Development of a Smart, Low-cost and IoT-enabled System for Energy Management

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***Abstract*—With the advent of the Internet comes not only the opportunity to send and receive data from our peers or fellow humans, but also the opportunity to send and receive data from our devices. This concept is known as the concept of Internet of things (IoT), and it proposes immense opportunities, part of which can be applied to solving the growing issue of power/energy management. The consumption of electricity has skyrocketed in recent years, and methods which are costly and of harm to the environment are also mostly used in electricity generation. Therefore, energy monitoring, management and efficiency is of utmost importance to improve the power sector of any economy. A solution to the growing issue of energy monitoring and management is a cheap and smart electricity socket that could show the users the amount of energy they spend at every point in time for each of their devices (in monetary terms). The socket allows users to set limits to their power usage by switching their devices on and off remotely. A database of home appliances is also set up to enable awareness on the various energy profiles for different devices and appliances and proffer energy efficient alternatives to such devices based on usage and region, using intelligent web systems. The Smart Socket makes use of the IoT concept of Smart Metering to measure key energy consumption data and will send instantaneous data to a web server to be saved to a database and accessed by permitted users. This project primarily addresses the need for access to data and proper information in making informed decisions concerning energy management and usage.**

Keywords—Energy management, Internet of Things, Intelligent Systems, Smart Homes, Home Automation, Smart Sockets.

I. INTRODUCTION

The pursuit of energy efficiency as part of everyday life is a necessary objective, both from an economic and ecological point of view. Our standard of living is based on the consumption of electricity, a limited and costly to generate resource whose consumption has skyrocketed in recent decades. Energy management is one of the major issues affecting the power sector of any economy. Many individuals are ignorant about how much power their devices consume and hence use these devices indiscriminately. A system that could show the users the amount of energy they expend at every point in time (in monetary terms), and also allow them set limits to their power use by switching their devices on and off remotely would be a good solution to the energy management issue. This solution is the use of Smart Metering technology in Smart Sockets, which would monitor important power and energy readings, store the gathered information and send such information via a network to an Internet server to be accessed by Smartphones, Tablets and Personal Computers. The sockets are also capable of switching the devices connected to them on and off remotely. A database of home appliances and devices is also developed to be used by every stakeholder in the power industry and the general public to enable awareness on the various energy profiles for different devices and also proffer energy efficient alternatives to such devices.

A. Significance/Motivation

The problem of energy management is especially a huge one in developing economies like Nigeria, as the generation and distribution companies are not able to attend fully to the needs of the nation in terms of power generation and distribution. The aim of the proposed metering and database solution would be to ensure that every citizen is aware of their power usage and are empowered to take steps to reduce their energy consumption, hence also reducing the amount of money they spend buying electricity. The sockets can also be used for home automation by enabling it to switch connected devices on and off remotely, and also enabling it to switch off automatically when above a particular energy spend. This will further drive energy conservation.

B. Aim/Objectives

The aim of this project is to apply the concept of Internet of Things to solve an age- old problem of energy management using a developed IoT (Internet of Things) Metering and Automation device and a Cloud based Open Access Home Appliances Database.

The developed smart metering device will accomplish the following major objectives:

- To design and develop a cheap and functional alternative to existing expensive smart meters, which are about $150 (~N45,000 as at this writing).
- The developed metering device will have a simple connection, which can be used to measure total energy use at connection points.

- Accurate energy consumption data will be measured as the sockets will measure real power and cost of power.
- The device will store energy consumption data to a web database to be used by individuals or organizations.
- A Simple Graphical User Interface (GUI) will be developed by which data from the Smart Meter can be accessed by personal computers, tablets and smartphones over an Internet connection.
- The socket will be able to be switched ON/OFF remotely.

The developed database will achieve the following objectives:

- It will be a web database of domestic appliances and their ratings and it will be accessible by all stakeholders in the power industry.
- It will have an Application Programming Interface (API) on which other rich applications can be built.
- It will have a minimalistic and easily accessible GUI, so as to enable ease of use to all key stakeholders.
- It will be open access and will be able to be contributed to by any stakeholder in the power system.

C. *Energy Management*

Energy management involves the planning and operation of energy production and consumption units. Energy management is necessary for resource conservation, cost savings and climate protection. Energy efficiency is an energy reduction technique that encourages energy customers to use less energy and still enjoy the same services. For example, using LED (Light Emitting Diode) lights in place of the more common incandescent bulbs to provide the same amount of illumination is an example of practicing Energy Efficiency. Energy efficiency results in reduced energy cost, and also reduces greenhouse gas emissions. Energy efficiency is said to be one of the pillars of sustainable energy, along with renewable energy [2]. According to the International Energy Agency, improved energy efficiency in various sectors could reduce the world's energy needs in 2050 by a third, and help control global emissions of greenhouse gases [1]. In some countries energy efficiency is also seen to have a national security benefit because it can be used to reduce the level of energy imports from foreign countries and may slow down the rate at which domestic energy resources are depleted. Energy conservation is also a management scheme that involves reducing or going without an energy service to reduce consumption. An example of energy conservation is switching off of light bulbs and using day lighting instead during the day in homes and companies. The proposed energy management solution utilizes both techniques of energy reduction discussed above in its operations to ensure quality energy control and cost savings.

D. *Energy Usage in Nigeria*

Even though, Nigeria is an energy-rich country, we have acted more as an energy store rather than an energy utilizing country over the years, up until now. The only major sources of energy utilized for generation are coal, crude oil, natural gas and hydro [3]. This, among other reasons has caused power supply to the citizen to be epileptic and inconsistent. Over the years, energy consumption in Nigeria has been on the rise. Figure 1 shows the Electricity consumption (in kilowatt-hours per capita) in Nigeria from the 1970s up till 2011 as obtained from data from the World Bank.

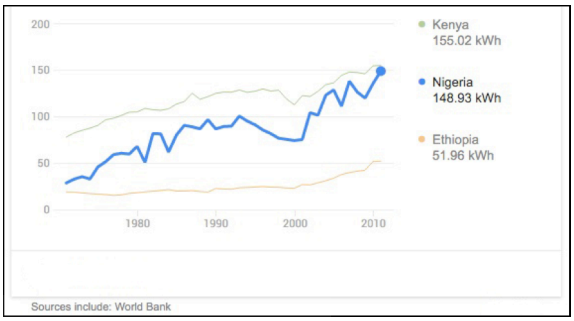

Fig. 1. Energy consumption per capita in Nigeria

Our current consumption, while seeming normal when compared to some other developing African nations, is far less than our counterparts in developed economies, as seen in Figure 2.

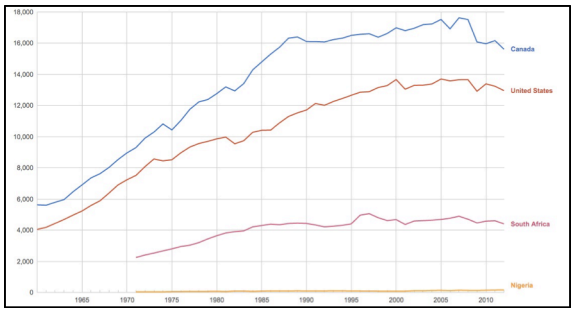

Fig 2. Energy consumption in Nigeria per capita compared to developed economies [Source: World Bank]

A report showed that the global average electricity consumption for households with electricity was roughly 3,500 kWh in 2010 [4], while in Nigeria, it was about 570 kWh. This emphasizes that there is a huge energy gap that needs to be filled if Nigeria is to claim its position as the giants of Africa. One way to improve on the power network and provide better quality of service in the energy sector is to implement energy reduction, conservation and efficiency programs. The low

energy per capita also affords the citizens with no option but to employ energy efficiency and conservation programs so as to maximize the little amount of energy available to them.

II. Literature Review

A. Smart Sockets and Meters

AC (Alternating Current) sockets are devices that allow electrically operated equipment to be connected to the primary alternating current (AC) power supply in a building. A smart socket is a power socket that communicates with the user via a network or communication interface such as the internet, or via SMS. It works like a smart meter and communicates energy consumption details to the user to see real time and also stores these consumption details in a database.

A smart meter is an electrical meter that records consumption of electric energy in intervals of an hour or less and communicates that information at least daily back to the utility or user for monitoring, billing and informational purposes. Smart meters enable twoway communication between the meter and the central system. Unlike home energy monitors, smart meters can gather data for remote reporting. Smart Meters differs from traditional automatic meter reading (AMR) in that it enables two-way communications with the meter.

Various research and design work has been done on Smart metering. van Gerwen et al [5] in their research work on Smart Metering highlighted that countries like the USA and other countries in Europe have implemented Smart Meters to improve energy efficiency and management, which shows that the concept is feasible. They explain that Smart Metering technology (also referred to as Automated Meter Reading) is mature and can be implemented. Their paper shows that the basic functions of Smart Meters are to: measure electricity, remotely switch customers (devices) on or off and to remotely control the maximum electricity consumption. According to them, the communication infrastructure for Smart Meters may include: Power Line Carrier (PLC), A wireless modem (GSM or GPRS), An existing permanent internet connection (ADSL).

Others have also investigated ways in which a single metering connection can be used to monitor and control various load sources from a single connection point. For example, Barsocchi et al [6] in their work; 'Smart Meter Led Probe for Real-Time Appliance Load Monitoring' experimented on a concept known as Non-Intrusive Appliance Load Monitoring (NIALM) to obtain appliance specific time and power draw characteristics of devices by disaggregating the information collected at the main break level. They were of the opinion that Home Automation networks may become the primary tools for smart energy management in the near future.

They stated that an extension of the original MIT (Massachusetts Institute of Technology) NIALM method can be used to recognize signatures in devices such as spikes in power draw and types of devices. Their solution is based on the use of optical sensors of the modern smart meters. It infers the domestic electric consumption from the readings of the smart meter's LED flashes, and using a Finite State Machine (FSM), it recognizes the most common appliances used in domestic activities. They focused on the non-intrusiveness of their system and developed a simple single device to get real time information about the energy consumption and usage of domestic appliances. As a proof of concept, they tested the proposed power monitoring solution to infer when the Electrical Microwave Oven in a home was on/off for a period of 6 (six) months, and recorded closely-accurate results. In conclusion, they were able to present a NIALM system that monitors the usage of a domestic appliance in order to recognize the associated activity of the user.

B. Web Applications

A web application is a Software Application that is stored on a remote server and is delivered to the final user through a Web Browser.

A comprehensive database application of Home Appliances and their energy ratings is not currently available on the internet. Even though some energy and utility companies have tried at various times to post information about home appliances and their energy ratings, such as Wholesale Solar [7], there is no consolidated collection showing the cost implications of usage and energy ratings of the different home appliances.

III. System Design

The design of the complete Energy Management System has been broken down into two (2) functional parts which would incorporate the metering, control and database aspects. The system design architecture is shown in Figure 3.

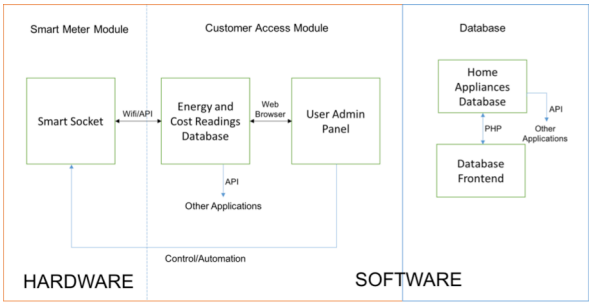

Fig. 3. System Architecture for Energy Management System

The design of the socket is based on the use of an open source Microcontroller board, the Arduino Uno R3, which is based on the ATmega328 MCU. It possesses an ESP8266 Wi-Fi module for communication, ACS 712 current sensing module and a voltage sensing unit for measuring consumption data.

A. Hardware Design

The hardware design involves all the components and tools used to design the Wi-Fi Based Smart Metering/Sockets System. There are four Units/Interface involved in the hardware design stage; Metering Unit, Control Unit, Processing Unit and Communication Interface. The block diagram in Figure 4 gives an overview of this stage and the flow of metering information.

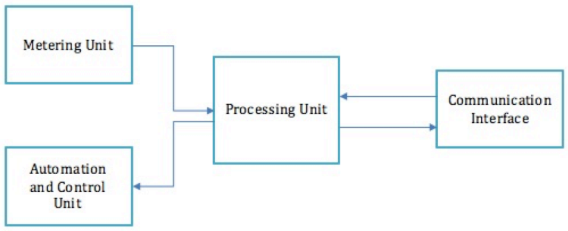

Fig. 4. Hardware Sub-System Block Diagram

The metering unit is responsible for measuring the amount of load connected to the meter and forwarding it to the processing system for the necessary computation to be done with it. The metering system uses a Voltage and Current Sensor connected to the Arduino to measure average active real power. A current sensor is a sensor that detects electric current in a wire, and generates a signal proportional to it.

The Automation and Control Unit coordinates the automatic switching of load connected to the smart socket. This is achieved by the use of a relay module. The Arduino Uno coordinates the switching of the relay hence switching whatever device is connected to the socket ON/OFF. A relay is an electrically operated switch.

The processing unit takes the values of quantities generated from the metering system and performs computation on them. The CM (Central Microcontroller) Block serves as the core of this system. The Arduino Uno was chosen as the Microcontroller as it is open source, affordable and can be easily adopted to interface with other components. Microcontrollers are electronic circuits that can be programmed to carry out a vast range of tasks. The Arduino Uno can be programmed using the Arduino IDE (Integrated development environment) and using the Arduino language, which is a variant of the C Programming language.

The communication interface is the main point of interaction between the Smart Meter and the Online Database. Communication is achieved by the use of a Wi-Fi module with a Microcontroller to send and receive information to and from the Server. The major component of the communication system is the Wi-Fi Module. The Microcontroller is responsible for sending the appropriate Attention Commands (AT) to the WiFi Module.

B. Software Design

This comprises of all the elements and technologies used in the development of the server side and frontend of the Energy management solution. It mainly comprises of the development involved in the creation of the following:

- Database to save customer energy usage
- API (Application programming interface) to enable the meter to save readings to a database and enable the Admin interface pull data from the database.
- Customer Access Module or Admin Interface for users to view meter readings
- Home Appliances Database (HADB) comprising of various Home Appliances and their energy profiling and costs based on customer usage.

A database management system (DBMS) is a computer software application that interacts with the user, other applications, and the database itself to capture and analyze data. A general-purpose DBMS is designed to allow the definition, creation, querying, update, and administration of databases. The database contains information sent by the meter and required by the user to understand how much energy they use and how much it costs. An online service called Thingspeak© was used to create a database to store the values of current, voltage and time and then serve that data to the user admin panel via it's API.

An API (application program interface) is a set of routines, protocols, and tools for building software applications. The API specifies how software components should interact and APIs are used when programming graphical user interface (GUI) components. The API used was built on the Thingspeak© service and was used to build other components of the system including the Graphical User Interface (GUI) for the user to view energy usage readings and to program the Microcontroller.

The Customer Access Module is responsible for interpreting results from the database which contains information from the Smart Socket to the user in a Graphical User Interface. It is built using web technologies: HTML, CSS, PHP and Javascript.

The Home Appliances Database Module involves the construction of a web application which would hold information about various home appliances and their energy profiles. It is built using web technologies such as HTML, PHP, Javascript, CSS and Laravel. An Admin backend is developed which aids to serve a supervisory role for adding, editing and removing appliances from the database using a GUI.

IV. Construction and Testing

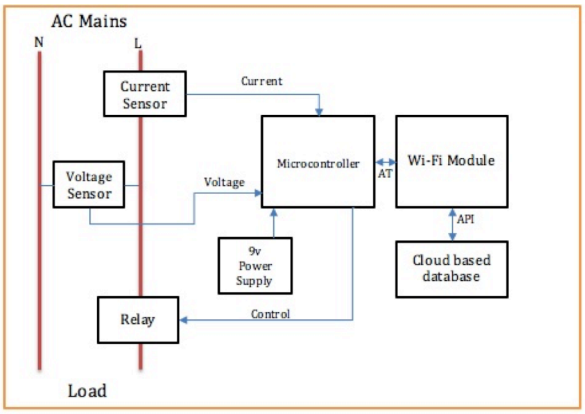

Fig. 5. Block diagram of Smart Socket

Figure 5 shows how the various components in the Smart Socket system interact with each other.

A. Phase 1

The Smart Socket system was first constructed and tested on a breadboard using a 9v battery as the power source and a DC motor as the load on which energy usage readings were gotten from. The ACS 712 current sensor was connected in series with the DC Motor load and was connected to the Arduino to collect current readings. The readings gotten were displayed on the Arduino IDE (Integrated Development Environment) serial monitor.

The voltage sensor unit consisting of a voltage transformer and 2 resistors of 10k Ohms and 100k Ohms was also tested.

B. Phase 2

At this phase, the relay was tested separately and was used to switch a 5v Relay ON and OFF via the serial monitor.

C. Phase 3

After the current reading connections were confirmed, the ESP8266 connection to the Arduino was implemented. The ESP 8266 enabled the system for communication over the internet via WiFi. The Customer Access module was also developed in this phase to grant users access to the reading via the Admin User Interface as a replacement to viewing via the Serial Monitor as in Phase 1.

The readings from the constructed system are monitored via the Customer Access Module as shown in Figure 6.

An export of the database showing some values gotten from the smart socket during testing are shown in Table 1.

D. Authors and Affiliations

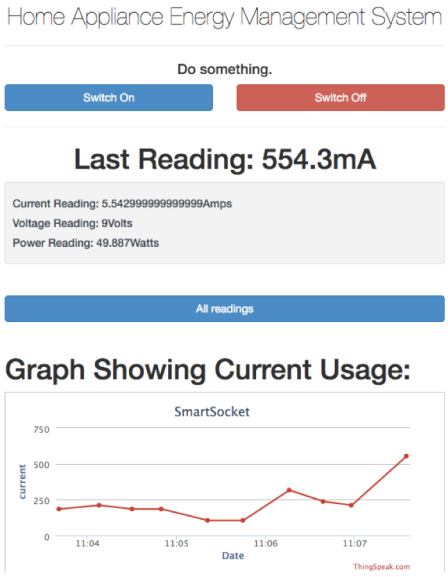

Fig 6. Example of a figure caption. (*figure caption*)

TABLE I. Database Entries of Smart Socket

	Created At	Entry ID	Current Value	Voltage Value	Time
2	2016-03-14 16:03:39 UTC	9	527.9		
3	2016-03-14 16:03:57 UTC	10	290.3		
4	2016-03-14 16:05:34 UTC	11	1055.7		
5	2016-03-14 16:05:52 UTC	12	1187.7		
6	2016-03-14 16:06:30 UTC	13	844.6		
7	2016-03-14 16:06:49 UTC	14	897.4		
8	2016-03-14 16:07:27 UTC	15	607.1		
9	2016-03-14 16:09:47 UTC	16	475.1		

V. Home Appliances Database Development

A. Phase 1

This involved setting up the MySQL relational database which had the various tables required for the Home Appliances Database system. A web application called *Phpmyadmin* was used to set up the MySQL database.

B. Phase 2

At this phase, the frontend (which is what the users sees) is developed using HTML, CSS and *Javascript*. The Admin frontend is first developed for admins to upload and edit appliances and their alternatives. After the admin frontend development, the user end was developed for users to view appliances, their energy ratings and alternatives.

C. Phase 3

This involved using PHP to do the server-side programming and add the functionality for the various parts of the software. The Laravel framework for PHP was installed and set up to enable faster prototyping. Controllers, Models and Views were then created for the various aspects of the application.

VI. CONCLUSION

The system developed allows monitoring of power consumption, with the aim of providing intelligent energy consumption information. In the domestic environment, the use of Smart Metering provides more information and control over the electricity consumed, to the user. By means of the Smart Metering prototype developed, users are able to discover their consumption habits. With this information, users can develop strategies to make their consumption more efficient and thus, most environmentally-friendly.

The project is able to accomplish the objectives defined in the 'Aim and Objectives' section as shown below:

- The total cost of the project is about $28 as compared to the price of $99 of the average Smart sockets, which enables it to accomplish purchase cost reduction.
- It can be connected to devices via a common socket, which enables it have a simple connection.
- It makes use of voltage and current sensors and a timer, which enables it capture key energy consumption data.
- It possesses a WiFi shield and a data logger on a web database which enables it store energy consumption data to be used by various persons.
- It possesses a simple GUI on a web server by which consumers can access their energy consumption data.
- It possesses a Relay for automatic switching of the devices connected to it.

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