



## DEVELOPMENT OF SMART METER FOR ENERGY BILLING AND POWER MANAGEMENT

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### ABSTRACT

Rising cost of energy tariff in Nigeria has brought to the fore the need for energy savings and power management. However, existing prepaid meters in the country are not user friendly. They do not give room for users to track power usage in a bid to observe the impact of load increase on units of energy purchased from utility providers. Load profiles like voltage, current and power of connected loads are not displayed on the energy meters making it impossible to conserve energy and manage power. In addition, these meters do not send notifications to consumers on the status of energy subscription. This study therefore developed a single-phase smart energy meter that availed consumers the opportunity of observing load changes on the screen from time to time. It notified customers via Short Message Service (SMS) when energy subscription was made and when unit of energy was low. The system consisted of hardware and software parts. The hardware parts composed of power supply unit, sensing unit, display unit, GSM module and energy meter. The software part involved programming ATMeg328P microcontroller enshrined on arduino Nano board using C# programming language. The system displayed energy worth of 50Wh for 4naira on the first recharge. This unit of energy was exhausted after leaving the system for several hours by connecting appliances like electric fan, soldering iron and electric iron. In particular, the system displayed power value of 114.73W when standing fan and two soldering irons were connected to the system. The power of connected load increased to 216W when electric iron was added. In addition, the system displayed unit of energy used and the remaining unit at every point in time. It also sent notifications to consumers through SMS to subscribe when energy unit was less than 5Wh and stopped working when energy unit was exhausted. It was therefore seen that the system was functional and displayed load profile (power and voltage) changes appropriately. The system is suitable for use in residential buildings, offices and applications where energy management is required.

### 1.0 Introduction

In the time past, electricity billing in Nigeria was done by officials of the defunct National Electricity Power Authority (NEPA) who moved from house to house to take energy readings on installed meters. These readings were used to generate energy bills given to the consumers at the end of the month. In the absence of installed meters, customers were given estimated bills based on assumed energy totals. This system of energy billing is not only time consuming but also tedious as it requires large work force to cover many households. It is prone to errors and a number of households may be left uncovered. This process may be hampered or affected

by weather conditions. It is also shrouded in secrecy as customers may not be aware of what constitutes energy bill they are expected to pay at the end of the month.

With advancement of technology, there came an introduction of electronic prepaid meters where households subscribe to utility providers before they are given access to use the energy (Adebisi et al., 2022). Though the prepaid meters give sound alarm when energy unit is low, many consumers are either oblivious of this alarm or do not understand the importance of sound alarm. Most often than not, customers wait until they exhaust all the energy units and are disconnected from supply before they make another recharge. In addition, these prepaid meters do not display how energy is consumed and customers may not be able to pinpoint which device is consuming more power, therefore giving no room for energy conservation and management.

A number of research works have addressed different aspect of metering problems. For example, Sheelasobanarani et al. (2014) simulated prepaid energy metering system on Proteus software while Rodrey et al. (2007) proposed automatic power meter reading solution that allowed energy providers to monitor energy consumption and produce corresponding bills which were sent to consumers by Short Message Service (SMS), Electronic Mail (e-mail) and postal service. Load monitoring and auditing system was developed by Adebisi et al. (2022) which informed users of the energy utilized and balance via Google mail. Customers in places with poor internet facility may not be able to access the Google mail to receive updates on energy consumption. An automatic energy metering system for gaining control over consumers load was developed by Okokpuji et al. (2020) and Bobade et al. (2016). Rachananjali et al. (2016) proposed an approach for preventing meter tampering. Other research works reported in the literature have focused on implementation of smart energy metering system based on Global System for Mobile (GSM) communication technology (Jain et al., 2012; Aniedu et al., 2016; Bhat et al., 2017; Mortuza et al., 2020; Odusami et al., 2019; Oyubu and Nwabueze, 2015 and Egwale and Odi, 2016) while Gupta et al. (2017) incorporated memory in its GSM based solution. Amhenrior et al. (2022) developed a low cost smart prepaid meter which integrated GSM and Wireless-Fidelity technology. Devi et al. (2019) developed an automatic energy meter reading system using Raspberry PI and Internet of Things (IoT). Ragul et al. (2020) designed and constructed IoT based smart energy meter that sent energy readings to the web server. Nwagbo et al (2019) developed an arduino based energy meter. Sabahat and Rajderkar (2019) constructed theft detecting energy meter that cut off users once energy theft was detected. A smart energy metering solution using Zigbee and GSM module was developed elsewhere (Myilsamy, 2015; Revidi et al., 2015 and Suresh and Mangaleswari, 2016). Muhammad et al. (2023) developed energy metering system that sent energy readings to utility providers via SMS. In addition, Ogidan et al. (2023) developed a GSM based smart energy meter for real time notification of consumers. These research works fail to address how users can monitor load profile changes that will afford them the opportunity of managing the power effectively by providing avenue for energy conservation and energy savings. Hence, this work develops smart energy meter that displays energy readings, power consumption of connected loads, units of energy use and balance. It gives notifications via SMS to consumers at different time instant to intimate them of when energy subscription is effected, when they are running low on energy subscription and after exhaustion of purchased energy. Consumers observe power utilized by connected loads at different time instant.

## 2.0 Materials and Methods

### 2.1 System Description

Figure 1 illustrates the basic building units of the system. It consists of power supply unit that transforms Alternating Current (A.C) source to the Direct Current (D.C) required to power the system components, sensing unit, GSM module, display unit, relay unit and energy metering unit.

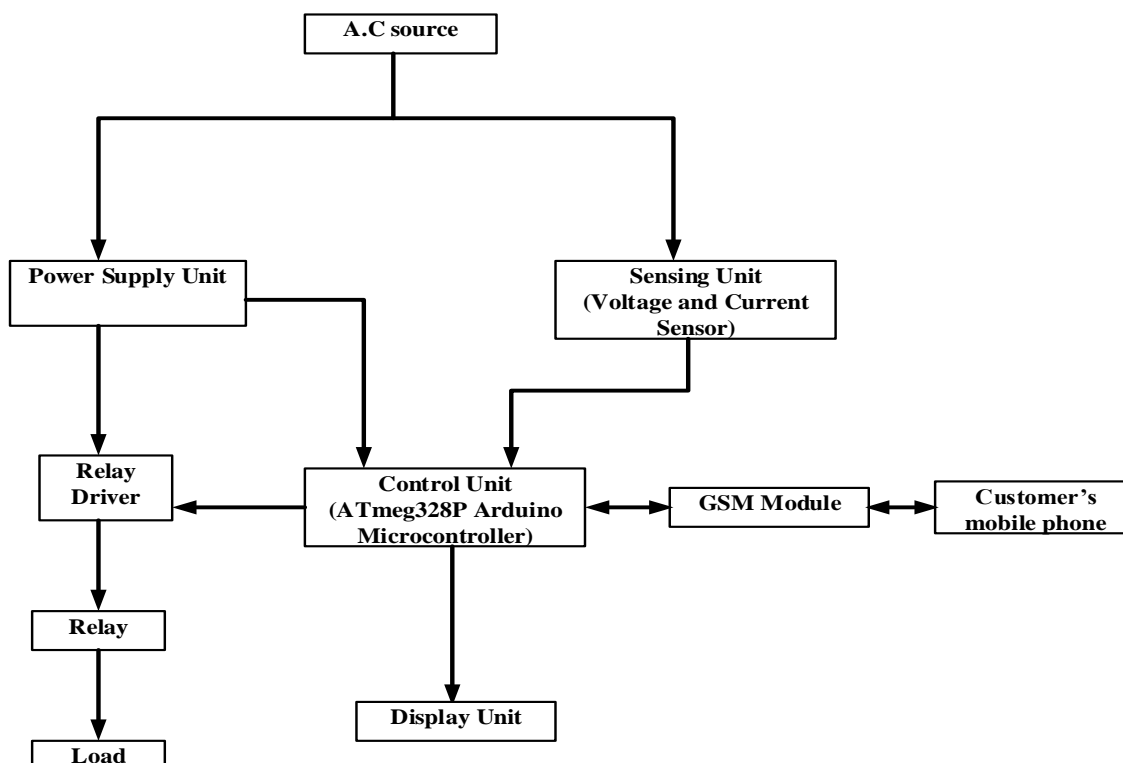


Figure 1: Block diagram of energy metering system

#### 2.1.1 Power Supply Unit

This unit provides the required voltage for the components of smart energy meter. Figure 2 shows the power supply unit simulated on Proteus software. The 220/12V transformer ( $TR_1$ ) steps down 220V A.C source to 12V A.C which is rectified to D.C form using bridge rectifier circuit ( $D_1 - D_4$ ) with four KBL406 diodes. The ripples in the D.C output waveform are removed by  $2200\mu F$  capacitor. 7805 and 7812 voltage regulators are utilized to regulate the D.C output voltage to 12V D.C and 5V D.C to power the Arduino board and relay unit.

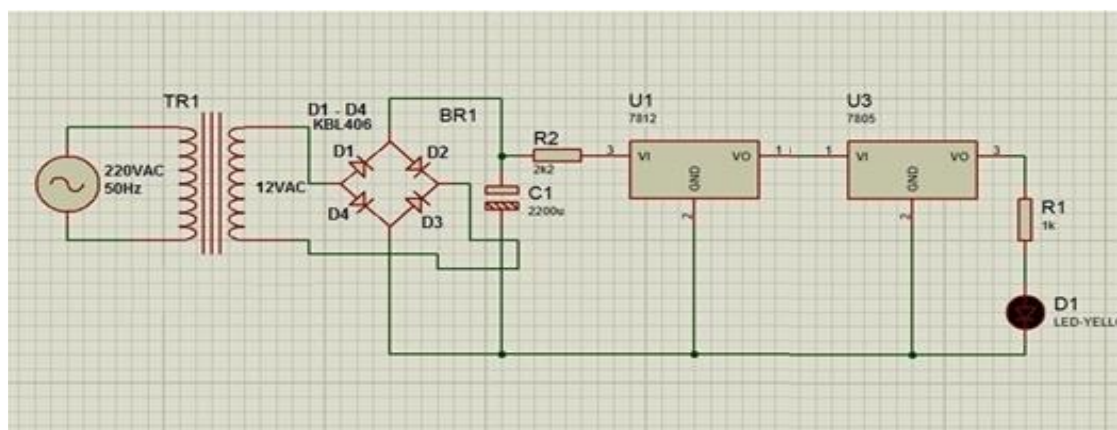
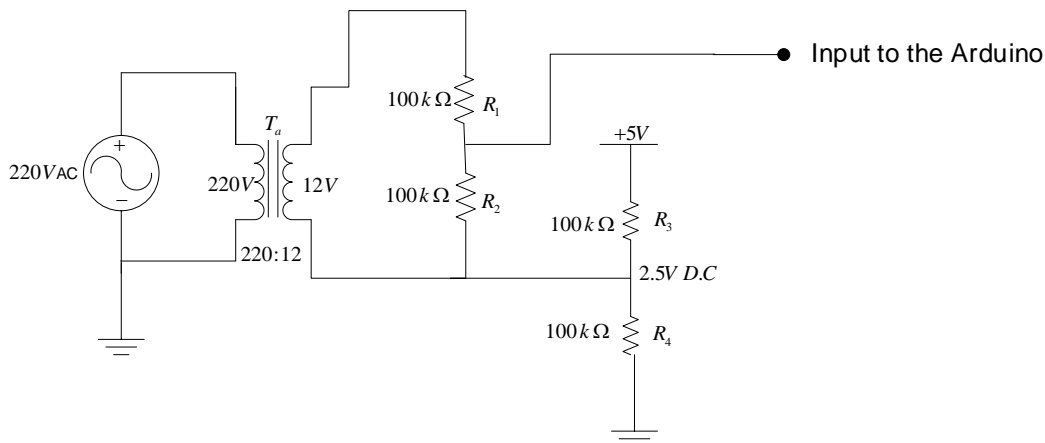


Figure 2: Power Supply unit

### 2.1.2 Sensing unit

This unit comprises current and voltage sensors. The current sensor determines or measures load current in the energy meter. An ACS-712 is utilized as the current sensor because of its non-invasive nature. The current sensor utilizes hall- effect technology for its operation. Voltage sensor on the other hand measures the supply voltage. Figure 3 depicts the circuit diagram of voltage sensor, wherein step down transformer  $T_a$  is utilized to reduce 220V A.C to 12V A.C. In a bid to reduce the voltage to within the operational voltage of arduino microcontroller in the range of 0-5V, a 2.5 D.C offset voltage is added by two  $100k\Omega$  resistors.



**Figure 3:** Voltage sensing circuit

### 2.1.3 Relay unit

The relay disconnects the load when the energy unit is zero and energizes the connected load when the customer subscribes or recharges his or her account. A 15A electromechanical relay is used to control the customer’s load. The relay driver interfaces between the relay and arduino microcontroller and is employed to drive the relay to disconnect and reconnect customer’s load. In this work, ULN2003 relay driver is utilized. It is made up of seven open collector Darlington pairs having common emitter. This implies that, the relay driver has the capability of controlling seven different relays at a time.

### 2.1.4 Control unit

The main brain behind the smart energy metering is arduino microcontroller (AT Mega 328P). Data fetching and overall circuit operation is centered on the microcontroller. It fetches the current and voltage values from current and voltage sensor and transforms them into power and energy values using equations (1) and (2)

$$Power (W) = IV \cos \Phi \tag{1}$$

and

$$Energy (Wh) = IV \cos \Phi \times t \tag{2}$$

in which W stands for Watt which is the unit of power, I is the current rating of the load in Ampere, V is the A.C power supply voltage in Volt and  $\cos \Phi$  is the power factor while t is the time in hour (h) for which the load is in operation. Here, 0.8 power factor is employed. In addition, the microcontroller sends signal to the relay to disconnect the load when the energy unit is zero and reconnects when the user recharges. It also communicates with the GSM module for transfer of SMS to users at appropriate time most especially when consumers subscribe, or energy unit is less than 5Wh and ultimately when customers run out of energy units.

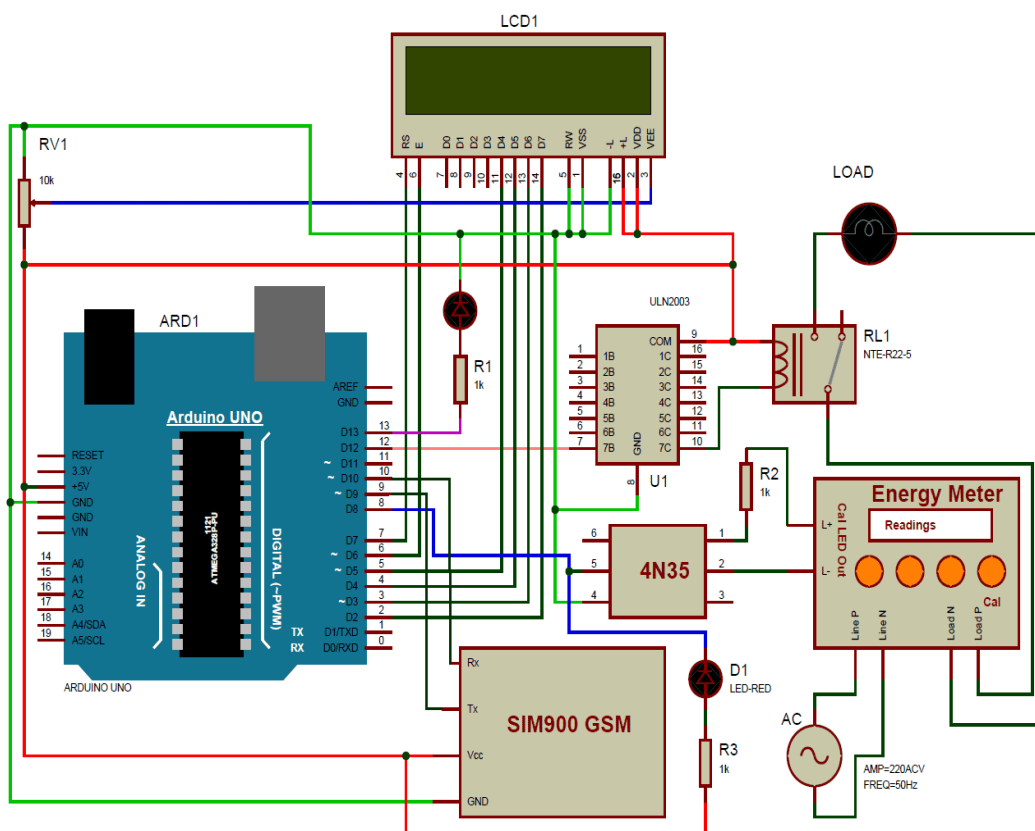
### 2.1.5 GSM module

An ultra-compact and wireless SIM900 GSM module is used which has a Modem that allows it to connect to Personal Computer (PC) and microcontroller serially. The module utilizes GSM technology for communication with the user with a mobile Subscriber Identification Module (SIM), for transferring SMS from utility provider to the customers. For the purpose of execution, an AIRTEL (telecom operator in Nigeria) SIM card is inserted into the GSM module for the transfer of SMS.

### 2.1.6 Display unit

This unit is utilized to display information concerning energy totals for a given subscription, remaining energy unit or balance, energy and power consumed as well as values of voltage and current of connected load. An 16×2 Liquid Crystal Display (LCD) module is employed to display aforementioned information on the screen.

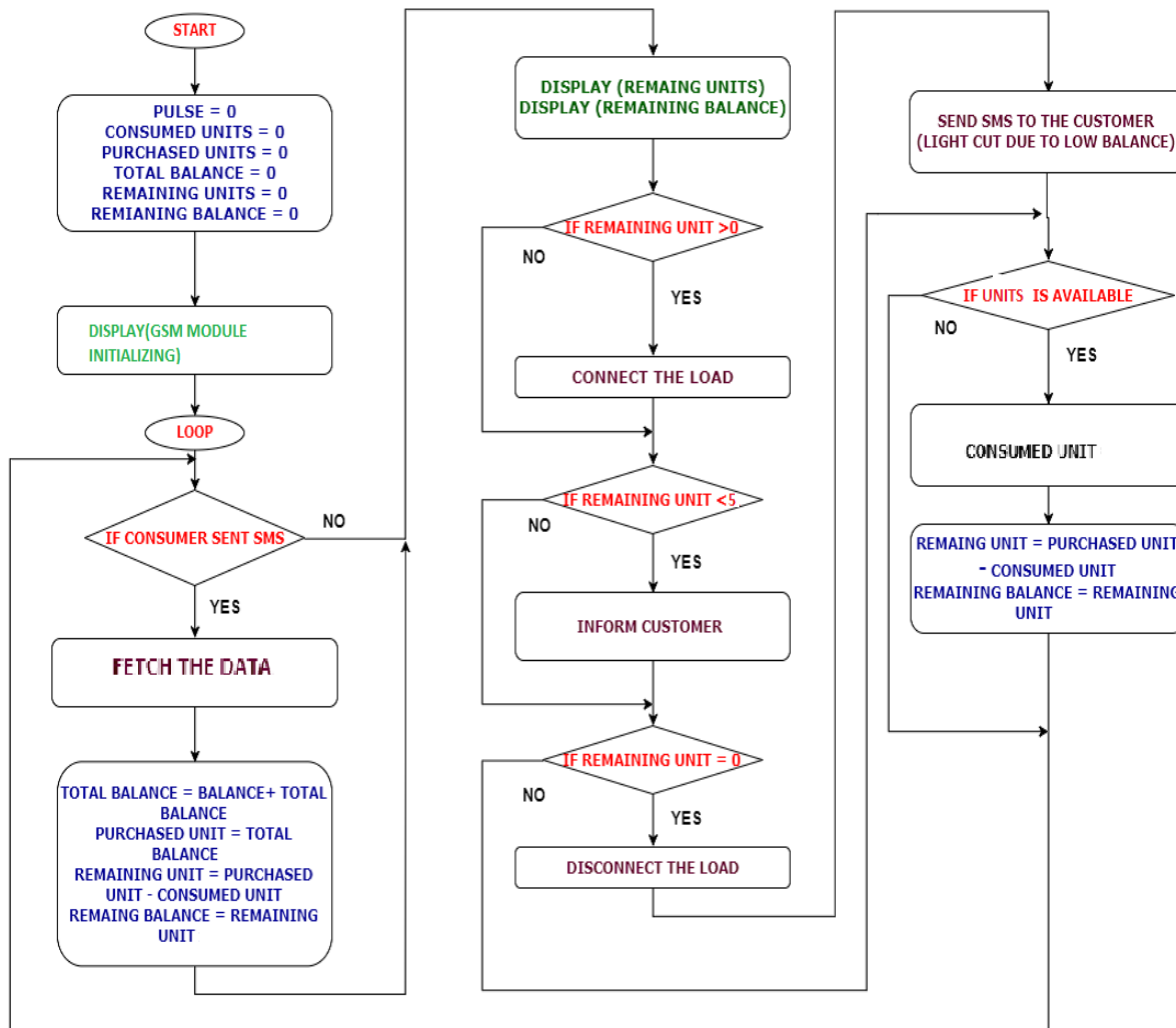
Figure 4 illustrates the circuit diagram of the energy meter linking various units of the system.



**Figure 4:** Circuit diagram of smart energy meter (Nwagbo et al., 2019)

### 2.1.7 System software design

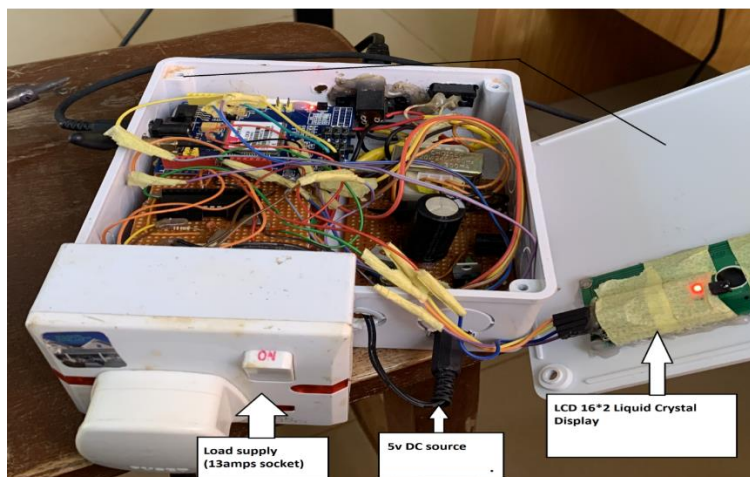
The main activity that is carried out here is implementation of equations (3.1) and (3.2) and development of code that controls the activities of the arduino microcontroller board using C# programming language. The basic operation of the system is guided by the flow chart presented in Figure 5.



**Figure 5:** Flow chart of the operation of smart energy meter

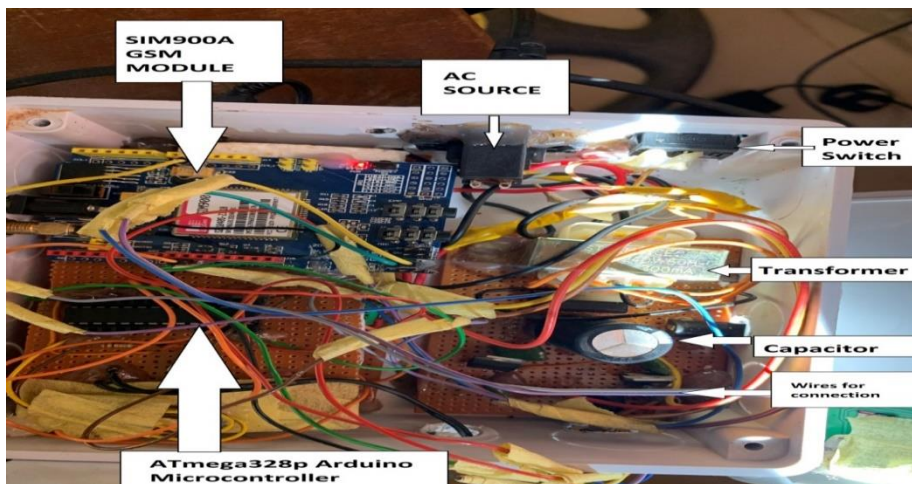
### 2.1.8 Performance test

The developed model of the smart energy meter is presented in Figure 6 which depicts the external features of the smart meter such as 13A socket for load supply, 5V D.C source and LCD screen while Figure 7 illustrates the internal features of the model showing basic components like GSM module, ATMEG 328 arduino microcontroller, 220/12V transformer, capacitor, power switch and connecting wires among others.



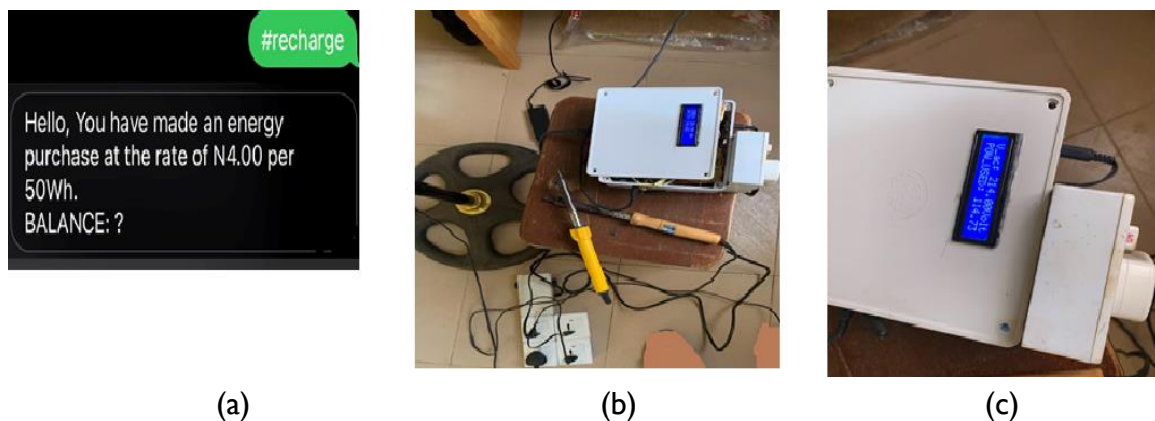
**Figure 6:** External feature of the smart energy meter





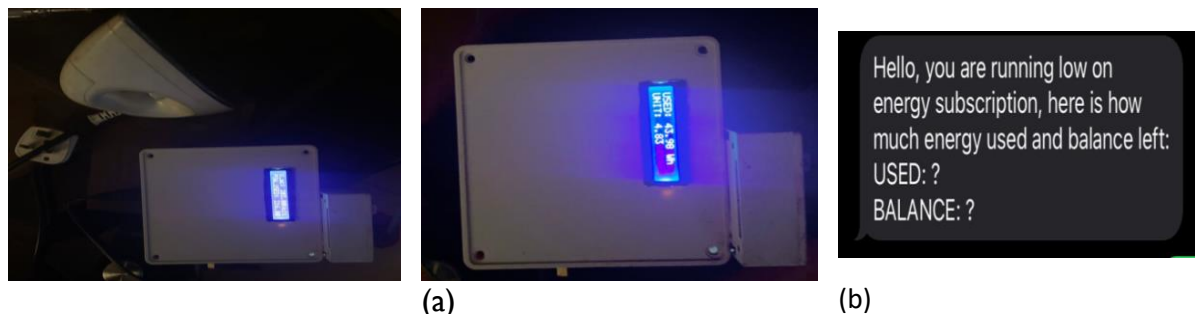
**Figure 7:** Internal circuitry of the smart energy meter

In order to test the operation of the system, an initial energy of 50Wh was purchased for 4 naira. Figure 8b showed the system under test with standing fan and two soldering irons.



**Figure 8:** System under test (a) SMS received for energy recharge (b) energy meter with connected load with LCD showing used energy and balance and (c) LCD displaying power, current and voltage values of connected load

However, in order to observe load changes and track power increase, a pressing iron was added to the load as shown in Figure 9. However, the system was left in operation for a number of hours.



**Figure 9:** Energy meter under test with connected load and showing increase in power consumption

**Figure 10:** System under test (a) energy unit is less than 5Wh and (b) SMS received

Figure 10a showed the system under test with LCD displaying the used energy while Figure 10b showed the SMS received in such an instance.

Furthermore, Figure 11 illustrated the system in operation when the energy unit is less than 2Wh and 1Wh.



(a)



(b)

**Figure 11:** System under test showing (a) energy unit that is less than 2Wh and (b) energy unit that is less than 1Wh



**Figure 12:** System under test with LCD displaying light cut off and recharge

Finally, when energy unit on the system is zero and the purchased energy unit is exhausted, Figure 12 showed the LCD displaying zero unit and zero balance and as well informed the customer regarding no balance and request for recharge.

### 3.0 Results and Discussion

It was observed from the performance test carried out in this work that the system displayed energy unit of 50Wh on recharge of 4 naira as indicated in Figure 8(a). It was seen that when loads including standing fan and two soldering irons were connected to the system, power value of 114.73W was displayed while the supply voltage of 220V was observed on the system as illustrated in Figure 8(c). However, on adding pressing iron to the existing load, the power increased to 216W which was observed in Figure 9. The system was left for several hours until the energy unit was less than 5Wh as presented in Figure 10. Furthermore, test revealed also that the system displayed 2Wh and 1Wh as the unit of the energy was further reduced. This was observed in Figure 11. Figure 12 showed the LCD screen of the system intimating customers to recharge when the customers exhausted all the energy units earlier purchased. In this case, it was observed that the system stopped working and failed to supply electricity to the connected loads.

### 4.0 Conclusion

The existing metering system in Nigeria does not provide avenue for consumers to observe instant changes in power utilized as load profile of connected devices is usually not displayed. The meter is also unable to provide notifications either by short message service or electronic mail to intimate consumers of status of energy subscription. It is in this connection that this work developed an alternative means of smart energy metering which monitored customers' energy usage, determined and displayed the energy and power used by consumers. It sent notifications to users when subscription was made and informed customers via SMS whenever customer was running low on energy as well as when customers were out of energy. A number of tests carried out showed that the system was functional and performed to expectation, facilitating SMS transfer using GSM module with AIRTEL SIM card mobile network. Appliances like fan, electric iron and soldering iron were used as candidates for testing the developed



system. The system displayed voltage value of 220V and power value of 114.73W when standing fan and two soldering irons were connected to the system. However, it was seen that the power increased to 216W when pressing iron was added to the system. These loads were left for hours until the energy unit was exhausted. It was seen that the system responded to changes in connected loads appropriately. The meter was efficient in obtaining energy readings and exhibited fast means of transfer of messages from utility provider to the customers. The smart meter is recommended for use in residential buildings, offices and hospitals.

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