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Cost Effective Wireless Network Based Automated Energy Meter Monitoring System for Sri Lanka Perspective

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Abstract—Many researchers and developers are focusing their curiosity on designing and implementing industrial automated systems based on modern wireless communication technologies. In the most of the developing countries like Sri Lanka, the effort of collecting electricity, water and other utility meter reading of every consumer is a very difficult task. It requires a great number of labors for collecting and processing the meters readings. This paper presents an implementation methodology of an Automated Energy Meter Monitoring System (AEMMS) based on Global System Mobile (GSM) and Zig-Bee technology incorporate with microcontroller that aims to diminish this difficult task by introducing an automated process for collecting meter reading data from energy meter in Sri Lanka. Use of GSM network as a medium for AEMMS establishes a cost-effective and two-way connected wireless data communication between energy provider and consumer's energy meter. Zig-Bee technology provides capability to establish fully coverage in the country by filling the area in which GSM coverage is absence. The AEMMS continuously monitors the energy system and sends information of energy usage and theft detection alert to utility company via Short Message Service (SMS) as well as it sends energy usage bill and power cut alert to the customer via SMS and Email. For these facilities, this system contains a software tool in a server computer at energy service provider to facilitate the utility bill generation and data communication.

Index Terms—Automated Meter Reading, GSM, Microcontroller, Energy Theft, Zig-Bee.

I. Introduction

Electricity is one of the very important requirements of human being for their comfortable life. It is a non-renewable energy source therefore we must use it judiciously for its sustainable utilization [1, 2]. In Sri Lanka, Ceylon Electricity Board (CEB) supplies the electricity in a huge ratio in which most of the consumers are not pleased and satisfied with the services of CEB; because of traditional meter reading and billing methods adopted which requires enormous number of labor and long working hours to collect metering data for billing process. Manual billing is sometimes restricted and slowed down by various reasons. Human operative traditional metering and billing method has high possibility to be inaccurate. Sometimes the energy meter is placed in a location where it cannot be easily accessible by the meter reader when it is located at mountain or large building [7]. Due to the increased population and industrialization in a country like Sri Lanka, it requires facilitated and trusted service with minimum operating cost. A better method of metering and billing process is proposed in this paper called Automated Energy Meter Monitoring System (AEMMS) to reduce the above mentioned disputes. AEMMS provides capabilities for remote metering and monitoring the energy supply to the consumer meter. It handles all the information of the consumer regarding energy consumption through Energy Management Software tool. Also it manages and automates the resources and other associated operations which were managed by manpower previously such as conventional meter reading and traditional bill payment.

Electricity theft is also a common problem to the power distribution sectors in Sri Lanka. Sri Lanka electricity board faces loss of near 30% of its total supply of electricity where a major portion of power loss is due to electricity theft [17]. During the year 2011, officials from electricity board have caught 2935 offenders who used electricity illegally and earned about 199 million LKR by imposing penalties on them [17, 19]. In an

attempt to counter the trend, Electricity Board Officials are forecasting to take in tough laws such as withdrawing electricity supplies to houses or industries who are engaged in the act of electricity theft. The economic impacts of theft reduce the income from the sale of electricity and increase the necessity of overcharging to consumers. Only generating more power is not enough to meet present day electricity requirements. Electricity consumption and losses have to be closely monitored and managed to efficiently utilize the generated power [18]. This proposed system also provides an effective mechanism for detecting electricity theft in household site.

The remainder of this paper is organized as follow: Section 2 and 3 discuss the problem definition and objectives of the study. Section 4 discusses the related work of this study and Section 5 is dedicated for research overview. From Section 6 to Section 9, research methodologies and implementation are shown. Section 10 expresses the results and discussion while Section 11 concludes the paper.

II. Problem Definition

Presently, the most of the houses and industries have mechanical watt hour meters (WHM) in Sri Lanka for measuring electricity consumption and the metering and billing system of electricity board is not fully monitored and automated. End of every month, a meter reader from the electricity board visits every household meter and collects the electricity utility meter reading manually which will later be entered manually in the billing software of electricity board for billing and payment collection. Customers often go to electricity board or other payment center for paying this bill.

Nevertheless, the effort of collecting electricity utility meter reading data related to the consumption of each and every consumer is a difficult task. It requires a great number of labors for collecting and processing the meters readings. The procedures of sending the bills to customer are very laborious and inept. This process is not secured and probability to be inaccurate is high. Further electricity board losses a high percentage of electricity revenue due to power theft, inaccurate meter reading and unwillingness of consumers to pay electricity bills due on time [7]. To solve the above mentioned problems, Sri Lanka electricity board is in need of an effective monitoring and controlling system.

III. Objectives

The main objective of this research is to develop and implementing a fully "Automated Energy Metering and Monitoring System" having advanced competences like remote metering and monitoring the electricity supply to the consumer energy meter. The research is about to handle all the information of the consumer regarding energy consumption using a software tool.

The study also aims the following objects:

- To remote monitoring and controlling the domestic energy meter reading without visiting the site.
- To reduce the labour cost, reading error and operational cost required in the manual metering.
- Provide an effective theft detection mechanism to the energy provider in case of altering the energy meter.
- Provide remote disconnect and re-connect facilities to deal with the customers who have large outstanding dues.

IV. Related Work

In this study, authors investigated the existing traditional meter reading system associated with CEB of Sri Lanka and discovered various drawbacks and difficulties. Here authors have studied different technologies and methods available to reduce or overcome the meter reading problems. Finally authors modeled out a worthy and feasible solution for Sri Lanka standpoint after analyzing the number of research papers and studies. Some of the important papers are summarized and evaluated in this section.

Reference [1] suggests a development of a GSM based automatic power meter reading (GAPMR) system to solve this traditional meter reading problems. The GAPMR system contains GSM digital power meters installed in every consumer unit and an electricity e-billing system at the electricity provider side.

In this study, it is failed to classify the area in which nonexistence of trusted third party GSM network coverage.

Reference [3] proposes a basic wireless sensor network based on IEEE ZigBee standards, with prominence to necessary used in the development of a wireless sensor network for automation of energy meter. Here the result shows that ZigBee can be used to transmit the data constantly for a distance of 85 meters. To extend the range of data transmission up to 100s of kilometers, it requires number of routers in the network.

Even though ZigBee is a good option for low data rate sensor network with small size low power requirement, the implementation cost of the initial network is higher as well as the maintenance cost is also inordinate. So that implementing a new sensor network using ZigBee is not a pertinent option for Sri Lanka standpoint.

Reference [7] suggests Electromechanical Energy meters are being replaced by more accurate prepaid digital energy meters. They also claim that a huge percentage of electricity income was lost due to inappropriate meter reading and monitoring. Considerable amount of revenue losses can be minimized by using Prepaid Energy Meters and prepaid cards. The prepaid card system communicates with the power service provider using mobile communication medium.

In this research, the proposed prepaid meter was a good solution for revenue collection from consumer, but it increases the effort of the billing process which is very problematic to consumers. In the meantime the authors

put forward about communication between prepaid energy meter and power utility using mobile communication infrastructure but the communication module and infrastructure are not clearly exposed in the proposed work.

Some other international literature propose a few solutions to solve this metering problem such as using Power Line Communication, Sensor Network and Radio Frequency as a communication media but all these ideas increase the initial implementation cost and maintenance cost [24, 26].

According to the survey, authors could not find any other work related to automation of metering system using GSM technology in Sri Lanka. In the most of the geographical area of Sri Lanka are covered by already implemented trusted third party GSM networks which were implemented using GSM towers. Selecting the GSM network as a main line communication media to enable communication between consumer and service provider location is an appropriate solution for a developing country like Sri Lanka. Further utilization of ZigBee technology in a few rural areas in which GSM towers are not available ensures the entire coverage of country by filling the gaps due to the unavailability of the GSM networks. Even more authors have introduced sophisticated solution in this study for reducing power theft and tampering detection in meter system.

V. Research Overview

In the AEMMS system, the wireless communication medias are envisioned to establish a network by which data can be transferred between the digital energy meter (user end) and the server computer of electricity supply companies (energy provider end). Various data communication technologies have been analyzed and proposed for AEMMS, including internet, embedded RF module, WiFi, Bluetooth, Zigbee, Radio Frequency, Power Line (PLC) and GSM [1, 6] however authors selected the GSM and Zigbee based communication media among these technology due to its scalability, reliability and security. The Zig-Bee sensor network is incorporated with AEMMS to cover the area in where the GSM network is not available in the country.

In this study, authors have suggested an embedded microcontroller is interfaced with digital energy meter and GSM modem to control both as shown in Fig. 1. The AEMMS system mainly divided into two sub systems namely Energy Monitoring System and Energy Management System.

The Energy Monitoring System is suitable for energy manufacturing plants or power service providers. The system provides the centralized energy supply monitoring mechanism which continuously monitors the energy meter of consumer and sends utility reading data on schedule or request of energy provider as SMS though GSM modem to energy provider station. The data received from an energy meter will be stored in a server computer which is located at energy provider station for further processing.

In the meantime, a remote control switch is attached at the AEMMS energy monitoring unit which has capabilities to disconnect or re-connect the distribution of energy remotely for a particular consumer. A theft detection unit (shown in Fig. 3.) is attached to the consumer's energy monitoring system to identify the illegal usage of energy. It saves cost devote for huge human labors or meter readers.

The Energy Management System is software tool that intended to manage and save the general cost. These savings may be from effective utilization of labors, saving in the energy wastage and losses. Energy provider sends electricity bill after processing bill either by e-mail or SMS to the customer using this energy management system. This system also allows the customers to pay bills online either by credit/ debit cards or any other electronic payment methods. It provides autonomy to electricity companies to take action against consumers who have outstanding dues; if they fail to pay their bill before due date, system disconnect the electricity supply of the particular customer otherwise service provider can continue the power supply of customer [2]. Service provider also can re-connect the power supply after paying the outstanding dues. It also gives the power cut information to consumer prior while gives tampering and theft detection alerts to service provider. Fig.1 shows the general structure of the AEMMS system whereas Fig. 2 shows the Network diagram of AEMMS.

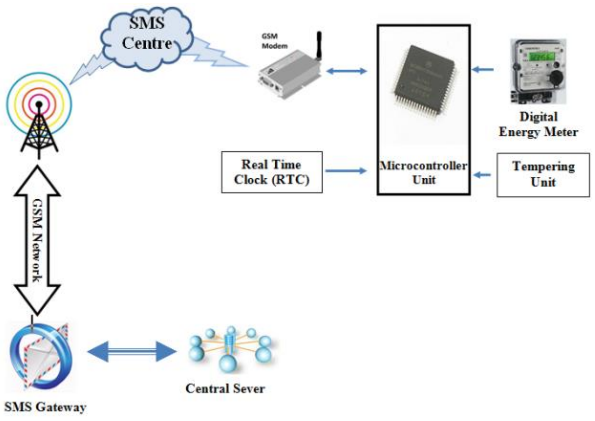

Fig.1. Block diagram of AEMMS

AEMMS is integrated with microcontroller and GSM modem to transmit the meter reading data over the data communication network. These reading data will be later stored into Energy Management System placed at energy provider station. Efficiently collecting meter reading from a large number of energy meters of several houses and buildings are still a challenging problem. In a country like Sri Lanka the GSM networks are networked using towers which are unavailable in some of the remote areas.

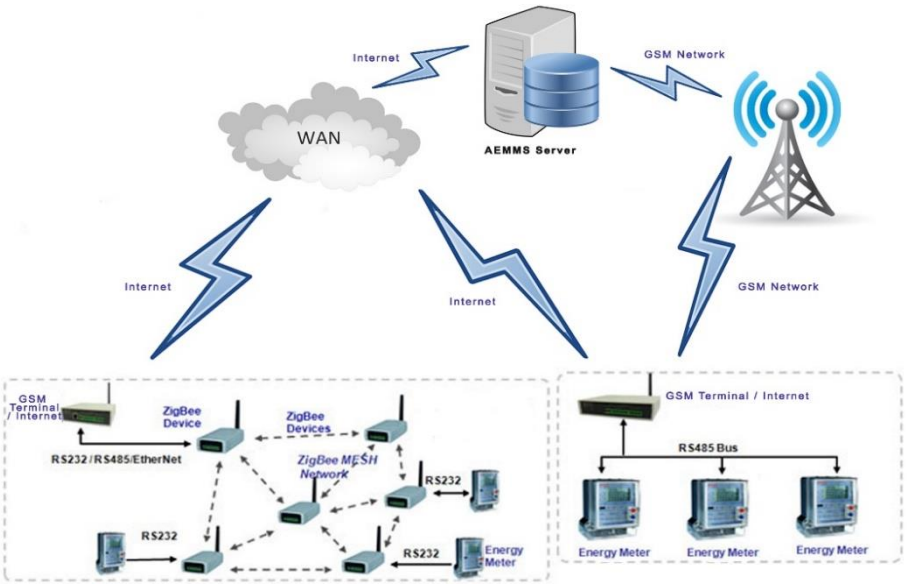

Fig.2. Network diagram of AEMMS

VI. Research Methodology

In AEMMS, a digital energy meter is used to measure the units of energy consumption at the consumer end where a microcontroller counts the number of units measured in the digital energy meter and store in its memory (RAM). The microcontroller is also interfaced with the Real Time Clock (RTC) and GSM modem to communicate with the energy provider's server in which RTC gives the relevant time of meter reading data collection whereas GSM modem sends the message containing meter reading at particular time and date. Every consumer has a separate unique number with respect to the SIM card installed in the GSM modem, which is controlled by the corresponding authority to identify the consumer.

At the same time, a server computer is interfaced with a GSM modem at energy provider end which is used to receive the message from consumer end and sends predetermined command messages to do respective operations on the consumer meter system.

The server computer calculates the bills from the reading of the energy meter with respect to the estimated total unit costs in the relevant interval and sends the bill to the consumer's mobile phone and E-mail. After sending the bill, if the customer got delayed to pay the outstanding bill before due date decided by service provider, a notification alert message will be sent to the customer requesting for paying outstanding dues. Even though if the dues are not paid, the energy supply to the customer will be disconnected by sending the appropriate command from the server. If the bill is paid before the due date, the supply will be re-connected or continuous without any interruption.

VII. Use of Zig-Bee Network

In new epoch of wireless applications, a new standard IEEE 802.15.4 has been invented that is named as ZigBee. ZigBee is a low cost, low power wireless mesh sensor networking standard [20]. This permits the technology to be widely deployed in wireless monitoring and controlling systems, the low power with smaller batteries allows longer life and mesh networking provides high reliability and scalability [3, 6, 8].

In this AEMMS implementation model, a separate network is implemented using ZigBee technology where the GSM Network is not accessible or available. The Zig-Bee communication system collects the meter reading data and sends to the further connected electricity regional/sub-regional office, which will rather act as a base station. Base station is connected with central server of energy provider which accumulates the reading data using ZigBee network and then sends to the main server. The result shows that ZigBee technology could be used to transmit the data continuously for a distance of 85 meters. To extend the range of data transmission up to 100s of kilometers, it is the best option adding routers in the network [3].

VIII. Methodology for Theft Detection

Electricity theft is a very communal problem in many developing countries like Sri Lanka. Mainly the electricity theft happens via bypassing the energy meter using a piece of wire, people simply bypass the energy meter which measure the consumption units by placing a wire before and after the meter reading unit [9, 10, 17].

For energy theft detection, a comparison module is set at the consumer digital energy meter that receives meter data of the measured power consumed by a customer (Pconsumed) and delivered power data that includes meter data of the power delivered to the customer (Psent). These two data will be sent through comparator that compares the two values (Pconsumed – Psent) and determines a difference between the sent power data and the delivered power data.

If the difference between the sent power data and the delivered power data is greater than a predetermined amount, indicates a discrepancy occurred. Then the microcontroller in the comparator takes the differences and customer identification ID and sends an alert message to the electricity substation through GSM based communication network. The block diagram in Fig. 3 shows the basic components of the comparison module.

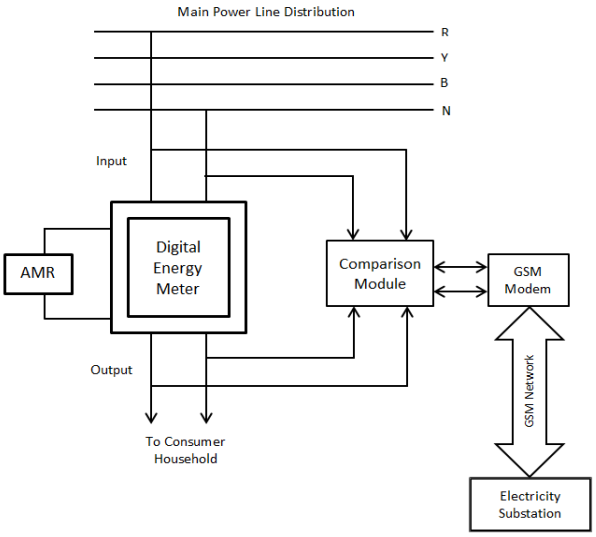

Fig.3. Block diagram of theft detection unit in AEMMS

On every occasion the input power passes from supplier to the consumer and the total amount of power receives by the receiver are not equal indicates a possibility of theft of power [9, 16]. Following mathematical comparison occurs in the comparison unit.

$$\Sigma Psent = \Sigma Pconsumed + Loss \rightarrow \text{No Energy Theft}$$

$$\Sigma Psent \neq \Sigma Pconsumed + Loss \rightarrow \text{Energy Theft Occurs}$$

Where, Psent is the Meter data of the power delivered to the customer, Pconsumed is the Meter data of the power consumed by a customer.

IX. System Implementation

The flow diagram shown in the Fig. 4 describes the general flow of the data and processes in the AEMMS, between the energy provider and the meter system installed in the consumer household. The energy provider often requests the data of reading from consumer site meter in every month or in a relevant interval. When the request message is received to the microcontroller, the digital energy meter constantly gives the reading as number of units consumed with the date and time of the corresponding reading to the energy provider using GSM modem. If any unauthorized message or alteration occurs, the microcontroller will send an alert to the energy provider.

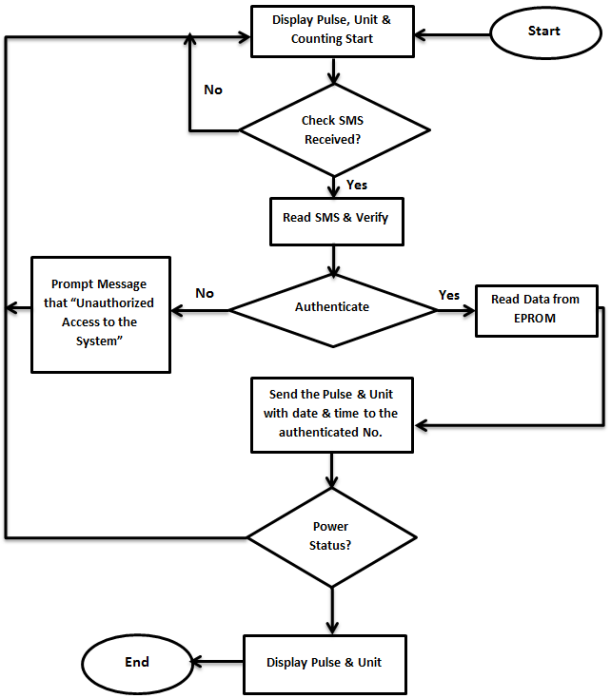

Fig.4. Flow diagram of AEMMS

The microcontroller application was programmed using C language in the Keil MCB2130 integrated development environment (IDE). All software development tasks including editing, compiling and debugging were done using the above mentioned IDE. The given algorithms show the clear function of the system in the consumer and service provider end. The tested prototype of the implemented system is shown in Fig. 5.

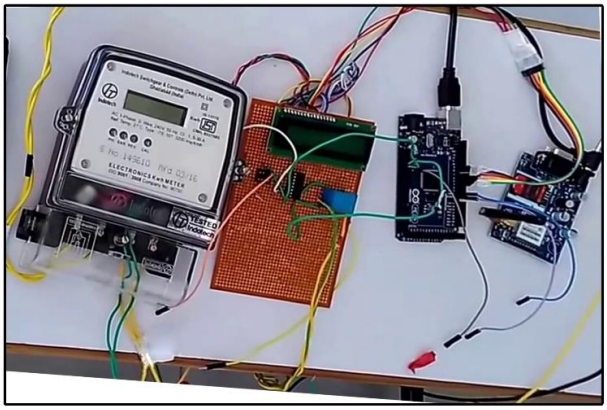

Fig.5. Prototype of AEMMS in a simulated environment

A. Algorithm for Automated Energy Meter Monitoring at Consumer's End

1. ***Start***
2. ***Initialize the AEMMS.***
3. ***Check the message status received from service provider.***
   If the message pulse is 1, connect energy supply and read the current meter reading.
   If the message pulse is 0, disconnect the energy supply.
   Else
   Go to step 2.
4. ***Measure the time of meter reading using RTC.***
5. ***Store the values at microcontroller and send the message (reading + time) using GSM modem.***
6. ***If the received message pulse is invalid then prompt an alert message to sever and repeat the step 2***

B. Algorithm for Energy Monitoring and Billing Process at Server End

1. ***Start***
2. ***Initialize the request signal***
3. ***If the reading is received from consumer meter, start data transfer to the server from microcontroller with the unique ID***
   Otherwise
   Go to step 2.
4. ***Calculate the total consumption cost + outstanding dues and send invoice to the customer via SMS and Email,***
5. ***Store the calculated values at server***
6. ***If the confirmation message is found, then erases the content of the message status and stop***
   Otherwise go to step 2.
7. ***If the consumer due is not paid, disconnect the energy supply and go to step 2.***

X. Results and Discussion

The traditional metering and billing methods requires huge number of manpower and long working hours. In Sri Lanka the Ceylon Electricity Board (CEB) is responsible for electricity distribution over the country which spends a large amount of money in the metering process. In this research authors have designated Kalmunai Division of CEB as an illustration area for cost analysis in the metering process. The Kalmunai CEB office obligates 37 employees for collecting the meter reading from 76,013 electricity consumers in 2015. The Table 1 shows the cost analysis related to metering in Kalmunai area in 2015 with details of consumers and meter readers. Through implementing this project, the CEB can save about 1,028,000 LKR (7700 USD) per month in Kalmunai region. The implemented AEMMS system was tested in a simulated environment and shown high accuracy in an acceptable range. The GSM based communication network has provided excellent performance in connecting devices and software system for wireless communication.

Table 1. Cost Analysis Related to Metering in Kalmunai Area in 2015

S.No	Types of Consumer	No. of Consumers
1.	Single Phase consumer	74,695
2.	3-Phase consumer	1269
3.	Bulk Supply consumer	49
Total Number of Consumers		**76,013**

Number of Meter Readers:- Permanent: 24 & Contract: 13
Unit cost per reading:- For Rural area: Rs.9.00,
For Urban area: Rs.8.00
Total meter reading cost (≈) per month:- Rs. 1,028,000.00 (7700 USD)

Fig.6. Home window for Energy Management software in the server computer

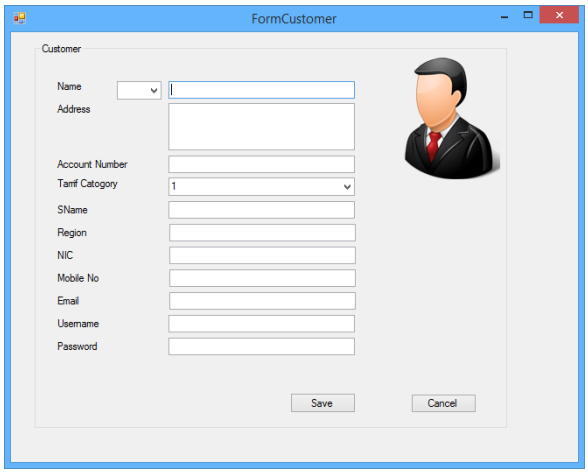

Fig.7. Customer Registration Window for Energy Management software

We have named the energy provider company as Green Life Energy (Pvt.) Ltd for demonstration purpose. Fig. 6 shows the home window for Energy Management software in the server computer where the administrator can do multiple functions such as adding new customer, check and pay bill of the particular customer and generate the email and SMS to the customer. Fig. 7 shows the customer registration window for Energy Management software in which new customer can be added by the administrator. As shown in the Fig. 8, the customer can check their bill and pay their bill using online customer support system after successful

authentication. A SMS alert sent by the Energy Management software to the customer is shown in the Fig. 9 whereas an E-mail message is shown in the Fig. 10 in the same type.

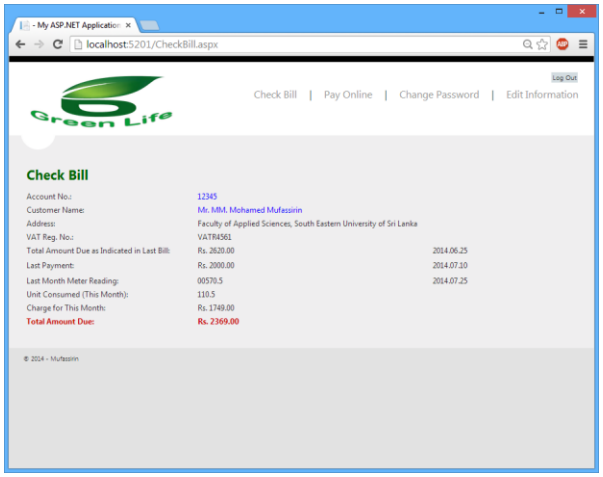

Fig.8. Check bill page of online customer support system

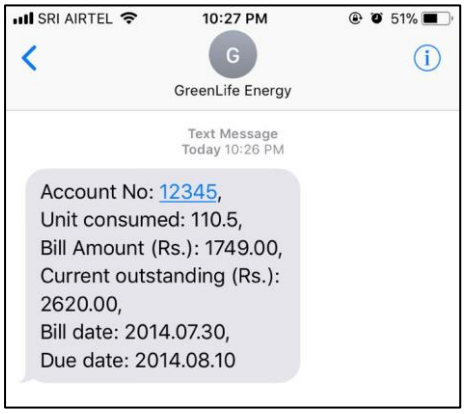

Fig.9. SMS alert of bill details sent by Energy Company to customer

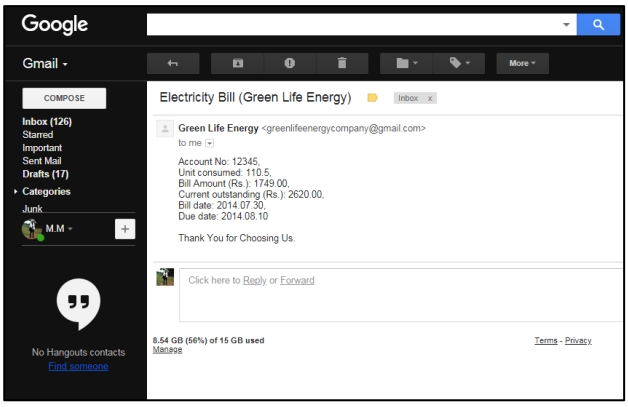

Fig.10. E –mail alert of bill details sent by Energy Company to customer

XI. Conclusion

The proposed AEMMS in this paper occupied many advanced study results in computer technology and communication technology. It presents an implementation methodology of an Automated Energy Meter Monitoring System based on GSM network and Zig-Bee technology which are incorporated with microcontroller. AEMMS avoids the task of manual metering by automating energy meter reading in Sri Lanka. The meter reading and controlling task can be done at the energy provider's management station without visiting the consumer energy meter. At the same time, the energy provider can control the distribution of power connection remotely.

The system provides many significant superiorities, such as wireless data transmission, low-workload, anti-theft mechanism and less-expenses to CEB. The using of embedded microcontroller and GSM modem improves the stability of wireless data transmission. By using this system the invoice will be sent to the customer directly via SMS and Email in which paper is not required for billing which saves paper and printing cost. The bill can be paid using online customer support system of AEMMS. For a long distance of transmission of data GSM based communication has shown admirable performance. Use of Zeg-Bee technology ensures the entire coverage of the country.

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Authors' Profiles

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