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AN IOT-BASED RESIDENTIAL ENERGY METERING AND PROTECTION SYSTEM

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ABSTRACT

The fairness of electricity services lies in the provider being able to deliver the expected quality power, and recover the returns on investment. Energy theft, metering lapses, billing errors, and cumbersome payment procedures constitute the bulk of the non-technical power losses and contribute majorly to the incapacity of electricity vendors to run a profitable business and serve customers effectively. A real-time approach has been identified as the innovative need at resolving the enumerated issues within the electricity value chain. This study is leveraging the Internet of Things (IoT) technology to propose an extended modelled system capable of providing real-time data management, residential power system control, and an interactive platform for vendors and consumers. The energy billing was modelled and developed from resourceful components. A website was developed with a user-friendly interface. The unique features of the system design are the possibility of customers loading their electricity credit online, and the supplier being able to lock or disconnect any defaulting customer remotely.

Keywords: electricity billing, energy theft, internet-of-things, residential power system, smart metering.

1. INTRODUCTION

Electricity is a commodity with high-valued demand and supply, as it contributes extensively to the economy and better life for both corporate and individual entities. The monitoring and protection of power devices in homes and facilities are very important. Meanwhile, ensuring that the actual electricity consumed is accurately tariffed is also crucial [1]. The fairness of any service relationship lies in the provider being able to deliver the expected quality service and recover the invested capital through profitable returns on investment (ROI). The process of monitoring the track of electricity being consumed for verification is presently tedious and non-assuring, as manual meters are employed for data reading and recording. The metering strategy of the customers' facilities has experienced various evolutions in recent times [2].

In Nigeria, energy metering by human data collection has been the major practice, until lately that pre-paid metering is gradually being introduced. The process involves human operators visiting the targeted facilities to collect the energy meter readings on a monthly basis and use the collected to bill the customers. The process has been faulted by many errors associated with human interference and lapses, thereby resulting in consumers being billed on an estimated basis. Also, the pre-paid metering being introduced in batches as the new solution is being reported with cases of energy theft by connection bypass, and credit inconsistency [3]. Energy theft largely results in huge revenue loss by the providers. Energy theft is a major problem that manual, analog, digital, and pre-paid meters have been unable to adequately curtail. In analog meters previously introduced, many consumers could slow down the rotation of the device by using the permanent magnet. In a similar way, digital and prepaid meters are being bypassed by consumers aiming at stealing electricity[4], [5]. The electricity theft, billing errors, and the customer's payment debts constitute the bulk of the non-technical power losses and the subsequent revenue losses. These are electricity problems that can, therefore, be mitigated by real-time energy monitoring and billing over the internet, innovative technologies, and integrated devices and infrastructure [6]. The growing population of electricity consumers [7], and the need to efficiently deliver their required electricity has made the adoption of the Internet of Things (IoT) imperative.

The IoT is a brilliantly evolving technology that has integrated the global space with established and intelligent computing. IoT enables interconnectivity among smart devices such as mobile phones and computers, the internet, people, and things. IoT has successfully formed a synergistic bond with other evolving technologies such as blockchain and machine learning to build autonomous systems that can communicate with, and control devices and objects necessary for various innovative solutions. The IoT technology has helped to propel the importance of improved electronic devices in the provision of better living conditions and enabling profitable business venturing through cost-effective and timely transactions and business executions. It has birthed attractive ideas for solution provision in various sectors including safety, protection, accounting, entertainment, and security [8]-[12].

IoT technology has been introduced in many other areas of the electricity value chain. The three cardinal sectors of the power chain: generation, transmission, and distribution have had the benefits of integrated IoT technology [13]–[21]. A transition towards a digitized and decentralized mode of energy billing and payment will be a major milestone in ensuring profitable ROI for interested investors. The energy billing system will be efficiently and effectively managed using the IoT. The management will involve such real time systems that can gather data on electricity connection status, metering, billing, consumer payment, and energy audit. Importantly, the stakeholders at both the supply and demand ends could be integrated into the interfacing platforms of such systems to benefit in the real time engagements for energy solutions[22].

The study in [1] is herewith leveraging IoT to extend the monitoring and protection of residential power systems capability to real-time billing, monitoring, recharge, and control. This paper presents an advanced metering, billing, and payment system with an interactive application interface for consumers and the electricity supplier. The remaining part of the paper is structured as thus. Section II consists of the material and method of the system. Section III contains the results and discussion, while the conclusion is presented in section IV.

2. METHODOLOGY

The approach is to advance the IoT model and design to make available a system capable to provide real-time metering, billing, and recharge payment, in addition to the monitoring, control, and protection of residential power systems. The modified system is modelled, hardware and software designed, and then implemented. The system is designed based on the energy consumed on a line within a power supply section.

2.1 System Model

The energy consumed on a line, j over a period interval, t is defined by $e_{j,t}$ as indicated in equation (1).

$$e_{j,t} = P_{j,t}t = I_{j,t}V_{j,t}\cos\theta \quad (1)$$

where $P_{j,t}$ defines the power consumed on the line within the period.

The tariff mechanism adopted is the progressive pricing technique referred to as the stepwise energy pricing (SEP) [23]. The assumption is that the energy quantity is categorized into n-steps, with each step corresponding to a unit price increase with the step. The monthly clearing price is equal to the sum of the product (SOP) of electricity quantity across all the steps and the corresponding price. Considering the SEP schematic as shown in Figure-1, the energy quantity vector across all the steps is given by equation (2) while the unit pricing vector is given by equation (3).

$$e_j = [e_{1,}, e_{2,}, \dots \dots .] \quad (2)$$

$$p = [p_1, p_2, p_3] \quad (3)$$

The monthly clearing price, P_c is a function of the price and the quantity of energy usage on a stepwise basis, as expressed by equation (4), where e_T is the total energy usage after the implementation of SEP.

$$P_c = p_1e_1 + p_2(e_2 - e_1) + p_3(e_T - e_2) \quad (4)$$

The stepwise tariff model can be optimized to encourage energy efficiency, using the genetic algorithm analysis.

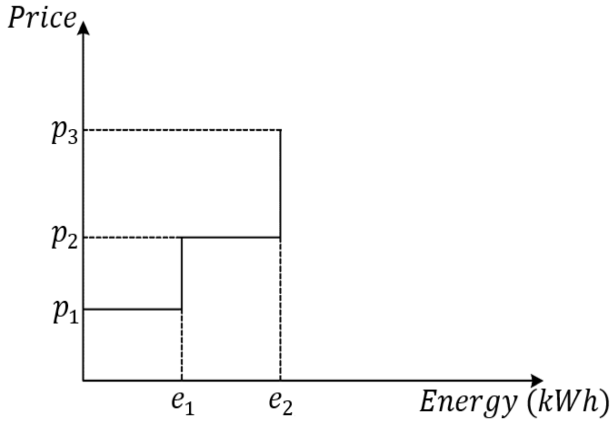

Figure-1. The schematic of the SEP model.

2.2 Hardware Design

The system architecture is shown in the block diagram of Figure-2. A unique website was designed for the system to connect and interface smart devices with the internet.

The building blocks of the system include four main units: the sensor module for current, voltage, and temperature parameters measurement; the transceiver unit being integrated with the WIFI and GPRS modules for internet connection for the website and the mobile application; the relay unit which performs the make-or-break connection to the end power users; and the Arduino microcontroller which processes the received signal and output control signal to the relay unit. The ACS712 current sensor combined with the LM35 temperature sensor, an input voltage capacity measurement of about 400Vac. The radio frequency XBee 2.4 GHz by Digimesh was the transceiver module integrated with the antenna as shown in the hardware connection of Figure-3.

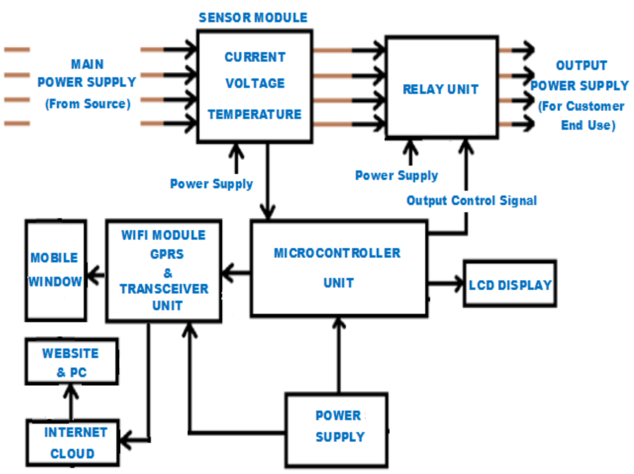

Figure-2. The system block diagram.

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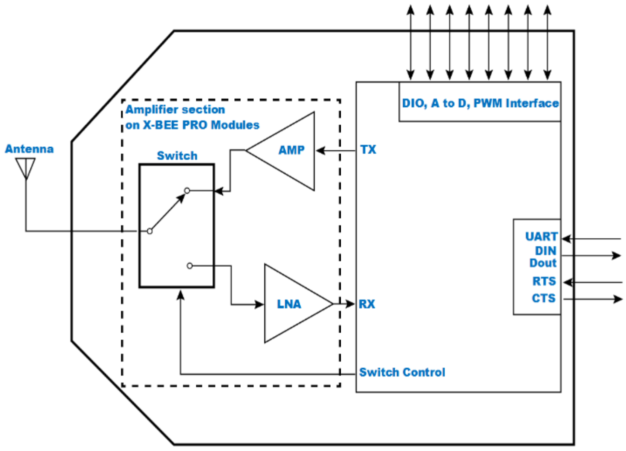

Figure-3. Internal block diagram of the transceiver module

2.3 Software Design

The software unit of the system is designed for a two-way communication feature. The main functions include the initialization with the commands over the internet website and to integrate the microcontroller and adjoining electronic units for control. The data for power consumption and the corresponding the billing information are directly transferred to the cloud and available on the website in real-time. The algorithm for the operational details of the system is as shown in Figure-4.

3. RESULTS AND DISCUSSIONS

The resulting system from the implementation of the design and the operation of the developed user platforms are presented in this section. The hardware components of the IoT-based metering system were developed as shown in Fig 5. It consists of an Arduino nano being connected to an integrated transceiver with the WIFI and GPRS module for internet connectivity. Also, there is a four-channel relay section for disconnecting the supply to the end user, while the LCD unit displays all the data in real time.

The webpage and mobile application window developed is as shown in Figure-6. The webpage has an easy-to-use interface with a good outlook. A user needs a unique identity number (ID) to log in and navigate through the page. After profile login, there is an option to select between a customer or supplier. A customer selects accordingly and reads the message available in the inbox. If there is no electricity credit, it is indicated, and then he cannot go further unless the system is recharged with a credit unit. The system is linked with a payment platform, to be activated, for automated payment.

The credit unit can be purchased and loaded manually. The sensor readings and the credit unit value are collected and stored. If any of the benchmarked parameters: current, voltage, or temperature exceeds the threshold, the affected line is tripped off. All data and notifications are displayed on the LCD and stored in the customer profile as a message. The supplier representative can also log in with a unique ID, view the status of any customer power supply facility to monitor any discrepancies in energy usage, and sends a control command to disconnect a defaulting customer. There is an automated 3 Kb/s data refreshing of the website every five seconds to allow for data updates in real time. Therefore, the data usage for the refresh is minimal.

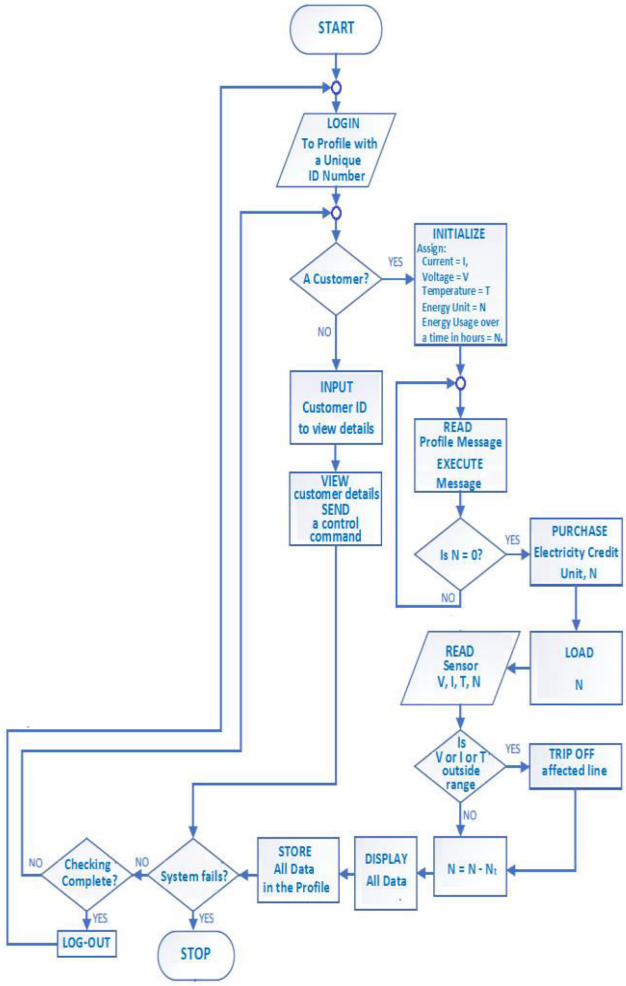

Figure-4. Flowchart of the system operation.

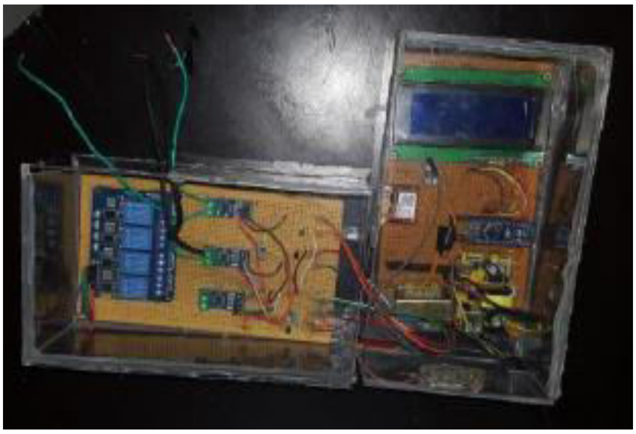

Figure-5. The developed hardware of the IoT-based metering system.

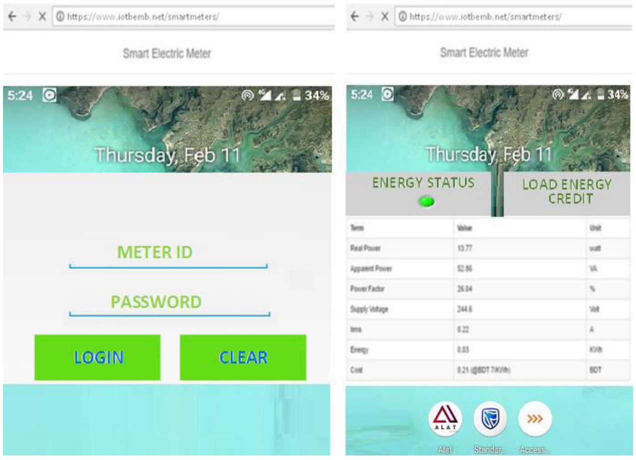

Figure-6. The user application interface.

4. CONCLUSIONS

In this paper, an Internet of Things (IoT) based energy metering system for residential facilities has been developed. The study has extended and improved the existing work on the real-time monitoring and protection of a residential power system using IoT technology. The various units of the system were implemented on a resourceful-selection basis of the electronic devices. A user-friendly website and mobile application interface were also designed for real-time monitoring and collection of the metering and billing information for both the supplier and the customers with exclusive access codes. Previous methods and approaches adopted in energy metering and billing such as demand side load method, analog meter reading, and digital prepaid metering were examined with relative flaws which have, therefore, been addressed with this IoT-developed system. The developed IoT-based system is a combination of subsystems such as an energy meter, billing device, payment platform, and residential power system controller. The customer credit is counted down according to the electricity unit's usage and automatically logs off whenever the credits are exhausted. The unique features of the system design are the possibility of customers loading their electricity credit online, and the supplier being able to lock or disconnect any defaulting customer remotely.

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