KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

COLLEGE OF ENGINEERING

DEPARTMENT OF TELECOMMUNICATIONS ENGINEERING

SMART METERING DATA INTERGRITY INFRASTRUCTURE FOR UTILITY GRID MANAGEMENT SYSTEMS – A CASE STUDY OF BASE TRANSCEIVER STATIONS

SUBMITTED FOR FULFILMENT OF THE DEGREE OF MSc.

TELECOMMUNICATIONS ENGINEERING

BY

ABDUL RAZIZ ARMAH

(BEng Hons)

MAY, 2016

DECLARATION

I hereby declare that, submission of this hypothesis for MSc is my own work which does not contain any material published by any other person except for explicit references that have been acknowledged. This study was done solely by me and neither has any part been submitted to the University or any other educational institute in award of a degree.

Signature……Date……

ARMAH, RAZIZ ABDUL (BEng Hon)

(Candidate)

Signature……Date……

EMMANUEL AKOWUAH (PhD)

(Supervisor)

Signature……Date……

E.A. FRIMPONG (PhD)

(Head, Department of Electrical/Electronic Engineering)

DEDICATION

This dedication is to my parents, the Late Madam Kadijatu Naa Ahima Quarcoo and Nii Adama Mills-Armah.

Glory be to God Almighty, for His Grace and Mercies that he has made it possible through his beloved son, Jesus Christ.

ACKNOWDLEGEMENT

I would like to offer my heartfelt appreciation to my supervisor Dr. Emmanuel Akowuah for accepting to supervise my work and his encouragement, and useful suggestions that have enable me complete this thesis work successfully.

I also want to offer my sincere appreciation to all the lecturers and staff of Electrical/Electronics, Computer and Telecommunication Engineering for the various ways they have all contributed to make this work a success.

I acknowledge the support of my course mates and all my friends.To Mr. Akwasi Sarfo-Adu; for accepting to read through my work.

Also my family and relatives, most especiallyto my wife Eunice Ama Armah, Ramatu Naa Dede Armah, Malik Nii Aryee Armah and Faisal Nii Okine Armah, you have all been my source of inspiration.

Finally and most of all, I will like to thank God, the giver and keeper of life, for blessing me with all these people.

ABSTRACT

The demand management side of the utility power system has evolved with some levels of communication processes and procedures between the consumers and providers. Sharing of data in terms of energy consumption data used in billing consumers have been done manually through meter reading agents with their share of discrepancies being recorded in the process. The providers had to introduce another type of metering system which requires that data and its related information are processed and submitted by the meters automatically and remotely. Based on the experienced with the conventional metering system of reading meters, we realised and proposed the involvement of the public utility regulator in this process of energy consumption data being shared between the stakeholders to assist in the validation of consumption data used prior to billing consumers in order to forestall these conflicting issues arising after submission of bills by utility providers. Field data taken from the BTSs confirmed the level of disparities in both data used for billing by the utility provider as against the data from the consumer's premises.MATLAB Simulink model was used to investigate and eliminate toally the disparities which were realised during the field data collection.The Virtual Machine Toolbox was also used to practically established the level of feasibility and viability of the model by ensuring a machine-to-machine communication system between the provider and the regulator so that manual interventions will be absolutely negligible in this process since its purpose is the establishment of trust and integrity among stakeholders. The results obtained during the tests showed that it is possible to achieve very high level of data error elimination in the billing system within the demand side management system.

TABLE OF CONTENTS

DECLARATION ii

DEDICATION iv

ACKNOWDLEGEMENT v

ABSTRACT vi

TABLE OF CONTENTS vi

LIST OF TABLES viii

LIST OF FIGURES ix

LIST OF ACRONYMS x

CHAPTER ONE 1

1.0 Introduction 1

1.1 Motivation 3

1.2 Problem Statement 4

1.3 Research Objective(General Objective) 5

1.4 Specific Objective 5

1.5 Research Significance 5

1.6 Structure of Thesis 6

CHAPTER TWO 7

2.0 Introduction 7

2.1 Traditional Grid 7

2.2 Smart Grid 9

2.2.1 Active Distribution Grid 10

2.2.2 Smart Metering 11

2.3 Overview of the Billing Infrastructure 13

2.4 Review of Existing Related Works 14

2.4.1 Existing Challenges in the Billing System..... 17
2.4.2. Data Collection at Meter Points 17
2.4.3. Manual Data Entry Points 17
2.4.4. Manual Data Query Mechanism. 18
2.5 Features of the Billing Infrastructure 18
2.5.1. Energy Consumption Meters 19

2.5.2 Data Acquisition and Authentication Process..... 24

CHAPTER THREE 25

3.1. System Modelling 25

3.2 Comparison of Energy Consumption between Consumer and Utility Provider 25

3.3 Existing Automatic Meter Reading Infrastructure 32

3.4 Developing a Model for Data Integrity in the Backhaul Network..... 34

3.5. Data Transmission Scheme in the Backhaul Network 39

3.6. Query of Energy Consumption Data..... 42

3.7. Validation of the Energy Consumption Data 44

CHAPTER FOUR 46

4.0 Data Analysis Results and Discussions 46

4.1 Consumption Data Collection 46

4.2 Data Model from Energy Meter Gateway 47

4.3 Model for Consumption Data Analysis 48

4.4 Comparison of Actual and Expected Consumption Data 50

4.5 Validation of Submitted Data 54

CHAPTER FIVE ..... 59 CONCLUSION AND RECOMMENDATION 59

5.0 Conclusion 59

5.1 Recommendation 60

5.3 Future Works 61

REFERENCE 62

APPENDIX 65

LIST OF TABLES

Table 2.1: Benefits derived from smart meter data [12] 12

Table 2-2 Communication Technologies used for smart grid [31] 23

Table 3-1 Monthly energy consumption recorded for Meter A 27

Table 3-2 Monthly energy consumption recorded for Meter B 28

Table 3-3 Monthly energy consumption recorded for Meter C 29

Table 3-4 Monthly energy consumption recorded for Meter D 30

Table 3-5 Monthly energy consumption recorded for Meter E 31

LIST OF FIGURES

Figure 2-1 Tradiional Grid [8] 7

Figure 2-2 Existing power consumption and billing infrastructure 13

Figure 2-3 Cause of metering losses in Ghana [29] 20

Figure 2-4 AMI solution architecture 21

Figure 3-4 Monthly energy consumption recorded for Meter D 30

Figure 3-6 Existing smart metering process 33

Figure 3-7 Proposed infrastructure for smart metering in Ghana 35

Figure 3-8: MATLAB-Simulink depicting the model in establishing the data integrity. 36

Figure 3.9: Oracle Virtual Box Manager used in the creation of machine-to-machine communication. 37

Figure 4-2 Model for ECG service provider data aggregation, query and analysis system web page 49

Figure 4.7 Flow diagram of the machine –to machine validation process 54

LIST OF ACRONYMS

3G	Third Generation
4G	Fourth Generation
ADC	Active Distribution Control

ADG	Active Distribution Grid
AMI	Automatic Metering Infrastructure
AMR	Automatic Meter Reading
CAPEX	Capital Expenditure
CP	Consumer Protection
DNP	Distributed Network Protocol
DSL	Digital Subscriber Line
DR	Demand Response
ECC	Elliptical Curve Cryptography
ECG	Electricity Company of Ghana
EIM	Electromechanical Induction Meter
FO	Fiber Optic
GPRS	General Packet Radio Service
GRA	Ghana Revenue Authority
GRIDCo	Grid Company
GSM	Global System Mobile
HAN	Home Area Network
IEC	International Electromechanical Commission
IED	Intelligent Electronic Devices
IP	Internet Protocol
IPP	Independent Power Producers
Kbps	Kilobits per second
LTE	Long Term Evolution
M2M	Machine-to-Machine
Mbps	Megabits per second
Neg	Negative
NHIA	National Health Insurance Authority
OPEX	Operational Expenditure
PLC	Power Line Communication
PMU	Phasor Measurement Unit
PURC	Public Utilities Regulatory Commission
QoS	Quality of Service

RF	Radio Frequency
SCADA	Supervisory Control and Data Acquisition
SLA	Service Level Agreement
SLT	Special Load Tarrif
TDM	Time Division Multiplexing
VM	Virtual Machine
VoIP	Voice over Internet Protocol
VRA	Volta River Authority
WAN	Wide Area Network
WiFi	Wireless Fidelity
WiMAX	Wireless Interoperable Multiple Access

CHAPTER ONE

INTRODUCTION

1.0 Introduction

Traditional grid has been useful to the nation for the past fifty years and beneficial to the socio-economic development of the country. This strategic investment has evolved from time to time and there have been some technological growths in the utility grid sector but not as will maximise the operational efficiencies required in the sector.

Relationships between the national utility power provider and their consumers have been fairly cordial but with some level of controversies. Some of these controversies have been meter tampering, energy consumption data disputes, billing issues etc. With regard to billing, the processes have been very challenging for the industry due to the management of consumption data from the consumers' premises to the billing processing office of the provider. The handling of data from the conventional meters through the meter reading agents to the provider has sometimes generated doubts in the minds of consumers, which results to the cases being referred to the utilities regulator for redress. For years, the national regulator in the utility grid sector has had to resolve and settle such issues. With these challenges a provider introduced the automatic meter reading to their special load tarrif (SLT) consumers to see how best the errors can be eliminated from the billing process, but since the introduction of these meters there are some consumers who still have disputes and mistrust in the data presented. As the adage goes "prevention is better than cure" hence the need for the regulator to prevent these issues and challenges from happening.

This thesis is to investigate and analyze how the provider and the regulator can be placed on the same platform to establish communication mechanism by sharing information instantly, real time and effectively to minimise the disputes and attain some level of integrity in the data shared among stakeholders. Existing communication infrastructure between the utility providers and consumers has been through bills, mobile van broadcast or consumers calling

providers toll lines or meeting provider's personnel face-to-face to present their complaints. On the other hand, the utility provider communicates with the regulatory authority through letters, electronic mails, submission of periodic reports both regular and on occasional events. All these means of communication have been fruitful but the aspect of machine to machine communication, which is currently deficient in the industry, when introduced will enhance and improve the existing communication system between these stakeholders in the utility power sector. Machine to machine means no human intervention while devices are communicating end to end [1]. Presently it will require that the utility providers, the consumer and the regulatory body must be able to access data or information from the energy meter accurately, real time and simultaneously. Same must be in the future for these stakeholders as well as potential ones in the future. The metering information is a vital issue for various consumers (public and private sector companies, commercial and residential customers, bulk power usage customers etc.) since it is the source for generating energy consumption invoices.

A common standard for metering, meter data collection, communication and reporting are required as the basis for utility providers' good performance.

Below are the few key points regarding metering functionality.

1. Energy counters and tariffs data – Energy counters and tariffs data are collected per a connected point and stored in the identity data base. This can be done according to the existing policy, preferably hourly etc.
2. Meter data – This is the management of meter data. The function provides handling of data to deliver various analysis reports including billing. The energy counters are stored over certain period of time and then they are used for the purpose of analysis and billing.
3. Information reporting – Energy and accounting information are handled by the function to provide analysis of reports for electronic media , hard copy depending on the standard of the agreement of each electricity market.

4. Meter information and statistics - This gives in details the operations regarding information of the metering communication system. It is important to know the status of the meter.
5. Consumer two way communications – This function is required to achieve the objectives of remote metering in a competitive market. In a two way communication data are transferred to the central data management station and in return data can be transmitted back to the meter device. The return data can be messages, direct command of meter devices [2].

The AMR power meters are typically utilized to monitor utility consumption or usage. In many cases the AMR acts as a smart utility meter configured to monitor usage and communicate usage data to a utility provider. In order to facility communication with a utility provider, the utility meter typically includes an interface configured to communicate over an Advanced Metering Infrastructure (AMI) network [3].

However, conventional utility meters only include a single AMI interface capable of facilitating communication with a single utility provider but in order for the meter to become a gateway, multiple AMI meter can be introduced to facilitate communication with a plurality of respective stakeholders.

1.1 Motivation

Utility grid service provision in the country has been done for the past decades but there are errors in terms of billing, faults analysis and decisions making processes by utility providers particularly in billing processes. Consumers continually dispute energy consumption data which the utility providers used in billing them. The situation has motivated me enough to research in this matter and proposed a win-win solution for all stakeholders (i.e. Ghana

Revenue Authority, Volta River Authority, Independent Power Producers, National Health Insurance Authority, Grid Company of Ghana, Public Utility Regulatory Commission, etc.) who have interests directly or indirectly in the final monthly revenue collected by the utility power provider. Also to ensure that both utility provider, consumers and other stakeholders do not feel cheated let alone say it. Hence the strong need to investigate further and research into a mechanism that will help all stakeholders establish some level of integrity in the data used in billing consumers. This proves that it is very essential to have the data shared between the major stakeholders in the utility industry which will facilitate the communication flow among them but the credibility of these data will be very much required to establish trust in the industry.

To the best of our knowledge there are no data integrity infrastructure systems between the relevant stakeholders which can help in the establishment of the needed trust and this is the aim of the thesis to attain. Consumers can only manually record the energy consumption on daily basis in order to establish whether the providers have cheated them or not and this is indeed a full time job to perform. It was realized that a consumer's data collected and in comparison with the provider's data had some inconsistencies and these inconsistencies were not minimal but also enormous.

1.2 Problem Statement

As the grid system experiences 10% expected growth annually [4] it requires that it grows in terms of integrity in the billing process by the providers. The regulator records approximately 40% of consumers' complaints being billing issues in the year 2008 and averagely 42.5% from year 2001 to 2008[5]. Annually the regulator is unable to resolve some of these complaints entirely leading to more mistrust among the stakeholders especially the consumers. This thesis seeks to investigate and review the existing infrastructure used by the providers in billing

consumers in the country and to determine an effective data integrity platform prior to billing of consumers which will bring satisfaction to all players in the industry.

1.3 Research Objective (General Objective)

The main objective of this thesis is to determine a smart metering data integrity infrastructure for the utility power system in Ghana.

1.4 Specific Objective

The specific objectives of this research are to:

1. Compare customer energy consumption to the utility providers' consumption bill.
2. Review and analyse inconsistency in billing information.
3. Develop a data integrity infrastructure for billing.

1.5 Research Significance

The power sector, in recent times, is facing several challenges. First it is a significant concern regarding changes, climate, socially and electricity consumption-wise and a strong effort needs to be done in order to catch up with the advancement of global changes. In addition to this, electric power infrastructure is reaching the limits, increasing the network congestion. Furthermore, the electricity demand is continuously growing making the current scenario even worst [6]. The demand for electricity supply expected growth annually is 10% in Ghana. This growth continues to make the distribution and data collection for analysis very cumbersome and time consuming hence depreciating the quality of services required by the stakeholders and even in data collection for analysis, quality of service is compromised. This therefore deepens the necessity to have an effective communication system which will facilitate the

service quality highly required by utility power providers, the consumers and regulatory body [7].

This research is very significant to the very present situation as the nation faces especially when the telecommunication platform in the country has been well established and there are options available to the utility providers to research and advance their communication mechanism by utilizing the platform available to them or even acquiring their own licensed frequencies to effectively established a form to support the applications required of them as providers.

1.6 Structure of Thesis

The remaining chapters of the thesis are organized as follows: Chapter 2 presents a review of existing [literature on data integrity in smart metering within the area networks. Chapter 3 introduces and discusses the various models employed in this thesis. Chapter 4 discusses the results of the research. The thesis is then concluded in chapter 5

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter presents an overview of existing infrastructure of the power consumption billing process and a review of the existing infrastructure including the challenges facing the infrastructure and it related work.

2.1 Traditional Grid

The traditional utility power grid designed in the 1950s, had a primary and only objective of providing electricity to industry and residents. The traditional grid could be divided into three subsystems namely, generation, transmission and distribution systems.

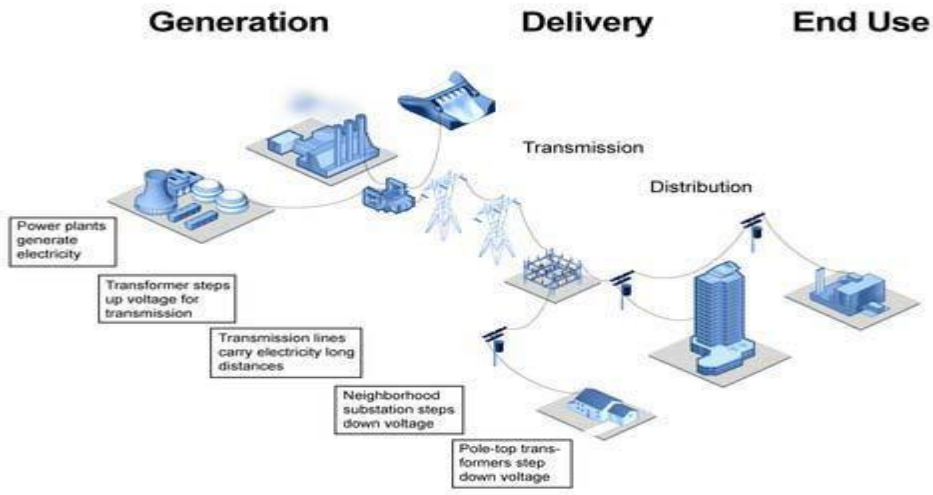


Figure 2-1 Tradiional Grid [8]

The figure 2.1 shows the traditional power grid with the transmission system that includes the power generation plants, step up transformers pole-top or ground mounted transformers, and medium voltage power lines. The power plants generate electricity and step up the voltage for long distance transmissions using step up transformers. Further, electricity is transmitted across the high power transmission lines over long distances to substations where the voltage is stepped down before transmitting over high tension voltage power lines to the consumer premises. The pole top or ground mounted transformers further step down the voltage to suit the residential and commercial specifications figure.

The traditional power grid infrastructure is largely analogue and electromechanical. It is built on a producer-controlled model where the power flows only in one direction; that is from the grid to the consumers. Even with great advances in computer systems, technologies like internet and electronic devices, there still remains a vast disconnect between the traditional grid infrastructure and these advances in technologies due to lack of investments into the industry. The traditional grid hasn't been very intelligent as required particularly in the distribution system where consumers have to report faults or outages to providers before they

become aware of these faults. Hence the need for smart grid because the following can be realized when smart meters are introduced into our present utility power system networks.

1. Reliability: In the current electricity architecture, the utility power providers are informed of the blackouts or outages, and only if a customer calls them up notifying an outage. This again, infrastructure which lacks the outage management system is directly affecting the reliability of the grid. To explain the effects of these blackouts, consider the many occasions when outages occur and these had some economic losses to the country.

An intelligent grid with effective communication infrastructure detects an outage immediately and notifies a utility office about the outage but these can be enhanced if the other two stakeholders which are the consumer and the regulatory body are also integrated to the infrastructure setup so that the real time notification will make these stakeholders contribute in the decision making process at that particular pont in time when their inputs are needed

2. Security: The current centralized grid is vulnerable to tourist attacks and any tampering activities because in case of such acts, there would be a complete outage or disruption of power availability and reconstruction of such huge centralized electricity infrastructure in a short time would be impractical. In case of attacks a significant area is affected with lack of power singly having the power generation distributed would help us reduce the devastating effect of terror attacks or any natural disaster [8]. Lastly, the losses incurred both by human errors and other means will be brought to a minimal level when the introduction of smart grid to the electrical power system is completely achieved.

2.2 Smart Grid

Smart grid is a framework to modernize the power generation, transmission and distribution system via the use of latest information technologies. It is the transformation from a centralized producer-controlled network to one that is less centralized and more customerinteractive,

efficiency, reliability, flexibility, remote monitoring and grid visibility are some of the key attributes used to define a smart grid.

Fundamental enabling technologies for smart grid are sensing and measurement technologies with data from the sensing and measurement devices integrated with the utility's integrated system communications. These technologies provide real time information and control to support faster and more accurate responses such as remote monitoring, energy consumption for power billing and demand side system management.

Within the smart grid, framework technologies like Advanced Meter Infrastructure (AMI) leverages smart devices deployed at homes and other end points to not only measure and analyze usage but also offer pricing base on time of use and device types. This is achieved via the use of two – way data transmission with the smart meter, wireless enables devices like smart meters are being adopted in AMI solutions. Utilizing the mobile wireless data network, a comprehensive approach in the planning, design and deployment of wireless AMI solution can help avoid some of the common pitfalls. A robust wireless AMI solution must account for faster like wireless coverage variability and end – point manageability [9].

2.2.1 Active Distribution Grid

The active distribution grid is the infrastructure from the providers substations, through their low voltage network to the meter installed at the consumers premises. From the meter, the consumer can access electricity to energise equipment that is being used at the premises. In this distributive network a lot of sensors and control mechanism are used to make the network real time and active in dispensing information to a particular control room which monitors the network for quick decisions to be made on situations which require human intervention. Although the meters installed at the consumers premises in the past were not manufactured to act as sensors, the present situation is gradually changing where meters are designed for special

load tarrif (SLT) consumers which the installed meters communicate directly to the providers premises thereby aiding the power provider to micro manage the grid system.

With these meters a communication infrastructure can be established within the demand management side where the regulator can be introduced to the platform to assist in resolving disputes between the consumers and the providers.

The demand management side has been passive; this will enhance and solve the billing issues which the regulator is always faced with in solving consumer/provider complaints especially with billing matters. Apart from the meters acting as sensors, there are other elements such as devices used in attaining high level of smartness for the distribution network. The intelligent contribution of these elements will satisfy the key needs for the Active Distribution Grid [10] The developing of utility-scaled active power regulation platforms that enable the providers worldwide to further leverage the investments of the past, confront the challenges of the present and evolve into an excellent power service in the future and so these platforms bridge the three experiences together.

2.2.2 Smart Metering

Smart metering is the process of using meters which are electronic with information technology features and operability to collect electrical signals base on the designated durations.These information from the smart meters are transmitted to the various recipnts on specific duration intervals.Smart meters are highly improved meters than the conventional electromechanical meters. Their introduction into the utility power infrastructure has aided utility providers to micro manage the system seamlessly and remotely with high level of reliability being achieved. Samrt meters are also to help consumers participate in the micro management of the demand management side of the power system.This can be achieved when consumers seldomly monitor their consumptions patterns and be able to make some savings on the usage of the power

available to them. The smart metrs have been designed to be robust and last for years when installed amid severe environmental conditions and physical stress tests.Its objective of being seamlessly integrated into the power system meets all standard electronic and communications protocols for meters and user-friendly [11]. Another issue, which is the main objective of this research, is the smart meter having the communication system that will have the operability means to serve as a multiple gateway between the consumer, the utility providers and the utility regulator. All events which occur, the data can be shared real time with the interested parties. This means that remote meter reading data will be shared among these stakeholders without any human intervention, remote fault detection at any point in time will be communicated to all stakeholders without doubts to aid them be on the same wavelength thereby speedily resolving matters of confusion and argument when such issues occurs. Demand response and remote connection/disconnection will be understood by all because of the real time information getting to all stakeholders, leading to reduction in complains and agitations. Often bills are brought to consumers and they confront utility providers on these bills because of the view that they're being over billed. But a lot of possible events occur in the absence of the consumers. The smart meter solutions must be able to provide consumers the option to choose their maximum load settings for themselves so that excess load when detected by the meter, the meter can go offline until the required load is used at the premises, office, home or any other place.

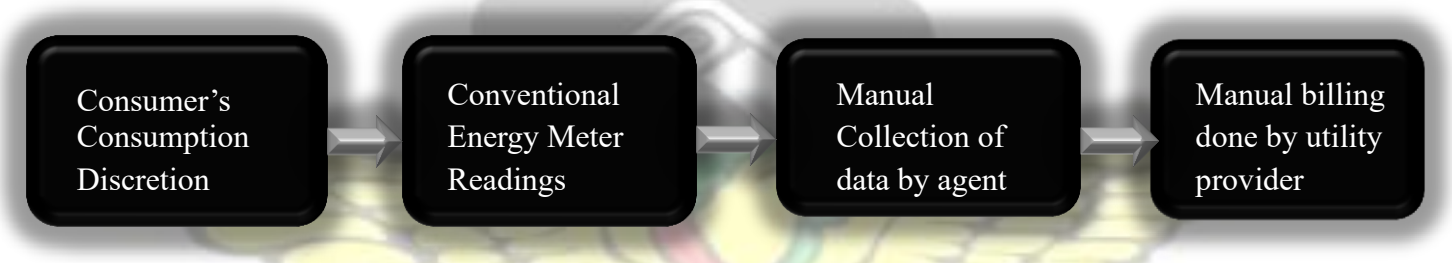
Table 2-1 shows some would-be beneficiaries of the smart metering data and why?

Table 2.1: Benefits derived from smart meter data [12]

Who wants smart meter data?	**How could the data be used?**
Exisiting Utility Power Providers	To monitor electricity usage and load; to determine bills
Potential Utility Power Companies	To study and analyse the consumption trends and consumer behaviours
Electricity usage advisory Companies	To promote energy conservation and Awareness

Insurance companies	To determine health care premiums based on unusual behaviours that might indicate illness
Marketing Institutions	To profile customers for targeted Advertisements
Law enforcers	To identify suspicious or illegal activity
Civil Litigators	To identify property boundaries and activities on premises
Landlords	To verify lease compliance
Private investigators	To monitor specific events
The press	To get information about famous people
Creditors	To determine behaviour that might indicate Creditworthiness
Criminals	To identify the best times for a burglary or to identify high-priced appliances to steal

2.3 Overview of the Billing Infrastructure



Power consumption and billing have been load monitoring, analysis and response which largely have been done by the utility providers. In conventional power grids, the two sides of the electricity demand and supply system are basically disconnected. As a result consumption and billing are performed exclusively by the utility providers using mainly raw data based on local operation monitoring and estimations. These approaches have significant drawbacks in terms of revenue collection for the other stakeholders which will be using the accurate financial projections to effectively prepare budgets, realize accurate investment projections for their institutions.

Figure 2-2 Existing power consumption and billing infrastructure

The majority of the meters have been electromechanical and mono directional in their operations hence the billing process has been manually done. The above diagram illustrates the energy consumed by the appliances which are recorded by the conventional meter on the consumer's premises. These readings in kilowatt-hours are manually recorded by the meter reading agents for onward submission and processes by the utility providers.

The data are entered into the provider's billing database and then analyzed before the bills are printed and circulated to the consumers for payment. During these stages in billing, the processes have been prone to errors leading to some disagreements between the provider and consumers forcing the regulator to spend huge resources in investigating and ensuring undoubtful resolution on these issues while establishing trust and integrity among these two stakeholders.

2.4 Review of Existing Related Works

The essence of the smart metering infrastructure is to have security, integrity and efficient levels achieved so that the objectives of deploying these smart meters into the distribution system will be reliably realized.

The available literature on reliability of power systems is extensive [13 and 4]. et al Chowdhury [15] investigates a reliability mode l to determine the distributed generation equivalence to a distribution facility based on comparable reliability rendered by distribution and generation solutions using a small illustrative distribution system but et al Cristina Alcaraz [16] echoes on proofs of storage for data that allows checking of the volumes of data stored in a server which produces high storage overhead and low communication time. An operational control with a minimal delay for ensuring performance in real time and quality of service in a control system which is robust to continue with its services in a secured manner irrespective of the situations

surrounding the system. A virtual SCADA approach via wireless cloud communication proposed to ensure some level of protection, integrity and accountability for the provider without much access being given to the regulator to monitor the performance of this control system.

Hazen et al. [17] proposed a management protocol for data communication between the utility provider's server and the customer smart meters. The model is mainly between the smart meter and a security associate in utility, which covers unicast and multicast communications. This protocol improves the network overhead caused by security management controlling products. [18] et al X Wang proposed security framework which will establish some level of cost effectiveness, flexible monitoring and control of end devices via wireless communication and networking functionalities being embedded in the distribution infrastructure with no monitoring mechanism for the regulator to be one of the pivotal contributor to the integrity and reliability required for the infrastructure. Collection of power usage information from the smart meters for the purpose of billing consumers through PLCs was expounded also but this is limited to the provider and no access to the regulator. B Vaidya, D. Makrakis [19] proposed an authentication and key establishment mechanism which is based on Elliptic Curve Cryptography (ECC) and public key mechanism which is

self – certified.

Y. Yan [20] proposed an in – network shared system to secure the data integrity using cryptographic keys established in the mutual authentication.

Efthymious [21] et al proposed an anonymization base approach to hide the identity of smart meters in high frequency metering data using pseudonyms. A mechanism which will involve the introduction of a third escrow party in the metering data anonymization verification process but does not preclude the provisions of attributable metering data required for billing purposes. The introduction of two separate identification mechanisms to be embedded in the smart meter

rather than the single ID as in the case with standard meters which being high frequency and low frequency related messages checks with much attention given to high frequency identification message checks assigned for anonymity purposes.

Garcia et al. proposed a no leakage protocol to aggregate partial share of smart meter readings in a neighborhood using an additively homomorphic encryption scheme [22]. Due to high communication overhead, the approach is not scalable but recently Li et al presented a distributed in – network aggregation approach [23], [24] to efficiently aggregate smart metering data along a spanning tree.

However it presents privacy protected data aggregation in a local area network without focusing on large scale aggregation which should have the regulator being within the systematic approach of ensuring absolute security in the data aggregated. The homomorphic encryption scheme was to instill privacy protection in the power usage data submitted to the utility provider's central management database facility where smart metering data are aggregated in the tree path form. The privacy issues were tackled by encrypting data with the semantically secured encryption scheme. All these processes are done without any

verification approach with the regulator so that a very high level of security is attained in the protection of consumers' privacy and confidentiality in the billing process in particular. The authors of [25] provided some of the early insights into how to smarten electricity systems leaving out integrity related issues.

Lu et al [26] reviewed the integrity threats towards communication networks in smart grid system and studied the impact of these threats. The authors worked on the top-to-down approach in eliminating attacks which will undermine the data integrity and information privacy as well as the feasibility of the approach. Although a network infrastructure was established in the approach within the backhaul network accessibility was limited to the utility

provider with no accessibility to the regulator who is also a key verifier and authenticator of data integrity and consumer information privacy in the grid distribution network.

[27] The authors focused on smart grid data integrity areas such as trust, confidentiality and its associated vulnerabilities in relation to the network which is only accessible to the provider. McDaniel et al [28].

Although these authors were emphatic on the data protection and integrity for the stakeholders much attention was not given to the impact which the regulator can contribute to the enormous protection needed by both the provider and consumer to continue having confidentiality and trust in the data which is used for billing purposes in particular which generally is the key concern of all the major players in the industry.

2.4.1 Existing Challenges in the Billing System

The billing system in the country has had some challenges which make the consumer and the utility providers to get into debates and arguments, partly because of disparities in figures during energy consumption capturing and billing processes. The utilities regulator calculates and sets electricity tariffs for the providers to charge consumers but after that there is no prior approval on accurate energy consumed by the regulator before consumers are billed. Due to these below issues are not addressed by the regulator before the consumers are billed.

1. Data collection at the meter end
2. Data entry permits by provider
3. Data query mechanism by provider
4. Data reliability

2.4.2. Data Collection at Meter Points

History teaches that human negligence and error create the most widespread risk to data. The utility providers, like nearly all other industries are vulnerable to negligence, human error and

the lack of adequate written information security programmes to ensure full proof security for data used particularly for billing processes. Utility providers' task agents to collate energy consumption data from the consumers' meters which sometimes data presented are problematic. The state and condition and mind frame of the human beings have adverse effects on the data being captured. These can lead to errors thereby undermining the integrity of the submitted data for billing.

2.4.3. Manual Data Entry Points

Utility power providers engage in manual data entry for most of their billing operations due to the few automatic meter reading meters they have deployed. The majority of the meters in the industry are still electromechanical and electronic meters which are not smart enough to communicate remotely with the control rooms of the providers therefore manual data entry is prevalent in energy management network. Although it is essentially ubiquitous, the process consists of an abundance of glaring inefficiencies. The reason has been that there is no option for collecting and cataloguing energy data by the utility providers. Most prominent short comings of manual data entry are experienced right from the consumer premises where contracted personnel are tasked to collect the consumption data monthly. These collected data are submitted and used throughout the process until the bills are generated.

2.4.4. Manual Data Query Mechanism.

Typically data are processed, stored and analyzed at a data entry center. Data management begins during the design of the data collection protocol and ends after the final database for statistical analysis and data archiving is complete. Data query mechanism should be built into data management system and carried out concurrently with other data management activities,

otherwise, the ability to detect and resolve anomalous study data is compromised. Some of the possible sources of errors which make the query mechanism necessary are the following.

1. Inaccurate, illegible or incomplete data recording;
2. Inaccurate, or incomplete data recording;
3. Excess data collection to the extent that it jeopardizes the quality of essential data;
4. Intentional data fraud;
5. Errors in summarizing and repeating data.

2.5 Features of the Billing Infrastructure

The consumer plays a major role in the consumption billing process. It is based on the decision of the consumer whether to consume energy or not before the billing process can commence. Electricity consumers group in Ghana consists of industrial, residential and non – residential users. The main issues for ordinary consumers are the price at which electricity is bought i.e. the bill they have to pay and how reliable the service being rendered to them. A great portion of the consumer categories are the residential users who are low – income earners and the cost of electricity is critical for them. The present lifeline tariff targets the rural and urban users whose consumption is less than 50kilowatt an hour per month and their tariff is typically 55 – 70 percent of the economic cost of supply [29]. Non – residential users comprise major offices, banks and small businesses, for major industries whose operations depend, to a large extent, on a reliable supply are also concerned about cost and reliability. This makes us know how critical the consumer is when energy consumption and billing issues are brought to the fore. The government of Ghana subsidies the lifeline consumers and the non - residential consumers occassionally receive some subsidies from the utility providers. There are a number of other challenges in resolving the distortions in electricity tariffs. The utility power industry needs to improve its operational efficiencies so that utilities can be financially sound and this requires

the upgrading and improving on technological inefficiencies. The regulator has benched marked 95% as the average tariff collection efficiency for the providers but their average tariff collection efficiency is around 75 – 85%. This then requires some level of participation and support from the regulator to build the lost trust in the eyes of the consumers who are of the notion that the regulator is on the side of the providers.

2.5.1. Energy Consumption Meters

The utility providers have deployed a number of metering technologies to address in the past and still ongoing with the view to improving tariff collection efficiency. These include; Electromechanical Induction Meters (EIM), Prepayment Card Electric Meters, Solid State Electric Meters or Electronic Meters. These meters have contributed to the losses incurred by the utility providers because of the vulnerability states some have been in for years. Here intruders manipulate readings by seldom reversing the meters; some have opened meters and bypassed them due to the low level anti tamper features on these meters. However, due to much improvement in wireless communication in the telecommunication sector, utility industry can take advantage of the available wireless network and provide efficient and reliable services in the country.

Fig 2-3 shows some of the causes of metering losses incurred by the utility power providers in the country.

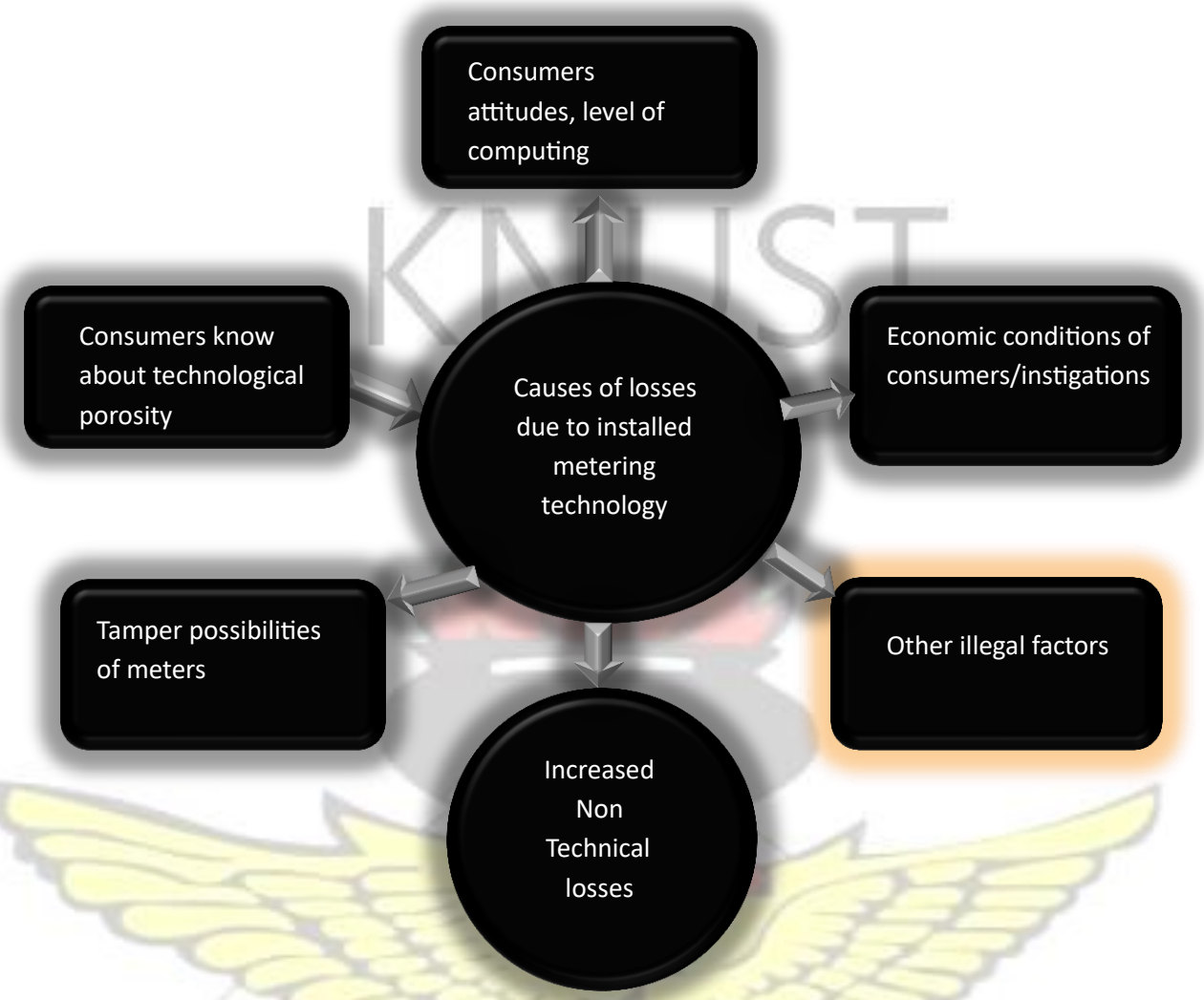


Figure 2-3 Cause of metering losses in Ghana [29]

The providers have realized that the smart meters can largely improve their efficiency in the billing process. The present goal is towards remote monitoring, reading and monitoring of electricity consumption referred to as Advanced metering infrastructure. (AMI) [30]. This will also require the providers engaging the telecommunication companies to assist in the efficiency improvement required by the providers.

Figure 2-4 AMI solution architecture

[source:http://www.nuritelecom.com/solutions/advanced-metering-infrastructure.html]

Today, power providers are aggressively pursuing communications options that will prepare them for Smart Grid deployment. This will result in improved operational efficiency and increased productivity as well. This means that many parameters must be kept in balance. First, the solution must be highly reliable. In a mission-critical environment, no compromise is acceptable. Second, CAPEX and OPEX must be minimized. Finally, the network should offer the opportunity to implement new services in a rapid and cost-effective manner. The ideal solution is one that offers at least the same level of reliability, QoS and security as that of traditional utility communications networks while supporting the full array of both TDM and new IP/Ethernet services that are needed for core utility operations and smart grid deployments. IP and Ethernet will be the key communications protocols for the Smart Grid infrastructure. IP technologies serve as a bridge between applications and the underlying communication medium. This provides utility providers with the opportunity to migrate traditional applications to more efficient IP and Ethernet-based implementations and to deploy new IPcentric Smart Grid applications, such as:

- IP-based supervisory control and data acquisition (SCADA) using protocols such as International Electromechanical Commission (IEC) 104 or Distributed Network Protocol (DNP3), and Modbus over IP that allow for a simplified network architecture, efficient bandwidth utilization, and faster commissioning and deployment.
- IEC 61850-based substation systems that take advantage of the increase in bandwidth that modern networking technologies offer. IEC 61850 intelligent electronic devices (IEDs) that use Ethernet and TCP/IP for efficient communications are easier to scale and implement than legacy approaches. Also there are open initiatives to migrate IEC 101, IEC 104 plus DNP and Modbus toward an international usage of IEC 61850 in the future. This will be complex and challenging but exciting to watch as it develops.
- Synchrophasor systems, for grid stability monitoring and disturbance recording, require IP multicast for effective phasor measurement unit (PMU) communications.
- Video surveillance systems are now required as a key element to ensure the physical security of critical assets. Modern video surveillance systems are IP-based, operate with higher bandwidth, and integrated with the information technology infrastructure of the utilities.
- Distribution automation requires communications to many smaller substations as well as connectivity to a very large number of device endpoints in the field area network to ensure distributed control and situation awareness.
- Advanced metering infrastructure requires a capable backhaul communications network to not only aggregate the meter data back to the head end but also to perform direct meter readings and outage management.
- Other applications that include voice over IP (VoIP), IP mobile radio, Wi-Fi mobility, physical substation security, corporate local area network (LAN) access, and more However, in parallel with deploying these forward looking applications and services, there are questions that every utility should consider. Will the network meet my needs now and also

in the future? Is it secure? Will it be reliable? Can I manage it? These are all compulsory inquiries that should be considered before building their smart network.

Table 2-2 is the communications technologies deployed for smart grid communication systems.

Table 2-2 Communication Technologies used for smart grid [31]

Technology		Frequency(MHZ)	Throughput	Range(km)	Application
Wired	DSL	~1-6	2-8Mbps	1-5km	AMI
					DR
	PLC	~1-30	2-3Mbps	1-3km	AMI
					DR
					HAN
	FO	>1THz	1--3Gbps	10-20km	All
Wireless	Zigbee	868,915 and 2400	250kbps	30-50m	HAN
	GSM	900-1800	< 14.4kbps	1-10km	AMI
					DR
	GPRS	900 -1800	>170kbps	1-10km	AMI
					DR
	3G	1920 -1980	384Mbps	1 -10km	AMI
		2110 - 2170	neg 2Mbps		DR
	4G	800, 1800	>173Mbps	1-5km	AMI
	LTE	2600			HAN
	4G WiMAX	2500, 3500 and 5400	> 70Mbps	1-5Km	AMI
					DR

2.5.2 Data Acquisition and Authentication Process

For many years, the general acquisitions of data by the providers have been manually done for billing consumers. Data acquired from the residential and industrial consumers premises are supposed to be queried and authenticated by the providers before bills are generated prior to payment by consumers. This has been the challenge of the provider, the authentication and comprehensive query of data submitted by the field agents. There are instances where average energy consumption data presented by an agent does not reflect the projections of the consumptions for a particular load for a month, yet the query system allows the data to be used to produce a bill for a consumer to pay. Data accountability is very key in the billing process which when not carefully considered undermines the entire billing scheme of the utility

provider. Accountability of data from the providers must be as reliable as the trust you have that they are doing and will do the right things. Consumers must always trust the providers with their data but that is not the present situation and therefore the aggregation and validation of data by the regulatory body will be required to put the consumer at peace without a shred of doubt on bills submitted to them for payment

CHAPTER THREE

RESEARCH METHODOLOGY

3.1. System Modelling

This chapter presents the models for the existing energy consumption by the consumer and the billing scheme used by the utility provider, the model for the present and existing smart metering infrastructure and the review of the infrastructure which makes the regulator a clearing agent for all energy consumption data successfully aggregated, queried and validated before billing to a consumer in order to establish data integrity among the interested parties.

3.2 Comparison of Energy Consumption between Consumer and Utility Provider

When the anomalies were detected five meters kilowatt hour readings were taken within the Ashanti Region to ascertain whether the problem was peculiar to a particular district and under provider's district office in particular or it was widespread across other district offices. A field test assessment on load and possible energy consumption was analysed for the scenario if no commercial power outage was recorded what would be the total energy consumption for the category of consumer's premises. These premises have the same basic equipment required at the site which are;

1. Two air conditioner (window type) units.
2. Lighting system (i.e. four fluorescent lights and one 400W halogen light).
3. Four 1500W rectifiers.
4. Socket for additional equipment usage when needed.

Total Load ((230V X 15A) + (230V X 10A) + (230V X 6A))/1000= 7.1kw **(3.1)**

Kwh/month = 7.13X24X31 = **5304.72**

An event that will cause high loads to be recorded is welding activity or two air conditioners switched on and working continuously.

Total Load ((230V X 15A) + (230V X 10A) + (230V X 16A))/1000= 9.4kw **(3.2)**

Kwh/month = 9.4X24X31 = **7015.92**

The premises where the meters were installed had the same class of energy consumption. This assessment was done to ascertain whether the stakeholders are getting the actual energy consumption data for billing so that based on that they can receive the actual expected revenues from the utility providers on monthly basis. The belief was that with such expected revenues to these stakeholders, they can plan properly with their raked in expected revenues in the investments and development of their businesses.

After the assessment test was done the data was compared with the providers' bills for one and half-year period as against the data recorded by the consumer for the same period.

The variance and error percentages were very enormous. The data collected for five different meters which spans the period of twelve months depicted the actual consumptions and forecasted consumption from the utility provider thereby making the percentage of errors recorded evident enough warranting the stated objective.

Mohamed Z et al discussed the various forecasting of models developed for electricity energy consumption model [32]. Consumer participation in demand management and responsibility sharing in consumption management by most consumers have been lackadaisical toward government subvention programmes as well as utility provider's application of obsolete marketing and revenue collection strategies and methods [33]. These have among other things contributed to the disparities and inconsistencies in data used in billing consumers. Tables 3-1 to 3-5 and figures 3-1 to 3-5 are some energy consumptions captured by Electricity Company of Ghana as against what the consumers recorded.

Table 3-

1 Monthly energy Consumption recorded for Meter A

MONTH	METER A KWH	ECG KWH	ERROR OF MARGIN	ERROR %
Jan-12	1649	1562	-0.055697823	-5.56978233
Feb-12	1575	1738	0.093785961	9.378596087
Mar-12	1076	1305	0.175478927	17.54789272
Apr-12	1991	1912	-0.041317992	-4.131799163
May-12	1589	1584	-0.003156566	-0.315656566
Jun-12	1921	2013	0.045702931	4.570293095
Jul-12	1690	1559	-0.084028223	-8.402822322
Aug-12	1713	1632	-0.049632353	-4.963235294
Sep-12	1968	1893	-0.039619651	-3.961965135
Oct-12	192	1875	0.8976	89.76
Nov-12	870	1617	0.461966605	46.19666048
Dec-12	1205	1889	0.362096347	36.20963473
Jan-13	5201	1829	-1.843630399	-184.3630399
Feb-13	3681	1729	-1.128976287	-112.8976287
Mar-13	4374	1506	-1.90438247	-190.438247
Apr-13	3102	1741	-0.781734635	-78.17346353
May-13	4000	1706	-1.344665885	-134.4665885
Jun-13	3453	1261	-1.738302934	-173.8302934
Jul-13	3923	791	-3.95954488	-395.954488

Table 3-

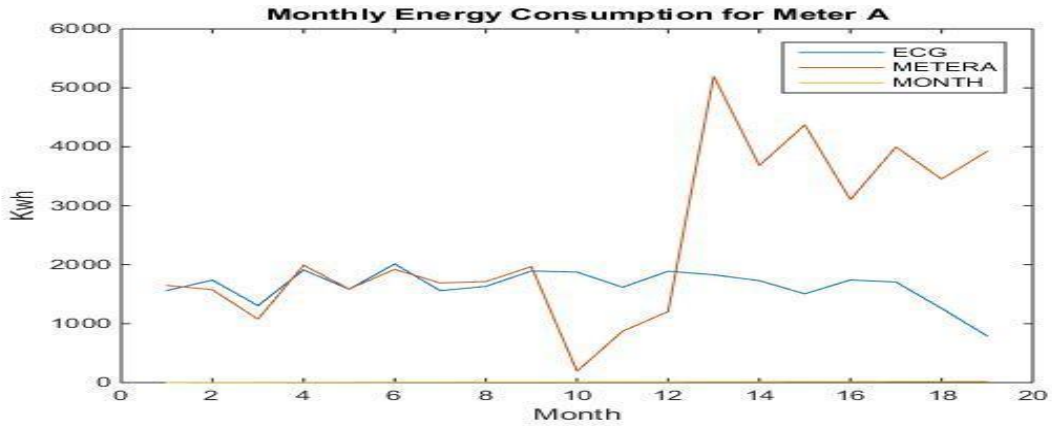


Figure 3-1 Monthly energy consumption recorded for Meter A

2 Monthly energy Consumption recorded for Meter B

MONTH	METER B KWH	ECG KWH	ERROR OF MARGIN	ERROR %
Jan-12	3603	4740	0.239873418	23.98734
Feb-12	3740	4740	0.210970464	21.09705
Mar-12	3241	4740	0.316244726	31.62447
Apr-12	3135	4740	0.338607595	33.86076
May-12	3724	4740	0.214345992	21.4346
Jun-12	4132	4740	0.128270042	12.827
Jul-12	3164	4740	0.332489451	33.24895
Aug-12	3999	4740	0.156329114	15.63291
Sep-12	3550	6650	0.466165414	46.61654
Oct-12	3982	2902	-0.372157133	-37.2157
Nov-12	4572	4212	-0.085470085	-8.54701
Dec-12	3908	4599	0.150250054	15.02501
Jan-13	3545	4174	0.150694777	15.06948
Feb-13	3435	3018	-0.138170974	-13.8171
Mar-13	2505	2662	0.058978212	5.897821
Apr-13	3619	3117	-0.161052294	-16.1052
May-13	3103	3422	0.093220339	9.322034
Jun-13	3785	3484	-0.086394948	-8.63949
Jul-13	3284	4205	0.21902497	21.9025

Table 3-

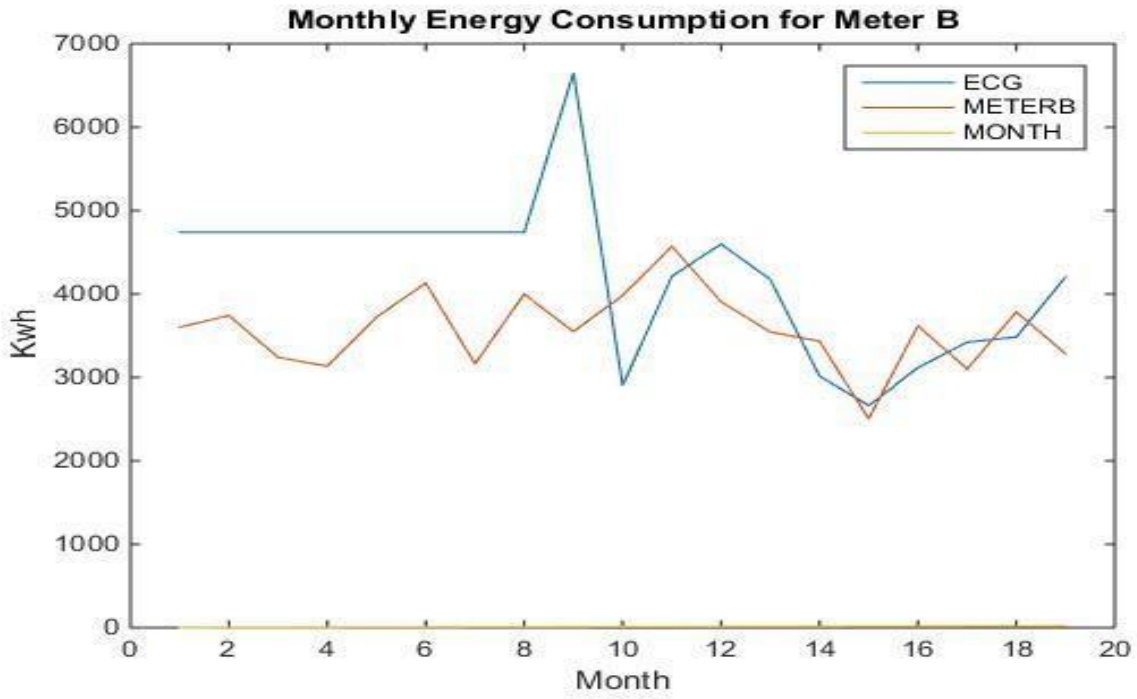


Figure 3-2 Monthly energy consumption recorded for Meter

3 Monthly energy consumption recorded for Meter C

MONTH	METER C KWH	ECG KWH	ERROR OF MARGIN	ERROR %
Jan-12	2824	1190	-1.373109244	-137.3109244
Feb-12	2905	1190	-1.441176471	-144.1176471
Mar-12	2245	1190	-0.886554622	-88.65546218
Apr-12	2361	1190	-0.984033613	-98.40336134
May-12	3254	1190	-1.734453782	-173.4453782
Jun-12	3315	1190	-1.785714286	-178.5714286
Jul-12	2592	1190	-1.178151261	-117.8151261
Aug-12	2748	1190	-1.309243697	-130.9243697
Sep-12	2793	1190	-1.347058824	-134.7058824
Oct-12	3717	1190	-2.123529412	-212.3529412
Nov-12	4148	1190	-2.485714286	-248.5714286
Dec-12	3358	1190	-1.821848739	-182.1848739
Jan-13	2285	1190	-0.920168067	-92.01680672
Feb-13	2972	1190	-1.497478992	-149.7478992
Mar-13	2379	1190	-0.999159664	-99.91596639
Apr-13	3035	1190	-1.550420168	-155.0420168
May-13	2337	1190	-0.963865546	-96.38655462
Jun-13	2668	1190	-1.242016807	-124.2016807

Table 3-

Jul-13	3361	1190	-1.824369748	-182.4369748

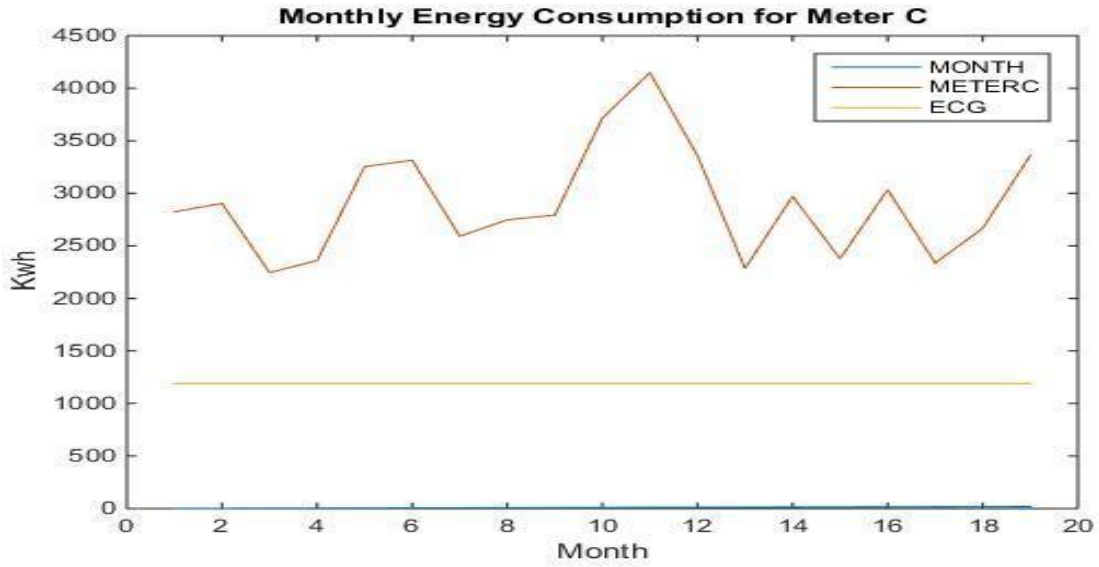


Figure 3-3 Monthly energy consumption recorded for Meter

4 Monthly energy consumption recorded for Meter D

MONTH	METER D KWH	ECG KWH	ERROR OF MARGIN	ERROR %
Jan-12	1234	1232	-0.001623377	-0.162337662
Feb-12	1621	1415	-0.145583039	-14.55830389
Mar-12	1480	1674	0.115890084	11.58900836
Apr-12	1625	1670	0.026946108	2.694610778
May-12	1840	1463	-0.257689679	-25.76896787
Jun-12	1706	1756	0.028473804	2.84738041
Jul-12	1765	1871	0.056654196	5.665419562
Aug-12	1779	1870	0.048663102	4.86631016
Sep-12	2003	1450	-0.38137931	-38.13793103
Oct-12	2003	1870	-0.071122995	-7.112299465
Nov-12	2003	1870	-0.071122995	-7.112299465
Dec-12	1320	1870	0.294117647	29.41176471
Jan-13	4660	1800	-1.588888889	-158.8888889
Feb-13	3822	1790	-1.135195531	-113.5195531
Mar-13	4570	1780	-1.56741573	-156.741573
Apr-13	2279	1830	-0.245355191	-24.53551913
May-13	4160	1820	-1.285714286	-128.5714286
Jun-13	3255	1820	-0.788461538	-78.84615385
Jul-13	3925	1810	-1.168508287	-116.8508287

Table 3-

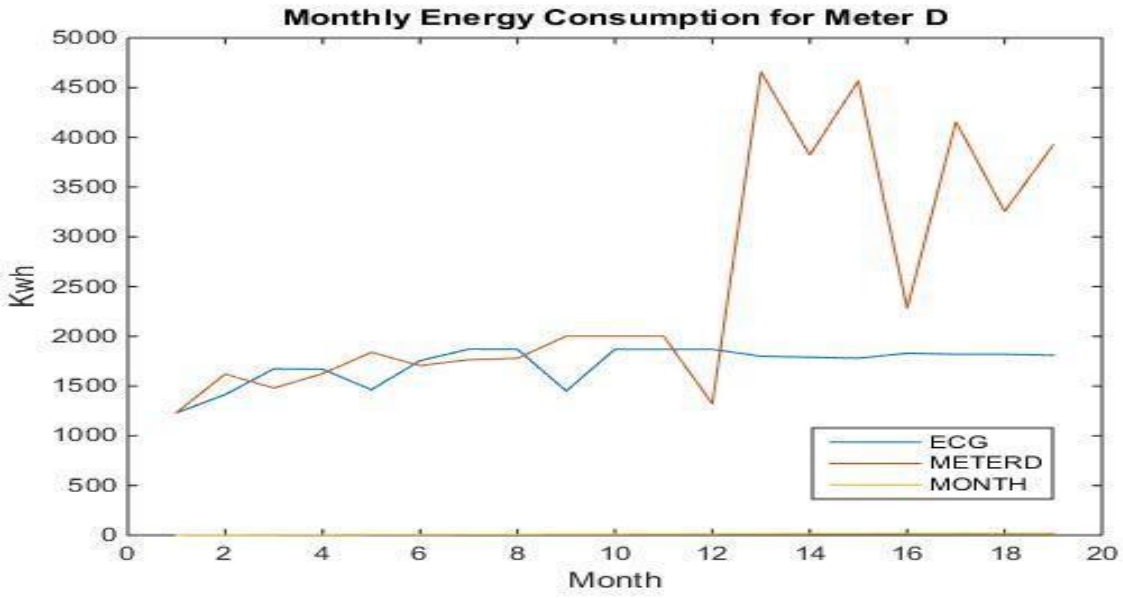


Figure 3-4 Monthly energy consumption recorded for Meter D

5 Monthly energy consumption recorded for Meter E

MONTH	METER E KWH	ECG KWH	ERROR OF MARGIN	ERROR %
Jan-12	2355	4036	0.416501487	41.65014866
Feb-12	3070	4040	0.24009901	24.00990099
Mar-12	2585	1864	-0.386802575	-38.68025751
Apr-12	3473	4040	0.140346535	14.03465347
May-12	2966	4040	0.265841584	26.58415842
Jun-12	3028	4040	0.25049505	25.04950495
Jul-12	3211	3111	-0.032144005	-3.214400514
Aug-12	3118	2850	-0.094035088	-9.403508772
Sep-12	4154	2650	-0.56754717	-56.75471698
Oct-12	2228	2420	0.079338843	7.933884298
Nov-12	3185	2150	-0.481395349	-48.13953488
Dec-12	3489	1979	-0.763011622	-76.3011622
Jan-13	3630	1460	-1.48630137	-148.630137
Feb-13	3705	2230	-0.661434978	-66.14349776
Mar-13	4277	2120	-1.01745283	-101.745283
Apr-13	2355	2040	-0.154411765	-15.44117647
May-13	3372	1970	-0.711675127	-71.16751269
Jun-13	3481	1940	-0.794329897	-79.43298969
Jul-13	3540	1960	-0.806122449	-80.6122449

Table 3-

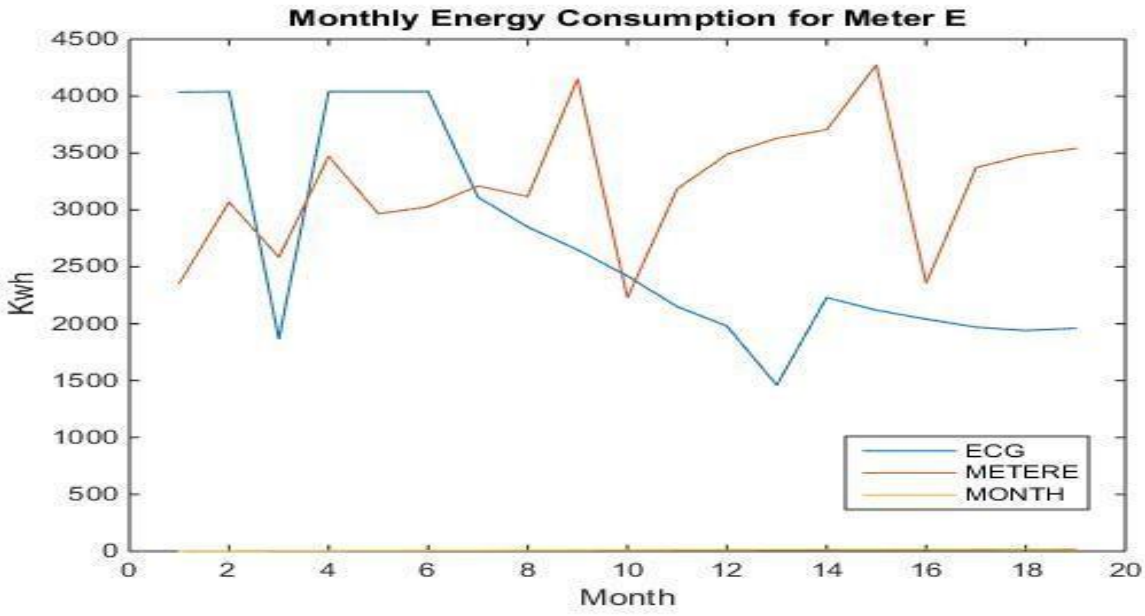


Figure 3-5 Monthly energy consumption recorded for Meter E

3.3 Existing Automatic Meter Reading Infrastructure

The present data aggregation model run by the utility provider for the automatic meter reading is done by the provider on behalf of both parties (the provider and consumer) without the involvement of the regulator. The regulator's involvement is only when a dispute arises before data requisition is made to the provider for investigation to be carried out. The meter acts as the sensor for the collection of voltage, current and other power related information directly for use in the distribution automation programmes.

The meter will provide end of consumptions, line voltages and other power attribute information for more accurate assessments to the utility provider and then to the regulator. The mandate of the regulator is to collect the attribute information and query the data generated which can then be validated before provider can go ahead and bill consumers. This methodology will instill some level of authenticity, transparency, confidentiality, and trust in the billing process that will curtail the back and forth questioning of bills generated by the utility providers. The present infrastructure has the provider doing the validation and authentication by itself hence some leading to the anomalies being generated in the billing processes.

Figure 3-6 depicts the data collecting, fusion, aggregation and validation being done by the utility provider and in a central database.

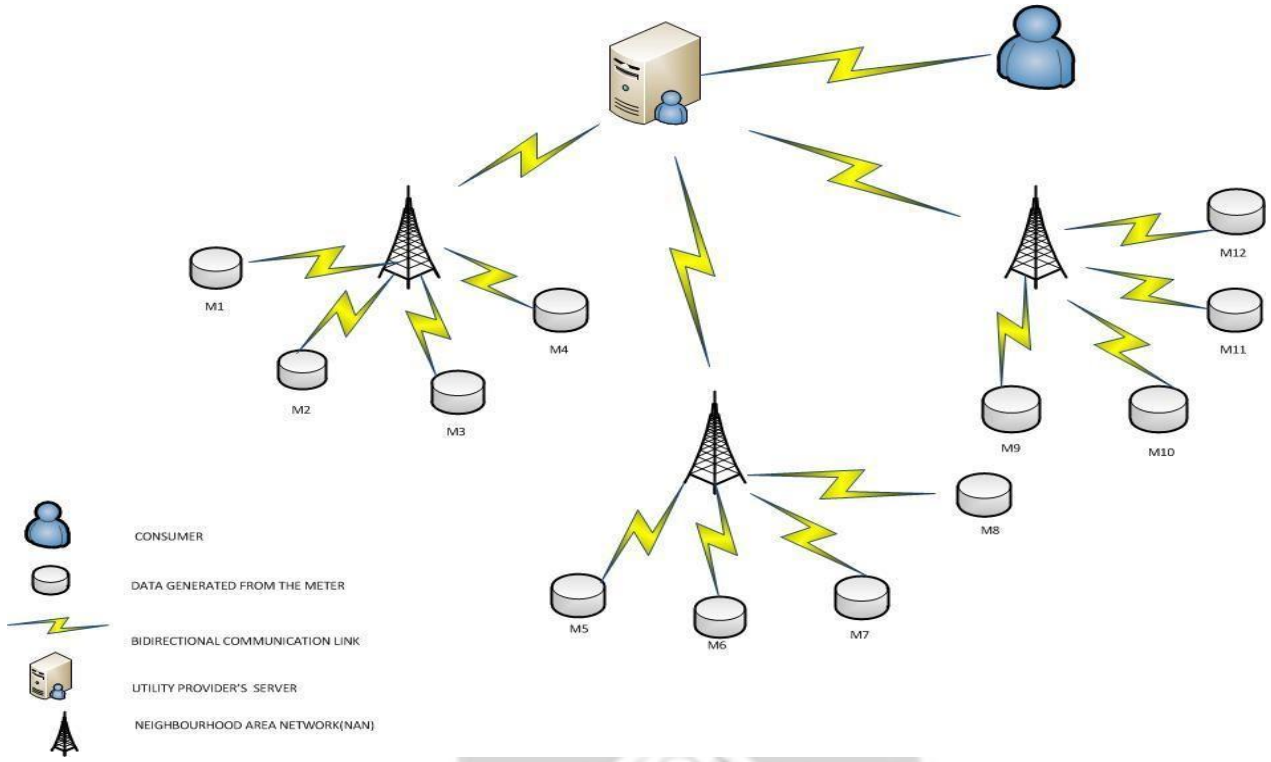


Figure 3-6 Existing smart metering process

One of the utility providers Electricity Company of Ghana has the automatic meter reading (AMR) system. As a way of improving efficiency level in the metering system the AMR meters have been installed at some of the industrial and commercial consumers' premises. These meters are programmable energy meters that can be set to function in a specific and required manner. The meter has the functionality of reading and storing energy consumption data like voltages, current and power factor at a particular time. The meters communication link is between it and the provider's headoffice and that is the data communication infrastructure. However the data communication is limited to the consumer and the provider on one and one basis. In this process, the provider is the validator of the energy consumption. In the near future the provider due to the drive to continuously improve the level of efficiency in the metering process will require deploying more of these meters to so many consumers and this will require

that the present infrastructure is changed to a more efficiency and easy data collection and analysis model of data communication infrastructure.

3.4 Developing a Model for Data Integrity in the Backhaul Network

The backhaul wireless communication is crucial for connecting the different entities involved such as consumers, utility providers, the regulatory body and other interest institutions. This is what the thesis seeks to model but in this methodology we concentrated on the wireless communication network between the utility provider and utility regulator as the main recipients of the data transmitted by the meter gateway. The backhaul wireless network is established between the meter gateway, the provider and the regular in this model.

To achieve this, three virtual machines were modelled.These machines represented the meter gateway which collects the data as programmed to perform occasionally from the five individual AMR meters and the other two virtual machines represented the database management systems for the provider and regulator which are installed in the server rooms of these institutions receiving the aggregated data from the meter gateway simultaneously. Both database management systems analyse and scrutinise the data sent and then the provider requests prior approval from the regulator based on the data sent to the regulator which must be error free during the comparison stage of these data by the regulator. The regulator's database management system approves the compared data from the provider and gives it the clearance to bill consumers. All these will be carried out by machine-to-machine communication without any intervention from any human being.

The model was demonstrated with MATLAB Simulink application and Oracle Virtual Machine Manager which are educational tools available to any students for such models. This was to establish the feasibility and possibility of practically achieving data integrity model for the

smart meters infrastructure deployed and will be deployed in the future that will aid the utility regulator in solving the billing complaints received prior to distribution of bills to consumers to prevent these issues emerging and for huge budgets and expenditures drawn. Figure 3-7 is the model which the smart meters transfer their readings to the meter gateway based on the duration setting and the meter gateway to both the regulator and provider within forty-eight hours on monthly basis.

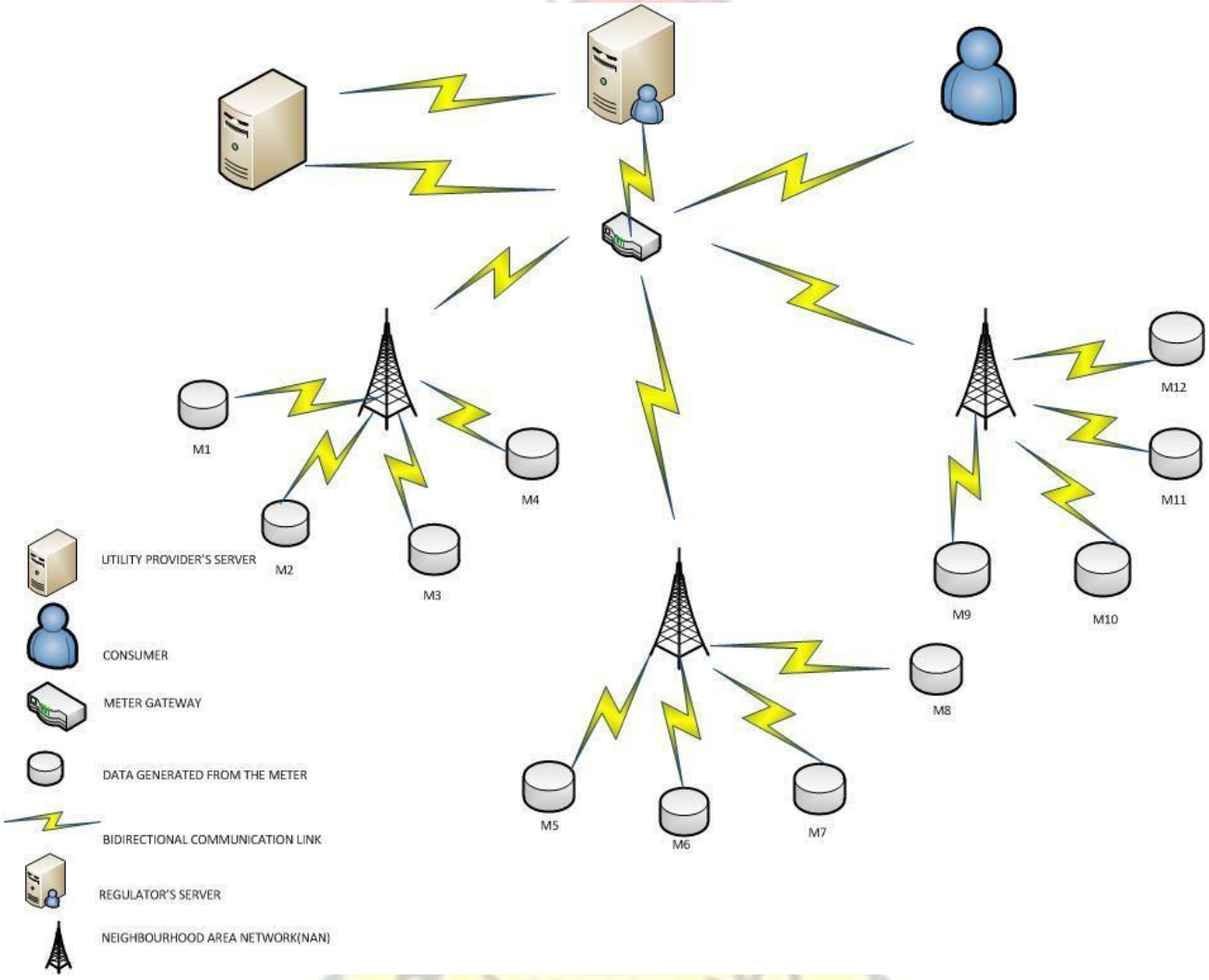


Figure 3-7 Proposed infrastructure for smart metering in Ghana

Figure 3-8 is the MATLAB simulink application design for the backhaul infrastructure. In the simulation we set up five individual meters with three having delay challenges but still being

able to transmit the required data within twenty-four hours to the meter gateway.The meter gateway collated the data and shared it with the servers of the provider and regulator. In this simulation we used the oscilloscope to represent the servers in order to achieve clarity with the comparison of data by the two parties.The utility provider and regulator oscilloscopes received the data at the same time and the initial comparison was done where the data was the same.

In the second scenario when the data from the provider was compromised the data was very different from the regulator's data depicting that if that happens the regulator will reject the data from the provider automatically and this is achieved without any human intervention.

Two servers are communicating together and one vetting the other's data.

After rejection of the compromised data the provider is tasked to investigate and perform due diligence on the rejected data for the final comparison and if that is achieved the regulator validates the corrected compromised data before the provider can bill the consumers.

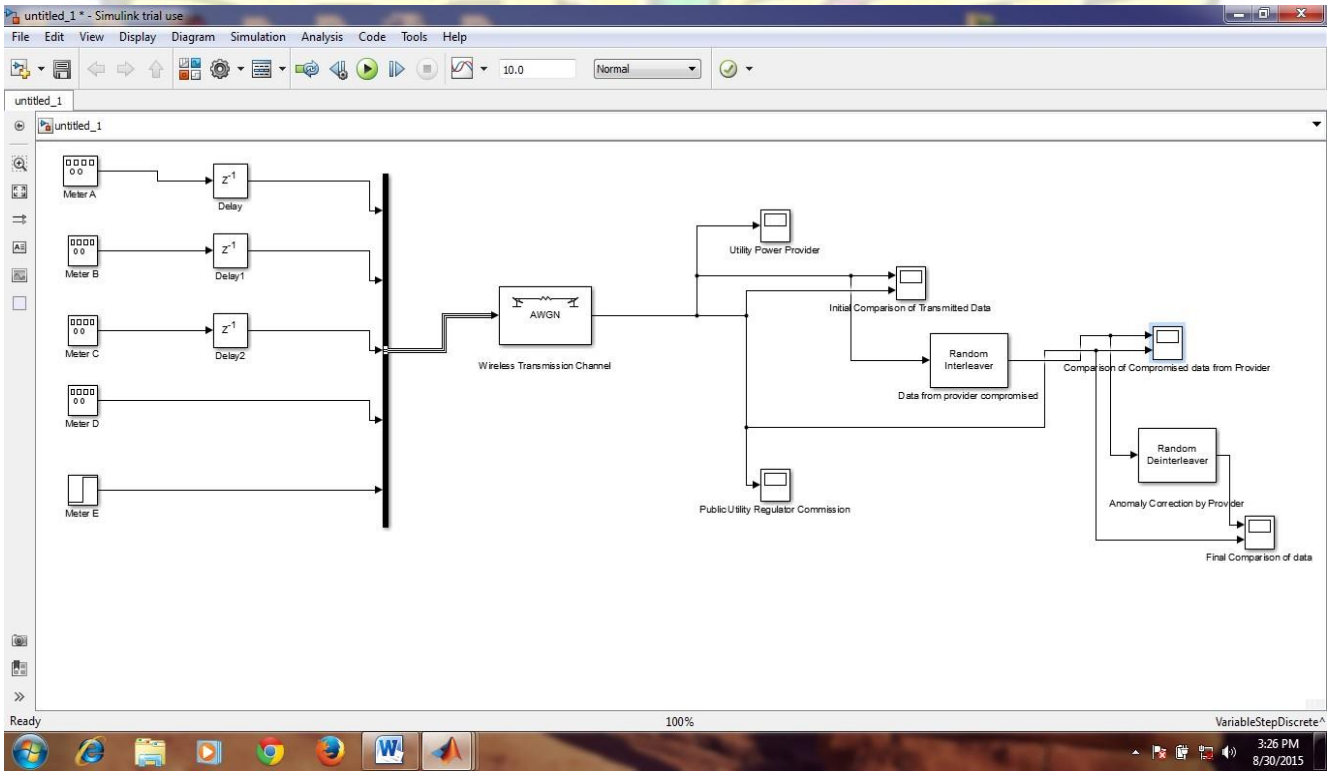


Figure 3-8: MATLAB-Simulink depicting the model in establishing the data integrity.

We needed to establish how practicable this model can be hence the Oracle Virtual Machine Manager Simulation software was used to achieve that. Five meters were created and setup within the meter gateway virtual machine and these meters read and submitted their reading data to the meter gateway. The gateway virtual machine shares the same data with the provider and the reglator's virtual machines. Based on the agreed protocols between the provider and regulator, the provider then requests authorization prior to billing of consumers from the regulator.

Within a few seconds the regulator authenticates and validates the provider's request provided the data is exactly what the regulator has received from the meter gateway. In the situation where the data is compromised, the regulator rejects the data automaticallly for the provider to ensure due diligence again before billing consumers.

Figures 3-9 and 3-10 are the virtual machines which were created.

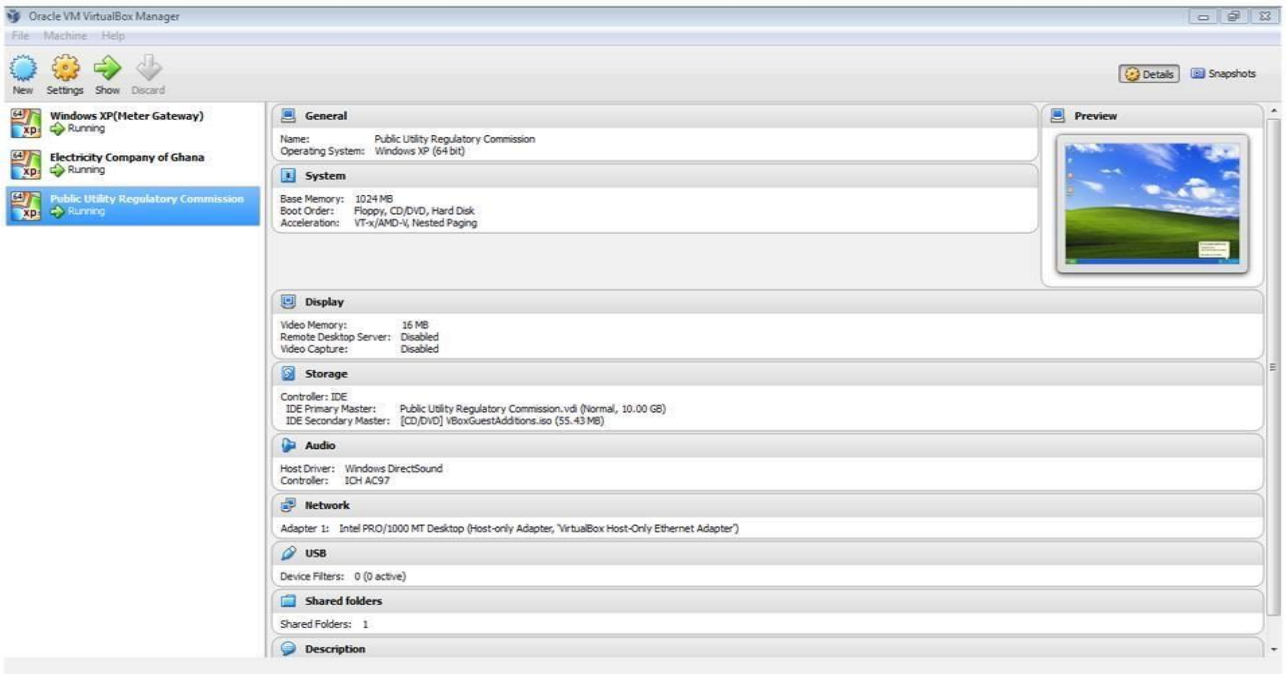


Figure 3.9: Oracle Virtual Box Manager used in the creation of machine-to-machine communication.

Oracle VM VirtualBox is an industrial-strength open source virtualisation tool that makes it easy to create virtual machines (VMs), simulated computers that run on your PC but act as though they were separate systems. It is a powerful capability that has many different applications.

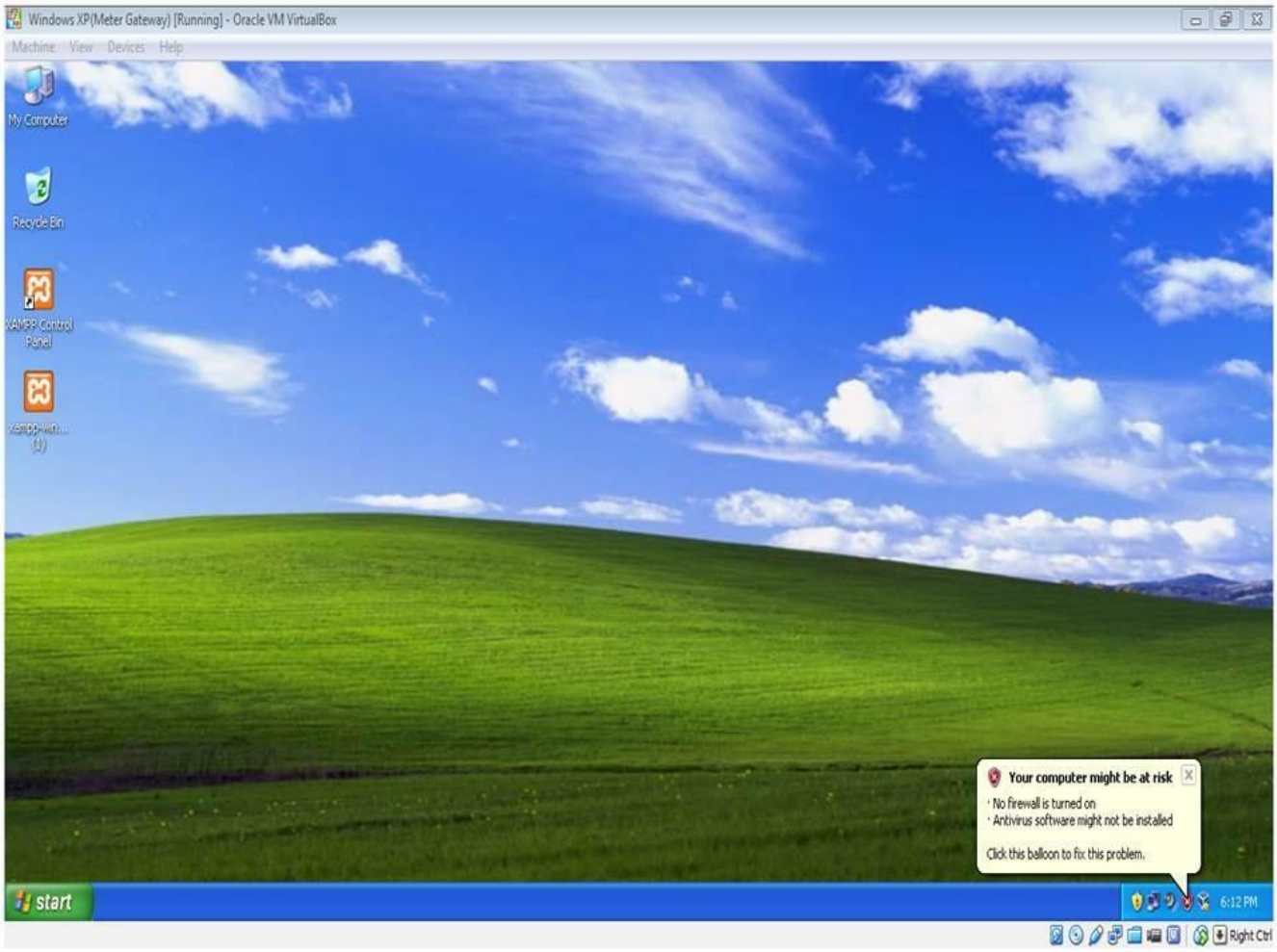


Figure 3-10 Virtual machine established for the meter gateway, ECG and PURC

The figure 3-10 is the three virtual machines machines which act as servers for the meter gateway, provider and regulator. The operating system is windows XP which is a robust operating system suitable for this simulation model.

3.5. Data Transmission Scheme in the Backhaul Network

The meter gateway will be needed for the collation of data from the smart meters installed at different geographical areas to aid in seamless delivery of data from them to the utility provider and the utilities regulator. The wireless backhaul network will be established between the meter gateway, the provider and the regulator.

The smart meters are IEC 62025 compliant and they have the features of a computer; hence, making them to work as computers in terms of communication with computers and servers so they are easily integrated into the backhaul network which provides right network capacity, expected data speed, low electromagnetic interference and high availability of radio frequency spectrum space.

With communication compliance the meters basicly have the following features [34].

1. Three independently working communication ports.
2. Optical port FLAG(IEC 62056-21) or ANSI Type 2(ANSI C12-18)
3. RS-232 with modem power supply(2G/3G supported)
4. RS-485 Multi-Drop(4 or 2 wire, RJ45 or screw terminal)
5. Option for second RS-232 port
6. UDP/IP GPRS/PPP cable
7. Option for Zigbee mesh RF

The transmission scheme adopted is the RF Mesh communication systems which the meter gateway (data concentrator) accommodates hundreds of individual smart meters but in the model five meters were used for the test bed which require wireless network to establish communication for the model to run.

The model requires any wireless network to work with because it establishes the communication transmission links between the meter gateway and two database management systems.

This secure communication quality in this particular network shall have the following parameters in order to achieve the required goals of establishing the network.

1. The scheme must provide a high level of energy conservation
2. Data received and transmitted must be delivered fast
3. Establishment of fault tolerance

The main purpose of the transmission scheme which secures communication quality is to prevent delay in data transfer and delivery as well as establishment of fault tolerance [35, 36]. This will facilitate the delivery of the needed quality of service for the network. Recent radio frequency transmission mechanisms use approximately 100nbps for a transmission distance of 10 to 100m, making communication very costly in comparison with data acquisition and processing [37]

The meters are capable of sampling, processing and transmitting data; the transaction among these tasks is an important issue in power handling.

Time delivery of data is required in this network. Applications such as real – time target tracker geographically due to the location of the meters and emergent event triggering monitoring systems. In such application, latency cannot be tolerated and data should be delivered within a certain period of time. This requires that data must be delivered based on timelines and deadlines fault tolerance mechanisms must be considered in both wireless links. As the meters are battery enabled devices, they may lose their power during large overtimes; however, the failure of some nodes should not affect the overall network.

The meter gateway will be positioned in such a way that although random effects of shadowing of some locations of the individual smart meters within the coverage area a higher percentage of the coverage area will be achieved.

For a circular coverage area having radius R, let there be some desire received signal threshold γ.

The percentage of useful service area U(γ) and a radial distance from the transmitting meters d= γ, it can be shown that

If Pr [Pr(γ)> γ] is the probability that the random received signal at d= γ exceeds the threshold γ within the incremental area dA, then U(γ) can be found by

$$U(\gamma)=\frac{1}{\pi R2} \quad \Pr \Pr \gamma \ > \gamma \ dA=\frac{1}{\pi R2} \ {}_0^{2\pi} \ {}_0^{R} \Pr \Pr \gamma \ > \gamma \ r \ dr \ d\theta \qquad \textbf{(3.3)}$$

Using equation (3.3), $Pr[Pr(\gamma) > \gamma]$ is given by

$$Pr \ Pr \ \gamma \ > \gamma \ = Q \ \frac{\gamma - \overline{Pr \ \gamma}}{\sigma} = \frac{1}{2} - \frac{1}{2} \text{erf} \ \frac{\gamma - \overline{Pr \ \gamma}}{\sigma \ \overline{2}} \qquad \textbf{(3.4)}$$

$$\frac{1}{2} - \frac{1}{2} \text{erf} \ \frac{\gamma - [Pr - (PL \ d0 \ + 10n \log(r \ d0))]}{\sigma \ \overline{2}}$$

In order to determine the path loss as reference to the cell boundary(r=R), it is clear that

$$PL(r) = 10n\log \ \frac{R}{d0} + 10n\log \ \frac{r}{R} + PL \ d0 \qquad \textbf{(3.5)}$$

And equation (3.4) may be expressed as

$$Pr[Pr(\gamma) > \gamma] \qquad \textbf{(3.6)}$$

$$\frac{1}{2} - \frac{1}{2} \text{erf} \ \frac{\gamma - [Pt - (PL \ d0 \ + 10n \log(R \ d0) + 10n \log \frac{r}{R} \ )]}{\sigma \ \overline{2}}$$

If we let a= $\gamma - [Pt - (PL \ d0 \ + 10n \log(R \ d0) + 10n \log \frac{r}{R} \ )] \ \sigma \ \overline{2}$ and

B= $10n \log e \ \ \sigma \ \overline{2}$

Then

$$\gamma = \frac{1}{2} - \frac{1}{R2} \int_0^R \gamma erf\ \ a + b \ln \frac{r}{R}\ \ dr \quad \textbf{(3.7)}$$

By substituting t=a+blog $\frac{r}{R}$ in equation (3.7), it can be shown that

$$\gamma = \frac{1}{2}\ 1 - \text{erf}\ a\ + exp\ \frac{1-2ab}{b2}\ \ 1 - erf\ \frac{1-ab}{b}\ ) \quad \textbf{(3.8)}$$

By choosing the signal level such that Pr $R = \gamma\ i.e. a = 0\ ,\quad \gamma\ \ can\ shown\ to\ be$

$$\gamma = \frac{1}{2}\ 1 - exp\ \frac{1}{b2}\ \ 1 - erf\ \frac{1}{b} \quad \textbf{(3.9)}$$

The determination of the network coverage and security is then established between the virtual machines.

3.6. Query of Energy Consumption Data

The querying of data is very essential in the billing process. This ensures the proper and efficient manner; bills will be accurately submitted to consumers to make payment but the regulator's backhaul system must query the data from the gateways. In this model data submitted by the meter gateways especially the energy consumption data to the utility provider and regulator are queried since the data must be progressive and not regressive. If some meter readings are standstill and regressive these must be identified within the data and queries raised first by the provider for such cases to be investigated before approval request is sent to the regulator.

J Nagi [38] used the Lagrange function to query abnormalities, when daily average consumption feature for each consume were extracted using

$X_h^{(m)} = \frac{P_{h+1}}{D_{h+1} - D_h}$, h= 1, 2……..24hrs **(3.10)**

Where $X^{(m)} = (X_h^{(m)}$, h = 1…….H)

H = 24hrs corresponding of time domain intervals based on average daily kilowatt hour consumption

P_{h+1} = the monthly consumption of the month.

$D_{h+1} - D_h$ = the difference of days with respect to meter reading data.

Liebman [39] depicted data validation and reconciliation formulation as a non-linear optimization problem.

Data reconciliation or validation is a technique that aims at correcting measurement errors that are due to measure average abnormalities and this can be mathematically expressed in the form

$$min_{x,y^*} \sum_{i=1}^{n} \left(\frac{y_i^* - y_i}{\sigma_i}\right)^2$$

Subject to $F(x,y^*) = 0$ **(3.11)**

$$y_{min} \leq y^* \leq y_{max}$$

$$x_{min} \leq x \leq x_{max}$$

Where y_i^* is the reconciled value of the i_{th} measurement (I=1,…….., n), y_i is the measured value of the i_{th} measurement(I=1,…….,n). x_j is the j_{th} unmeasured variable(j=1…….,m) and σ_i is the standard deviation og the i_{th} measurement (i=1,……i,n); $F(x,y^*)=0$ are the p process equality constraints and $x_{min}, x_{max}, y_{min}, y_{max}$ are the bounds on the measured and unmeasured variables.

The term $\left(\frac{y_i^* - y_i}{\sigma_i}\right)^2$ is called the penalty of measurement.

i, The objective function is the sum of the penalties which will be denoted in the following by

$$F(y) = \sum_{i=1}^{n} \left(\frac{y_i^* - y_i}{\sigma_i}\right)^2 \quad \textbf{(3.12)}$$

But this model focused on the exact monthly data reading figures which the meters send through the gateway which need to progress and not to regress on monthly basis. If there is a regression in figures queries will be raised for further investigation of these meters.

The regulator has the mandate to query any consumption data submitted by the provider to ensure that there is integrity in the data thereby benefitting both the consumer and service provider. The query is necessary because of the enormous data which are and can be prone to manipulation by anyone with a negative motive and purpose to put a stakeholder at a disadvantage position.

In this thesis Xampp programming language tool (which consists of the PHP language and MySQL language tools) was used in the establishment of query and analysis of the communication establishment between the virtual machines which when data from the meter gateway are queried and analysed by both the regulator and the utility provider to ensure data integrity in submitted data by the gateway.Codings inserted in Appendix [A5]

3.7. Validation of the Energy Consumption Data

Data validation is the process of ensuring that a programme operates on clean, correct and useful data. The validation rules which are routine check correctness and security of data must be agreed on between the provider and regulator. This algorithm then acts as the check between the regulator's data and provider's data.

The algorithm becomes the clearing agent for the regulator in the protection of consumers' interest as well as the other stakeholders' interests. The validation is done after the regulator clears the provider's data from all anomalies and errors which will be associated with the individual meters. Data which are realized to be accurate from the remaining meters will be allowed to have the billing done by the provider.

The validation process by the regulatory body is supposed to provide some level of guarantees for accuracy, and consistency for any of various kinds of user input into an application or automated system.

Data validation can be defined through declarative data integrity. Johnson [40] had to apply the validation to check the operation of the system according to a number of logical consistency checks where all nodes within wireless transmission range of each other, no data packets experience collision and that each node is able to make progress sending data.

Shrirang Mare [41] validated an analytical model for a single flow TCP connection. It was realized that even when nodes are close to each other the packet error probabilities are high to affect the analytical results, hence, the need to measure the error probabilities

$$P_e = \frac{number\ of\ retries}{total\ number\ of\ attempts}$$

P_e = probability of channel errors

The channel of error probability changes with time and environment; hence, new is calculated where the failure probability (γ) includes both collision probability and channel error probability.

$$\gamma = \frac{number\ of\ retries}{total\ number\ of\ attempts} \qquad \textbf{(3.13)}$$

The MySQL language was used to establish the final validation process between the utility provider and regulator virtual machines. This meant that data submitted by the meter gateway will have to be the same between the two institutions when the provider sends a request for validation and authorization of data prior to billing consumers. Coding inserted in appendix [A5].

CHAPTER FOUR

RESEARCH RESULTS AND DISCUSSIONS

4.0 Data Analysis Results and Discussions

In this chapter we will evaluate the actual consumption data generated by the meter gateways with the expected consumption data which has been agreed on by all stakeholders as the maximum allowable percentage error if there is an attempt to have zero integrity in the submitted data by the provider.

4.1 Consumption Data Collection

The collection of data generated by the meters is done by the meter gateway (data concentrator) which then are forwarded to the provider and regulator where further aggregation and queries carried out to ensure consistency in the data. The inconsistencies in the used data have the tendency to affect both the consumer and provider adversely especially when other revenue generating institutions such as Ghana Revenue Authority in relations to NHIS and VAT rely on the used data in calculating their percentages in terms of taxes due them. When the data is not accurate enough the burden comes back to the consumer to make some forcibly unplanned payments to the provider which sometimes is very uncomfortable. The existing billing system for the electromechanical and electronic meters are still recording disparities and even for the AMR meters still disparities are recorded in data submitted to consumers for payments to be made by them. If the regulator takes the oversight

responsibility of ensuring integrity in submitted data and as well as establishing service level agreements (SLAs) among stakeholders, this will greatly improve the billing system and

increase the efficiency in revenue generation and collection for all the stakeholders in the industry. The existing billing system produced marginal errors in the energy meter consumption data used in billing but with the introduction of the regulator as a mandatory clearing agent prior to billing the marginal errors were eliminated totally.

4.2 Data Model from Energy Meter Gateway

The meter gateway was modelled to have individual meters capturing monthly energy consumed and submitting the figures to the provider and regulator within the backhaul network. These meters submit their readings for a period whether they generated some figures or not for the analysis to be done by the stakeholders.

Below figure 4-1 is showing the individual meters with their displays. This is a machine –to – machine communication between the individual meters and the meter gateway.

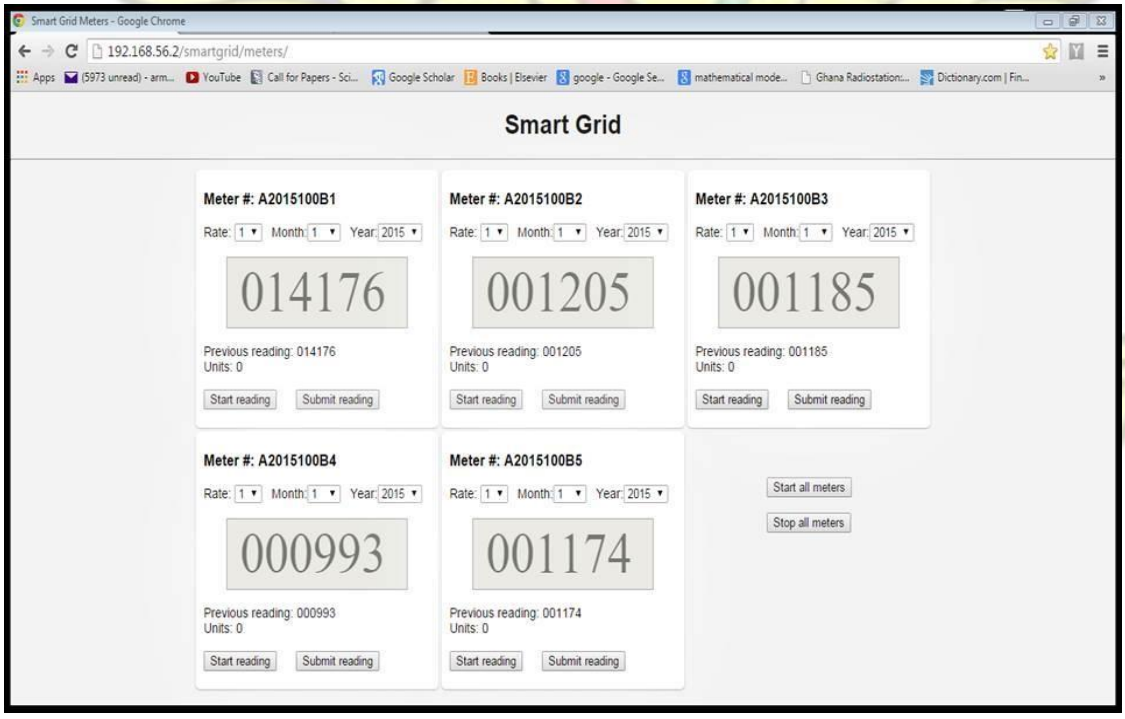


Figure 4-1 Model for smart metering reading system web page

4.3 Model for Consumption Data Analysis

The generated meters when aggregated by the provider and regulator will then be analyzed with each meter agreed on average consumption which was submitted by the consumer in order to have the energy consumed by the consumer not extremely exceeding what he or she is expecting and making plans and preparation to pay for at the end of the month.

The provider has been mandated to work closely with the consumer when queries are raised during the analysis to have integrity established within the data which will be submitted to the regulator for authorization prior to billing. This will facilitate in the prevention process of unnecessary engagement between consumer and provider after the bill has been generated because the regulator will not approve anything which is not within the maximum allowable percentage error.

The figure 4-2 below shows each consumer meter readings taken monthly with the average consumption as the reference to initiate the analysis by the provider.

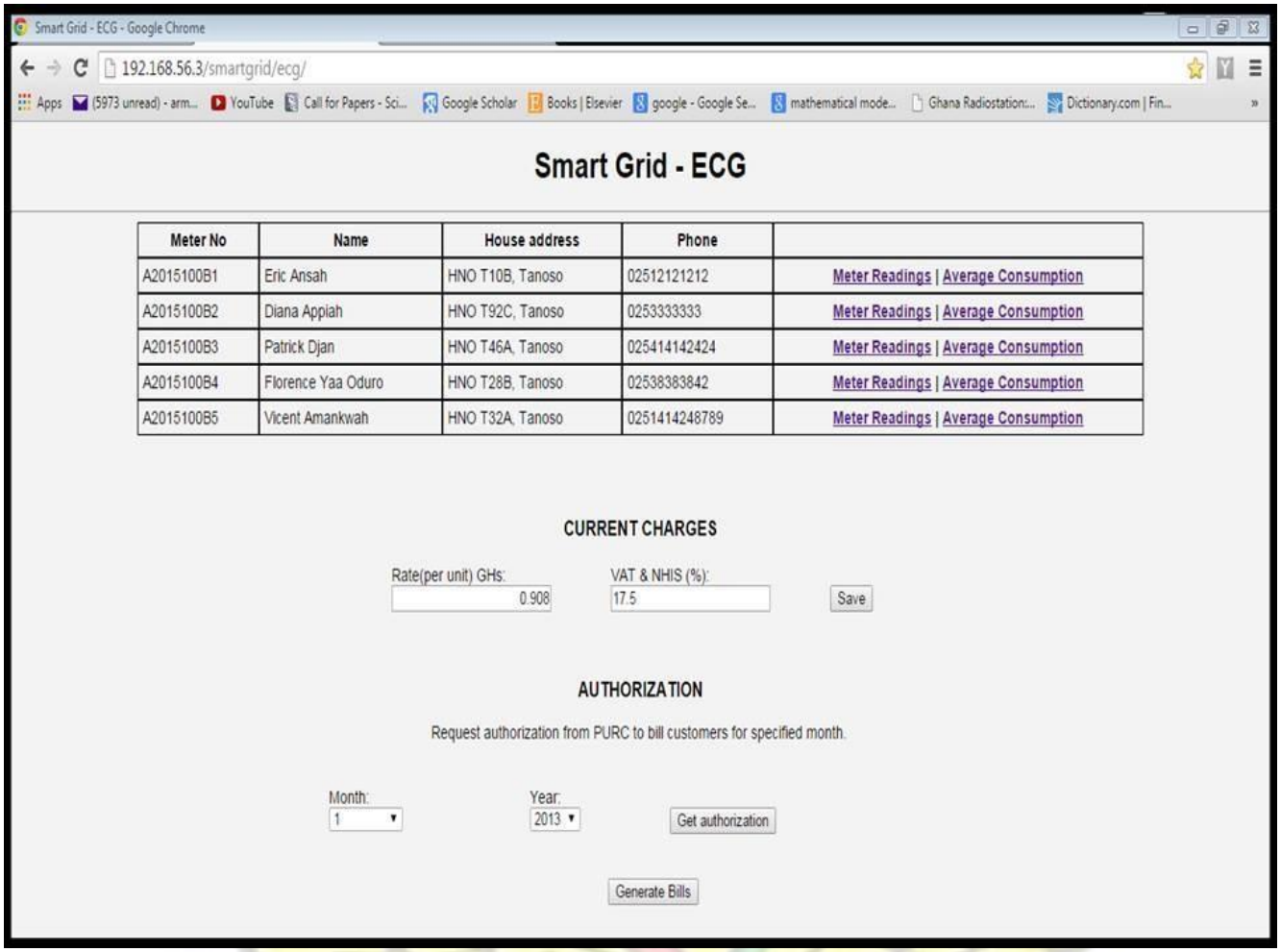


Figure 4-2 Model for ECG service provider data aggregation, query and analysis system web page

Also any discrepancies in the categorization of a consumer whether a commercial or residential consumer will not be accepted by the regulator since all these data have already been submitted to the regulator as the actual information on each consumer. The regulator knowing very well the implication of these inconsistencies have grievous effects not only on provider and consumer but also on other governmental agencies will require to do ensure due diligence in final data submission for billing.

The regulator ensures protection in the demand management so as not to have mistrust emanating from all players.

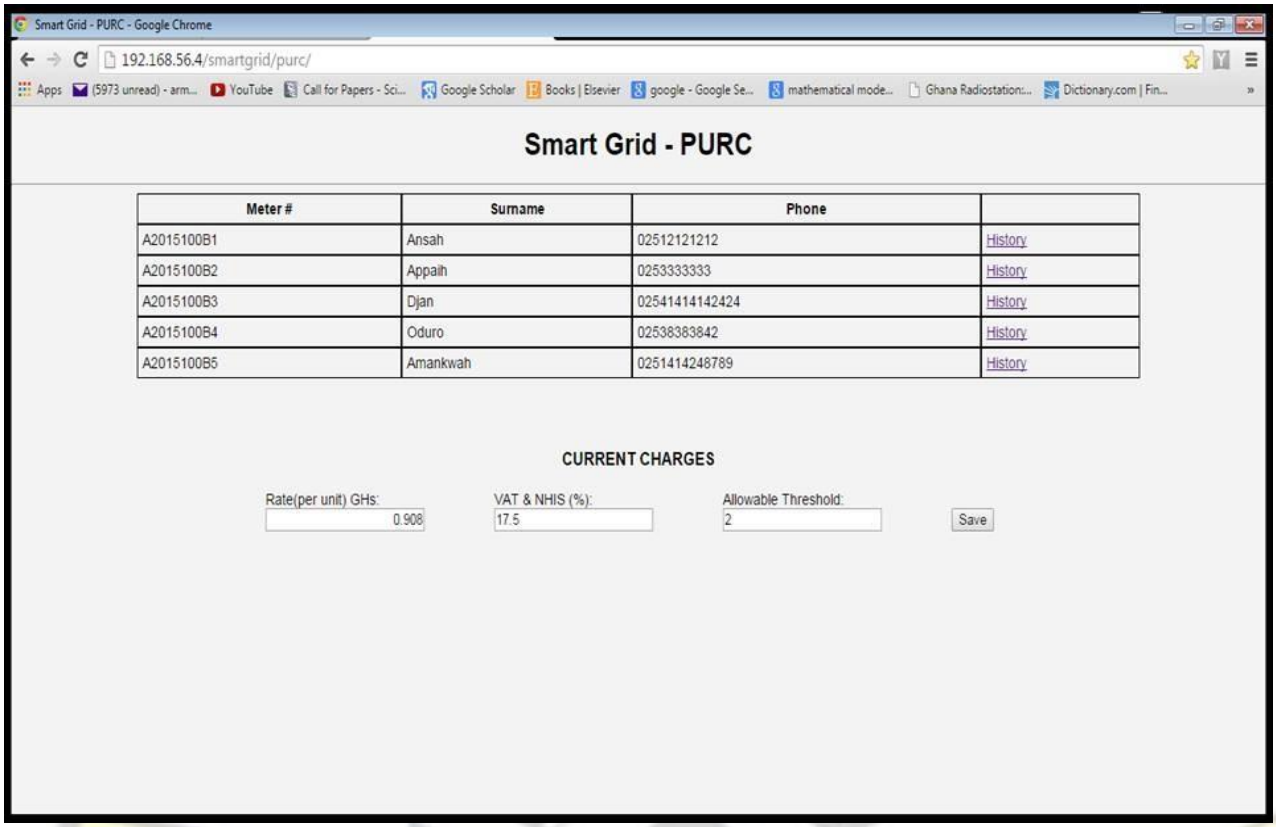


Figure 4-3 Model for public utility regulator analysis and authorization system web page

4.4 Comparison of Actual and Expected Consumption Data

When the analysis has been completed by the provider the data is submitted to the regulator for final authorization prior to billing of consumers. Based on the agreed protocols the regulator scrutinizes the data before authorization is given. All these are done without human intervention. The machine-to-machine communication is done within the backhaul network so the data submitted by the provider are queried and the inconsistent data are rejected by the regulator with the required reasons attached to each data for each meter.

During the Simulink tesbed, the initial comparison of the submitted data below in figure 4-4 was obtained.

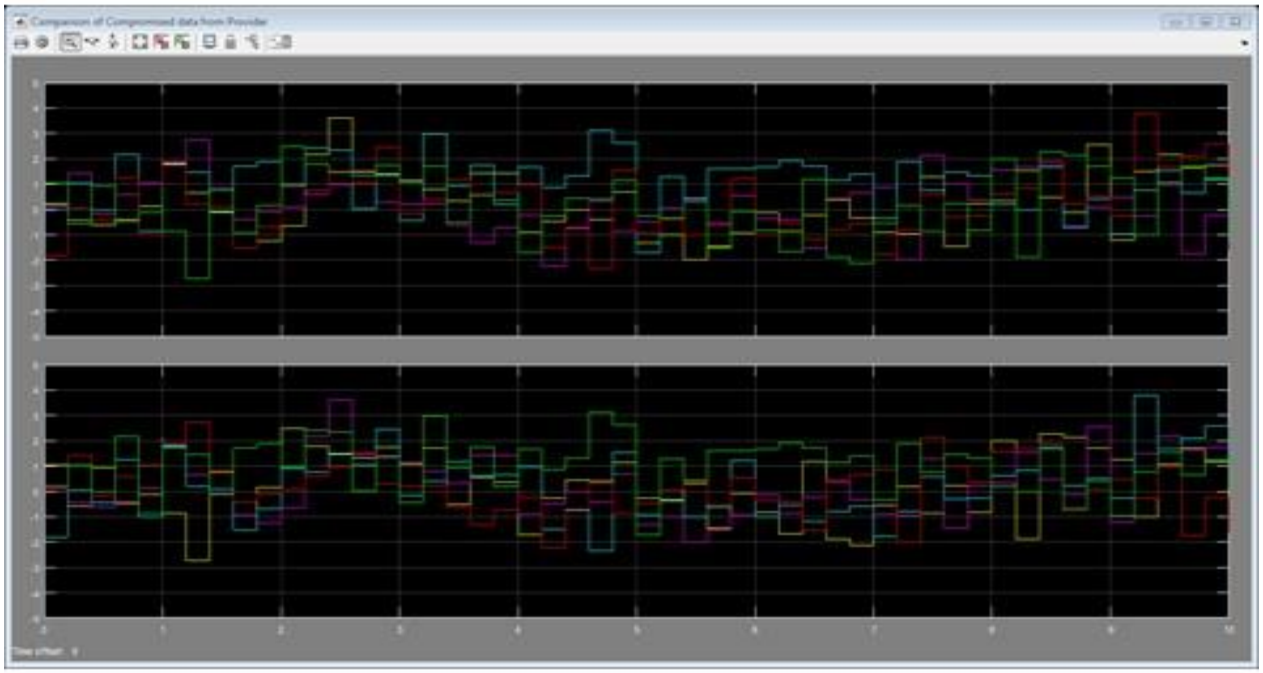


Figure 4-4 Simulink model depicting the initial data comparison between ECG and PURC

It was realized that during the initial comparison the data were exactly the same and this makes it easier for the regulator to authorize billing of consumers. In the figure 4-4 the data are represented in colours and in oscilloscope form, In comparison the results which were on different oscilloscopes.The first oscilloscope being the providers data and the second being the regulator's data. The second scenario in which the data from the provider's end were compromised and in comparison with the regulator's data was established that the provider's data were flawed; hence the affected data were rejected.

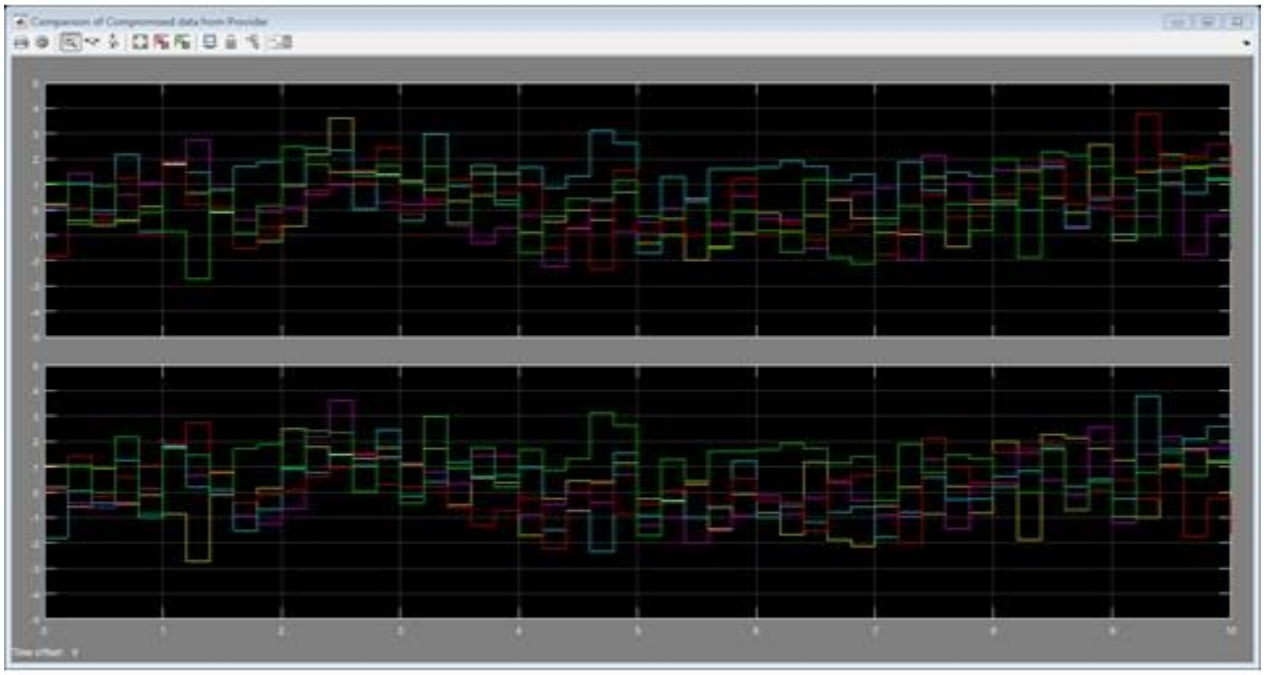


Figure-4.5 Simulink model depicting the compromised data comparison between ECG and PURC

The scenario figure 4-5 the data (in colours) representing the provider are very different from what the regulator is expecting, hence, the rejection. In this case the regulator then tasks the provider to put in much effort to perform due diligence on the rejcted data for final approval.

The third scenario is after due diligence performed by the provider and the final submission is done comparison is again done with the regulator's data for the approval to be given the provider to bill consumers.

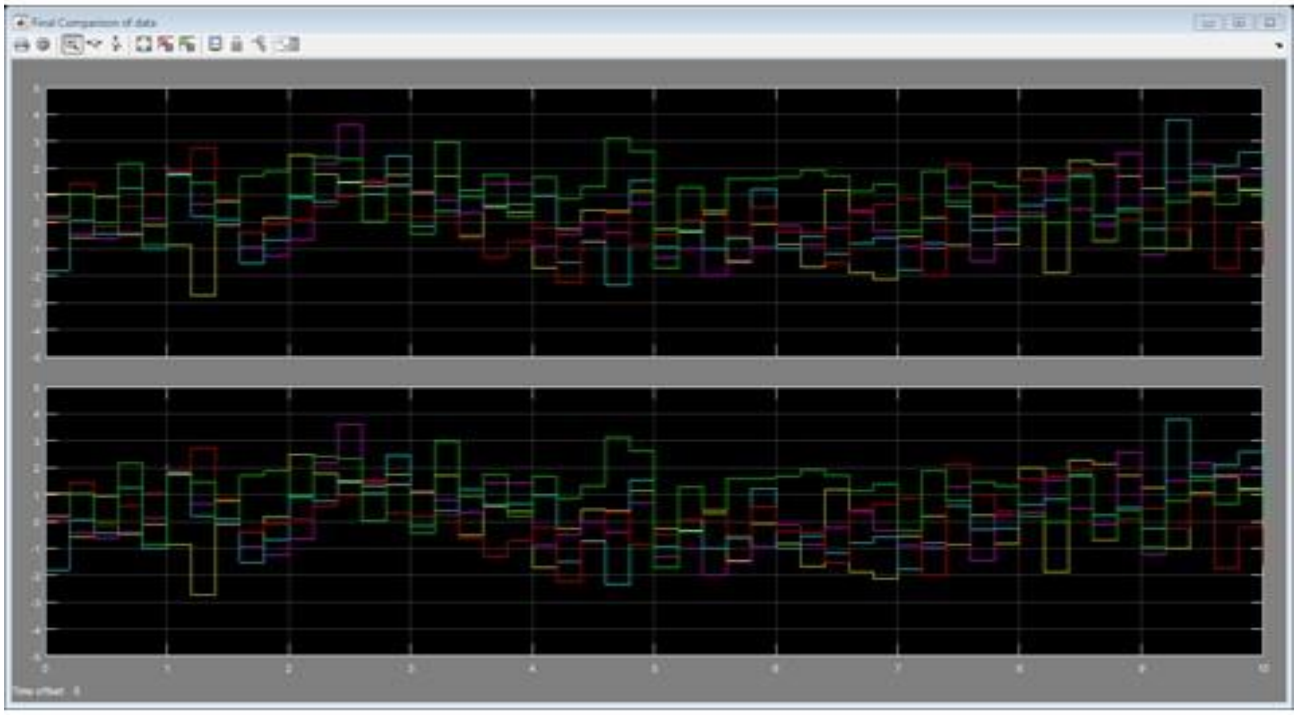


Figure 4-6 Simulink model depicting the corrective compromised data comparison between ECG and PURC

Here in figure 4-6 the colours are exactly as expected by the regulator so the authorization is given to the provider to issue out bills to consumers.

Each consumer authorized or unauthorized feedback is sent to the provider to either generate the bill automatically for the consumer for onward payment or to perform due diligence again on the unauthorized accounts before final billing within a stipulated period.

4.5 Validation of Submitted Data

Figure 4-7 shows the flow chart for the process which ensure due diligence on the part of the provider before billing the consumer

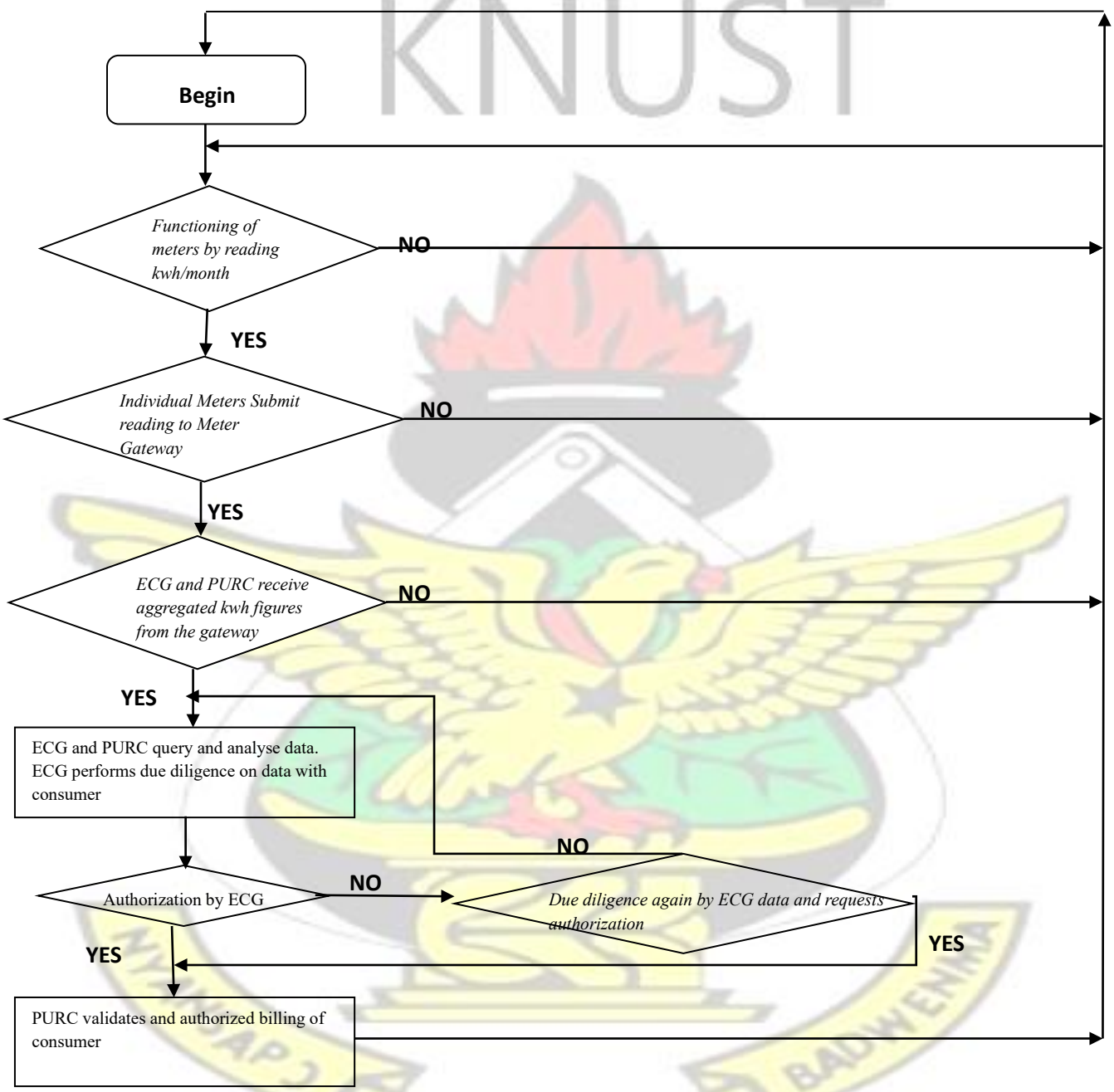
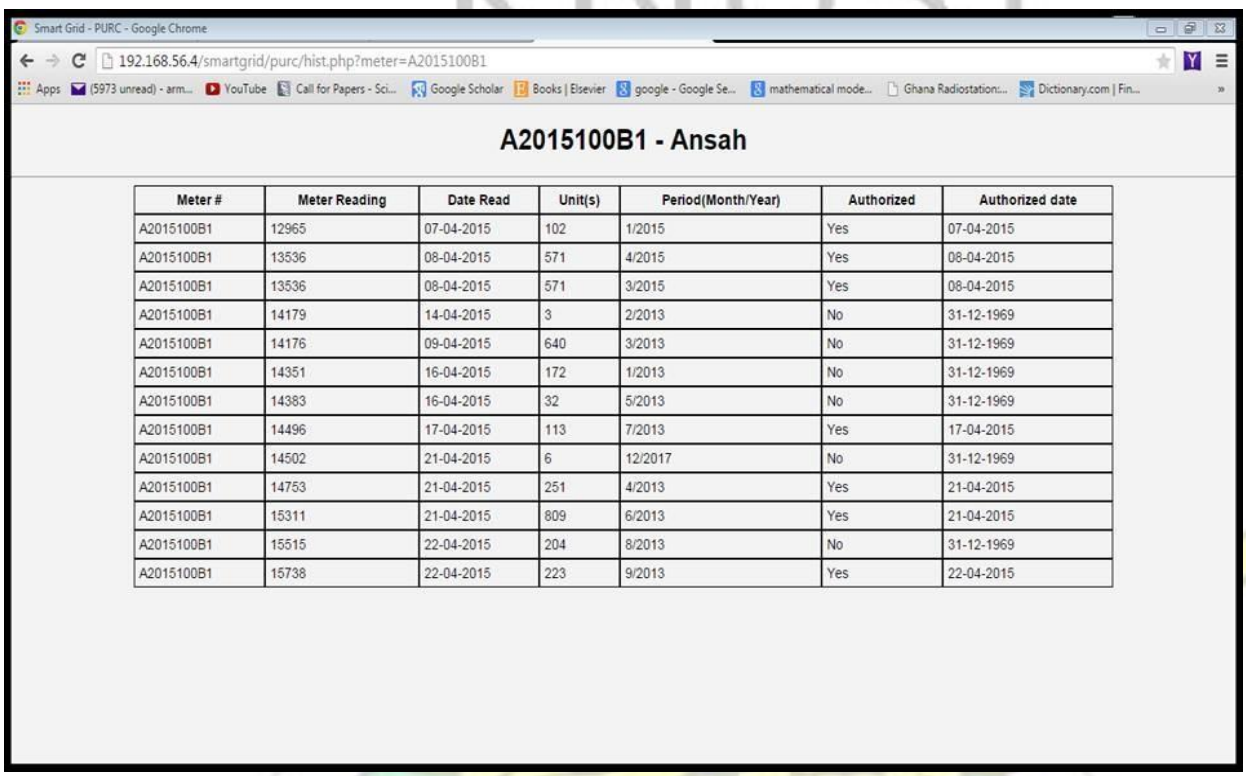


Figure 4.7 Flow diagram of the machine –to machine validation process

The regulator has the right to calculate and set tarrif rates prior to charging of consumers and so the same institution must be in a position to validate and approve billing data before the

utility power providers bill the consumers. This was done in the simulation pocess and the error of margins and variances were eliminated to zero, making the data very credible and trustworthy, thereby making it easily acceptable by all stakeholders.

Below figure 4-8 is a sample of the validation history result for one of the consumers in the simulation.



Meter #	Meter Reading	Date Read	Unit(s)	Period(Month/Year)	Authorized	Authorized date
A2015100B1	12965	07-04-2015	102	1/2015	Yes	07-04-2015
A2015100B1	13536	08-04-2015	571	4/2015	Yes	08-04-2015
A2015100B1	13536	08-04-2015	571	3/2015	Yes	08-04-2015
A2015100B1	14179	14-04-2015	3	2/2013	No	31-12-1969
A2015100B1	14176	09-04-2015	640	3/2013	No	31-12-1969
A2015100B1	14351	16-04-2015	172	1/2013	No	31-12-1969
A2015100B1	14383	16-04-2015	32	5/2013	No	31-12-1969
A2015100B1	14496	17-04-2015	113	7/2013	Yes	17-04-2015
A2015100B1	14502	21-04-2015	6	12/2017	No	31-12-1969
A2015100B1	14753	21-04-2015	251	4/2013	Yes	21-04-2015
A2015100B1	15311	21-04-2015	809	6/2013	Yes	21-04-2015
A2015100B1	15515	22-04-2015	204	8/2013	No	31-12-1969
A2015100B1	15738	22-04-2015	223	9/2013	Yes	22-04-2015

Figure 4-8 Validation history web page from the public regulator for a consumer prior to billing of the consumer.

The validation process for the submitted data resulted to high level integrity established where zero variance and error margins were obtained.

Below figures 4-9 to 4-13 are the attained results for the five simulated consumers.

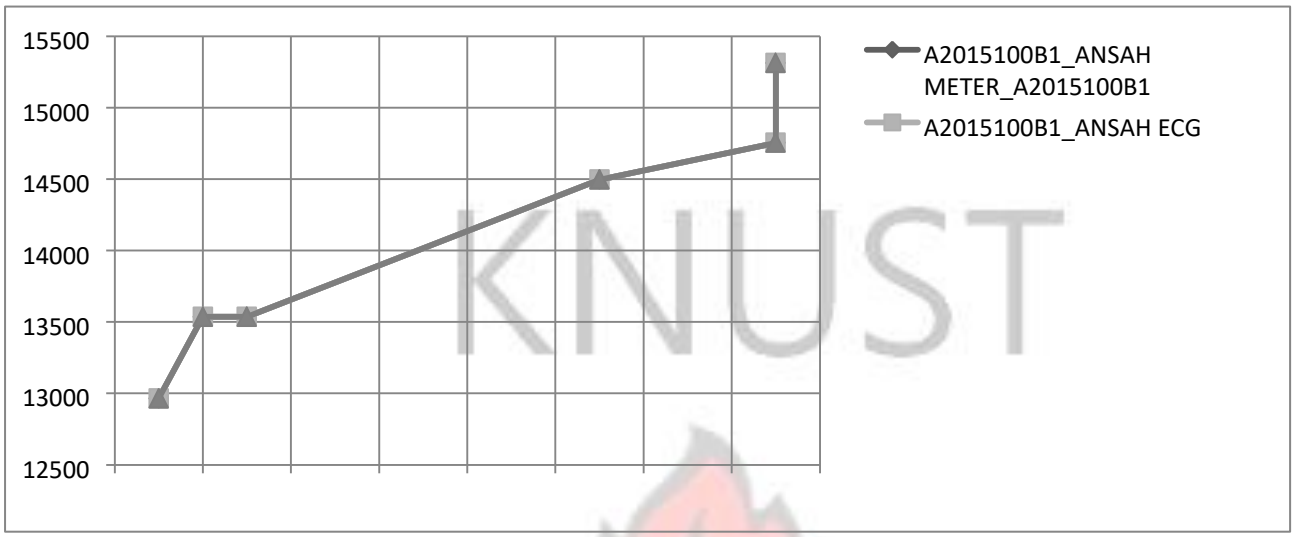


Figure 4-9 Model showing testbed results after PURC's validation for consumer Ansah's meter A2015100B1 readings

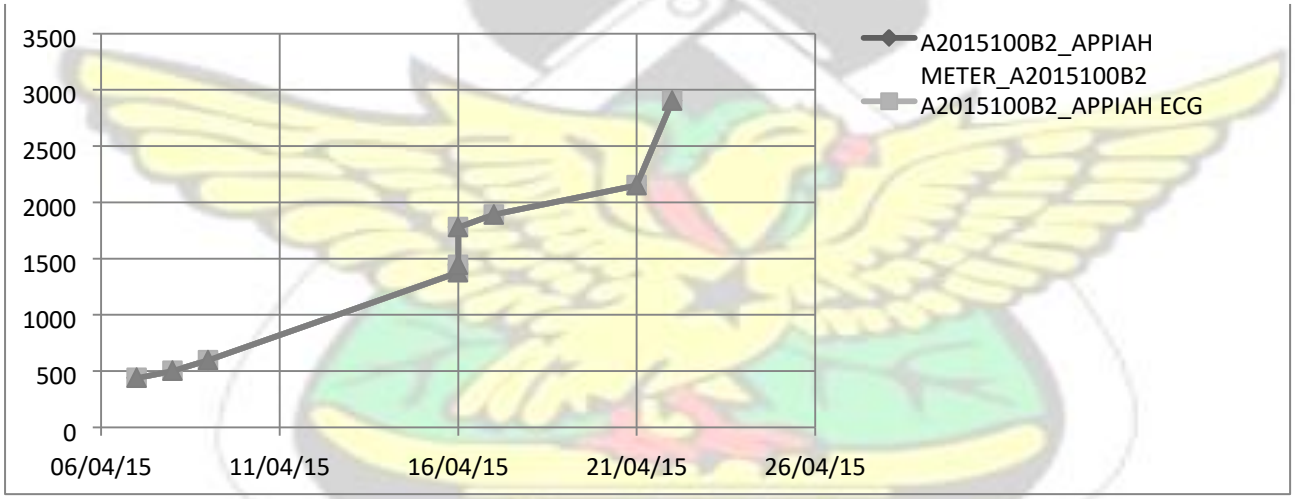


Figure 4-10 Model showing testbed results after PURC's validation for consumer Appiah's meter A2015100B2 readings.

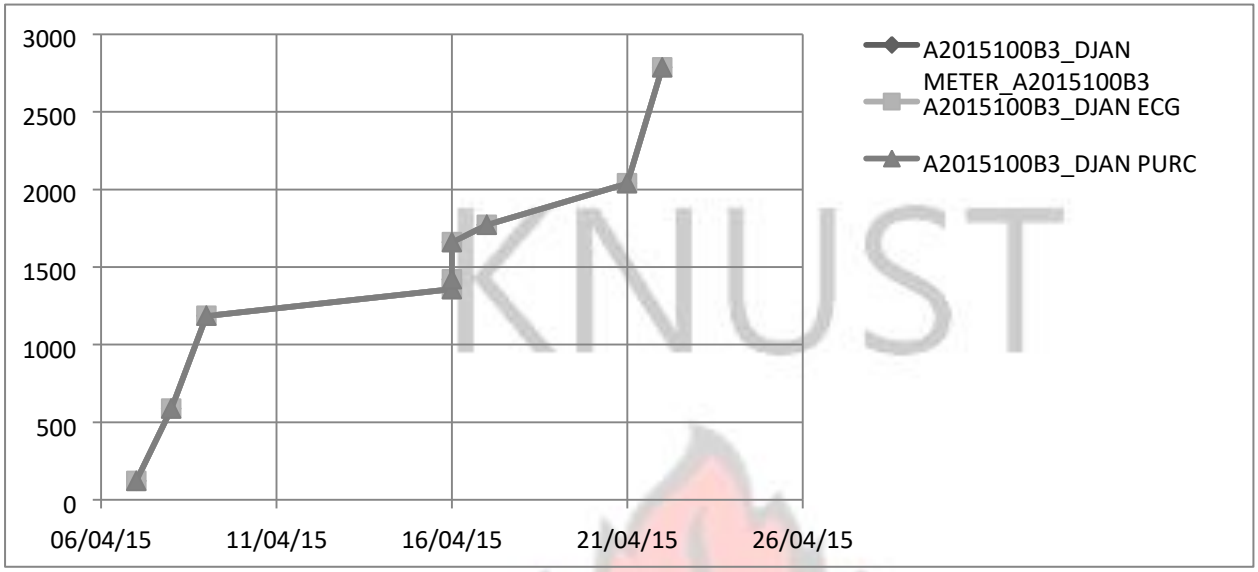


Figure 4-11 Model showing testbed results after PURC's validation for consumer Djan's meter A2015100B3 readings.

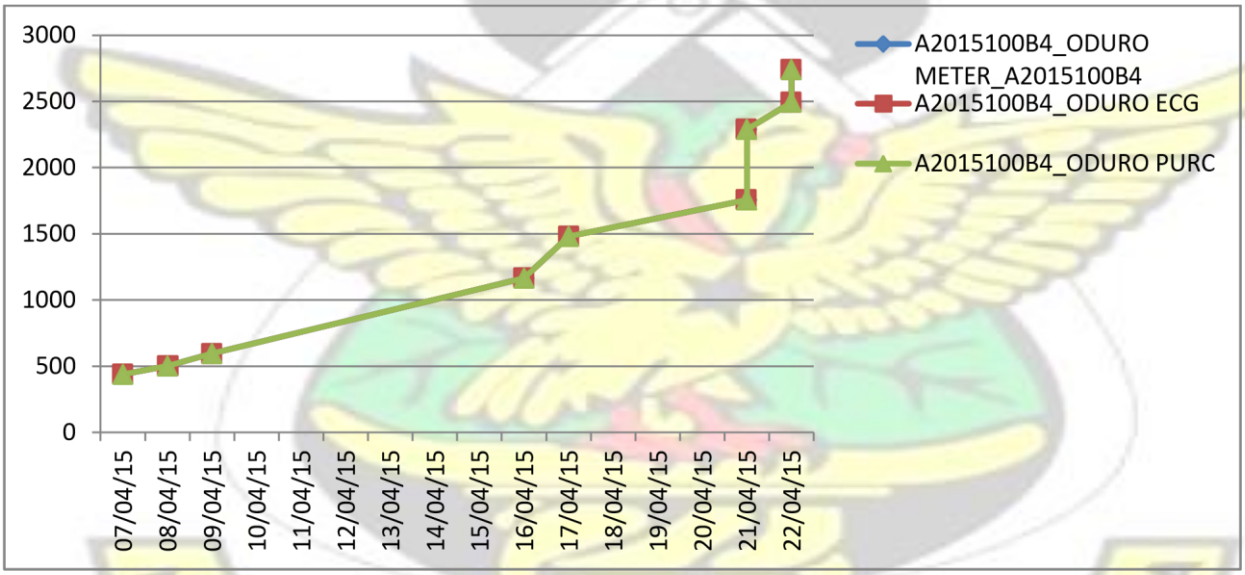


Figure 4-12 Model showing testbed results after PURC's validation for consumer Oduro's meter A2015100B4 readings

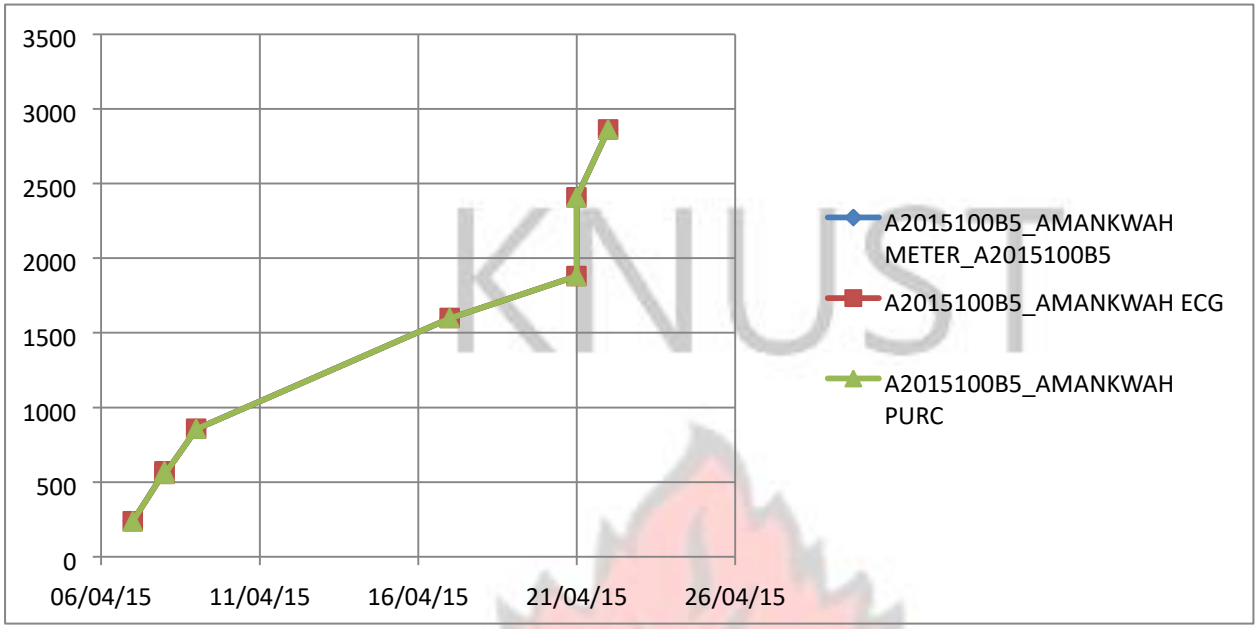


Figure 4-13 Model showing testbed results after PURC's validation for consumer Amankwah's meter A2015100B5 readings.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.0 Conclusion

This research is to evaluate and establish the integrity in consumption data used by the utility power provider in the billing process of consumers. The Electricity Company of Ghana Limited data were used as a case study as against consumer's data collected from their premises [Appendix A.1].

It was found out that although the utility provider requests the number of appliances the consumers will be using at their premises, the energy consumption calculation is not done by the provider to know the average monthly energy consumptions to be expected from the consumer's premises so that queries can be immediately be raised when higher consumptions are used for billing queries can be raised for due diligence to be carried out.

These have a significant impact on expected monthly revenue collection, investments and business developments for all stakeholders directly or indirectly involved in the utility power industry. If this is properly realized, it will facilitate a proper service level agreement (SLA) between the stakeholders where accountability can be established for better work performance to be achieved for all. This was discovered during the site load assessment exercise carried out which meant that routinely the utility providers must engage in this exercise at consumers' premises to aid them in proper planning of the demand management network.

This also makes it necessary for the utilities regulator to no longer wait to rely on second hand information from the utility providers but rather get first hand information for the benefit of all. With the introduction of the smart meters, it is possible to evaluate within a well established backhaul network with the communication effectiveness between the consumers' meters. The provider's analysis processes prior to billing and the role which the regulator is required to play in ensuring the protection of both parties. This meant that machine-to-machine communication

would be required to establish the needed data integrity. A model was used to create these virtual machines: one for the meter data collector, one for the utility provider and then the regulator which are connected together within the communication backhaul network. Three meters generated their readings and are submitted to the provider and regulator via the meter gateways. With the agreed protocols established, the provider submits data to the regulator for approval and onward billing but any inconsistency detected by the regulator for any particular meter, the regulator rejects for the provider to do due diligence again before approval can be given. The Virtual Machine Simulation proved the feasibility of the data integrity model for the utility power industry and its positive impact, it can bring on the industry when implemented.

This mechanism will ensure a high level of integrity, trust and transparency in the billing process which will benefit the entire nation because there will be no room for anybody to manipulate the data not even from the provider's premises.

5.1 Recommendation

This thesis is limited to the establishment of integrity in the energy meter consumption data and value for money for all the stakeholders in the credit metering system. The prepayment system must also have some form of model designed to establish some level of integrity within the system to ensure that the demand management side of the grid system becomes robust and authentic as required. Currently, the only mode of submission of data is from the smart meters to the utility provider's database management system. There must be an alternative mechanism to make the system establish a ring network where data will get to the server if one mechanism fails.

5.3 Future Works

This thesis was to establish data intetrigy in the demand management systems for smart metering. In the future some works can be done on investigating and coming out with a model that will establish integrity in the purchase of prepaid units by consumers without them being cheated. There has been an instance were a consumer purchased an amount of prepaid units and the amount paid to the prepaid vendor was different and less than the original amount issued out by the consumer. This was realized during a print out of the purchase history for that consumer's meter.

REFERENCE

[1] M Doler, D. B. (2012). *" Machine to Machine in Smart Grids and Smart Cities.Technologies Standard Applications"* .

[2] (August, 2010). In L. A. Luhusa, *" Service Oriented Architecture(SOA) for Electric Utilities in Electrical Distribution".*

[3] (Jan 31, 2013.). In J. P. Hanley, *" Utility Meter COnfigured To Execute Multiple Collection Agents".* Decator,GA, US.

[4] (July, 2006). In E. C. Ghana, *"Smart National Energy Plan 2006-2020"* (p. 22).

[5] (2008). In P. U. Commission, *" Public Utilities Regulatory Commission Annual Report 2008"* (p. 46).

[6] (2012). In M. M. Kezunovic, *" Smart Grids and Beyond:Achieving the Full Potential of Electrical System" IEEE Proceedings,Vol 100* (p. 1329).

[7] (October 2010). In D. o. (USA), *" Communications Requirements of Smart Grid Technologies".*

[8] (Fall 2010). In A. Shreyas, *" Ananlysis of Communication Protocols for Neighborhood Area Network for Smart Grid"* (pp. 2-3).

[9] (n.d.). In *WMV wireless att.com/business center/pdf/Deploying AMI solutions.*

[10] (n.d.). In *systems.com/downloads, http://gridco A -New Era-in-Active GridInfrastructure Gridco System:pdf* (p. 12).

[11] (September 2010). In O. Panzat, *" Cellular Communications and the Future of Smart Metering" Sierra Wireless Inc.* (pp. 2-4).

[12] (30-32). In N. I. Technology, *" Potential Privacy Impacts that Arise from the Collection and Use of Smart Grid Data" Volume 2, Table 5-3 .*

[13] (n.d.). In *http://spectrum.ieee.org/energy/the-smart-grid/privacy-on-the-smart-grid.*

[14] (2002). In E. R. Brown, *" Electrical Power Distribution Reliability" CRC Press 2nd Endition.*

[15] (2003). In S. A. A. Chowdhury, *" Reliability Modeling of Distributed Generationin Conventional Distribution Systems Planning and Analysis" IEEE Transactions on Industry Applications,39(5)* (pp. 1493-1498).

[16] (n.d.). In I. A. Chritina Alcaraz, *"Mananging Incidents in SMart Grid a la Cloud"* (pp. 4-5).

[17] (2011). In P. J. H. Nicanfar, *" Smart Grid Authentication and Key Management for Unicast and Multicast Communications in Innovative Smart Grid Technologies" Asia(ISGT), IEEE DES 2011* (pp. 1-8).

[18] (2011). In X. W. Yi, *" Security Framework for Wireless Communication in Smart Distribution Grid" IEEE Transaction Smart Grid Vol 2 no. 4* (pp. 809-818).

[19] (2011). In D. M. B Vaidya, *" Device Authentication for Smart Energy Home Area Networks" IEEE International Conference on Consumer Electronics.*

[20] (March 2011). In Y. Q. Y. Yan, *" A Secure and Reliable in Network Collaborative Communication Scheme for Advance Metering Infrastructure in Smart Grid" in IEEE Wirless Communications and Networking Conference(WCNC)* (p. 909).

[21] (2010). In C. E. Kalogridis, *" Smart Grid Privacy via Anonymization of SMart Meter Data" 2010 First IEEE International Conference on Smart Grid Communications* (pp. 238-243).

[22] (2011). In F. G. Jacobs, *" Privacy-Friendly Energy Metering via Homomorphic Encryption" in Proceedings of the 6th International Conference on Security and Trust Management.STM 10,2011* (pp. 226-238).

[23] (2010). In B. L. F. Li, *" Secure Information Aggregation for Smart Grid Communication 2010.First IEEE International Conference on October 2010* (pp. 237332).

[24] (2011). In B. L. F. Li, *"Secure and Privacy Information Aggregation for Smart Grid " International Journal Secure Network vol 6. No.1* (pp. 28-39).

[25] (2005). In A. M. Wollenberg, *" Toward a Smart Grid Power Delievry for the 21st Century" Ieee Power and Energy Magazine, vol 3,no.5* (pp. 34-41).

[26] (2010). In X. L. Z. Lu, *" Review and Evaluation of Security Threats on the Cmmunication Networks in the Smart Grid", in Proceedings of IEEE Military Communications Conference* (pp. 1830-1835).

[27] (2010). In G. P. J Steven, *" Smart Grid Security Issues", IEEE Security and Privacy* (pp. 81-85).

[28] (June 2009). In S. M. P. McDaniel, *" Security and Privacy Chamllenges in the Smart Grid" , IEEE Security and Privacy vol 7, no. 3* (pp. 75-77).

[29] (2014). In E. E. Owusu, *" Evolution and Efficiencies of Energy Metering Technologies in Ghana" Global Journal of Reseaches in Engineering: Electrical and ELectronics Engineering, Volume 14 Issued 6 Version 1.0* (p. 40).

[30] (April 2014). In A. F. Ramyar Rashed Mohassel, *" A Survey on Advance Metering Infrastructure"* (pp. 473-474).

[31] (April 2013). In F. M. J. F. Aguirre, *" Viability of WiMax for Smart Grid Distribution Network" Vol 2,No. 3 European International Journal of Science and Technology* (p. 184).

[32] (n.d.). In M. Z. P.S., *" Analysis of the Logistic Model for Predicting New Zealand EElectricity Consumption" presented at the Electricity of Engineers Association(EEA) New Zealand 2003 Conference, Christchurch, New Zealand.* Christchurch.

[33] (2007). In E. I., *" Tarrifs and the Poor" in A. Brew-Hammond and F. Kemasour(Eds) " Energy Crisis in Ghana,Droughts,Techologiy or Policy", KNUST, COllege of Engineering.*

[34] (n.d.). In *http://www.google.comgh/webhp?sourceid=chromeinstat&ion=1&espv=2&ie=UTF-8#q=edmi+mk108(smart specification).*

[35] (June 2006). In H. Z. Chipara O., *" Real -Time Power Aware Routing in Sensor Networks" Proceeding of the 14th IEEE International Workshop on Quality of Service* (pp. 83-92). New Haven CT, USA.

[36] (14 August 2006). In S. V. Pothuri P.K., *" Delay-Constrained Energy Efficient Routing in Wireless Sensor Networks Through Topology Control Proceeding in International Conference on Networking Sensing and Controls", ICNSC* (pp. 35-41). Lauderdale, FL, USA.

[37] (2003). In W. S. Goldsmith A. J., *" Design Challenges for Energy-Constrained adhoc Wireless Networks", IEEE Wireless Communications* (pp. 8-27).

[38] (n.d.). In K. Y. J. Nagi, *" Detection of Abnormalities and Electricity Theft Using Genetic Support Vector Machine".*

[39] (1992). In T. E. M. J. Liebman, *" Efficient Data Reconciliation and Estimation for Dynamic Processes Using Nonlinear Programming Techiniques, Computers Chem Eng. 16* (pp. 963-986).

[40] (May 1999). In D. Johnson, *" Validation of Wireless and Mobile Network Models and Simulation" in DARPA/NIST Network Simulation Validation Workshop.*

[41] (n.d.). In D. K. Shrivang Mare, *" Experimental Validation of Analytic Performance Models for IEEE 802.11 Networks.*

APPENDIX

A1 Field Data

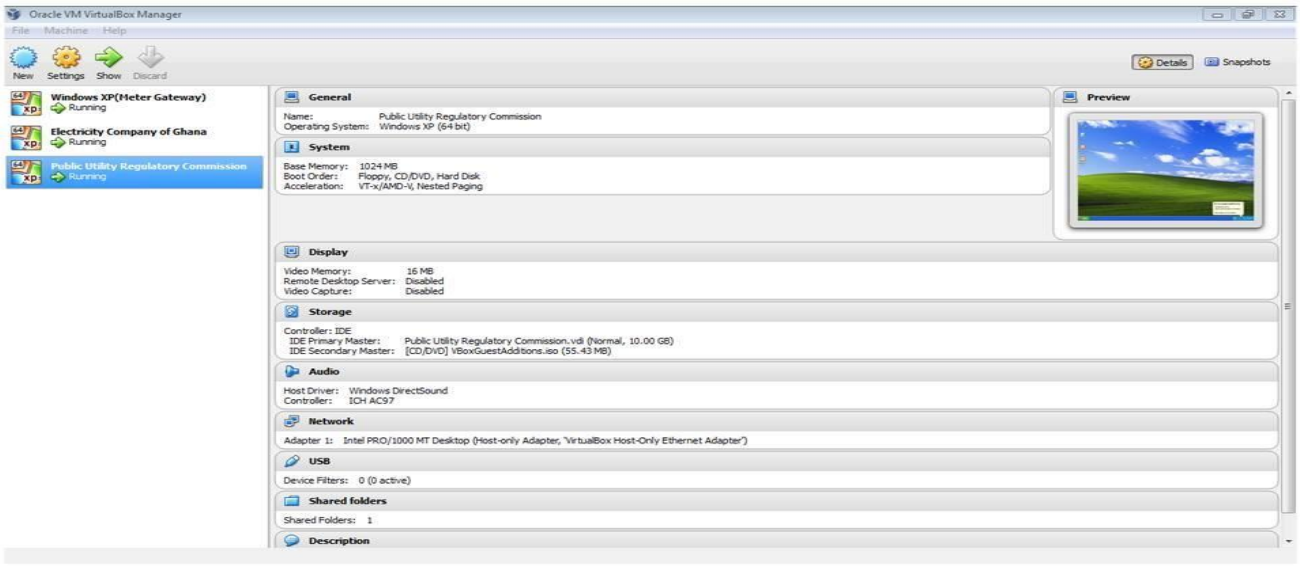
Below depicts power consumptions recorded over a period of one year from ECG bills and energy consumptions recorded at five cell sites across Ashanti region.

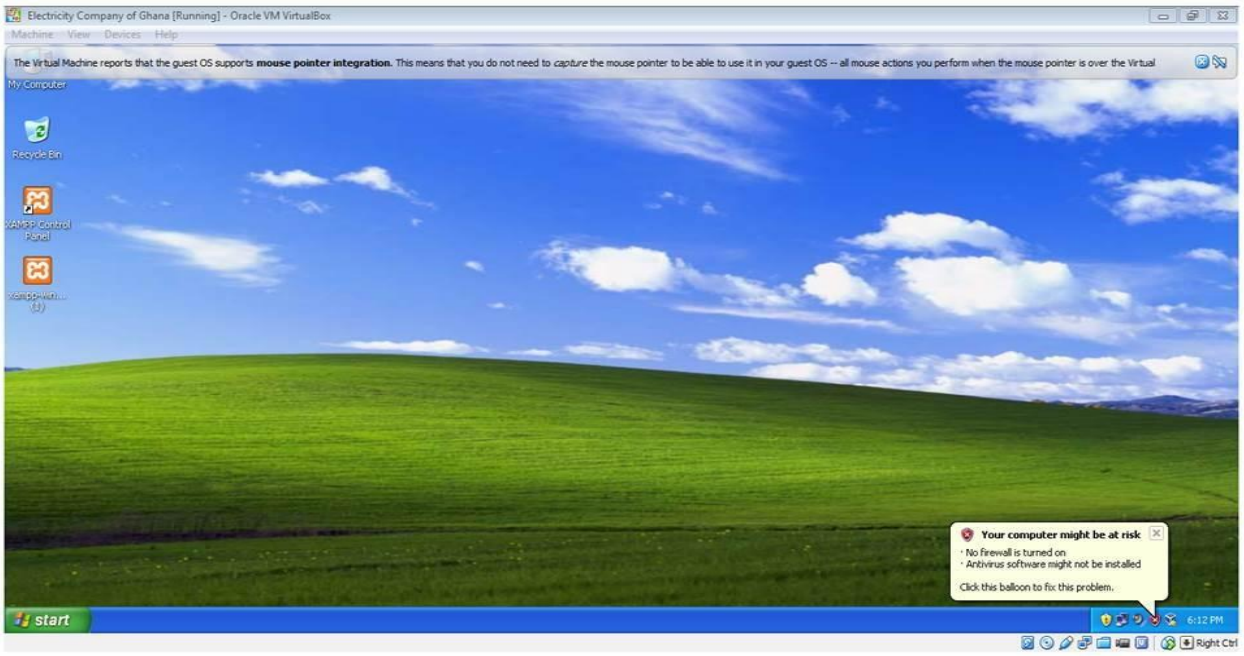
MONTH	ECG RECORDED CONSUMPTION(UNITS) AND BILLING(GHC)									
	METER A	BILL(GHC)	METER B	BILL(GHC)	METER C	BILL(GHC)	METER D	BILL(GHC)	METER	BILL(GHC)
Jan-12	1562	677.57	4740	2024.64	1190	471.38	4036	1,861.02	1232	524.6
Feb-12	1738	753.91	4740	2024.64	1190	471.38	4040	1862.86	1415	602.52
Mar-12	1305	566.80	4740	2024.64	1190	471.38	1864	859.50	1674	712.8
Apr-12	1912	829.39	4740	2024.64	1190	471.38	4040	1862.86	1670	711.1
May-12	1584	687.11	4740	2024.64	1190	471.38	4040	1862.86	1463	622.96
Jun-12	2013	873.2	4740	2024.64	1190	471.38	4040	1862.86	1756	747.72
Jul-12	1559	651.53	4740	2024.64	1190	471.38	3111	1628.53	1871	803.87
Aug-12	1632	1099.03	4740	2024.64	1190	471.38	2850	1693.72	1870	1215.23
Sep-12	1893	814.61	6650	3556.84	1190	471.38	2650	1184.22	1450	598.31
Oct-12	1875	805.82	2902	1307.25	1190	471.38	2420	1071.91	1870	803.38
Nov-12	1617	679.84	4212	1946.84	1190	471.38	2150	940.1	1870	803.38
Dec-12	1889	748.21	4599	1821.86	1190	471.38	1979	783.85	1870	803.38
Jan-13	1829	769.2	4174	1928.89	1190	471.38	1460	603.2	1800	769.2
Feb-13	1729	1424.36	3018	2053.71	1190	471.38	2230	1668.98	1790	1454.15
Mar-13	1506	625.66	2662	1190.07	1190	471.38	2120	925.44	1780	759.44
Apr-13	1741	740.4	3117	1421.21	1190	471.38	2040	886.37	1830	783.85
May-13	1706	723.31	3422	1561.12	1190	471.38	1970	852.2	1820	778.96
Jun-13	1261	506.04	3484	1591.41	1190	471.38	1940	837.55	1820	778.96

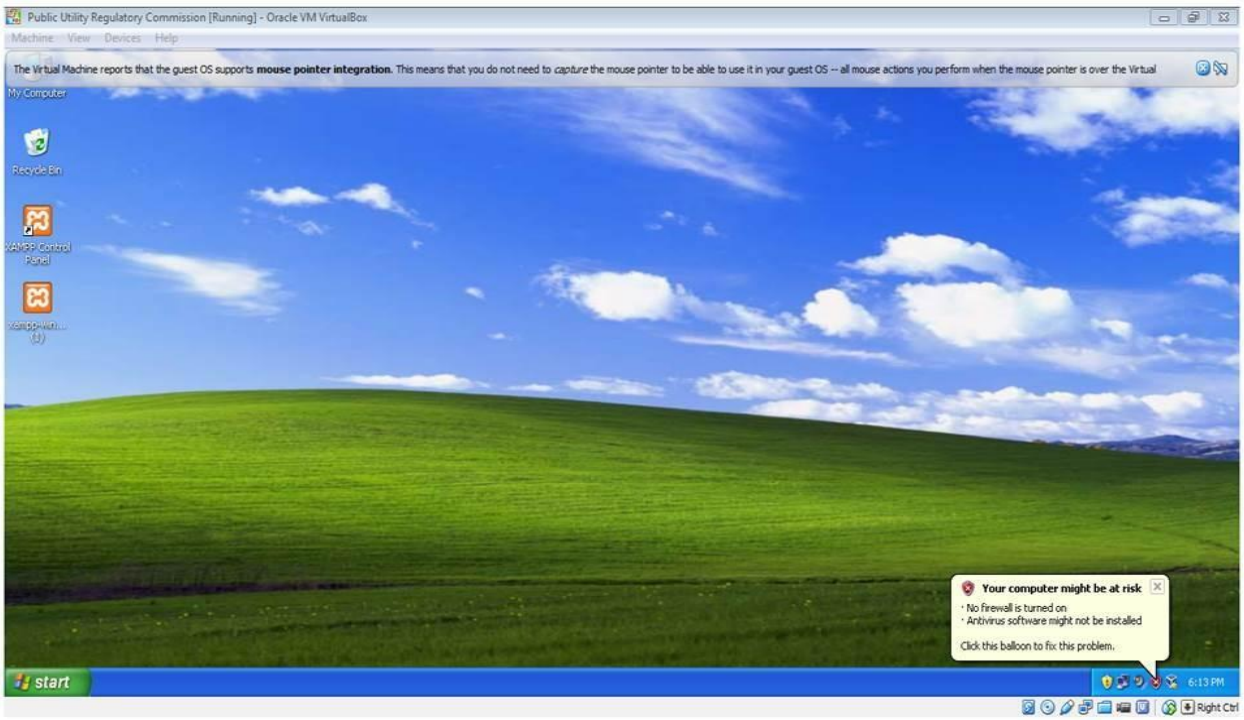
Jul-13	791	298.67	4205	1965.54	1190	471.38	1960	869.43	1810	796.19

A2 Oracle Virtual Machines

Below depicts various virtual machines programmed to establish the machine-tomachine communication required between the meter gateway,the utility provider and utilities regulator.







A.3 Comparison of ECG and PURC virtual machines received data

Below depicts various consumption data received by ECG and PURC virtual machines from the five meters through the meter gateway during the testbed.

A2015100B1_ANSAH						
MONTH	**METER_A2015100B1**	**ECG**	**PURC**	**ERROR OF MARGIN(±)**	**ERROR %**	**VARIANCE(±)**

07/04/15	12965	12965	12965	0	0	0
08/04/15	13536	13536	13536	0	0	0
09/04/15	13536	13536	13536	0	0	0
17/04/15	14496	14496	14496	0	0	0
21/04/15	14753	14753	14753	0	0	0
21/04/15	15311	15311	15311	0	0	0

A2015100B2_APPIAH						
MONTH	**METER_A2015100B2**	**ECG**	**PURC**	**ERROR OF MARGIN(±)**	**ERROR %**	**VARIANCE(±)**
07/04/15	439	439	439	0	0	0
08/04/15	501	501	501	0	0	0
09/04/15	596	596	596	0	0	0
16/04/15	1377	1377	1377	0	0	0
16/04/15	1444	1444	1444	0	0	0
16/04/15	1778	1778	1778	0	0	0
17/04/15	1891	1891	1891	0	0	0
21/04/15	2151	2151	2151	0	0	0
22/04/15	2904	2904	2904	0	0	0

A2015100B3_DJAN						
MONTH	**METER_A2015100B3**	**ECG**	**PURC**	**ERROR OF MARGIN(±)**	**ERROR %**	**VARIANCE(±)**
07/04/15	122	122	122	0	0	0
08/04/15	588	588	588	0	0	0
09/04/15	1185	1185	1185	0	0	0
16/04/15	1357	1357	1357	0	0	0
16/04/15	1421	1421	1421	0	0	0
16/04/15	1659	1659	1659	0	0	0
17/04/15	1772	1772	1772	0	0	0
21/04/15	2039	2039	2039	0	0	0
22/04/15	2785	2785	2785	0	0	0

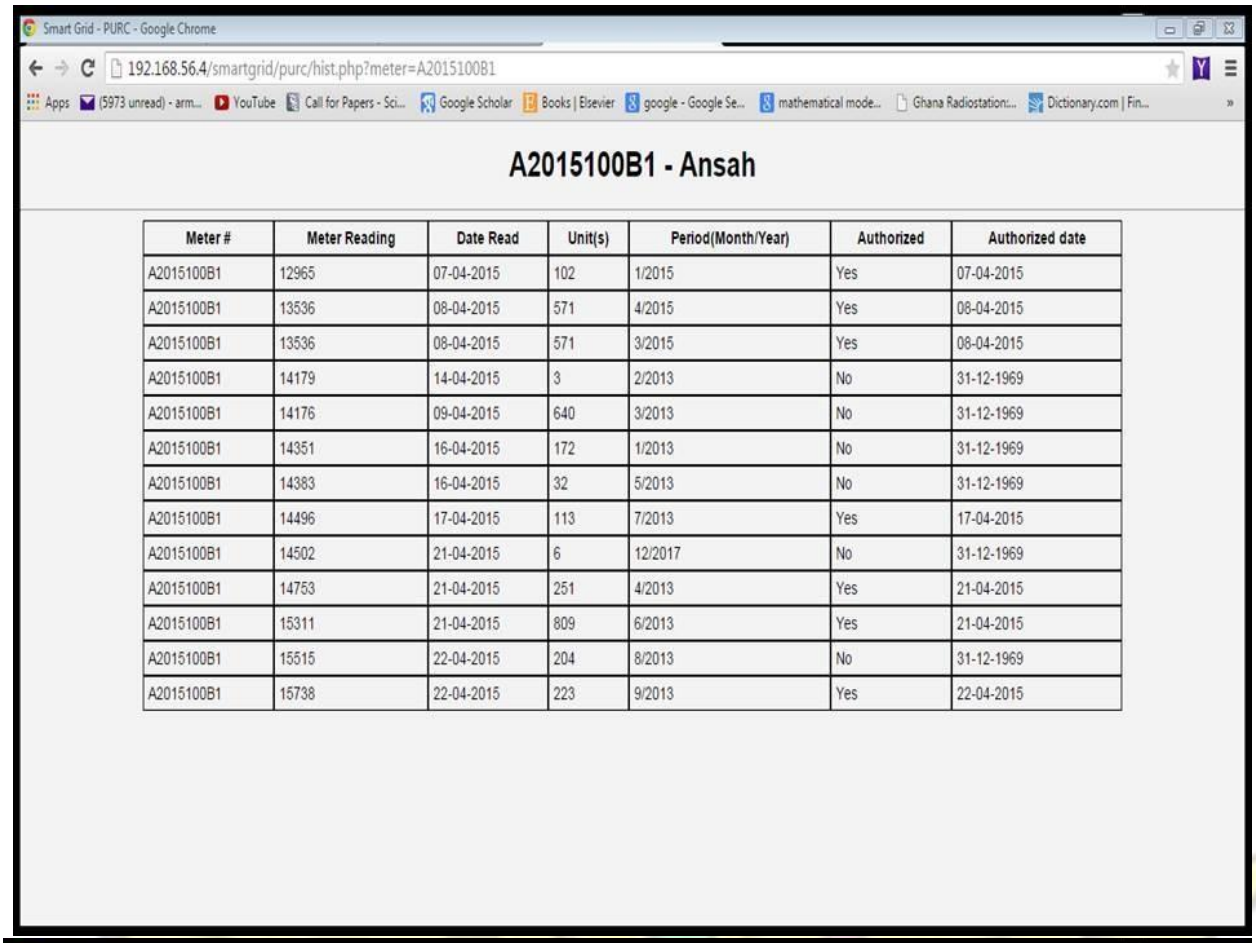
A2015100B4_ODURO						
MONTH	**METER_A2015100B4**	**ECG**	**PURC**	**ERROR OF MARGIN(±)**	**ERROR %**	**VARIANCE(±)**

07/04/15	439	439	439	0	0	0
08/04/15	501	501	501	0	0	0
09/04/15	596	596	596	0	0	0
16/04/15	1165	1165	1165	0	0	0
17/04/15	1480	1480	1480	0	0	0
21/04/15	1756	1756	1756	0	0	0
21/04/15	2289	2289	2289	0	0	0
22/04/15	2493	2493	2493	0	0	0
22/04/15	2739	2739	2739	0	0	0

A2015100B5_AMANKWAH						
MONTH	**METER_A2015100B5**	**ECG**	**PURC**	**ERROR OF MARGIN(±)**	**ERROR %**	**VARIANCE(±)**
07/04/15	237	237	237	0	0	0
08/04/15	572	572	572	0	0	0
08/04/15	554	554	554	0	0	0
09/04/15	856	856	856	0	0	0
17/04/15	1598	1598	1598	0	0	0
21/04/15	1880	1880	1880	0	0	0
21/04/15	2407	2407	2407	0	0	0
22/04/15	2862	2862	2862	0	0	0

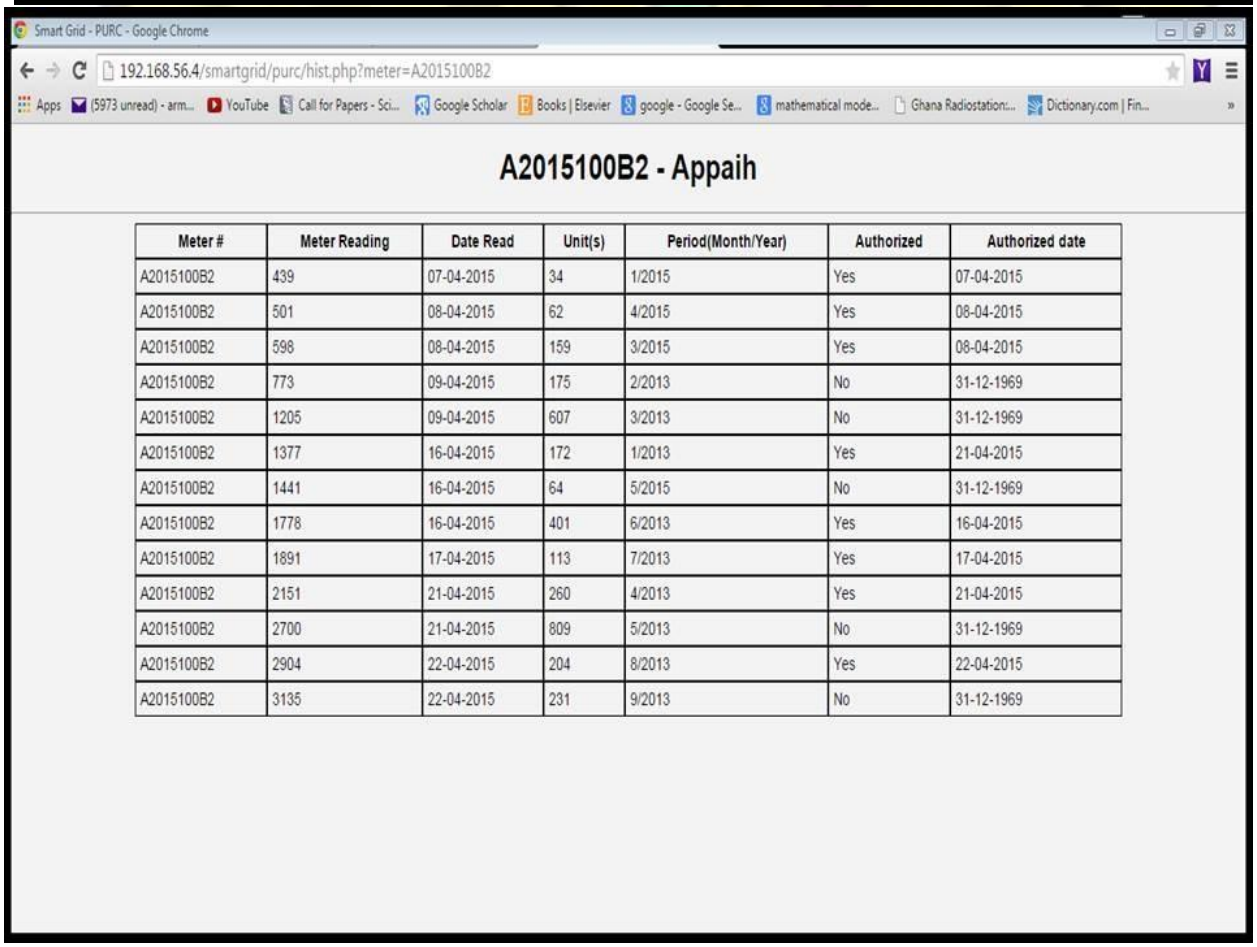
A.4 Validation model by PURC

Below depicts the validation process one by PURC prior to the utility provider billing the five consumers.



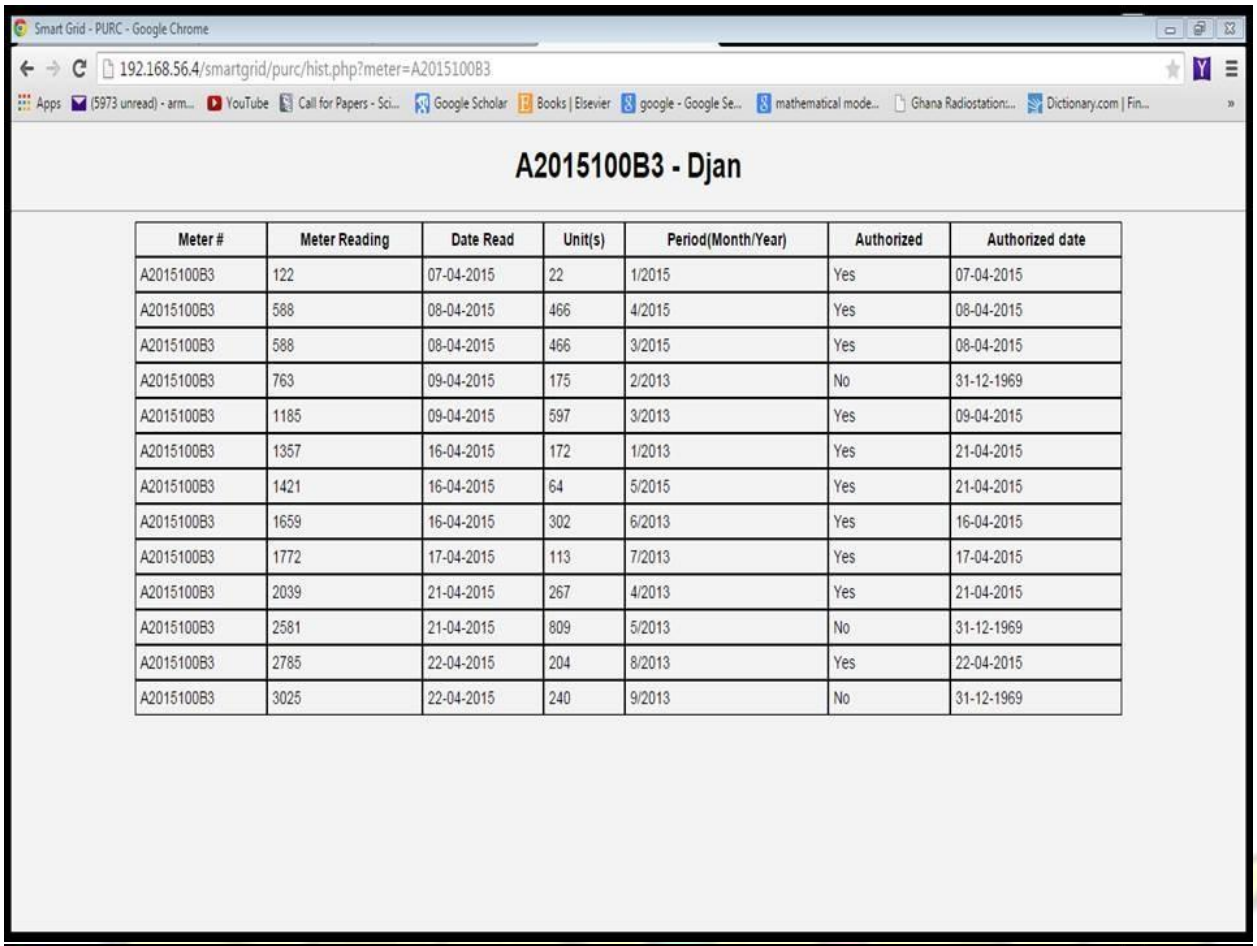
A2015100B1 - Ansah

Meter #	Meter Reading	Date Read	Unit(s)	Period(Month/Year)	Authorized	Authorized date
A2015100B1	12965	07-04-2015	102	1/2015	Yes	07-04-2015
A2015100B1	13536	08-04-2015	571	4/2015	Yes	08-04-2015
A2015100B1	13536	08-04-2015	571	3/2015	Yes	08-04-2015
A2015100B1	14179	14-04-2015	3	2/2013	No	31-12-1969
A2015100B1	14176	09-04-2015	640	3/2013	No	31-12-1969
A2015100B1	14351	16-04-2015	172	1/2013	No	31-12-1969
A2015100B1	14383	16-04-2015	32	5/2013	No	31-12-1969
A2015100B1	14496	17-04-2015	113	7/2013	Yes	17-04-2015
A2015100B1	14502	21-04-2015	6	12/2017	No	31-12-1969
A2015100B1	14753	21-04-2015	251	4/2013	Yes	21-04-2015
A2015100B1	15311	21-04-2015	809	6/2013	Yes	21-04-2015
A2015100B1	15515	22-04-2015	204	8/2013	No	31-12-1969
A2015100B1	15738	22-04-2015	223	9/2013	Yes	22-04-2015



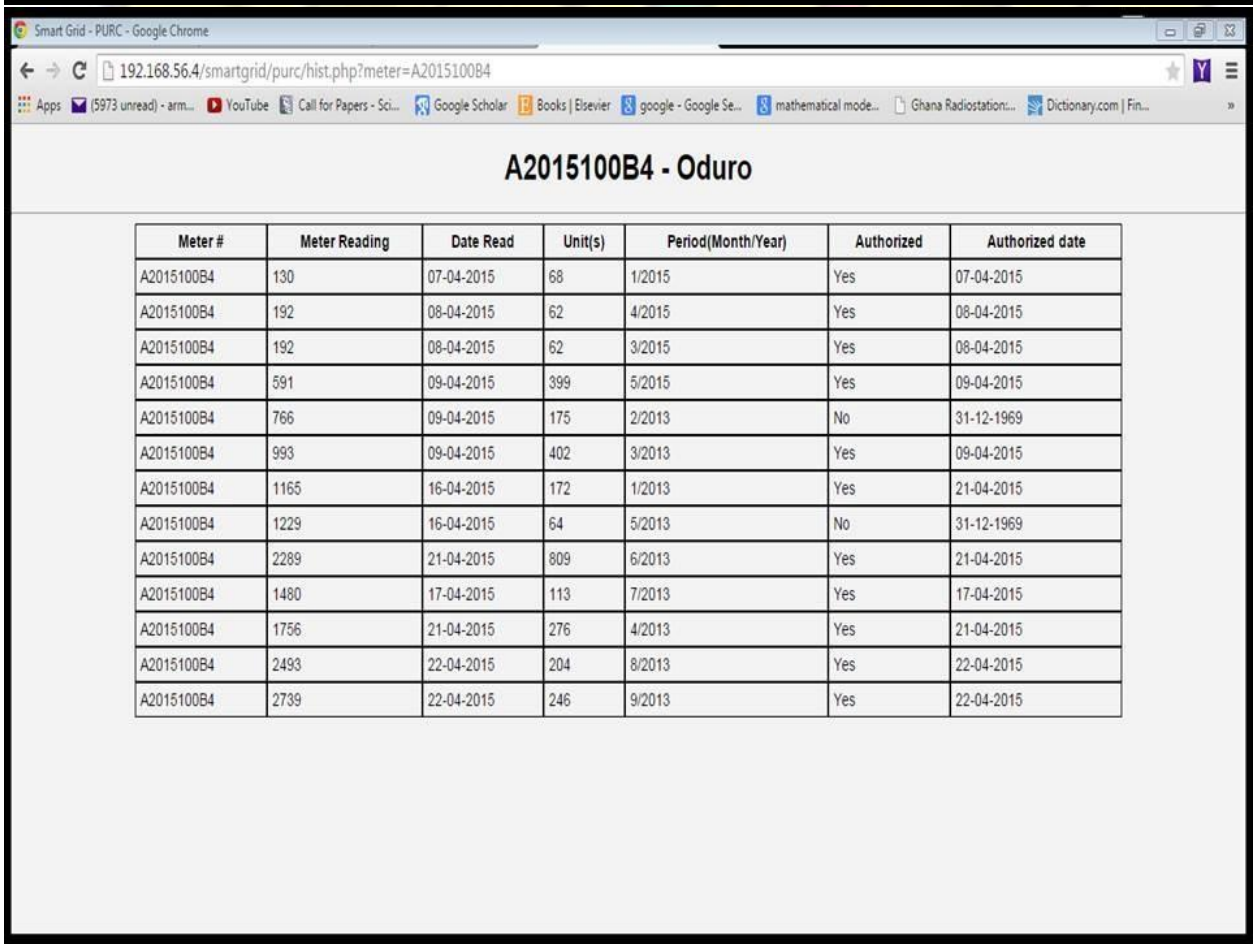
A2015100B2 - Appaih

Meter #	Meter Reading	Date Read	Unit(s)	Period(Month/Year)	Authorized	Authorized date
A2015100B2	439	07-04-2015	34	1/2015	Yes	07-04-2015
A2015100B2	501	08-04-2015	62	4/2015	Yes	08-04-2015
A2015100B2	598	08-04-2015	159	3/2015	Yes	08-04-2015
A2015100B2	773	09-04-2015	175	2/2013	No	31-12-1969
A2015100B2	1205	09-04-2015	607	3/2013	No	31-12-1969
A2015100B2	1377	16-04-2015	172	1/2013	Yes	21-04-2015
A2015100B2	1441	16-04-2015	64	5/2015	No	31-12-1969
A2015100B2	1778	16-04-2015	401	6/2013	Yes	16-04-2015
A2015100B2	1891	17-04-2015	113	7/2013	Yes	17-04-2015
A2015100B2	2151	21-04-2015	260	4/2013	Yes	21-04-2015
A2015100B2	2700	21-04-2015	809	5/2013	No	31-12-1969
A2015100B2	2904	22-04-2015	204	8/2013	Yes	22-04-2015
A2015100B2	3135	22-04-2015	231	9/2013	No	31-12-1969



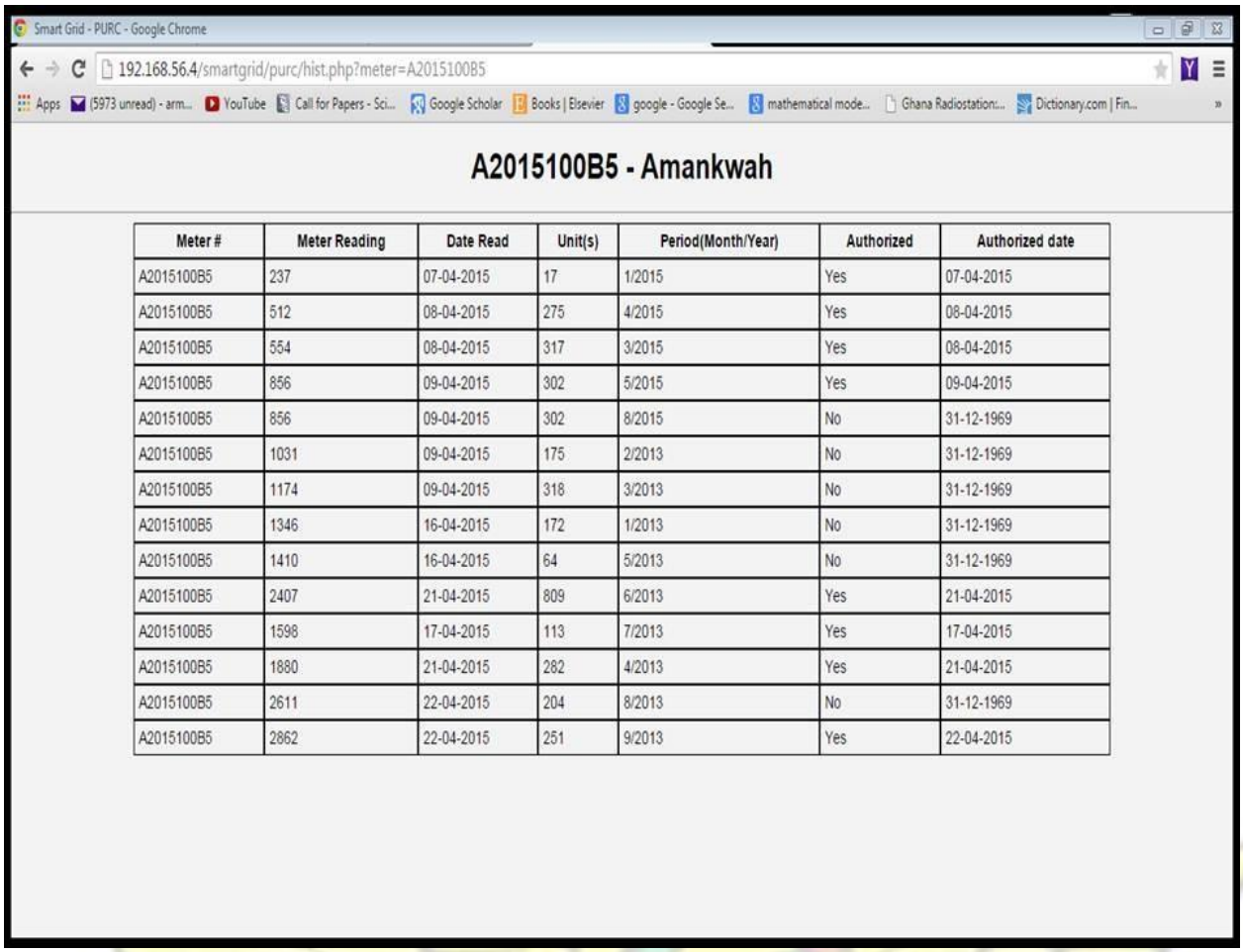
A2015100B3 - Djan

Meter #	Meter Reading	Date Read	Unit(s)	Period(Month/Year)	Authorized	Authorized date
A2015100B3	122	07-04-2015	22	1/2015	Yes	07-04-2015
A2015100B3	588	08-04-2015	466	4/2015	Yes	08-04-2015
A2015100B3	588	08-04-2015	466	3/2015	Yes	08-04-2015
A2015100B3	763	09-04-2015	175	2/2013	No	31-12-1969
A2015100B3	1185	09-04-2015	597	3/2013	Yes	09-04-2015
A2015100B3	1357	16-04-2015	172	1/2013	Yes	21-04-2015
A2015100B3	1421	16-04-2015	64	5/2015	Yes	21-04-2015
A2015100B3	1659	16-04-2015	302	6/2013	Yes	16-04-2015
A2015100B3	1772	17-04-2015	113	7/2013	Yes	17-04-2015
A2015100B3	2039	21-04-2015	267	4/2013	Yes	21-04-2015
A2015100B3	2581	21-04-2015	809	5/2013	No	31-12-1969
A2015100B3	2785	22-04-2015	204	8/2013	Yes	22-04-2015
A2015100B3	3025	22-04-2015	240	9/2013	No	31-12-1969



A2015100B4 - Oduro

Meter #	Meter Reading	Date Read	Unit(s)	Period(Month/Year)	Authorized	Authorized date
A2015100B4	130	07-04-2015	68	1/2015	Yes	07-04-2015
A2015100B4	192	08-04-2015	62	4/2015	Yes	08-04-2015
A2015100B4	192	08-04-2015	62	3/2015	Yes	08-04-2015
A2015100B4	591	09-04-2015	399	5/2015	Yes	09-04-2015
A2015100B4	766	09-04-2015	175	2/2013	No	31-12-1969
A2015100B4	993	09-04-2015	402	3/2013	Yes	09-04-2015
A2015100B4	1165	16-04-2015	172	1/2013	Yes	21-04-2015
A2015100B4	1229	16-04-2015	64	5/2013	No	31-12-1969
A2015100B4	2289	21-04-2015	809	6/2013	Yes	21-04-2015
A2015100B4	1480	17-04-2015	113	7/2013	Yes	17-04-2015
A2015100B4	1756	21-04-2015	276	4/2013	Yes	21-04-2015
A2015100B4	2493	22-04-2015	204	8/2013	Yes	22-04-2015
A2015100B4	2739	22-04-2015	246	9/2013	Yes	22-04-2015



A2015100B5 - Amankwah

Meter #	Meter Reading	Date Read	Unit(s)	Period(Month/Year)	Authorized	Authorized date
A2015100B5	237	07-04-2015	17	1/2015	Yes	07-04-2015
A2015100B5	512	08-04-2015	275	4/2015	Yes	08-04-2015
A2015100B5	554	08-04-2015	317	3/2015	Yes	08-04-2015
A2015100B5	856	09-04-2015	302	5/2015	Yes	09-04-2015
A2015100B5	856	09-04-2015	302	8/2015	No	31-12-1969
A2015100B5	1031	09-04-2015	175	2/2013	No	31-12-1969
A2015100B5	1174	09-04-2015	318	3/2013	No	31-12-1969
A2015100B5	1346	16-04-2015	172	1/2013	No	31-12-1969
A2015100B5	1410	16-04-2015	64	5/2013	No	31-12-1969
A2015100B5	2407	21-04-2015	809	6/2013	Yes	21-04-2015
A2015100B5	1598	17-04-2015	113	7/2013	Yes	17-04-2015
A2015100B5	1880	21-04-2015	282	4/2013	Yes	21-04-2015
A2015100B5	2611	22-04-2015	204	8/2013	No	31-12-1969
A2015100B5	2862	22-04-2015	251	9/2013	Yes	22-04-2015

A5 Compilation of codes used in the simulating the virtual machines and running the programme.

Below depicts the codes used in setting up the meter gateway virtual machine in the Oracle Virtual Machine Manager.

METER GATEWAY

```
<?php

$hostname_conn = "localhost";
$database_conn = "smartgrid";
$username_conn = "root";
$password_conn = "1234";
$conn = mysql_connect($hostname_conn, $username_conn,
$password_conn) or trigger_error(mysql_error(),E_USER_ERROR);
mysql_query('use '.$database_conn);

$control="http://192.168.56.5/secure/control/auth.php";
//$control="http://localhost/secure/control/auth.php"; function
getValueFromControl($url,$data){
    $ch = curl_init($url);
    curl_setopt($ch, CURLOPT_SSL_VERIFYHOST, 0);
curl_setopt($ch, CURLOPT_SSL_VERIFYPEER, 0);
curl_setopt($ch, CURLOPT_POST, 1);     curl_setopt($ch,
CURLOPT_HTTPHEADER, array('Content-Type:
application/x-www-form-urlencoded'));
curl_setopt($ch, CURLOPT_POSTFIELDS, "$data");
curl_setopt($ch, CURLOPT_RETURNTRANSFER, 1);
    $output = curl_exec($ch);
curl_close($ch);
return $output;
}

?>



<?php
include_once 'connection.php'; if(isset($_GET['code'])=="A1"){
    //save reading
    mysql_query("update meters set
preading={$_GET['reading']},Last_Submited=now() where
MeterNo='{$_GET['meter']}'");
echo "1";     return;
}
?>
<!DOCTYPE html>
<html>
    <head>
        <title>Smart Grid Meters</title>
        <link  rel="stylesheet" href="css/doc.css"/>
        <script src="js/script.js" type="text/javascript"></script>
<script src="js/jquery.js" type="text/javascript"></script>
    </head>
    <body>
    <center>
```

```
        <h1>
            Smart Grid
        </h1>
        <hr/>

    <table>
        <tbody>
            <tr>
                <td>
                    <div class="login">
                        <h3>Meter #: A2015100B1</h3>
                        <form action="index.php" method="post"
onsubmit="return false;">
                            <input type="hidden" name="run"
value="100"/>
                            <input type="hidden" name="meter"
value="A2015100B1"/>
                            Rate:
                            <select id="B1S">
<option value="1" selected>1</option>
                                <option value="2" >2</option>
                                <option value="3" >3</option>
                                <option value="4" >4</option>
                                <option value="5" >5</option>
                            </select>  
                            Month:<select name="month1" id="month1">
                                <?php
                                for($i=1;$i<=12;$i++)
echo "<option value='$i'>$i</option>";
                                ?>
                            </select>  
                            Year:<select name="year1" id="year1">
                                <?php
                                for($i=-2;$i<=2;$i++)
echo "<option
".(date('Y')==(date('Y')+$i)?'selected':"")."
value='".(date('Y')+$i)."'>".(date('Y')+$i)."</option>";
                                ?>
                            </select>
                            <br/><br/><center>
                                <input type="text" class="Readings
c1" id="B1R" disabled="true" value=" <?php
                            echo str_pad(
mysql_result(mysql_query("select PReading from meters where
MeterNo='A2015100B1'"),0),
                                    6, "0", 0);
                            ?>"/>
                            </center><br/>
                            Previous reading: <span id="p1"><?php
echo  str_pad(
mysql_result(mysql_query("select PReading from meters where
MeterNo='A2015100B1'"),0),
                                    6, "0", 0);
```

```
                                ?></span>
<br/>Units: <span
id="unit1">0</span><input type="hidden" value="0" name="units"
id="units1"/>
                                <br/><br/>
<button id="B1"
onclick="startRead(1,'B1');">Start
reading</button>      <input
type="submit" onclick="Send(1,this.form)" value="Submit reading"/>
                            </form>

                        </div>
                    </td><td>
                        <div class="login">
                            <h3>Meter #: A2015100B2</h3>
                            <form action="index.php" method="post"
onsubmit="return false;">
                                <input type="hidden" name="run"
value="100"/>
                                <input type="hidden" name="meter"
value="A2015100B2"/>
                                Rate:
                                <select id="B2S">
                                    <option selected>1</option>
                                    <option >2</option>
                                    <option >3</option>
                                    <option >4</option>
                                    <option >5</option>
                                </select>  
                                Month:<select name="month2" id="month2">
                                    <?php
                                    for($i=1;$i<=12;$i++)
echo "<option value='$i'>$i</option>";
                                    ?>
                                </select>  
                                Year:<select name="year2" id="year2">
                                    <?php
                                    for($i=-2;$i<=2;$i++)
echo "<option
".(date('Y')==(date('Y')+$i)?'selected':"")."
value='".(date('Y')+$i)."'>".(date('Y')+$i)."</option>";
                                    ?>
                                </select>
                                <br/><br/><center>
                                    <input type="text" class="Readings
c1" id="B2R" disabled="true" value=" <?php
echo str_pad(
mysql_result(mysql_query("select PReading from meters where
MeterNo='A2015100B2'"),0),
                                        6, "0", 0);
                                ?>"/>
                                </center><br/>
```

```
                            Previous reading: <span id="p2"><?php
echo  str_pad(
mysql_result(mysql_query("select PReading from meters where
MeterNo='A2015100B2'"),0),
                                        6, "0", 0);
                            ?></span>
<br/>Units: <span
id="unit2">0</span><input type="hidden" value="0" name="units"
id="units2"/>
                            <br/><br/>
<button id="B2"
onclick="startRead(2,'B2');">Start
reading</button>      <input
type="submit" onclick="Send(2,this.form)" value="Submit reading"/>
                        </form>

                    </div>
                </td>
                <td>
                    <div class="login">
                        <h3>Meter #: A2015100B3</h3>
                        <form action="index.php" method="post"
onsubmit="return false;">
                            <input type="hidden" name="run"
value="100"/>
                            <input type="hidden" name="meter"
value="A2015100B3"/>
                            Rate:
                            <select id="B3S">
                                <option selected>1</option>
                                <option >2</option>
                                <option >3</option>
                                <option >4</option>
                                <option >5</option>
                            </select>  
                            Month:<select name="month3" id="month3">
                                <?php
                                for($i=1;$i<=12;$i++)
echo "<option value='$i'>$i</option>";
                                ?>
                            </select>  
                            Year:<select name="year3" id="year3">
                                <?php
                                for($i=-2;$i<=2;$i++)
echo "<option
".(date('Y')==(date('Y')+$i)?'selected':"")."
value='".(date('Y')+$i)."'>".(date('Y')+$i)."</option>";
                                ?>
                            </select>
                            <br/><br/><center>
                                <input type="text" class="Readings
c1" id="B3R" disabled="true" value=" <?php
echo str_pad(
```

```
mysql_result(mysql_query("select PReading from meters where
MeterNo='A2015100B3'"),0),
                                        6, "0", 0);
                                ?>"/>
                                </center><br/>
                                Previous reading: <span id="p3"><?php
echo  str_pad(
mysql_result(mysql_query("select PReading from meters where
MeterNo='A2015100B3'"),0),
                                        6, "0", 0);
                                ?></span>
<br/>Units: <span
id="unit3">0</span><input type="hidden" value="0" name="units"
id="units3"/>
                                <br/><br/>
<button id="B3"
onclick="startRead(3,'B3');">Start
reading</button>      <input
type="submit" onclick="Send(3,this.form)" value="Submit reading"/>
                            </form>

                        </div>
                    </td>
                </tr>
                <tr>
                    <td>
                        <div class="login">
                            <h3>Meter #: A2015100B4</h3>
                            <form action="index.php" method="post"
onsubmit="return false;">
                                <input type="hidden" name="run"
value="100"/>
                                <input type="hidden" name="meter"
value="A2015100B4"/>
                                Rate:
                                <select id="B4S">
                                    <option selected>1</option>
                                    <option >2</option>
                                    <option >3</option>
                                    <option >4</option>
                                    <option >5</option>
                                </select>  
                                Month:<select name="month4" id="month4">
                                    <?php
                                    for($i=1;$i<=12;$i++)
echo "<option value='$i'>$i</option>";
                                    ?>
                                </select>  
                                Year:<select name="year4" id="year4">
                                    <?php
                                    for($i=-2;$i<=2;$i++)
echo "<option
".(date('Y')==(date('Y')+$i)?'selected':"")."
```

```
value='".(date('Y')+$i)."'>".(date('Y')+$i)."</option>";
                                ?>
                            </select>
                            <br/><br/><center>
                                <input type="text" class="Readings
c1" id="B4R" disabled="true" value=" <?php
echo str_pad(
mysql_result(mysql_query("select PReading from meters where
MeterNo='A2015100B4'"),0),
                                6, "0", 0);
                            ?>"/>
                            </center><br/>
                            Previous reading: <span id="p4"><?php
echo  str_pad(
mysql_result(mysql_query("select PReading from meters where
MeterNo='A2015100B4'"),0),
                                6, "0", 0);
                            ?></span>
<br/>Units: <span
id="unit4">0</span><input type="hidden" value="0" name="units"
id="units4"/>
                            <br/><br/>
<button id="B4"
onclick="startRead(4,'B4');">Start
reading</button>      <input
type="submit" onclick="Send(4,this.form)" value="Submit reading"/>
                        </form>

                    </div>
                </td>
                <td>
                    <div class="login">
                        <h3>Meter #: A2015100B5</h3>
                        <form action="index.php" method="post"
onsubmit="return false;">
                            <input type="hidden" name="run"
value="100"/>
                            <input type="hidden" name="meter"
value="A2015100B5"/>
                            Rate:
                            <select id="B5S">
                                <option selected>1</option>
                                <option >2</option>
                                <option >3</option>
                                <option >4</option>
                                <option >5</option>
                            </select>  
                            Month:<select name="month5" id="month5">
                                <?php
                                for($i=1;$i<=12;$i++)
echo "<option value='$i'>$i</option>";
                                ?>
                            </select>  
```

```
                                Year:<select name="year5" id="year5">
                                    <?php
                                    for($i=-2;$i<=2;$i++)
echo "<option
".(date('Y')==(date('Y')+$i)?'selected':"").""
value='".(date('Y')+$i)."'>".(date('Y')+$i)."</option>";
                                    ?>
                                </select>
                                <br/><br/><center>
                                    <input type="text" class="Readings
c1" id="B5R" disabled="true" value=" <?php
echo str_pad(
mysql_result(mysql_query("select PReading from meters where
MeterNo='A2015100B5'"),0),
                                            6, "0", 0);
                                ?>"/>
                                </center><br/>
                                Previous reading: <span id="p5"><?php
echo  str_pad(
mysql_result(mysql_query("select PReading from meters where
MeterNo='A2015100B5'"),0),
                                            6, "0", 0);
                                ?></span>
<br/>Units: <span
id="unit5">0</span><input type="hidden" value="0" name="units"
id="units5"/>
                                <br/><br/>
<button id="B5"
onclick="startRead(5,'B5');">Start
reading</button>      <input
type="submit" onclick="Send(5,this.form)" value="Submit reading"/>
                            </form>

                        </div>
                    </td>
                    <td><br/><br/><br/><center>
                        <button onclick="startAll();">Start all
meters</button><br/><br/>
                        <button onclick="stopAll();">Stop all
meters</button><br/><br/><br/>
                        <span id="msg"
style="fontsize:18px;color:blue"></span>
            </center>
                    </td>
                </tr>
            </tbody>
        </table>
            </center>
        </body>
</html>
```

Below depicts the codes used in setting up the utility provider (ECG) virtual machine in the Oracle Virtual Machine Manager.

ECG

```
<?php
include_once 'connection.php';
?>
<!DOCTYPE html>
<html>
    <head>
        <title>Smart Grid - ECG </title>
        <link  rel="stylesheet" href="css/doc.css"/>
        <script src="js/script.js" type="text/javascript"></script>
        <script src="js/jquery.js" type="text/javascript"></script>
    </head>
    <body>
    <center>
        <h1>
            Smart Grid - Authorization Request
        </h1>
        <hr/><br/><br/>
        Rate: GHs<?php echo mysql_result(mysql_query("select val
from settings where item='rate'"), 0);?> per unit
  VAT & NHIS: <?php echo
mysql_result(mysql_query("select val from settings where
item='vat'"), 0);?>% <br/><br/>
        <table width="80%" border="1" cellspacing="0"
cellpadding="5">             <thead>
                <tr><th>Meter
#</th><th>Reading</th><th>Units</th><th>Amount</th><th>VAT &
NHIS</th><th>Total</th><th>Status</th></tr>
            </thead>
            <tbody>
                <?php
                $rate=  mysql_result(mysql_query("select val from
settings where item='rate'"), 0);
                $vat= mysql_result(mysql_query("select val from
settings where item='vat'"), 0);
                $res=  mysql_query("select meterno, units,reading
from readings where year={$_POST['year']} and
month={$_POST['month']} and authorised=0 order by meterno");
                $count=0;
                while($row=          mysql_fetch_array($res)){
echo           "<tr><td           id='$row[0]'>$row[0]</td><td
id='$row[0]F'>$row[2]</td><td    id='$row[0]E'>$row[1]</td><td
style='text-align:right'
id='$row[0]A'>".number_format(($row[1]*$rate),2)."</td>"
. "<td style='text-align:right'
id='$row[0]B'>".number_format((($row[1]*$rate)*($vat/100)),2)."</td>
"
```

```
                            ."<td style='text-align:right'
id='$row[0]C'>".number_format((($row[1]*$rate)+(($row[1]*$rate)*($va
t/100))),2)."</td>"
                            . "<td id='$row[0]D'></td><td
style='visibility:hidden' id='$row[0]G'>".
                            mysql_result(mysql_query("select
avg_units from customers where meterno='$row[0]'"), 0)."</td></tr>";

                    $meters[$count++]=$row[0];
                }
                /*$res=  mysql_query("select meterno,avg_units from
customers order by meterno asc");                $count=0;
                while($row=  mysql_fetch_array($res))
                        $avg[$count++]=$row[1];*/
                ?>
            </tbody>
        </table>
        <br/><br/>
        <center><button onclick="Process();">Send
request</button></center>

    </center>
</body>
<script type="text/javascript">
            var meters=<?php echo json_encode($meters);?>;
//var avg=<?php echo json_encode($avg);?>;            var
month=<?php echo $_POST['month']?>;            var
year=<?php echo $_POST['year']?>;
</script>
</html>



"></script>
    </head>
    <body>
    <center>
        <h1>
            Smart Grid - ECG (Average consumption for <?php echo
$_GET['Meter'];?>)
        </h1>

        <hr/><br/><br/><br/>
        <center>
            <div style="width:40%;text-align: left">
                Average Consumption (units):
                <br/><form method="GET" onsubmit="return false;"
action="avg.php">
                    <input type="hidden" name="run" value="100"/>
<input type="hidden" name="Meter" value="<?php echo $_GET['Meter'];
?>"/>
```

```
                    <input style='width:200px' type="text"
name="avg" value="<?php echo mysql_result(mysql_query("select
avg_units from customers where meterno='{$_GET['Meter']}'"), 0)?>"/>
                            <br/><br/><br/>
                            <input type="submit" value="Update"
onclick="UpdateAvg(this.form)"/>

                </form>
            </div>
        </center>
```



```
<?php

$hostname_conn = "localhost";
$database_conn = "smart_ecg";
$username_conn = "root";
$password_conn = "1234";
$conn = mysql_connect($hostname_conn, $username_conn,
$password_conn) or trigger_error(mysql_error(),E_USER_ERROR);
mysql_query('use '.$database_conn);

$control="http://192.168.56.5/secure/control/auth.php";
//$control="http://localhost/secure/control/auth.php"; function
getValueFromControl($url,$data){
    $ch = curl_init($url);
    curl_setopt($ch, CURLOPT_SSL_VERIFYHOST, 0);
curl_setopt($ch, CURLOPT_SSL_VERIFYPEER, 0);
curl_setopt($ch, CURLOPT_POST, 1);     curl_setopt($ch,
CURLOPT_HTTPHEADER, array('Content-Type:
application/x-www-form-urlencoded'));
curl_setopt($ch, CURLOPT_POSTFIELDS, "$data");
curl_setopt($ch, CURLOPT_RETURNTRANSFER, 1);
    $output = curl_exec($ch);
    curl_close($ch);
return $output;
}

?>

<?php
/*************************************************************
************
*     FPDF
*
*     *
*     Version: 1.7
*
*     Date:    2011-06-18
*
*     Author:  Olivier PLATHEY
*
```

```
*******************************************************************
***********/

define('FPDF_VERSION','1.7');

class FPDF
{
var $page;               // current page number var $n;
// current object number var $offsets;              //
array of object offsets var $buffer;              //
buffer holding in-memory PDF var $pages;                //
array containing pages var $state;               //
current document state var $compress;            //
compression flag
var $k;                  // scale factor (number of points in user
unit)
var $DefOrientation;     // default orientation
var $CurOrientation;     // current orientation
var $StdPageSizes;       // standard page sizes
var $DefPageSize;        // default page size var
$CurPageSize;        // current page size
var $PageSizes;          // used for pages with non default sizes or
orientations
var $wPt, $hPt;          // dimensions of current page in points
var $w, $h;              // dimensions of current page in user unit
var $lMargin;            // left margin var $tMargin;            //
top margin var $rMargin;              // right margin var $bMargin;
// page break margin var $cMargin;              // cell margin
var $x, $y;              // current position in user unit
var $lasth;              // height of last printed cell
var $LineWidth;          // line width in user unit var
$fontpath;           // path containing fonts var
$CoreFonts;          // array of core font names var
$fonts;              // array of used fonts var
$FontFiles;          // array of font files var $diffs;
// array of encoding differences var $FontFamily;
// current font family var $FontStyle;          //
current font style var $underline;          //
underlining flag
var $CurrentFont;        // current font info var
$FontSizePt;         // current font size in points var
$FontSize;           // current font size in user unit var
$DrawColor;          // commands for drawing color var
$FillColor;          // commands for filling color var
$TextColor;          // commands for text color
var $ColorFlag;          // indicates whether fill and text colors
are different
var $ws;                 // word spacing var
$images;             // array of used images var
$PageLinks;          // array of links in pages var
$links;              // array of internal links var
$AutoPageBreak;      // automatic page breaking
var $PageBreakTrigger;   // threshold used to trigger page breaks
var $InHeader;           // flag set when processing header var
```

```
$InFooter;           // flag set when processing footer var
$ZoomMode;           // zoom display mode var $LayoutMode;
// layout display mode var $title;              // title var
$subject;            // subject var $author;             //
author var $keywords;           // keywords var $creator;
// creator
var $AliasNbPages;       // alias for total number of pages var
$PDFVersion;         // PDF version number

/*******************************************************************
************
*     *
*     Public methods                                        *
*     *
*******************************************************************
***********/
function FPDF($orientation='P', $unit='mm', $size='A4')
{
      // Some checks
      $this->_dochecks();
      // Initialization of properties
      $this->page = 0;
      $this->n = 2;
      $this->buffer = '';
      $this->pages = array();
      $this->PageSizes = array();
      $this->state = 0;
      $this->fonts = array();
      $this->FontFiles = array();
      $this->diffs = array();
      $this->images = array();
      $this->links = array();
      $this->InHeader = false;
      $this->InFooter = false;
      $this->lasth = 0;
      $this->FontFamily = '';
      $this->FontStyle = '';
      $this->FontSizePt = 12;
      $this->underline = false;
      $this->DrawColor = '0 G';
      $this->FillColor = '0 g';
      $this->TextColor = '0 g';
      $this->ColorFlag = false;
      $this->ws = 0;
// Font path
      if(defined('FPDF_FONTPATH'))
      {
            $this->fontpath = FPDF_FONTPATH;
            if(substr($this->fontpath,-1)!='/' &&
substr($this>fontpath,-1)!='\\')
```

```
                $this->fontpath .= '/';
        }
        elseif(is_dir(dirname(__FILE__).'/font'))        $this-
>fontpath = dirname(__FILE__).'/font/';
        else
                $this->fontpath = '';
        // Core fonts
        $this->CoreFonts = array('courier', 'helvetica', 'times',
'symbol', 'zapfdingbats');
        // Scale factor
if($unit=='pt')
$this->k = 1;
        elseif($unit=='mm')
                $this->k = 72/25.4;
elseif($unit=='cm')
                $this->k = 72/2.54;
elseif($unit=='in')        $this-
>k = 72;
        else
                $this->Error('Incorrect unit: '.$unit);
        // Page sizes
        $this->StdPageSizes = array('a3'=>array(841.89,1190.55),
'a4'=>array(595.28,841.89), 'a5'=>array(420.94,595.28),
                'letter'=>array(612,792), 'legal'=>array(612,1008));
        $size = $this->_getpagesize($size);
        $this->DefPageSize = $size;
        $this->CurPageSize = $size;
        // Page orientation
        $orientation = strtolower($orientation);
        if($orientation=='p' || $orientation=='portrait')
        {
                $this->DefOrientation = 'P';
                $this->w = $size[0];
                $this->h = $size[1];
        }
        elseif($orientation=='l' || $orientation=='landscape')
        {
                $this->DefOrientation = 'L';
                $this->w = $size[1];
$this->h = $size[0];
        }
        else
                $this->Error('Incorrect orientation: '.$orientation);
        $this->CurOrientation = $this->DefOrientation;
        $this->wPt = $this->w*$this->k;
        $this->hPt = $this->h*$this->k;
        // Page margins (1 cm)
        $margin = 28.35/$this->k;
        $this->SetMargins($margin,$margin);
```

```
      // Interior cell margin (1 mm)
      $this->cMargin = $margin/10;
      // Line width (0.2 mm)
      $this->LineWidth = .567/$this->k;
      // Automatic page break
      $this->SetAutoPageBreak(true,2*$margin);
      // Default display mode
      $this->SetDisplayMode('default');
      // Enable compression
      $this->SetCompression(true);
      // Set default PDF version number
      $this->PDFVersion = '1.3';
}
function SetMargins($left, $top, $right=null)
{
      // Set left, top and right margins
      $this->lMargin = $left;    $this-
>tMargin = $top;      if($right===null)
            $right = $left;
      $this->rMargin = $right;
}  function
SetLeftMargin($margin)
{
      // Set left margin    $this-
>lMargin = $margin;
      if($this->page>0 && $this->x<$margin)
            $this->x = $margin;
}
function SetTopMargin($margin)
{
      // Set top margin
      $this->tMargin = $margin;
}  function
SetRightMargin($margin)
{
      // Set right margin
      $this->rMargin = $margin;
}
function SetAutoPageBreak($auto, $margin=0)
{
      // Set auto page break mode and triggering margin
      $this->AutoPageBreak = $auto;
      $this->bMargin = $margin;
      $this->PageBreakTrigger = $this->h-$margin;
}
function SetDisplayMode($zoom, $layout='default')
{
      // Set display mode in viewer
      if($zoom=='fullpage' || $zoom=='fullwidth' || $zoom=='real' ||
$zoom=='default' || !is_string($zoom))
```

```
            $this->ZoomMode = $zoom;
else
            $this->Error('Incorrect zoom display mode: '.$zoom);
if($layout=='single' || $layout=='continuous' ||
$layout=='two' || $layout=='default')
$this->LayoutMode = $layout;     else
            $this->Error('Incorrect layout display mode:
'.$layout); }
function SetCompression($compress)
{
      // Set page compression
if(function_exists('gzcompress'))
$this->compress = $compress;     else
            $this->compress = false;
}
function SetTitle($title, $isUTF8=false)
{
      // Title of document
if($isUTF8)
            $title = $this->_UTF8toUTF16($title);
      $this->title = $title;
}  function SetSubject($subject,
$isUTF8=false)
{
      // Subject of document
if($isUTF8)
            $subject = $this->_UTF8toUTF16($subject);
      $this->subject = $subject;
}  function SetAuthor($author,
$isUTF8=false)
{
      // Author of document if($isUTF8)
            $author = $this->_UTF8toUTF16($author);
      $this->author = $author;
}
function SetKeywords($keywords, $isUTF8=false)
{
      // Keywords of document
if($isUTF8)
            $keywords = $this->_UTF8toUTF16($keywords);
      $this->keywords = $keywords;
}
function SetCreator($creator, $isUTF8=false)
{
      // Creator of document
if($isUTF8)
            $creator = $this->_UTF8toUTF16($creator);
      $this->creator = $creator;
}
function AliasNbPages($alias='{nb}')
{
```

```
      // Define an alias for total number of pages
      $this->AliasNbPages = $alias;
}
function Error($msg)
{
      // Fatal error
      die('<b>FPDF error:</b> '.$msg);
}
function Open()
{
      // Begin document
      $this->state = 1;
}
function Close()
{
      // Terminate document       if($this-
>state==3)
            return;
      if($this->page==0)         $this-
>AddPage();
      // Page footer
      $this->InFooter = true;
      $this->Footer();
      $this->InFooter = false;
      // Close page
      $this->_endpage();
      // Close document
      $this->_enddoc();
}
function AddPage($orientation='', $size='')
{
      // Start a new page   if($this-
>state==0)
            $this->Open();
      $family = $this->FontFamily;
      $style = $this->FontStyle.($this->underline ? 'U' : '');
      $fontsize = $this->FontSizePt;
      $lw = $this->LineWidth;
      $dc = $this->DrawColor;
      $fc = $this->FillColor;
      $tc = $this->TextColor;
$cf = $this->ColorFlag;
      if($this->page>0)
      {
            // Page footer
            $this->InFooter = true;
            $this->Footer();
            $this->InFooter = false;
            // Close page
            $this->_endpage();
```

```
        }
        // Start new page
        $this->_beginpage($orientation,$size);
        // Set line cap style to square
        $this->_out('2 J');
        // Set line width
        $this->LineWidth = $lw;
        $this->_out(sprintf('%.2F w',$lw*$this->k));
        // Set font
if($family)
            $this->SetFont($family,$style,$fontsize);
        // Set colors    $this-
>DrawColor = $dc;     if($dc!='0
G')
            $this->_out($dc);     $this-
>FillColor = $fc;     if($fc!='0 g')
            $this->_out($fc);
        $this->TextColor = $tc;
        $this->ColorFlag = $cf;
        // Page header
        $this->InHeader = true;
        $this->Header();
        $this->InHeader = false;
// Restore line width
        if($this->LineWidth!=$lw)
        {
            $this->LineWidth = $lw;
            $this->_out(sprintf('%.2F w',$lw*$this->k));
        }
        // Restore font if($family)
            $this->SetFont($family,$style,$fontsize);
        // Restore colors
        if($this->DrawColor!=$dc)
        {
            $this->DrawColor = $dc;
            $this->_out($dc);
        }
        if($this->FillColor!=$fc)
        {
            $this->FillColor = $fc;
            $this->_out($fc);
        }
        $this->TextColor = $tc;
        $this->ColorFlag = $cf;
}
function Header()
{
        // To be implemented in your own inherited class
}
```

```
function Footer()
{
      // To be implemented in your own inherited class
}
function PageNo()
{
      // Get current page number
      return $this->page;
}
function SetDrawColor($r, $g=null, $b=null)
{
      // Set color for all stroking operations
if(($r==0 && $g==0 && $b==0) || $g===null)
$this->DrawColor = sprintf('%.3F G',$r/255);
      else
            $this->DrawColor = sprintf('%.3F %.3F %.3F
RG',$r/255,$g/255,$b/255);       if($this-
>page>0)
            $this->_out($this->DrawColor);
}
function SetFillColor($r, $g=null, $b=null)
{
      // Set color for all filling operations
if(($r==0 && $g==0 && $b==0) || $g===null)
$this->FillColor = sprintf('%.3F g',$r/255);
      else
            $this->FillColor = sprintf('%.3F %.3F %.3F
rg',$r/255,$g/255,$b/255);
      $this->ColorFlag = ($this->FillColor!=$this->TextColor);
      if($this->page>0)
            $this->_out($this->FillColor);
}
function SetTextColor($r, $g=null, $b=null)
{
      // Set color for text       if(($r==0 && $g==0 &&
$b==0) || $g===null)             $this->TextColor =
sprintf('%.3F g',$r/255);
      else
            $this->TextColor = sprintf('%.3F %.3F %.3F
rg',$r/255,$g/255,$b/255);
      $this->ColorFlag = ($this->FillColor!=$this->TextColor);
}
function GetStringWidth($s)
{
      // Get width of a string in the current font
      $s = (string)$s;
      $cw = &$this->CurrentFont['cw'];
      $w = 0;
      $l = strlen($s);
for($i=0;$i<$l;$i++)
$w += $cw[$s[$i]];
```

```
      return $w*$this->FontSize/1000;
}
function SetLineWidth($width)
{
      // Set line width     $this-
>LineWidth = $width;       if($this-
>page>0)
            $this->_out(sprintf('%.2F w',$width*$this->k));
}
function Line($x1, $y1, $x2, $y2)
{
      // Draw a line
      $this->_out(sprintf('%.2F %.2F m %.2F %.2F l
S',$x1*$this>k,($this->h-$y1)*$this->k,$x2*$this->k,($this->h-
$y2)*$this->k));
}  function Rect($x, $y, $w, $h,
$style='')
{
      // Draw a rectangle
if($style=='F')
            $op = 'f';
      elseif($style=='FD' || $style=='DF')
            $op =
'B';        else
      $op = 'S';
      $this->_out(sprintf('%.2F %.2F %.2F %.2F re
%s',$x*$this>k,($this->h-$y)*$this->k,$w*$this->k,-$h*$this-
>k,$op));
}
function AddFont($family, $style='', $file='')
{
      // Add a TrueType, OpenType or Type1
font       $family = strtolower($family);
if($file=='')         $file = str_replace('
','',$family).strtolower($style).'.php';
$style = strtoupper($style);
if($style=='IB')
            $style = 'BI';
      $fontkey = $family.$style;
      if(isset($this->fonts[$fontkey]))
            return;
      $info = $this->_loadfont($file);
$info['i'] = count($this->fonts)+1;
      if(!empty($info['diff']))
      {
            // Search existing encodings
            $n = array_search($info['diff'],$this->diffs);
            if(!$n)
            {
                  $n = count($this->diffs)+1;
                  $this->diffs[$n] = $info['diff'];
```

```
            }
            $info['diffn'] = $n;
      }
      if(!empty($info['file']))
      {
            // Embedded font
if($info['type']=='TrueType')                $this-
>FontFiles[$info['file']] =
array('length1'=>$info['originalsize']);
            else
                  $this->FontFiles[$info['file']] =
array('length1'=>$info['size1'], 'length2'=>$info['size2']);
      }
      $this->fonts[$fontkey] = $info;
}
function SetFont($family, $style='', $size=0)
{
      // Select a font; size given in points
if($family=='')
            $family = $this->FontFamily;
else
            $family = strtolower($family);
$style = strtoupper($style);
if(strpos($style,'U')!==false)
      {
            $this->underline = true;
            $style = str_replace('U','',$style);
      } else
            $this->underline = false; if($style=='IB')
            $style = 'BI';
      if($size==0)
            $size = $this->FontSizePt;
      // Test if font is already selected
      if($this->FontFamily==$family && $this->FontStyle==$style &&
$this->FontSizePt==$size)
            return;
      // Test if font is already loaded
$fontkey = $family.$style;
      if(!isset($this->fonts[$fontkey]))
      {
            // Test if one of the core
fonts             if($family=='arial')
            $family = 'helvetica';
            if(in_array($family,$this->CoreFonts))
            {
                  if($family=='symbol' || $family=='zapfdingbats')
                        $style = '';
                  $fontkey = $family.$style;
if(!isset($this->fonts[$fontkey]))                    $this-
>AddFont($family,$style);
```

```
            }
            else
                  $this->Error('Undefined font: '.$family.' '.$style);
      }
      // Select it
      $this->FontFamily = $family;
      $this->FontStyle = $style;
      $this->FontSizePt = $size;
      $this->FontSize = $size/$this->k;
      $this->CurrentFont = &$this->fonts[$fontkey];    if($this-
>page>0)
            $this->_out(sprintf('BT /F%d %.2F Tf
ET',$this>CurrentFont['i'],$this->FontSizePt));
}
function SetFontSize($size)
{
      // Set font size in points
      if($this->FontSizePt==$size)
return;
      $this->FontSizePt = $size;       $this-
>FontSize = $size/$this->k;
      if($this->page>0)
            $this->_out(sprintf('BT /F%d %.2F Tf
ET',$this>CurrentFont['i'],$this->FontSizePt));
}
function AddLink()
{
      // Create a new internal link
      $n = count($this->links)+1;
$this->links[$n] = array(0, 0);
return $n;
}
function SetLink($link, $y=0, $page=-1)
{
      // Set destination of internal link
      if($y==-1)            $y
= $this->y;      if($page==-1)
      $page = $this->page;
      $this->links[$link] = array($page, $y);
}
function Link($x, $y, $w, $h, $link)
{
      // Put a link on the page
      $this->PageLinks[$this->page][] = array($x*$this->k,
$this>hPt-$y*$this->k, $w*$this->k, $h*$this->k, $link);
}
function Text($x, $y, $txt)
{
      // Output a string
      $s = sprintf('BT %.2F %.2F Td (%s) Tj ET',$x*$this->k,($this-
```

```
>h-$y)*$this->k,$this->_escape($txt));      if($this-
>underline && $txt!='')
            $s .= ' '.$this->_dounderline($x,$y,$txt);
if($this->ColorFlag)
            $s = 'q '.$this->TextColor.' '.$s.' Q';
      $this->_out($s);
}
function AcceptPageBreak()
{
      // Accept automatic page break or not
return $this->AutoPageBreak;
}
function Cell($w, $h=0, $txt='', $border=0, $ln=0, $align='',
$fill=false, $link='')
{
      // Output a cell
$k = $this->k;
      if($this->y+$h>$this->PageBreakTrigger && !$this->InHeader &&
!$this->InFooter && $this->AcceptPageBreak())
      {
            // Automatic page break
            $x = $this->x;
      $ws = $this->ws;
            if($ws>0)
            {
                  $this->ws = 0;
                  $this->_out('0 Tw');
            }
            $this->AddPage($this->CurOrientation,$this->CurPageSize);
            $this->x = $x;
            if($ws>0)
            {
                  $this->ws = $ws;
                  $this->_out(sprintf('%.3F Tw',$ws*$k));
            }
      }
      if($w==0)
            $w = $this->w-$this->rMargin-$this->x;
      $s = '';
      if($fill || $border==1)
      {
            if($fill)
                  $op = ($border==1) ? 'B' : 'f';
            else
                  $op = 'S';
            $s = sprintf('%.2F %.2F %.2F %.2F re %s
',$this>x*$k,($this->h-$this->y)*$k,$w*$k,-$h*$k,$op);
      }
      if(is_string($border))
      {
```

```
            $x = $this->x;
            $y = $this->y;
            if(strpos($border,'L')!==false)
                  $s .= sprintf('%.2F %.2F m %.2F %.2F l S
',$x*$k,($this->h-$y)*$k,$x*$k,($this->h-($y+$h))*$k);
if(strpos($border,'T')!==false)
                  $s .= sprintf('%.2F %.2F m %.2F %.2F l S
',$x*$k,($this->h-$y)*$k,($x+$w)*$k,($this->h-$y)*$k);
if(strpos($border,'R')!==false)
                  $s .= sprintf('%.2F %.2F m %.2F %.2F l S
',($x+$w)*$k,($this->h-$y)*$k,($x+$w)*$k,($this->h-($y+$h))*$k);
      if(strpos($border,'B')!==false)
                  $s .= sprintf('%.2F %.2F m %.2F %.2F l S
',$x*$k,($this->h-($y+$h))*$k,($x+$w)*$k,($this->h-($y+$h))*$k);
      }
      if($txt!=='')
      {
            if($align=='R')
                  $dx = $w-$this->cMargin-$this->GetStringWidth($txt);
            elseif($align=='C')
                  $dx = ($w-$this->GetStringWidth($txt))/2;
            else
                  $dx = $this->cMargin;            if($this-
>ColorFlag)
                  $s .= 'q '.$this->TextColor.' ';
            $txt2 =
str_replace(')','\\)',str_replace('(','\\(',str_replace('\\','\\\\',
$txt)));
            $s .= sprintf('BT %.2F %.2F Td (%s) Tj ET',($this-
>x+$dx)*$k,($this->h-($this->y+.5*$h+.3*$this->FontSize))*$k,$txt2);
            if($this->underline)
                  $s .= ' '.$this->_dounderline($this->x+$dx,$this-
>y+.5*$h+.3*$this->FontSize,$txt);
            if($this->ColorFlag)
                  $s .= ' Q';
            if($link)
                  $this->Link($this->x+$dx,$this->y+.5*$h-.5*$this-
>FontSize,$this->GetStringWidth($txt),$this->FontSize,$link);
      }
      if($s)
            $this->_out($s);
      $this->lasth = $h;
      if($ln>0)
      {
            // Go to next line
$this->y += $h;
if($ln==1)
                  $this->x = $this->lMargin;
      }
```

```
      else
            $this->x += $w;
}
function MultiCell($w, $h, $txt, $border=0, $align='J', $fill=false)
{
      // Output text with automatic or explicit line breaks
      $cw = &$this->CurrentFont['cw'];
      if($w==0)
            $w = $this->w-$this->rMargin-$this->x;
      $wmax = ($w-2*$this->cMargin)*1000/$this->FontSize;
      $s = str_replace("\r",'',$txt);
      $nb = strlen($s);
if($nb>0 && $s[$nb-1]=="\n")
            $nb--;
      $b = 0;
if($border)
      {
            if($border==1)
            {
                  $border = 'LTRB';
                  $b = 'LRT';
                  $b2 = 'LR';
            }
            else
            {
                  $b2 = '';
                  if(strpos($border,'L')!==false)
                        $b2 .= 'L';
                  if(strpos($border,'R')!==false)
                        $b2 .= 'R';
                  $b = (strpos($border,'T')!==false) ? $b2.'T' : $b2;
            }
      }
      $sep = -1;
      $i = 0;
      $j = 0;
      $l = 0;
      $ns = 0; $nl
      = 1;
      while($i<$nb
      )
      {
            // Get next character
            $c = $s[$i];
if($c=="\n")
            {
                  // Explicit line break
                  if($this->ws>0)
                  {
                        $this->ws = 0;
```

```
                        $this->_out('0 Tw');
                    }
                    $this->Cell($w,$h,substr($s,$j,$i-
$j),$b,2,$align,$fill);
                    $i++;
                    $sep = -1;
                    $j = $i;
                    $l = 0;
                    $ns = 0;
                    $nl++;
                    if($border && $nl==2)
                        $b = $b2;
                    continue;
                }
                if($c==' ')
                {
                    $sep = $i;
                    $ls = $l;
                    $ns++;
                }
                $l += $cw[$c];
                if($l>$wmax)
                {
                    // Automatic line break
                    if($sep==-1)
                    {
                        if($i==$j)
                            $i++;
                        if($this->ws>0)
                        {
                            $this->ws = 0;
                            $this->_out('0 Tw');
                        }
                        $this->Cell($w,$h,substr($s,$j,$i-
$j),$b,2,$align,$fill);
                    }
                    else
                    {
                        if($align=='J')
                        {
                            $this->ws = ($ns>1) ? ($wmax-
$ls)/1000*$this->FontSize/($ns-1) : 0;
                            $this->_out(sprintf('%.3F Tw',$this-
>ws*$this->k));
                        }
                        $this->Cell($w,$h,substr($s,$j,$sep-
$j),$b,2,$align,$fill);
                        $i = $sep+1;
```

```
                }
                $sep = -1;
                $j = $i;
                $l = 0;
                $ns = 0;
                $nl++;
                if($border && $nl==2)
                      $b = $b2;
          }
          else
          $i++;
    }
    // Last chunk
    if($this->ws>0)
    {
          $this->ws = 0;
          $this->_out('0 Tw');
    }
    if($border && strpos($border,'B')!==false)
          $b .= 'B';
    $this->Cell($w,$h,substr($s,$j,$i-$j),$b,2,$align,$fill);
    $this->x = $this->lMargin;
}
function Write($h, $txt, $link='')
{
    // Output text in flowing mode
    $cw = &$this->CurrentFont['cw'];
    $w = $this->w-$this->rMargin-$this->x;
    $wmax = ($w-2*$this->cMargin)*1000/$this->FontSize;
    $s = str_replace("\r",'',$txt);
    $nb = strlen($s);
    $sep = -1;
    $i = 0;
    $j = 0;
    $l = 0;
$nl = 1;
while($i<$nb)
    {
          // Get next character
    $c = $s[$i];
if($c=="\n")
          {
                // Explicit line break
                $this->Cell($w,$h,substr($s,$j,$i-
$j),0,2,'',0,$link);
                $i++;
                $sep = -1;
```

```
                $j = $i;
            $l = 0;
            if($nl==1)
                {
                    $this->x = $this->lMargin;
                    $w = $this->w-$this->rMargin-$this->x;
                    $wmax = ($w-2*$this->cMargin)*1000/$this-
>FontSize;
                }
                $nl++;
      continue;
            }
            if($c==' ')
            $sep = $i;
            $l += $cw[$c];
            if($l>$wmax)
            {
                // Automatic line break
                if($sep==-1)
                {
                    if($this->x>$this->lMargin)
                    {
                        // Move to next line
                        $this->x = $this->lMargin;
                        $this->y += $h;
                        $w = $this->w-$this->rMargin-$this->x;
                        $wmax = ($w-2*$this->cMargin)*1000/$this-
>FontSize;
                        $i++;
                $nl++;
      continue;
                    }
                    if($i==$j)
                        $i++;
                    $this->Cell($w,$h,substr($s,$j,$i-
$j),0,2,'',0,$link);
                }
                else
                {
                    $this->Cell($w,$h,substr($s,$j,$sep-
$j),0,2,'',0,$link);
                    $i = $sep+1;
                }
                $sep = -1;
                $j = $i;
      $l = 0;
if($nl==1)
                {
                    $this->x = $this->lMargin;
```

```
                        $w = $this->w-$this->rMargin-$this->x;
                        $wmax = ($w-2*$this->cMargin)*1000/$this-
>FontSize;
                }
                $nl++;
            }
            else
            $i++;
      }
      // Last chunk
      if($i!=$j)
            $this->Cell($l/1000*$this-
>FontSize,$h,substr($s,$j),0,0,'',0,$link);
}
function Ln($h=null)
{
      // Line feed; default value is last cell height
      $this->x = $this->lMargin;
if($h===null)
            $this->y += $this->lasth;
else
            $this->y += $h;
}
function Image($file, $x=null, $y=null, $w=0, $h=0, $type='',
$link='')
{
      // Put an image on the page
      if(!isset($this->images[$file]))
      {
            // First use of this image, get info
if($type=='')
            {
                  $pos = strrpos($file,'.');
                  if(!$pos)
    $this->Error('Image file has no extension and no type was
specified: '.$file);
                  $type = substr($file,$pos+1);
            }
            $type =
strtolower($type);
if($type=='jpeg')
$type = 'jpg';
            $mtd = '_parse'.$type;
if(!method_exists($this,$mtd))
                  $this->Error('Unsupported image type: '.$type);
            $info = $this->$mtd($file);
            $info['i'] = count($this->images)+1;
            $this->images[$file] = $info;
      }
      else
```

```
            $info = $this->images[$file];

      // Automatic width and height calculation if needed
      if($w==0 && $h==0)
      {
            // Put image at 96 dpi
            $w = -96;
            $h = -96;
      } if($w<0)
            $w = -$info['w']*72/$w/$this->k; if($h<0)
            $h = -$info['h']*72/$h/$this->k; if($w==0)
            $w = $h*$info['w']/$info['h'];
if($h==0)
            $h = $w*$info['h']/$info['w'];

      // Flowing mode
      if($y===null)
      {
            if($this->y+$h>$this->PageBreakTrigger && !$this>InHeader
&& !$this->InFooter && $this->AcceptPageBreak())
            {
                  // Automatic page break
                  $x2 = $this->x;
                  $this->AddPage($this->CurOrientation,$this-
>CurPageSize);
                  $this->x = $x2;
            }
            $y = $this->y;
            $this->y += $h;
      }

      if($x===null)
            $x = $this->x;
      $this->_out(sprintf('q %.2F 0 0 %.2F %.2F %.2F cm /I%d Do
Q',$w*$this->k,$h*$this->k,$x*$this->k,($this->h-($y+$h))*$this-
>k,$info['i']));
      if($link)
            $this->Link($x,$y,$w,$h,$link);
}
function GetX()
{
      // Get x position
      return $this->x;
}  function
SetX($x)
{
      // Set x position
if($x>=0)
$this->x = $x;   else
            $this->x = $this->w+$x;
```

```
}
function GetY()
{
      // Get y position return
      $this->y; }
function SetY($y)
{
      // Set y position and reset
x     $this->x = $this->lMargin;
if($y>=0)             $this->y =
$y;   else
           $this->y = $this->h+$y;
}
function SetXY($x, $y)
{
      // Set x and y positions
      $this->SetY($y);
      $this->SetX($x);
}
function Output($name='', $dest='')
{
      // Output PDF to some destination
      if($this->state<3)
            $this->Close();
      $dest = strtoupper($dest);
if($dest=='')
      {
            if($name=='')
            {
                  $name = 'doc.pdf';
                  $dest = 'I';
            }
            else
                  $dest = 'F';
      }
      switch($dest)
      {
            case 'I':
                  // Send to standard output
$this->_checkoutput();
                  if(PHP_SAPI!='cli')
                  {
                        // We send to a browser
header('Content-Type: application/pdf');
                        header('Content-Disposition: inline;
filename="'.$name.'"');
                        header('Cache-Control: private, max-age=0,
must-revalidate');
                        header('Pragma: public');
                  }
```

```
                echo $this->buffer;
                break;     case
      'D':            //
      Download file
      $this->_checkoutput();
                header('Content-Type: application/x-download');
                header('Content-Disposition: attachment;
filename="'.$name.'"');
   header('Cache-Control: private, max-age=0, mustrevalidate');
                header('Pragma: public');
                echo $this->buffer;
                break;
case 'F':
                // Save to local file
           $f = fopen($name,'wb');
                if(!$f)
                     $this->Error('Unable to create output file:
'.$name);
                fwrite($f,$this->buffer,strlen($this->buffer));
                fclose($f);
           break;
case 'S':
                // Return as a string
      return $this->buffer;
default:
                $this->Error('Incorrect output destination:
'.$dest);
      }
      return '';
}
/*******************************************************************
************
*     *
*     Protected methods                                 *
*     *
*******************************************************************
***********/ function
_dochecks()
{
      // Check availability of %F
if(sprintf('%.1F',1.0)!='1.0')
           $this->Error('This version of PHP is not supported');
      // Check mbstring overloading
      if(ini_get('mbstring.func_overload') & 2)
           $this->Error('mbstring overloading must be disabled');
      // Ensure runtime magic quotes are disabled
if(get_magic_quotes_runtime())
@set_magic_quotes_runtime(0);
}
function _checkoutput()
{ if(PHP_SAPI!='cli')
```

```
      {
            if(headers_sent($file,$line))
                  $this->Error("Some data has already been output,
can't send PDF file (output started at $file:$line)");
      }
      if(ob_get_length())
      {
            // The output buffer is not empty

      if(preg_match('/^(\xEF\xBB\xBF)?\s*$/',ob_get_contents()))
            {
   // It contains only a UTF-8 BOM and/or whitespace, let's clean it
                  ob_clean();
            }
            else
   $this->Error("Some data has already been output, can't send PDF
file");
      }
}
function _getpagesize($size)
{
      if(is_string($size))
      {
            $size = strtolower($size);            if(!isset($this-
>StdPageSizes[$size]))                  $this->Error('Unknown page
size: '.$size);
            $a = $this->StdPageSizes[$size];
            return array($a[0]/$this->k, $a[1]/$this->k);
      }
      else
      {
            if($size[0]>$size[1])
return array($size[1], $size[0]);
            else
                  return $size;
      }
}  function _beginpage($orientation,
$size)
{
      $this->page++;
      $this->pages[$this->page] = '';
      $this->state = 2;
      $this->x = $this->lMargin;
      $this->y = $this->tMargin;
      $this->FontFamily = '';     //
Check page size and orientation
      if($orientation=='')
            $orientation = $this->DefOrientation;
      else
            $orientation = strtoupper($orientation[0]); if($size=='')
```

```
            $size = $this->DefPageSize;
      else
            $size = $this->_getpagesize($size);
if($orientation!=$this->CurOrientation ||
$size[0]!=$this>CurPageSize[0] || $size[1]!=$this->CurPageSize[1])
      {
            // New size or orientation
            if($orientation=='P')
            {
                  $this->w = $size[0];
                  $this->h = $size[1];
            }
            else
            {
                  $this->w = $size[1];
                  $this->h = $size[0];
            }
            $this->wPt = $this->w*$this->k;
            $this->hPt = $this->h*$this->k;
            $this->PageBreakTrigger = $this->h-$this->bMargin;
            $this->CurOrientation = $orientation;
            $this->CurPageSize = $size;
      }
      if($orientation!=$this->DefOrientation || $size[0]!=$this-
>DefPageSize[0] || $size[1]!=$this->DefPageSize[1])
            $this->PageSizes[$this->page] = array($this->wPt,
$this>hPt);
}
function _endpage()
{
      $this->state = 1;
}
function _loadfont($font)
{
      // Load a font definition file from the font
directory       include($this->fontpath.$font);       $a =
get_defined_vars();   if(!isset($a['name']))
  $this->Error('Could not include font definition file');  return
$a;
}
function _escape($s)
{
      // Escape special characters in strings
      $s = str_replace('\\','\\\\',$s);
      $s = str_replace('(','\\(',$s);
      $s = str_replace(')','\\)',$s);
$s = str_replace("\r",'\\r',$s);
      return $s;
}
function _textstring($s)
```

```
{
      // Format a text string    return
'('.$this->_escape($s).')';
}
function _UTF8toUTF16($s)
{
      // Convert UTF-8 to UTF-16BE with BOM
      $res = "\xFE\xFF";
      $nb = strlen($s);
$i = 0;    while($i<$nb)
      {
            $c1 = ord($s[$i++]);
            if($c1>=224)
            {
                  // 3-byte character
                  $c2 = ord($s[$i++]);
                  $c3 = ord($s[$i++]);
                  $res .= chr((($c1 & 0x0F)<<4) + (($c2 & 0x3C)>>2));
                  $res .= chr((($c2 & 0x03)<<6) + ($c3 & 0x3F));
            }
            elseif($c1>=192)
            {
                  // 2-byte character
                  $c2 = ord($s[$i++]);
                  $res .= chr((($c1 & 0x1C)>>2);
                  $res .= chr((($c1 & 0x03)<<6) + ($c2 & 0x3F));
            }
            else
            {
                  // Single-byte character
                  $res .= "\0".chr($c1);
            }
      }
      return $res;
}
function _dounderline($x, $y, $txt)
{
      // Underline text
      $up = $this->CurrentFont['up'];
      $ut = $this->CurrentFont['ut'];
      $w = $this->GetStringWidth($txt)+$this->ws*substr_count($txt,'
');  return sprintf('%.2F %.2F %.2F %.2F re f',$x*$this->k,($this>h-
($y-$up/1000*$this->FontSize))*$this->k,$w*$this->k,-
$ut/1000*$this->FontSizePt);
}
function _parsejpg($file)
{
      // Extract info from a JPEG file
      $a = getimagesize($file); if(!$a)
```

```
            $this->Error('Missing or incorrect image file: '.$file);
if($a[2]!=2)
            $this->Error('Not a JPEG file: '.$file);
      if(!isset($a['channels']) || $a['channels']==3)
            $colspace = 'DeviceRGB';
elseif($a['channels']==4)
$colspace = 'DeviceCMYK';  else
            $colspace = 'DeviceGray';
      $bpc = isset($a['bits']) ? $a['bits'] : 8;
$data = file_get_contents($file);
      return array('w'=>$a[0], 'h'=>$a[1], 'cs'=>$colspace,
'bpc'=>$bpc, 'f'=>'DCTDecode', 'data'=>$data);
}
function _parsepng($file)
{
      // Extract info from a PNG file
      $f = fopen($file,'rb');
if(!$f)
            $this->Error('Can\'t open image file: '.$file);
      $info = $this->_parsepngstream($f,$file);
      fclose($f);
      return $info;
}
function _parsepngstream($f, $file)
{
      // Check signature
      if($this-
>_readstream($f,8)!=chr(137).'PNG'.chr(13).chr(10).chr(26).chr(10))
            $this->Error('Not a PNG file: '.$file);

      // Read header chunk        $this-
>_readstream($f,4);   if($this-
>_readstream($f,4)!='IHDR')
            $this->Error('Incorrect PNG file: '.$file);
      $w = $this->_readint($f);
      $h = $this->_readint($f);
      $bpc = ord($this->_readstream($f,1));
      if($bpc>8)
            $this->Error('16-bit depth not supported: '.$file);
      $ct = ord($this->_readstream($f,1));
if($ct==0 || $ct==4)
$colspace = 'DeviceGray';  elseif($ct==2
|| $ct==6)            $colspace =
'DeviceRGB';     elseif($ct==3)
            $colspace = 'Indexed';
else
            $this->Error('Unknown color type: '.$file); if(ord($this-
      >_readstream($f,1))!=0)          $this->Error('Unknown
      compression method: '.$file);    if(ord($this-
      >_readstream($f,1))!=0)
```

```
            $this->Error('Unknown filter method: '.$file);
if(ord($this->_readstream($f,1))!=0)
            $this->Error('Interlacing not supported: '.$file);
      $this->_readstream($f,4);
      $dp = '/Predictor 15 /Colors '.($colspace=='DeviceRGB' ? 3 :
1).' /BitsPerComponent '.$bpc.' /Columns '.$w;

      // Scan chunks looking for palette, transparency and image
data
      $pal = '';
      $trns = '';
      $data = '';
      do
      {
            $n = $this->_readint($f);
$type = $this->_readstream($f,4);
            if($type=='PLTE')
            {
                  // Read palette
                  $pal = $this->_readstream($f,$n);
                  $this->_readstream($f,4);
            }
            elseif($type=='tRNS')
            {
                  // Read transparency info
      $t = $this->_readstream($f,$n);
                  if($ct==0)
                        $trns = array(ord(substr($t,1,1)));
elseif($ct==2)
                        $trns = array(ord(substr($t,1,1)),
ord(substr($t,3,1)), ord(substr($t,5,1)));
                  else
                  {
                        $pos = strpos($t,chr(0));
                  if($pos!==false)
            $trns = array($pos);
                  }
                  $this->_readstream($f,4);
            }
            elseif($type=='IDAT')
            {
                  // Read image data block
                  $data .= $this->_readstream($f,$n);
                  $this->_readstream($f,4);
            }
            elseif($type=='IEND')
            break;
            else
                  $this->_readstream($f,$n+4);
```

```
      } while($n);
      if($colspac
      e=='Indexed
      ' &&
      empty($pal)
      )     $this-
      >Error('Mis
      sing
      palette in
      '.$file);
      $info = array('w'=>$w, 'h'=>$h, 'cs'=>$colspace, 'bpc'=>$bpc,
'f'=>'FlateDecode', 'dp'=>$dp, 'pal'=>$pal, 'trns'=>$trns);
      if($ct>=4)
      {
            // Extract alpha channel
if(!function_exists('gzuncompress'))
                  $this->Error('Zlib not available, can\'t handle
alpha channel: '.$file);
            $data = gzuncompress($data);
            $color = '';
$alpha = '';
if($ct==4)
            {
                  // Gray image
      $len = 2*$w;
                  for($i=0;$i<$h;$i++)
                  {
                        $pos = (1+$len)*$i;
                        $color .= $data[$pos];
                        $alpha .= $data[$pos];
                        $line = substr($data,$pos+1,$len);
                        $color .= preg_replace('/(.)./s','$1',$line);
                        $alpha .= preg_replace('/.(.)/s','$1',$line);
                  }
            }
            else
            {
                  // RGB image
      $len = 4*$w;
                  for($i=0;$i<$h;$i++)
                  {
                        $pos = (1+$len)*$i;
                        $color .= $data[$pos];
                        $alpha .= $data[$pos];
                        $line = substr($data,$pos+1,$len);
                        $color .=
preg_replace('/(.{3})./s','$1',$line);
                        $alpha .=
preg_replace('/.{3}(.)/s','$1',$line);
                  }
```

```
            }
            unset($data);
            $data = gzcompress($color);
$info['smask'] = gzcompress($alpha);        if($this-
>PDFVersion<'1.4')                $this->PDFVersion =
'1.4';
      }
      $info['data'] = $data;
      return $info;
}
function _readstream($f, $n)
{
      // Read n bytes from stream
      $res = '';
      while($n>0 && !feof($f))
      {
            $s = fread($f,$n);
if($s===false)
                  $this->Error('Error while reading stream');
            $n -= strlen($s);
            $res .= $s;
      }
      if($n>0)
            $this->Error('Unexpected end of stream');
      return $res;
}
function _readint($f)
{
      // Read a 4-byte integer from stream  $a =
unpack('Ni',$this->_readstream($f,4));
      return $a['i'];
}
function _parsegif($file)
{
      // Extract info from a GIF file (via PNG conversion)
if(!function_exists('imagepng'))
            $this->Error('GD extension is required for GIF support');
if(!function_exists('imagecreatefromgif'))            $this-
>Error('GD has no GIF read support');
      $im = imagecreatefromgif($file);
if(!$im)
            $this->Error('Missing or incorrect image file:
'.$file);        imageinterlace($im,0);      $f =
@fopen('php://temp','rb+');
      if($f)
      {
            // Perform conversion in
memory           ob_start();
imagepng($im);         $data =
ob_get_clean();
```

```
imagedestroy($im);
fwrite($f,$data);
            rewind($f);
            $info = $this->_parsepngstream($f,$file);
fclose($f);
      }
      else
      {
            // Use temporary file
            $tmp = tempnam('.','gif');
            if(!$tmp)
                  $this->Error('Unable to create a temporary file');
            if(!imagepng($im,$tmp))
                  $this->Error('Error while saving to temporary
file');
            imagedestroy($im);
            $info = $this->_parsepng($tmp);
            unlink($tmp);
      }
      return $info;
}
function _newobj()
{
      // Begin a new object
      $this->n++;
      $this->offsets[$this->n] = strlen($this->buffer);
      $this->_out($this->n.' 0 obj');
}
function _putstream($s)
{
      $this->_out('stream');
      $this->_out($s);
      $this->_out('endstream');
}
function _out($s)
{
      // Add a line to the document    if($this-
>state==2)
            $this->pages[$this->page] .= $s."\n";
      else
            $this->buffer .= $s."\n";
}
function _putpages()
{
      $nb = $this->page;
      if(!empty($this->AliasNbPages))
      {
            // Replace number of pages
for($n=1;$n<=$nb;$n++)
                  $this->pages[$n] = str_replace($this-
```

```
>AliasNbPages,$nb,$this->pages[$n]);
      }
      if($this->DefOrientation=='P')
      {
            $wPt = $this->DefPageSize[0]*$this->k;
            $hPt = $this->DefPageSize[1]*$this->k;
      } else
      {
            $wPt = $this->DefPageSize[1]*$this->k;
            $hPt = $this->DefPageSize[0]*$this->k;
      }
      $filter = ($this->compress) ? '/Filter /FlateDecode ' : '';
      for($n=1;$n<=$nb;$n++)
      {
            // Page
            $this->_newobj();
            $this->_out('<</Type /Page');          $this-
>_out('/Parent 1 0 R');          if(isset($this-
>PageSizes[$n]))
                  $this->_out(sprintf('/MediaBox [0 0 %.2F
%.2F]',$this->PageSizes[$n][0],$this->PageSizes[$n][1]));
            $this->_out('/Resources 2 0 R');
            if(isset($this->PageLinks[$n]))
            {
                  // Links
                  $annots = '/Annots [';
                  foreach($this->PageLinks[$n] as $pl)
                  {
                        $rect = sprintf('%.2F %.2F %.2F
%.2F',$pl[0],$pl[1],$pl[0]+$pl[2],$pl[1]-$pl[3]);
                        $annots .= '<</Type /Annot /Subtype /Link
/Rect ['.$rect.'] /Border [0 0 0] ';
                        if(is_string($pl[4]))
                              $annots .= '/A <</S /URI /URI '.$this-
>_textstring($pl[4]).'>>>>';
                        else
                        {
                              $l = $this->links[$pl[4]];
                              $h = isset($this->PageSizes[$l[0]]) ?
$this->PageSizes[$l[0]][1] : $hPt;
                              $annots .= sprintf('/Dest [%d 0 R /XYZ 0
%.2F null]>>',1+2*$l[0],$h-$l[1]*$this->k);
                        }
                  }
                  $this->_out($annots.']');
            }
            if($this->PDFVersion>'1.3')
                  $this->_out('/Group <</Type /Group /S /Transparency
/CS /DeviceRGB>>');
```

```
            $this->_out('/Contents '.($this->n+1).' 0 R>>');
            $this->_out('endobj');
            // Page content
            $p = ($this->compress) ? gzcompress($this->pages[$n]) :
$this->pages[$n];
            $this->_newobj();
            $this->_out('<<'.$filter.'/Length '.strlen($p).'>>');
            $this->_putstream($p);
            $this->_out('endobj');
      }
      // Pages root
      $this->offsets[1] = strlen($this->buffer);
      $this->_out('1 0 obj');
      $this->_out('<</Type /Pages');
      $kids = '/Kids [';  for($i=0;$i<$nb;$i++)
            $kids .= (3+2*$i).' 0 R ';
      $this->_out($kids.']');
      $this->_out('/Count '.$nb);
      $this->_out(sprintf('/MediaBox [0 0 %.2F %.2F]',$wPt,$hPt));
      $this->_out('>>');
      $this->_out('endobj');
}
function _putfonts()
{
      $nf = $this->n;
      foreach($this->diffs as $diff)
      {
            // Encodings
            $this->_newobj();
            $this->_out('<</Type /Encoding /BaseEncoding
/WinAnsiEncoding /Differences ['.$diff.']>>');
            $this->_out('endobj');
      }
      foreach($this->FontFiles as $file=>$info)
      {
            // Font file embedding
            $this->_newobj();
            $this->FontFiles[$file]['n'] = $this->n;
            $font = file_get_contents($this->fontpath.$file,true);
            if(!$font)
                  $this->Error('Font file not found: '.$file);
$compressed = (substr($file,-2)=='.z');
            if(!$compressed && isset($info['length2']))
                  $font =
substr($font,6,$info['length1']).substr($font,6+$info['length1']+6,$
info['length2']);
            $this->_out('<</Length '.strlen($font));
if($compressed)
                  $this->_out('/Filter /FlateDecode');        $this-
>_out('/Length1 '.$info['length1']);
```

```
            if(isset($info['length2']))
                  $this->_out('/Length2 '.$info['length2'].' /Length3
0');
            $this->_out('>>');
            $this->_putstream($font);
            $this->_out('endobj');
      }
      foreach($this->fonts as $k=>$font)
      {
            // Font objects
            $this->fonts[$k]['n'] = $this->n+1;
            $type = $font['type'];
      $name = $font['name'];
            if($type=='Core')
            {
                  // Core font
                  $this->_newobj();
                  $this->_out('<</Type /Font');
                  $this->_out('/BaseFont /'.$name);
                  $this->_out('/Subtype /Type1');
            if($name!='Symbol' && $name!='ZapfDingbats')
            $this->_out('/Encoding /WinAnsiEncoding');
                  $this->_out('>>');
                  $this->_out('endobj');
            }
            elseif($type=='Type1' || $type=='TrueType')
            {
                  // Additional Type1 or TrueType/OpenType font
                  $this->_newobj();
                  $this->_out('<</Type /Font');
                  $this->_out('/BaseFont /'.$name);
                  $this->_out('/Subtype /'.$type);
                  $this->_out('/FirstChar 32 /LastChar 255');
                  $this->_out('/Widths '.($this->n+1).' 0 R');
      $this->_out('/FontDescriptor '.($this->n+2).' 0 R');
                  if(isset($font['diffn']))
                        $this->_out('/Encoding
'.($nf+$font['diffn']).' 0 R');
                  else
                        $this->_out('/Encoding /WinAnsiEncoding');
                  $this->_out('>>');
                  $this->_out('endobj');
                  // Widths
                  $this->_newobj();
                  $cw = &$font['cw'];
                  $s = '[';
                  for($i=32;$i<=255;$i++)
            $s .= $cw[chr($i)].' ';
                  $this->_out($s.']');
```

```
                $this->_out('endobj');
                // Descriptor
                $this->_newobj();
                $s = '<</Type /FontDescriptor /FontName /'.$name;
                foreach($font['desc'] as $k=>$v)
                $s .= ' /'.$k.' '.$v;
if(!empty($font['file']))
                        $s .= ' /FontFile'.($type=='Type1' ? '' :
'2').' '.$this->FontFiles[$font['file']]['n'].' 0 R';
                $this->_out($s.'>>');
                $this->_out('endobj');
            }
            else
            {
                // Allow for additional types
      $mtd = '_put'.strtolower($type);
if(!method_exists($this,$mtd))
                        $this->Error('Unsupported font type: '.$type);
                $this->$mtd($font);
            }
      }
}
function _putimages()
{
      foreach(array_keys($this->images) as $file)
      {
            $this->_putimage($this->images[$file]);
unset($this->images[$file]['data']);
            unset($this->images[$file]['smask']);
      }
}
function _putimage(&$info)
{
      $this->_newobj();
      $info['n'] = $this->n;
      $this->_out('<</Type /XObject');
      $this->_out('/Subtype /Image');
      $this->_out('/Width '.$info['w']);    $this-
>_out('/Height '.$info['h']);    if($info['cs']=='Indexed')
            $this->_out('/ColorSpace [/Indexed /DeviceRGB
'.(strlen($info['pal'])/3-1).' '.($this->n+1).' 0 R]');
      else
      {
            $this->_out('/ColorSpace /'.$info['cs']);
if($info['cs']=='DeviceCMYK')
                $this->_out('/Decode [1 0 1 0 1 0 1 0]');
      }
      $this->_out('/BitsPerComponent '.$info['bpc']);
if(isset($info['f']))
```

```
            $this->_out('/Filter /'.$info['f']);
if(isset($info['dp']))
            $this->_out('/DecodeParms <<'.$info['dp'].'>>');
if(isset($info['trns']) && is_array($info['trns']))
      {
            $trns = '';
            for($i=0;$i<count($info['trns']);$i++)
                  $trns .= $info['trns'][$i].' '.$info['trns'][$i].'
';
            $this->_out('/Mask ['.$trns.']');
      }
      if(isset($info['smask']))
            $this->_out('/SMask '.($this->n+1).' 0 R');
      $this->_out('/Length '.strlen($info['data']).'>>');
      $this->_putstream($info['data']);
      $this->_out('endobj');
// Soft mask
      if(isset($info['smask']))
      {
            $dp = '/Predictor 15 /Colors 1 /BitsPerComponent 8
/Columns '.$info['w'];
            $smask = array('w'=>$info['w'], 'h'=>$info['h'],
'cs'=>'DeviceGray', 'bpc'=>8, 'f'=>$info['f'], 'dp'=>$dp,
'data'=>$info['smask']);
            $this->_putimage($smask);
      }
      // Palette
      if($info['cs']=='Indexed')
      {
            $filter = ($this->compress) ? '/Filter /FlateDecode ' :
'';
            $pal = ($this->compress) ? gzcompress($info['pal']) :
$info['pal'];
            $this->_newobj();
            $this->_out('<<'.$filter.'/Length '.strlen($pal).'>>');
            $this->_putstream($pal);
            $this->_out('endobj');
      }
}
function _putxobjectdict()
{
      foreach($this->images as $image)
            $this->_out('/I'.$image['i'].' '.$image['n'].' 0
R'); }
function _putresourcedict()
{
      $this->_out('/ProcSet [/PDF /Text /ImageB /ImageC /ImageI]');
      $this->_out('/Font <<');    foreach($this-
>fonts as $font)
            $this->_out('/F'.$font['i'].' '.$font['n'].' 0 R');
```

```
        $this->_out('>>');
        $this->_out('/XObject <<');
        $this->_putxobjectdict();
        $this->_out('>>');
}
function _putresources()
{
        $this->_putfonts();
        $this->_putimages();
        // Resource dictionary
        $this->offsets[2] = strlen($this->buffer);
        $this->_out('2 0 obj');
        $this->_out('<<');
        $this->_putresourcedict();
        $this->_out('>>');
        $this->_out('endobj');
}
function _putinfo()
{
        $this->_out('/Producer '.$this->_textstring('FPDF
'.FPDF_VERSION));
        if(!empty($this->title))
                $this->_out('/Title '.$this->_textstring($this->title));
if(!empty($this->subject))
  $this->_out('/Subject '.$this->_textstring($this>subject));
        if(!empty($this->author))
                $this->_out('/Author '.$this->_textstring($this-
>author));
        if(!empty($this->keywords))
                $this->_out('/Keywords '.$this->_textstring($this-
>keywords));
        if(!empty($this->creator))
  $this->_out('/Creator '.$this->_textstring($this>creator));
        $this->_out('/CreationDate
'.$this>_textstring('D:'.@date('YmdHis')));
}
function _putcatalog()
{
        $this->_out('/Type /Catalog');   $this-
>_out('/Pages 1 0 R');      if($this-
>ZoomMode=='fullpage')
                $this->_out('/OpenAction [3 0 R /Fit]');    elseif($this-
>ZoomMode=='fullwidth')
                $this->_out('/OpenAction [3 0 R /FitH null]');
elseif($this->ZoomMode=='real')
                $this->_out('/OpenAction [3 0 R /XYZ null null 1]');
elseif(!is_string($this->ZoomMode))
                $this->_out('/OpenAction [3 0 R /XYZ null null
'.sprintf('%.2F',$this->ZoomMode/100).']');       if($this-
>LayoutMode=='single')
```

```
            $this->_out('/PageLayout /SinglePage');     elseif($this-
>LayoutMode=='continuous')              $this->_out('/PageLayout
/OneColumn');    elseif($this->LayoutMode=='two')
            $this->_out('/PageLayout /TwoColumnLeft');
}
function _putheader()
{
      $this->_out('%PDF-'.$this->PDFVersion);
}
function _puttrailer()
{
      $this->_out('/Size '.($this->n+1));
      $this->_out('/Root '.$this->n.' 0 R');
      $this->_out('/Info '.($this->n-1).' 0 R');
}  function
_enddoc()
{
      $this->_putheader();
      $this->_putpages();
      $this->_putresources();
// Info
      $this->_newobj();
      $this->_out('<<');
      $this->_putinfo();
      $this->_out('>>');
      $this->_out('endobj');
      // Catalog
      $this->_newobj();
      $this->_out('<<');
      $this->_putcatalog();
      $this->_out('>>');
      $this->_out('endobj');
      // Cross-ref
      $o = strlen($this->buffer);
      $this->_out('xref');
      $this->_out('0 '.($this->n+1));       $this-
>_out('0000000000 65535 f ');    for($i=1;$i<=$this->n;$i++)
  $this->_out(sprintf('%010d 00000 n ',$this>offsets[$i]));
      // Trailer
      $this->_out('trailer');
      $this->_out('<<');
      $this->_puttrailer();
      $this->_out('>>');
      $this->_out('startxref');
      $this->_out($o);
      $this->_out('%%EOF');
      $this->state = 3;
}
// End of class
}
```

```
// Handle special IE contype request
if(isset($_SERVER['HTTP_USER_AGENT']) &&
$_SERVER['HTTP_USER_AGENT']=='contype')
{
      header('Content-Type: application/pdf');
      exit;
}

?>
```



```
<?php
include_once 'connection.php';
?>
<!DOCTYPE html>
<head>
    <title><?php echo $_GET['Meter'];?></title>
    <link  rel="stylesheet" href="css/doc.css"/>
</head>
<body>
    <center>
        <h1>
            Meter Readings - #<?php echo $_GET['Meter'];?>
</h1>

        <hr/><br/><br/>
        <?php $result=mysql_query("select * from readings where
meterno='{$_GET['Meter']}'");?>
        <table width="70%" cellpadding="5" cellspacing="0"
border="1">
            <thead><tr><th>Period (Month/Year)</th><th>Reading
Date</th><th>Meter Reading</th><th>Authorised</th></tr></thead>
            <tbody>
<?php
            while($row= mysql_fetch_array($result)){
echo
"<tr><td><center>$row[5]/$row[6]</center></td><td><center>".date('d
M, Y',
strtotime($row[2]))."</center></td><td><center>".str_pad($row[3],6,"
0",0)."</center></td><td><center>".($row[4]=="0"?"No":"Yes <a
href='readings.php?code=ECG2&meter=$row[1]&month=$row[5]&year=$row[6
]'>Bill</a>")."</center></td></tr>";
            }
            ?></tbody>
        </table>
    </center>
</body>



<?php
```

```
include_once 'connection.php'; if(isset($_POST['run'])){
switch($_POST['run']){          case "100":
mysql_query("update settings set val='{$_POST['rate']}' where
item='rate'");
            mysql_query("update settings set val='{$_POST['vat']}'
where item='vat'");             break;
    }
}
?>
<!DOCTYPE html>
<html>
    <head>
        <title>Smart Grid - ECG </title>
        <link  rel="stylesheet" href="css/doc.css"/>
        <script src="js/script.js" type="text/javascript"></script>
    </head>
    <body>
    <center>
        <h1>
            Smart Grid - ECG
        </h1>

        <hr/>
        <table width="80%" cellspacing="0" cellpadding="5"
border="1">             <thead>
                <tr><th>Meter No</th><th>Name</th><th>House
address</th><th>Phone</th><th></th></tr>
            </thead>
            <tbody>
                <?php
                $result = mysql_query("select * from customers");
while ($row = mysql_fetch_array($result))
echo "<tr><td>$row[0]</td><td>$row[2]
$row[1]</td><td>$row[3]</td><td>$row[4]</td><th><a
href='hist.php?Meter=$row[0]'>Meter Readings</a> | <a
href='avg.php?Meter=$row[0]'>Average Consumption</a></th></tr>"
                    ?>
            </tbody>
        </table><br/><br/><br/>
        <form method="post" action="index.php" onsubmit="return
false;">
            <input type="hidden" name="run" value="100"/>
            <h3>CURRENT CHARGES</h3>
            <table width="40%"><tr><td>
                        Rate(per unit) GHs:<br/><input name="rate"
style="text-align: right" type="text" value="<?php echo
mysql_result(mysql_query("select val from settings where
item='rate'"), 0); ?>"/>                        </td>
                    <td>VAT & NHIS (%):<br/><input type="text"
name="vat" value="<?php echo mysql_result(mysql_query("select val
from settings where item='vat'"), 0); ?>"/> </td>
                    <td><br/><input type="submit" value="Save"
onclick="SaveSettings(this.form);"/></td> </tr></table>
```

```
        </form><br/><br/>
        <form action="auth.php" method="post">
            <h3>AUTHORIZATION</h3>
            Request authorization from PURC to bill customers for
specified month.
            <br/><br/><br/>
            <table width="50%"><tr><td>
                        Month:<br/><select id="month"
name="month"><?php for ($i = 1; $i <= 12; $i++)
                echo "<option value='$i'>$i</option>"; ?></select>
</td><td>Year:<br/><select name="year" id="year"><?php for ($i = -
2; $i < 4; $i++)                    echo "<option value='" .
(date('Y') + $i) . "'>" .
(date('Y') + $i) . "</option>"; ?></select></td>
                    <td><br/><input type="submit" value="Get
authorization"/></td>

                </tr></table>
        </form><br/>
        <br/>       <button
onclick="Bills();" >Generate Bills</button>
    </center>

</body>
</html>



<?php
switch ($_SERVER['HTTP_ORIGIN']) {
case 'http://localhost':
    header('Access-Control-Allow-Origin: '.$_SERVER['HTTP_ORIGIN']);
header('Access-Control-Allow-Methods:   GET,   PUT,   POST,   DELETE,
OPTIONS');
    header('Access-Control-Max-Age: 1000');
    header('Access-Control-Allow-Headers: Content-Type,
Authorization, X-Requested-With');
break; }
if (isset($_GET['code'])) {
include_once 'connection.php';
include_once 'fpdf.php';
switch ($_GET['code']) {
case "ECG1":
            if (mysql_result(mysql_query("select count(*) from
readings where meterno='{$_GET['meter']}' and month={$_GET['month']}
and year={$_GET['year']}"), 0) == "0") {
mysql_query("insert into readings
values(null,'{$_GET['meter']}',now(),{$_GET['reading']},0,{$_GET['mo
nth']},{$_GET['year']},{$_GET['units']})");
echo "1";
            } else if (mysql_result(mysql_query("select count(*)
from readings where meterno='{$_GET['meter']}' and
month={$_GET['month']} and year={$_GET['year']} and authorised=0"),
```

```
0) != "0") {
                mysql_query("update readings set
reading={$_GET['reading']},rdate=now(), units={$_GET['units']} where
meterno='{$_GET['meter']}' and month={$_GET['month']} and
year={$_GET['year']}");                 echo "1";             } else
{ //refused                 echo "0";
            }
break;         case
"ECG2":
            $pdf = new FPDF();
            //$pdf->AliasNbPages();
            $pdf->SetAuthor('SmartGrid');
            $pdf->SetCreator('ECG');
            //$pdf->SetDisplayMode('real');
            $pdf->SetTitle("ELECTRICITY COMPANY OF GHANA");
            $pdf->AddPage("L","A5");
            $pdf->SetFont('Arial', 'B', 18);
            // Move to the right
            $pdf->Cell(1);
            $pdf->Cell(200,10,"ELECTRICITY COMPANY OF
GHANA",0,0,'C');
            $pdf->SetFont('Arial', '', 12);
            $pdf->Ln(10);
            $pdf->Cell(40,30,"NAME: ".
mysql_result(mysql_query("select concat(concat(surname,'
'),othernames) from customers where meterno='{$_GET['meter']}'
"),0),0,0,'');
            $pdf->Cell(140,30,"PHONE: ".
mysql_result(mysql_query("select phone from customers where
meterno='{$_GET['meter']}' "),0),0,0,'R');
$pdf->Ln(1);
            $pdf->Cell(40,45,"ADDRESS: ".
mysql_result(mysql_query("select address from customers where
meterno='{$_GET['meter']}' "),0),0,0,'');
            $pdf->Ln(1);
            $pdf->Cell(40,65,"METER #: ".$_GET['meter'],0,0,'');
            $pdf->Cell(70,65,"DATE: ".  date("d-m-Y"),0,0,'C');
            $pdf->Cell(60,65,"METER READING:
".mysql_result(mysql_query("select reading from readings where
meterno='{$_GET['meter']}'   and   year={$_GET['year']}   and
month={$_GET['month']}"),0)  ,0,0,'C');
            $pdf->Ln(1);
            $pdf->Cell(40,85,"UNIT(S):
".mysql_result(mysql_query("select units from readings where
meterno='{$_GET['meter']}'   and   year={$_GET['year']}   and
month={$_GET['month']}"),0)  ,0,0,'');
            $pdf->Cell(70,85,"PERIOD: ".date('M Y',
strtotime("01/{$_GET['month']}/{$_GET['year']}")),0,0,'C');
            $pdf->Cell(45,85,"RATE:
GH".chr(162).mysql_result(mysql_query("select rate from bills where
meterno='{$_GET['meter']}'     and     year={$_GET['year']}     and
month={$_GET['month']}"),0)."/unit"  ,0,0,'R');
            $pdf->Ln(1);
```

```
            $pdf->SetFillColor(50,100,150);
            $pdf->SetTextColor(255);
            $pdf->Rect(10, 100, 190, 40 ,"F") ;
            $pdf->SetFont('Arial', '', 11);
            $pdf->Cell(1);
            $pdf->Text(15,110,"AMOUNT (GH".chr(162).")");
$pdf-
>Text(175,110,number_format(mysql_result(mysql_query("select
rate*units from bills where meterno='{$_GET['meter']}' and
year={$_GET['year']} and month={$_GET['month']}"),0),2));
$pdf->Text(15,120,"VAT & NHIS  (GH".chr(162).")");              $pdf-
>Text(175,120,number_format(mysql_result(mysql_query("select
(rate*units)*(vat/100) from bills where meterno='{$_GET['meter']}'
and year={$_GET['year']} and month={$_GET['month']}"),0),2));
            $pdf->Text(15,130,"TOTAL  (GH".chr(162).")");
$pdf-
>Text(175,130,number_format(mysql_result(mysql_query("select
(rate*units)+ ((rate*units)*(vat/100)) from bills where
meterno='{$_GET['meter']}' and year={$_GET['year']} and
month={$_GET['month']}"),0),2));

            $pdf->Output();
break;
        case "ECG3": //save bill info
mysql_query ("insert into bills
values(null,'{$_GET['meter']}',{$_GET['month']},{$_GET['year']},{$_G
ET['units']},".            mysql_result(mysql_query("select val
from settings where item='rate'"), 0) .",".
mysql_result(mysql_query("select val from settings where
item='vat'"), 0).")");
            mysql_query("update readings set authorised=1 where
meterno='{$_GET['meter']}' and year={$_GET['year']} and
month={$_GET['month']}");            break;          case
"ECG4":
            $pdf = new FPDF();
            //$pdf->AliasNbPages();
            $pdf->SetAuthor('SmartGrid');
            $pdf->SetCreator('ECG');
            //$pdf->SetDisplayMode('real');
            $pdf->SetTitle("ELECTRICITY COMPANY OF GHANA");
$result=     mysql_query("select   *   from   bills   where
year={$_GET['year']}      and      month={$_GET['month']}");
while ($row=  mysql_fetch_array($result)){

            $pdf->AddPage("L","A5");
            $pdf->SetFont('Arial', 'B', 18);
            // Move to the right
            $pdf->Cell(1);
            $pdf->Cell(200,10,"ELECTRICITY COMPANY OF
GHANA",0,0,'C');
            $pdf->SetFont('Arial', '', 12);
            $pdf->Ln(10);
```

```
            $pdf->Cell(40,30,"NAME: ".
mysql_result(mysql_query("select concat(concat(surname,'
'),othernames) from customers where meterno='$row[1]' "),0),0,0,'');
            $pdf->Cell(140,30,"PHONE: ".
mysql_result(mysql_query("select phone from customers where
meterno='$row[1]' "),0),0,0,'R');
            $pdf->Ln(1);
            $pdf->Cell(40,45,"ADDRESS: ".
mysql_result(mysql_query("select address from customers where
meterno='$row[1]' "),0),0,0,'');
            $pdf->Ln(1);
            $pdf->Cell(40,65,"METER #: $row[1]",0,0,'');
            $pdf->Cell(70,65,"DATE: ".  date("d-m-Y"),0,0,'C');
            $pdf->Cell(60,65,"METER READING: $row[4]"  ,0,0,'C');
            $pdf->Ln(1);
            $pdf->Cell(40,85,"UNIT(S):
".mysql_result(mysql_query("select units from readings where
meterno='$row[1]' and year={$_GET['year']} and
month={$_GET['month']}"),0)  ,0,0,'');
            $pdf->Cell(70,85,"PERIOD: ".date('M Y',
strtotime("01/{$_GET['month']}/{$_GET['year']}")),0,0,'C');
            $pdf->Cell(45,85,"RATE:
GH".chr(162).mysql_result(mysql_query("select rate from bills where
meterno='$row[1]'        and        year={$_GET['year']}        and
month={$_GET['month']}"),0)."/unit"  ,0,0,'R');
            $pdf->Ln(1);
            $pdf->SetFillColor(50,100,150);
            $pdf->SetTextColor(255);
            $pdf->Rect(10, 100, 190, 40 ,"F") ;
            $pdf->SetFont('Arial', '', 11);
            $pdf->Cell(1);
            $pdf->Text(15,110,"AMOUNT (GH".chr(162).")");
            $pdf-
>Text(175,110,number_format(mysql_result(mysql_query("select
rate*units from bills where meterno='$row[1]' and
year={$_GET['year']} and month={$_GET['month']}"),0),2));
$pdf->Text(15,120,"VAT & NHIS  (GH".chr(162).")");
            $pdf-
>Text(175,120,number_format(mysql_result(mysql_query("select
(rate*units)*(vat/100) from bills where meterno='$row[1]' and
year={$_GET['year']}   and   month={$_GET['month']}"),0),2));
$pdf->Text(15,130,"TOTAL  (GH".chr(162).")");
            $pdf-
>Text(175,130,number_format(mysql_result(mysql_query("select
(rate*units)+ ((rate*units)*(vat/100)) from bills where
meterno='$row[1]' and year={$_GET['year']} and
month={$_GET['month']}"),0),2));        $pdf-
>SetTextColor(0);

            }
            $pdf->Output();
break;
    }
```

```
} ?>
```

Below depicts the codes used in setting up the Public Utilities Regulatory Commission (PURC) virtual machine in the Oracle Virtual Machine Manager.

PURC

```
<?php


$hostname_conn = "localhost";
$database_conn = "smart_purc";
$username_conn = "root";
$password_conn = "1234";
$conn = mysql_connect($hostname_conn, $username_conn,
$password_conn) or trigger_error(mysql_error(),E_USER_ERROR);
mysql_query('use '.$database_conn);

$control="http://192.168.56.5/secure/control/auth.php";
//$control="http://localhost/secure/control/auth.php"; function
getValueFromControl($url,$data){
    $ch = curl_init($url);
    curl_setopt($ch, CURLOPT_SSL_VERIFYHOST, 0);
curl_setopt($ch, CURLOPT_SSL_VERIFYPEER, 0);
curl_setopt($ch, CURLOPT_POST, 1);     curl_setopt($ch,
CURLOPT_HTTPHEADER, array('Content-Type: application/x-www-
form-urlencoded'));     curl_setopt($ch, CURLOPT_POSTFIELDS,
"$data");     curl_setopt($ch, CURLOPT_RETURNTRANSFER, 1);
    $output = curl_exec($ch);
curl_close($ch);
return $output;
}

?>



<?php
include_once 'connection.php';
?>
<!DOCTYPE html>
<html>
    <head>
        <title>Smart Grid - PURC </title>
        <link  rel="stylesheet" href="css/doc.css"/>
        <script src="js/script.js" type="text/javascript"></script>
    </head>
    <body>
    <center>
        <h1>
            <?php echo "{$_GET['meter']} -  ".
```

```
mysql_result(mysql_query("select surname from ecg_customers where
meterno='{$_GET['meter']}'"), 0);?>
        </h1>
        <hr/>
        <table border="1" cellspacing="0" cellpadding="5"
width="80%">

            <thead><tr><th>Meter #</th><th>Meter
Reading</th><th>Date
Read</th><th>Unit(s)</th><th>Period(Month/Year)</th><th>Authorized</
th><th>Authorized date</th></tr>
            </thead>
            <tbody>
                <?php
                $res=  mysql_query("select * from readings where
meterno='{$_GET['meter']}'");
                while($row=  mysql_fetch_array($res)){
echo
"<tr><td>$row[1]</td><td>$row[2]</td><td>".date('d-m-
Y',strtotime($row[4]))."</td><td>$row[8]</td><td>$row[6]/$row[7]</td
><td>".($row[3]=="1"?"Yes":"No")."</td><td>".date('d-m-
Y',strtotime($row[5]))."</td></tr>";
                }
                ?>
            </tbody>
        </table>
            </center>

    </body>
</html>



<?php
include_once 'connection.php'; if (isset($_POST['run'])) {
switch ($_POST['run']) {         case "100":
mysql_query("update settings set val='{$_POST['rate']}' where
item='rate'");
            mysql_query("update settings set val='{$_POST['vat']}'
where item='vat'");             break;
    }
}
?>
<!DOCTYPE html>
<html>
    <head>
        <title>Smart Grid - PURC </title>
        <link  rel="stylesheet" href="css/doc.css"/>
        <script src="js/script.js" type="text/javascript"></script>
    </head>
    <body>
    <center>
        <h1>
```

```
            Smart Grid - PURC
        </h1>

        <hr/>
        <table border="1" cellspacing="0" cellpadding="5"
width="80%">


            <thead><tr><th>Meter
#</th><th>Surname</th><th>Phone</th><th></th></tr>
            </thead>
            <tbody>
                <?php
                $res = mysql_query("select * from ecg_customers");
while ($row = mysql_fetch_array($res))                    echo
"<tr><td>$row[0]</td><td>$row[1]</td><td>$row[2]</td><td><a
href='hist.php?meter=$row[0]'>History</a></td></tr>";
                ?>
            </tbody>
        </table>
        <br/><br/><br/>
        <form method="POST" action="index.php" onsubmit="return
false;">
            <input type="hidden" name="run" value="100"/>
            <h3>CURRENT CHARGES</h3>
            <table width="60%"><tr><td>
                        Rate(per unit) GHs:<br/><input name="rate"
style="text-align: right" type="text" value="<?php echo
mysql_result(mysql_query("select val from settings where
item='rate'"), 0); ?>"/>                    </td>
                    <td>VAT & NHIS (%):<br/><input type="text"
name="vat" value="<?php echo mysql_result(mysql_query("select val
from settings where item='vat'"), 0); ?>"/> </td>
                    <td>Allowable Threshold:<br/><input type="text"
name="thresh" value="<?php echo  mysql_result(mysql_query("select
val from settings where item='threshold'"),0);?>"/></td>
<td><br/><input type="submit" value="Save"
onclick="SaveSettings(this.form);"/></td> </tr></table>
        </form><br/><br/>
    </center>

</body>
</html>



<?php
switch ($_SERVER['HTTP_ORIGIN']) {
case 'http://localhost':
    header('Access-Control-Allow-Origin: '.$_SERVER['HTTP_ORIGIN']);
header('Access-Control-Allow-Methods:  GET,  PUT,  POST,  DELETE,
OPTIONS');
    header('Access-Control-Max-Age: 1000');
```

```
    header('Access-Control-Allow-Headers: Content-Type,
Authorization, X-Requested-With');
break; }
if (isset($_GET['code'])) {
include_once 'connection.php';
switch ($_GET['code']) {
case "PURC1":
            if (mysql_result(mysql_query("select count(*) from
readings where meterno='{$_GET['meter']}' and month={$_GET['month']}
and year={$_GET['year']}"), 0) == "0") {
                mysql_query("insert into readings
values(null,'{$_GET['meter']}',{$_GET['reading']},0,now(),null,{$_GE
T['month']},{$_GET['year']},{$_GET['units']})");
echo "1";
            } else if (mysql_result(mysql_query("select count(*)
from readings where meterno='{$_GET['meter']}' and
month={$_GET['month']} and year={$_GET['year']} and authorised=0"),
0) != "0") {
                mysql_query("update readings set
readings={$_GET['reading']},readingdate=now(),units={$_GET['units']}
where meterno='{$_GET['meter']}' and month={$_GET['month']} and
year={$_GET['year']}");                    echo "1";             } else
{ //refused                  echo "0";
            }
break;          case
"PURC2":
            $units = mysql_result(mysql_query("select units from
readings where meterno='{$_GET['meter']}' and year={$_GET['year']}
and month={$_GET['month']}"), 0);
            if (mysql_result(mysql_query("select Readings from
readings where meterno='{$_GET['meter']}' and year={$_GET['year']}
and month={$_GET['month']}"), 0) != $_GET['reading']) {
                $out = "Reading rejected";
            } else if ($units != $_GET['units']) {
                $out = "Units rejected";            }
else if (number_format($units *
mysql_result(mysql_query("select val from settings where
item='rate'"), 0), 2) != $_GET['amount']) {
$out = "Amount rejected";            } else if
(number_format($units * mysql_result(mysql_query("select
val from settings where item='rate'"), 0) +
                        (($units *
mysql_result(mysql_query("select val from settings where
item='rate'"), 0)) * (mysql_result(mysql_query("select val from
settings where item='vat'"), 0) / 100)), 2) != $_GET['tot']) {
                $out = "Total rejected";
            } else {
                $per=  sprintf("%u",(($_GET['avg']-
$units)/$_GET['avg'])*100);
if($per>=2){
                    $out="Rejected. Units out of allowable
threshold";
                }else{
                $out = "1";
```

```
                mysql_query("update readings set
authorised=1,authoriseddate=now() where meterno='{$_GET['meter']}'
and year={$_GET['year']} and month={$_GET['month']}");
                }
}             echo
$out;
break;
    }
}
?>
```



```
-- MySQL dump 10.13  Distrib 5.1.38, for Win32 (ia32)
--
-- Host: localhost    Database: smart_ecg
-- ------------------------------------------------------ --
Server version  5.1.38-community

/*!40101 SET @OLD_CHARACTER_SET_CLIENT=@@CHARACTER_SET_CLIENT */;
/*!40101 SET @OLD_CHARACTER_SET_RESULTS=@@CHARACTER_SET_RESULTS */;
/*!40101 SET @OLD_COLLATION_CONNECTION=@@COLLATION_CONNECTION */;
/*!40101 SET NAMES utf8 */;
/*!40103 SET @OLD_TIME_ZONE=@@TIME_ZONE */;
/*!40103 SET TIME_ZONE='+00:00' */;
/*!40014 SET @OLD_UNIQUE_CHECKS=@@UNIQUE_CHECKS, UNIQUE_CHECKS=0 */;
/*!40014 SET @OLD_FOREIGN_KEY_CHECKS=@@FOREIGN_KEY_CHECKS,
FOREIGN_KEY_CHECKS=0 */;
/*!40101 SET @OLD_SQL_MODE=@@SQL_MODE,
SQL_MODE='NO_AUTO_VALUE_ON_ZERO' */;
/*!40111 SET @OLD_SQL_NOTES=@@SQL_NOTES, SQL_NOTES=0 */;

--
-- Table structure for table `bills`
--

DROP TABLE IF EXISTS `bills`;
/*!40101 SET @saved_cs_client     = @@character_set_client */;
/*!40101 SET character_set_client = utf8 */;
CREATE TABLE `bills` (
  `ID` bigint(20) NOT NULL AUTO_INCREMENT,
  `MeterNo` varchar(20) DEFAULT NULL,
  `month` int(11) DEFAULT NULL,
`year` int(11) DEFAULT NULL,
  `units` int(11) DEFAULT NULL,
  `rate` double DEFAULT NULL,
  `vat` double DEFAULT NULL,
PRIMARY KEY (`ID`),
  KEY `MeterNo` (`MeterNo`),
  CONSTRAINT `bills_ibfk_1` FOREIGN KEY (`MeterNo`) REFERENCES
`customers` (`MeterNo`) ON DELETE CASCADE
) ENGINE=InnoDB DEFAULT CHARSET=latin1;
```

```
/*!40101 SET character_set_client = @saved_cs_client */;

--
-- Dumping data for table `bills`
--

LOCK TABLES `bills` WRITE;
/*!40000 ALTER TABLE `bills` DISABLE KEYS */;
/*!40000 ALTER TABLE `bills` ENABLE KEYS */;
UNLOCK TABLES;

--
-- Table structure for table `customers`
--

DROP TABLE IF EXISTS `customers`;
/*!40101 SET @saved_cs_client     = @@character_set_client */;
/*!40101 SET character_set_client = utf8 */;
CREATE TABLE `customers` (
  `MeterNo` varchar(25) NOT NULL,
  `surname` varchar(100) NOT NULL,
  `othernames` varchar(255) DEFAULT NULL,
  `address` varchar(255) DEFAULT NULL,
  `phone` varchar(25) DEFAULT NULL,
  PRIMARY KEY (`MeterNo`)
) ENGINE=InnoDB DEFAULT CHARSET=latin1;
/*!40101 SET character_set_client = @saved_cs_client */;

--
-- Dumping data for table `customers`
--

LOCK TABLES `customers` WRITE;
/*!40000 ALTER TABLE `customers` DISABLE KEYS */;
INSERT INTO `customers` VALUES ('A2015100B1','Ansah','Eric','HNO
T10B, Tanoso','02512121212'),('A2015100B2','Appiah','Diana','HNO
T92C, Tanoso','0253333333'),('A2015100B3','Djan','Patrick','HNO
T46A, Tanoso','025414142424'),('A2015100B4','Oduro','Florence
Yaa','HNO T28B,
Tanoso','02538383842'),('A2015100B5','Amankwah','Vicent','HNO T32A,
Tanoso','0251414248789');
/*!40000 ALTER TABLE `customers` ENABLE KEYS */;
UNLOCK TABLES;

--
-- Table structure for table `readings`
--

DROP TABLE IF EXISTS `readings`;
/*!40101 SET @saved_cs_client     = @@character_set_client */;
/*!40101 SET character_set_client = utf8 */;
CREATE TABLE `readings` (
```

```
  `ID` bigint(20) NOT NULL AUTO_INCREMENT,
  `MeterNo` varchar(25) DEFAULT NULL,
  `RDate` date DEFAULT NULL,
  `Reading` bigint(20) DEFAULT NULL,
  `authorised` int(11) DEFAULT '0',
  `month` int(11) DEFAULT NULL,
`year` int(11) DEFAULT NULL,
  `units` int(11) DEFAULT NULL,
  PRIMARY KEY (`ID`),
  KEY `MeterNo` (`MeterNo`),
  CONSTRAINT `readings_ibfk_1` FOREIGN KEY (`MeterNo`) REFERENCES
`customers` (`MeterNo`)
) ENGINE=InnoDB DEFAULT CHARSET=latin1;
/*!40101 SET character_set_client = @saved_cs_client */;

--
-- Dumping data for table `readings`
--

LOCK TABLES `readings` WRITE;
/*!40000 ALTER TABLE `readings` DISABLE KEYS */;
/*!40000 ALTER TABLE `readings` ENABLE KEYS */;
UNLOCK TABLES;

--
-- Table structure for table `settings`
--

DROP TABLE IF EXISTS `settings`;
/*!40101 SET @saved_cs_client     = @@character_set_client */;
/*!40101 SET character_set_client = utf8 */;
CREATE TABLE `settings` (
  `item` varchar(20) NOT NULL,
  `val` varchar(255) NOT NULL,
  PRIMARY KEY (`item`)
) ENGINE=InnoDB DEFAULT CHARSET=latin1;
/*!40101 SET character_set_client = @saved_cs_client */;

--
-- Dumping data for table `settings`
--

LOCK TABLES `settings` WRITE;
/*!40000 ALTER TABLE `settings` DISABLE KEYS */;
INSERT INTO `settings` VALUES ('rate','0.25'),('vat','5');
/*!40000 ALTER TABLE `settings` ENABLE KEYS */;
UNLOCK TABLES;
/*!40103 SET TIME_ZONE=@OLD_TIME_ZONE */;

/*!40101 SET SQL_MODE=@OLD_SQL_MODE */;
/*!40014 SET FOREIGN_KEY_CHECKS=@OLD_FOREIGN_KEY_CHECKS */;
/*!40014 SET UNIQUE_CHECKS=@OLD_UNIQUE_CHECKS */;
```

```
/*!40101 SET CHARACTER_SET_CLIENT=@OLD_CHARACTER_SET_CLIENT */;
/*!40101 SET CHARACTER_SET_RESULTS=@OLD_CHARACTER_SET_RESULTS */;
/*!40101 SET COLLATION_CONNECTION=@OLD_COLLATION_CONNECTION */;
/*!40111 SET SQL_NOTES=@OLD_SQL_NOTES */;

-- Dump completed on 2015-04-07 11:07:32

-- MySQL dump 10.13  Distrib 5.1.38, for Win32 (ia32)
--
-- Host: localhost    Database: smart_purc
-- ------------------------------------------------------ --
Server version  5.1.38-community
/*!40101 SET @OLD_CHARACTER_SET_CLIENT=@@CHARACTER_SET_CLIENT */;
/*!40101 SET @OLD_CHARACTER_SET_RESULTS=@@CHARACTER_SET_RESULTS */;
/*!40101 SET @OLD_COLLATION_CONNECTION=@@COLLATION_CONNECTION */;
/*!40101 SET NAMES utf8 */;
/*!40103 SET @OLD_TIME_ZONE=@@TIME_ZONE */;
/*!40103 SET TIME_ZONE='+00:00' */;
/*!40014 SET @OLD_UNIQUE_CHECKS=@@UNIQUE_CHECKS, UNIQUE_CHECKS=0 */;
/*!40014 SET @OLD_FOREIGN_KEY_CHECKS=@@FOREIGN_KEY_CHECKS,
FOREIGN_KEY_CHECKS=0 */;
/*!40101 SET @OLD_SQL_MODE=@@SQL_MODE,
SQL_MODE='NO_AUTO_VALUE_ON_ZERO' */;
/*!40111 SET @OLD_SQL_NOTES=@@SQL_NOTES, SQL_NOTES=0 */;

--
-- Table structure for table `ecg_customers`
--

DROP TABLE IF EXISTS `ecg_customers`;
/*!40101 SET @saved_cs_client     = @@character_set_client */;
/*!40101 SET character_set_client = utf8 */;
CREATE TABLE `ecg_customers` (
  `MeterNo` varchar(25) NOT NULL,
  `surname` varchar(100) DEFAULT NULL,
  `phone` varchar(25) DEFAULT NULL,
  PRIMARY KEY (`MeterNo`)
) ENGINE=InnoDB DEFAULT CHARSET=latin1;
/*!40101 SET character_set_client = @saved_cs_client */;

--
-- Dumping data for table `ecg_customers`
--

LOCK TABLES `ecg_customers` WRITE;
/*!40000 ALTER TABLE `ecg_customers` DISABLE KEYS */;
INSERT INTO `ecg_customers` VALUES
('A2015100B1','Ansah','02512121212'),('A2015100B2','Appaih','0253333
333'),('A2015100B3','Djan','02541414142424'),('A2015100B4','Oduro','
02538383842'),('A2015100B5','Amankwah','0251414248789');
/*!40000 ALTER TABLE `ecg_customers` ENABLE KEYS */; UNLOCK
TABLES;
```

```
--
-- Table structure for table `readings`
--

DROP TABLE IF EXISTS `readings`;
/*!40101 SET @saved_cs_client     = @@character_set_client */;
/*!40101 SET character_set_client = utf8 */;
CREATE TABLE `readings` (
  `ID` bigint(20) NOT NULL AUTO_INCREMENT,
  `MeterNo` varchar(25) DEFAULT NULL,
  `Readings` bigint(20) DEFAULT NULL,
  `authorised` int(11) DEFAULT '0',
  `ReadingDate` date DEFAULT NULL,
  `AuthorisedDate` date DEFAULT NULL,
  `Month` int(11) DEFAULT NULL,
`Year` int(11) DEFAULT NULL,
  `units` int(11) DEFAULT NULL,
  PRIMARY KEY (`ID`),
  KEY `MeterNo` (`MeterNo`),
  CONSTRAINT `readings_ibfk_1` FOREIGN KEY (`MeterNo`) REFERENCES
`ecg_customers` (`MeterNo`)
) ENGINE=InnoDB DEFAULT CHARSET=latin1;
/*!40101 SET character_set_client = @saved_cs_client */;

--
-- Dumping data for table `readings`
--

LOCK TABLES `readings` WRITE;
/*!40000 ALTER TABLE `readings` DISABLE KEYS */;
/*!40000 ALTER TABLE `readings` ENABLE KEYS */;
UNLOCK TABLES;

--
-- Table structure for table `settings`
--

DROP TABLE IF EXISTS `settings`;
/*!40101 SET @saved_cs_client     = @@character_set_client */;
/*!40101 SET character_set_client = utf8 */;
CREATE TABLE `settings` (
  `item` varchar(20) NOT NULL,
  `val` varchar(255) NOT NULL,
  PRIMARY KEY (`item`)
) ENGINE=InnoDB DEFAULT CHARSET=latin1;
/*!40101 SET character_set_client = @saved_cs_client */;

--
-- Dumping data for table `settings`
--
```

```
LOCK TABLES `settings` WRITE;
/*!40000 ALTER TABLE `settings` DISABLE KEYS */;
INSERT INTO `settings` VALUES ('rate','0.25'),('vat','5');
/*!40000 ALTER TABLE `settings` ENABLE KEYS */;
UNLOCK TABLES;
/*!40103 SET TIME_ZONE=@OLD_TIME_ZONE */;

/*!40101 SET SQL_MODE=@OLD_SQL_MODE */;
/*!40014 SET FOREIGN_KEY_CHECKS=@OLD_FOREIGN_KEY_CHECKS */;
/*!40014 SET UNIQUE_CHECKS=@OLD_UNIQUE_CHECKS */;
/*!40101 SET CHARACTER_SET_CLIENT=@OLD_CHARACTER_SET_CLIENT */;
/*!40101 SET CHARACTER_SET_RESULTS=@OLD_CHARACTER_SET_RESULTS */;
/*!40101 SET COLLATION_CONNECTION=@OLD_COLLATION_CONNECTION */;
/*!40111 SET SQL_NOTES=@OLD_SQL_NOTES */;

--
```