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Effective Energy Measurement, Management And Data Communication: A Gsm-Based Smart Metering Framework

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***Abstract*— Energy measurement and management are amongst the major grid challenges and research efforts have been geared towards addressing them. The emergence of smart meters in consonance with the smart grid concept is as a result of these efforts. This paper explores the integration of Energy Management and Control System (EMCS) technologies into smart meters to mitigate energy wastages and ensure energy accountability. The integrated system presented in this paper leverages on the Global System for Mobile Communication (GSM) to provide a tripod communication between the meter, utility and the consumers. Results from the system prototype show that the system offers the consumer the opportunity to make personal energy budgets in line with the energy conservation, provides more consumption details than the traditional meters and provides for the utility a better management platform of the consumer component of the grid.**

Keywords — energy, consumption, measurement, management, metering

I. Introduction

The electric grid is a large interconnection of both generation and transmission electrical subsystems usually managed by utilities to facilitate efficient distribution of electricity to consumers [1]. Providing adequate, reliable and sustainable energy has always been the focus as well as a perennial challenge for utilities. This challenge is evident in the frequent experiences of supply-demand imbalance, outages, electricity theft, leakages and wastages, improper billing etc. Residential and business buildings consume large portions of the generated energy in most national grids and significant part of the consumed energy is due to improper use of appliances and wastages [2,3,4]. For proper billing and energy management culture to be achieved, in addition to effective data communication between consumers and the utility, traditional meters should be replaced with smart meters.

Smart meters have generated a lot of interest in recent times as a technology to tackle significant parts of the grid challenges. The smart meter is an electronic device that records consumption of electric energy in intervals of an hour or less and communicates the information at least daily back to the utility for monitoring and billing and to the consumer for awareness [5]. Smart meters are propelled by the smart grid concept which defines a power grid system that serves millions of consumers and has an intelligent communication and self–healing infrastructure, enabling new energy sources and timely, secure, and adaptable information flow, needed to provide adequate, reliable and sustainable power to the evolving digital economy [6,7,8]. Smart meters provide the smart grid interface between the consumer, utility and the society. It provides for the utility improved operational efficiency, monitoring, regulatory compliance, secure and accurate data collection, commercial losses detection and prevention. For the consumer, savings from improved energy management, adaptable consumption to different tariff schemes and flexible billings and a monitoring platform for how energy impacts on consumers' bills. For the society, it reduces energy consumption carbon footprint, improves outage management and provides better information to regulatory bodies.

This paper outlines a framework for a wireless smart energy management meter system. Aware of the popularity the GSM has gained over other wireless communication technologies as a result of its accessibility and wide coverage area, the paper particularly explores the use of the GSM as a communication platform between the consumer, the utility and the meter. To improve functionality of the smart meter beyond measuring and communication of energy and its data, its integration with energy management and control features is also explored.

II. Previous Works

As research and development on smart grid continue to increase, smart meters and Energy Management and Control Systems (EMCS) have also received adequate attention. These two technologies play significant roles in achieving the revolutionary vision and mission of smart grid in integrating advanced information, communication and networking technologies in traditional electric grid to improve its efficiency.

Since the early 21st century, research has taken advantage of improvements in electronic communication technology to resolve the limitations of traditional meters in the development of smart meter.

From reviewed literatures, it is common that smart

TABLE I. WAN TECHNOLOGIES AND THEIR FEATURES [13]

Technology	Max. Data Rate(Mbps)	Coverage range (km)	Frequency Band(GHz)	Band Licensed
GSM	0.8	1-10	0.9-1.8	Licensed
3G	2	1-10	1.92-1.98, 2.11-2.17	Licensed
WiMAX	75	1-5	2.5, 3.5, 5.8	Licensed
PLC	2-3	1-3	0.001-0.030	Free

meters also loosely referred to as Advanced Metering Infrastructure (AMI) measure consumption data in more details than the existing traditional meters, communicates the measured data remotely and wirelessly to the utility. However, differences exist in the communication technology employed, networking hierarchy/topology, grid technologies, frequency of data communication, and vendors.

In the bid to develop a smart energy monitoring system for Malaysia, Fakharuddin et al 9 employed the GSM as a communication network for their smart meter. The designed smart meter provided real time energy consumption details to the utility. On evaluation, the meter proved to eliminate the use of estimated bills, ensured that consumers pay only for what they actually used, a development the researchers feel will inculcate energy management culture in consumers. Achieving a smart house through the design and implementation of a smart meter was explored in [10]. The key cell in this design is the assumption of smart house hold devices which communicate with the smart meter through embedded wireless cards. The communication between the smart meter to town server is through Public Switched Telephone Network (PSTN) and Power Line Communication (PLC). The town server takes consumption of power for each instant from the smart meter, saves it and also using the PSTN and PLC sends it to main server of the utility after each hour.

In [11], a hybrid smart meter comprising of two smart meters – the consumer owned which runs over the ZigBee wireless platform and the distributor owned which employs the ModBus protocol wired environment. The hybrid system is connected to a Supervisory Control and Data Acquisition (SCADA)

that supervises a network of Programmable Logic Controllers (PLC). The SCADA system/PLC network integrates different types of information coming from several technologies present in modern buildings. The developed control strategy implements a hierarchical cascade controller where inner loops are performed by local PLCs, and the outer loop is managed by a centralized SCADA system, which interacts with the entire local PLC network. In order to implement advanced controllers, a communication channel was developed to allow communication between the SCADA system and MATLAB software.

Smart meters can allow integration in home energy management systems through communication protocols where the provided information is related to energy flow and price signals [11,12]. The focus of this research is the integration of EMCS technology in smart meters for improved functionality and efficiency.

So this paper presents the integration of intelligent technology of the EMCS with that of the smart grid to develop an energy management smart metering system that adopts the GSM as its communication technology.

III. SYSTEM ARCHITECTURE AND METHODOLOGY

Figure 1 illustrates the system architecture of the Wireless Smart Energy Management Meter System. The architecture can be divided into three major sub-systems viz: the communication network, the smart meter and the utility. The system architecture will be discussed under these major sub-systems. The architecture in figure 1 permits the exploration of different communication technologies, different features of the wireless smart meter and different structural organization of the consumer - utility component of the grid for effective management.

A. Communication Network

A variety of wireless communication technologies can be explored for the design of the system's communication network. The goal in employing any of these technologies is nearly always to optimize signal-to-noise ratio, subject to specific constraints like power consumption, bandwidth requirements, cost, reliability, equipment and antenna size [14]. From the architecture shown in Figure 1, a Wide Area Network (WAN) can be established for the communication between the utility and smart meter and the remote

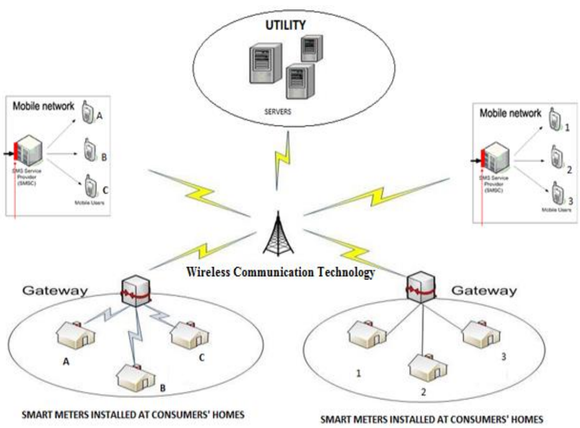


Fig. 1. *Architecture of a Wireless Smart Energy Management Meter System [13]*

control of the smart meter by the consumer. Table 1 presents features of the different WAN technologies that can be explored in the architecture.

TABLE II. LAN TECHNOLOGIES AND THEIR FEATURES [13]

Technology	Data Rate(Mbps)	Coverage range (m)	Band Licensed	Cost
Ethernet	10-100	100	Free	High
PLC	10-100	10-10	Free	Medium
Wi-Fi	5-100	30-100	Free	Medium
ZigBee	0.02-0.2	10-75	Free	Low
Bluetooth	0.7-2.1	10-50	Free	Low

Other communication technologies like the Bluetooth, Wifi and ZigBee can however be used to set up a Local Area Network (LAN) depending on the communication hierarchy established by the utility. In such cases, a gateway as shown in the system architecture in Fig. 1 may be needed to manage, collate, and send the data to the utility's WAN. Table II presents the features of some of these LAN technologies and it can be seen that they all have free license, which means that the key parameters requiring tradeoff here are data rate, coverage, and cost.

The communication network adopted in this paper is the GSM as shown in Fig. 2. The choice of GSM is informed by the advantage of its existing and common infrastructure, coverage and its Short Messaging System (SMS) cell broadcasting feature. This saves the time, cost of installation of new infrastructure and also the environment. This is in line with the colocation technology which encourages mobile communication vendors to cite their servers and other equipment in a single location [15]. The SMS feature of the GSM network is employed by the utility and consumer to query the smart meter for energy consumption data. It could also be used by the utility to disconnect and reconnect a consumer from and to the grid. The consumer can employ it to ascertain his bills and also set energy budgets. The store and forwarding features of SMS allow reliable meter reading delivery when GSM signal is affected by poor weather conditions and attenuation. This feature allows the stored SMS to be archived in the mobile operator and retrieved at a later time.

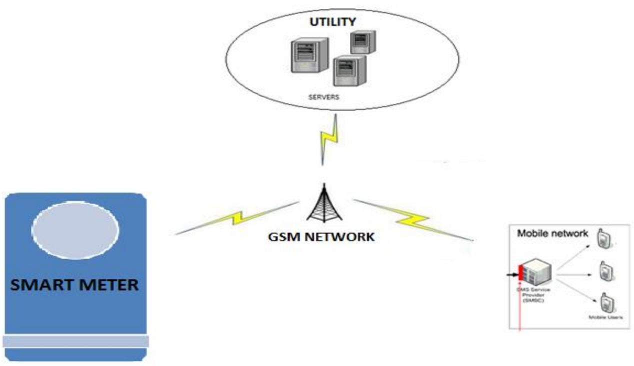


Fig. 2. *System Architecture of a GSM Smart Energy Management Meter*

B. Smart Meter

This is the heart of the system. Asides the traditional function of measuring energy usage, the smart meter presented in this paper combines aspects of an EMCS. The system permits consumers to set energy budgets in line with energy conservation interests. The functional block diagram of the smart meter discussed in this paper is shown in Fig. 3. The design includes a microcontroller unit (Arduino Mega2560) which operates on the Real Time Operating System (RTOS) and coordinates the interaction between the EMCS subsystems and the traditional meter functionality. Other units of the design include real-time clock, the GSM shield, keypad interface, liquid crystal display, RF transceiver, voltage and current sensors with signal conditioners, encoder, and decoder.

The microcontroller is interfaced with the GSM Shield and the energy meter. The GSM shield houses a Subscriber Identity Module (SIM) card from an established mobile network operator for the remote communication with the smart meter. Fig. 4 illustrates the flow process of the remote control of the smart meter. There is also a human-machine interface at the front panel of the meter comprising of the keypad and the LCD. This interface can be used by the consumer to make basic settings like energy budget and also to obtain consumption data. The human-machine interface summarily provides additional control of the smart meter besides the remote control from a mobile phone.

C. Utility

The utility is expected to provide the operational management of the systems described in both Fig. 1

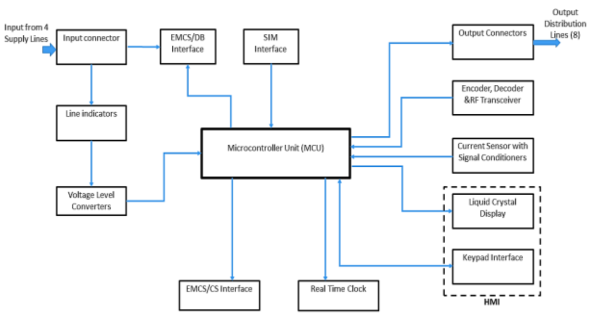


Fig. 3. *Block Diagram of the Smart Energy Management Meter*

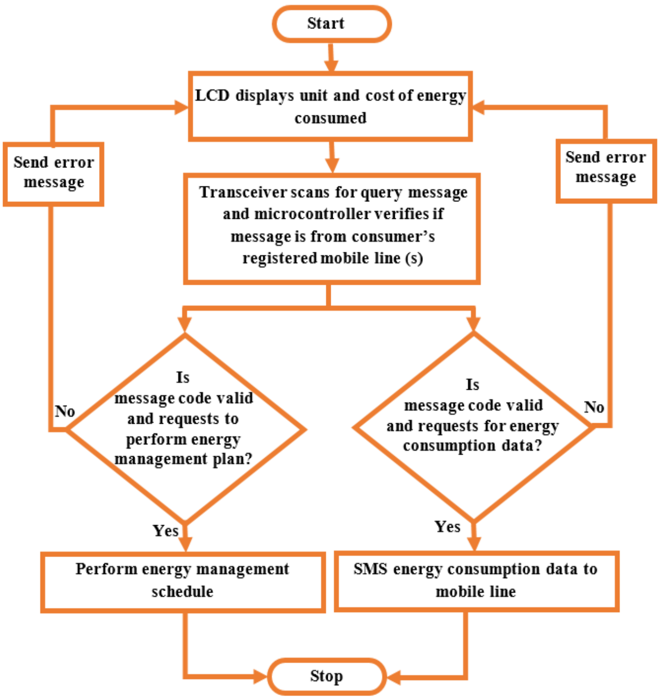


Fig. 4. *Flow chart of the remote control of the smart meter via GSM network*

and Fig. 2. From both figures, the utility comprises of servers which houses the consumers' database. The utility leverages on the wireless communication infrastructure to periodically or in real time remotely request the energy consumption data of consumers via the GSM network. The utility through this same medium can broadcast bills or any other information to consumers' mobile lines and can also remotely disconnect or reconnect consumers to and from the grid depending on their bill compliance status. These are great improvements over the laborious, time consuming and error prone method of manual house-to-house meter reading and disconnection still used in some developing countries [16]. Fig. 5 shows how the utility use the system to request for energy consumption data and to disconnect the smart meter from the grid.

IV. Results

Fig. 6a, 6b and Fig. 7 are images of a prototype GSM smart energy management meter. Figure 6a shows the smart meter measuring the energy consumed by a load of three (3) 60 Watts bulbs. Figure 6b shows the internal circuitry of the smart meter and a display of the measured energy consumption data by the LED of the human-machine interface. The LED displays both the energy unit consumed in kilowatt hour (kWh) and the bill in naira. Fig. 7 is a picture of a mobile phone that has received energy consumption data (consumed unit and amount) from both the smart meter and the utility.

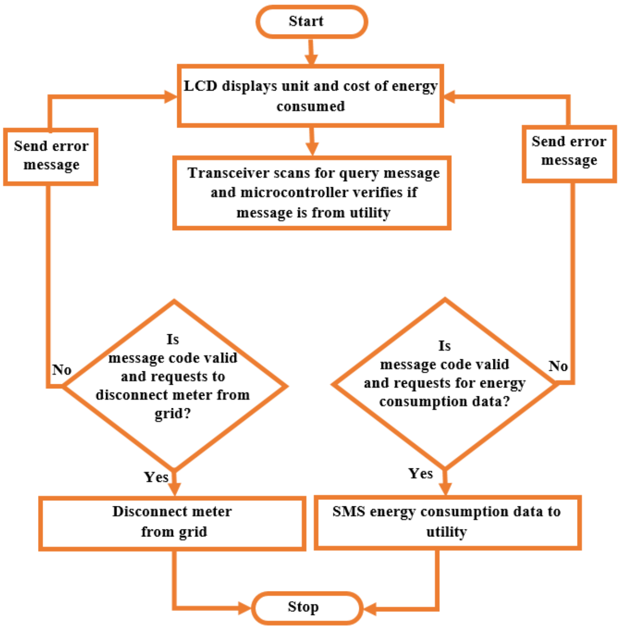
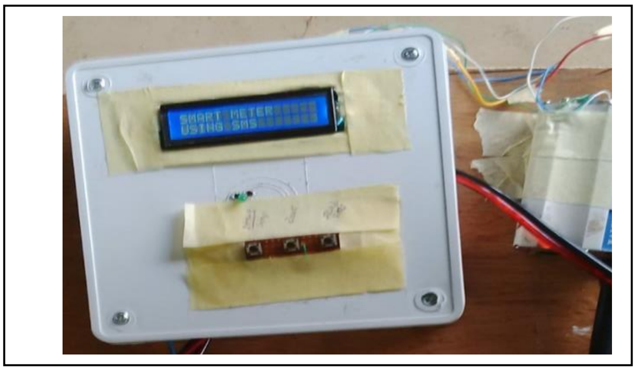
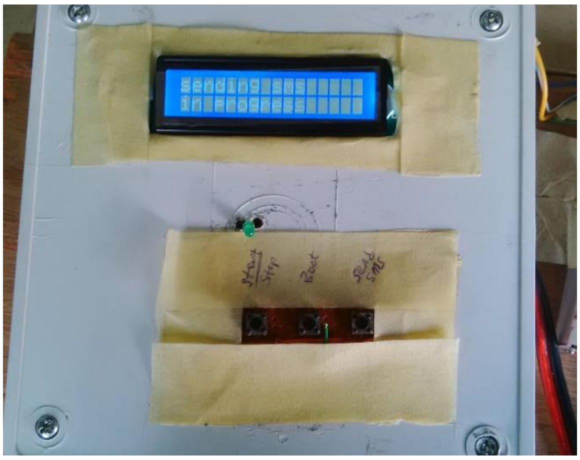


Fig. 5. *Flowchart illustrating the request of energy consumption data and disconnection of the smart meter by the utility.*



(a)



(b)

Fig. 6. *Sending SMS using the smart meter prototype*

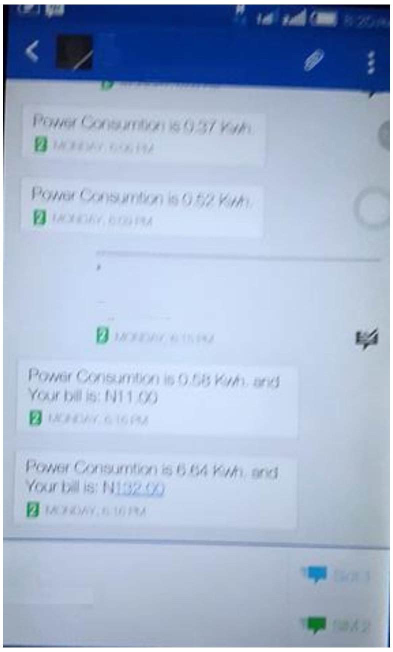


Fig. 7. *Picture of a consumer's mobile phone that has received energy consumption data via SMS.*

V. Conclusion and Future Work

As revolutionary as the smart grid is to traditional grid so are the smart meters to the traditional meters. Smart meters surpass the basic functionality of measuring power typical of the traditional meters. They GSM energy management smart meter discussed in this paper does not only adequately measure consumed power, but manages and effectively communicates same to both utility and consumers. This no doubt will reduce energy wastage, ensure accountability, reduce drudgery and give for better management of the consumer component of the grid by the utility. It is therefore necessary that continuous attention be encouraged to research and development of smart meters so as to exploit their capabilities for the needed improvement on the traditional meters and grids still being used in many developing nations.

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