Development Of Smart Internet Of Things Energy Management System For Household Electrical And Electronic Appliances

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***Abstract*— In this paper, the development of smart Internet of Things (IoT) energy management system for household electrical and electronic appliances is presented. The implementation of the system is in two parts; the hardware devices and a smartphone application. Both worked together to actualize the objectives of this system. Basically, the system monitors and controls the electrical energy utilization of household electric appliances from four different electrical outlets (socket), using the concept of load shedding as a mechanism for managing energy dissipation. When the set value (maximum permitted energy consumption level) is approached, the energy of the peak consumption is shed so as not to exceed the limit. Also, the system monitors inappropriate dissipation of energy on electric and electronic appliances and also inform the user of the tariff system when energy consumption exceeds the set maximum consumption value in order to control energy waste. The control mechanism is based on microcontroller and other electronic circuit designed to achieve the above stated purposes. The input subsystem of the hardware is made up of sensors, designed and implemented using some already existing principles to achieve optimum performance. The control unit is realized by two microcontrollers (ATMEGA328P-PU and ESP32 board) and a microcontroller-based control program, which interprets the input qualifiers to produce a desired output. The output interface is realized by the use of output transducer (20x4 LCD) and other simple electronic components to enable meaningful output. These three subsystems are integrated to form a complete smart Internet of Things (IoT) energy management system for household electric and electronic appliances. Apart from the microcontroller-based device for sensing and controlling the operation of the electric and electronic appliances, the system also has the smartphone application and the Internet of Things application using cloud Google firebase through an access point. The applications (smartphone application and the Internet of Things application) enable the daily energy consumption of the household the electric and electronic appliances to be viewed remotely using smartphones and limit's notification about the functioning of the system is also received by the user's smartphones. The description of the system design, the implement system and the cost implications are all presented.**

Keywords*— Internet of Things, Firmware, Smart System, Microcontroller-Based Hardware Device, Energy Management System, Smartphone Application

1.0 Introduction

The advancement and synergy of electronic and communication technologies have given rise to Internet of Things [1,2,3,4,5], embedded systems, smart systems and other emerging solutions that take advantage of wireless communication networks [6,7,8,9,10,11,12,13,14]. Today, it is possibly to utilize terrestrial wireless communication or satellite-based wireless technologies to enable remote monitoring and control of devices and systems from any location across the globe [15,16,17,18,19,20,21]. The focus in this paper is the development of smart Internet of Things energy management system for household electrical and electronic appliances [21,22].

Energy management today is an essential part of smart systems as more 'things', devices and system are required to be Internet-ready in order to be part of the IoT network [23,24,25]. To be Internet-ready, the 'thing', device or system is required to be powered with electricity or equipped with sensors and communication capability for it to be able to connect and communicate via the wireless IoT network. Having more things requiring electrical energy means more energy demand and hence, the need to manage the available energy to avoid wastage and also to reduce cost of energy [26,27,28].

More importantly, in Nigeria, there is persistence shortage of electric energy supply from the national grid [29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45, 46]. The generated energy is grossly inadequate and some factors on the transmission and distribution lines makes it difficult to efficiently and effectively deliver the generated energy to the end users. More so, many households and organizations are relying on alternative energy source like solar power, wind power, diesel power and other power sources to meet their energy need [47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63, 64,65,66]. As such, the households need to manage the energy they generate to reduce the cost of acquiring, running and sustaining those self-help energy generating systems.

In order to achieve meaningful energy management in a household, effective monitoring of the energy consuming devices and systems in the household is required along with automatic communication of the energy consumption data records to individuals and systems that can effect control on the household energy usage is required [67,68]. In this paper, the automatic remote monitoring and control of the household energy consumption is implemented using a smart IoT energy management system for household electrical and electronic appliances. Accordingly, this paper presents the design and implementation of the smart IoT energy management system.

2.0 Methodology

The Internet of Things (IOT) energy management system consist of both microcontroller-based hardware device with its control firmware program along with a smartphone application. The system is realized through the development of its input subsystem, control unit with control program (firmware) and output subsystem. Its implementation is in two parts; the hardware devices and a smartphone application which worked together to control, monitor and enable communication to and fro the firebase cloud service platform.

The input subsystem of the hardware is made up of sensors, designed and implemented using some already existing principles to achieve optimum performance. The control unit is realized by two microcontrollers (ATMEGA328P-PU and ESP32 board) and a microcontroller-based control program, which interprets the input qualifiers to produce a desired output. The output interface is realized by the use of output transducer (20x4 LCD) and other simple electronic components to enable meaningful output. These three subsystems are integrated to form a complete smart Internet of Things (IoT) energy management system for household electric and electronic appliances. The system monitors and controls the electrical energy utilization of household electric appliances from four different electrical outlets (socket), using the concept of load shedding as a mechanism for managing energy dissipation. When the set value (maximum permitted energy consumption level) is approached, the energy of the peak consumption is shed so as not to exceed the limit. The block diagram of the smart IoT energy management system for electric appliances is presented in Figure 1.

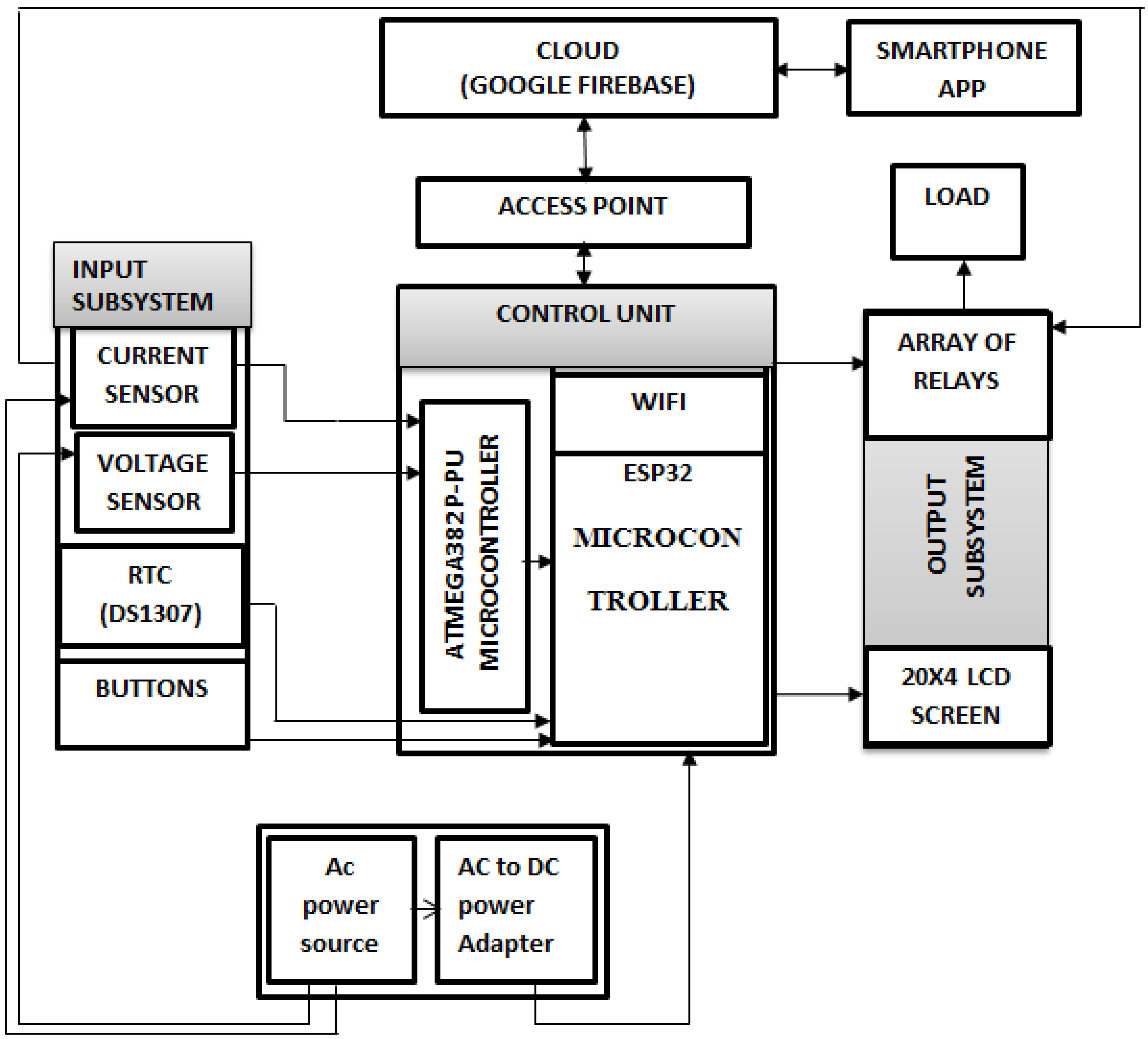

Figure 1 The block diagram of the smart IoT energy management system for electric appliances

The system monitors inappropriate dissipation of energy on electric and electronic appliances and also inform the user of the tariff system when energy consumption exceeds the set maximum consumption value in order to control energy waste. The control mechanism is based on microcontroller and other electronic circuit designed to achieve the above stated purposes. The monitoring medium makes use of current sensor and voltage sensor respectively to monitor the changes in current and voltage of the electric and electronic appliances. The analogue signal from the sensors is converted to digital values using the analog-to-digital converter in the microcontroller while the control program translates the received signal from the sensors to useful information about the functioning and control of the system. The schematic diagram of the system architecture for the smart Internet of Things (IoT) energy management system for household electric and electronic appliances is shown in Figure 2.

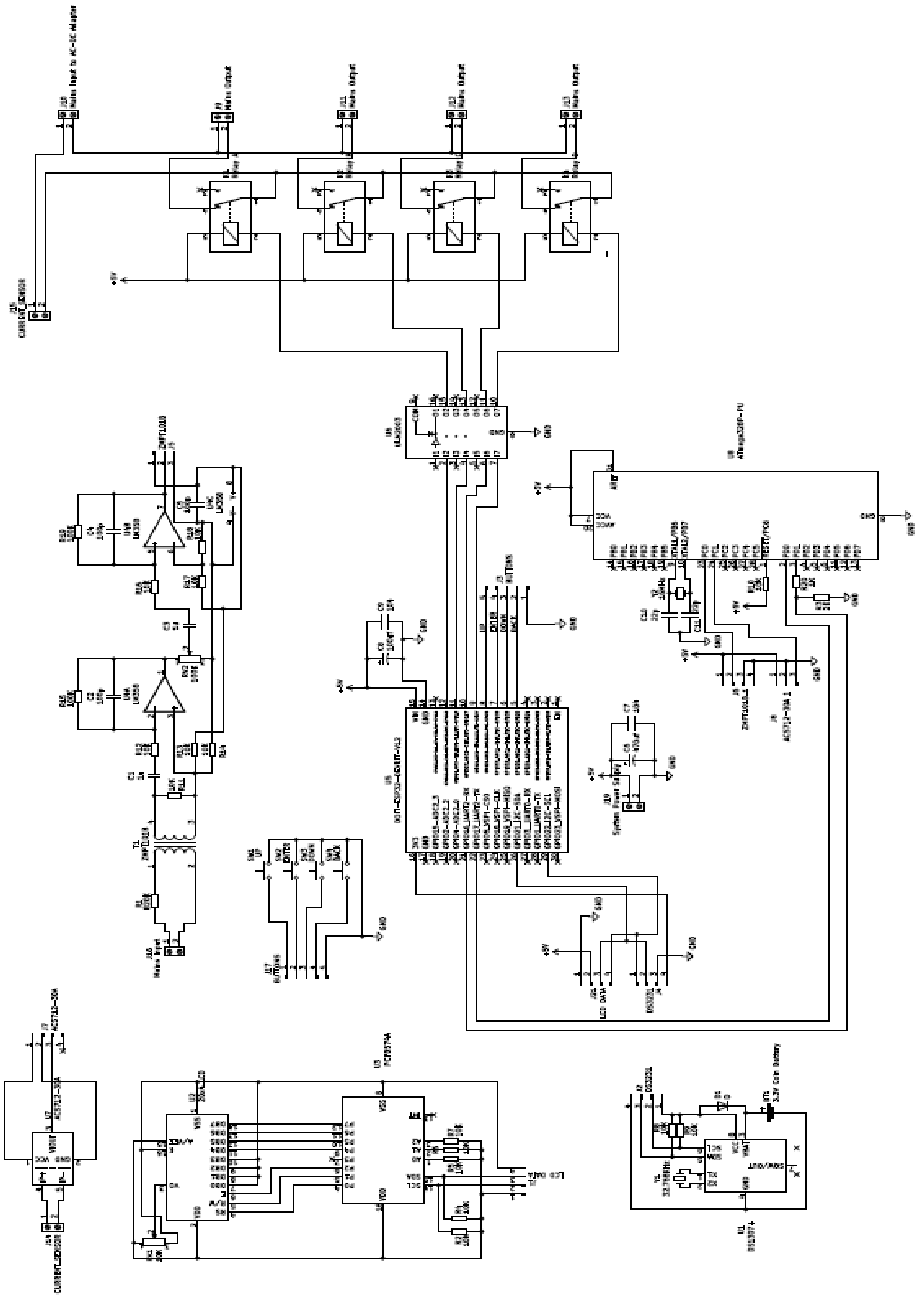

Figure 2 schematic diagram of the system architecture for the smart Internet of Things (IoT) energy management system for household electric and electronic appliances

Apart from the microcontroller-based device for sensing and controlling the operation of the electric and electronic appliances, the system also has the smartphone application and the Internet of Things application using cloud Google firebase through an access point. The applications (smartphone application and the Internet of Things application) enable the daily energy consumption of the household the electric and electronic appliances to be viewed remotely using smartphones and limit's notification about the functioning of the system is also received by the user's smartphones. The process flowchart of the smart Internet of Things (IoT) energy management system for household electric and electronic appliances is shown in Figure 3.

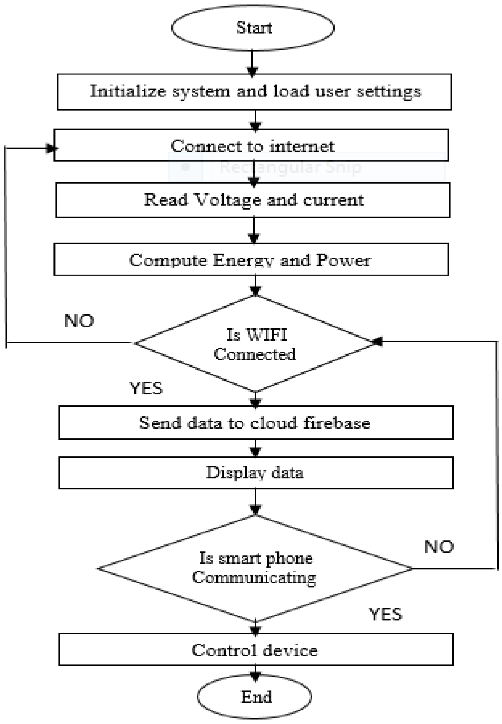

Figure 3: The process flowchart of the smart Internet of Things (IoT) energy management system for household electric and electronic appliances

2.1 The Control program

The control program is the driver that interprets the input signal received from the input subsystem (sensor circuits). The input received is processed by the control program which is finally sent out as pattern that will represent meaningful output information (data reading of the meter); another pattern also triggers communication between the user and the device.

The microcontroller-based control program used in the IoT-based system is written in C and C++ languages along with Arduino integrated development enviroment (IDE). The coding in this IoT-based system defines all the libraries used to instruct the hardware components in the IoT-based system. The hardware device is instructed by the C-programing language. The hardware device with the help of the control program controls, monitors and enable communication to and fro the firebase real-time database of the cloud service platform.

The Aduino IDE is an integrated development enviroment is used in writing the control program for arduino compatible boards. In the arduino ID enviroment, a new project was created with source files in a specified directory, the codes were written, ready to be uploaded to the chip. After writing the codes, the uploader device (Aduino board) was connected via USB port of the computer, for it to connect with the arduino development enviroment. The programmer software became opened and the program file located for the burning process. The screenshot of a sample Aduino IDE enviroment used for the enegy management softaware development is shown in Figure 4.

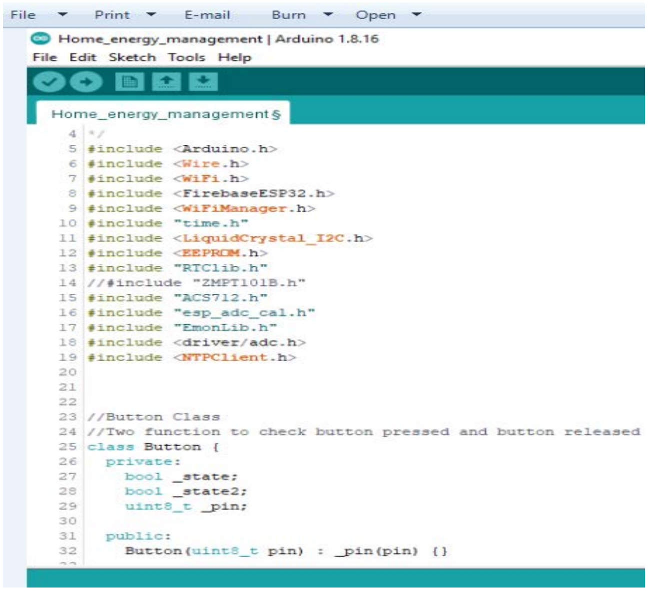

Figure 4. The screenshot of a sample Aduino IDE enviroment used for the enegy management softaware development

3.0 Results and Discussion

The implementation of the system is in two parts; the hardware devices and a smartphone application. Both worked together to actualize the objectives of this system. The system has four 13 ampere socket outlets and four led indicators (as shown in Figure 5). It can be operated manually from the buttons and online through android phone hotspot. The system reads the voltage consumption, the current, power and energy dissipation of each house hold electric and electronic appliances connected to it. The knowledge of these parameters enables the system to manage the energy consumed by the appliances when the power consumption exceeds the set power limit.

The WIFI in the microcontroller, the powery smart phone application, the smart android phone with internet access communicates together for the operation of the system. The screenshot of the smart phone app. Interface IS SHOWN IN Figure 6. The screenshot of the LCD screen display is shown in Figure 7. The LCD screen displays the following information among others that are displayed during device settings:

i. The status of the four 13 amps' socket outlets (OFF or ON) at which devices are connected to (socket A, B, C and D).

ii. The date – time display

iii. The voltage, current, power and energy usage computation of the system

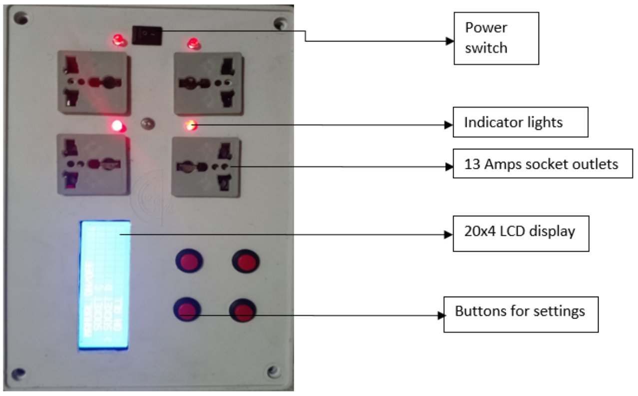

Figure 5 The picture of the system showing the four 13 ampere socket outlets and four led indicators

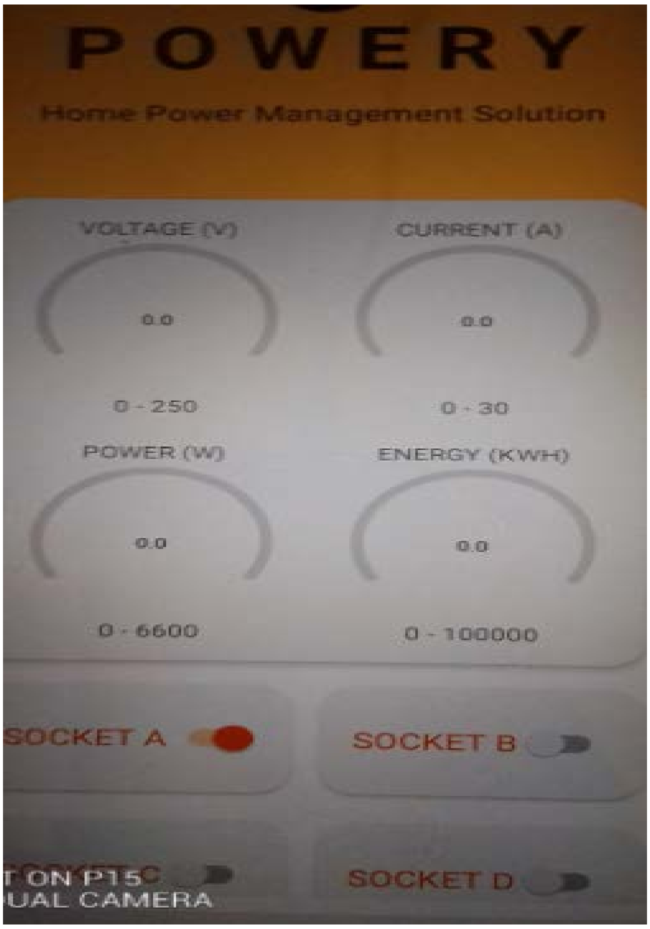

Figure 6 The screenshot of the smart phone app. interface

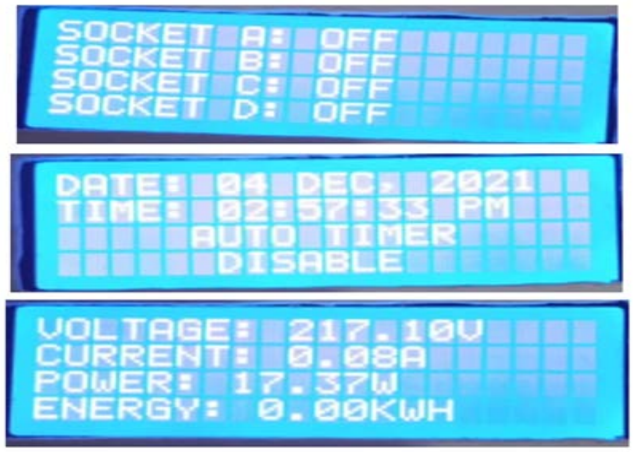

Figure 7 The screenshot of the LCD screen display

The smart Internet of Things (IoT)-based energy management system for household electric and electronic appliances was implemented with the readily available integrated circuit chips and other circuit components that are readily available in our local market as at the time of the design and implementation. The cost was evaluated as shown in the Table 1. This cost analysis is based on the prevailing market price as at the time of implementation of the design.

Table 4.7 Bill of engineering materials and evaluation

S/NO.	MATERIALS	MATERIALS		Unit Price (Naira)	Total Cost (Naira)
		References	Value		
1	U5	ESP32	1	6500	6500
2	U3	ULN2003	1	200	200
3	Voltage Sensor module	ZMPT101B	1	2200	2200
4	U3	LCD I2C Module	1	1000	1000
5	U2	20x4 LCD	1	5000	5000
5	U7	ACS712-30A	1	1800	1800
6	U1	DS1307 RTC Module	1	800	800
7	K1, K2, K3, K4	Relays	4	350	1400
8	SW1, SW2, SW3, SW4	SW_Push	4	250	1000
9	Power Source Connection	Sockets and Wires	1	3500	3500
10	Solder		1	1500	1500
11	copper clad board	10x15 cm	1	1200	1200
12	PCB powdered etchant		1	2800	2800
13	glue stick		5	150	750
14	AC to DC Power adapter	5V 3A	1	3500	3500
15	4 Pins JST Cable		2	200	400
16	Female Header	40 pins	1	120	120
17	PCB Terminal Block	2 way	6	100	600
18	6 Pins JST Cable		1	300	300
19	Akylic		1	700	700
20	Cutton wool		1	300	300
23	IC Socket (14 Pins)		1	60	60
24	AC Cable		1	1800	1800
25	Power Switch		1	100	100
26	Gum		1	300	300
27	LEDs		4	20	80
28	Resistors		8	10	80
29	Electrolytic Capacitors		2	40	80
30	Ceramic Capacitors		4	20	80
31	Bots and Nuts		8	30	240
32	Pespex Board		1	500	500
33	Adaptable Box		1	2200	2200
34	Coin Battery		1	150	150
		Components			35570
		Transport			4500
		Total			40070

4. Conclusion

The development of smart Internet of Things (IoT)-based energy management system for household electric and electronic appliances is presented. The system gives the user the ability to control the electrical energy consumption of appliances in the house. The system monitors inappropriate dissipation of energy on electric and electronic appliances and also inform the user of the tariff system when energy consumption exceeds the set maximum consumption value in order to control energy waste. The control mechanism is based on microcontroller and other electronic circuit designed to achieve the above stated purposes.

The system is realized through the development of its input subsystem, control unit with control program (firmware) and output subsystem. Its implementation is in two parts; the hardware devices and a smartphone application which worked together to control, monitor and enable communication to and fro the firebase cloud service platform.

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