Development and Performance Evaluation of An Electrical Energy Smart Prepaid Meter.

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Abstract- Energy crisis has been one of the major issues encountered by the nation. Mostly the power distributing companies has no proper means of quantifying the amount of electricity used by the customers. Due to the imbalance of the voltage supplied in some locations, home appliances got spoiled while customers utilize the electricity supplied. These issues brought about the design of a digital prepaid meter that can be controlled using a mobile phone via Internet of Things (IOT). This novel device uses an analogue meter connected to a microcontroller which harnesses the pulse generated by the meter and uploads it to an online (cloud) server. A mobile application software was developed to control the prepaid meter system. This application software helps to monitor the current unit of electric energy credit available on the meter. It has a platform for recharging through an online card payment interface. This device enables users to switch off their prepaid meter anywhere in the world once there is internet connection.

Indexed Terms- Energy, Smart prepaid meter, Microcontroller, Mobile phone, Internet of Things (IoT).

I. INTRODUCTION

The electric energy meter is a device designed to quantify the amount of electricity consumed per time by an electrically powered device, residence, commercial premises or industrial complex [1]. There have been complaints from customers about unreliable supply from the distribution companies along their distribution networks in Nigeria. Also, customers experience high estimated bills for energy used or/and presumed used. A load applied to an electrical circuit would draw necessary amount of energy. To every household been supplied with electricity, there is a need to know the amount of electric energy consumed so as to compensate for same amount of money to be paid. The traditional way, that is, electro-mechanical way of measuring quantity of energy used had been characterized with flaws and blunders. Metering system was introduced to Nigeria in 2005, so as to eradicate the issue of customers' complaints of over-billing and other related issues [1]. In Nigeria, the domestic and commercial sector consume 80% of the electricity generated, while energy account for 27% of household expenditure [2].

The conventional metering and charging framework is not error-proof and also time and labour-intensive [3, 4]. Hence, many researchers have worked on the concept of prepaid energy meter accompanied with the Global System for Mobile communication (GSM) Automatic Power Meter Reading System (GAPMR) [5, 6, 7, 8, 9]. One of the advantages of this concept is elimination of conflicts among tenants occupying apartments in a building by making payments for units of electricity used straightforward [10, 11].

The billing process of electricity consumption has been an issue between energy customers and providers. Inaccuracies and over-billing had resulted into confrontational hot arguments and sometimes dirty fight. Many methods and processes have been put in place to overcome these challenges [8, 12, 13, 14]; leading to the proposed automated billing system. The advent of this automated billing system goes a long way to prevent going to each consumer's house to generate the bill. This is a laborious task that requires lots of man power and time [12, 15, 16]. The tendency of eliminating errors such as: human errors while noting the site that the meter reading is for, errors with the electro-mechanical meter and processing errors in paid and due bills; is guaranteed.

The availability of automated metering device and billing system have done much to control the consumption rate of energy by the customers; these have made them more careful with their consumption [17, 18, 19, 20]. The possibility of monitoring the meter reading and the consumption level of energy has not only reduced the labour cost but also increased meter reading accuracy, thereby saving a huge amount of time and money [21, 22]. The prepaid meter is an innovation with precise and error-free facilities of which payment is made for units of energy before its consumption. The process is recharge-based and could be done by an online system with GSM technology [23, 22]. The customers are satisfied with the prepaid meter facility than the traditional way of billing. Prepaid meter helps customers to pay as they need. This is reliable, flexible and cost effective [24].

The importance of electricity to development of socio-economic life of man cannot be overemphasized. Therefore, the need for effective control of available energy calls for the design of a prepaid metering system. Population increase and limited amount of energy available, necessitate a system to eliminate overuse and abuse, leaving no room for people using energy without paying their bills, as well as people stealing electric energy [25]. The developed prepaid meter has been tested on energy rates and billing processes. The system allows individual customer to buy an amount of energy he/she could afford and recharge on demand. This work goes further to consider the usage of energy with respect to time and place especially to eliminate waste. Whenever a facility is not in use or forgotten to be put off, the system can put off the electricity. This innovation is good for homes, offices and industries; as it can be activated from any place with internet facility.

II. MATERIALS AND METHODS

This work was done in hardware and software stages of implementation.

2.1 Hardware implementation

The hardware part consists of a digital energy meter, relay and one esp32 microcontroller. These hardware parts form a system that turns a digital meter into a prepaid meter with a control unit. The above listed hardware parts are discussed below.

Digital energy meter

A digital single phase energy meter was considered for this design. It has the ability to send an electrical pulse signal on every count of energy unit. There are 2 types of pulse rate of energy meter which are 1600 imp/kwh and 3200 imp/kwh. This (selected) digital meter has the following specifications: 1600 imp/kwh, 100A, 50 Hz and 220v capacity.

Relay

A power relay module is an electrical switch that is operated by an electromagnet. The magnet is activated by a separate low-power signal from a microcontroller. When activated, the electromagnet pulls, to either open or close an electrical circuit. A simple relay consists of a wire coil wrapped around a soft iron core or solenoid, an iron yoke that delivers a low reluctance path for magnetic flux, a moveable iron armature and one or more sets of contacts. This system was designed for residential use, as such, a relay of 60 A was utilized.

Esp32 board

ESP32 is a series of low-cost, low-power system on a chip microcontroller with integrated Wi-Fi and dual-mode Bluetooth. The ESP32 series employs either a Tensilica Xtensa LX6 microprocessor in dual-core and single-core variations, an Xtensa LX7 dual-core microprocessor or a single-core RISC-V microprocessor. It includes built-in antenna switches, RF balun, power amplifier, low-noise receiver amplifier, filters and power-management modules. This microcontroller was adopted for its ability to access internet on its own when programmed. It also has the ability to read and write digital signals.

Hardware interference with one another.

The energy meter measures the kw/h of electricity used by the applied load. From the above calculation, it was observed that the unit consumed by the load applied was calculated by the pulse generated by the meter. This pulse signal will be harnessed by the microcontroller for used energy unit calculation. There is a program on the microcontroller that checks periodically, the available energy unit on the smart prepaid meter (system). Once there is no more available unit on the system the microcontroller sends a signal to the relay to put off the flow of electricity to the applied load. The microcontroller stands as a moderator between the digital meter and the relay that controls the flow of electricity.

2.2 Software Implementation

The system of Internet of Things (IoT) was adopted in this design. IoT involves the use of internet to communicate between the meter and the user. The current status of the meter would be sent through internet to an online cloud server. The information would be stored in the server's database. The stored data can be accessed by the meter and the user to perform any necessary operation.

Monitoring aspect

This is where the microcontroller was programed to always check for any update from the digital meter, which the microcontroller needs for its 'newly used' energy unit calculation. Once there is no more available unit, this aspect will put off the flow of electricity and put it on when there are available energy units. The microcontroller was programed to digitally read the electricity token of the meter pulse and store it on the microcontroller EEPROM. In the event of power outage, it would reset things back to the previously used energy unit. The controller was programed to send the calculated unit to the online cloud server since it has the ability to connect to internet directly.

Recharge aspect

This is where the microcontroller was programed to access the cloud server, if there is a new recharge task. This aspect also checks every time to see if there is no more available unit and to switch to recharge mode. Once there is a new recharge it would switch back to monitoring aspect.

Control aspect

This is where the microcontroller was programed to put off the flow of electricity at the will of the user. This aspect runs every 10 seconds to see if the user has made any change to the status of the meter.

User interface aspect

This is the aspect where control and physical monitoring takes place. This is a website protocol that operates via web server. The IoT application was incorporated to allow a user to control and monitor the energy meter from anywhere in the world once there is an internet connection. The energy units used by the external or applied load would be calculated by the microcontroller and sent to the cloud server

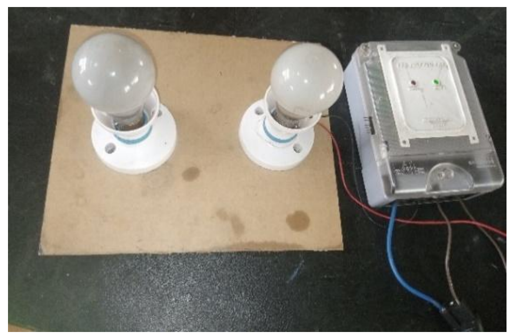

Figure 1: The smart energy meter when electricity is 'OFF'.

Figure 2: The smart energy meter when electricity is 'ON'.

and stored. All these operations are performed by the user interface aspect.

2.3 The Microcontroller (Arduino IDE).

The software application used in the development of this smart energy control system is microcontroller Xtensa LX7 dual-core. It is programed using C language with Arduino IDE software. It is a development environment that employs a user interface for adding and editing in the Arduino coding language. This program was used to program the monitoring, recharge and control aspects of the system.

2.4 Android application

A smart phone is used as an interface for controlling and monitoring the prepaid meter. An android application was developed using Android studio. The choice of Android phone is made because Android phones are incorporated with internet-based facilities. It is easy to program an app that can easily send data wirelessly to the prepaid meter. This is where the user can check for the current unit, recharge and control the meter status.

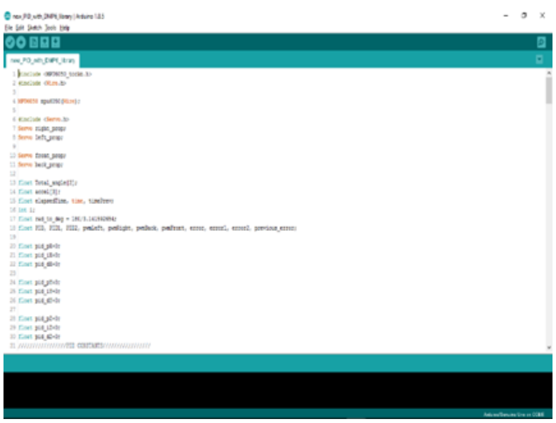

Figure 3: The microcontroller - Arduino IDE for the system.

Figure 3: The Android application for the system.

2.5 Theory and Calculation

The following are the theoretical calculations considered for the smart system design.

Before proceeding to the calculations, first is to keep in mind the pulse rate of the energy meter. There are two pulse rates of energy meters, first is 1600 imp/kwh and second is 3200 imp/kwh. 1600 imp/kwh pulse rate energy meter is considered in this calculation.

At first, the pulse for 100 watts is calculated, which means how many times the Pulse LED will blink in a minute, for the load of 100 watts.

$$Pulse = \frac{(Pulse\ rate \times watt \times time)}{1000 \times 1600}$$

So pulse for 100 watt bulb in 60 seconds, with energy meter of 1600 imp/kwh pulse rate can be calculated as below:

$$Pulse = \frac{1600 \times 100 \times 60}{1000 \times 1600}$$

$$Pulse = \frac{9600000}{1600000}$$

$$Pulse = 6\, pulse\ per\ minute$$

Therefore, we need to calculate the Power Factor of a single pulse, that is, how much electricity will be consumed in one pulse?

$$PF = \frac{Watt}{(hour \times pulse)}$$

$$PF = \frac{100}{60 \times 6}$$

$$PF = 0.2778\, watt\ in\ a\ single\ pulse$$

$$Units = \frac{PF \times Total}{1000}$$

$$Total\ pulses\ in\ an\ hour\ is\ around\ 6 \times 60 = 360$$

$$Units = \frac{0.2778 \times 360}{1000}$$

$$Units = 0.100008\, per\ hour$$

If a 100 watt bulb is lighting for a day, then it will consume

$$Units = 0.1 \times 24$$

$$Units = 2.4\, Units$$

Assuming unit rate of 50 Naira per unit at a particular region, then 2.4 Unit at 50 Naira per unit is given as: $50 \times 2.4 =$ 120 Naira.

III. WORKING PRINCIPLE

The pulse signal of a digital single phase energy meter was connected to esp32 digital pin, so that any time a load is applied, the pulse generated by the energy meter will be captured by the microcontroller. A series of commands was written on the microcontroller to check if a pulse is being sent. The program was written to sense if 'the current unit on the system is below 0.01 units', then, 'the meter should stop allowing the flow of electricity' to the external load. While the unit is below 0.01 the system was programed to wait for any recharge activity. Once it is confirmed online that a proper payment has been made, the equivalent of the money will be credited to the customer's energy credit account and immediately the meter will allow the passage of electricity to the external load. The recharge unit can be checked on the customer's platform using the Android application. In case of controlling the meter, the system is programed to run scans every 10 seconds to see if the customer has made any change to it in terms of 'ON' or 'OFF' status. The status of the meter would be displayed on the customer's online platform.

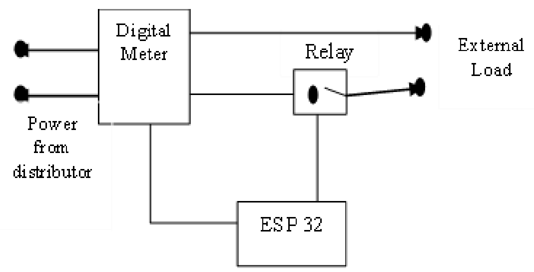

Figure 4: The control loop of the smart energy meter.

IV. RESULTS AND DISCUSSION

The results from the theoretical calculation were compared with those measured by the system itself. This was based on the amount estimated by the calculation. An energy credit of 2.4 units was loaded on the system and the period of time and load usage were observed. One hour interval results were considered. The applied load was 100 Watt for a period of 24 hrs (or one day). Table 1 shows the observations during a test-run of the smart energy meter.

Table 1: Experimental results from a test-run of the smart energy meter.

S/N	Current unit	Deducted unit	Time (hrs)
1	2.4	0.0	0
2	2.302	0.098	1
3	2.205	0.097	2
4	2.106	0.099	3
5	2.008	0.098	4
6	1.912	0.096	5
7	1.813	0.099	6
8	1.716	0.097	7
9	1.617	0.099	8
10	1.520	0.097	9
11	1.421	0.099	10
12	1.323	0.098	11
13	1.225	0.098	12
14	1.126	0.099	13

15	1.029	0.097	14
16	0.931	0.098	15
17	0.832	0.099	16
18	0.7324	0.098	17
19	0.636	0.098	18
20	0.537	0.099	19
21	0.440	0.097	20
22	0.341	0.099	21
23	0.244	0.097	22
24	0.145	0.099	23

Adding up the total deducted units, the smart prepaid system uses 2.255 units for lighting up a 100 Watt bulb over 24 hrs. It was observed that the difference between the theoretical deducted units and the system deducted units was a variation of 0.004 units. The above result shows that the system used 2.255 units for an applied load of 100 Watt per day. Mostly the electricity distributors charge the way they like, but with a system like this the exact units a customer (or, consumer) uses will be accounted for.

CONCLUSION

The amount of energy units purchased by a customer needs to be effectively monitored, utilized and controlled appropriately. The place of a smart prepaid meter for control and monitoring is to provide a means of cutting down energy wastage. At any time, energy may be wasted by negligence. At other times, one may not need it and so can save it. Also, the place of checking for a bye-pass of supply to the meter is considered as feedback to the monitoring platform. The commercialization of this prepaid meter will go a long way to ensure value for money in energy utilization.

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