Automated Real-Time Electricity Supply Monitoring System

Otuekong E. Ekong[1], Anthony U. Etim[2] & Anietie P. Ekong[3]
Department of Computer Science,
Akwa Ibom State University, Akwa Ibom State, Nigeria
E-mails: OtuekongEkong@aksu.edu.ng[1], AnthonyEtim101@yahoo.com[2], AnietieEkong@aksu.edu.ng[3]
Phones: +2348135406037, +2348133862346, +2348035467965

ABSTRACT

In many developing countries, several homes are yet to be fitted with the traditional electro-mechanical meter or newer smart meter for measuring electricity consumption. As such, distribution network operators resort to estimated billing. This work proposes a low cost and easy-to-install alternative capable of monitoring the duration of supply which can be used as the basis to generate bills for unmetered customers. The Recursive Waterfall model guided its design and implementation. The system comprises of Electricity Supply Monitoring (ESM) Hub and ESM App. The Hub is the sensing unit and is designed using ATmega328 microcontroller on Arduino Uno board together with HC-05 Bluetooth module for communication. The App is the display/storage unit and comes with two variants: ESM Mobile App developed using Python and ESM Desktop App developed using C#. Results show the system is capable of providing timely feedback for consumers and real-time transparency for electricity supply industry stakeholders.

Keywords: Energy consumption, energy informatics, meter reading, power measurement, smart meters.

Proceedings Reference Format
Otuekong E. Ekong, Anthony U. Etim, Anietie P. Ekong (2021): Automated Real-Time Electricity Supply Monitoring System. Proceedings of the 27th iSTEAMS Multidisciplinary Innovations & Technology Transfer (MINTT) Conference. Academic City University College, Accra, Ghana. June, 2021. Pp 10-16 www.isteams.net/ghana2021. DOI - https://doi.org/ 10.22624/AIMS/iSTEAMS-2021/V27P2

1. INTRODUCTION

A typical power system consists of many components such as: widely dispersed power generating systems, transmission lines, substations, switches, transformers, and loads. The various components can be grouped into three subsystems: generation, transmission and distribution. The distribution network consists of all the components necessary to link consumers to the grid and is usually where most failures (also referred to as outages) occur (Sinkala and Phiri, 2020). Electricity consumption meters are typically fitted wherever the mains supply branches into a customer's property. In recent years, distribution network operators (DNOs) have been increasingly migrating new and existing consumers to smart meters capable of automated meter reading (AMR).

Smart meters offer consumers more accurate measurements than the traditional electro-mechanical meter reading systems. Smart meters are also able to automatically transmit data real-time; hence can support pre-paid billing whereas electro-mechanical meters require DNO personnel to manually monitor and compute consumption and can only support post-paid billing. In addition, smart meters can support several other features such as power quality measurements and outage reporting.

In many developing countries, several households are yet to be metered either with the traditional electro-mechanical or the newer smart meters. In Nigeria, for instance, a report by the National Electricity Regulatory Commission (NERC) disclosed that as at March 2020, only 4,231,940 (40.39 per cent) of the 10,477,856 registered electricity customers were metered; implying that 59.61 per cent were still on estimated billing (Okafor, 2020). Without meters, it is difficult to gauge how a customer's estimated bill reflects the reality on ground.

In addition, there is a huge shortfall between the quantity of energy generated and quantity of energy demand in many developing countries. For instance, Nigeria has the potential to generate 12,522 megawatts of electricity from existing plants but only about 4,000 megawatts is generated in most days (USAID, 2020 April 16). This is grossly insufficient to be distributed to the approximately 180 million population. As such, DNOs resort to constant load scheduling, overloading, under-voltage, and in extreme cases cutting off some communities so as to balance the load in their network.

Acute electricity problems hinder development regardless of the availability of vast natural resources in any country. In Nigeria, the extreme poverty headcount rate was estimated at 53.5 percent in 2009 using the international poverty line of $1.90 per person per day (2011 PPP) according to the official Nigeria Living Standard Survey (NLSS) carried out by the country's National Bureau of Statistics (NBS) (World Bank Group, 2020). Adequate supply of electricity is vital for improving living standards, boosting socio-economic development, and maintaining national security.

1.1 Statement of Problem

There are two major problems faced in the electricity network in many developing countries. First, there is insufficient power available for distribution which forces DNOs to favour some consumers, communities and regions over others. Second, there is a huge metering gap which gives an avenue for many consumers to resort to electrify theft. Electricity theft forms a main chunk of non-technical losses (NTL). NTL affects the quality of supply, increase the load on the generating station, and affects the tariff forced on actual consumers.

1.2 Objective

This study proposes a system that measures the duration of supply such that the readings so obtained can be used as the basis to generate consumption bills. The system should also be capable of making the readings available online on an open visualization platform for the evaluation of the load scheduling program effected for a given household, community, or region without the need for physical visits. The proposed system comprises of Electricity Supply Monitoring (ESM) Hub and ESM App. ESM Hub is the sensing unit and houses the various sensors and communication module. ESM App refers to the display/storage unit which comes in two variants: ESM Mobile App and ESM Desktop App.

2. RELATED WORKS

This section highlights some recent research work undertaken towards developing alternative low-cost AMR and load scheduling (LS) solutions. The study conducted by Bonganay, Magno, Marcellana, Morante and Perez (2014) proposed an AMR system that uses the ZigBee protocol to transmit meter readings to a personal computer (the coordinator) for conversion into a CSV file. Thereafter, the CSV file is uploaded to a MySQL database hosted on the Internet for ease of access by both the consumer and DNO personnel.
In their proof-of-concept, Boganay et al. (2014) used Raspberry Pi micro-computer, programmed using Python, to carry out voltage and power consumption readings. Sonandkar, Bhati, Gupta, Chouhan, Kinhekar and Padhy (2016) devised a similar system but used Atmega328 microprocessor on an Arduino Uno board.

For homes already fitted with the traditional electro-mechanical meters, Chandra, Vamsi, Manoj and Mary (2016) proposed a system uses a light sensor module mounted on a raspberry Pi micro-computer to detect the pulses on the traditional meters and use the sensor readings as an alternative approach for computing the meter readings. Python programming language was used to compute the energy consumption and send the values via Wi-Fi communication protocol to a Google spreadsheet for storage. The information in the Google spreadsheet acts as a central repository which can be accessed on a Webpage or through an Android mobile app by the consumer and DNO personnel.

Presently in many developing countries, consumers are cast with the burden of telephoning or physically visiting the DNO office to report power failure. To address this challenge, Sinkala and Phiri (2020) proposed a system that incorporates power failure reporting through a cloud-based repository. The system uses a Voltage sensor circuit, Arduino Uno board with ATmega328 microprocessor, SIM808 GSM/GPRS/GPS module, Cloud architecture, Web application and Google Map API. The benefits of this approach include a possible reduction in the response time of field personnel granted that materials are immediately available to effect needed repairs. However this system does not provide a means of ascertaining the energy consumption in buildings yet to be fitted with smart meters.

A number of factors can lead to power failure, such as inadequate power distribution, human error fault, malfunctioning of power equipment and poor distribution upgrade. In a recent study, Okoro, Idoniboyeobu and Braide (2020) carried out power flow investigations in a distribution network in Rivers State, Nigeria. Upon analysing the data using Newton-Raphson method, results showed that many of the transformers were heavily overloaded; hence resulting in a never-ending occurrence of epileptic power supply. The Newton-Raphson and the Gauss Seidel procedures are conventional techniques for carrying out load flow investigations. Load flow studies evaluate the voltage magnitudes and phase angles ascertained at each bus in a distribution network in the stable state and can be calculated within a distinct boundary. Once the bus voltage magnitudes and their angles are determined using the load flow, the real and reactive power flow through each network can also be determined.

From the review of related work, it can be observed that there are potential benefits to be derived from the use of low-cost sensors to feed data to a central repository for the purpose of monitoring electricity supply. This can help to significantly close the huge metering gap in many developing countries. It can also be deduced from literature that there exist a number of research gaps in the design and development of systems that provide low-cost and easy-to-install energy informatics.

This work proposes an electricity supply monitoring system that can function as a suitable alternative where smart meters are yet to be fitted or where there is no smart grid that provides real-time transparency to all relevant electricity supply industry stakeholders.

3. CONCEPT DESIGN

A. Research Design

The Recursive Waterfall Model guided the development of this prototype capable of sensing and reporting the duration of electricity supply at a given location.

B. System Design

The smart meter data intelligence framework specified by the National Institute of Standards and Technology (NIST) and the Smart Grid Architectural Model (SGAM) framework forms the basis for the system requirements specification and model design. The infrastructure of smart meters, if used properly, can provide electricity consumption history, serve as a decision support tool for users to monitor energy usage, enable easier processing of billing, provide automated meter reading (AMR) and data processing, detect energy losses (possible fraud), provide early warning of blackouts, report disturbances in energy supply, support real-time pricing schemes, and monitor demand-response (DR) for energy saving and efficient use of energy generated (Alahakoon & Yu, 2015). However, where smart meters and the requisite smart grid are lacking, there is a need to devise a model capable of providing a suitable alternative.

Fig. 1 shows the proposed model of the electricity supply monitoring system (ESM) used in this study. It comprises of two components: the ESM Hub (which houses the power sensors and Bluetooth transmitter) and the ESM App (available in a mobile app version and a desktop app version). The ESM can monitor electricity supply data and send readings to a coordinating computer (mobile device or desktop PC) via the Bluetooth communication protocol. In the mobile version, the coordinating mobile device stores the raw data on a Google spreadsheet which acts as a central repository that can be accessed on a Webpage or through the Android mobile app. In the desktop version, the coordinating desktop PC stores the raw data on a CSV file that is subsequently uploaded to the central repository. The information in the central repository is accessible by both the consumer and DNO personnel and can subsequently be used as the basis for billing or comparing the fairness of the LS program.

C. Prototype Design

In the proposed model, the ESM Hub is designed to sit at the branch off from the electricity grid into the building (also referred to as on-grid supply). The ESM Hub is designed to function as an alternative meter in buildings yet to be fitted with a smart meter. Whether or not a smart meter has been fitted in a building, the ESM Hub can provide consumers with real-time consumption information as well as supply data that can be used for real-time comparisons of electricity supplied to other households, communities and regions. Fig. 2 shows the prototype of the ESM Hub which consists of: 12V transformer, 12V voltage regulator, full wave rectifier, 1 kilo Ohms resistor, 220 micro Farad capacitor, Arduino Uno board with ATmega328 microcontroller, and HC-05 Bluetooth module.

The microcontroller has 14 digital input/output pins (of which six can be used for pulse width modulation (PWM) outputs), six analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. In the prototype implementation, an electric bulb was used to represent the load consumption of a building. From the on-grid supply, voltage is stepped down from 230V AC to 12V AC. Thereafter, it is rectified by the full wave rectifier and a potential divider ensures input of approximately 2V DC to the analog input pins of the Arduino Uno board. From the analog input pins, the voltage readings is converted to 1 to signify the POWER ON status and sent to the HC-05 Bluetooth module. This is for transmission to the coordinating computer. The software used in the prototype implementation was: Arduino integrated development environment (IDE) for programming the microcontroller board using simplified C++; Python for developing the ESM Mobile app; and Visual Studio and C# for developing the ESM desktop app.

D. Prototype Testing
To measure success and performance, the prototype was setup and tested in a laboratory environment.

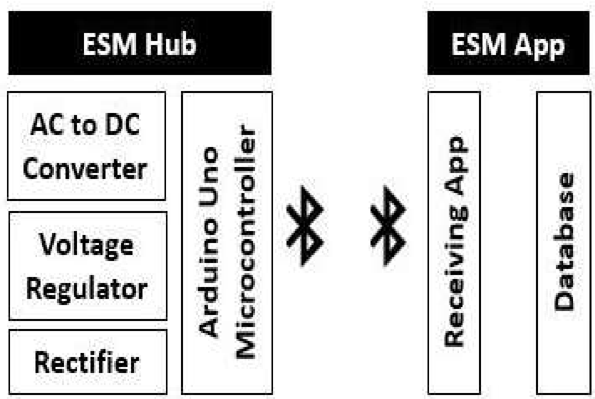

Fig. 1: Model of the ESM System

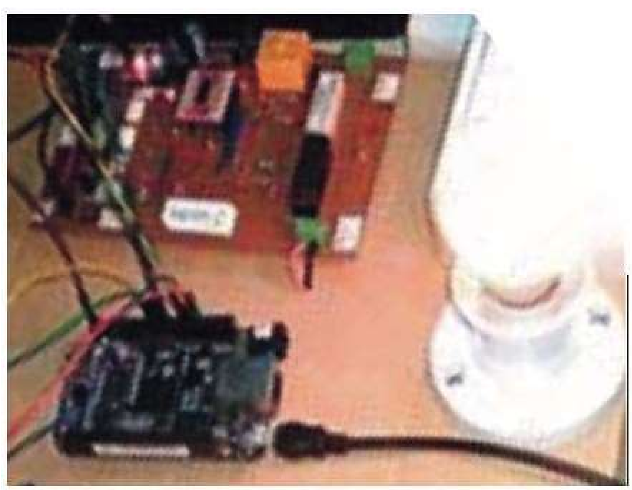

Fig. 2: Prototype of the ESM System

6. RESULTS

From the review of literature, an electricity supply monitoring model was proposed to address the challenge of real-time consumption transparency and real-time load scheduling transparency. In this model, the date, time and location information of the POWER ON status of a building is automatically monitored and reported form the moment the power supply was switched on. For the desktop version, the location information is manually inserted. For the mobile version, the location coordinates of the building is automatically acquired using the smart phone's GPS sensor. The system successfully displayed the electricity supply status updates on both the mobile app (Fig. 3) and the desktop app (Fig. 4). The system logs the POWER ON date and time and updates the log every five seconds. The entries in the log are subsequently used to perform various kinds of descriptive analysis of the duration of electricity supply to a building.

7. CONCLUDING REMARKS

Electricity plays a vital role in the socio-economic development of a nation. In many developing countries where many households are yet to be metered, it is not uncommon to find consumers complaining about outrageous electricity bills which they feel do not necessarily reflect the situation on ground. Tests conducted on the prototype confirm that it can serve as an *ad hoc* AMR solution. The proposed model would contribute to a reduction in customer complaints about outrageous electricity bills and provide real-time transparency of the DNO's load scheduling program. This system can be adopted as a low-cost alternative for use in developing countries where the smart grid infrastructure is yet to be fully operational.

8. CONTRIBUTIONS TO KNOWLEDGE

This work proposes a model and developed a prototype to illustrate an electricity supply monitoring system capable of measuring the duration of electricity supply to a building. When adopted, this system will:

(1) Provide readings that can be used to compute energy bills where a smart meter is yet to be fitted.
(2) Enable real-time consumption transparency for individual households.
(3) Enable real-time load scheduling transparency for communities and regions.

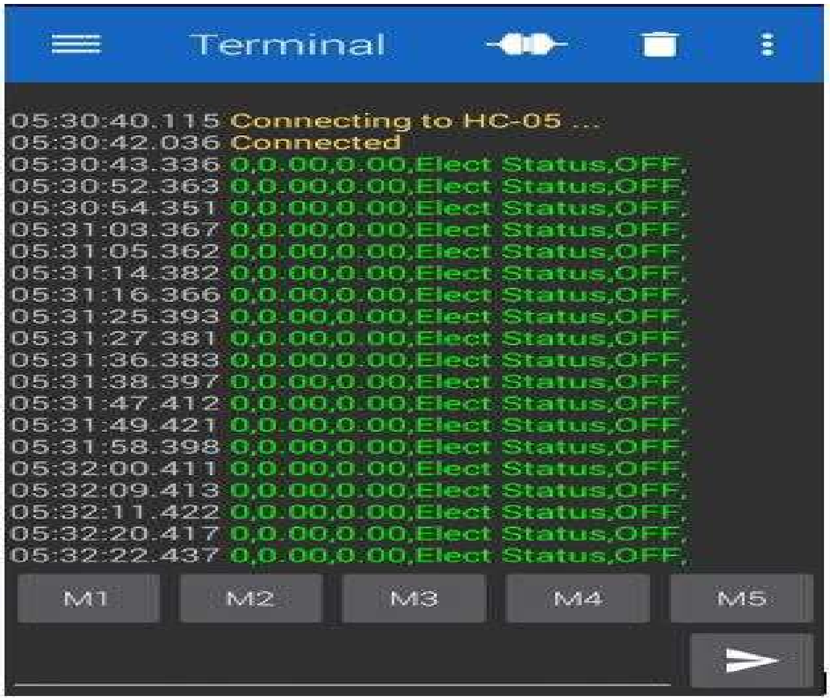

Fig. 3: ESM Mobile App displaying electricity supply status updates

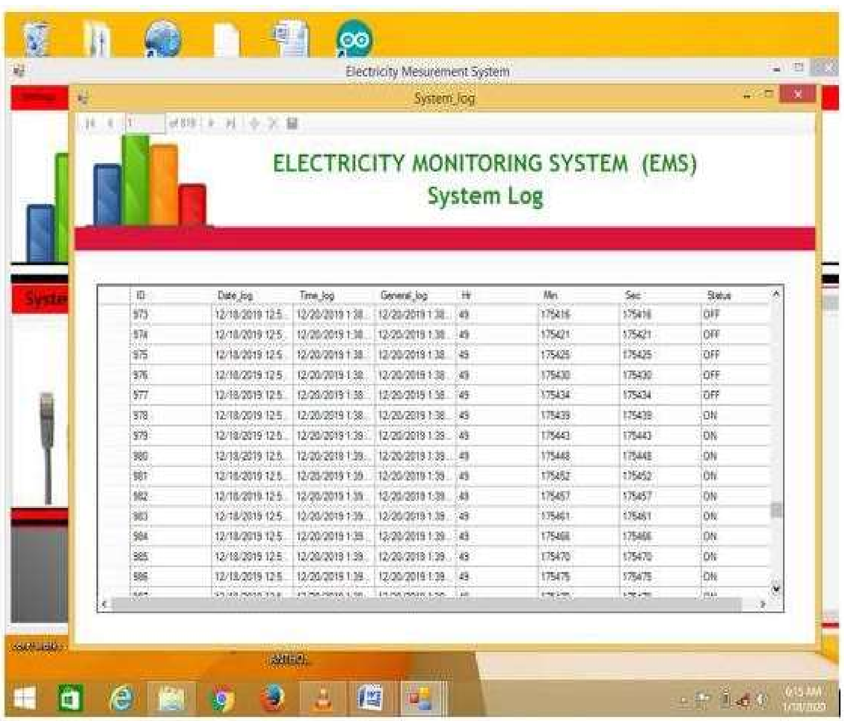

Fig. 4: ESM Desktop App displaying electricity supply status updates

9. RECOMMENDATION AND FUTURE WORK

A. Recommendation

Where smart meters are yet to be fitted and the smart grid yet to be fully operational, there is a need to consider this model as a suitable alternative that can serve the needs of both the consumers and the electricity supply industry stakeholders.

B. Future Work

In future, the ESM hub can be enhanced with additional sensors and functionalities to support other power measurements such as actual consumption and power quality. Lastly, robust descriptive analytical tools can be applied on the raw data in the central repository to ensure that information is presented in a manner that is comprehensible and actionable by the consumers and DNO personnel.

REFERENCES

- Sinkala, J. N., & Phiri, J. (2020). Cloud based power failure sensing and management model for the electricity grid in developing countries: a case of Zambia. *International Journal of Advanced Computer Science and Applications*, 11(2), 392-402.
- United States Agency for International Development (2020, April 16). *Nigeria: Power Africa fact sheet*. Retrieved from https://www.usaid.gov/powerafrica/nigeria
- Okafor, P. (2020, November 03). Electricity: 59.6% of consumers still on estimated billing - NERC. *Vanguard Newspaper*. Retrieved from https://www.vanguardngr.com/2020/11/electricity-59-6-of-consumers-still-on-estimated-billing-nerc/
- World Bank Group (2020, April). *Poverty and Equity Brief: Sub-Saharan Africa - Nigeria*. Retrieved from http://www.worldbank.org/poverty
- Bonganay, A. C. D., Magno, J. C., Marcellana, A. G., Morante, J. M. E., & Perez, N. G. (2014). Automated electric meter reading and monitoring system using ZigBee-integrated raspberry Pi single board computer via Modbus. In *Proceedings of the 2014 IEEE Students' Conference on Electrical, Electronics and Computer Science*, 1-6. doi: 10.1109/SCEECS.2014.6804531
- Sonandkar, V., Bhati, A., Gupta, D., Chouhan, S., Kinhekar, N., & Padhy, N. P. (2016, March). Power measurement using Arduino for effective demand response. In *Proceedings of the 2016 IEEE 6th International Conference on Power Systems (ICPS)*, 1-5. doi: 10.1109/ICPES.2016.7584140
- Chandra, P. A., Vamsi, G. M., Manoj, Y. S., & Mary, G. I. (2016). Automated energy meter using WiFi enabled raspberry Pi. In *Proceedings of the 2016 IEEE International Conference on Recent Trends in Electronics, Information & Communication Technology (RTEICT)*, 1992-1994. doi: 10.1109/RTEICT.2016.7808186
- Okoro, J., Idoniboyeobu, D. C., & Braide, S. L. (2020). Power Flow Investigation of 33kv Distribution Network Using Electrical Transient Analyzer Program: A case study of Agip Estate Mile 4, Port Harcourt, Nigeria. *Iconic Research and Engineering Journals*, 3 (10), 1702114.
- Alahakoon, D. & Yu, X. (2015). Smart electricity meter data intelligence for future energy systems: A survey, *IEEE Transactions on Industrial Informatics*, 12(1), 425-436.