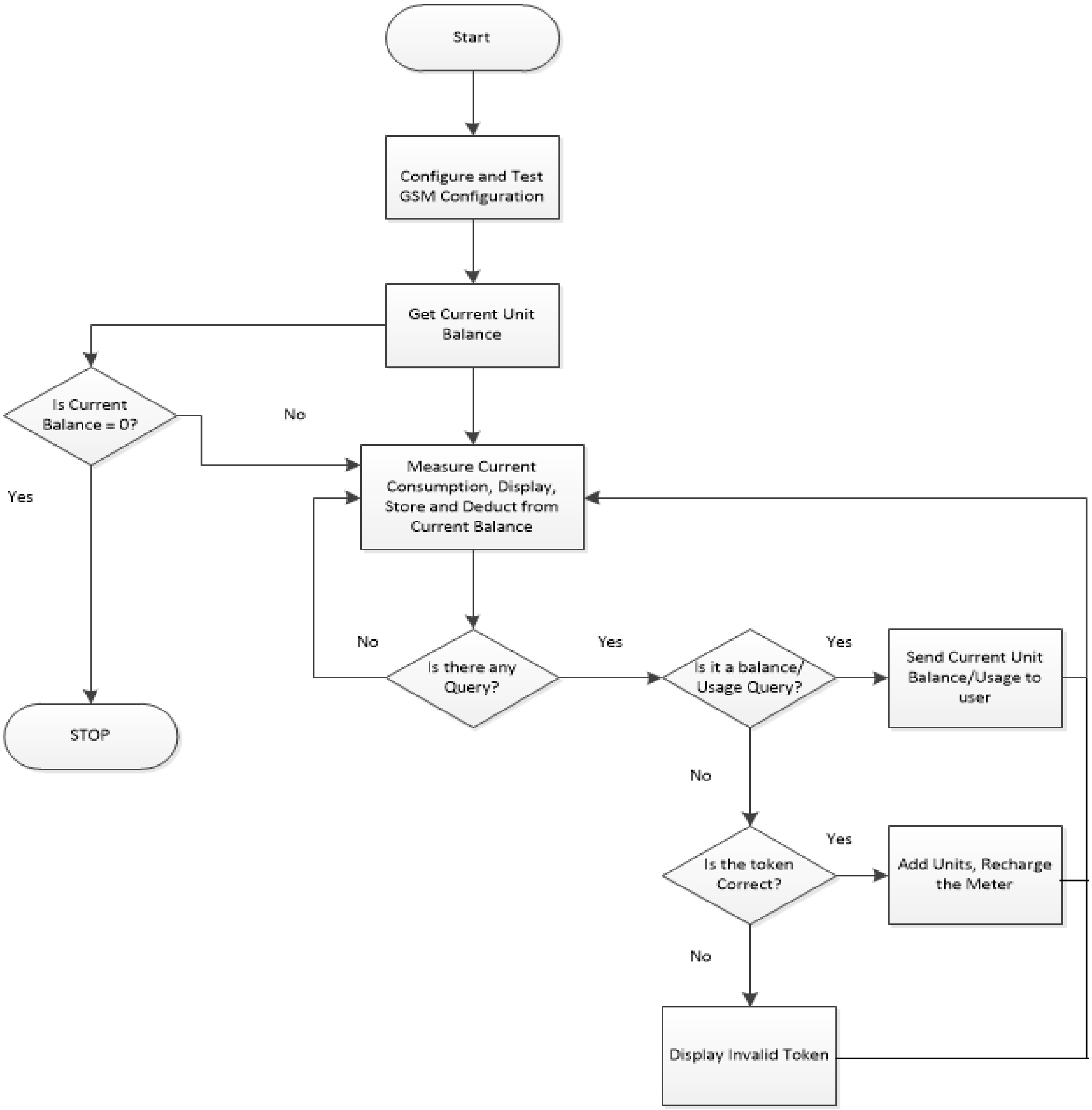

Figure 3: The Flow Chart of GSM based Smart Energy Meter

3.2 Token Generation

The Token Generator used was created in a Visual Basic Environment which will be used to generate tokens/pin code for the energy meter.

The PIN code used to recharge the meter is an encryption of three key parameters. They are:

1. The Meter Serial Number
2. Supply Group Code (SGC)
3. The number of units that consumer want to purchase.

For the design, I used the combination of the meter serial number, number of units to be loaded into the meter and the state code. When the utility sales personnel insert the user's state code, unique meter serial number as well as the number of units he/she wants to purchase, the token generator will generate a unique token for the user.

When the generated token is loaded into the meter via the keypad or SMS by the user, the meter decrypt this information, cross check if it is correct before it loads it. If the token is invalid, the meter makes an alarm sound and invalid token is displayed on the LCD. If the token is valid, the meter is recharged and an SMS notification is sent to the user as well as being displayed on the LCD.

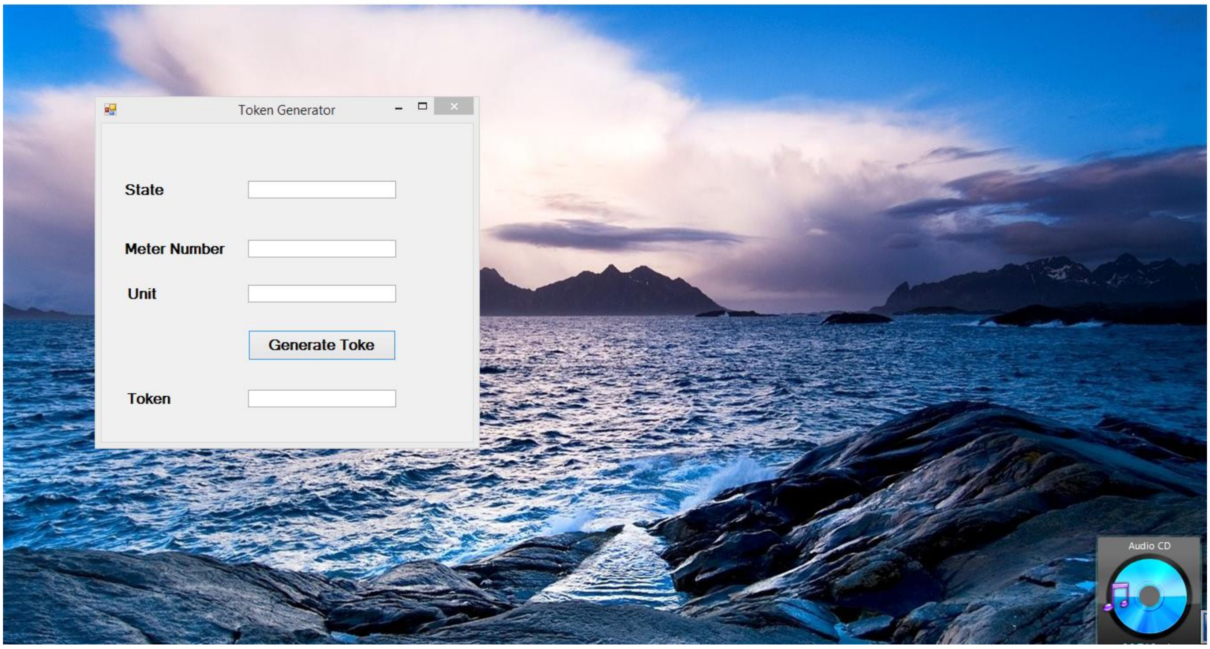

Figure 4: The Token Generator for the GSM based Smart Energy Meter

4.0 Test and Discussion

This test was carried out to ensure that the meter readings are correct. I loaded the meter with various loads and my observations are shown below:

Table 4.1: GSM based Smart Energy Meter Observation Table

S/N	Item	Meter's Power Output
1	HP Laptop with 65W power output with a Nokia Phone with	80-95W
2	HP Laptop with 65W power output	63-70W

With the following observations, it is safe to say that the power measurement in within acceptable range. Since energy is a function of power and time (equation 1.1), the GSM based Smart Meter is good shape for energy measurement and monitoring.

Conclusion

The GSM based Smart Energy Meter was designed and constructed. This project has really exposed me to the use of electronic components. To a large extent I have come to appreciate the theories learned over the years.

This work will improve the metering system in Nigeria as well as aid the user to remotely monitor the energy consumption as well as remotely recharging the meter.

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