Uniport Journal of Engineering and Scientific Research (UJESR)

Vol. 7, Issue 1, 2023, Page 58-69
ISSN: 2616-1192

(www.ujesr.org)

Development of a Low-Cost GSM-based Smart Energy Meter for real-time Notifications

Ogidan, O.K*, Temikotan, K.O and Omale, L
Department of Electrical and Electronics Engineering, Elizade University, Ilara-Mokin, Ondo State, Nigeria
*Corresponding author's email: olugbengaogidan@gmail.com

Abstract
To bridge the metering gap in Nigeria, a smart energy meter is developed. The uniqueness of this approach is that it focuses more on the consumer in terms of its affordability and its user-friendliness. The meter uses microcontroller technology coupled with voltage and current sensors and employs the Global System for Mobile communication to transmit measured energy to consumers. It costs N40,590 ($57.9) at the prototype stage, and the consumer can receive information on when to recharge the meter before the credit is used up remotely from the mobile device without going to the electricity provider. Based on information received about the status of the electricity, the consumer can disconnect or reconnect the load (load shed) from a remote location using the device switching circuit, operated from the mobile phone as a means of energy management. Voltage and current measurements were performed using the developed smart meter and digital multimeter and correlation was computed to validate the developed device. The tests showed a correlation of 0.9358 compared with digital multimeter. The uniqueness of this work is that it puts into consideration the multidimensional poverty index (MPI) of the consumer in providing affordable and user-friendly smart energy meters to large population of unmetered Nigerians. The availability of smart meters for the unmetered populace will also help to discourage estimated billing that exploits the people thereby making them poorer.

Keywords: *GSM, Real-time, Smart energy meter, Low-cost smart meter*

Received: 22nd January, 2023 *Accepted: 27th March, 2023*

1. Introduction

The electricity system in Nigeria is plagued with many challenges. These include the unavailability of meters, energy theft, and vandalism to mention a few. According to the Nigeria Electricity Regulation Company (NERC), 55% of Nigerians are unmetered (Africaoilgasreport, 2021). This accounts for a population of about 110 million people. This metering gap gives room for estimated billing that is used to exploit the people by making them pay for much more than they have consumed, thereby encouraging corruption in the sector. Out of the metered consumers, a large number of them are still using the conventional electromechanical meter. When digital meters are used, they are not user-friendly enough. As a result, consumers are unaware of their electricity usage pattern such that they can make an informed decision such as load-shedding to reduce their power usage. In many cases, consumers are not able to recharge (credit) their meters unless they physically go to the utility office to buy tokens. Another challenge is of affordability. Many Nigerians are not able to afford energy meters due to poverty (Global Multidimensional Poverty Index, 2022) as shown in Figure 1. Since the significance of electrical vitality to the financial welfare of a society cannot be overemphasized, this research, therefore, provides a way of responding to some of the challenges outlined by developing an affordable and user-friendly energy meter in an attempt to fill the metering gap in Nigeria.

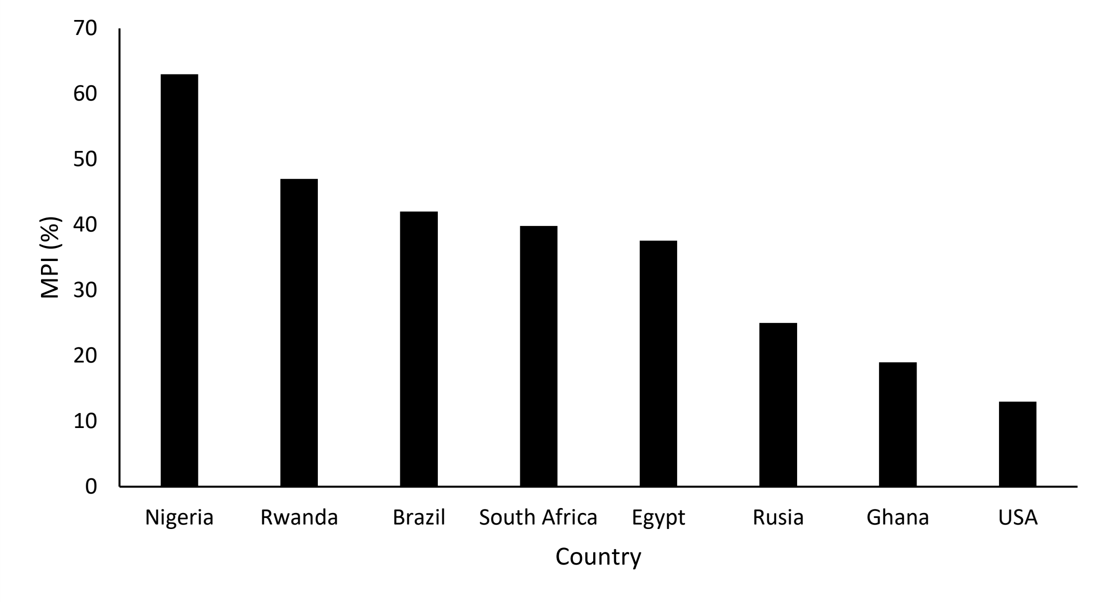

Fig. 1: Multidimensional poverty index by country

Metering is the process of effectively determining and monitoring power consumption. Meters in use can be classified into analog and digital metering systems. Analog metering includes the utilization of electromechanical meters whose mode of estimation is through a coil and turning disc. The electromechanical meters are installed at the user's end (household or office) and at intermittent interims, utility men who are concerned with electricity billing are sent to physically observe the unit on the meter, and the data from the analog meter is then utilized to calculate the electric charges for the client (Mir et al., 2019). This framework is slow, cumbersome, and costly due to the labour involved and inaccurate due to human error. It is also incapable due to limited information about the power usage (monthly energy consumption bills) given to the customer making it difficult for them to alter their vitality utilization to possibly reduce the power charge. The electromechanical meters cannot display real-time information on energy usage (Mir et al., 2019). Digital metering is an upgrade of analog metering (Shomuyiwa et al., 2013). Digital meters display the utilization of power (energy consumption) in digits on a Liquid Crystal Display and these meters are profoundly precise, reasonable, and robbery hesitant to mention a few of its advantages. These meters measure energy usage by highly integrated circuits, by capitalizing the voltage and current that give the instantaneous power in watts. In most digital metering frameworks, communication is built between the meter, client, and utility company. In this framework (metering system), the user is updated with power utilization, tariff, and other notifications sent by the utility company. This is often called a Smart metering system (Mir et al., 2019).

The Smart metering system addresses the problems of manual collection of power utility bills and conjointly opens a channel for the users to be included in energy preservation. Furthermore, other than inaccessible checking of power utilization, smart metering frameworks can remotely turn switch power supply, remotely identify cases of energy theft, remotely identify flaws, and are capable of checking power quality (Mir et al., 2019; Shomuyiwa et al., 2013). The recently available prepaid meter only communicates with the Utility Company. The customer does not get notified of low credit or when to renew the pre-paid meter. Customer only gets to know by a LED light indicator on the body of the prepaid meter and this often has hampered the user from renewing the bills earlier than the normal time. This issue sometimes has led to the customer's electrical supply being cut off before realizing the unit is depleted, or the balance is exhausted. With that in mind, this system proffers a solution that allows power companies to have total control over energy meters and have real-time information on the meter from a remote location with little human effort and at a reduced cost as compared to conventional methods. The customer is also notified of energy usage, and this helps the customer to conserve energy when necessary. It resolves the issue of unreliability, and power theft as well as customer awareness.

Different researchers have worked on the smart energy meter. Pandit et al. (2017) proposed a method that automatically measures the current consumption rate at a low level. The primary goal of this proposed system was to lower the amount of energy used by various appliances. The Arduino Uno microcontroller and Internet of Things (IoT) techniques were used to implement the project. This system immediately shuts the power supply if any critical conditions such as over-current were detected. A lot of work had been done in different areas of improving metering. These areas include Energy theft (Sawyer and Ariyo, 2019; Ayanlade and Sawyer, 2021). In Sawyer and Ariyo (2019), a GSM-based energy theft detection in a single-phase smart meter was developed to guide against energy theft detection; meter bypassing, and tampering, The authors used a differential current sensor and voltage sensor module to measure current and voltage respectively while measuring values were transmitted to users (consumers) and electricity provider via SIM 800 GSM module.

In an attempt to transmit the measured values from current and voltage and the computed power and energy to the consumers, different technologies have been adopted. These technologies include GSM (Enughwure, 2019; Aina et al., 2020; Sawyer and Ariyo, 2019; Shankar et al., 2019; Ayanlade and Sawyer, 2021), WI-FI (Sayed et al., 2019; Dahunsi et al., 2022), Bluetooth (Alubodi et al., 2021), and LoRa (Dahunsi et al., 2022). Based on investigations conducted, some authors proposed the combine use of these technologies to provide varieties to clients depending on their needs and coverage area for the network. In the past, consumers have to go to the electricity provider's office to obtain their bills but with the emergence of new technologies (Shankar et al., 2019; Baloyi et al., 2020), we have a situation that ensures that bills are generated for customers without leaving their homes. On the issue of two-way or bi-directional communication to the meter; that is from electricity provider to the meter and customer to the meter and electricity providers, a lot of work had been done (Enughwure, A. 2019; Sayed et al., 2019; Alubodi et al., 2021, Aina et al., 2020; Sawyer and Ariyo, 2019; Shankar et al., 2019; Ayanlade and Sawyer, 2021; Baloyi et al., 2020). According to the National Bureau of Statistics (NBS), 63% of Nigerians are living below the poverty level which accounts for about 133 million people (Global Multidimensional Poverty Index, 2022) therefore, this research proposes the development of a low-cost smart energy meter that will be quite affordable for the people. This meter will be customer-friendly such that information about their power usage including recharging of electricity credit will be done at their convenience on a mobile device without having to go to the electricity utility office to get it done. Electricity usage information will be made available to the customer to assist them to make an informed decision about their electricity usage such as load shedding; to manage available electricity within their income limit.

2. Materials and methods

To develop a smart energy meter that measures energy consumed by a load connected to it, interface between the utility grid and the user's load (house appliances) helping the utility company monitor the electric energy consumed by the user or customer and communicate with the customer on when the electricity bill payment is due, the smart energy meter must consist of three fundamental functions. These include sensing the voltage and current at the supply to calculate the power consumption of the user, checking the remaining electrical unit, and sending of low balance alert to the user's phone. Therefore, the development of the system involved hardware design and software design.

2.1 Hard ware design

This section examined briefly the hardware used in the development of the system and how they were interconnected (Figure 2). The ATmega320P microcontroller being the brain of the system is powered by a 5V DC power source and in turn, controls the entire functioning of the system. It receives current and voltage reading directly from the current sensor (ACS712) and voltage sensor (ZMPT101B) respectively. These readings are then used to calculate the power and in turn, the energy consumed and the available unit. The microcontroller communicates with the user through the GSM module and cut-off or connects the user's load by sending a command to a relay (switching circuit) based on the available unit. Figure 3 shows the schematic connection of these components while Figure 4 shows the arrangement of the components when it was being coupled.

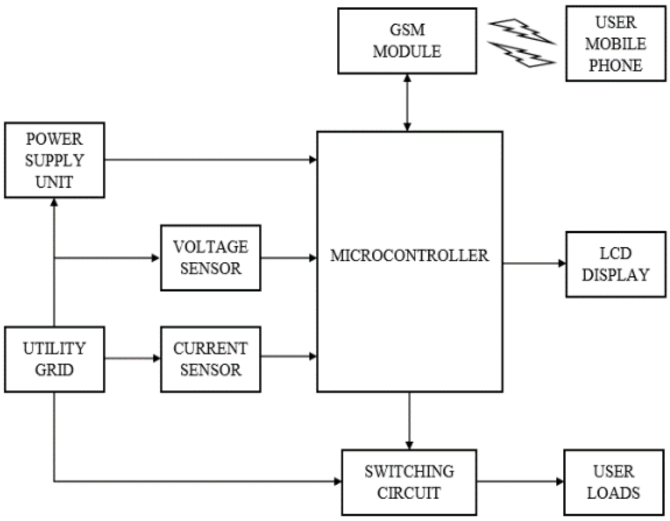

Fig. 2: Block diagram of the hardware design

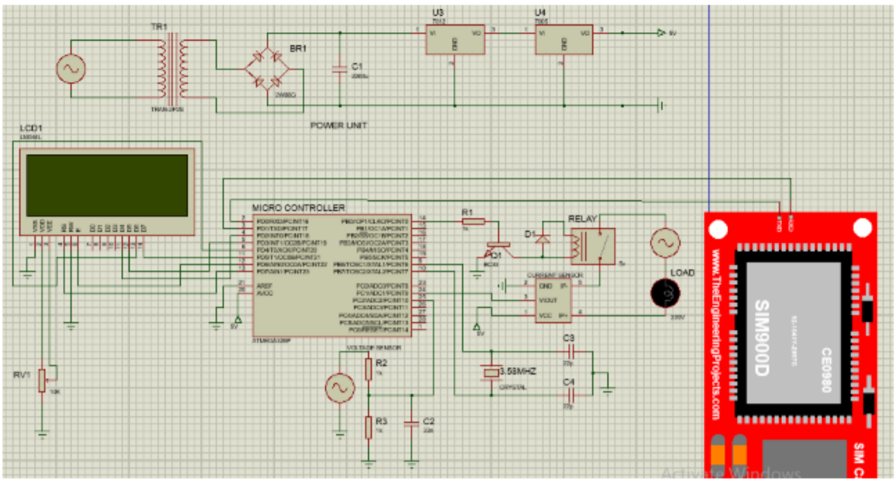

Fig. 3: Schematic diagram of the smart energy meter

Fig. 4: Physical interconnection of the Components of the system

2.2 Software design

The ATmega32P microcontroller cannot function on its own without a code to control its intelligence. Therefore, the software design of the system was achieved using an Arduino IDE (Integrated Development Environment). The Arduino IDE is a cross-stage software (for Windows, macOS, and Linux) that is written in capacities from C and C^{++}. It is utilized to write the program which was later uploaded to the Arduino-compatible boards. The code was written in embedded C Programming language with an implementation of the formulae illustrated by Equations (1) to (3). The system operation is shown in the flowchart in Figure 5. The process starts when it senses an electrical supply. The system boots up by checking that all components are well-connected and in place. This is an initialization process. For instance, it checks if the GSM module has access to the GSM network to enable communication between the user and the system. It also checks the memory of the system for an available unit. Once all required components with their parameters are in place, the system will send a "System Ready" alert to the user's mobile phone and the load will also be put on immediately with a display of the current, voltage, power, energy consumed and available unit on the LCD. To be able to compute the power of the load connected to the system, Equations (1) to (4) were used.

$$Real\ Power = Voltage\ x\ Current\ x\ \cos\phi \quad (1)$$

$$Power\ =\ IV cos\ \phi\ (Watt) \quad (2)$$

$$Where;\ cos\ \phi\ =\ power\ factor\ =\ 0.8 \quad (3)$$

$$Energy = Real\ Power\ x\ Time\ (kW - hr) \quad (4)$$

To recharge the meter, the user sends an SMS from mobile phone to the default phone number pre-programmed in the meter using the code, "#amount*". The amount is then converted to a unit in line with Equation (5)

$$Unit\ =\ \frac{Amount}{20} \quad (5)$$

where; $1 unit\ =\ NGN\ 20$

The system displays the recharge alert on the LCD and sends a balance alert to the user stating the new balance on the meter. Also, from Equation (6), to obtain the available unit, a code is written to perform subtraction of the used unit from the initial unit loaded on the system by the customer and the user. This action makes the user receive a response of the unit balance on the meter.

$$Available\ unit\ =\ Recharged\ unit - Used\ unit \quad (6)$$

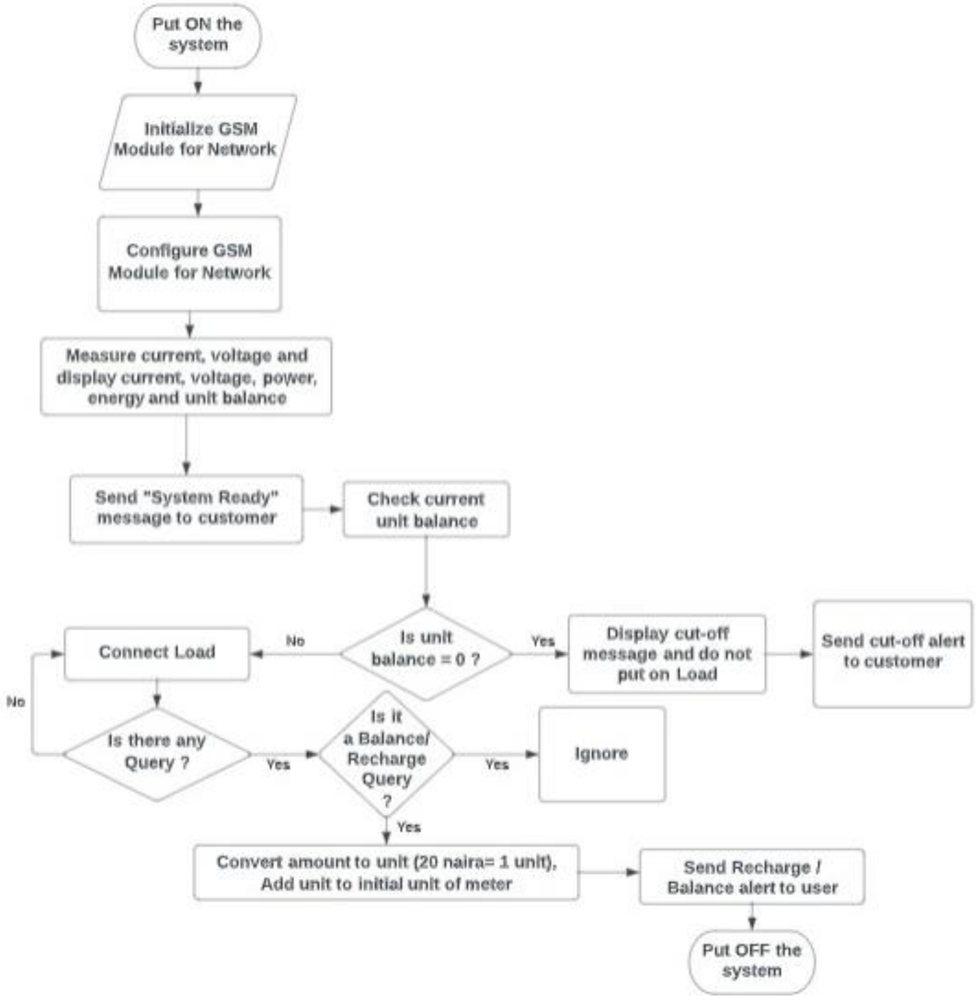

Fig. 5: Flowchart of the smart energy meter

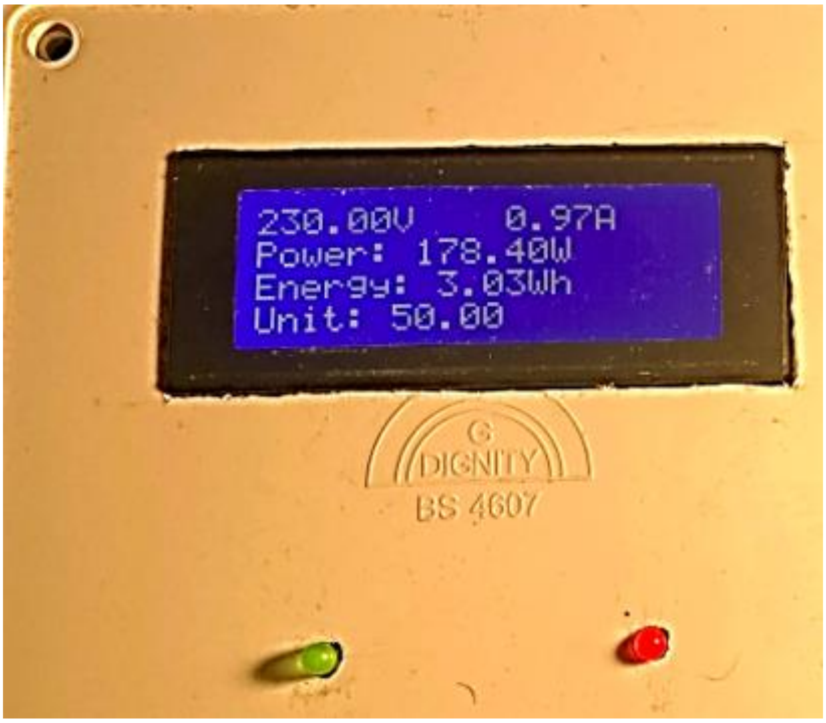

Fig. 6: Full system during testing

3. Results

The developed system was tested by connecting it to a 220 V alternating current supply and the load on the output port was varied with different loads using a standard digital multimeter connected to measure the current and voltage readings. These readings were compared to the readings displayed on the LCD of the developed system as shown in Table 1. After this, the correlation between the values obtained from the developed smart meter and the ones obtained from the digital multimeter was computed. The correlation graph obtained is as shown in Figures 7 and 8. When the system is put on, the current sensor measures the current drawn by loads connected to the system at a particular time and uses this current and voltage values to calculate the power consumption as well as the energy being consumed per hour using Equations (1) to (6). The available unit is also displayed on the LCD of the system as shown in Figure 6. Once the system comes on when there is a supply, it sends a "System Ready" message to the user's phone number connected to the system. Also, when the user recharges, a balance alert is sent to the user's phone number. The messages received are shown in Fig. 9 and 10.

Table 1: Voltage and current measurements using the developed smart meter and digital multimeter

S/N	Load (W)	Developed Smart Meter		Digital Multimeter	
		Voltage (V)	Current(A)	Voltage (V)	Current (A)
1.	65	220	0.08	239	0.05
2.	65	220	0.18	240	0.07
3.	65	220	0.17	238	0.05
4.	65	220	0.16	235	0.06
5.	65	220	0.14	218	0.05
6.	65	220	0.14	220	0.04
7.	65	220	0.13	217	0.06
8.	65	220	0.16	235	0.06
9.	65	220	0.17	238	0.05
10.	65	220	0.18	240	0.07
11.	80	220	0.21	213	0.08

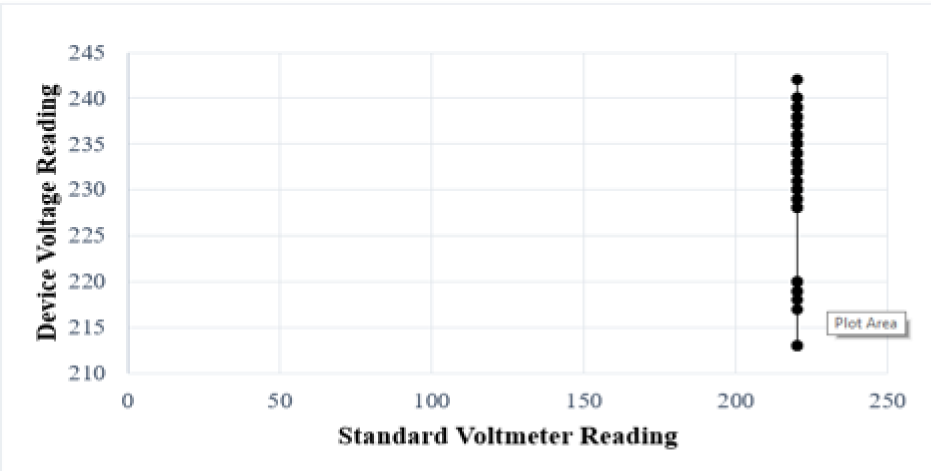

Fig. 7: Correlation graph of standard ammeter reading and system reading

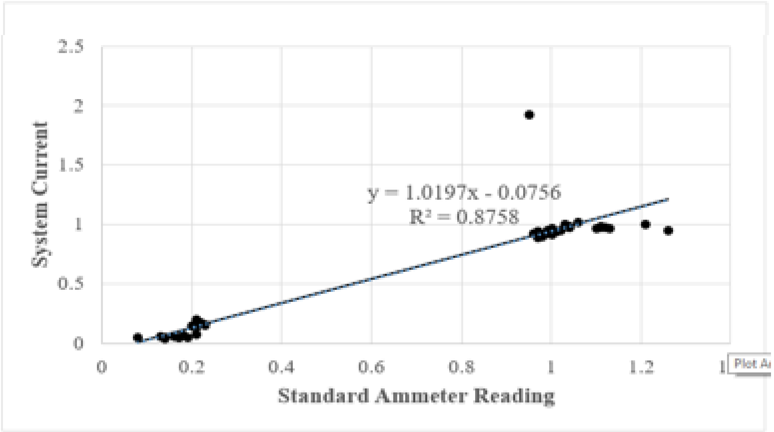

Fig. 8: Correlation graph of standard voltmeter reading and system reading

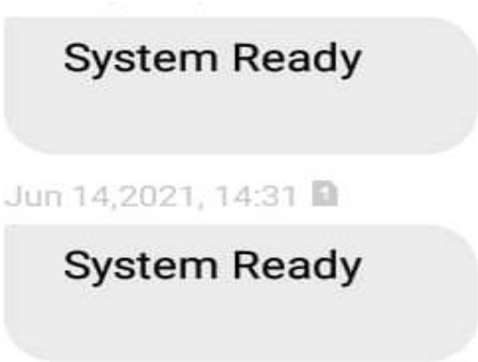

Fig. 9: System Startup Message to the Customer's Phone

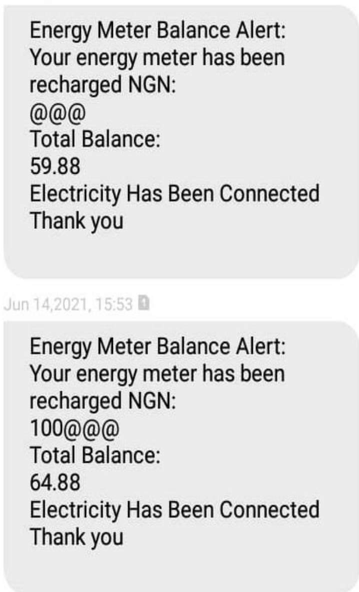

Fig. 10: Renewal message (SMS) received by user during testing

4. Discussion

The ability of the developed smart-energy meter to display the measured current, voltage, and power on LCD and transmit the same information to the mobile phone of the user in real-time gives the user instantaneous information about users' energy usage. This is shown in Figures 6 and 9. The user's ability to also check credit balance remotely and credit account on a real-time basis from remote locations through the mobile phone gives the ability to make an informed decision about the proper use of available power, plan load-shedding policy, and so on. When the developed smart energy meter readings of voltage and current were compared to a standard multimeter reading as shown in Table 1, a correlation of 0.9358 was obtained. A correlation of 0.9358 (tending towards 1) indicates a high level of accuracy of the developed smart energy meter. A Bill of Engineering Measurements and Evaluation (BEME) was computed in Table 2. It was revealed that the developed device costs an average of N40,590 ($57.9) at the prototype stage. This low-cost device could be scaled-up to meet the metering deficit needs of the populace, especially in Nigeria and other African countries. The availability of smart meters would also go a long way to discourage estimated billing through which people are made to part with their meager resources thereby making them poorer (Mir et al., 2019; Alubodi et al., 2021, Shankar et al., 2019).

As a result of the financial capability of the Nigerian communities, where the smart meter is to be used, affordability of the device became a major factor in the choice of the components used for the smart energy meter. This was to be done without compromising the quality of service of the device. Bill of Engineering Measurements and Evaluation (BEME) for components under different technologies such as GSM, Wi-Fi and LoRa (Dahunsi et al., 2022) were carried out to determine the choice of transmission technology which was most affordable. In the choice of microcontroller, Atmega 328p chip was programmed and used directly as shown in Figure 4 rather than using the complete Arduino board which had Atmega 328p chip as one of the components. This was a way of reducing cost of production. In choosing the technology to transmit the measured values from current and voltage sensors, GSM technology was chosen instead of Wi-Fi or LoRa due to the fact that it was found to be cheaper to implement and the fact that GSM technology operation in Nigeria cuts across most villages and urban settlements unlike Wi-Fi and LoRa which are limited in spread. It can be seen from Table 2 that it would cost the sum of N40,590 ($57.9) to implement GSM technology with Atmega 328p chip. Table 3 is a comparative analysis of the different network components required to implement each of the architectures shown in Figure 10. From Table 3 one could see that an additional sum of N31,400 would be required to implement Wi-Fi technology with Arduino Uno board having Atmega 328p on-board. This will bring the total Wi-Fi cost to N71,790 ($102.5). Also from Table 3, an additional cost of N41,000 would be required to implement LoRa network with Atmega 328p chip on Arduino Uno board bringing total cost to N81,590 ($116.5). This is because for Wi-Fi, apart from ESP-01 Wi-Fi module, it required additional equipment such as ZTE 4G wireless router to access the Internet. Also, the LoRa technology apart from SX1278 LoRa module needed a Dragino LG01 Gateway to transmit data to remote locations on the wide area network (Dahunsi et al., 2022). These architectures are shown in Figure 10. These additional devices put extra financial burdens on the consumer. However, in the case of GSM technology, the base station infrastructures would be used for this purpose and they were already existing in most Nigerian communities. This was the reason for choosing GSM technology in line with affordability need of the consumer. Correlation gives the relationship between two sets of data. Therefore, from the value of correlation above, the value tends towards positive 1, meaning that the sets of data are near each other. From this analysis, it can be ascertained that the smart meter measurement of current is accurate to a large extent.

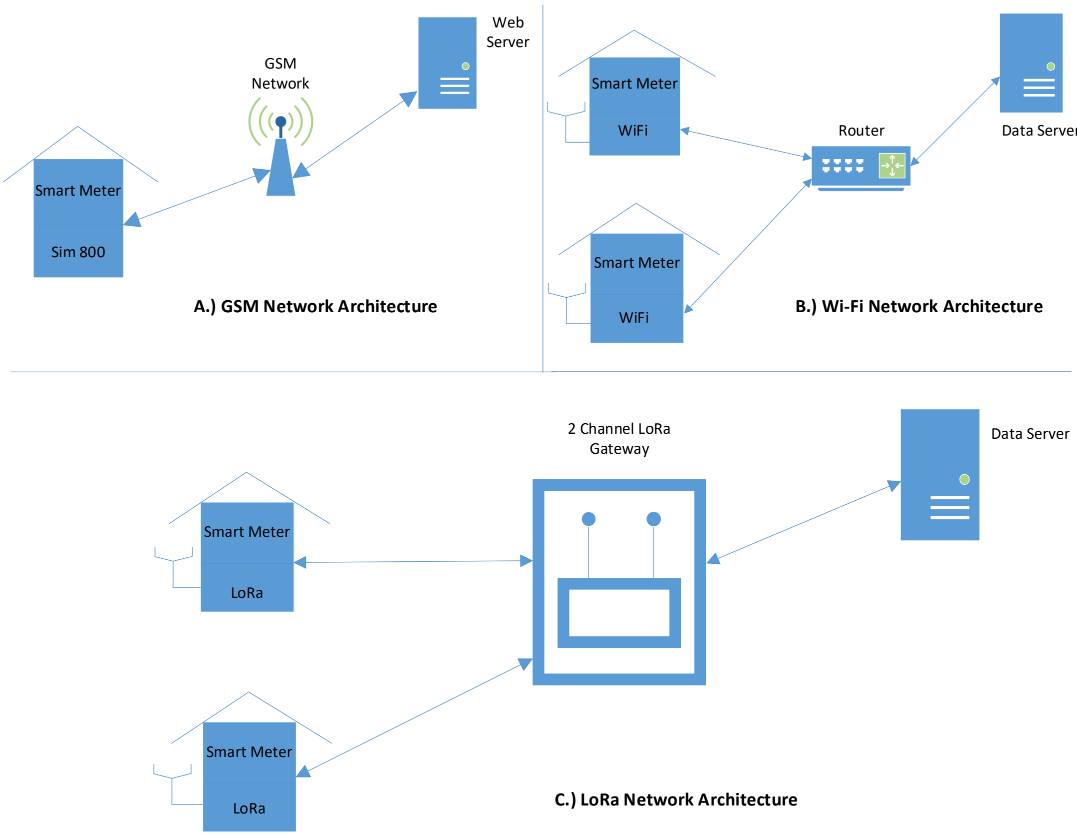

Fig. 10: Network architectures of (a.) GSM, (b.) Wi-Fi, (c.) LoRa networks (Dahunsi et al., 2022)

Table 2: BEME for ATMega328P chip with GSM-based smart meter

Component Description	**Quantity (Unit)**	**Unit Price (₦)**	**Total Cost (₦)**
ATMega328P Microcontroller chip	1	3500	3500
ACS712 Current Sensor	1	4000	4000
ZMPT101 voltage sensor	1	3000	3000
20*4 LCD	1	3000	3000
12V Relay 30A	1	3000	3000
Transistor (BC548)	1	50	50
GSM Module (SIM800L)	1	5500	5500
Crystal oscillator (16MHz)	1	50	50
12V and 5V DC Output Power supply unit	1	6000	6000
Mica capacitor (22pF)		50	50
Resistor (1K Ω, 10KΩ)	12	50	600
Variable resistor (10KΩ)	1	100	100
LED – (Red, Green)	2	20	40
Jumpers	LOT	1200	1200

Lamp holder and bulb (as load)	1	1000	1000
PCB design and construction	LOT	4500	4500
Transportation			2000
Miscellaneous			3000
TOTAL			**40,590**

Table 3: Comparative cost of components for different network architectures

Network	Component	Quantity (Unit)	Unit Price (₦)	Total Cost (₦)	Total cost per network (₦)
GSM	Sim 800 GSM module	1	3500	3500	8000
	ATMega328P Microcontroller chip	1	4500	4500	
Wi-Fi	ESP-01 Wi-Fi	1	1400	1400	31,400
	ZTE 4G wireless router	1	25500	25500	
	ATMega328P Microcontroller chip on Arduino board	1	4500	4500	
LoRa	SX1278 LoRa	1	3250	3250	41,000
	Dragino LG01 Gateway	1	33250	33250	
	ATMega328P Microcontroller chip on Arduino board	1	4500	4500	

This work in its user-friendliness considered the cost of the developed meter by carrying out a BEME to see if the consumer will be able to afford it. This is lacking in many previous approaches (Aina et al., 2020, Shankar et al., 2019, Dahunsi et al., 2022, Baloyi et al., 2020) in which smart energy meters were developed without consideration for the poverty index of the community where it will be used. Another merit of this approach is that the consumer would not need to use a keypad to check the metering status or recharge the meter as obtained in Enughwure (2019). The use of GSM technology (Enughwure, 2019, Alubodi et al., 2021) favours the consumer in the sense that a large number of Nigeria populations have mobile phones and the GSM technology is found in many villages and urban settings (Dahunsi et al., 2022).

5. Conclusion

In this paper, an affordable, user-friendly smart energy meter was developed. Using GSM technology, the smart energy meter can communicate with the consumer and vice versa to renew the pre-paid unit even before energy is used up. The system can notify the customer when there is need to renew his electricity bill through the mobile phone. Tests carried out show a correlation of 0.9358 when compared with reading from a digital multimeter. The device also helps the consumer conserve more energy by making an informed decision about electricity consumption. Future work would include the implementation of a meter bypass notification to curb energy theft.

References

Africaoilgasreport (2021) Nigeria’s Electricity Metering Gap: Behind the Numbers are Human lives. Festac News Press Ltd. https://africaoilgasreport.com/2022/10/power-deficit/nigerias-electricity-metering-gap-behind-the-numbers-are-human-lives/_Accessed on 17 December 2022.

Aina, F., Osanaiye, O., and Unogwu, S. (2020) A GSM module-based smart electric meter reader. Acta Electrotechnica et Informatica, 20(4): 38-45.

Alubodi, A.O.A., Al-Mashhadani, I.B.N., and Mahdi, S. S. (2021) Design and Implementation of a Zigbee, Bluetooth, and GSM-Based Smart Meter Smart Grid. In IOP Conference Series: Materials Science and Engineering, 1067(1): 012130.

Ayanlade, S.O. and Sawyer, T. (2021) Application of Current Differential Principle in the Detection of Energy Theft in a GSM-Based Single-Phase Smart Meter. International Journal of Engineering Technology and Scientific Innovation, 6(4): 80-90.

Baloyi, N., Chowdhury, S.D., Mnisi, J. and Mashee, T. (2020) Design of GSM Based Energy Meter: A Review. 6th IEEE International Energy Conference (ENERGYCon), Gammarth, Tunisia, pp 836-840.

Dahunsi, F.M., Ijadunola, H., Melodi, A.O., and Ponnle, A.A. (2022) Analysis of GSM, Wi-Fi and LPWAN communication technologies for Smart energy metering circuits, IEEE Nigeria 4th International Conference on Disruptive Technologies for Sustainable Development (NIGERCON), Abuja, Nigeria, pp 1-5.

Enughwure, A. (2019) Design and Construction of GSM-Based Smart Energy Meter. FUPRE Journal of Scientific and Industrial Research, 3(2): 12-24.

Mir, S.H., Ashruf, S., Bha, Y., and Beigh, N. (20.19) Review on smart electric metering system based on GSM/IOT. Asian Journal of Electrical Sciences, 8(1): 1-6.

Sawyer, D.T. and Ariyo, F.K. (2019) Design and Implementation Of GSM-Based Energy Theft Detection A Single-Phase Smart Meter. In Faculty of Technology Conference 2019 (OAUTEKCONF 2019), Ile-Ife, Nigeria, p 46.

Sayed, S., Hussain, T., Gastli, A. and Benammar, M. (2019) Design and realization of an open-source and modular smart meter. Energy Science & Engineering, 7(4): 1405-1422.

Shankar, M., Kumar, K.R., Goud, G.S. and Rani, D.N. (2019) AMR and GSM based Energy smart meter reading for billing purpose. International Journal of Research in Management Studies, 4(5): 15-21.

Shomuyiwa, D.A. and Ilevbare, J.O. (2013) Design and Implementation of Remotely-Monitored Single Phase Smart Energy Meter via Short Message Service (SMS). International Journal of Computer Applications, 74(9): 14-22.

Pandit, S., Mandhre, S. and Nicha, M. (2017) Smart energy meter using internet of things (IOT). Vishwakarma Journal of Engineering Research, 1(2): 125-133.

Global Multidimensional Poverty Index (2022). United Nations Development Programme. Online material accessed 18 December 2022.