IMPACT: International Journal of Research in Engineering & Technology
ISSN(P): 2347–4599; ISSN(E): 2321–8843
Vol. 7, Issue 11, Nov 2019, 15–28

DEVELOPMENT OF A POWER LINE COMMUNICATION AND GSM BASED ELECTRICAL DEMAND MANAGEMENT SYSTEM FOR AFRICA COUNTRIES

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Received: 06 Nov 2019 **Accepted:** 16 Nov 2019 **Published:** 30 Nov 2019

ABSTRACT

Electric power is energy generated through the conversion of other forms of energy, it is easier to convey, distribute and represents the most efficient way of consuming energy. However, the high demand of electrical power in African countries have put the continent into electrical global crisis in which open data website internet availability is limited in most of the African countries. Most of the African country relies on load shedding where electricity is supplied to certain area at a particular time interval to reduce the power demand in the area. Therefore, there is the need to implement a Power Line Communication (PLC) that can transfer data and voice signals from one communication system to another via electric power network and Global System for Mobile (GSM) that will improve electric power sector reform in the continent. This work describes a demand management system based on PLC and GSM technologies which can be used by the electricity utilities to improve electric power supply in African countries. In this research, automated metering system was used which measures the electricity consumption by consumer at different time interval. The meter imposes power load allocation by the electricity supply authority on domestic, commercial and industrial consumers and regulates power-over consumption. The result shows that the method is efficient in monitoring, managing and controlling of electrical demand management system.

KEYWORDS: *Electric Power, Power Line Communication, Global System for Communication, Electrical Demand Management, Automated Metering System, Internet*

INTRODUCTION

Electrical power is a rate per unit time at which electrical energy is transferred by electric circuit and also a livelihood of global economic development. However, most of the people living in rural areas in African countries lack access to electricity due to the countries power shortages and insufficient electricity generation capacity, and therefore have heavily impact on the continent economy [1], [9]. Alex (2009) explained that the annual energy demand in Nigeria is increasing by 6 % and the current supply is 10% behind the demand in peak hours while in Ethiopia it is 6-12 % and is forecasted that electricity generating capacity should be doubled in the next decade to meet the growing demand. Bakkali (2015) showed that most of the Africa countries face the longest average duration of power outage hours such as Uganda, in which power outage is about 25 hours during dry seasons. These make most African countries to depend on load shedding where electricity is not supplied to certain regions at particular time intervals so as to reduce the energy demand. However, this approach has a highly negative impact on the daily lives of people in the region. Limited numbers of studies have been done to provide a solution to this problem; however, most of the approaches are open data website internet in which its availability is limited in most African countries [8].

Quant, (2009) presented a GSM and ZigBee based Automatic meter reading system to improve electricity supply of a community. The system proved to take electric energy reading of large power consumers. The strength of the work reduced the cost of ZigBee network by using GSM technology with the ZigBee modules. This therefore reduced cost in meter reading and provided efficient services to their consumers. However, the limitations of the method included: communication process for many users since ZigBee transfers information at low data rate as compared to GSM technology which can make the communication process slow for many users.

Ahmed *et al.* (2012) developed a Worldwide Interoperability for Microwave Access (WIMAX) technology based AMR system for monitoring the usage of electricity in communities. The system was divided into four units and the strength includes: high performance, high data rate and high coverage area. The WIMAX technology provides AMR system with good efficiency and reliability; however, it is complex to implement and capital intensive.

Kumal and Ballala, (2012) developed a GPRS based AMR system using the advancement in the mobile communication technology to reform electricity market. This technology measured the energy reading from a meter regularly. The data obtained were sent to the utility centre through SMS. However, GPRS based AMR system used in the work was mainly for monitoring purposes and generation of the appropriate billing information at the required period. It has no system set to detect energy theft and no remote disconnection capacity.

Kuruppu, Gunathilake and Subramaniam, (2017) analyzed a demand management system based on narrow band PLC and GSM technologies for Asian countries using Blum-Goldwasser cryptosystem for secure PLC which can be used by electricity provider to reduce electrical load by turning off non-essential equipment in establishments during high demand periods where enough electricity cannot be supplied. This solution is thought to have less impact on the lives of the public.

In addition, Gunasekaran *et al*. (2017) explained that electricity be analyzed and measured through the energy meter, but this required huge number of labor and took more time to complete the process. To avoid time consumption, Automatic Meter Reading (AMR) becomes an executable option, the measured values are in kWh. The main advantage of this system is a low cost system that produces very encouraging results and it can be implemented upon existing electro-mechanical meters.

According to Fakharuddin*et al.* (2012) radio frequency automatic metering system was the most type of metering systems. The inherent limitation of the meter include: reduced range of radio signal, susceptibility to interferences from weather condition, difficulty in receiving from some specific area shielded by structures. In addition, Knauth *et al.* (2008) presented an AMR that utilized ZigBee technology to build up home area networks of connected metering devices. Although, the method reduced manpower requirement but it still required the consumers to deliberately take pictures of energy meter in their premises.

Therefore, in order to cope with the increase demand for electric power in Africa countries, as most of the countries are unable to meet their peak demands, Power Line Communication (PLC) and Global System for Mobile (GSM) based electrical demand management system that can reduced the overall energy demand is required. In this system, the consumer can manually reduce the electrical load of the building by switching off appliances in order to keep the electrical supply. If the total electrical load of the building surpasses the allowed amount of 2000 units per day, the whole building will automatically lose electric power supply [3]–[7].

Power Line Communication

Power Line Communication (PLC) is home network technology that allows consumers to use the existing wiring system to connect home appliances to the internet. PLC technologies have proved useful for control applications and in a system where communication signals can be sent and received on household or industrial current carrying power lines [2], [20]. PLC transmitting a high frequency signal at low energy levels over electrical signal by superimposing a modulated carrier signal on line voltage. This data signal is transmitted via the power line and can be received and decoded at another location in the same electrical network. PLC modems are used to make communication in power supply networks [5], [6], [21]. Data signal from conventional communication devices is converted by PLC modem in a form that is suitable for transmission over power lines. Reduction in operational costs and expenditures for communication is the main feature of power line communication. For internal communication of electrical utilities, PLC is used in electrical installation within buildings and homes for various communication applications [5]–[10].

For successful communication, the communication channel must be first modeled and analyzed accordingly. The channel between any two outlets in a home has the transfer function of an extremely complicated line network. PLCs are usually made of a variety of conductor types, joined almost at random, and terminating into loads of varying impedance [4], [14], [19]. Over such a transmission medium, the amplitude and phase response vary widely with frequency while the signal arrived at the receiver with very little loss over some frequencies. However, the channel transfer function itself is time varying since plugging in or switching off of devices connected to the network would change the network topology. Hence, the channel is described as random and time varying with a frequency dependent Signal to Noise Ratio (SNR) over the transmission bandwidth [1], [7], [12], [18].

The major component of a PLC include: transmitters, receivers, line tuners, filter, line traps, couplers, injectors and extractor. The problem associated with the PLC channel is the requirement to put the carrier signal onto the high voltage line without damaging the carrier equipment. Once the signal is on the power line it must be directed in proper direction in order for it to be received at the remote line terminal [11], [17], [9].

Transmitters and Receivers

A transmitter and receiver are radio carrier signal that consists of a power supply and an oscillator which are usually mounted in a rack in the control house, and the line tuner is out in the switchyard. This then means there is a large distance between the equipment and tuner, and the connection between the two is made using a coaxial cable. The coaxial cable is connected to the line tuner which is mounted at the base of the coupling capacitor. If there is more than one transmitter involved per terminal, the signal must go through isolation circuits, typically hybrids, before connection to the line tuner [13], [19].

Hybrids and Filters

The hybrid circuits help in the connection of two or more transmitters on one coaxial cable without causing intermodulation distortion due to the signal from one transmitter affecting the output stages of the other transmitter. The hybrids are also required between transmitters and receivers, but depending on the application. The hybrid circuits must be used appropriately so as to reduce the losses in the carrier path. High/low-pass and band-pass network may also be used, in some applications, to isolate carrier equipment from each other [16], [20]

Line Tuners

The line tuner in conjunction with the coupling capacitor provides a low impedance path for the carrier energy to the transmission line and a high impedance path to the power frequency energy. The line tuner or coupling capacitor combination provides a low impedance path to the power line by forming a series resonant circuit tuned to the carrier frequency. On the other hand, the capacitance of the coupling capacitor is high impedance to the power frequency energy. This function is provided by the drain coil, which is in the base of the coupling capacitor. The drain coil is designed to be low impedance at the power frequency and because of its inductance; it will have high impedance to the carrier frequency [16], [17], [21].

Coupling Capacitors

The coupling capacitor is the device that provides a low impedance path for the carrier energy to the high voltage line, and also blocks the power frequency current with a high impedance path at those frequencies. It can only perform its function of dropping line voltage across its capacitance if the low voltage end is at ground potential [14], [19].

Global System for Mobile (GSM)

Global System for Mobile (GSM) is a digital mobile network that uses a variation of Time Division Multiple Access (TDMA) and is the most widely used of the three digital wireless telephony technologies; TDMA, GSM and Code-Division Multiple Access (CDMA). GSM digitizes and compresses data, then sends it down to a channel with two other streams of user data, each in its own time slot. It operates at either the 900 MHz or 1800 MH frequency band [1]. In addition, mobile networks have become the predominant infrastructure in emerging markets and more people are now covered by mobile networks than have access to energy. In recent year, more than one in three Africans had at least one mobile subscription and GSM coverage was estimated to reach 80% of the African population. This has shown that more than 358 million people in rural area of Africa are covered by mobile networks but do not have access to electricity [9], [15], [18].

According to Hélène *et al.* (2014), more than 60% of the population does not have access to electricity in sub-Saharan Africa which amounting to over approximately 600 million people without access as shows in Figure 1. The majority of this population lives in rural areas, where 82% of the population is not electrified.

Increased mobile connectivity has led to the development of a range of mobile enabling services, with mobile financial services being one of the most lucrative. Another key service enabled by mobile networks is machine-to-machine technology (M2M). This technology solution enables mobile data transmission between two or more machines such as electric meters. The conventional energy metering system employed by energy service providers is based on analog meters placed at consumer end. This involves a lot of time and effort, and still does not produce accurate results [9].

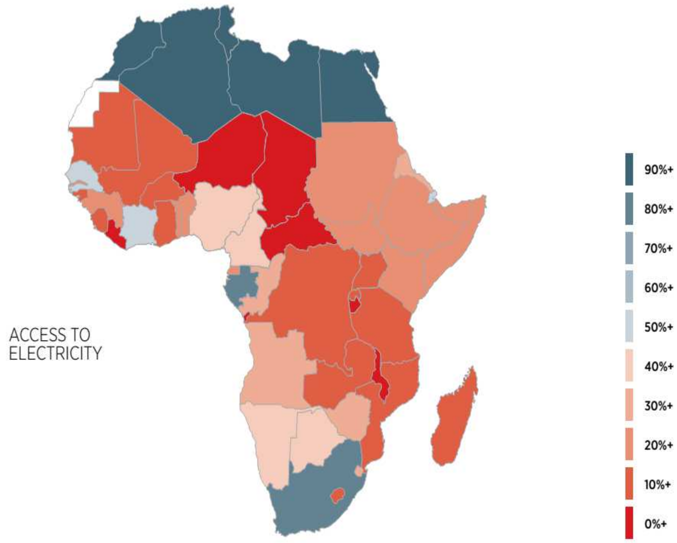

Figure 1: Africa's Energy Access Market.

However, in GSM technology, after a predefined time, the number of units consumed by the consumer will be transmitted to the main super computer, with consumer code number. This is achieved by sending the Short Message Service (SMS) to main service provider. One dedicated mobile will be interfaced to the Personal Computer (PC) of service provider, which will go on receiving SMS from different users [3], [8]. This operation of smart solutions provide energy providers with improved management of connections, remote monitoring and more efficient billing processes, thereby reducing losses so they can recover the costs they need to ensure reliable services and connect more customers. Therefore, mobile technology can provide a range of smart solutions for energy services, from basic connectivity, and machine to machine communication, to platforms for mobile payments and data management services. In addition, bringing together the ubiquity of mobile networks, the growth of mobile money services, and the availability of M2M has created new opportunities to leverage mobile services and technology in smart solutions to improve energy access in Africa [4], [7], [11].

The GSM network has four separate parts that work together to function as a whole; the mobile device itself, the Base Station Subsystem (BSS), the Network Switching Subsystem (NSS) and the Operation and Support Subsystem (OSS) [10], [18].

Mobile Device

The mobile device is connected to the network via the hardware. The subscriber identity module (SIM) card provides the network with identifying information about the mobile user [17].

Base Station Subsystem

The Base Station Subsystem (BSS) handles traffic between the cell phone and the Network Switching Subsystem (NSS). It consists of two main components: the Base Transceiver Station (BTS) and Base Station Controller (BSC). The BTS contains the equipment that communicates with the mobile phones, largely the radio transmitter receiver and antennas and equipment for encrypting and decrypting communications with the Base Station Controller (BSC). The BSC provides and classifies the intelligence behind the BTS. The BSC handles allocation of radio channels, receives measurements from the mobile phones, and controls handover from BTS to BTS [15], [21].

Network Switching Subsystem

The Network Switching Subsystem (NSS) called the core network, tracks the location of callers to enable the delivery of cellular services. Mobile carriers own the NSS. The NSS has a variety of parts, including Mobile Switching Center (MSC) and Home Location Register (HLR). These components perform different functions, such as routing calls and Short Message Service (SMS) and authenticating and storing caller information via SIM cards. The MSC server is a soft-switch variant of the mobile switching center, which provides circuit-switched calling mobility management, and GSM services to the mobile phones roaming within the area that it serves. The HLR is a central database that comprises details of each mobile phone subscriber that is authorized to use the GSM core network [13]–[16].

Operation and Support Subsystem

Operation and Support Subsystem (OSS) are computer systems used by telecommunications service provider to manage their networks. They support management functions such as network inventory, service provisioning, network configuration and fault management. Together with Business Support System (BSS), they are used to support various end-to-end telecommunication services [10], [20].

Automatic Meter Reading System Communications Requirements

Automatic Meter Reading System (AMR) is the remote collection of consumption data from customers' utility using radio frequency, telephony, power-line and processing the data to generate the bill. AMR is used for collecting reading and billing purposes [3]. In Africa, especially Nigeria, the electricity billing system is completely manual. An AMR system can use more than a single communication technology. Hybrids of radio and telephone, or telephone and power line carrier, or radio and power line carrier have advantages in some applications. Hybrid systems use an intermediate communication node between the gateway and the utility to combine and distribute information to a limited number of devices within a particular area. These concentrating units allow data to be processed locally and the results to be forwarded to the end users [8], [14].

Security

Secure information storage and transportation are extremely vital for power utilities, especially for billing purposes and grid control. To avoid cyber-attacks, efficient security mechanisms should be developed and standardization efforts regarding the security of the power grid should be made [3]

System Reliability, Robustness and Availability

System reliability has become one of the most prioritized requirements for power utilities. Some of the reasons that create unreliability issues for the power grid include; aging power infrastructure and increasing energy consumption and peak demand. Harnessing the modern and secure communication protocols, the communication and information technologies, faster and more robust control devices, Intelligent Embedded Devices (IEDs) for the entire grid from substation and feeder to customer resources, will significantly strengthen the system reliability and robustness [1], [3].

Quality of Service

The communication between the power supplier and power customers is a key issue of the AMR meter. Performance degradation like delay or outage may compromise stability, therefore, a Quality of Service (QoS) mechanism must be provided to satisfy the communications requirements and a QoS routing protocol must be applied in the communications network. Figure 2 shows some of the AMR functions [2], [18].

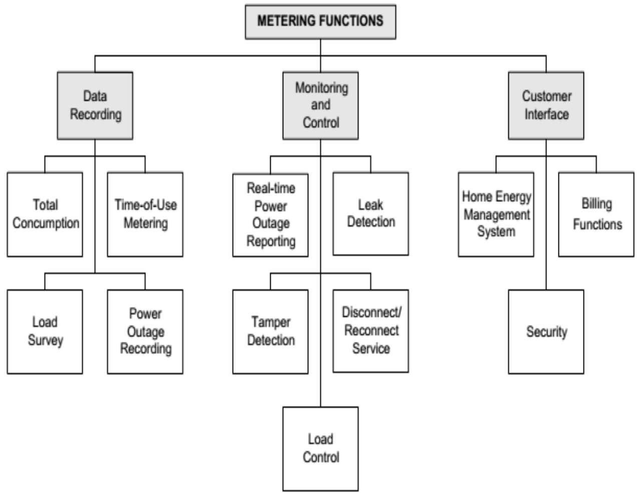

Figure 2: Automatic Metering Reading Functions [8].

MATERIALS AND METHODS

In this research, for the development of a Power Line Communication (PLC) and Global System for Mobile (GSM) based electrical demand management system for African countries, an automated metering system was used to measure the electricity consumption by consumer at different time intervals. The meter imposes power load allocation by the electricity supply authority on domestic, commercial and industrial consumers and regulates the power consumption. The metering system will monitor the load demand for different houses and communicate to a pre-created database via PLC and GSM base. Furthermore, automated metering system has ability to OFF and ON demand power load from the power supply sending request SMS to supply authority. The specific power consumption should be in the limit of 2000 units per day.

The material needed includes for this study are; GSM modules (SIM8001), Current Transformer, Liquid Crystal Display (LCD), Real Time Clock (RTC), Atmega328p, AC to DC converter and Relay.

The Atmega328p was used to handle all of the controls in the design of the management system; a firm-ware code was written and uploaded into the atmega328p chip via an Arduino-uno board. The firmware code was written in C-programming language using the Arduino-IDE. The current transformer was used in the design to sense the current flowing through the circuit per time and multiplied with voltage supplied in order to get the power consumed by users.

$$P = I_t V \quad (1)$$

Where; P is the power consumed by users, I_t is the current flow per time and V is the supplied voltage.

After the power consumed has been sensed, the value is sent to LCD in order to display the power and also the voltage at which the power is being supplied will be displayed to the user. This same system is connected to the power grid management database (Central Control System (CCS)) in order to check the power allocation per device. CCS is the power line transmitter of the system. It maintains information about the receiver nodes and acts as the gateway between GSM communication and PLC. It processes the commands sent via SMS, create appropriate command packets and transmit them via the power line.

In case the power consumed is greater than power allocation of the device on the database, the system will be alerted by sending an SMS to the user and also to the power management system. After this, the power connection to the load is tripped off. The module is responsible for connecting the database and message in the GSM module. The relay is responsible for switching on and off the load while the RTC module tells the real time all of the operations occur for record keeping purpose.

The simulation was done using protoues 8.0 software for the circuit. The specific power consumption, power over consumption, reduces power consumption and power break down consumption are calculated and recorded. The developed AMR meter was tested on domestic, commercial and industrial consumers in Nigeria. The main concept of designed is to provide maximum benefits to the users. The facilities contain the current consumption detail and price, history of consumption, current package running and information about peak/off peak time. The consumers which are domestic, commercial and industrial electricity consumers were allowed to consume up to 5000, 25000 and 50000 Watts respectively. The algorithm flowchart for developed AMR is depicted in Figure 3.

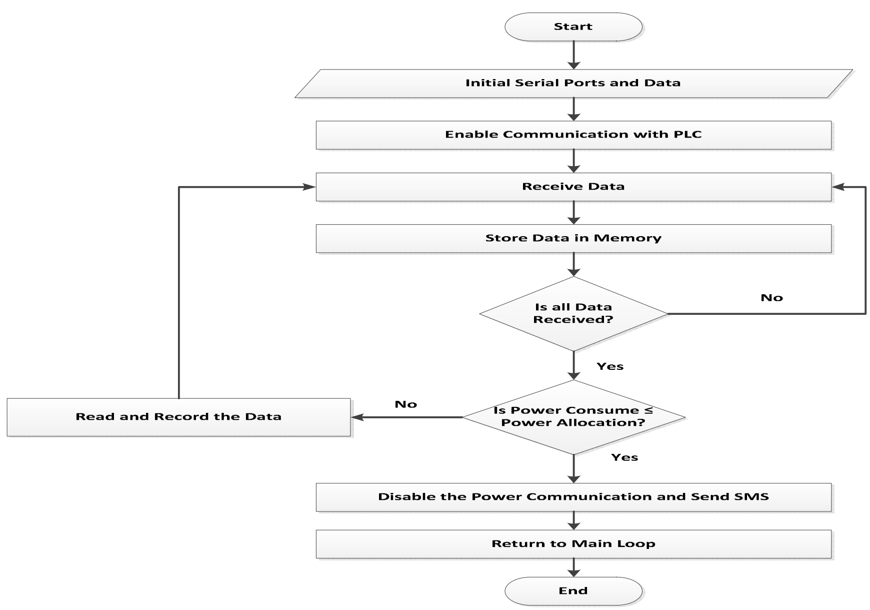

Figure 3: The Sequence of Instruction Flowchart of Central Node.

RESULTS AND DISCUSSIONS

The simulation and testing results of developed Automatic Meter Reading (AMR) system for electric demand management system based on Power Line Communication (PLC) and Global System for Mobile (GSM) technologies which can be used to reduce electrical load during high demand periods is presented in Figure 4 to Figure 7 based on the specific power consumption, power over consumption, reduced power consumption and power break down consumption.

Figure 4 indicates the relationship between specific power consumption level and the time interval for domestic consumers. The result shows that the level of electricity consumption by the consumers is from 8:00 Am to 8: 00 Pm. The consumer has 2000 units allocated electricity by supply authority and is allowed to consume up to 2000 units per day. When the electric power usage is within 2000 units, the AMR system registers the power supply to the consumer.

Figure 5 shows the relationship between power over-consumption level and time interval when the consumers exceeded initial allocation unit of 2000 units given by supply authority. Then the AMR system sends a warning Energy Limit Exceeded (ELE) message to domestic consumers as well as supply authority and waits for short to time interval. When the consumers reduce power consumption level, the AMR system continues supply electric power to consumer.

Figure 6 illustrates the correlation between reduced power consumption level and time interval after the consumers receiving a warning message from the AMR system. The consumers reduce is power to consumption level from 2035 units up to 1615 power units and then AMR system continues to supply power to the consumers.

Figure 7 shows the power breakdown when consumer received energy limit exceeded the message sent by AMR system. If the consumer does not reduce his power consumption level, then the AMR system disconnects the power supply to the consumer and also notifies the consumer and supply authority by power breakdown message.The results showed that the developed AMR system for electric demand management system based on PLC and GSM technologies can be used by the electricity provider to reduce electrical load by turning off nonessential equipment in establishments during high demand periods. As the goal of demand-side management is to encourage the consumer to use less energy during peak hours, or to move the time of energy use to off-peak times such as nighttime and weekends. This solution has less impact on the lives of the public because it requires no internet connectivity. Therefore, the method is ideal for Africa countries with less internet coverage.

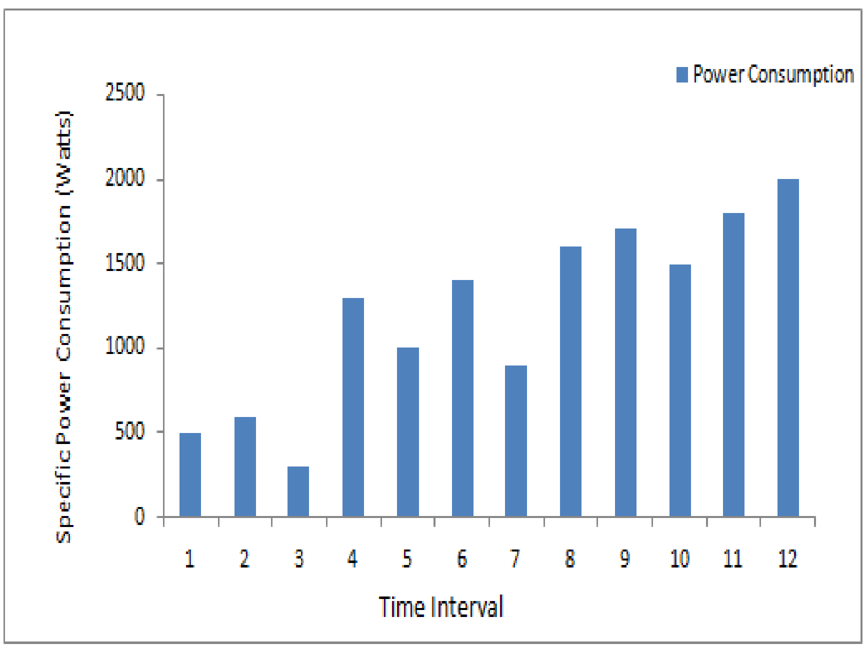

Figure 4: Specifi Power Consumption of Consumers.

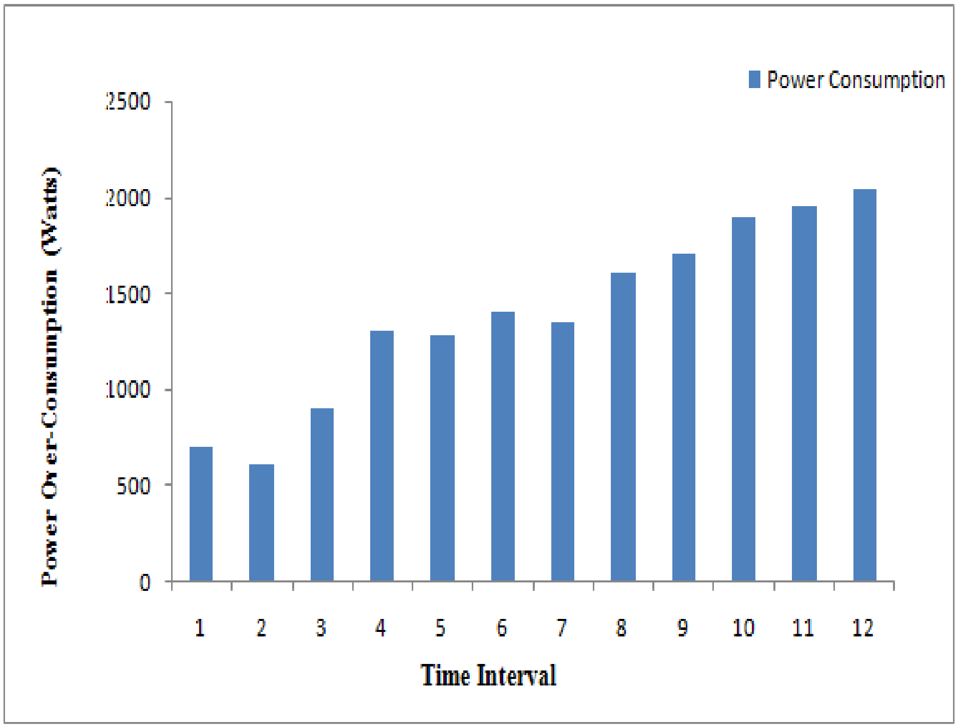

Figure 5: Power Over-Consumption of Consumers.

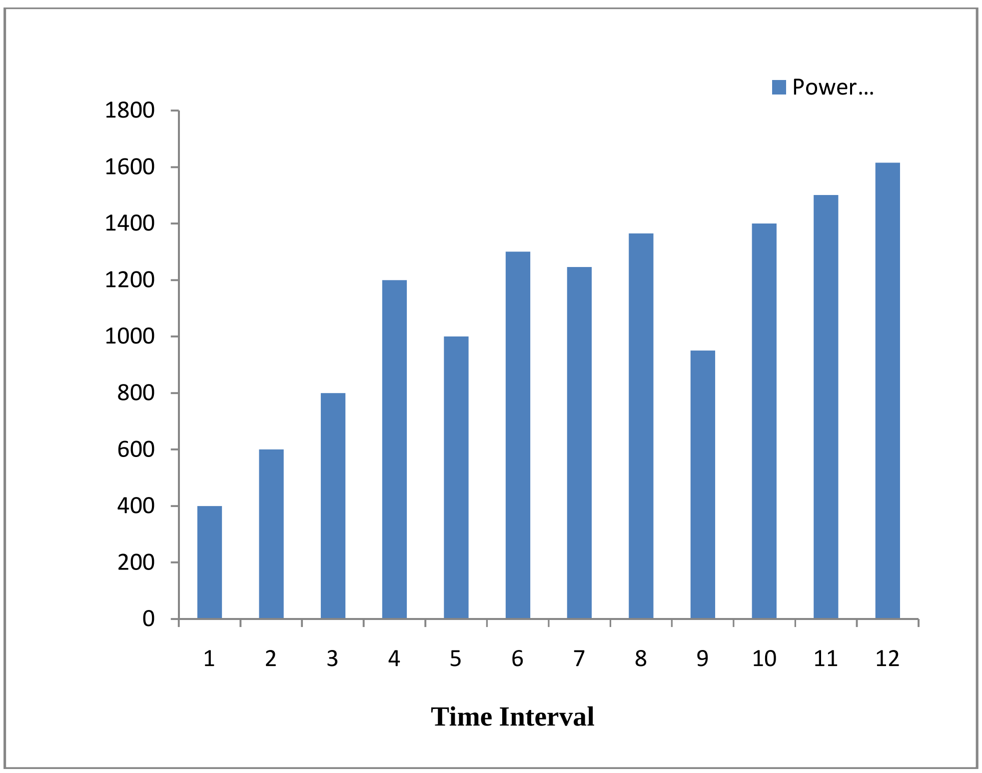

Figure 6: Reduce Power Cosumption of Consumers.

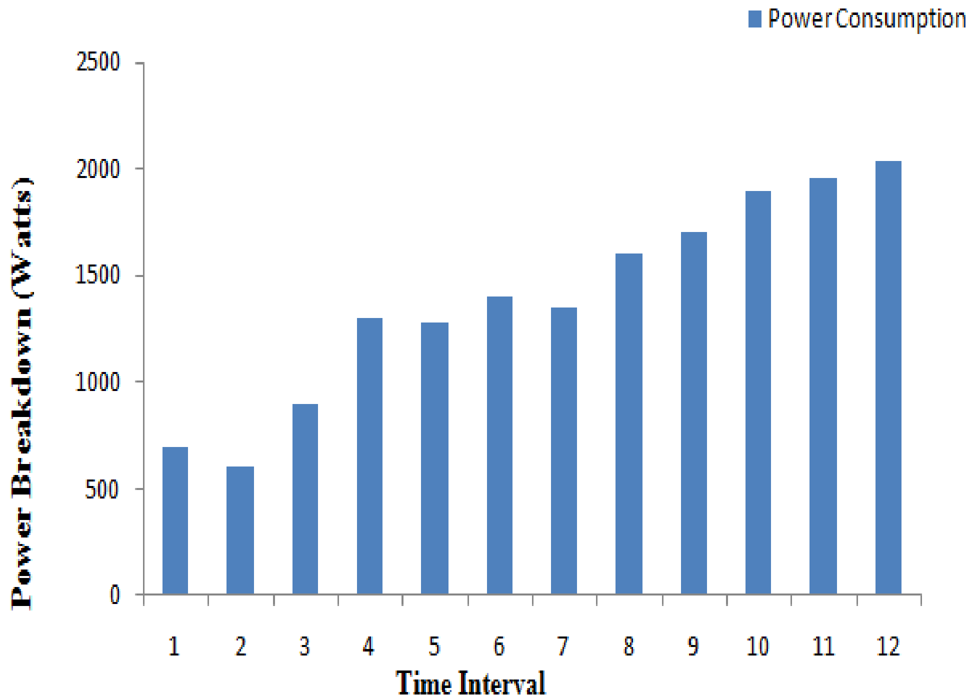

Figure 7: Power Breakdown of Consumers.

CONCLUSIONS

This research paper has analyzed and verified an electric demand management system based on PLC and GSM technologies by designing an Automatic Meter Reading (AMR) system that enables electricity providers to control none essential equipment by sending SMS to houses and establishments. Different electric power loads were allocated to domestic, commercial and industrial consumers respectively in order to establish accurate energy usage by imposing power limit and monitor electricity consumption patterns of various consumers. When consumers utilize electric power according to their allocation, the system performs the electric power consumption measurement and sends power consumption data to electric power authority. In addition, the system generates a message to electric power authority as well as consumer in case of power over consumption. Moreover, the AMR system will breakdown the electricity of home after a specific time interval when consumers do not respond to power over-consumption message sent by AME system.

Furthermore, the developed electric demand management based on PLC and GSM technologies system provides more rapid access to detailed information about energy flows and consumption. Improved access to data via remote monitoring and reduce technical and non-technical losses by detecting theft, losses, or a service problem to a particular area. It eliminates the need for costly and time-consuming manual meter reading which is also prone to error and corruption, therefore making billing and cost recovery more efficient. It makes available, reliable and regular consumption information for consumers to help them manage the usage and pave way for pre-paid services which can reduce non-payment. It increases data on energy flows and service levels to provide transparency and accountability for improved governance and demonstrate the need for greater investment.

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