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Design and Implementation of IoT Based Energy Efficient Smart Metering System for Domestic Applications

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KEYWORDS

ESP8266, Measurement, Monitoring, SmartMeter

ABSTRACT

In an era of smart and connected devices, it has become easier for measurement and monitoring to be doneremotely. Of recent, most homes have been adopting the use of pre-paidmeters for their energy consumption measurement and billing. However, this does not provide them with the ease of making payments automatically or remotely viewing and visualizing their energy usage. The smart meter makes use of a current sensor to accurately measure the amount of current being draws by the load connected to it at any given time. This analogue signal is then sampled and quantized in a bid to convert it to digital signals that can be processed by the microcontroller (ESP 8266 – Node MCU). The processed value is sent to a server and stored in a database. This is then parsed by the mobile application (Smartvac) and displayed to the consumer through a mobile application. The smart meter helps measure the instant aneous current, power, total power and total energy consumed. The meter also keeps check of power consumption and automatically put offs the load when the power reading is above a set value (this would put on the buzzer, and turn off the appliances connected to the meter. This system helps to prevent energy wastage and give consumers a sense of their energy consumption. It also helps ensure that consumers can easily pay for their electricity usage without the hassles of going to an office to get can activation code.

1. INTRODUCTION

1.1 BACKGROUNDOFSTUDY

In recent years, domestic and industrial users have shifted from traditional meters to smart meters. Electromechanical meters were a dominant part of electricity measurement before 1970 [1]. However, it had been identified that the requirement of a meter which could communicate and measure the electrical energy along with other electrical parameters was essential. Therefore, solid state electronic meters were introduced to measure the overall electrical parameters. Between 1970 and 2000, automatic meter reading was added to electronic meters and it was a great achievement since it could send the data in near time. However, it could only provide one-way communication. This limitation was overcome by the introduction of smart meters which can provide two-way communication. Smart meters can measure all the electrical parameters like electronic meters and communicate data in a meaningful way. The consumer is updated with details such as energy consumption, the number of electricity units remaining and other required information.

Before the invention of smart meters, we had the electromechanical meters. Electromechanical energy meter is themost traditional and widely used energy meter forover acentury. It can measure only the active energy which is typically display edonamechanical counter.

It is basically designed with four major systems which are driving system, moving system, braking system, and registering system. The driving system consists of two electromagnets while the moving system consists of an aluminium disc. The permanent magnet acts as the braking system while the gear train and counter act as the registering system.

The electromagnetic force is produced by the arrangement of voltage and current coils. The voltage coil is connected across the supply while the current coil is connected in series with the load. The voltage coil produces a magnetic flux in proportion to the voltage and the current coil produce samagnetic flux proportional to the current. The aluminium discis mountedon a rigid axis. A mechanical force is exerted on the disc by the Eddy currents produced.

There gister mechanism in tegrates the speed of the disk over the time by counting the number of revolutions. Current coil or the series coil produces alternating flux which is proportional andin phase with the load current.Voltagecoilortheshuntcoilcarriesacurrentproport ional to the supply voltage. The flux produced by the voltage coil is not in phase with the supply voltage [2].

Above is the basic principle of an Electromechanical Meter.

Figure1:ElectromechanicalEnergyMeter

The use of microcontrollers in electricity metering is gaining ground when it comes to electricity distribution. Here, the Node MCU is used to collect the current sensor data and send this data over the internet. Here, we utilize the concept of Advanced Metering Infrastructure (AMI). Advanced metering infrastructure (AMI) refers to systems that measure, collect, and analyze energy usage, and communicate with metering devices such as electricity meters, gas meters, heat meters, and water meters, either on request orona. schedule. These systems include hardware, software, communications, consumer energy displays and controllers, customer as sociated systems, meter data managements of tware, and supplier business systems.

1.2 PROBLEMSTATEMENT:

Estimated billing is commonplace in most African countries including Nigeria. Despite Government efforts, over 4.6 million Nigerians are on the estimated billing system. Nigeria has one of the highest aggregate technical, commercial and collection lossesat 43.65%, which has been attributed to low investments in distribution networks exacerbated by the slow progress of metering of customers which has posed a protracted liquidity challenge to the industry. There is a need to reduce these losses. [3]

The National Pre-Paid Metering Program initiated by the Federal Government, prior to the privatization, sought to address this gap but failed, due to corruption, lack of coordination, in efficiency, etc. The failure to completemetering of customers priorto the privatization was worsened by the absence of data onthetotal numberof registered customers, now estimated

At 7.47 million (likely still an underestimation of the number of customers, with the associated outcome of an even larger metering gap).

Consequently, the huge metering gap in Nigeria presents a Herculean challenge for the DisCos when it comes to measuring the consumption of their unmetered customers. In recognition of the impossibility of comprehensive metering within the near to mid-term period, the regulator, the Nigerian Electricity Regulatory Commission enacted a regulation on Estimated Billing Methodology to guide the DisCos in their billing. Nonetheless, application of the methodology remain savery contentious process, as we have seen cases of overbilling (otherwise known as crazy billing) and cases of underbilling which, we, the consumers never talk about.Understandably, estimated billingi savexing issue toun-metered customers, due to the perception of over billing situations[4].

1.3 AIM/OBJECTIVES

This project aims to solve the issue of estimated billing and wastage in power consumption. This it does by utilizing the concept of Internet of Things.

The specific objectives of this project include:

To design and implementan automated top-up electricity smart meter. To design as martmeter that turn off the load onceits ensesan over – load in the home (Once load exceeds consumers set limit). To design an dimplement an accompany in gmobile application that allows the user to monitor her energy consumption, check for alarms and set reminders. To design asystemth at helps manage energy billing and is cost effective.

This system can send out real time power consumption reading over the internet to a server. These reading is then consumed by an Application Programming Interface (API). Theextracted values are being displayed to the customers in the form of interactive dashboards.

Here, the NodeMCU microcontroller is utilized to send data over the internet and collect current readingsfromacurrenttransformer;todothiswewouldbe makinguseofanACS712currentsensor module.

This Data Acquisition System (DAQ) consists of the Smart Meter Kit (Hardware) and an Android Mobile application which we called Smartvac. The aim of the Smart Meter Kit is to measure theamountof current thata loadwhich isbeingconnected toitconsumes.The mobile application (Smartvac) helps the consumer monitor his/her energy consumption, pay for her electricity bills , notifies the customer when his or her power consumption exceeds a set limit and reminds the user to put off lights and appliances at home.

1.4 SIGNIFICANCEOFTHESTUDY:

There are manyproblems in metering and billing processes likethe goingof meter reader to each customer meter to manually take the meter reading, the probability of the non- existence of the customers at their houses during that time, the lack of integrity and credibility of some of the meter readers etc.

These myriadof problems leads to th eneed for asolution; a solution that removes the hassles of energymeasurement and management.This iswhere anelectricitysmart meter comesin. A smart meter is an integrated system equipped with a communication network, linking sensors, do mestic appliances, and other electronic and electrical devices, that can beremotely

monitored [8], accessed or controlledand which provides services that respond to the needs of the users. The existence of a communication network is central to the concept of smart metering systems as it is a key feature which distinguishes smart meters from other meters merely equipped with standalone features.

1.5 SCOPEOFWORK

This project is designed to measure changes in electricity consumption readings over time, thishelpswiththecalculationofenergyusage(KWh).However,voltageiskeptataconstant 220v. This is because the

NodeMCU has only one analog pin and as such cannot easily be connected to both a current and voltage sensor.

This project also allows users to monitor their energy consumption via the accompanying mobile application. Users can set reminders which include but is not limited to "reminders notifying users to switch off the light before going to bed". Users are also sent E-mail messages which notifies them when their average power consumption exceeds the limit that hasbeensetbytheminthemobileapplicationtohelpensurepowerconservationand

budgeting of electricity billing. The load connected to the smart meter is also put off once excess power consumption is sensed.This is however limited as users do not have the flexibility to remotely switch on or put off their appliances remotely.

II. LITERATUREREVIEW

2.1 BACKGROUNDOVERVIEW

On the development of this project, a few reviews were carried out. These reviews were carriedouttogiveabetterinsightandunderstandingregardingthedevelopmentandworking of the system. Different sources like journals, books, internet sources and previous projects provide concrete references and understanding for the study. This project is focusedon the designandimplementationofanenergysmartmeter.There viewscarriedoutpinpointssmart metering, Internet of Things, micro controllers as well as sampling techniques.

2.2 AUTOMATICMETERREADING

Currently, numerous systems of Automatic Meter Reading (AMR) are implemented using Bluetooth, General Packet Radio Access (GPRS) and Global System for Mobile communication. Utilizing GSM technology remote sharing of information of energy consumption to consumers is possible. But there can be chances of missing SMS thus result in decreasing the reliabilityand efficiencyof the system. GPRS is difficult to implement for long distance two-way communication between utility and consumers.

Here, we begin by looking at a couple of projects and papers on electricity smart meters. Milanpreet Kauretalin their paper titled "Implementation of Smart Metering based on Internet of Things "describes the monitoring of energy consumption with Arduino Unoboard and Ethernet using IoT (Internet of Things) concept. This proposed designe liminates human inclusion in the conservation of electricity. The consumer can receive the information about consumption of energy by using IP address on their devices. The web client code is uploaded for checking the client information such as location, content, connection, and disconnection to the web server. This proposed system gives reliable and accurate information regarding electrical energy management system (EMS) through Internet of things (IoT) [6]. Here, it is observed that an Arduino Uno microcontroller is used.

Also, AMR is enabled by using Zig Beeand GSM module in which Zig Beeisinter faced with energy meter to collect data and GSM is used for transmitting message/SMS to the utility. Here,theuserdoesnothavethelibertytoeasilyviewhistoricalpowerconsumptiondata,and information that could have been sent across can be lost due to network failure.

In another paper titled "An IOT based smart metering development for energy management system" by S. G. Priyadharshini et al where they examined the design of an IOT based platform for remote monitoring of the metering infrastructure in the real time. The data visualization is carried out in a webpage and the data packet loss is investigated in there mote monitoring of the parameters [9]. Here the authors proposed system that allows alertness to beset for consumption levels above and below "user set trigger levels" and to forecast future energy use. To measure bidirectional flow of energy to enable customers

participate in energy management and to perform occupancy detection algorithm to automatically on/off the appliances when not in use. To categorize the loads into levels and perform load shedding in peak hours and hence loads to effective energy management and to allow the system operator to control the appliances

remotely by accessing through IOT in case of peak load shaving and power quality issues. This work did not how evergo beyond the proposal phase and failed to examinein-depthhow blocks could be put together to build a truly smart electricity meter.

2.3 CURRENTMEASUREMENT:

Measurement of analog signals (in this case current) is essential in a system such as this. Several papers have made use of different approach esinthe measurement of current signals from AC and/or DC sources.

The currents ensing technology used plays a vitalrole inthe accuracy and sensitivity of the current measurement.Here, the current sensor made use of has the ability to measure both AC and DC current and measure current of up to 30Amps.

2.4 NODEMCU:

The Node MCU microcontroller plays a paramount role when it comes to communication betweendevicesovertheinternet.InapaperbyD.V.N.Ananthetaltitled"SmartElectricity Billing Using Node-MCU" [10], They designed a project where the user receives his or her billing periodically and is automatically cutoff in a case where the credit that is available is finished. This project however improves on this by not only alerting consumers when their available number of unitis about to finish but also helping them to automatically top -uptheir credit unit.

In another paper by Win Adiyansyah Indraetaltitled "GSM-Based Smart Energy Meter with Arduino Uno" [11]. Users were able to monitor their current power consumption with the help of SMS alerts. This was made possible by the use if an Arduino Microcontroller and a GSM module. However, this is not efficient and makes it difficult for users to stillbeable to monitor their power consumption should they leave the country or visit an area where their local service operator does not operate.

Here, the smart meter being designed comes along with a mobile application that allows the user to monitor her power consumption real time from anywhere in the world. This is also cost effective and updates in real time when compared against an SMS based system.

III. MATERIALS/METHODOLOGY

3.1 MATERIALS

Listofmaterialsthatwereused

- LCDDisplay
- Veroboard
- I2C
- ESP8266(NodeMCU)
- Buzzer
- LED
- ConnectingWires
- Battery(PowerBank)
- Switches
- CurrentSensor
- Lampholder
- Bulb
- BoxforPackaging
- Smartphone(MobileApplication)
- CurrentSensor

1) SoftwarePackage:

- EasyEDA
- ArduinoIDE
- Flutter
- Golang

3.2 BLOCKDIAGRAM:

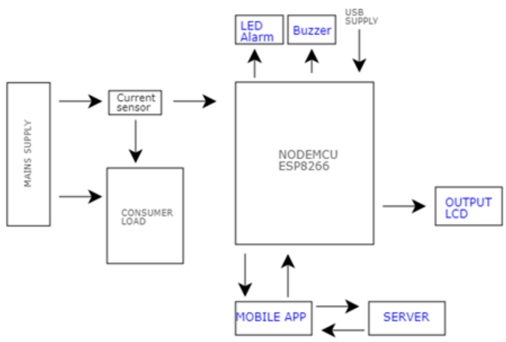

Figure 3.2:BlockDiagramoftheSmartMeterSystem

IV. RESULTSANDDISCUSSION

4.1 RESULTS

The results obtained from testing our project during the circuit design and analysis, the coupling of the project and the testing of the project which spanned the beginning of the project till the end of the project is explained below.

These testing's includes hardware testing such ascurrent sensor testing, Esp8266 testing, load testing, LCD testing and buzzerandled testing (forindication and alarm) and software testing such as

4.2 CURRENTSENSORTESTING

After connecting the current sensor to the Node MCU, it was essential to ensure that the values being displayed on the console of the Arduino is equivalent to the current valueone would get should she use a multimeter.

To perform this test and calibration, we made use of a known power ratedbulb (60watts) and performed a basic analysis to help us finetune the calibration reading of our current sensor.

Once this was done, we were assured that our readings got ten from the current sensor were accurate and less prone to noise.

Figure12:CurrentSensorTesting

4.3 ESP8266TESTING

This testing was performed to ensure that the Esp8266 successfully connects to the router (in this case my mobile hotspot) and sends out the required parameters to the server. To ensure that a successful connection is established, we are expecting a code 200 HTTP response. This code shows that there was indeed a successful connection. Below is alistof HTTP response codes and their meaning.

200OK-Standard response for successful HTTP requests. The actual response will depend on the request method used. In a GET request, the response will contain an entity corresponding to the requested resource. In a POST request, the response will contain an entity describing or containing the result of the action.

201Created The request has been fulfilled, resulting in the creationo fanew resource.[9]

202Accepted The request has been accepted for processing, but the processing has not been completed. The request might or might not be eventuallyacted upon, and maybe disallowed when processing occurs.

203 Non – Authoritative Information (since HTTP/1.1): Theserver is atrans forming proxy (e.g.aWeb accelerator) that received a 200OK from its origin, but is returning a modified version of the origin's response.

204 No Content: The server successfully processed the request and is not returning any content.

205 Reset Content: The server successfully processed the request, asks that the requester reset its document view, and is not returning any content.

206 Partial Content (RFC 7233): The server is delivering only part of the resource (byte serving) due to arange header sent by the client. Therange header isused by HTTP clients to enabler esuming of interrupted downloads or split a download into multiple simultaneous streams.

207 Multi – Status (WebDAV; RFC4918): The message body that follows is by defaultan XML message and can contain a number of separate response codes, depending on how many sub-requests were made.

208 Already Reported (WebDAV; RFC 5842): The members of a DAV binding have already been enumerated in apreceding part of the (multistatus) responseand are not being included again.

226 IM Used (RFC 3229): The server has fulfilled a request for the resource, and the responseisare presentation of the result of one ormoreinstance – manipulations applied to the current instance.

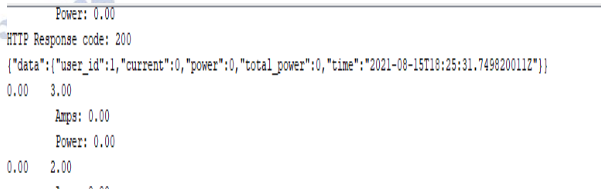

Figure13:HTTPResponsewhenaConnectionwasSuccessful.

4.4 LOADTESTING:

This testing is done to ensurethat the current sensoris connect edproperly to the loadand there is an absence of short circuit/ current leakage.

To perform this test, the smart meter is loaded and the lcd is monitored to ensurethat the reading being displayed on the lcd reacts to the change in load. Below is apicture that shows the load test being carried out.

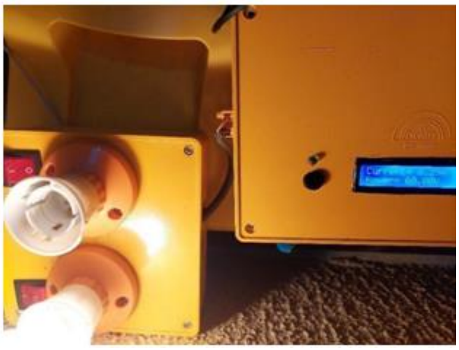

Figure4:LoadTesting

4.5 APPTESTING

The application was thoroughlytested to ensure that it met all the software requirements and specifications while following the design closely. Firstly, all endpoints from the Application Programming Interface was tested using a tool called Postman to ensurethey were working and also record there sponsere turned by the server. Secondly, this tool also served as away to generate documentation for who ever is using the application to follow.

Here are the Authentication pages. These pages ensure that the user sare correctly signed up and also supply the correct password before giving access to the dashboard as it contains information peculiar to each user

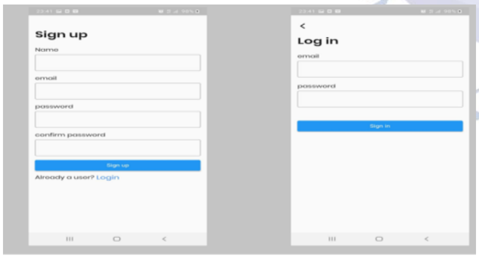

Figure15:APPAuthentication Testing There are energy consumption pages that total the user's energy users on an hourly, daily or weekly basis and display it in a digestible manner.

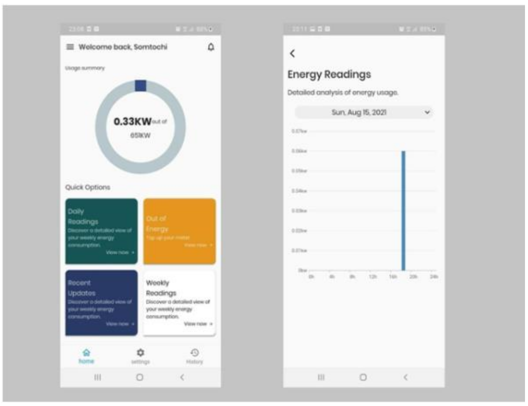

Figure16:Dashboard andVisualizationTesting

Here are the pages for making payments. These pages tell the user how he is charged for the units, allow him to input his card details and then makes a payment to the card company. All the pages we retested both manually and automatically by code

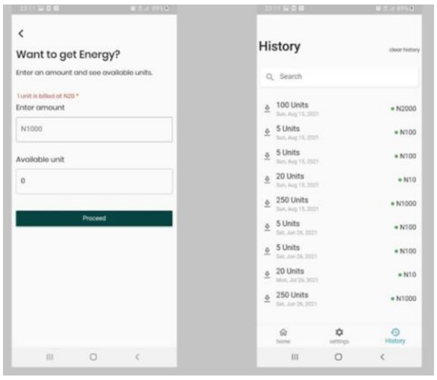

Figure17:ElectricityPaymentTesting

V. CONCLUSION

The main objectives of this project is to prevent power wastage and optimize power consumption. This project also provides users with the ease of making payments. We assembled a smart meter which uses the aid of a current sensor that is capable of measuring up to 30A and DC /AC current to measure changes in current signal. With the aid of an ESP8266 Node MCU the analog current signal was able to be converted to a digital signal and sent over the internet via the WIFI module.

This data is sent to a Heroku server via a GET request and processed by our mobile application "Smartvac". The mobile application allows users to view their daily power consumption, notifies them when they are running short of units and helps users make payment. With this, we were able to assemble a smart meter kit that utilizes the power of Internet of Things in power measurement and monitoring.

VI. FUTURE TRENDS

This design of this system has the potential to change the face of energy consumption especially in developing countries. This design can be made smarter by incorporating the power of machine learning. Incorporating machine learning intothis product wouldenable utility firms easily shed load asit would beeasier to predict energy consumption. Also, anomaly detection algorithms can also be implemented to detect power theftin a power distribution system when inconsistent readings are detected.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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