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# Digital Energy Meter Implemented with a Remote Transceiver

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## ABSTRACT

*This paper presents the design and implementation of a digital energy meter with a remote transceiver that will accurately measure and calculate the amount of energy consumed by a certain facility while displaying its cost. The energy meter provides the utility company and consumer with regular status of the meter on a predefined interval and also disconnects the facility when requested so as to increase the efficiency of energy management. The meter, having a measuring capacity of minimum and maximum loads of 2 mA and 80 A respectively, could increment time with its inbuilt timer and counter subsystem in the microcontroller based on the embedded system code written into it. The meter with its communication facility aided with SIM800l module could be remotely monitored and controlled. This was demonstrated by sending off, on and watts commands via SMS. The energy meter responded to the commands as expected.*

**Keywords:** *SIM800l, Microcontroller, LCD, Embedded system, energy meter, wireless*

## INTRODUCTION

One of the problems faced in Nigeria electricity industry is energy loss. Many consumers use energy without paying at all because of the way and manner energy is being handled in the country, ranging from corruption of energy officials who take bribes from consumers at the point of collection of money, and our poor metering system. This results in losses to utility companies and the nation at large (Warudkar et al, 2014; Ogujor, 2017). Bad metering systems are common to electromechanical meters, basically due to errors which occur at the billing stages of the electromechanical meters. They could be human errors in writing down meter readings, errors while processing the paid bills and due bills, and errors from malfunctioning parts of the electromechanical meters (Carlson, 2003; Katz, 2008; Omijie and Ighalo, 2012). An improvement to the electromechanical meters is the development of the DC meter that enables consumers to easily read the meter and verify consumption. However, the DC meter could not measure energy. Rather, it measured charge in ampere-hours (Gooday, 2004). To take care of these challenges, there is the need for an appropriate metering system that can be monitored, controlled and communicated with.

A bluetooth facilitated energy meter was designed and implemented by Koay et al. (2003). However, it has its major drawback as Bluetooth technology works best with close proximity range. The digital energy meter with a remote transceiver that is presented in this paper will reduce the phenomenon of energy theft and losses, and will take care of the shortcomings associated with Bluetooth technology. It provides the utility company and consumer with regular status of the meter on a predefined interval through short message service (sms) and also disconnects the consumer facility upon request so as to increase the efficiency of energy management. With this digital energy meter, consumers can switch off the loads from the meter anywhere via sms. Also, the energy consumed by a consumer location can be monitored from the head office of the utility company via a wireless communication system, to enable the office ascertain the amount of energy consumed. The consumer can still wirelessly monitor his energy usage when away from home. Hence, either the consumer or the utility office could give a feedback to the meter to interrupt the power supplied to the home.

## DESIGN METHODOLOGY

This section presents an overview of the design calculations for the digital energy meter.

### Power Supply Unit

The power supply unit shown in figure 1 receives its input power source from the 230 V AC mains supply and steps it down to 9 V with the aid of the step down transformer. The bridge rectifier BR1 rectifies the 9 V AC from the transformer to pulsating DC voltage. The DC voltage is then filtered by the 1000 uF capacitor which is connected to the 7805 voltage regulator to give out a constant voltage of +5 V (Theraja and Theraja, 2005). This is further filtered by two 47 uF bypass capacitors. The function of this section is to make sure there is no fluctuation in voltage and current supplied to the microcontroller, LCD and the SIM800l module. This unit is responsible for the supply of a well regulated power to the system.

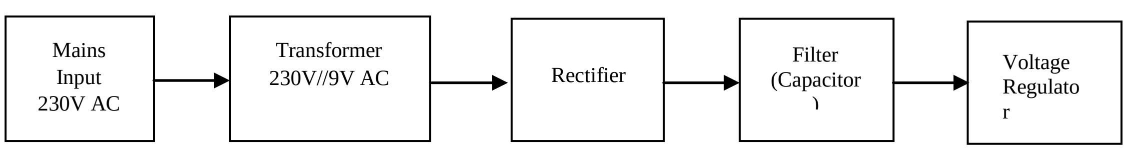



**Figure 1: Block diagram of the power supply unit**

From transformer equation, we have:

$$\frac{Vp}{Vs} = \frac{Is}{Ip} \quad (1)$$

For:

Vp = 230 V
Ip = 500 mA
Vs = 9 V

Using (1) with the parameters given,
$Is = \frac{Vp \times Ip}{Vs} = \frac{230 \times 0.5}{9}$ = 12.78 Amps
The DC voltage $V_{dc}$ = 0.636 Vm

So for the 9 V secondary transformer, where Vm is 9 V,
$V_{dc} = 0.636 \times 9 = 5.724$ V

For the peak inverve voltage (PIV) rating analysis of the diode used for the bridge rectifier circuit construction, the highest possible value of Vm is used.

$$PIV = Vm\,(max) - V_D\,(ON) \quad (2)$$

$V_D$ (ON) = 1.4 V for a bridge rectifier circuit
Vm (max) = 9 V
Thus,

PIV = 9 V - 1.4 V = 7.6 V

The smoothing/filtering capacitor should charge to the above calculated PIV value. The capacitor voltage rating is expected to be equal to or above 38.7 V but not less for effective smoothing. The capacitance of this capacitor is calculated below for a ripple voltage of 2.0 V. The ripple voltage for a given capacitance is given by (3).

$$V_R = \frac{Idc}{2fC} \quad (3)$$

$$C = \frac{Idc}{2fVR}$$

Where,
$I_{dc}$ - Rectifier output current (200 mA)
f - Supply frequency (50 Hz)
C - Capacitance
$V_R$ - Ripple voltage (2.0 V)

$$C = \frac{0.2}{2 \times 50 \times 2} = 1000\ \mu F$$

A capacitor of 1000 μF, 50 V was chosen and used for the construction of the filtering circuit.
For regulation to be maintained:
$V_{in\,(min)}$ = +7.5 V
Where $V_{in\,(min)}$ is the minimum input voltage to the IC voltage regulator.

For 7805:
$V_{out}$ = 5 V
Thus, to maintain the regulated +5 V dc supply from the output of the IC regulator 7805,
Vin (min) ≥ +7.5 V
V (i.e. supply voltage from filtering circuit) = 9 V
Hence, since + 9 V > +7.5 V, regulation is possible. Thus, a regulated output of +5 V D.C. is supplied to the circuit.
Maximum output current required (Imax) = 1 mA
Maximum output voltage (Vout) = 5 V
Maximum power requirement of regulator,

$$Pmax = Imax\ Vout \quad (4)$$
$$= 0.001 \times 5 = 5\ mW$$

**Voltage Sensor**

The voltage sensor is needed to measure the voltage applied across the load accurately, and is expected to behave linearly in some specific voltage range. The sensor is designed to be connected to the main power on the input side and to the energy meter microcontroller on the output side.

**Current Sensor**

The current sensor is needed to measure the current used up by the load accurately, and is expected to behave linearly in some specific current range. The circuit of the current sensor is shown in figure 2. It is designed to be connected to the main power on the input side and to the microcontroller on the output end.

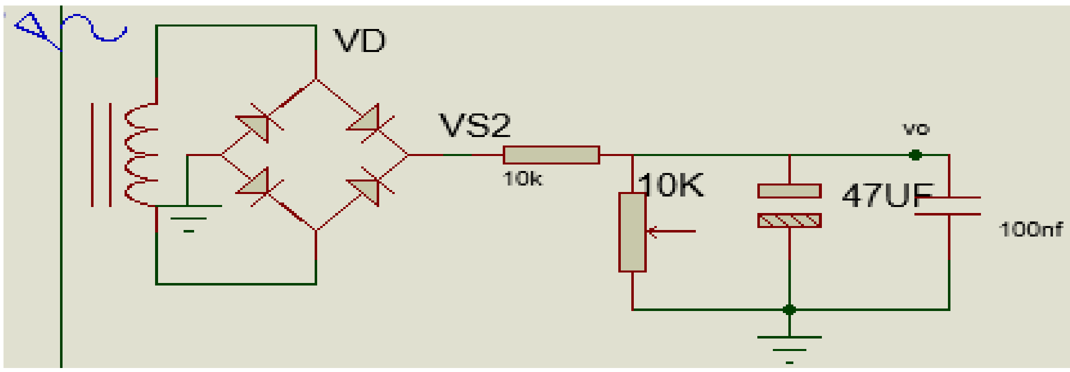



**Figure 2: Current Sensor Circuit**

**Designing the Current Sensor**

$V_d$ is the voltage drop across the two diodes and $V_o$ is output voltage. Therefore, for secondary voltage of 9 V and diode voltage of 0.7 V, the output voltage is calculated as follows:

$$V_{S2} = V_S - 2V_d \quad (5)$$

$$V_{S2} = 9 - (2 \times 0.7) = 7.6 \text{ V}$$

$$V_o = \frac{R_o}{R_o + R_{s2}} \times V_{S2} \quad (6)$$

Where Ro and $R_{s2}$ are both 10 kΩ.

$$V_o = \frac{10000}{10000+10000} \times 7.6 = 3.8 \text{ V}$$

To get the secondary current,

$$I_s = \frac{V_o}{R_o} \quad (7)$$

$$I_s = \frac{3.8}{10000} = 0.38 \text{ mA}$$

**The control unit**

The microcontroller is the heart of the meter. It senses the current used up by the load and the voltage applied across it aided by the current and voltage sensors of the system respectively. This is actually carried out by the analog to digital converter (ADC) subsystem of the controller where samples of the duo are taken in a free running mode, and calculations are made internally based on the written code for calculating energy burned into the controller. The controller is interfaced with 2N2222 transistor, LCD, and SIM800L module. This is to ensure adequate control as the transistor switches on and off the output power from the relay which is energized by the transistor. The instantaneous currents, voltages, power, and the cumulative cost are displayed on the LCD. Meanwhile, with the SIM800L module the meter can be communicated with remotely via SMS.

The resistor value that was used to provide the necessary current that will saturate the transistor is calculated thus:

Base-emitter voltage $V_{be}$ = 0.7V

Collector-emitter voltage $V_{ce}$ = 0.25V

Amplification factor $\beta = h_{fe} = 100$

The $V_{be}$, $V_{ce}$ and $h_{fe}$ values are from the 2N2222 transistor's data sheet.

At saturation, $I_c$ is designed to be greater than or equal to 100 mA so that it can give enough current to the relay or load.

The amplification factor of the transistor is given as:

$$\beta = \frac{Ic}{Ib} \tag{8}$$

$$I_b = \frac{Ic}{\beta}$$

$h_{fe} = \beta = 100$ and $I_c = 100$ mA

$$I_b = \frac{100 \text{ mA}}{100} = 1 \text{ mA}$$

From the voltage equation:

$$V_o = VRb + Vbe = IbRb + Vbe \tag{9}$$

Where $V_o$ = microcontroller output voltage

$V_{Rb}$ = voltage across the base resistor

$R_b$ = base resistor

$I_b$ = base current

$V_{be}$ = Base emitter voltage,

$$R_b = \frac{(Vo - Vbe)}{Ib}$$

$V_o$ = 5 V, $V_{be}$ = 0.7 V and $I_b$ = 1 mA

$$R_b = \frac{(5-0.7)}{0.001} = 4.3 \text{ k}\Omega$$

Therefore for the transistor to be in saturation, that is maximum current, $R_b$ must not be greater than 4.3 kΩ. Hence, a 1 kΩ resistor was chosen.

**Flow chart of the system**

The design flow diagram in figure 3 shows the flow of algorithm programmed into the microcontroller. It illustrates the command given to the chip as input and the output given out.

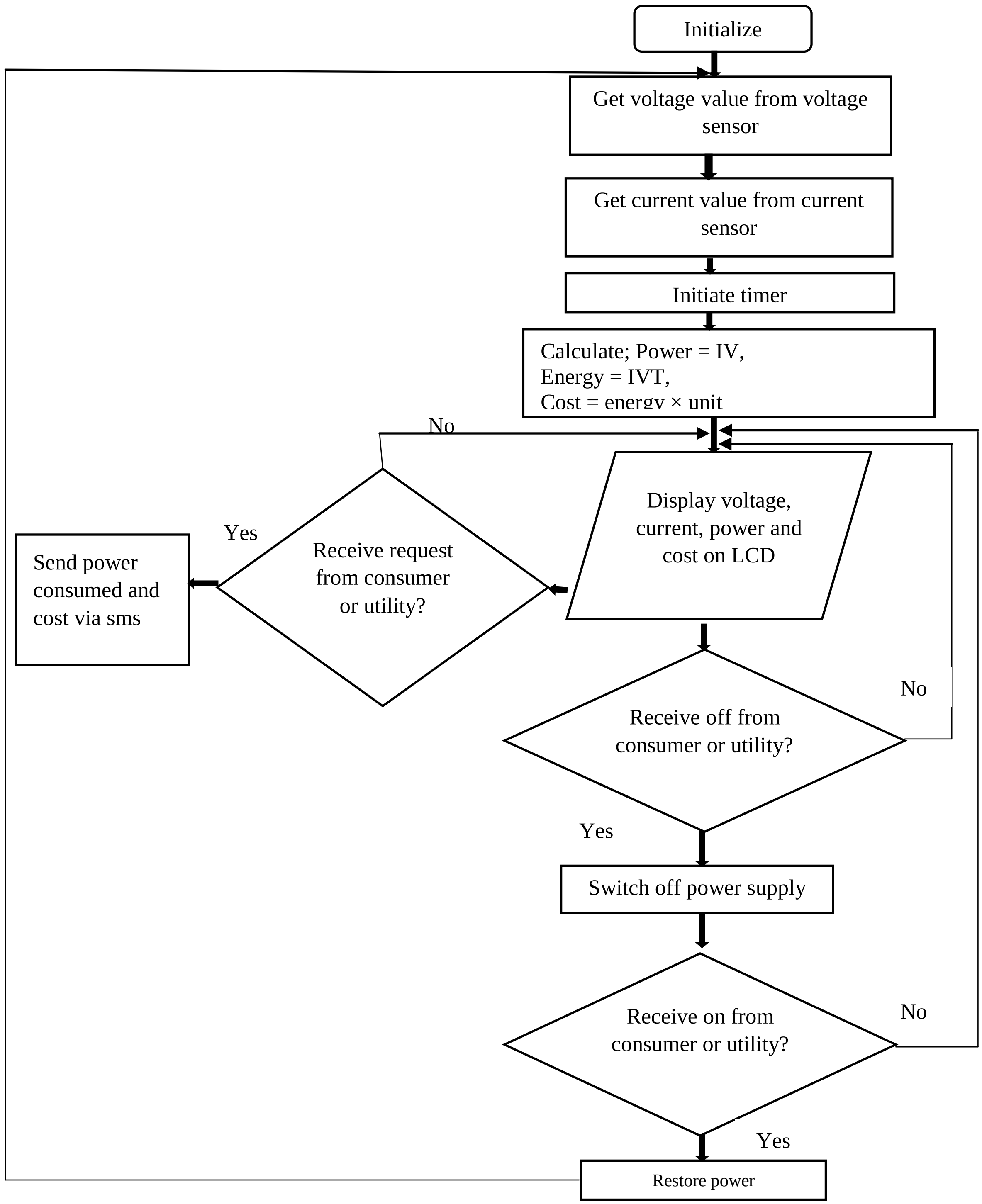



**Figure 3: Flow chart of the digital energy meter with remote transceiver**

**Basic Design Theory**

Energy is the total power delivered or consumed by a facility over a time interval (Ebole et al, 2016).

The energy consumed is calculated as follows:

Energy, E = Power, P x Time, T (10)

Where,

Power = voltage x current = VI watts = $\frac{\text{VI}}{1000}$ kW

Time = $\frac{\text{T(sec)}}{3600}$ hour

Total Charge = Energy x unit cost= IVT x unit cost (11)

Assuming one kilowatt-hour cost 24.08 naira, the total charge will be:

Total charge = Energy × 24.08 = IVT X 24.08

So if 200 W bulb with 1 A rating was used for 20 seconds when a voltage of 196 V was applied, the calculated total charge is:

Total charge = Energy x unit cost = IVT × 24.08

Total charge = $\frac{(1 \times 196 \times 20 \times 24.08)}{(3600 \times 1000)}$ = ₦ 0.0262204

If 200 W lamp, 2400 W electric kettle and 30 W soldering iron are used continuously for 5 hours per day, the total power used in that day = 200 + 2400 + 30 = 2630 W or 2.6 KW

Energy = 5 × 2.6

= 13 KWh

Total energy used in 10 weeks = (10 × 7) × 13 = 910 KWh

If 1 KWh, or Board of Trade unit, costs 24.08 naira, then total charge

= 910 × 24.08 = ₦ 21912.80

**Mode of Operation**

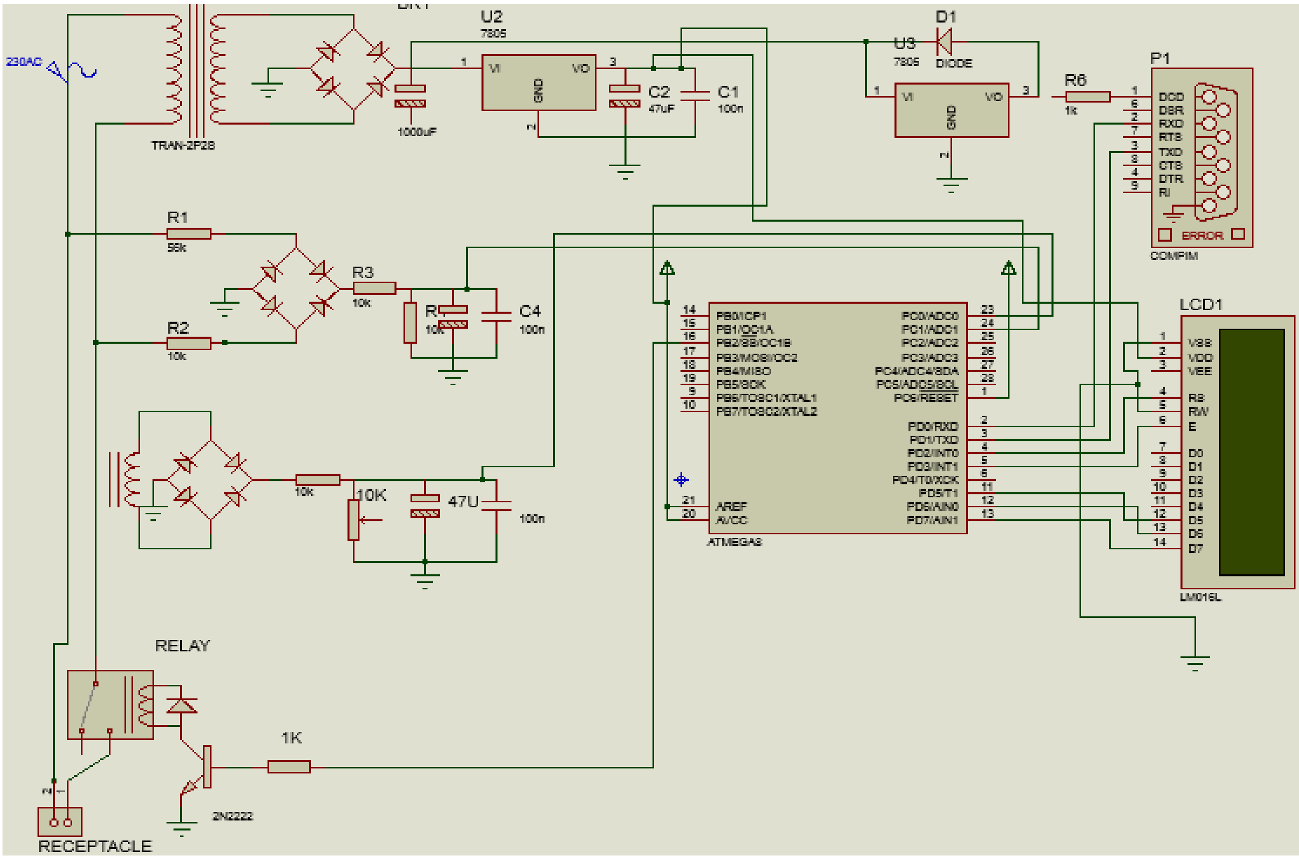
The purpose for designing the digital energy meter with remote transceiver is to measure the instantaneous power consumed in watt-hour (Wh) and add it up cumulatively for a given load. Using the network of all interconnections, the current and voltage of the line are obtained from their appropriate sensor circuits. Microcontroller coding was done in Atmel Studio 6.2s. At first using the ADC subsystem of the microcontroller, analog data inputs of voltage and current are taken from the sensors. The ADC is set to free running mode; the ADC is constantly sampling and updating the ADC Data Register. Free Running mode is selected by writing the ADFR bit in ADCSRA to one. The first conversion is started by writing a logical one to the ADSC bit in ADCSRA. In this mode the ADC will perform successive conversions independently of whether the ADC Interrupt Flag, ADIF is cleared or not. Digital value is generated for both the sinusoidal waves of voltage and current. After getting all necessary values, the energy consumption is calculated and updated according to the time.

After the calculations have been made, power consumption and cost value is transmitted using wireless transmitter upon request. The microcontroller (Atmega 8) has a working voltage of 4.5

to 5.5 V, which if exceeded will damage it. The current transformer is connected in series and the voltage circuit in parallel with the line. From the current transformer, one output is taken as input of the microcontroller at the port ADC (0) pin 23. ADC (0) takes in current value as input for calculating current rating. Similarly, from the voltage circuit, one output is taken as input of the microcontroller at the port ADC (1) pin 24. A set of outputs from the potential transformer is taken as input of a full bridge rectifier to convert 230 V AC to a 9 V DC. The rectified voltage is then passed through a network of capacitors and a voltage regulator to obtain a voltage of 5 V, which is sufficient as the working voltage for the microcontroller and LCD. To convert the 9 V DC to a fixed 5 V DC voltage, a voltage regulator was used. A capacitor bank was used to minimize noise in the output voltage.

The desired power is calculated from $P = VI$. The value of voltage, current and power is displayed in the LCD with a one second interval. So after each second, power is calculated. This time is converted to hour and multiplied with the power value to get the energy consumption (i.e. $E = P * Time$ = Watt-hour). For this design, it is assumed that 1 kWh cost 24.08 naira. Hence, total charge on the energy used, $C = E \times 24.08$. The power and charge are transmitted to the utility office or the consumer upon request via SMS. Figure 4 shows the circuit diagram of the digital energy meter with remote transceiver.

Figure 4: Circuit diagram of the digital energy meter with remote transceiver




## IMPLEMENTATION

After the design, the circuit was implemented on a vero board as shown in figure 5.

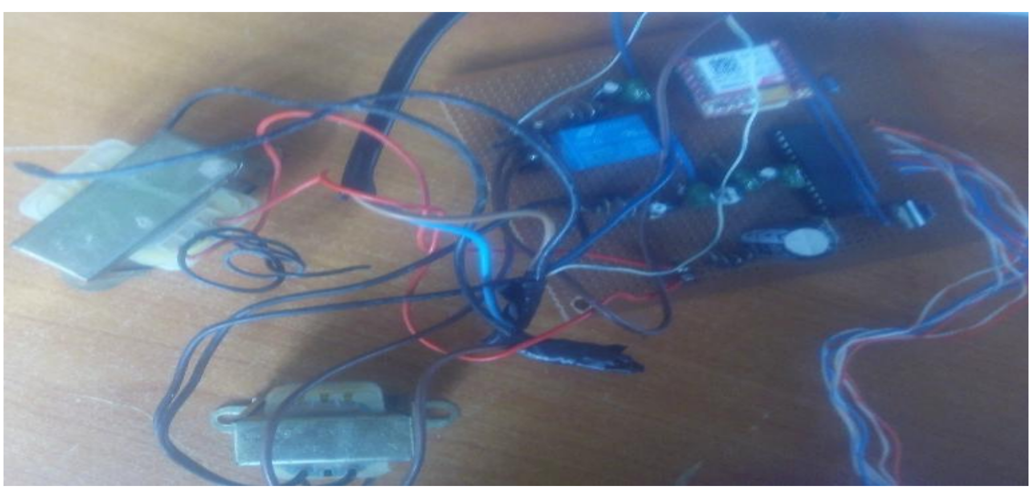


Figure 5: Vero-Board implementation of the energy meter

The Vero board was first inspected to ensure there were no wrong linkages between the dotted lines. Components were placed on the plain side of the board, with their leads protruding through the holes. The leads are then soldered to the copper tracks on the other side of the board to make the desired connections. After soldering each unit, continuity test was carried out to ensure that proper soldering was done. Thereafter, the soldered circuit and all associated components were housed in a case as shown in figure 6.


Figure 6: Constructed digital energy meter

**PERFORMANCE AND EVALUATION**

To check the accuracy of the constructed digital energy meter, a test was carried out to compare the readings displayed on the LCD of the digital energy meter and the values obtained from a multimeter and from calculation. The results presented in table 1 were obtained using a 200 W tungsten lamp. When the lamp was connected to the digital wireless energy meter as depicted in figure 7, the voltages, currents, power, and costs that were displayed on the LCD of the energy meter at various time intervals were tabulated concurrently with the measured values of voltages and currents obtained from a multimeter, together with the values of power and cost calculated using the measured values. This is done to ascertain the conformity of the energy meter to the expected values.

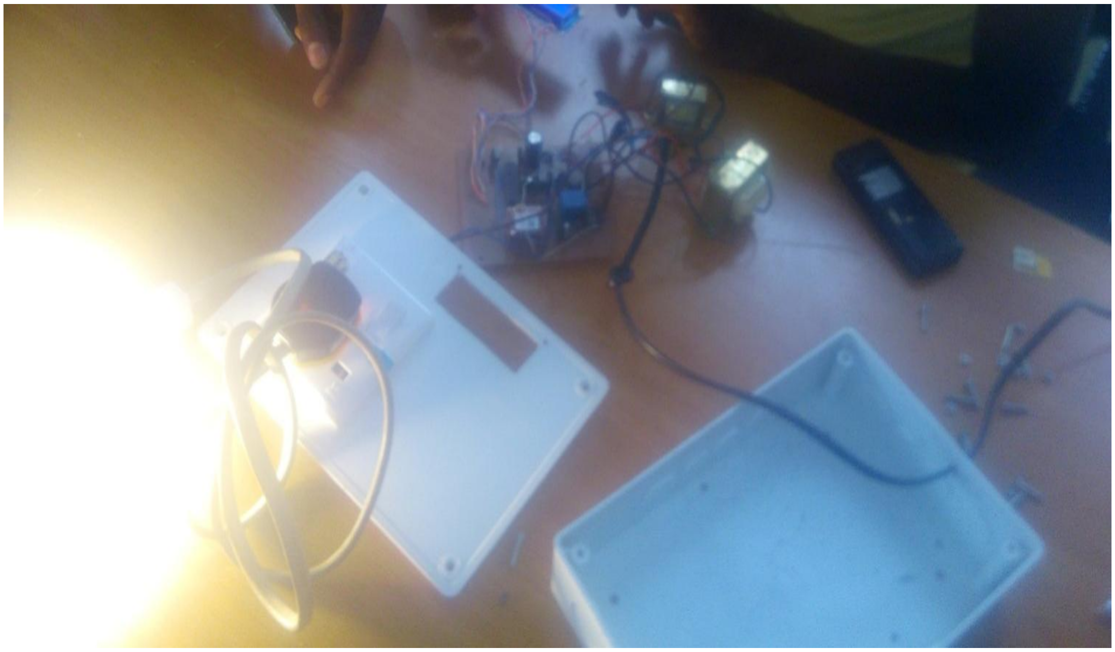


Figure 7: Testing With a 200 W tungsten lamp

Table 1: Results obtained from a 200 W tungsten lamp

| Time (s) | Voltage (V) obtained from experiment | Current (A) obtained from experiment | Power (W) obtained from experiment | Cost (₦) obtained from experiment | Measured Voltage (V) | Measured Current (A) | Calculated Power (W) [P = IV] | Calculated Cost (₦) [C = IVT × 24.08] |
|---|---|---|---|---|---|---|---|---|
| 20 | 187 | 1 | 187 | 0025 | 187 | 1 | 187 | 0025 |
| 40 | 196 | 1 | 196 | 0052 | 198 | 1 | 198 | 0053 |
| 60 | 190 | 1 | 190 | 0076 | 190 | 1 | 190 | 0076 |
| 80 | 188 | 1 | 188 | 0101 | 187 | 1 | 187 | 0100 |
| 100 | 187 | 1 | 187 | 0125 | 187 | 1 | 187 | 0125 |

It can be seen from table 1 that the values obtained from the energy meter matches closely with the expected values obtained from measurement and calculation. In addition, a 2400 W electric kettle was connected as load to the implemented energy meter. The values of voltage, current, power and cost displayed on the LCD of the energy meter at different time intervals were noted and recorded in table 2 as experimental values. At the same time, a multimeter was used to measure the voltage and current so that they can be compared with the displayed values. The readings obtained are recorded as measured values in table 2. The power consumed and the costs are calculated using the measured voltages and currents and the results are also tabulated in table 2.

Table 2: Results obtained from a 2400W electric kettle

| Time (s) | Voltage (V) obtained from experiment | Current (A) obtained from experiment | Power (W) obtained from experiment | Cost (₦) obtained from experiment | Measured Voltage (V) | Measured Current (A) | Calculated Power (W) [P=IV] | Calculated Cost (₦) [C = IVT × 24.03] |
|---|---|---|---|---|---|---|---|---|
| 20 | 240 | 10 | 2400 | 0321 | 239 | 10 | 2390 | 0319 |
| 40 | 238 | 9 | 2142 | 0573 | 239 | 9 | 2151 | 0574 |
| 60 | 239 | 11 | 2629 | 1055 | 240 | 11 | 2640 | 1057 |
| 80 | 240 | 12 | 2880 | 1541 | 239 | 12 | 2868 | 1531 |
| 100 | 238 | 8 | 1904 | 1274 | 239 | 8 | 1912 | 1276 |

As shown in table 2, the values obtained from the digital energy meter conform closely to the expected values obtained from measurement and calculation, with only a slight variation in the values.

## CONCLUSION

The aim of this paper which is the design and implementation of a digital energy meter with remote transceiver was achieved. The implemented energy meter is able to accurately measure the amount of energy consumed by an electrically installed facility, display the result on an LCD, and send it via SMS to the utility head office or to the consumer upon request. From the test results, the energy meter was able to function in accordance with the design objective. This energy meter is of great economic value and very important to our everyday lives as it can be used in homes, schools, hospitals, industries, and wherever electrical facility is being installed. The energy meter can be monitored, controlled and communicated with remotely. The energy meter provides the utility company with regular status of the meter on a predefined interval with increased efficiency of energy management since the metering could be regularly viewed, suspicious readings could easily be taken note of, and appropriate action could be taken against defaulters. Hence, this system provides a simple, accurate, and useful method of reducing losses and curbing theft associated with electrical energy usage.

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