A Novel Interactive IoT-Based Smart Electricity Power Consumption Management System

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Abstract. Effective and efficient management of electric power is of significant benefit to the end users and a nation's economy at large. The unnecessary huge bills and feuds that occur very often in developing countries like Nigeria after every billing period are often because of energy wastage and improper use of energy. This challenge hereby presents us with the need to not only create awareness but to also develop systems that allow for efficient and economic use of electric power. The existing meters that attempt to handle this challenge are in some cases analog, or not interactive, expensive and imposing. These systems are said to be imposing because they do not afford the user the right of deciding what he/she wants to spend in a billing period. Even with the emergence of prepaid meters, users are still unable to interact with individual connection points and decide what is consumed there so as to enhance conservation. These problems have already brought to table the need to develop systems that are automated, yet interactive and smart. The solution is an interactive smart electric consumption management system. Thus, this research work is formed around interaction and smartness. A linPrec Scheduling Algorithm is used to predict what each connection point requires in a billing period by interpolating between previous data points on the system. With the Android App, the User is allowed to communicate with every connection point in the apartment and comfortably determine how much they are willing to spend on electricity in a billing period. The http client guarantees data arrival with a worst-case average response time of 2.095s and a best-case average response time of 0.894s. Also, the power measurement had a Mean Absolute Error of 8.89% which implies high accuracy of 91.1%.

Keywords: Electrical Power, Power Consumption, Interactive, Scheduling Algorithms, Monitoring and Control

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1 Introduction

Over time, there has been a tremendous increase in the number of electric power consumers – both domestic and commercial consumers of electricity [1, 2]. This is caused mostly by the increase in the use of electronics or electrical devices [3, 4]. Hence, the need for managing power consumption has become a prime challenge in the world today especially in developing nations like Nigeria [5, 6]. It has been determined through research that over the last century, the number of electric power consumers has increased exponentially [6, 7]. The International Energy Agency (IEA) reported that the demand for electricity by just the Agriculture, residential, commercial and public sectors is 57% in 2015 and will increase by 2% annually until 2030 [8]. Traditionally, electric power consumption was monitored manually. This involves much human intervention in collecting and managing the data obtained from the field. This method was efficient at some point but the continuous increase in the number of consumers soon made it too difficult to continue hence affecting the integrity of data collected from the field and also resulted to continuous feud between electric power suppliers and consumers in the country. In recent times however, smart systems able to monitor and even control power consumption have been developed but the major setback with these systems is that they do not allow the user decide how much he/she wants to spend and how he/she wants to spend their money. Vignesh and Dr. Sathish [9] recommended that it is important to consider cost when developing such smart systems. One will be right to say that existing systems are not as interactive as power consumers will want them to be. A smart system guaranteeing interaction and the ability to advice users on power consumption will be handy in this contemporary society.

2 Related Works

Afonso, et al. [8] in their work titled Wireless Monitoring and Management of Energy Consumption and Power Quality Events developed a power management system. Their system was cost efficient, measures numerous required electric parameters(such as current, voltage, frequency, active power and power factor)associated with each monitored electrical load using sensors and gives the user information about measured parameters along with the date and time, total power consumed in Kwh and also displays the monthly and annual power consumption cost. Electric power monitoring and control was done using a distributed network. On the downside, their system uses out of date devices such as 8051 as microcontroller, can only get details of previous power consumption. No provision made for forecasting and cannot intelligently guide its user on how to use appliances for optimized power consumption. Similarly, Nuhu, et al. [10] proposed an energy efficient structural monitoring system using expert fuzzy system. The system reduced energy consumption by 30%.

Anastasi, et al. [11] developed An Intelligent System for Electrical Energy Management in Buildings. The system uses Wireless Network Sensors to monitor electric power consumption, made provision for energy conservation, sends alert message to notify user of events that requires attention like when a device that should be off is on and also suggest ways to conserve that energy been consumed and gives instantaneous report of what each electric appliance is consuming. It also has a module to handle devices on standby. The system allows user select time he wants certain appliances to come ON. This is because power rate is lower at night than in the day time and it provided UI for both PC and smaller devices like Smart Phones. The Challenge with this system is that it is robust and thus very expensive such that it tends to consume back the money conserved from using it in energy saving. It is also difficult to implement as system requires much programming and design.

Fakharuddin, et al. [5] also developed A smart energy management system for monitoring and controlling time of power consumption. The System is found to be accurate and nearly precise when implemented for testing. It has a robust database where electrical parameters collected are stored for further processing and queries and detect faults and makes decisions where necessary. The pitfall is that the System is only a hypothesis since it has not yet been implemented in a large scale and it has a slow response time.

Srividyadevi, et al. [7] built a system for the Measurement of Power and Energy Using Arduino. The system design is simple and a simple circuit diagram based on elementary physics with low cost electric devices. The system was controlled using Arduino as Microcontroller which is easy to program, open source, cheap and available. But, the system is not very safe as all connections are wired not wireless and since everything is wired, once the physical ports are exhausted, a physical limit is reached and future expansion becomes difficult. Also, the System can only measure power consumed. No room for control or interaction.

3 Materials and Methods

This section defines the techniques or procedures amd the methods adopted in the development of the electric power management system. It gives an overview of the steps followed in developing the system providing block diagrams, circuit diagrams and flow charts.The system comprises of two modules: The software module and the hardware module. The Hardware module performs the task of power measurement, establishing connections and interactivity. The current and voltage measured at each connection point is used to compute the instantaneous power consumed at that point and is also used to estimate the aggregate consumption from all connection points. A nodeMCU ESP8266 performs these operation at the connection points after which it uses its ESP Wi-fi module to connect to a hotspot that operates on the 2.4Ghz frequency so as to transfer measured parameters to the internet. The firebase database on the internet receives data from the apartment as well as the Android App. Also, from the Android App, the user is authorized to determine the amount to spend on electricity in a billing period and to also query data from the database. Figure 1 shows the block diagram of the whole system.

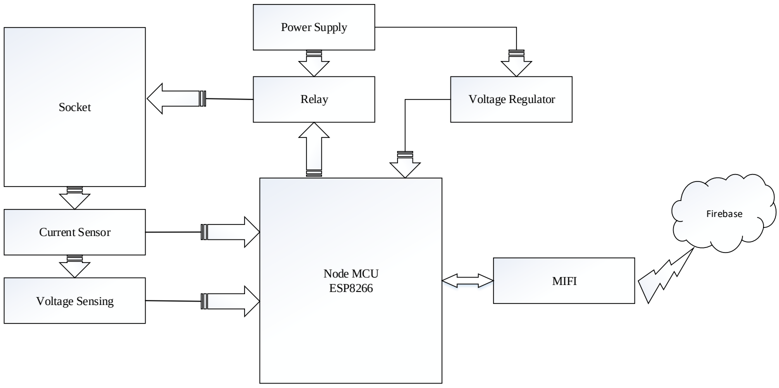

Fig. 1 Block Diagram of the Power Management System

3.1 The Network Connection

The network connection unit is located centrally in the apartment. It provides ISP services to the system. A MIFI is used as the basic component at this point. It creates a hotspot which every connection point in the apartment connects to using the ESP8266 Wi-Fi module through which they can transmit their measured parameters to the firebase database. Figure 2 shows the Block Diagram of the network connection unit.

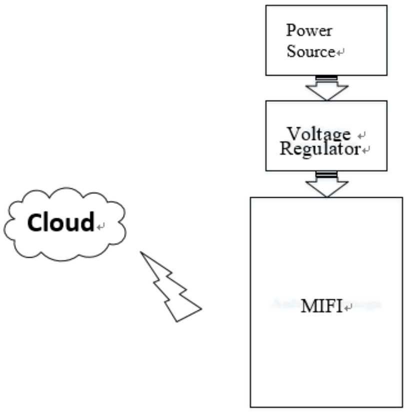

Fig. 2 Block Diagram of the Network Connection Unit

3.2 The Android App

The Android App is developed using the Java Programming Language. The Android Studio IDE is used in creating the App. Through this App, the user can view the current power usage; amount consumed thus far within the billing period, monitors each socket and controls them. Through the same App, the User can interact with the Scheduling Algorithm built into the System.

3.3 The Server App

The Server is controlled by a collection of programs domicile in the cloud. The Google based firebase platform was used in this work. The firebase has a database that receives data from sockets as well as from the user via the Android App. The Server stands as the intermediary between the hardware parts and the Android App on the User's mobile device. The Server App has its database for storing all information sent to it and allows the authorized user query such data.

3.4 Scheduling Algorithm

The linPrec Scheduler uses a normal sequential computer program to schedule units to the sockets in the Apartment for the first ten (10) billing periods. A billing period is approximately one month (30 days). After the tenth billing period, a Linear Regression Algorithm is used to automatically schedule the power rating purchased by the system user in any billing period. The Algorithm is developed using Java programming language and embedded in the Android App installed on the User Android supported mobile phone.

3.5 Mathematical Computations

This is also been carried out at the connection point where the electric appliance interfaces with the system. The power consumed at each point is computed using the inputs from the current and voltage divider sub-circuit used at the point. The computation was carried out on the nodeMCU ESP8266 microcontroller at the point of measurement. A relay is connected at each socket for switching (control) purposes.

$$\text{Power} = \text{voltage} * \text{Current} = VI \quad (1)$$

$$Vp = Vpp/2 \quad (2)$$

$$Vrms = Vp * 0.0707 \quad (3)$$

$$\text{Apparent Power} = Vrms * Irms * \sin\Theta \quad (4)$$

$$\text{Real Power} = V * I * \cos\Theta \quad (5)$$

$$\text{Power Factor (pf)} = \text{Real Power}/\text{Apparent Power}$$

3.6 System's Working Principle

Basic operation begins with the power supply into the apartment. an ACS712 current sensor that with the task of measuring the amount of current consumed at each socket by an electric load connected to it and uses a voltage divider sub-circuit for voltage sensing. This sub-circuit alongside the nodeMCU ESP8266, measures the voltage drop across connected devices. Once the voltage drop and the current consumed at each socket is measured, the power consumed is computed using the mathematical relationship Power, $P = \text{Current}(I) \times \text{Voltage}(V)$. Since the nodeMCU ESP8266 is a Microcontroller and a transceiver also, it transmits the information measured at each socket wirelessly through the connection unit to the cloud precisely, a firebase database hosted by Google. All data sent by the sockets are received and stored in the cloud database. An android App installed in the user's smart phone provides the user an suitable platform to interact with the entire system. The linPrec algorithm takes as input from the user, the total amount of Money he/she is willing to spend on electricity in a specified billing period and uses the Linear Regression model to schedule it across the sockets in the user's apartment after converting them to power unit. Figure 3 and 4 are the flow charts of the entire system and the linPrec Algorithm respectively.

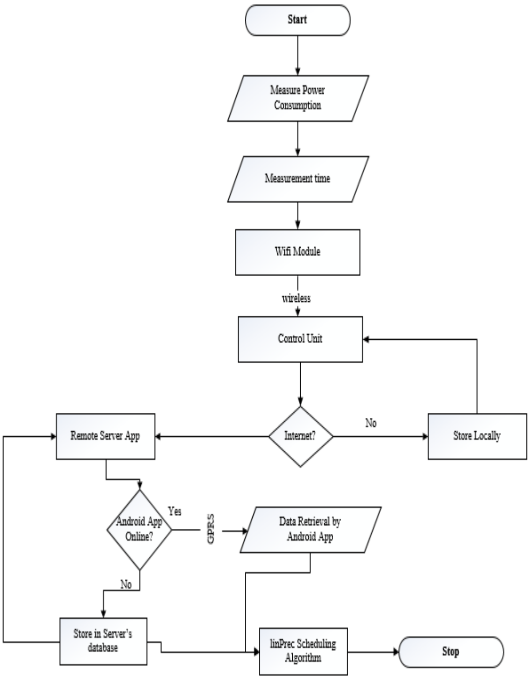

Fig. 3 Flowchart of the Developed System

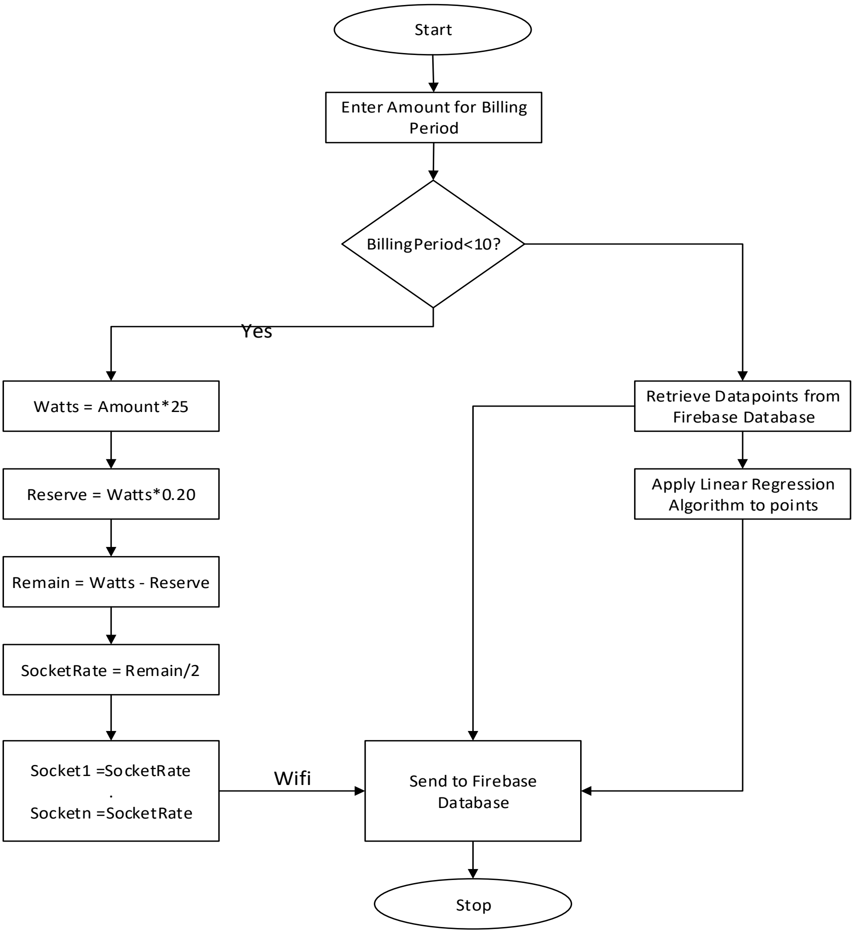

Fig. 4 Flowchart of linPrec Algorithm

4 Results and Discussions

This section consists of results obtained from tests carried out on the system during and after the system design. The performance metrics considered are the response time and accuracy of the system. Figure 5 is the developed hardware prototype of the system whereas figure 6 is the dashboard of the User App.

Fig. 5 Hardware Prototype of the System

Fig. 6 The Dashboard or Landing Page

On the dashboard, the User can control connection points and access consumption rates and behaviours of the various connection points in the apartment.

Also, the Navigation panel is located at the top left corner of this page. The entire App comprises of five(5) different pages starting with the Home Page. Hence, to navigate across the pages, the Navigation panel has to be accessed and the target page selected. Figure 7 is the Navigation Panel.

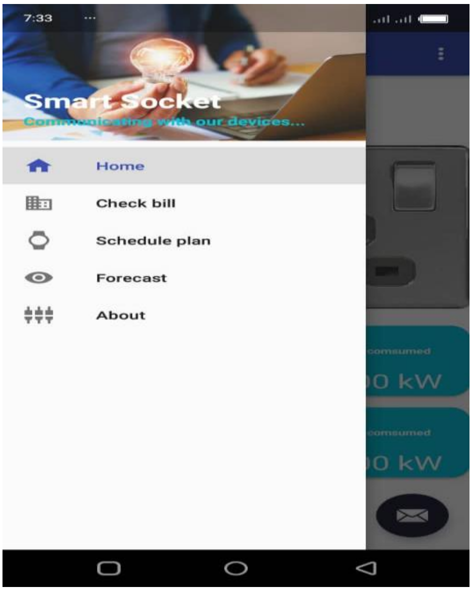

Fig. 7 The Navigation Panel

4.1 Performance Evaluation

The response time was measured under two different network conditions. The first condition has the following network information:

Network type: 3G ISP: Airtel

Network Remark: Low Network grade: 12-19 Signal Strength: -105dBm to -99dBm

The response time table for the low network scenario is Table 1.

Table 1. Response time table for low network area

No. of trials	Response time(s)
1	1.85
2	2.55
3	2.64
4	1.68
5	1.27
6	1.32
7	1.68
8	2.45
9	3.51
10	2.00

Figure 8 is the response time graph for 10 different trials.
Average response time = $\sum_{i=1}^{n} R_i$ = 2.095s. This implies a good response time.

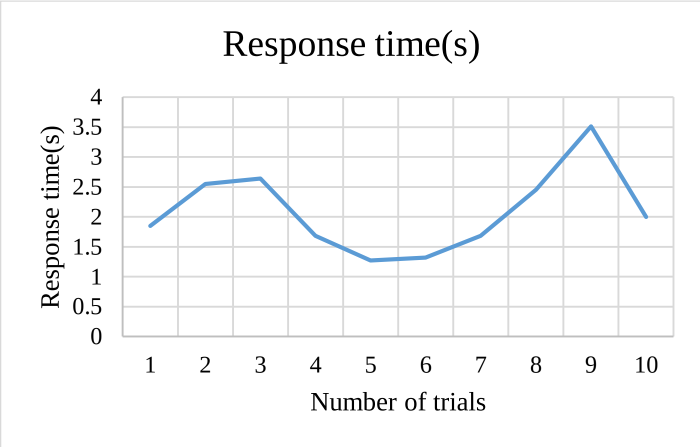

Fig. 8 Response time graph for low network area

The second scenario has the following network information:
Network type: 4G ISP: Airtel Network Remark: Good Network grade: 48-60 Signal Strength: -94dBm to -83dBm
The response time table is Table 2 for the Good network scenario and figure 9 is the response time graph for 10 different trials.

Table 2. Response time table for good network area

No. of trials	Response time(s)
1	0.89
2	0.70
3	1.16
4	0.76
5	0.97
6	0.28
7	0.96
8	1.26
9	0.97
10	0.99

Also, Figure 9 is the response time graph for 10 different trials.
Average response time = $\sum_{i=1}^{n} R_i$ = 0.894s. Which implies a high response time?

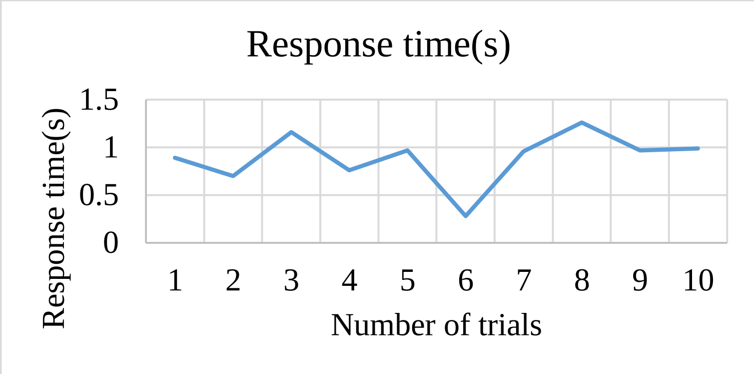

Fig.9 Response time graph for good network area

The second performance metric is accuracy in power measurement. To achieve this, four electrical devices of different power rating were connected to the system and the power computed by system is compared to the actual power rating on the device. Table 3 is the result obtained and Figure 10 is the graph of this relationship.

Table 3. Efficiency test result

Electrical Device	Actual Rating(W)	Measured Rating(W)
Phone Charger	4	3.8
Soldering Iron	80	60
Dell Laptop	130.5	129
Infinix	34.4	33.97

Percentage Accuracy (Efficiency) = $\sum(M_a - M_p / M_a) * 100$
Average M_p = 56.625 watts
Average M_a = 62.225 watts
% Error = ((62.225 – 56.625)/62.225) * 100 = 8.89%
% Accuracy = 100 – 8.89 = 91.11%

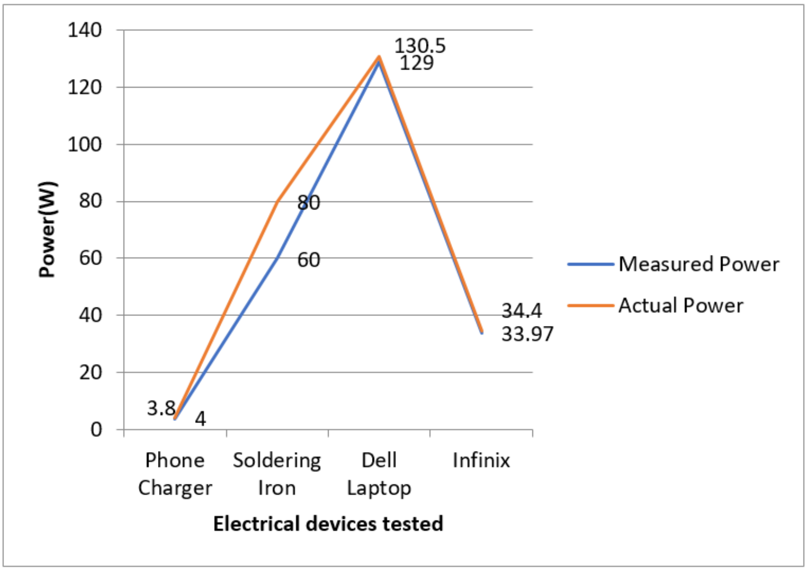

Fig. 10 Accuracy test Graph

5 Conclusion and Future work

In this work, we have presented an efficient power management system high interactive and of low cost providing Users with the freedom of spending only what they are willing to spend in every billing period. Many people believe that the problem in the power sector of the nation is the low power supply when compared to the aggregate demand. This is partly correct but not entirely so. A large chunk of the insufficiency can be credited to consumer negligence and ignorance. The advent of power management systems makes it possible to not only monitor when power is consumed, but to also control, forecast and even schedule power over appliances. This tremendous addition has made power management possible by increasing power consumers' awareness and making their ignorance become of less consequence since these systems can make intelligent decisions for the consumer with little or no active involvement from the user. The developed system can be further improved on by making:

i. The Android Application to be cross-platformed so that non Android users can also use.
ii. The Desktop version of the Application portable across different Operating Systems.
iii. Cable health monitoring should be included to curtail fire outbreak cases.

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