Development of an Internet Based Prepaid Energy Meter

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Abstract: Energy fuels the growth and development of any country, and as such effective monitoring, measurement, billing and access control is imperative. This paper presents a device that uses the evolving Internet of Things (IoT) technology in the design and implementation of an Internet based prepaid energy meter often referred to as smart meters. The energy measurement and billing system is automated. The system employs the ATMega328p and ESP8266 to operate a dual core microprocessor unit with one core dedicated to energy sensing and measurements, while the other handles the network connectivity, storage, computations and overall system performance. This work uses the HTML5 technology to develop a highly interactive mobile and web frontend Graphic User Interface (GUI) application that allows for consumers to have access to monitor and control their consumption pattern while the utility companies can monitor and control customers and their billing systems.

Keywords: Internet of Things, Energy Meters, HTML5, ESP8266, Microcontroller

I. INTRODUCTION

Energy meters are used to measure the amount of energy consumed by domestic, commercial and sometimes industrial users [1]. With the growing population of energy consumers, smart meters are timely innovation which eases the energy management system. Utility companies can monitor consumption, automatically disconnect defaulting consumers, update tariff, and have a secured database and consumption pattern of a mapped location. The consumers on the other end can also monitor their energy consumption in real-time, recharge their accounts, monitor tariff rates and hence improves the demand response. Unfortunately, the energy sector is bedevilled by several challenges resulting from the deployment of electricity smart meters. They are energy theft, cyber-attacks, mismanagement and erroneous billing etc. [2] and thus, various research aspects to curb the challenges have been ongoing. This paper proffers a solution of reducing human involvement in energy management for both utility companies as well as consumers. All the monitoring and control features are provided access via a dedicated web portal, anywhere, anytime provided there is Internet connection.

II. RELATED WORKS

Smart meters data are collected, stored and analysed for proper planning and billing of consumers [3]. Various designs have been implemented as presented below from some selected works. In [4], Omijeh and Ighalo, introduced a tamper detect feature for a GSM solution for prepaid energy meter, however this work didn't provide an interactive interface for real-monitoring, access control as well as a robust database. A modelled GSM-based Energy Recharge System for prepaid metering was presented in [5] with focus on proffering solution to human error, processing error as well as electro-mechanical errors while [6] aims at proposing a system that will reduce the loss of power and revenue due to power thefts and other illegal activities. It uses an AT89S52 microcontroller which acts as the primary controller. The energy meter reading is compared with the smart card information by the microcontroller for effective monitoring and control of switching depending on the credit status. Bluetooth technology was employed in [7] where the meters were made to communicate with a master PC but all communications were limited to within the 100-meter range for Bluetooth connections. In [8], a digital signal processor based meter to measure electricity consumption of users in a residential area was presented exploring Power Line Communication (PLC) technique. The limitation of this

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system is that it cannot detect tampering by consumers. IoT technology was explored in [9], where each user was provided a unique IP (Internet Protocol) address to enable access to the Consumer Premises Equipment (CPE) which in this case is a smart meter through a web interface. However, the "inefficient handling of the IP address" as well as the latency that may occur in communication between the CPE and the web interfaces made it inefficient. A simplified design protocol and robust Automated Meter Reading System (ARMS) was developed to address the problems of complexity, multiple incompatible standards and expensive design as presented in [10].

In this work, a robust and scalable protocol in achieving a seamless communication between the unique systems and applications is proposed. A web application messaging protocol (WAMP) is used to implement persistent and full-duplex web socket connect, using JSON (JavaScript Object Notation) data serialization for data exchange between the embedded firmware and server. It provides an efficient and cost effective solution by eliminating the need for dedicated IP addresses for the individual CPE.

III. SYSTEM ARCHITECTURE

The main architecture of an Internet Based Prepaid Energy Meter (IBPEM) can be classified into two main subsystems, the hardware and software control interface as depicted in Figure 1.

A. HARDWARE SUBSYSTEM

The hardware subsystem forms the CPE which provides the necessary interface for the power sensing circuit for connecting the mains to the client's home. This subsystem is coordinated by ESP8266 and Atmega328P microcontrollers both running on C/C++ written firmware. This subsystem contains mainly the power measuring unit (PMU), processing unit (PU) and the interfacing unit (IU). The PMU consists of current sensing unit, voltage sensing unit and the computing unit [11]. This unit computes the energy used over a period and sends it to the PU using serial communication link. The PU is made up of the low power 32-bit CPU based ESP8266 WIFI module which is a complete system-on-chip (SoC) with an integrated 10-bit ADC, Integrated PLL, power management units, Integrated TR switch, balun, LNA, power amplifier and matching network and an Integrated TCP/IP protocol stack [12]. While the IU is made up of a screen, a relay and a power control switch. The screen is an Organic Light Emitting Diode (OLED). The OLED is a flat light emitting technology, made by placing a series of organic thin films between two conductors. It consumes low power, has higher image quality, simpler design and a better durability [13]. The screen displays the current tariff and the prepaid balance for a local observer.

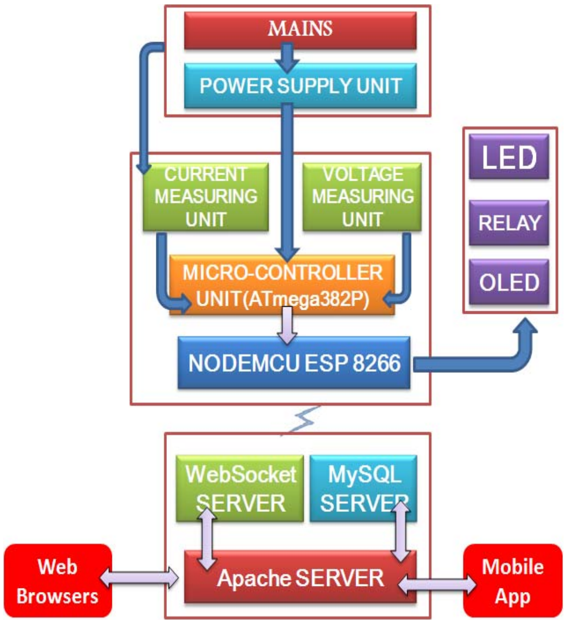

Fig. 1 Block diagram of an Internet Based Prepaid Energy Meter (IBPEM)

B. SOFTWARE CONTROL EQUIPMENT

This subsystem is made up of three key components; the web server, client application and the embedded software.

The web server is the unit responsible for managing, all activities on the system. It is developed using mainly PHP programming language. The client application provides a means for the user to access the system from a remote location over the Internet. It provides a Graphical User Interface (GUI) for client's operation to facilitate excellent user friendly experience. The web application is open-source using the HTML5 technology – HTML, PHP, JavaScript, CSS and MySQL. The embedded software is written in embedded C/C++ language. This is to program the Atmega328P and ESP8266 microcontrollers to make them function in a regulated and controllable manner. The system firmware flowchart is as presented in Fig 2.

C. COMMUNICATION INTERFACE

Communication between the two controllers is done using the USART communication protocol while communication between the CPE and the server is implemented using Websocket communication protocol. Once a WebSocket connection is established, the connection stays open until the client or server decides to close this connection. With this open connection, the client or server can send a message at any given time [14].

D. WEB SERVICE SECURITY

Traditional internet security techniques were employed in the applications as well as the communications between them. These includes authentication built into web application to ensure that no unauthorized user has access to the system. Also, the Websocket server requires an authentication before communication can proceed between the server and the CPE. The authentication parameters include a One Time Password (OTP) which is generated during the connection.

E. DESIGN ANALYSIS

The whole device is designed in a modular structure. It is made up of different modules or subsystems in order to allow for good maintainability, and to ensure that the system is scalable and interchangeable. The device uses a dual controller unit. The first controller is an Arduino AT328p micro-controller unit which is used for voltage and current sensing as well as energy computations while the second controller is an esp8266 NodeMCU. It serves as the main controller unit of the system. It handles internet connectivity, communication peripherals, connection to load, control process, display system and general system utility and functionalities. The two MCU's communicate through a Serial Peripheral Interface (SPI). The esp8266 is the brain of the system and it features the following a 32-bit RISC CPU: Tensilica Xtensa L106 running at 80 MHz, 64 KiB of instruction RAM, 96 KiB of data RAM External QSPI flash: 512 KiB to 4 MiB* (up to 16 MiB is supported), Wi-Fi 802.11b/g/n, low power MCU, integrated 10 bit ADC, integrated TCP/IP protocol stack, supports antenna diversity, Wi-Fi 2.4 GHz, and supports WPA/WPA2, very low power consumption, has a data transmission rate of about 110-460800bps[12]. However it has only one analog pin and as such will not be sufficient by itself to read voltage and current which are both analog parameters. The Arduino UNO provides for six (6) analog pins which made it a suitable choice for voltage and current sensing. The voltage sensing circuit is made up of a step down transformer, which steps down the voltage and steps up the current following the transformer formula. The current transformer on the other hand is used to step down the line current which is then passed through a burden resistor to convert it to a voltage level measurable by the Arduino analog pins. To prevent negative outputs of these two sensing units, their outputs are biased by a D.C voltage and it is ensured that the outputs will always be between 0 V and 5 V for all measurements within the device specification. The project consists of a rectification circuit which provides 5 V and up to 2000 mA to drive the relay, this is used instead of the 5 V from the Arduino board because the load will draw current up to 1A, which the board cannot support. The display unit is made up of Organic Light Emitting Diode (OLED). It is a low power display as it does not have backlight. It supports Inter Integrated Circuit (I^2C) protocol which makes it compatible with ESP8266. With just 4 wire connection required, its Pin requirement is fewer than most other displays. The esp8266 NodeMCU provides activating signal to the relay, controls display and connectivity as stated earlier.

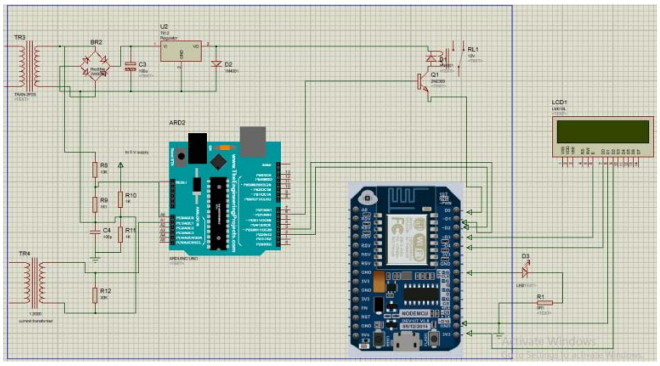

Fig. 2 Complete Circuit Diagram

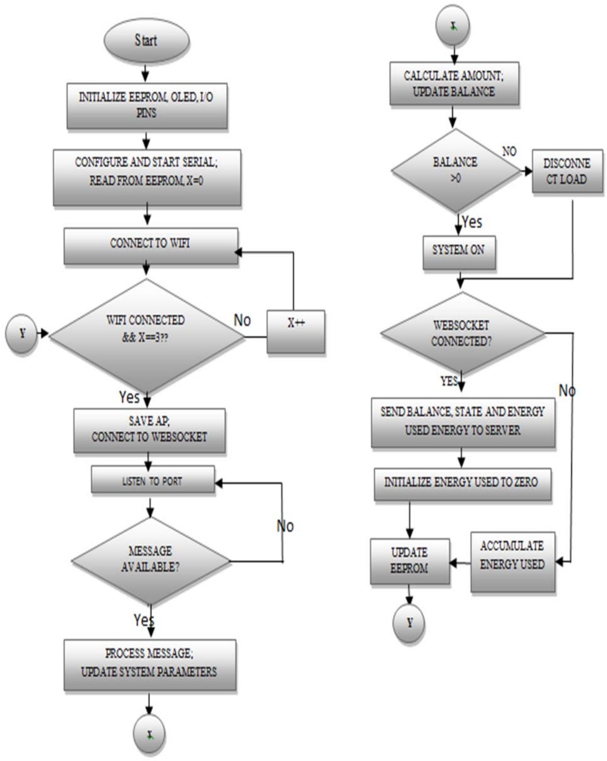

Fig. 3 The main Embedded System Firmware Flowchart

IV. IMPLEMENTATION AND RESULTS

The hardware components were mainly modular in nature and hence, the system was implemented unit by unit. The software components were implemented with some frameworks such as

Laravel PHP framework, Ratchet PHP framework and twitter bootstrap CSS framework. For the embedded system, open source repository such as Websocket, EEPROM and many more libraries were used to ensure efficient and more compact codes. The applications and services used are up and running and can be accessed via [http://meter.djade.net]. The Internet Based Prepaid Energy Meter (IBEPM) was implemented with very reliable individual components to ensure considerable level of redundancy. Use of Websocket and JSON based communication will ensure very small data size and a very compact message line with very little latency needed for real time communication. Also, the small data size helps in saving cost, bandwidth and memory space both on the cloud and locally on the device. The constructed IBEPM is shown in Fig 3. The graph in Fig 4 shows the power consumed by a 2 watt LED lamp. The device was put on and off intermittently which accounts for the spikes on the plot. The result shows that the system is accurate and very responsive to load change.

Fig. 4 Constructed Internet Based Prepaid Energy Meter

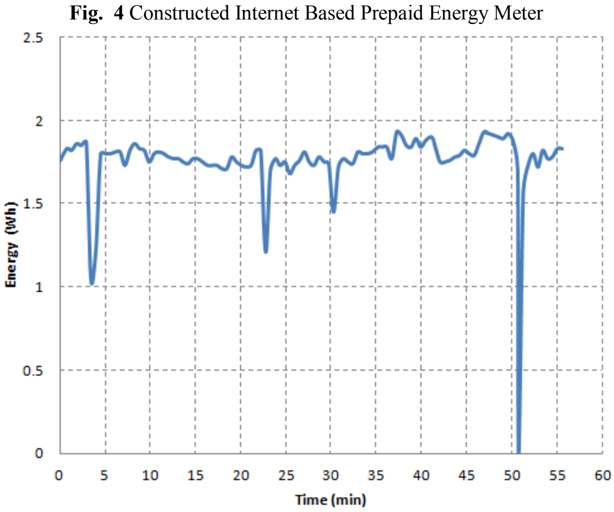

Fig. 5 Graph of the Energy Reading from the Meter

V. CONCLUSION

The IBEPM is an improvement over the conventional prepaid meters; it uses the IoT technology in proffering solutions to the energy monitoring and management. Unlike the conventional prepaid meters, this solution offers a highly interactive GUI interface for both consumers and utility companies. It also automates the energy system, as it relates to achieving a smart grid system. The system has been designed to resort to a local server and database, upon resumption of internet connection, all information are synchronized with the web server. However, it is important to point out that for the purpose of this work, the billing is handled locally by the web server and has not been interfaced with any online payment platform agencies. Also further improvements could be made on the project to include load control on the consumer platform for a high Demand Side Management (DSM).

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