INVESTIGATING THE VALUE PROPOSITION OF ADVANCED METERING INFRASTRUCTURE IN DEVELOPED AND EMERGING ECONOMIES WITH A FOCUS ON SOUTH AFRICA

Hinesh Madhoo

A dissertation submitted to the Faculty of Engineering and the Built Environment, of the University of the Witwatersrand, in fulfilment of the requirements for the degree of Master of Science in Engineering.

Johannesburg 2014

DECLARATION

I declare that this dissertation is my own unaided work. It is being submitted to the Degree of Master of Science in Engineering to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

____

H Madhoo (530406)

Signed this ___ day of ____________ year ________

ABSTRACT

South Africa's power utility, Eskom Holdings SOC Limited, is currently working towards implementing aspects of a Smart Grid with the initial introduction of an Advanced Metering Infrastructure (AMI), similar to utilities internationally. The primary reasons for transitioning towards a Smart Grid could be attributed to the challenges of unprecedented capacity constraints experienced on the power networks in 2008, continually increasing demand, aging infrastructure and the need for improved asset management.

The global definition of a Smart Grid may however vary for utilities around the world; and can be defined as embedded intelligence through hardware infrastructure built into the existing electrical network to provide visibility, automatic control and intelligent decision making over the entire electrical architecture from generation to the end user with the aim of increasing efficiency, improving reliability and enhancing decision making.

AMI provides the foundation for any utility's vision towards a Smart Grid, as it promotes the direct interaction between a specific customer and the utility. An AMI system is a hardware infrastructure which provides the customer the ability to either pay more for electricity in known peak demand periods or communicates the actual grid demand in real-time to customers so the electricity price increases proportionally with the demand on the grid. This then influences the customer to either manually move electric loads to lower demand periods or implement automated systems that has the ability to make use of electricity according to their preferences. All of this ensures that electricity is used at the lowest possible cost to the customer and that the grid adapts to its constraints at that point in time. AMI incorporates functionality such as time-of-use tariffs, automated meter reading, remote connect or disconnect, bi-directional communication infrastructure, integration with utility backend systems for improved customer care and, has the ability to improve existing operations and maintenance processes.

This research focuses on a comparative analysis of the value propositions of AMI in developed and emerging countries, analysing market driving forces and the challenges associated with AMI deployment. The research will also provide for a case study to evaluate Eskom's AMI deployment and the customer's reaction and acceptance to the technology, such as behavioural changes, changes in energy usage and relationship with the utility. A qualitative and quantitative analysis of the case study questionnaire responses will be reviewed to determine customer perceptions, behavioural changes, comparative consumption patterns for the traditional conventional meter to that of the AMI smart meter, and the acceptance of the AMI solution in an emerging economy focusing on South Africa.

ACKOWLEDGEMENTS

All praise and glory to God for the guidance, talents, mental ability and opportunity given to me to be able to complete this study

I wish to express my sincere gratitude to the following persons for the roles played in making this study possible:

- ✓ The accomplishment of this study is owed to my loving parents Mr Visu Madhoo and Mrs Ramila Madhoo for all the support and encouragement they have given to me throughout the years.
- ✓ To my colleague, Mr Kennedy Subramoney (AMI Programme Manager, Eskom Holdings SOC Limited) for the mentorship, career guidance, technical quality assurance and motivation in completing my dissertation.
- ✓ To my manager, Mrs Ronel Clarke (Centre of Excellence Manager – Demand Management) for allowing me the opportunity to further my studies, the support and motivation given to me throughout the period of my studies.
- ✓ The success and acceptance of the result is due to the guidance and co-operation of my supervisor, Professor Willie Cronje (University of Witwatersrand – School of Electrical Engineering), for steering me in the correct direction and the assistance provided through this period of my studies.
- ✓ To my colleagues from the Eskom Advanced Metering Infrastructure project team and Eskom Research, Testing and Development for their contribution and continued support in providing their professional advice and consulting where necessary.

I would also like to acknowledge and extend my appreciation to my employer, Eskom Holdings SOC Limited for allowing me the opportunity to register and complete the Master of Science in Engineering programme (EMR000 – ELEN8000) through the Faculty of Engineering and the Built Environment with the University of Witwatersrand.

The University of Witwatersrand, for allowing me the opportunity to present my research in the form of two discussion papers at the International Symposiums for High Voltage, held in Hannover Germany during 2011 and Seoul South Korea in 2013.

"Tamaso Mā Jyotir Gamaya"
From darkness, lead me to light!

H. Madhoo

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ACD	Appliance Control Device
AMI	Advanced Metering Infrastructure
AMR	Automated Meter Reading
ANSI	American National Standards Institute
CC&B	Customer Care and Billing
CIM	Common Information Model
CIU	Customer Interface Unit
COSEM	Companion Specification for Energy Metering
DC	Data Concentrator
DLMS	Device Language Message Specification
DMS	Distribution Management System
DR	Demand Response
DSM	Demand Side Management
EE	Energy Efficiency
EMS	Energy Management System
EPRI	Electric Power Research Institute
ESLC	Electricity Suppliers Liaison Committee
GPRS	General Packet Radio Service
HAN	Home Area Network
HV	High Voltage
IEC	International Electro-technical Commission
IHD	In-Home Display
LAN	Local Area Network
LSM	Living Standard Measurement
LV	Low Voltage
MDMS	Meter Data Management System
MVIL	Multi-Vendor Integration Layer
NERSA	National Energy Regulator of South Africa
NRS	National Rationalized Specification
PG&E	Pacific Gas & Electric
PLC	Power Line Communication
RF	Radio Frequency
SABS	South African Bureau of Standards
SCADA	Supervisory Control and Data Acquisition
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric
SMS	Short Message Services
SOC	State Owned Company
ToU	Time-of-Use
WAN	Wide Area Network
Wi-Fi	Wireless Fidelity
Wi-MAX	Worldwide Interoperability for Microwave Access
XML	Extensible Mark-up Language

CHAPTER 1: INTRODUCTION TO THE DISSERTATION

1.1 BACKGROUND

Internationally, utilities are seeking different approaches to align electricity demand with electricity supply and to promote energy efficiency to their end users. There are many energy sources such as electricity, gas, water, heat etc., however, for this study only electricity as a source of energy provided by the utility to the end user will be considered and discussed. Electricity price signal is one of the mechanisms used by utilities to encourage efficient use of electricity. This involves charging different energy rates during different time periods and seasons in order to more accurately reflect the shape of the utilities long-run marginal energy cost of supply at different times. This also results in a more balanced load profile i.e. flatter peaks, which contributes to the delayed construction of additional power generation or the purchase of energy from higher priced electricity sources such as gas turbines [1].

In many developing countries, electricity markets have been deeply reformed, aiming at introducing market principles to increase efficiency and benefit customers directly via low energy prices. These markets are facing new challenges mainly driven by a rapid increase in energy consumption and a not-so-fast system capacity expansion, with customers fearing energy curtailment [2].

The electromechanical and electronic meters as shown in Figure 1 are referred to as traditional conventional electricity meters in this study. These meters cannot support Time-of-Use (ToU) tariffs as they only measure total consumption and provide no information about when the electricity is consumed. To enable such functionality utilities have begun implementing an Advanced Metering Infrastructure (AMI), also commonly known as smart metering, where the smart meter records the readings either in different registers based on date and time or 30 minute profile readings with a timestamp, and remote communications.

AMI can be defined as a system that is integrated of smart meters, communication networks and data management systems which enables bi-directional communication between the utility and the end user. AMI uses electronic meters and supporting devices as opposed to a single register conventional meter.

The arrival of solid state meters (electronic meters) has meant a major breakthrough in terms of measurement technology, replacing the old system (electromechanical meters) for electronic components. This has greatly improved the accuracy, reliability and size of these devices, which can also measure – without major additional costs – a greater number of variables, such as reactive power, power factor, harmonic currents and maximum power, among others [2].

Figure 1 illustrates the global evolution of electricity metering as discussed above.

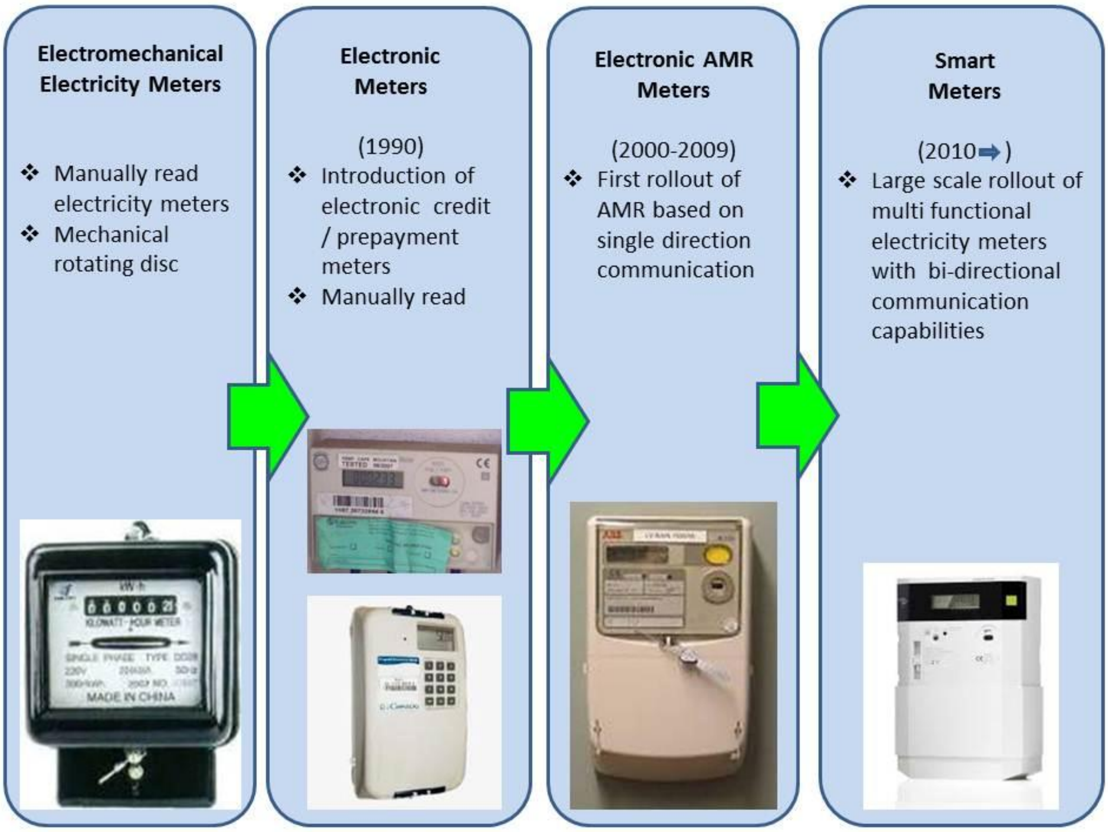


Figure 1: The evolution of electricity metering

This research study investigates the value proposition of AMI in emerging economies focusing on South Africa. The differences between emerging economies and developed economies in this regard, will be highlighted throughout.

The term value proposition varies within the financial sector and can be defined in three parts consisting of all benefits customers receive from a market offering, all favourable points of difference a market offering will have relative to the next best offering and resonating focus on whose improvement will deliver the best value to the customer in the future [4]. The value proposition for this study can be defined as the ability of an organisation, in this case the power utility, to deliver the benefits, cost savings and value of the AMI technology, promised to its customers and prospective customers. The value proposition of AMI in terms of benefit realisation to both the utility and end user can be expected to achieve the following [5]:

- ✓ Yield invaluable information to help improve operational costs, business efficiency, and end customer services through automated meter management
- ✓ Reduce the number of internal business process requirements and the costs thereof, thereby increasing operational efficiency
- ✓ Allows for large scale AMI rollouts and continued benefits of the technology
- ✓ Data from the smart meter can be streamlined for meter-to-cash to allow for effective decision making, improved grid operations, enterprise level processes used for planning and customer services

An emerging economy is classified according to the World Bank by the gross national income (GNI) per capita based on low, middle or high income, and can be defined as, influenced by financial criteria, a nation with social or business activity in the process of advancement, rapid growth and industrialisation [6],[7]. These include the BRIC countries i.e. Brazil, Russia, India and China and MIKT i.e. Mexico, Indonesia, South Korea and Turkey [7]. South Africa is also amongst the Big Emerging Markets (BEM) economies [7].

A developed economy can be defined as a country most developed in terms of its economy and capital markets having high incomes as measured by the World Bank, includes openness to foreign ownership, ease of capital movement and efficiency of market institutions [8]. Developed economies include countries such as the United States, Western Europe, Japan, Canada, Singapore, Hong Kong and Australia [8].

1.2 THE HYPOTHESIS

The value proposition of implementing an AMI solution exists in an emerging economy and justifies the significant investment for such a solution.

The implementation of an AMI solution would improve the end user’s perception around energy consumption, increasing efficiency and the value added from the AMI technology.

1.3 THE RESEARCH OBJECTIVES

AMI related projects have worked well in developed economies such as the United States and Europe, with the environmental objective of reducing their carbon footprint. In developing economies such as South Africa, the value propositions in addition to environmental factors is vastly different and is based on managing increasing demand for electricity, significant costs for upgrading the existing aging infrastructure and building of new capacity.
The South African power utility, Eskom, will be considered as the focal point for this study and is discussed in detail in Chapter 4.

The aim of this research can be achieved and validated by pursuing the following objectives:

- ✓ Study and research the international developments on adopting AMI with a focus on utility market driving forces, utility and customer challenges, lessons learnt and benefits of AMI deployment;
- ✓ Study and research AMI deployment in an emerging economy with a focus on the Eskom;
- ✓ Conduct a case study to evaluate Eskom’s AMI deployment and the customers’ reaction to the technology such as behaviour changes, energy usage and relationship with the utility.

1.4 THE SCOPE OF THE RESEARCH

The research work is expected to be conducted from 2011 to 2013. The research study will comprise of three parts as described below:

Table 1: Scope of the research

Part 1	Literature Review
	➢ Chapter 2: Market driving forces for AMI deployment. ➢ Chapter 3: Utility and customer challenges and lessons learnt. ➢ Chapter 4: AMI deployment in and emerging economy with a focus on the South African power utility, Eskom.
Part 2	Case Study: AMI Deployment in South Africa
	➢ Chapter 5: Case study survey to evaluate Eskom's AMI deployment and the customers' acceptance to the technology. ➢ Chapter 6: Analysis and discussion of case study results. This component will be discussed in two sections: ✓ Section 1: Qualitative analysis of the pilot groups' perceptions on AMI ✓ Section 2: Quantitative analysis of energy usage of the pilot group
Part 3	Compiling of the Research Dissertation
	➢ Chapter 7: Conclusions, recommendations and future work

1.5 RELATED RESEARCH

A literature review of related research projects was conducted. The following research documents were sourced:

- ✓ Assessment of the introduction of smart metering in a developing country, an IEEE paper published in 2009 by Ramila P and Rudnick H. [2]
- ✓ A synergistic approach to implement demand response, asset management and service reliability using smart metering, AMI and MDM systems, an IEEE paper published in 2009 by Mak S.T. [9]
- ✓ A synergistic approach to using AMR and intelligent electronic devices to determine outages in a distribution network, an IEEE Paper by Mak S.T. [10]
- ✓ Advanced Metering Infrastructure for Smart Grid applications, an IEEE paper published in 2012 by Chenthamarai S and Khota S. [11]
- ✓ Functional analysis of Advanced Metering Infrastructure in Smart Grid, an IEEE paper published in 2010 by Xiao-min B and Ning-hui Z. [12]

A search within the international industry reveals volumes of conferences and presentations on the areas relating to AMI deployment.

Although literature and published work are to be used as the basis of this research, the following experts and utilities were also consulted during the duration of the research study:

- ✓ San Diego Gas and Electric (Californian Power Utility) [13]
- ✓ Pacific Gas and Electric (Californian Power Utility) [14]
- ✓ Eskom’s AMI project team

The above mentioned literature and discussions held with the respective utilities are referenced in the dissertation.

CHAPTER 2: MARKET DRIVING FORCES FOR AMI DEPLOYMENT

This chapter focuses on a literature review of market driving forces; in order to provide the basis for the investigation of the value proposition for AMI deployment in developed and emerging economies. A comparison will be drawn to highlight these driving forces from a governmental and utility perspective to introduce AMI solutions. This section also analyses North America (United States and Canada) and Europe as developed economies; and South Africa as an emerging economy.

2.1 INTRODUCTION

The value proposition for smart metering or AMI varies according to the maturity and focus of the energy market in which it is deployed [15].

The deployment of AMI may result in many benefits being realised not only to the utility but to the customer as well. Table 2 lists some of these benefits.

Table 2: Benefits of AMI

Customer Benefits	
More energy usage information	The new "smart" meters communicate personalised energy use information to customers through a customer interface unit or in-home device or multiple other customer communication channels, such as on the Web, cell phone applications and SMS. This personalised communication helps customers make smarter energy decisions that could translate into savings. Customers are more inclined to conserve more electricity when they know exactly how much energy is being consumed and the amount of money being spent.
Pricing plans that work for the customer	"Smarter" meters bring "smarter" pricing plans or tariffs that give customers more choices based on lifestyle and convenience. For example, customers are able to select tariffs that allow them to save money on energy use during off-peak hours.
Peak energy alerts	The advanced communications system alerts customers to periods of peak pricing and grid emergencies by sending a message directly to a cell phone, computer or other in-home display(s).
Convenience when customer moves or goes away for prolonged periods; i.e. overseas or holiday	Customers have the convenience of remote service turn-ons. If a customer is moving, for example, they no longer need to leave gates open, worry about pets, or wait for a field service representative.

Keeping the lights on	Information provided by the new "smart" meters informs the utility smart grid operators when an outage occurs and how extensive it is, enabling a faster response for quicker service restoration.
ENVIRONMENTAL BENEFITS	
Reducing peak electricity demand	The new smart metering system sends peak energy and pricing alerts directly to a customer's cell phone, computer or other in-home display, and "smart" homes programmed to respond to these alerts and reduce overall peak demand.
Sustained conservation	With more energy use information, customers can make smarter energy choices. This is expected to result in sustained energy conservation, reducing the emission of greenhouse gases and pollutants.

Internationally, utilities have undertaken significant work with respect to enhancing power grid intelligence using smart meters capabilities to also act as power grid sensors. Utilities deploying smart meters to act as sensors on the power grid to achieve LV intelligence could realise some of the benefits mentioned in Table 3 [2], [9], [46] and [11].

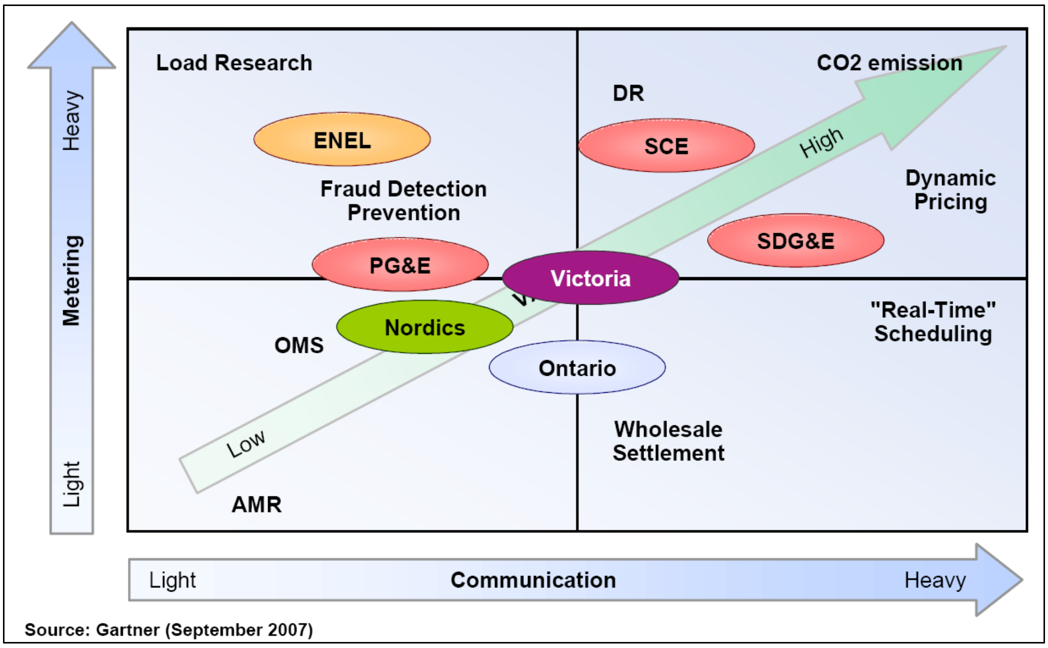
Table 3: Grid intelligence through smart meters acting a smart grid sensor

Power quality monitoring	Power quality is determined by monitoring the dips in voltage and is measured to assist with obtaining the voltage dip charts.
Voltage regulation	The meter records the voltage performance every 30 minutes. Voltage readings are used to monitor the voltage dips on each phase.
Outage reporting	AMI meters are able to recognise losses of power to the customers' premises. At the end of a set period, a manual reporting process informs the utility in retrospect of outages that have occurred on the meters.
Remote disconnect or reconnect	In the event that a customer has defaulted to non-payment, the meter remotely disconnects or remotely reconnects when the customer has settled his account. This action is executed on the vendor master station. Also assists in identifying customers moving in or out of a premise.
Reduce, monitor, and identify non-technical losses	Identify customers not on the billing system. Perform energy balancing at a mini-substation level by balancing energy delivered versus energy consumed at the meter level. Identify tampers and bypasses at the meters in the field i.e. removal of the meter terminal cover will flag as a tamper. Imbalance in currents will create alarms whereby a supply has been tapped prior to the meter (i.e. the customer consuming electricity illegally).

Literature indicates that the application of smart meters as sensors require the efficient and effective collection of data, storage thereof and ease of access by applicable stakeholders in order to realise the anticipated benefits [9],[46].

In the North American market, the focus is on peak reduction (particularly in California following the energy crisis in 2001), as well as operational cost reduction and asset optimisation [15]. In Europe, the main driver is energy efficiency and CO_2 reduction, whereas in Asia or Pacific countries the focus is on reducing the cost of customer service and meeting the metering requirements of the competitive retail and wholesale markets.

As a result, the AMI solutions considered in the different markets, the AMI solutions require different levels of smart meter functionality and communication complexity, as represented in Figure 2.



DR = Demand Response; OMS = Outage Management Systems

Figure 2: AMI Value proposition in different energy markets [15]

Figure 2 depicts the AMI value offerings and are portrayed in the above quadrants (e.g. OMS – Outage Management Systems, AMR – Automated Meter Reading, Real-time Scheduling etc.), while the most prominent AMI implementations (e.g. Enel – Italy, PG&E, SCE, SDGE – California, Hydro One Ontario – Canada, Victoria – Australia) are placed based on the expected benefits of AMI. Furthermore, the figure also highlights that the different benefits have different metering and communication technology requirements. This suggests for instance that pursuing an unnecessary complex combination of benefits could require investment in multiple technologies whereas the utility can focus on one or two benefits and spend less on implementing AMI. Another risk is that being an early entrant in the market could result in technology lock-in.

There is a direct relationship between the value proposition of AMI in a particular market and the functional requirements of smart meters. These relationships were assessed in the electricity markets in North America, Europe, the UK and Australia and are summarised below. The relationship between South African market drivers and Eskom's requirements for smart meters are also discussed.

2.2 MARKET DRIVERS - AMI IN DEVELOPED ECONOMIES

Smart Metering In North America (U.S. and Canada)
North American AMI Trends

Chartwell's 2007 AMR research report [16], based on a survey of 111 North American utilities, reports the growth of electricity smart meters to be as presented in Figure 3.

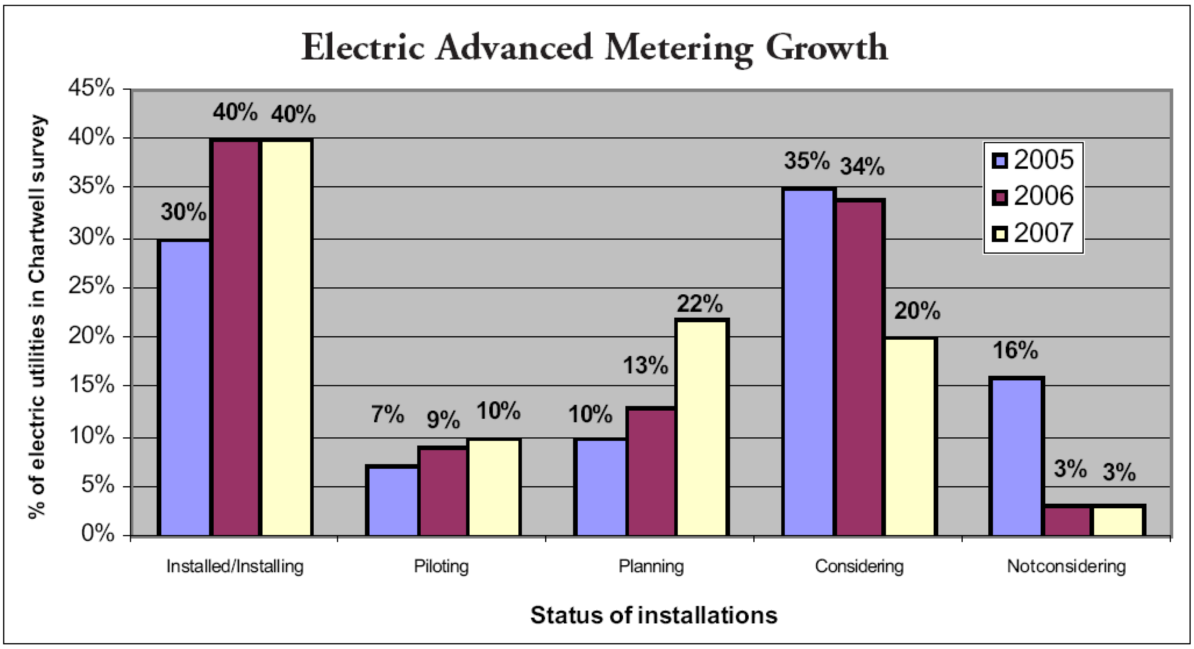


Figure 3: AMI growth in North America

Figure 3 indicates that 40% of electricity utilities have installed or are installing smart meters. Fifty-two percent of utilities are planning, considering or piloting advanced metering systems, while only 3% stated that they are not interested in advanced metering at the present time.

One of the main drivers for the increasing interest in smart metering is the Energy Policy Act of 2005 which sets various timelines and plans for smart metering and demand response in the U.S. This has effectively removed a lot of regulatory uncertainty, which was previously one of the main reasons why utilities had been reluctant to invest in smart metering systems.
Section 1252 of the Act states that: utilities should offer customers a time-based rate schedule (including ToU, critical peak pricing, credits for interruptible load etc.) [17]. It also requires utilities to provide smart meters, which can support these tariffs, to customers.

In terms of smart metering functions, Chartwell reports the following as shown in Figure 4 [16]:

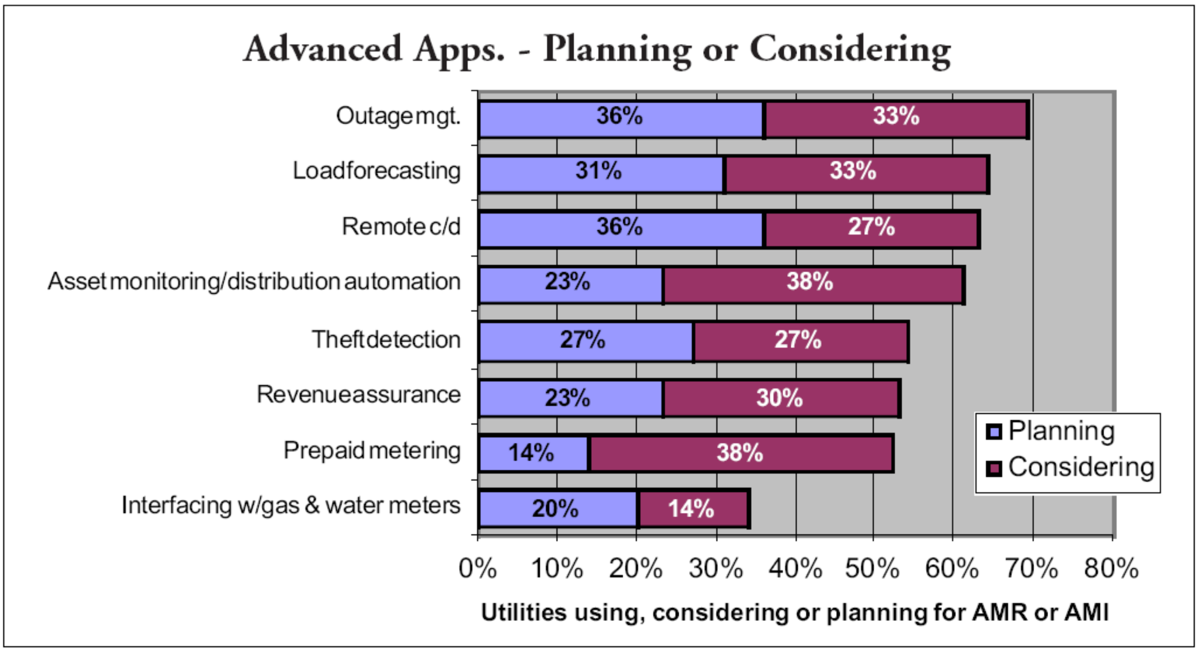


Figure 4: Smart metering functions used or considered by North American utilities

Outage management is regarded as one of the main benefits of AMI, because controlling or preventing outages typically translate to large revenue and labour savings as well as improved customer service. Load forecasting is also rated high, as it aids utilities in making the right decisions with regards to buying and generating power and correctly managing existing infrastructure.

Utilities that have implemented smart meters or are considering and planning to do so, have recognised that smart metering not only ensures regulatory (Energy Policy Act) compliance, but that it can also assist in improving overall utility efficiency in a competitive market.

Nonetheless, the following are main obstacles to the implementation of smart meters:

- ✓ Loss of revenue as a result of customer load reduction
- ✓ Lack of open communication standards, and prevalence of proprietary systems
- ✓ Regulatory uncertainty and the risk of stranded assets should influence policy change
- ✓ Rapidly changing telecommunications technology that could result in technology and protocols being outdated very quickly.

Smart Metering in California

The California energy crisis in 2001 triggered an order by the California Public Utilities Commission (CPUC) that electric utilities must develop programs to reduce energy peaks through "price-responsive" load. In 2002 the CPUC and California Energy Commission (CEC) concluded that this could best be achieved through the installation of AMI systems. In 2005 the CEC conceived OpenAMI – an industry organisation with the purpose to develop an AMI reference design [18]. However, despite these initiatives no specific timeline was set for AMI implementation in California [15].

In California AMI applications have been divided in utility functions and customer benefits as summarised in Table 4.

Table 4: Main AMI functions identified in California

Utility functions	Customer benefits
Automated meter reading (AMR)	Customer rate choice
Outage detection	Customised billing information
Theft detection	Energy consumption information
Load survey	Dynamic tariffs
Customer load profiles	Enhanced billing

As part of the drive to reduce peak demand, the CEC piloted various ToU rates and critical peak pricing for residential and small commercial customers during 2003. From the pilots they determined that [19]:

- ✓ Customers respond to pricing signals even without automatic load management;
- ✓ The customer response and expected savings is greater with automatic load management than without;
- ✓ The combination of ToU and automatic load management resulted in the largest savings;
- ✓ Savings of up to 10% were achieved on specific days.

To meet the CPUC and CEC requirements, California's three largest Independently Owned Utilities (IOUs): Pacific Gas & Electric (PG&E), Southern California Edison (SCE) and San Diego Gas & Electric (SDG&E) developed the following smart metering strategies:

- ✓ SDG&E have decided to only perform a rollout of smart meters with the goal to reduce 75 hours a year of high peak demand.
- ✓ PG&E prefers a full deployment of smart meters to 8.8 million customers over a 5-year period using multiple vendors and technologies. (Total cost $1 billion)
- ✓ SCE concluded that existing commercial smart meter solutions are inadequate and subsequently embarked on a programme to develop a new smart meter that could meet their exact requirements.

Reasons for the different approaches, even though the market drivers are the same, have been attributed to cost-benefit analyses, labour relations and risk of reducing the number of meter readers, impact on utility revenue etc. The three utilities submitted their cost-benefit analyses and business cases to the California Public Utilities Commission in 2005 [19]. All three are working towards the installation of advanced meters in the near future [16].

Table 5 summaries AMI deployment's at the top 5 utilities in the United States of America (USA).

Table 5: AMI deployment in the top 5 utilities in USA [20]

Top 5 Utilities	Total number of AMI meters installed	AMI vendor	Deployment details
Southern California Edison	5.3 million	ITRON	Started in 2008 and expected to complete in 2012.
Pacific Gas & Electric	5.1 million	GE, Landis & Gyr, Silver Spring Networks	Started in 2008 and expected to complete in 2012.
Southern Company	4.4 million	Sensus	Began its 3 year deployment in 2008. In February 2009 - 1 million meters were installed.
AEP	5 million	IBM, Landis & Gyr, GE	Plan to deploy 11 state service areas by 2015.
ONCOR	3 million	Landis & Gyr	Began in May 2008 and expected to complete by 2012.

Smart Metering in Canada

In 2004 the Minister of Ontario ordered the Ontario Energy Board to develop a plan to install 800 000 smart meters by end 2007, and the installation of smart meters to all 4.3 million customers by 2010. Reducing peak demand has been the main focus, and it has been estimated that smart meters could reduce peak demand by 5% or 1250MW by 2007, as well as provide additional, less quantifiable benefits such as reducing pollution.

Smart meter requirements included support for ToU tariffs and critical peak pricing, remote reading capability, and the ability to provide feedback to consumers regarding their consumption. Ontario will implement smart meters in conjunction with a regulated ToU price plan. Ontario's installation is regarded as the first full-scale smart meter system in North America [17].

Table 6 summarises market driving forces and deployments in North America and Canada [21].

Table 6: Market driving forces and deployments in North America and Canada

Drivers	• Demand management • Market deregulation • Operational efficiency • Energy efficiency
Market	• North America has the largest installed base of smart meters in the world • More than 65 million contracted end points in the US and Canada (2008 to 2015) • Multi-energy (electricity, water and gas)

Smart Metering In Western Europe

Despite a significant pioneering deployment by Enel in Italy and several other contract announcements in 2006, Europe has traditionally lacked regulatory-driven demand response initiatives. Table 7 summarises the smart meter deployment in Europe.

Table 7: Smart meter deployments in Europe [22], [23]

Country	Number of smart meters	2007	2008	2009
Scandinavia (Sweden, Finland, Denmark)	500 000	Pilot / Evaluation / Rollout	Rollout	Rollout
Italy	21 million	Rollout	Rollout	Rollout
Spain	570 000	Pilot	Rollout	Rollout
Netherlands	240 000	Pilot	Rollout	Rollout
UK	41 000	Evaluation	Pilot	Rollout
Germany	125 000	Evaluation	Pilot	Rollout
France	300 000	Evaluation	Pilot	Rollout

The main drivers for smart metering in Europe were based on the following [21]:

- ✓ The Energy Services Directives (2006/32/EC, ESD)
  - Article 13(1) of the ESD demands that member states ensure that final customers are provided with competitively priced individual meters that accurately reflect consumption and provide information on the actual time of use.
  - The goal of this Directive and the objective of introducing individual meters and frequent bills are to ultimately save energy.
- ✓ Third Energy Package and particularly Directive 2009/72/EC.
  - This Directive demands in Art. 3(11), in order to promote energy efficiency, Member States or regulatory authorities shall strongly recommend that electricity undertakings optimise the use of electricity by, for example, introducing intelligent metering systems or smart grids.

- ✓ The Energy Performance of Buildings directive (2010/31/EU, EPBD) includes a provision on the introduction of intelligent metering systems.
- ✓ The Smart Grid Task Force of the European Commission and the ongoing work of European standardisation bodies.

However, in May 2006, the European Union published the Energy End Use and Energy Service Company (ESCO) Directive [24] which has to be implemented by all 25 European states by May 2008 [25]. The Directive requires all the member states to develop National Energy Efficiency Action Plans (NEEAP) to reduce national energy consumption by 1% from 2008 with an expectation of a 9% energy saving by 2017) [22], [24]. The main focus is on:

- ✓ Improved energy-use efficiency
- ✓ A reduction in primary energy consumption and carbon emissions

The Measuring Instruments Directive (MID) was also implemented in November 2006 [15]. This, like the Energy Services Directive, stipulates that consumers must regularly be made aware of their energy consumption and its associated costs. Effectively this means that all 25 member states of the European Union (EU) need to deploy full-scale smart metering solutions within the next few years. Initiatives such as the European Smart Metering Alliance (ESMA), led by the British Electro-technical and Allied Manufacturers Association (BEAMA), exist to assist distribution networks and retailers with the successful implementation of the ESCO directive. (ESMA is funded in part by the European Union's Intelligent Energy programme)

It is believed that smart meters will have the following impact in the EU:

- ✓ Providing energy usage information data to customers will deliver energy savings (5-10% reduction).
- ✓ Providing customers with much better and more accurate bills will influence the buying decisions of customers to purchase more energy efficient appliances.
- ✓ Possibly facilitate demand response mechanisms.

However, to date neither of the directives has been translated into concrete regulatory mandates by the EU member countries [15]. The deployment of AMI is further complicated by regional competitive markets consisting of electricity wholesalers, retailers and network owners, which complicate meter asset ownership and cost-recovery models. These contribute to a situation where European utilities are reluctant to invest in meters that provide benefits beyond traditional AMR. In the Nordic countries the deployment of smart meters has mostly been focused on reducing meter reading labour costs, as regulators have mandated monthly meter reads.

Table 8 summarises market driving forces and deployments in France [21].

Table 8: Market driving forces and deployments in France

Drivers	• Market deregulation • To allow new resellers • Architecture for smart grid • Energy efficiency
Pilot	• Date of installation: 2010 • Quantities: 300 000 meters • Selected areas: Lyon and Tours
Mass deployment	• Deployment date: 2012 • Quantities: 35 000 000 points

Table 9 summarises market driving forces and deployments in Netherlands [21].

Table 9: Market driving forces and deployments in Netherlands

Drivers	• Energy saving objectives consistent with EU Directives • Realize cost savings through more efficient network operations and data exchange • Simplicity for the end consumer
Pilot / Rollout	• Dutch Senate rejected proposed legislation including a compulsory roll out of smart metering for reasons of privacy and security. Proposed legislation and smart meter standards were being revised. • Dutch Parliament adopted legal framework for voluntary installation of smart metering in November 2010. Customers may choose between four alternatives (from keeping conventional meters to full AMM). • Compatibility and interoperability issues to be addressed. Collaborative effort with parties in energy sector defining the functionalities of the smart meter: National Technical Agreement (NTA 8130) and now the DSMR V4.0

Smart Metering in the United Kingdom

The UK Government's White Paper on Energy [26] identifies smart meters and real time displays, so that consumers can track their energy use and make informed energy choices, as part of a strategy to reduce national energy consumption. It has been legislated that all new electricity meters need to have real time displays from 2008 onwards, and it is envisaged that smart meters and ToU tariffs will be rolled out over the next 10 years. The EU's ESCO directive will be one the delivery mechanisms. It is believed that smart meters will help to achieve demand shifting from peak periods, but that energy savings (demand reduction) will be minimal – only 1-3% in the domestic sector. Other benefits will include CO_2 emission reductions.

Based on experience the price responsiveness of electricity-load is believed to be modest in the UK. For example, during 2004 – 2006 domestic electricity demand grew an average of 1.5% per annum. However, for the period 2005 – 2006 demand actually fell by 0.2%. This has been attributed to a 29% increase (in real terms) in domestic electricity prices between 2004 and 2006 [27]. Electricity ToU tariffs are believed to offer savings to consumers; provided there are sufficient “discretionary load” high-use appliances. “Discretionary load” appliances or “non-essential” appliances are appliances that can be used off-peak, where-as “non-discretionary” appliances are unlikely to respond to ToU tariffs. Since gas is commonly used for cooking and heating in the UK, the only significant discretionary loads are typically wet domestic appliances such as washing machines, dishwashers etc.

Since wet appliances typically only constitute 20-25% of total domestic appliance load, much of the domestic load in the UK will be non-responsive to time-of-use tariffs (and hence the projected demand reduction of only 1 – 3%, compared to 5% in most other countries). Instead it is believed that improved product standards (specifying lower energy consumption) will play a more important role than ToU tariffs. Consequently smart meters are expected to be initially aimed at the Commercial and Industrial (C&I) sector, as opposed to the residential section, as potential energy savings are bigger with larger users [27] (65% of total electricity consumption is in the C&I sector).

Nonetheless, the Energy Retail Association (ERA), which represents Britain’s domestic electricity and gas suppliers in Great Britain, have since 2006 been working on its “Supplier Requirements for Smart Metering” project to develop agreed smart meter specifications and interoperability frameworks. The electricity smart meter functional specification defines a minimum specification (mandatory requirements) for a domestic smart meter, as well desired functions or features, which will require consideration based on a cost-benefit analysis. Some of the main functions and features of the domestic smart meter are summarised in Table 10.

Table 10: Standardised functions and features of domestic smart meters for the UK [28]

No.	Category	Description of functionality (M) is Mandatory function and (P) is Preferred function
1	Meter functionality	(M) Single phase meter, measuring the supply side (M) Measure and display consumption in kWh (P) 4 Quadrant measuring element (P) Remote connect or disconnect with battery back-up. Requires manual confirmation for re-connection.
2	Installation and maintenance	(M) Conform to relevant terminal spacing and fixing screw specifications (M) Suitable for installation in existing electricity meter locations (M) Local retrieval of configuration / data possible in case of communications failure (M) Fault and tamper logs only accessible by authorised personnel (M) Send meter event / diagnostic alerts to authorised party
3	Modes of operation	(P) Support both credit / prepayment modes through remote command (M) Configurable as a multi-rate meter
4	Communications	(M) Reliable two-way communications between meter and energy supplier (M) Resilient communications to local devices in the customer's premises
5	Functionality	(M) Provide on demand readings (AMR functionality) (M) Send readings according to pre-configured calendar (M) Internal clock for date and time (accurate to ± 2h over meter life) (M) Remotely configurable (M) Respond to requests for data (M) Remote software/firmware upgrades (P) Load limiting capability with reset switch (M) Import / Export capability
6	Meter display	(M) Electronic display of meter reading (M) Indicate mode of operation: credit / prepaid (P) Display tariff rate price, usage on each rate, standing charges (P) Display account data, critical peak pricing (P) Display consumption over pre-configured time period (P) Receive & display messages/instructions to the customer with customer acknowledgement
7	Data storage	(M) Store meter data e.g. serial number, site details, tariff information etc. (M) Record consumption over configurable time period (P) Record energy efficiency information (M) Record meter diagnostic information

8	Memory	(M) Capable of storing 3 months of half-hourly import + export values (M) Sufficient capacity to store all data listed under "data storage"
9	Security	(M) Protection against corruption, fraud, tampering and unauthorised access. (P) Secure data protocols for communication (M) Appropriate access control for meter reading / configuration
10	Revenue protection	(M) Issue tamper / theft detection alert (P) Disable meter upon tamper / theft detection via contactor
11	Prepayment mode	(M) Disconnect supply when credit is used up (M) Prevent disconnection of power on certain days e.g. Christmas (M) Support emergency credit facility (M) Accept credit remotely (M) Process payment manually where payment has not reached the meter due to communications failure (P) Display low credit warning
12	Future proofing	(P) Replaceable communications module

Barriers to smart meter implementation in the UK include:

- ✓ The high cost of smart meters;
- ✓ A lack of interoperability standards; and
- ✓ Uncertainty regarding what government will mandate with regards to the implementation of smart meters in the domestic sector.

As discussed in this section, Table 11 summarises the market driving forces for AMI deployment in the Unites Kingdom [21].

Table 11: Market driving forces and deployments in United Kingdom

Drivers	• Market deregulation • Moderate consumption at peak times • Boost energy efficiency • Reduce carbon emissions • Transform customer experience • Evolve prepayment to smart payment
Market	• Both electricity and gas meters of more than 47 million • Mandatory rollout for larger customers until 2014 • Mandate in place for domestic electricity and gas rollout until 2020 • The main energy suppliers, rather than distribution networks, are responsible for the rollout

2.3 MARKET DRIVERS - AMI IN EMERGING ECONOMIES FOCUSING ON SOUTH AFRICA

In South Africa three Governmental policies or plans support the implementation of smart metering and ToU tariffs:

- ✓ The Energy White Paper (1998) [29] alludes to the potential of implementing demand management in middle and high income households through strategies such as ToU electricity tariffs, energy efficient lighting, insulation and solar heating as means to achieve greater energy efficiency. It also stipulates that domestic electricity tariffs should be cost-reflective and allow for capacity-differentiation, and be sophisticated to the extent that they provide incentives for load shifting.
- ✓ The Department of Energy (DoE), previously known as the Department of Minerals and Energy's (DME) Electricity Pricing Policy [30] stipulates that all future tariffs should be based on the ToU principle and associated generation costs. Furthermore, the National Energy Regulator of South Africa (NERSA) needs to incentivise utilities that promote the effective utilisation of electricity by load shifting and transparent, flexible pricing structures.
- ✓ The DME's Energy Security Master Plan [31] calls for "energy efficiency to be promoted in all energy demand sectors of the economy".

The main driver for smart metering in South Africa was based on the Regulatory requirements. South African AMI programmes were to assist with addressing the current electricity constraints, as required by the Electricity Regulations in Government Notice 773 [32] of 2008. Regulation 773 requires distributors to ensure that all customers consuming over 1000kWh per month are on time-of-use tariffs and that non-essential electricity loads are managed by smart systems by 1 January 2012.

Historically several South African municipalities have implemented geyser load management as a means to reduce their notified maximum demand, upon which their Eskom bills were calculated. Nelson Mandela Bay Municipality in Port Elizabeth recently piloted a voluntary ToU tariff and smart meter as a means to increase payment levels (revenue management) while at the same persuading customers to use electricity efficiently [33], [34]. A number of other municipalities are reported to be considering similar smart metering pilots and projects.

Eskom has piloted a number of separate domestic load management and ToU pilot systems since the mid 90's. The results of these studies [35] have shown that 5% load shifting can be achieved through a combination of automatic geyser load management and ToU tariffs. Potentially Eskom could shift 84MW of load if smart meters and ToU are implemented at all 120 000 suburban medium-to-high consumption residential customers. Peak demand reduction through load shifting remains the key driver for Eskom, especially at a time when generating capacity constraints exists and reserve margin is only at 8% instead of the required 15% [36].

The regulator approved a TOU tariff called Homeflex many years ago and this was used in the pilots mentioned. This tariff should again be restructured and submitted to NERSA for review and approval. Only once this has been approved can Eskom continue to roll-out its planned ToU tariff and smart meters. In addition to the 120 000 residential customers, it is estimated that a further 2 161MW of uncontrolled peak demand geyser load (not yet under ripple control) could be shifted out of peak time nationally. It is believed that a further 1 104 MW could be shifted if automatic load management is applied to wet appliances (washing machines, dishwashers etc.) and swimming pool pumps.

Besides the regulatory driver, Eskom's AMI programme also has the following business drivers:

- ✓ <u>Shift Residential Peak Load</u> - to reduce the morning and evening peaks
- ✓ <u>Promote Customer Behaviour Change</u> - Incentivise the efficient use of electricity, promoting energy conscience lifestyle changes and empowering customers with their consumption information.
- ✓ <u>Improve Customer Service & Maximize Operational efficiencies</u>
    - Reduce meter reading costs and the need for estimations through automated meter readings.
    - Reduce non-technical losses through tamper detection and usage monitoring.
    - Reduce call-outs through remote meter disconnects and reconnects and supports proactive maintenance through low voltage (LV) network visualisation monitoring.
- ✓ <u>Develop a Standardised Solution</u> - Design, develop, implement, test and refine a standardised solution that should become the base standard for all residential metering, including prepaid metering.

<u>*Eskom Smart Metering Functionality*</u>

Eskom has identified the need to introduce smart meters with load management capability and a ToU tariff as part of the Demand Side Management (DSM) strategy. The current generation capacity shortages are one of the main drivers for the DSM strategy which aims to encourage peak load shifting and energy efficiency consumer responses.

At a high level Eskom requires smart meters to perform the following functions and benefits.

- ✓ Remote meter reading
- ✓ Interval meter reading with load profile data
- ✓ Load management
- ✓ Real-time breaker limit-setting.
- ✓ Remote connect / disconnect and demand limiting
- ✓ Real time ToU billing as a means to encourage load shifting from peak times.
- ✓ Split metering solution with display unit so that consumers can access billing information.
- ✓ Tamper/theft detection
- ✓ Home area network integration
- ✓ Power Quality monitoring
- ✓ Value added customer services and additional benefits to discourage bypassing.

In order to provide these benefits Table 12 summarises the high level functionality for smart meters and the Meter Data Management System (MDMS) identified as part of the Homeflex RFP [37], the Future Metering Strategy [38], and Distribution's specification for domestic AMI metering equipment [39]:

Table 12: High level smart meter functionality required by Eskom

No.	**Category**	**Description of functionality** (M) is Mandatory function and (P) is Preferred function
1	Meter functionality	(M) Single/three phase meter, measuring import active energy (P) 4 Quadrant metering (M) Support ToU tariff including off-peak, standard, peak and critical peak periods. (M) Register and display kWh readings (total, peak, off-peak) (P) Register and display kWh, kVarH (P) Support credit as well as pre-payment mode.
2	Installation and maintenance	(M) Conform to SANS 62052 and SANS 62053 standards in terms of casing, terminals, terminal covers, rating plates etc. (M) Suitable for installation in place of mechanical meters (M) Three levels of access control security (M) Remote firmware upgradeability
3	Communication	(M) Two-way communications between meter and master station (GPRS is preferred) (M) Separate replaceable plug-in communications module (P) Preferred functionality: allow Internet access for VOIP applications (P) Support DLMS/COSEM (P) Communication protocols (including proprietary protocols) to be made available to 3rd party users (P) Support GPS location data (M) Wireless communication to load control devices / in-home display
4	Display	(M) Separate in-house customer display unit (i.e. split meter) (M) Display meter number, date, time (M) Display total kWh, current demand (kW), interval kWh (M) Display cost (total & previous day) (M) Display tariff period (M) Display load switching times + status of load devices (M) Display current capacity limit (M) Display test messages (< 255 characters)
5	Interfaces	(M) Port for meter reading and configuration (M) Port (e.g. RS232) for remote communications
6	Remote time clock synchronisation	(M) Remote time synchronisation (M) Time-stamping of meter events
7	Load management (separate device or integrated)	(M) Remotely/locally programmable switching sequences (M) Ability to switch ≥ 3 appliances at distribution board level (M) Support real-time on demand switching (M) Customer should be able to override load management locally (M) Sequence to reset automatically after override or real-time load management
8	Supply capacity control	(M) Normal and emergency current limit (M) Remotely/locally configurable and enabled/disabled

9	Data storage	(M) Store total energy & energy per ToU period (M) Data integration over 15 / 30 / 60 minutes (configurable) (M) Store all events (tamper, supply outage, over/under voltage, disconnect/reconnect)
10	Memory	(M) Capable of storing 100 days of half-hourly import energy (M) Sufficient capacity to store data listed under “data storage”

In addition to the above Eskom’s smart meters also had to meet the following requirements:

- ✓ In prepaid mode the meter has to conform to Standard Transfer Specification (STS) compliance standards.
- ✓ The meter has to comply with all the relevant Eskom specifications.
- ✓ Communication standards should conform to relevant IEC standards.
- ✓ Communication devices should have ICASA approval.
- ✓ The meter has to support multiple communication mediums e.g. GPRS, PLC, Fixed RF etc.
- ✓ The final smart meter solution should accommodate multiple vendors with Eskom having access to the metering / device protocols to align with Eskom’s non-vendor lock-in strategy.

As discussed in this chapter, Table 13 summarises the South African [21] market as an emerging economy for AMI deployment.

Table 13: Market driving forces and deployments in South Africa

Drivers	• Generation supply shortage • Revenue protection issues • Energy efficiency (Power Conservation Programs)
Key requirements	• Specified in NRS049 standards [48] • Complex tariffs • Real-time data to consumer • Load restriction in the meter • Load management • Remote disconnection /reconnection • Smart payment/prepayment • Split metering • Micro-generation and export energy considerations • Modular communication options • Remote software and firmware upgrades
Market	• High-end residential customers (LSM7-10) [66] using more than 1000kWh per month • Estimated 670 000 – 1 million conventionally billed customers
Feedback from Pilot	• Key requirements specified in NRS049 standards which is being revised presently • Complex tariffs for real-time • Lack of available unified smart metering standards encompassing prepayment and post payment needs

	• RF, PLC, long wave radio solutions • Many proprietary solutions installed • Lack of sufficient funding limiting pilot size • Lack of end consumer involvement

2.4 Costing Models and Funding Mechanisms for AMI Deployment

This section discusses costing models and funding mechanisms for AMI deployment in developed economies and South Africa as an emerging economy.

A review of international studies has revealed that large scale AMI implementation differs across various developed countries such as Italy, Netherlands, Canada, US and Australia; and is dependent on the scale of the installations, the technology used and the requirements of each market [2]. The average costs of these AMI projects were around US$132 per point installed which included the meter installed and communication costs. These costs were based on the installation cost model as shown in Figure 5 [2]:

Meter and Data Concentrator	: US$91.27
Installation	: US$15.02
IT Support	: US$25.70
Total (costs per metering point)	: **US$131.99**

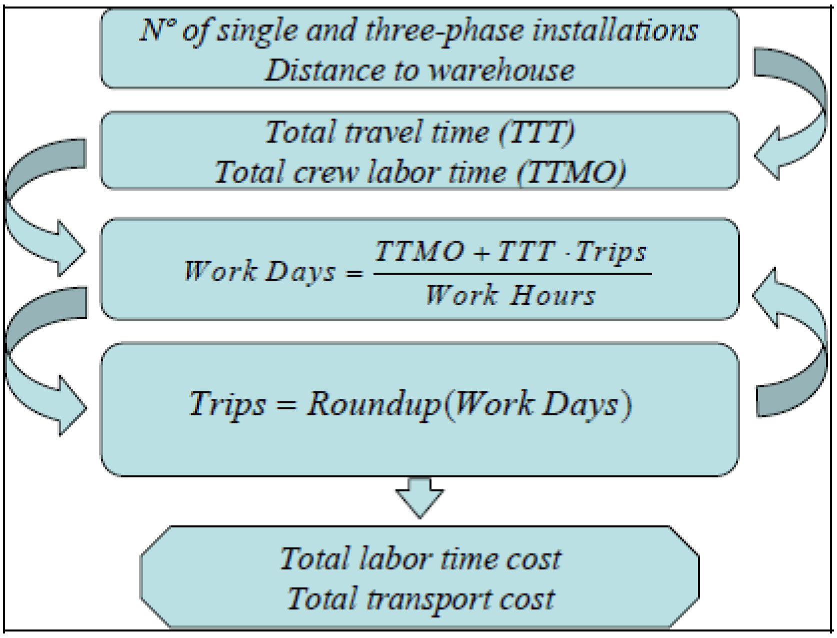


Figure 5: Costing model based on international experiences [2]

In emerging economies such as South Africa the magnitude of AMI projects have been on a much smaller scale, hence due to the economies of scale, the costs per point installed have been approximately 4 times higher, where AMI pilots have been in the "thousands" as compared to the "millions" rolled out in developed countries. The exact cost calculations could not be disclosed due to confidentiality reasons. The cost breakdown was based on average estimated costs obtained telephonically from various AMI solution vendors in South Africa as shown below per point installed:

Meter, Data Concentrator and Customer Display Unit	: R1500 + (R12000/*20) + R650
Installation costs	: R700
Infrastructure and IT costs	: R1500
Total (costs per metering point)	: **R4950**

Note: ***Denotes a meter to data concentrator ratio of 20:1

From this it can be seen that in an emerging economy, the cost of implementing of AMI would be much more to that of a developed economy. The reasons for this could be attributed to multifaceted and deceptively simple, i.e. difficulties during installation, insufficient manufacturing facilities and increased complexity of hardware. However, the validity of the price comparison is still uncertain, due to the detail of the price calculations not being comparable.

The City of Tshwane, a municipality or energy distributor in South Africa, has followed a different approach in their investment of deploying AMI. The municipality approved a 10-year arrangement to outsource its entire electricity metering and revenue collection activity to a private company. Therefore, according to the outsourcing contract between the city of Tshwane and the private company, the private company will be responsible for all metering and electricity revenue collection on behalf of Tshwane for a period of ten years [65].

2.5 SUMMARY OF MARKET DRIVING FORCES FOR AMI DEPLOYMENT

In this chapter the author performed a comparative analysis of the market driving forces in developed and emerging economies.

Despite a lot of international interest in smart metering, literature has shown that to date very few AMI pilot projects have progressed to full scale deployments. A summary of international smart metering deployments is presented in [APPENDIX A-5]. Based on research by KEMA most U.S. utilities have recognised that AMI technologies are maturing, but they cannot be characterised as being fully mature at this point [40]. However, many companies believed that AMI technology is either near maturity, or that it has sufficiently evolved enough that it is reasonably priced to result in a positive cost-benefit analysis. Furthermore, electric utilities are choosing different technologies and smart meter functions based on their specific requirements.

This study has shown that the key drivers for smart metering or AMI globally, for both developed and emerging economies can therefore be summarised in the categories as listed below:

Developed economies

- ✓ Market Deregulation
- ✓ Energy Efficiency
- ✓ Deferring of Generation Capacity Investment
- ✓ Distributed Generation
- ✓ Architecture towards a Smart Grid

Emerging economies

- ✓ Revenue Protection for fraud and default in payment by customers
- ✓ Revenue Protection through prepayment metering
- ✓ Supply side shortage or capacity constraints on the electric network

The research study has indicated that different countries tend to have their own unique requirements for smart meters and AMI systems based on local market drivers. Table 14 provides a summary of the countries and markets that were analysed, the major obstacles faced by utilities and approach followed to develop and specify AMI systems.

Table 14: Summary of international drivers, obstacles and approaches for smart metering

Continent / Country	Main AMI drivers	Main obstacles to large scale deployment	Approach to smart meter development
North America	• Regulatory directives • Desire for customer service enhancements • Greater operational efficiencies	• High meter cost • Lack of open standards	• State Regulators specify minimum smart meter functionality
Western Europe & U.K.	• Improved energy-use efficiency • Reduction in primary energy consumption and carbon emissions	• High meter cost • Lack of open standards • Lack of national regulatory directives • Complex energy markets	• Minimum functionality standard developed by the Energy Retail Association (industry collaborative effort)
Australia	• Improve efficiency of electricity market • Reduce peak demand	• Cost-recovery in complex energy market	• Minimum functionality facilitated by the Ministerial Council on Energy (MCE) (industry collaborative effort)
South Africa	• Reduce peak demand • Revenue improvement through theft reduction	• Unclear functional requirements • High meter cost • Lack of open standards • Lack of regulatory directive	• Each utility / municipality develops its own smart meter specification – no national coordination

Market drivers determine the functional requirements for smart meters in each particular market. In most countries the drivers include regulation, legislation and/or specific government and utility initiatives. Typically the high level requirements are translated by industry into a set of commonly agreed minimum smart meter functionalities. The set of smart meter functions determines amongst others the complexity of the communication system that is required.

Additionally, automated metering is a fundamental building block of a smart grid. In an emerging market environment, the challenges around effective business analysis and strategy development due to AMI deployment will place enormous demands on the information infrastructure of the power utility. Meter data volume growth and interoperability amongst new applications will be key characteristics of AMI towards a smart grid [63].

CHAPTER 3: AMI DEPLOYMENT - UTILITY AND CUSTOMER CHALLENGES

3.1 INTRODUCTION

This chapter analyses utility and customer challenges experienced during AMI deployments. The analysis reviews case studies comparing AMI deployment in a developed country (Unites States of America – Californian utility: San Diego Gas and Electric) [13] to a power utility in an emerging country (South Africa – Eskom SOC Limited). The case study literature made available in this dissertation and evaluation thereof was as a result of meetings held with SDG&E during a visit to the United States in October 2011. The Eskom case study will present the utility and customer challenges in comparison to that of the developed countries.

3.2 UTILITY AND CUSTOMER CHALLENGES IN DEVELOPED ECONOMIES

Table 15, summarises the key challenges that are currently facing the developed countries.

Table 15: Key challenges faced by developed economies

Economic barriers	✓ There were many parties involved, and the benefits of smart metering may benefit parties than do not necessarily bear the costs. ✓ Large scale AMI deployments take long and are costly. Opposition from regulators to increase the tariffs further and ask final users to pay for it. ✓ Business case Justification or target segment strategy not always clear. ✓ Funding Issues - Many AMI Pilots planned but delayed.
Deployment challenges	✓ Initial expected deployment plans (2005-2010 projections) of smart metering did not materialise as envisaged. ✓ There are large numbers of “Pilots” of varying sizes in progress to evaluate impact and learn while technical, legal and social issues are addressed. A significant slowing down of execution indicating a cautious approach. ✓ Lack of skilled resources and general capacity to deploy projects on a large scale without proper planning and prior to evaluation of pilot results. ✓ Indications are that momentum picking up in 2011 and new targets set towards 2020.
Technology challenges	✓ Standardisation taking longer than expected. ✓ Convergence of Technology well progressed but not fully there in totally inter-operable manner. ✓ Lack of interoperability between different smart meter systems. No open registered standards exists which properly scopes all of the different functions (metering, communications, presentation, and network).

	Availability of multi-vendor Technology modularity progressing especially in larger scale multi-vendor pilots.
End consumer challenges	✓ Initial lack of involvement/education. (Dutch case, Improving in UK) ✓ Need to be convinced of benefit and savings to them. ✓ Concerns about security, privacy & health.

Case Study – San Diego Gas and Electric (SDG&E)

The following is a case study on challenges within the SDG&E utility in California, USA.

As a result of the 2002 energy crisis in California, SDG&E has deployed a total of 2.2 million AMI meters of which 1.4 million are electricity meters, as of 2005. SDG&E decided on the ITRON OpenWay solution, using solid state meters. The following is a summarisation of the technical functionalities of the AMI solution, challenges and lessons learnt.

✓ Key functionalities of the SDG&E AMI system [13]:

- Interoperability - Meters could be replaced and still be able to operate on the same solution i.e. smart synchronisation.
- SDG&E created a "My Account Online billing" - Customers were notified via email when their bill was due, and bills could be paid online. Customers could register and view their account online and track the last 25 months of their account information. Customers could manage their account by means of tools to improve energy efficiency, identify exactly where the household was using energy and learn how to conserve energy.
- Dynamic pricing signals – SDG&E scheduled 15 days of Critical Peak Days per year. Peak time rebate to residential customers were based on the baseline savings.
- Head-end or backend system (i.e. AMI Master Station). Head end system was situated within SDG&E and ITRON had to dial in to the MDMS. Firmware updates were done from the head-end system.
- Home automation - SDG&E customers had the ability to remotely control smart appliances within their home using the computer.

SDG&E has encountered many challenges with their AMI deployment. Some of these challenges and lessons learnt are discussed below [13].

✓ Challenges - Customer related issues:

- Customer high bill issues were experienced. High bills mitigation process ensured transparency with customers. Customers were contacted or notified before bills had gone out, i.e. if the bills were too high. The billing department or call centre agent had to contact the customer to explain the high bill.
- SDG&E has their own call centre and expert team (technical problems) to deal with AMI related queries. ITRON resources were based at SDG&E and worked together with the AMI PMO resources to address technical concerns. Customer issues were resolved immediately or within 5 days.

- Customer communication, interaction and marketing were done via media, SMS and mass communications. 30 days before installation, contractors had gone out to visit the customer and explain AMI solution and other demand response or energy efficiency programmes. Three days before the actual installation, SDG&E's call centre phoned customers to inform them of the meter installation.
- Customer information packs were used for educating customers on smart meter rollout e.g. reading of the meter. Letters were sent out to customers, preparing customers for the meter installation.

✓ <u>Challenges - Technical field issues</u>:

- Experienced meter and data collect or failure rate of 1% which was within the tolerance range.
- Experienced LCD display failure and battery failure.
- Meter disconnection due to battery leakage.
- Communication issues of RF mesh network (900MHz) and Zigbee (300 feet range) to talk to meters. Relays had to be replaced.

✓ <u>Internal engagement and communication processes</u>:

- Employee engagement - every 3 months employees are educated, trained and feedback provided on the AMI rollout.
- Customer incentives - SDG&E have incentivised the customers with energy efficient showerheads as a bonus with the smart meter programme enrolment.
- Security, data privacy and data protection challenges - 3rd party laboratory (ITRON) dealt with security issues, testing and embedded devices.
- SDG&E's communication process included communication before, during and after installation; as listed below:

    - 60-90 days: Meet with elected officials and community leaders
    - 30-60 days: Community outreach - Participate in community events
    - 30 days: Mail customer notification letter
    - 3 days: Day ahead phone call - Outbound dialler notification
    - Day of: Personal contact by installer and SDG&E
    - Less than 2 weeks after installation: Personal follow-up by SDG&E with a sample of customers to answer questions and offer information on programs and services

✓ <u>Lessons Learnt</u>:

- Customer service relations empowerment

    - SDG&E provided "enhanced" smart meter training and create a dedicated "escalated" desk to resolve queries.

- High bill mitigation
  - Perform 'High/Low" billing checks to identify billing issues before sending out bills.
  - Ensured proactive customer contact on high bills.

The SDG&E case study has shown results in line with related AMI implementations for developed economies internationally.

3.3 Utility and Customer Challenges in Emerging Economies

Case Study – Eskom

Eskom has experienced many challenges during the pilot AMI deployment. The categories of these challenges are illustrated in Figure 6.

Figure 6: Utility Challenges for AMI deployment experienced by Eskom

Table 16 summarises the challenges and lessons learnt for AMI deployment in emerging economies.

Table 16: Utility challenges in emerging economies

	Challenges	Lessons learnt
Meter system issues	✓ Meters disconnecting customers and changing functional mode randomly ✓ Communication problems; between meter and CIU; meter and DC; DC and head-end ✓ CIU and meter display failures ✓ Incorrect meter register values ✓ Meter recalls ✓ Inconsistency of information display between CIU and Meter	✓ Ensure that the regulatory, performance, quality, security and reliability certifications for the devices and head-end is available ✓ Perform comprehensive solution (end to end) testing ✓ Perform meter accuracy tests and sample testing of meter functionality, accelerated life testing
Field installation issues	✓ DC installations were dependant on 5 week lead times for transformer outages ✓ Identified field issues, e.g. faulty circuit breakers, hot connections, unlocked kiosks / customer locked kiosks, ant mounds in transformers, meter bypasses / tampers, meters installed with customer premises ✓ Space constraints in certain existing transformer and meter housings for DC and Meter installations respectively ✓ Contractors do not comply with installation specification, safety, quality and data capture requirements ✓ Dependence on area personnel availability - outages and maintenance work ✓ CIU installations introduced complexity: • Customers were required to be available for basic CIU training and sign for CIU acceptance • Customer billing data had to be correct and synchronised with head end	✓ Undertake pre-installation audits and plan to rectify field issues identified ✓ Ensure that the installation designs, safety and quality requirements are standardised and adhered to automate the field installation data capture process

Figure 7 illustrates examples of poor quality field installation issues encountered.

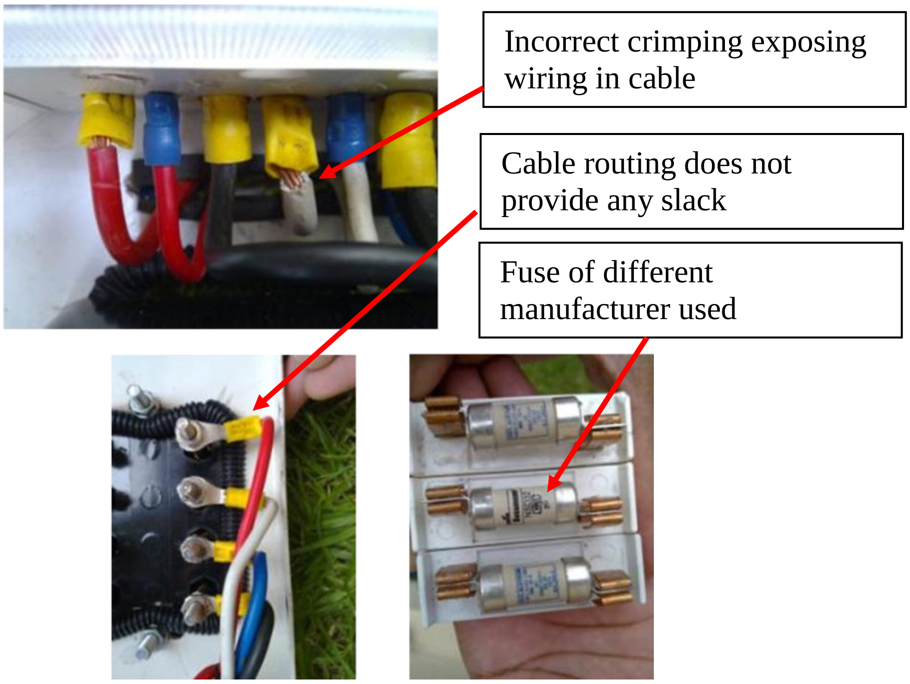


Figure 7: Poor quality field installations experienced in Sunninghill

Figure 8 illustrates space constraint issues in the meter kiosk.

Figure 8: Space constraint issues in the meter kiosk in Sandton

Figure 9 illustrates ant mound found in transformer mini substation.

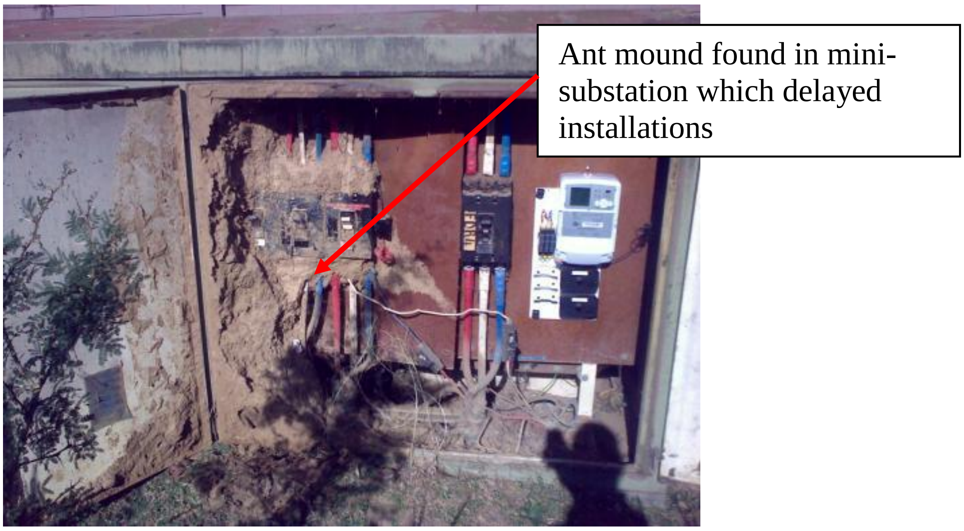


Figure 9: Ant mound in transformer mini substation in Sunninghill

Figure 10 illustrates hot connections where cables were not tightened properly.

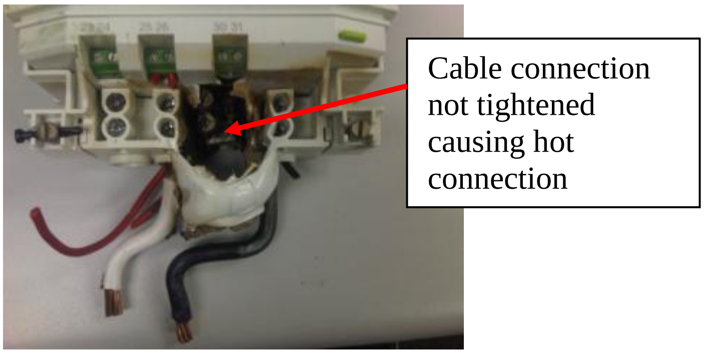


Figure 10: Hot connections experienced in Sandton

Figure 11 illustrates vandalism of locks at mini substations.

Figure 11: Vandalism of locks at mini substations in Sandton

Figure 12 illustrates SIM cards stolen from data concentrators in mini substations.

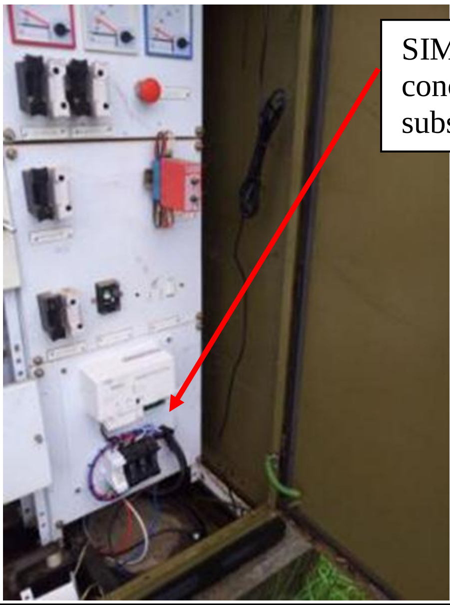


Figure 12: Theft of SIM card from data concentrator in mini substation in Sandton

One of the primary objectives of the AMI Operations team was to address customer related queries during the AMI deployment. Some of the key customer challenges encountered and responsibilities of the team in resolving these challenges include the following:

- ✓ Billing Cycle – To correct billing data errors on the upload and download flat file for each AMI Read Route. This ensures that correct data is uploaded on the billing system and customers are not estimated.

    - Customer Care and Billing (CC&B) System Billing Cycle Errors (To-Do's) – completing To-Do's timeously ensuring that there are no bill errors and estimations.
    - Customer issues queries – resolving customer billing queries.
    - CC&B meter changeouts – ensure that every AMI customer is correctly registered on CC&B. Identify and signup electricity supply contracts for customers not in the billing system.
    - AMI field audits – conduct field audits to obtain customer information and to perform switch ON/OFF test to ensure that customer meter is linked to correct unit. Assisted by the Revenue Protection department. The information obtained on the field is used to correct the data on CC&B.

- ✓ AMI Meter, Data Concentrator (DC) and Customer Interface Unit (CIU) installations - AMI Field Engineering to co-ordinate with meter vendors and Work Management Centre (WMC) - coordinates outages.
- ✓ Meter Asset Tracking System (MATS) capturing - scanning and capturing of AMI meters into MATS.
- ✓ Monitor and Analyse AMI Field Engineering issues - maintain register documenting all field issues.
- ✓ Monitor and analyse customer issues register - maintain register documenting all customer issues.

Table 17 highlights utility related challenges and lessons learnt for AMI deployment in emerging economies such as South Africa.

Table 17: AMI operational and customer related challenges and lessons learnt

	Challenges	Lessons learnt
AMI Operational	✓ Inaccurate Customer Network Link (CNL) data - meter to transformer link • Lack of knowledge of the Low Voltage (LV) network diagrams • Inaccurate AMI DC installation schedules. ✓ Discrepancies between billing and field data in billing system • Meter installations and movements / change outs not captured • Meter installations incorrectly captured • Meter in kiosks are not properly marked as to the premise being supplied • Unlocked meter kiosks • Inaccurate AMI meter installation schedules.	✓ Perform pre-installation audits to verify and correct CNL data. ✓ Perform pre-installation billing data versus field data audits.

Figure 13 shows the team marketing the Homeflex tariff to target customers where smart meters were installed; and handing out the CIU to customers. The marketing team was appointed to assist the utility due to resource constraints. Face to face meeting with customers was required to introduce the project and its objectives, introduce the ToU tariff and analyse customer's consumption patterns to determine if the customer will benefit from the tariff.

Figure 13: Marketing Company: MediaShop [3] *(*Photo courtesy of Eskom)*

Table 18 presents the key challenges and lessons learnt during the customer engagement sessions.

Table 18: Challenges and lessons learnt during customer engagement sessions

	Challenges	Lessons learnt
Customer interaction and marketing	✓ ToU tariff marketing and installations • Customer non-availability for forums and appointments • Historically incorrect customer contact information on record • Lack of historical load profile data made marketing more difficult ✓ Perceived abnormal increase in customer bills: • Due to the annual tariff increased (meters installed just prior) • Colder winter resulted in increased consumption therefore increased bill • Old mechanical meters have a probability of inaccuracy	✓ Customer centric approach is required • Utilise different channels to engage customers • Incentivise customers to participate (if possible). ✓ Ensure all meters have an accuracy test report and the meters can be tested for accuracy in situ.

3.4 Summary of Utility and Customer Challenges for AMI Deployment

In this chapter the author performed a comparative analysis of the utility and customer challenges encountered in developed and emerging economies. Some of the key conclusions on the challenges, both utility and from customer perspective are listed below.

- ✓ Refining and enhancing the functional, technical, interoperability and performance requirements of the AMI solution.
- ✓ Strengthening the IT and telecommunications infrastructure. The communication network needs to be extremely reliable to transfer large amounts of information to the data concentrator and master station.

- ✓ Reliability of communications is critical and is not always guaranteed in developing countries.
- ✓ Enhancing the field installation and business processes.
- ✓ Review and alignment of the current business processes to include the AMI requirements.
- ✓ Install the additional smart meters to act as sensors on the network to achieve LV intelligence.
- ✓ The measured data from the smart meters stored in the master station can be used for new customer billing strategies e.g. time of use tariff, critical peak day pricing, prepaid metering etc.
- ✓ Customer access to information about how one uses the electric energy imposes new requirements on how the metering data is stored, its format and accessibility.
- ✓ The smart meter is the enabling technology to ensure that the utility improves their service to customers through implementing complex tariffs as well as provide near real time electricity usage information to customers.

Table 19 summarises the challenges and lessons learnt for AMI deployment.

Table 19: Summary of AMI deployment challenges and lessons learnt

Summary of AMI deployment challenges
✓ Resource constraints • Capturing MMFs (CC&B and MATS)
✓ Customer - Meter data (bill estimations) • CNL data issues • Discrepancy between field and data - Audits • Data entry errors • Data Synchronisation between CC&B and Master Stations. • Meter Communications issues
✓ Bill queries • Perceived “High Bills” by customers. Customers did not realise the effected annual Tariff increases just prior to the smart meters being installed • Colder than usual winter resulting in increased consumption • Old meters may have been inaccurate
Lessons learnt and way forward
✓ Internalising the lessons learnt
✓ Completing some outstanding scope items – ACD implementations
✓ Refining and enhancing the functional, technical, interoperability and performance requirements
✓ Pre-installation Prerequisites • Pre-installation audits • Correction of customer and meter data on CC&B. • Accurate installation schedules
✓ Audits of all the AMI installations and correcting the required data is critical.
✓ Enhance the field installation and business process designs
✓ Revise AMI implementation plans

The adoption of AMI at an international level are the lack of a set of widely accepted open standards capable of guaranteeing interoperability of both systems and devices produced by different manufacturers and the lack of regulatory harmonization within the United States and European Union countries for electricity, gas, water and heat metering.

CHAPTER 4: AMI DEPLOYMENT IN AN EMERGING ECONOMY – A FOCUS ON SOUTH AFRICA

4.1 OVERVIEW OF SOUTH AFRICA'S NATIONAL POWER UTILITY - ESKOM

South Africa's power utility, Eskom, is a state owned company or government parastatal established in 1923, responsible for generation, transmission and distribution of electricity to industrial, mining, commercial, agricultural and residential customers and other distributors. Eskom directly provides electricity to about 45% of all end-users in South Africa (mostly large power users). The other 55% is resold by other distributors (including municipalities which have the bulk of the residential market) [1].

Figure 14 shows the South African power grid; and Eskom key facts are listed below [1]:

- ✓ Eskom generates, transmits and distributes power in South Africa;
- ✓ Generates approximately 95% of electricity used in South Africa;
- ✓ Generates approximately 45% of electricity used in Africa;
- ✓ Number of employees - 41 778;
- ✓ Number of electricity customers - greater than 4.7 million;
- ✓ Total electricity sales - 224 446GWh;
- ✓ 27 Power stations - 13 Coal fired, 6 Hydro-electric, 1 Wind energy, 4 Gas turbine, 2 Pumped Storage and 1 Nuclear;
- ✓ Net maximum capacity - 41 194MW;
- ✓ Transmission lines - 28 790km, 132-765kV.

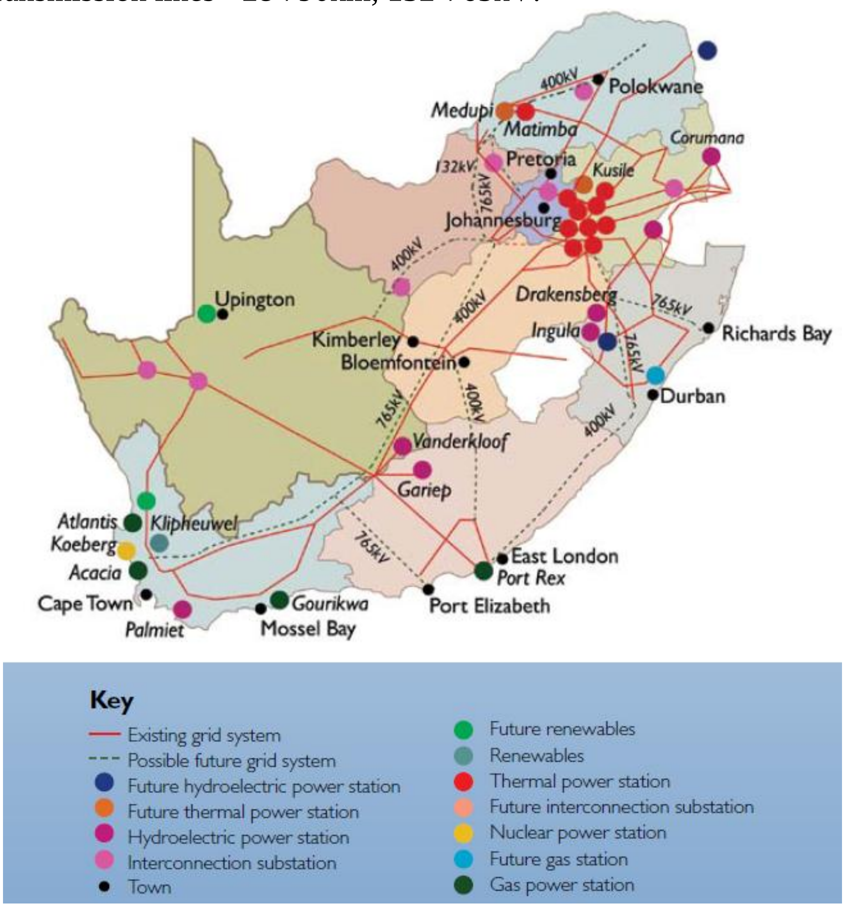


Figure 14: Map indicating the South African power network [1] *(*Map courtesy of Eskom)*

4.2 JOURNEY TOWARDS AMI IN ESKOM

Eskom has been mandated by the National Energy Regulator of South Africa (NERSA) to implement a comprehensive Demand Side Management (DSM) strategy to reduce peak electricity demand and enhance energy efficiency. The Eskom DSM programme is informed by the Regulatory Policy on Energy Efficiency and Demand Side Management for the South African electricity industry [49].

DSM refers to a process by which electric utilities in collaboration with consumers achieve predictable and sustainable changes in electricity demand. These changes are effected through a permanent reduction in the power demand of buildings and end-use equipment (energy efficiency) as well as temporary, short-duration reductions in power demand levels (demand response).

Demand response refers to actions to change the short-term consumption (demand) of electric power in response to price signals, incentives, or requests from utilities [50], [51]. The changes in electricity use are designed to be short-term in nature, centred on critical hours during a day or year when demand is high or when reserve margins are low.

This is achieved through two main techniques:

- ✓ Direct load control
- ✓ Time-based rates, which includes:
    - Time-of Use (ToU) pricing
    - Critical Peak Pricing (CPP); and
    - Real Time Pricing (RTP)

In 1995, Eskom identified the need to introduce a ToU tariff called Homeflex to residential customers. The ToU tariff structure establishes two or more daily periods that reflects hours when the electrical power system load is higher (peak) or lower (off-peak), and charges a higher rate during peak hours. ToU tariffs can also be implemented on a seasonal basis with prices that vary by season [52].

The existing electromechanical and electronic electricity meters did not have the capabilities for ToU metering. Therefore, more advanced metering technology was required to meter and charge customers on a ToU basis which is able to tell time i.e. time of the day or season to charge different prices according to the different times that they use electricity.

In 2006, Eskom undertook a proof of concept (POC) project, which included a test of the residential ToU tariff. The tariff was tested in isolation to any load management or energy efficient programmes using the three-phase ToU meters. The consumption data was manually read by specially trained meter readers on a monthly basis so that customers could be billed monthly as required by the tariff.

Although the POC was very small (approximately 450 consumers) the study concluded that:

- ✓ The residential ToU tariff had no noticeable effect on consumer consumption patterns; however it was believed to provide an incentive to the consumers not to bypass or remove the load control devices.
- ✓ Direct control over the geysers resulted in an average load reduction of 0.7kWh per customer during peak times. This translates to a potential total peak load reduction of 84 MW, considering that Eskom has 120 000 medium-to-high consumption (e.g. ≥ 500kWh / month) residential customers.

HomeFlex was not effective on its own to achieve demand and energy savings; to do so it needs to be implemented in conjunction with load control. (Theoretically however, a ToU tariff structure that sufficiently differentiates between peak and off-peak tariffs should result in changing consumer consumption patterns on its own). According to international case studies [50], [51], customer consumption patterns are best influenced by combining ToU tariffs with real-time feedback regarding their energy consumption through for example an in-home display.

Even though Eskom was not able to demonstrate the effectiveness of the HomeFlex ToU tariff through its pilot projects, it nonetheless embarked on a programme to implement such a tariff through smart meters. Direct load control however remains one of Eskom's main smart meter requirements.

4.3 Eskom – AMI Pilot

In January 2008, Eskom experienced unprecedented capacity constraints on the network which consequently resulted in national blackouts and load shedding. To assist in addressing the electricity challenges, the South African National Government passed a Regulation 773 [32] mandating the use of smart systems and time-of-use tariffs for customers consuming over 1000kWh per month, by 2012.

Eskom initiated a pilot project to comply with the regulation. The pilot was aimed to test the technology, process impacts and further pilot the residential ToU tariff.

4.3.1 AMI Pilot Solution Architecture

AMI systems deployed in South Africa are regulated by a national standard NRS049 [48], a South African industry standard prepared by the Electricity Suppliers Liaison Committee (ESLC) and for use by South African electricity supply authorities, in collaboration with the South African Bureau of Standards (SABS). The standard was accepted by Industry and published by SABS in 2008. Figure 15 illustrates the AMI architecture as described in NRS049.

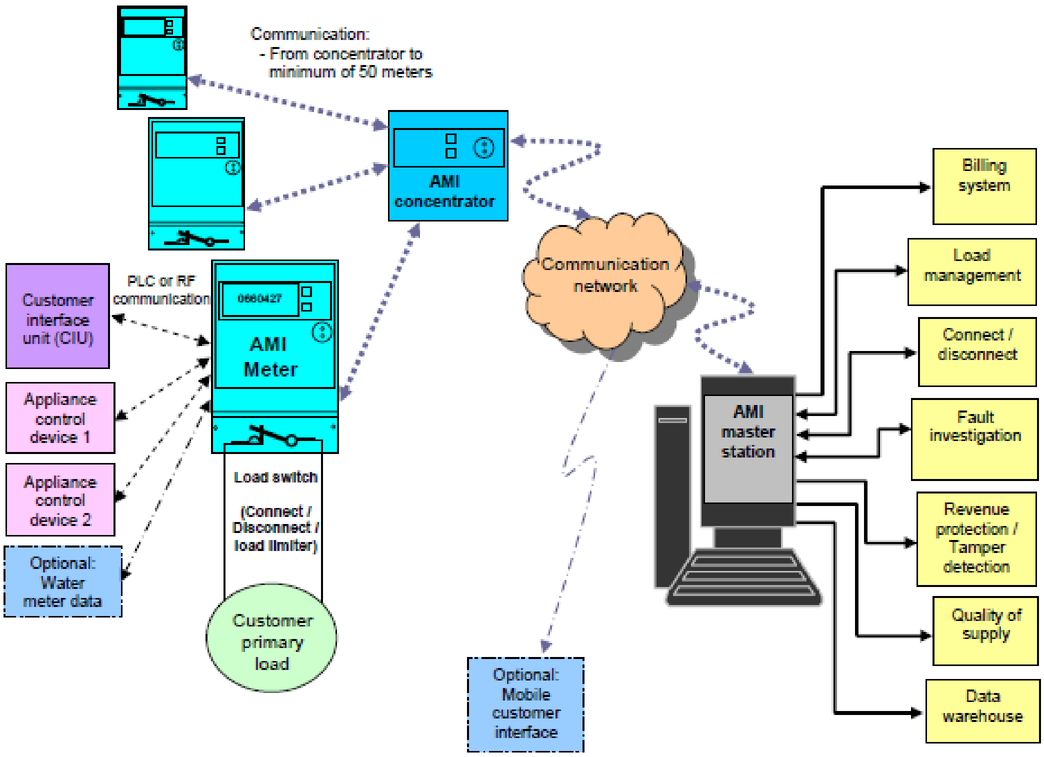


Figure 15: NRS049 AMI architecture [48]

This section presents the Eskom AMI solution architecture based on the NRS049 national standard. The AMI pilot solution architecture is illustrated below:

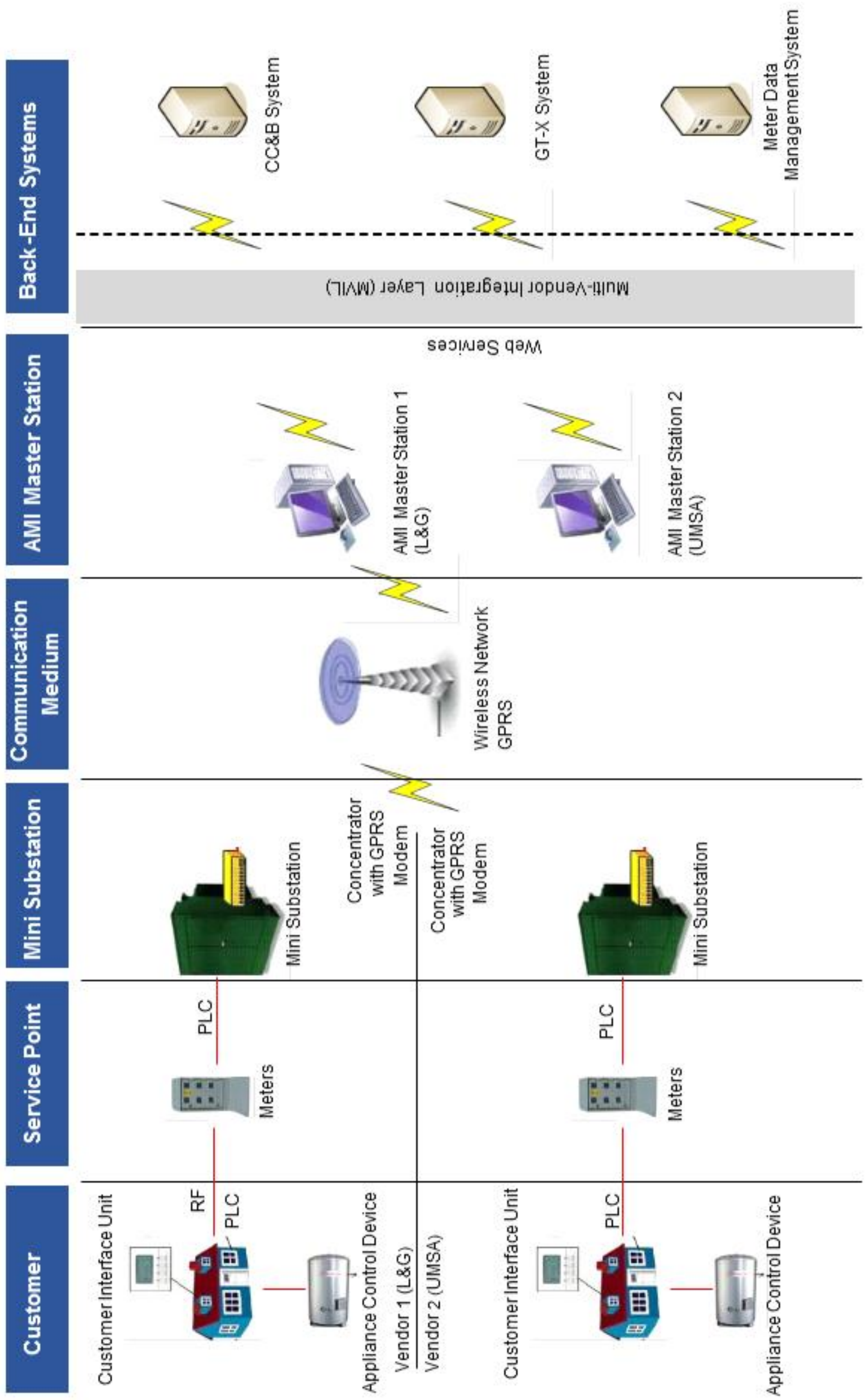


Figure 16: Eskom's AMI solution architecture

The key components of Eskom's pilot solution architecture are discussed below [3]:

- ✓ *Smart or AMI electricity meters* – are field devices that provide that traditional metering functionality with remote communications capabilities. These meters also include additional smart functionality such as, disconnection/reconnection, time-of-use metering, interval metering, tamper detection, outage detection, demand management and basic power quality measurements.
- ✓ *Customer Interface Units (CIU) or In-home Displays (IHD)* – are field devices that are normally located within the customer's premises and which communicate with the customer's smart meter. It displays to the customer a range of information such as, consumption data, demand data, rate of consumption and specific or generic customer messages.
- ✓ *Appliance Control Devices (ACD)* – are field devices that are normally located within the customer's premises and provide similar functionality as a traditional "ripple" relay. The ACD would connect or disconnect specific appliances based on a schedule or on-demand instructions via the smart meter.
- ✓ *AMI data communication network* – is a communication network through which the AMI field devices communicate to the AMI master station and supports the transfer of data. This network usually consists of two sub-networks:
  - Backhaul network, that is, communication network between field devices and the master station. The public cellular 3G / GPRS data network is commonly utilised for AMI backhaul communications.
  - Field area networks, that is, communication network between field devices in a particular area. A private, radio frequency (RF) mesh or power line communication (PLC) network, is commonly utilised for field area networks.
- ✓ *Data Concentrators* – are intermediate network communication field devices, which facilitates communication between an AMI master station and several smart meters associated with that concentrator. It also acts as gateway between the backhaul and field area network.
- ✓ *Meter Data Management System (MDMS)* - A MDMS performs long term data storage and management for the vast quantities of data delivered by smart metering systems. This data consists primarily of usage data and events that are imported from the data collection systems in AMI solutions.
- ✓ *AMI Master Stations or Head-ends* – are data collection systems that collect data, sends control / configuration instructions and monitors availability of the AMI field devices and the AMI data communication network. It also transfers data to the MDMS.

4.3.2 DEPLOYMENT OF THE PILOT SOLUTIONS

A request for proposal (RFP) tender process [47] for AMI solutions was initiated in March 2009, based on the South African industry standard for AMI, NRS049:2008 [48]. The standard was prepared by the Electricity Suppliers Liaison Committee (ESLC) for use by South African electricity supply authorities, in collaboration with the South African Bureau of Standards (SABS) [48]. The solutions were required to provide the following functionality, ToU metering, automated metering reading, non-technical loss detection, remote disconnect/reconnect, residential demand response (load limiting and appliance control) and low voltage (LV) network visualisation.

In September 2009, the tender process was concluded with the selection of two qualifying AMI solution providers for the pilot project. The scope of the solution providers were:

- ✓ Replacement of 5000 existing conventional meters, with 5000 smart meters.
- ✓ Installation of customer interface units (CIUs).
- ✓ Installation of data concentrators (DCs).
- ✓ Installation, setup and commissioning of the AMI Master Station or Head-end.
- ✓ Deployment of a Multi-vendor Integration Layer (MVIL) for integration between the Master Station and Eskom's billing system.

The AMI pilot project also required the following internal Eskom system developments:

- ✓ Deployment of the Multi-vendor Integration Layer (MVIL) for integration between Eskom's billing system and AMI Master Stations.
- ✓ Updates to the Eskom billing system to support automated meter reading (AMR), appliance control functionality and AMI meter types.

There were two meter vendor solutions that were selected from the RFP process for Eskom's AMI pilot deployment namely Unique Mbane South Africa (UMSA) and Landis and Gyr (L&G). The AMI installations commenced in 2010, in the Sandton and Sunninghill residential suburbs of Johannesburg, South Africa.

The UMSA and L&G solutions were very similar however they did have some differences listed below:

- L&G utilised RF for Meter to CIU communication whereas UMSA utilised PLC. PLC proved more reliable as distance and obstacles negatively affected the RF communication.
- The UMSA solution also supported the standard transfer specification (STS) prepayment standard whereas the L&G solution did not provide support for STS. However, STS prepayment was not a requirement of the original tender request.

The L&G solution provided a separate ACD transmitter device that connected to the meter and a separate ACD receiver device to control the nominated appliance. The UMSA solution built the ACD transmitter into the meter and only provided a separate ACD receiver device to control the nominated appliance. Both the L&G and UMSA ACD functionality have not been field trialled due to SABS certification not being obtained.

The field installation solution for the UMSA is illustrated in Figure 17.

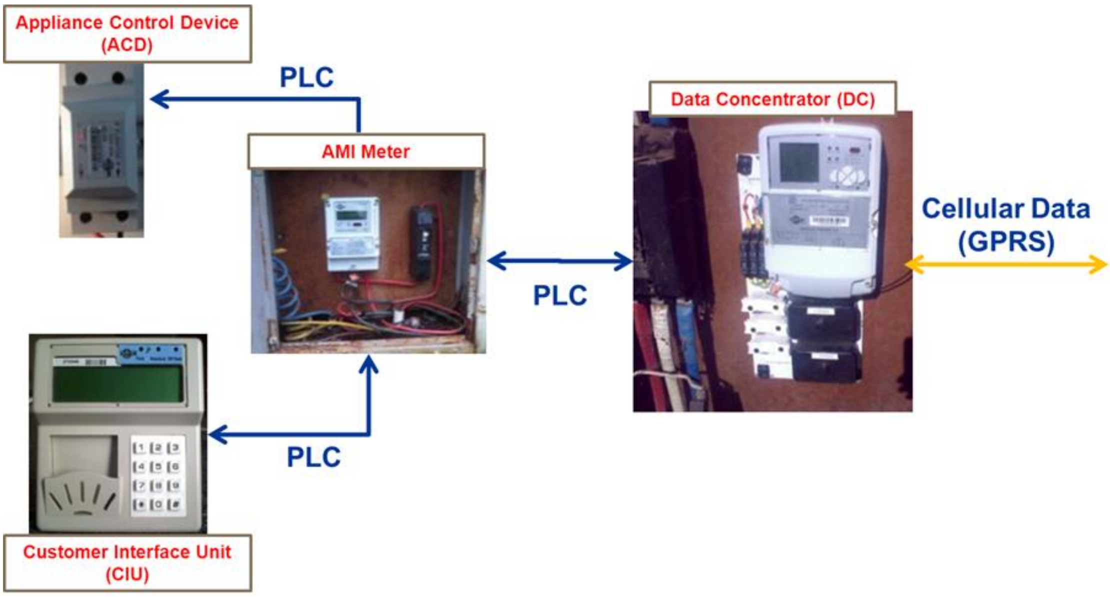


Figure 17: Unique Mbane solution components [3], *(*Photos courtesy of Eskom)*

The field installation solution for the Landis and Gyr is illustrated in Figure 18.

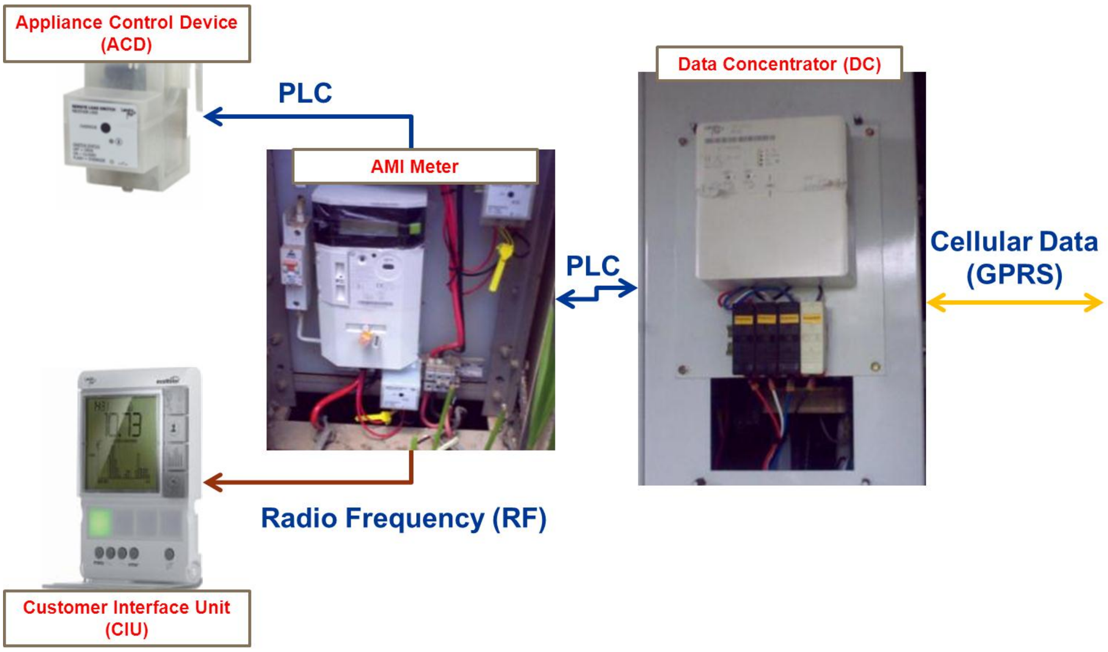


Figure 18: Landis and Gyr solution components [3] *(*Photos courtesy of Eskom)*

4.4 SUMMARY OF AMI PILOT DEPLOYMENT AND WAY FORWARD

In this chapter the author, being a part of the Eskom's AMI pilot project, has highlighted the practical experiences of AMI deployment in an emerging economy focusing on Eskom. The key findings are summarised below:

Like most international utilities Eskom also requires a smart metering solution that supports open communications protocols. Reasons include [54], [55]:

- ✓ Avoidance of propriety meter and master station software.
- ✓ System interoperability – any system can read any meter, and any meter can be read by any system.
- ✓ Avoidance of vendor lock-in.
- ✓ Lower prices through competitive market entry.
- ✓ Supplier exit from the market does not present a large risk.
- ✓ No special involvement from vendors in terms of customisation.

Open source protocols and standards are the most important factor to achieve system interoperability. Interoperability can be defined as the ability of a system or product to work with other systems or products without special effort on the part of the customer. To achieve interoperability standards are needed. The lack of open standards has been a major obstacle in the large scale deployment of AMI systems internationally [55], [17].

Despite the many challenges and lessons learnt during the AMI deployment process, there were many benefits that were realised; some of which are highlighted below:

- ✓ Automated meter reading of 3 232 customers.
- ✓ Identified more than 200 customers that were not on the billing system.
- ✓ Identified more than 70 metering and billing errors.
- ✓ Identified more than 10 incidents of non-technical losses.
- ✓ Designed and deployed an open (non-proprietary) multi-vendor interface layer (MVIL) to accommodate multiple metering system suppliers.
- ✓ Developed standardised meter and data concentrator installation specifications and practices.
- ✓ Implemented remote customer supply disconnection and reconnection processes.
- ✓ Converted 38 customers on the Homeflex ToU tariff – on a voluntary basis.
- ✓ Learnt several invaluable lessons on in various areas of AMI technology implementation.
- ✓ Developed significant AMI skills and knowledge within the organisation.
- ✓ Eskom is now more informed and therefore better placed and to make decisions with regards future AMI implementation strategies and investments.

CHAPTER 5: CASE STUDY - A SURVEY EVALUATING ESKOM'S AMI DEPLOYMENT AND THE CUSTOMERS' ACCEPTANCE TO THE TECHNOLOGY

5.1 INTRODUCTION

As discussed in Chapter 4, Eskom has currently embarked on a programme to implement an AMI solution for Eskom's residential customers to encourage demand and energy efficient customer responses. The focus of the AMI pilot project is in a phased approach to Eskom-direct customers whose average monthly consumption is in excess of 500 kWh. The pilot targeted 10000 customers affording customers an AMI solution with ToU and demand control capability.

The AMI programme is a specific intervention to assist with addressing the current electricity constraints. The AMI programme also supports the Eskom 49M® initiative by empowering customers with information on their energy usage patterns and encouraging energy efficient customer behaviour.

This chapter focuses on the comparison of the pre-AMI meter (conventional meter) to the AMI smart meter. The aim of the survey is to evaluate Eskom's AMI deployment and the customer's reaction to the technology; such as behaviour changes, energy usage and relationship with the utility.

5.1.1 CASE STUDY OBJECTIVES

The objective of the case study is to ascertain the customer behavioural changes and the business impacts once AMI was implemented.

The key objectives include the following:

Customer aspects:

- ✓ Analyse customer response to the technology,
- ✓ Monitor customer behavioural change,
- ✓ Monitor customer energy consumption,
- ✓ Monitor customers' perception on AMI and relationship with the utility.

Business aspects:

- ✓ *Improve customer service & maximize operational efficiencies* - Reduce meter reading costs and the need for estimations through automated meter readings. Reduce non-technical losses through tamper detection and usage monitoring. Reduce call-outs through remote meter disconnects and reconnects and supports proactive maintenance through low voltage (LV) network visualisation monitoring.
- ✓ *Shift residential peak load* - to reduce the morning and evening peaks.
- ✓ *Promote customer behaviour change* - Incentivise the efficient use of electricity, promoting energy conscience lifestyle changes and empowering customers with usage information.

5.1.2 CASE STUDY HYPOTHESIS

The implementation of an AMI solution would improve the end user's perception around energy consumption, increasing efficiency and the value added from the AMI technology.

5.2 APPROACH AND METHODOLOGY

A survey was developed in order to test the hypothesis. After several consultations with Eskom Statisticians [56], a questionnaire design was developed. The questionnaire was designed to cover all aspects that could affect energy consumption in order to be able to conclude the effect of AMI solution. If the questionnaire design did not cover all aspects, it would have been difficult to conclude statistically if the change in consumption is assisted by the AMI solution. This is called confounding effect. The case study questionnaire design is briefly described below for each of the sections [APPENDIX A-1]:

Section 1: Biographical information

This section relates to general information pertaining to the customer. The customer is to complete this section by filling in his/her Name, Physical Address, Contact details and Account number. The information provided in this section will then be validated on the Eskom Customer Care and Billing System (CC&B), and hence be used for the case study.

Section 2: Energy provision information

This section requires the customer to list the major electrical appliances that they have at their residence. From this information we will ascertain the high consuming electrical appliances.

This section also establishes if the customer has installed any energy efficient products and their participation to the power alert broadcasts.

Section 3: Pre-AMI meter information installation (Old meter)

This section aims to determine the customers' ability to understand the electricity bill, paying attention to whether the bill was based on an actual or estimate read.

This section also establishes if the customer provided Eskom with meter readings and/or has queried accounts based on estimations; and therefore rate the service provided by Eskom. The customer was requested to provide the average amount spent on a monthly basis for electricity usage. This information will be compared to a similar question in section 4, after the AMI meter was installed.

Section 4: Post-AMI meter information installation (New meter)

This section is based on the AMI solution being installed and determines the same information as Section 3 to perform a comparative analysis.

This section also includes questions around the CIU to determine the effectiveness thereof. The CIU will promote energy efficiency to the customer and directly aid the utility in reducing capacity.

The methodology and approach followed to conduct the case study survey is listed below:

- ✓ Identify the sample selection of participants through an appropriate statistical analysis technique,
- ✓ Contacting of the participants through the Home owners association chairpersons for the respective complexes to be participating in the case study,
- ✓ Scheduling of appointments telephonically with each participant,
- ✓ Handing out of questionnaires and explaining to the participants the nature of the case study,
- ✓ Collection of the questionnaires back from the participants,
- ✓ Undertake a "Qualitative" analysis of the participants' responses as per completed questionnaires,
- ✓ Undertake a Quantitative analysis to compare the results with the participants electricity consumption patterns extracted from the Eskom billing system,
- ✓ Analyse and discuss the results and findings of the case study.

5.3 Statistical Techniques – Sample Selection

Various statistical sampling techniques were considered for the case study. There were three main types of sampling techniques that were reviewed:

- ✓ Random
- ✓ Systematic
- ✓ Stratified

During the sampling selection process of the most appropriate sampling technique to be used for this case study, statisticians [56] were consulted for their guidance and input.

The most appropriate method for this study was found to be the "Random Sampling" technique [57], [58]which can be defined as, a sample selected such that every member of the population has an equal chance of being selected to be a member of the sample independent of the other chosen members of the population. The "Random Sampling" technique selected was based on the following advantages [59]:

- ✓ Least biased of all sampling techniques, there is no subjectivity – each member of the total population has an equal chance of being selected,
- ✓ To devise a randomisation test for the hypothesis of no difference between the meters which do not depend on the distribution of the response. In many cases the distribution of this test statistic can be approximated by the Student's t-test [64] (Statistical method of testing the hypothesis),
- ✓ Ensure the validity of the inferences made even if the test statistics are not exactly normally distributed.
- ✓ Can be obtained using random number tables,
- ✓ Microsoft Excel has a function to produce random numbers using the function "=RAND ()".

5.3.1 SELECTION CRITERIA OF AMI INSTALLED COMPLEXES

The customers targeted for the pilot were selected based on pre-determined criteria. This criterion was determined in consultation with the Eskom AMI project team as well as in accordance with the South Africa Regulation 773. The selection criteria were thus:

- ✓ Target approach of medium to high consuming customers i.e. 500kWh and above focusing on Living Standard Measurement (LSM) groups 7, 8, 9 and 10 [66], [APPENDIX A-4],
- ✓ Single phase conventional metering technology customers,
- ✓ Eskom direct supplied customers only in urban areas.

The following AMI installed complexes in the Johannesburg suburbs of Sunninghill and Buccleuch were randomly sampled and complied with the selection criteria:

- ✓ Shambala
- ✓ Hampton Court
- ✓ Castle Rock Estates
- ✓ Badger Park 1
- ✓ Kalypso
- ✓ Naivasha Manor
- ✓ Riverside Manor
- ✓ Hilton Sands

As discussed in section 5.2, the case study questionnaires were handed out to the participants. The timeframe for the case study were as follows:

- ✓ Questionnaires were hand delivered to each complex mentioned above during the month of July 2012.
- ✓ Questionnaires were collected on an on-going basis from August until October 2012.

5.3.2 RANDOM SAMPLING OF CUSTOMERS IN AMI INSTALLED COMPLEXES

The random sampling technique based on reasons mentioned in section 5.3 was used to determine the target participants; and is shown in Table 20.

- ✓ The total number of Questionnaires handed out = 344
- ✓ The total number of Questionnaires received = 79

Table 20: Random sampling of population for the case study participants

SITES (AMI)	No. in complex	Questionnaires handed out	Questionnaires received (no. of respondents)
Riverside Manor	110	110	32
Hilton Sands	52	52	0
Kalypso	70	70	17
Shambala	26	26	13
Hampton Court	27	27	4
Badger Park 1	52	52	3
Castle Rock	26	26	6
Naivasha Manor	33	33	4
TOTALS	396	344	79

✓ To determine if the sample size is representative:

If sampling was done randomly, the sample is a good representative of the entire population. The size of the sample determines the power (ability of the test to reject a false hypothesis) of the test. If the sample size is too small, the power of the test is also reduced.

✓ To determine the sample size for the population:

The sample size was determined using "Table for Determining Minimum Returned Sample Size for a Given Population Size for continuous and Categorical Data" [60]

The following information was obtained from table [APPENDIX A-2]:

- Continuous (Margin error = 0.1)
- 90% Confidence level; alpha=.1 t=1.65
- Population size range of between 300 – 400, corresponding to the sample size range 65 - 69

Therefore, for a population size of 344, a sample of between 65 and 69 participants is sufficient to give a 90% confidence in the test.

In this study, the sample size is 79 which is more than the required sample size and is therefore sufficient to give 90% confidence. Although the desired confidence was 95%, the available sample size is too small for this power and therefore less power was chosen.

✓ To determine the number of questionnaires to be handed out using random sampling technique per complex:

Table 21 shows the number of questionnaires to be handed out in each complex as calculated using the random sampling technique.

Table 21: Number of questionnaires to be handed out using the random sampling technique per complex

AMI INSTALLATIONS	**Population Size = 344**	Number of units in complex	% Ratio per complex to total population size	**Sample Size**
	Riverside Manor	110	32.0%	49
	Hilton Sands	0	0.0%	0
	Kalypso	70	20.3%	31
	Shambala	26	7.6%	11
	Hampton Court	27	7.8%	12
	Badger Park 1	52	15.1%	23
	Castle Rock	26	7.6%	11
	Naivasha Manor	33	9.6%	15
				152

Therefore, the number of questionnaires per complex to be handed out was as follows:

Riverside Manor = 49
Kalypso = 31
Shambala = 11
Hampton Court = 12
Badger Park = 23
Castle Rock = 11
Naivasha Manor = 15

✓ To remove bias in selecting the unit numbers per complex where questionnaires are to be handed out:

As presented in Table 22 the random sampling technique in MS Excel® (Data analysis-random generation) was used to remove any bias in selecting the unit numbers in each complex.

Table 22: Example - Calculating the unit numbers for complex "Shambala"

Random Sample for SHAMBALA		Rounded off	Rounded off	Final Sample - Stand/Unit No's
16.87267678	9.324686	16	9	3
14.86379589	5.402295	14	5	4
7.276894436	8.808924	7	8	6
12.37348552	25.81689	12	25	7
4.717154454	22.90924	4	22	12
3.393414106	20.03439	3	20	25
18.52754295	22.22486	18	22	14
17.83629872	10.68123	17	10	16
6.227820673	20.47844	6	20	17
18.15903195	12.01489	18	12	18
7.678975799	12.70385	7	12	22
12.92281869	4.852199	12	4	
23.41355632	5.863887	23	5	
18.07052828	18.38334	18	18	
22.31412702	11.43199	22	11	
			COUNT	11

Therefore, the total count of 11 unit numbers in Shambala, where questionnaires are to be handed out is listed below:

> Unit 3, Unit 4, Unit 6, Unit 7, Unit 12, Unit 25, Unit 14, Unit 16, Unit 17, Unit 18, Unit 22

The data analysis iteration process was then done for all the complexes as shown in [APPENDIX A-2] to obtain the unit numbers in each complex where the questionnaires were to be handed out.

5.4 ASSUMPTIONS

The following assumptions were made with respect to the analysis of the case study design and analysis thereof:

- ✓ All AMI Meters installed in the deployed areas had correct data on the billing system.
- ✓ The information provided by the customer on the survey is correct and still applicable at the time the analysis was done.
- ✓ Customers understood the questions that were posed in the questionnaire.
- ✓ The "number of people" in the households that participated in the case study has not changed during the period - before and after.
- ✓ The increases in "Electricity Tariffs" have been noted for the case study. The participants energy consumption (kWh) was taken into consideration for the Quantitative analysis i.e. comparison on the energy consumption of the participants, between years 2010 to 2013, having the "old" conventional meter to that of the AMI smart meter.

- ✓ For statistical purposes, it is assumed that for all households, consumption in one household does not depend or affect consumption in any other household.
- ✓ For statistical comparison purposes, potential outliers or influential observations for the conventional and AMI smart meters were not removed during the data cleansing process.

CHAPTER 6: CASE STUDY - ANALYSIS AND DISCUSSION OF RESULTS

6.1 INTRODUCTION

This section discusses the findings and results of the questionnaires handed out to participants. A detailed analysis and discussion of results for each question within the respective sections as per the questionnaire will be highlighted and aid in addressing the Hypothesis.

The discussion of the results of the case study will be presented in 2 parts. The first part will focus on the Qualitative analysis where "qualitative" type questions from the questionnaire, discussing the responses provided in the questionnaires by the participants. The second part will focus on a Quantitative analysis where the "quantitative" type questions from the questionnaire will be compared to actual data from Eskom's Customer Care and Billing (CC&B) system.

6.2 QUALITATIVE ANALYSIS: PRE AND POST QUESTIONNAIRE

This section will present the qualitative results in section 6.2.1 and analysis of the questionnaires in section 6.2.2 respectively.

6.2.1 RESULTS OF QUESTIONNAIRE

Table 23, Table 24 and Table 25 presents the responses of the participants. The results are structured as per the section in the questionnaire [APPENDIX A-1].

Table 23: Results from questionnaires for Section 2 – Energy provision information

SECTION 2 - Energy Provision Information

2.1 Major Home Appliances

Under-floor Heating	*Electric Stove*	*Air Conditioner*	*Geyser*	*Swimming Pool Pump*	*Fridge*	*Other*
29.1%	***89.9%***	***34.2%***	***97.5%***	***32.9%***	***94.3%***	***2.5%***

2.2 Has the customer installed any Energy Efficient products or solutions (e.g. Solar Water Heater, Heat Pump etc.)? If Yes, State the solution installed?

YES	*NO*
34.2%	***64.6%***

2.3 Did the customer change his behaviour patterns as a result of the Eskom Power Alerts on TV /Radio?

YES	*NO*
72.2%	***27.8%***

Table 24: Results from questionnaires for Section 3 – Pre AMI installation information

SECTION 3 - Pre - AMI Meter Installation Information (OLD METER)

3.1 Does the customer check his/her Eskom Bill to see if the bill is an "Actual Read" or an "Estimate"?

YES	*NO*
68.4%	***31.6%***

3.2 How often are you billed on an "Actual Read"?

Every month	*Every 3 months*	*More than 3 months*	*Unsure*
41.8%	***20.3%***	***2.5%***	***35.4%***

3.3 Did the customer read his/her own meter and phone/sms the meter readings to Eskom?

YES	*NO*
22.8%	***74.7%***

3.4 Did the customer call the Contact Centre or visit an Eskom Customer Services Office due to dissatisfaction or a query with a bill (too high) based on Estimation?

YES	*NO*
21.5%	***72.2%***

3.5 Please rate the service provided by Eskom? (Scale of 1- 5, where 1 is most disappointed and 5 extremely satisfied)

Most Disappointed	*Disappointed*	*Fair*	*Satisfied*	*Extremely Satisfied*
1.3%	***6.3%***	***44.3%***	***32.9%***	***7.6%***

3.6 What was the customers' bill on average before the Smart Meter was installed?

Less than R500/month	*Between R501 – R1000/month*	*More than R1000/month*	*No Comment*
41.8%	***40.5%***	***7.6%***	***10.1%***

3.7 What was the customers overall feeling of the conventional meter? (Scale of 1- 5, where 1 is most disappointed and 5 extremely satisfied)

Most Disappointed	*Disappointed*	*Fair*	*Satisfied*	*Extremely Satisfied*
2.5%	***12.6%***	***51.9%***	***20.3%***	***0%***

Table 25: Results from questionnaires for Section 3 – Post AMI installation information

SECTION 4 - Post - AMI Meter Installation Information (NEW METER)

4.1 How often was the customer's meter read?

Every month	*Every 3 months*	*More than 3 months*	*Unsure*
37.9	***3.8%***	***1.3%***	***51.9%***

4.2 Did the customer read his/her own meter and phone/ sms the readings to Eskom?

YES	*NO*
6.3%	***87.3%***

4.3 Did the customer call the Contact Centre or visit an Eskom Customer Services Office due to dissatisfaction or a query with a bill (too high) based on Estimation?

YES	*NO*
8.9%	***83.5%***

4.4 What was the customer's bill on average after the Smart Meter was installed?

Less than R500/month	*Between R501 – R1000/month*	*More than R1000/month*	*No Comment*
44.3%	***24.1%***	***21.5 %***	***10.1%***

4.5 Did the customer find the Customer Interface Unit (CIU) easy to operate and user friendly?

YES	*NO*
26.6%	***48.1%***

4.6 Is the CIU assisting the customer in managing his/her electricity consumption?

YES	*NO*
22.8%	***58.2%***

4.7 Has the customer noticed a decrease in the bill / consumption after installation of the AMI Solution?

YES	*NO*
12.7%	***68.4%***

4.8 What was the customers overall feeling of the new AMI solution (Smart meter and CIU)? (Scale of 1- 5, where 1 is most disappointed and 5 extremely satisfied)

Most Disappointed	*Disappointed*	*Fair*	*Satisfied*	*Extremely Satisfied*
5.1%	***12.7%***	***40.5%***	***27.8%***	***2.5%***

4.9 Please rate the service provided by Eskom in regard to the installation of the AMI solution? (Scale of 1- 5, where 1 is most disappointed and 5 extremely satisfied)

Most Disappointed	*Disappointed*	*Fair*	*Satisfied*	*Extremely Satisfied*
3.8%	***7.6%***	***25.3%***	***41.8%***	***8.9%***

6.2.2 Discussion and Analysis of Questionnaire Results

This section will present a discussion and analysis for each section in the questionnaire.

6.2.2.1 Section 2 – Energy Provision Information

Analysis of major home appliances

Major home appliances account for a significant portion of residential energy consumption. Therefore, to determine the extent of energy consumption in a particular household, one should first identify the major appliances the house uses daily. Question 2.1 was formulated with the aim of identifying these appliances.

The objective of Question 2.1 was to determine the type of appliances the participants had in their homes, and to ascertain if these customers were using high energy consuming appliances or had energy efficient appliances such as solar water heating, heat pumps etc. The participant was given six major appliances, and had to select those that were used in their homes. Figure 19 gives a graphical summary of the results from Question 2.1 and shows that the geyser (25.6%), refrigerator (24.8%) and electric stove (23.6%) are the most prevalent appliances. Based on the results, a majority of the customers that responded to the survey use high amounts of energy on a daily basis. This further supports the need to create awareness amongst customers regarding the extent of their energy consumption.

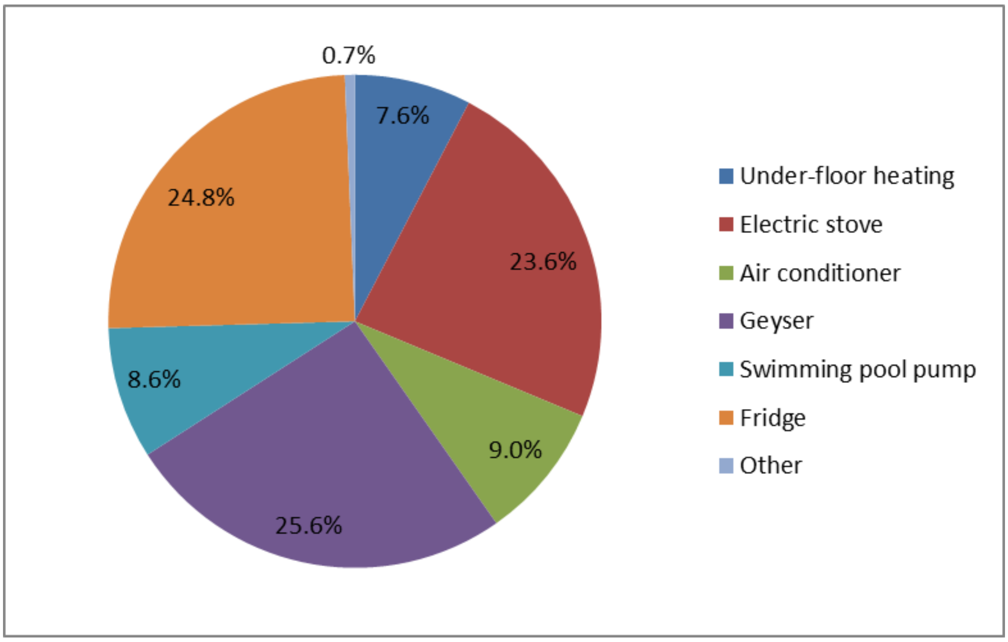


Figure 19: Analysis of major home appliances

Analysis of installed energy efficient (EE) products or solutions

Figure 20 shows that only 34.62% of the participating customers have invested in EE appliances while a majority of 65.38% are without EE solutions. A majority of the interviewed consumers have not installed energy efficient products. This means that a change in energy consumption (if any), cannot be associated with the installation of energy efficient solutions. The unwillingness to invest in EE appliances could be attributed to the high upfront costs, lack of information and, possibly, disruption of normal lifestyle.

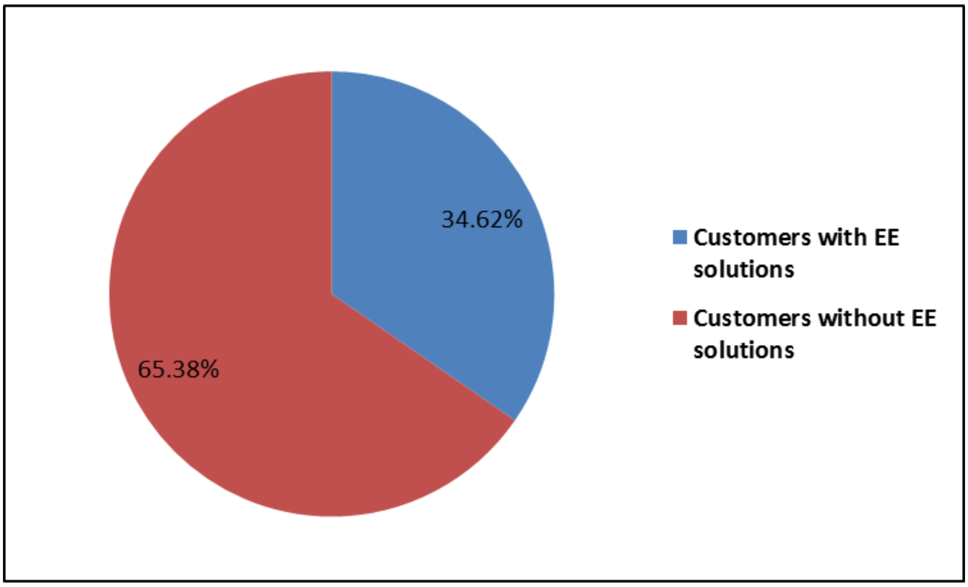


Figure 20: Analysis of installed energy efficient products and solutions

Analysis of behavioural change due to Eskom Power Alert initiative

The Power Alert [67] is an innovative residential load management tool that uses media (television, radio, etc.) to inform the general public on the status of South Africa's electricity supply capacity as well as how to assist in reducing demand during capacity constraints.

The objective of Question 2.3 was to determine how much influence or effect the Power Alert had on the behaviour of the customers. Figure 21 shows that over 72.2% of the customers responded that their behaviour was changed because of the Power Alert and only 27.8% did not change their behaviour. The survey results indicate that the customers' perception is that the Power Alert campaign has been very successful in influencing customer behaviour with regard to the use of energy. This attributed to the fact that the Power Alert only requires the customers to switch off appliances during supply capacity constraints only, and offers recommendations as to which appliances to switch off. Further to this, regular feedback is given back to customers to ensure that customers are aware of the impacts of their actions on the South Africa's electricity supply capacity.

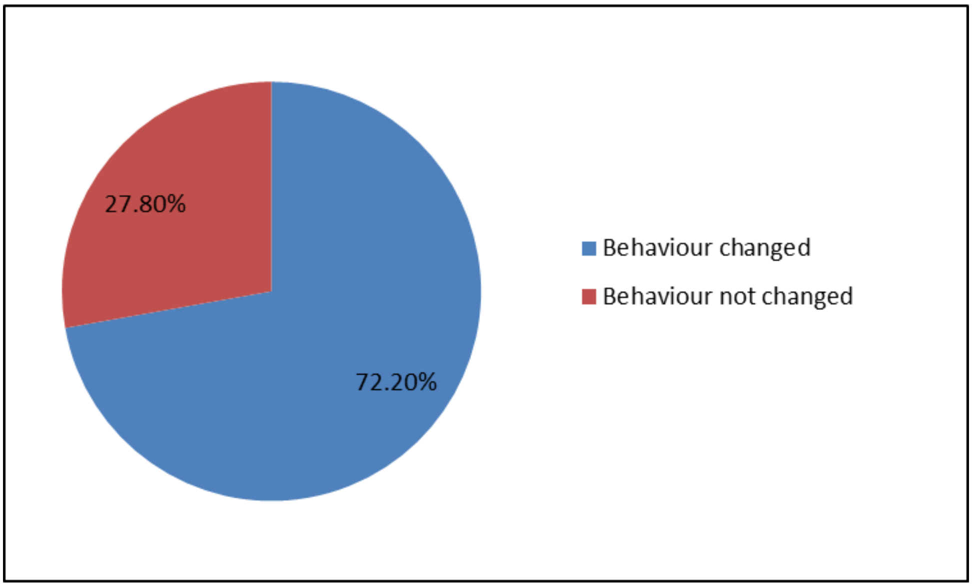


Figure 21: Analysis of impact on Power Alert

6.2.2.2 Section 3 and 4 – Comparative analysis of Pre and Post AMI Meter

Customers understanding of the billing process

Prior to the installation of smart meters, Eskom's customers' bills were based on a combination of actual and estimated meter readings (i.e. the meters were read every 3 months and between the monthly reading intervals the readings were estimated).

With smart meters, the readings can be performed remotely without the need to dispatch a team of meter readers to the customers' home. Thus, it is less expensive to bill the customers based on actual readings on a monthly basis.

As part of Eskom's AMI programme, efforts were made to educate the customers on the changes in the billing and meter readings as a result of smart meter installations. These efforts involved the hosting of a number of customer engagement forums; and compilation and distribution of "Customer Information Packs".

In order to effectively render the AMI technology in influencing customer behaviour, customers had to be able to interpret their energy bill in terms of the calculations used therein.

For this reason, the customer behaviour questionnaire included questions aimed at establishing the following:

- ✓ If the customer could verify whether his/her bill is based on actual or estimated meter readings (Question 3.1)
- ✓ If the customer knew how often he/she was billed on actual meter readings (Question 3.2)
- ✓ If the customer read his/her own meter and forwarded the readings to Eskom (Question 3.3 and 4.2)

✓ Customers' understanding of the frequency of AMI meter reading (Questions 4.1)

The results of the questionnaire, listed under Section 6.2.1, showed that 68.4% of the participants were able to verify whether their bills were based on estimated or actual readings i.e. a majority of the participants could interpret their bills.

The responses from the participants for question 3.2 indicated that 41.8% were billed on actual readings every month, 20.3% every three months and 35.4% were unsure how often they were billed on actual readings. As the majority could interpret their bills, the uncertainty about the frequency of bills based on actual readings could have been due to the shortcomings of the manual meter reading process which is prone to data capturing human errors, etc.

Questions 3.3 and 4.2 enquired if customers read their own meters, i.e. during the use of conventional meters and after the installation of smart meters, respectively. Figure 22 reflects that after the installation of smart meters there was a 16.5% decrease in the number of customers who read their own meters. This can be attributed to the fact that after the installation of smart meters the customers were billed only on actual readings and thus there was no need to submit readings for correction of estimates.

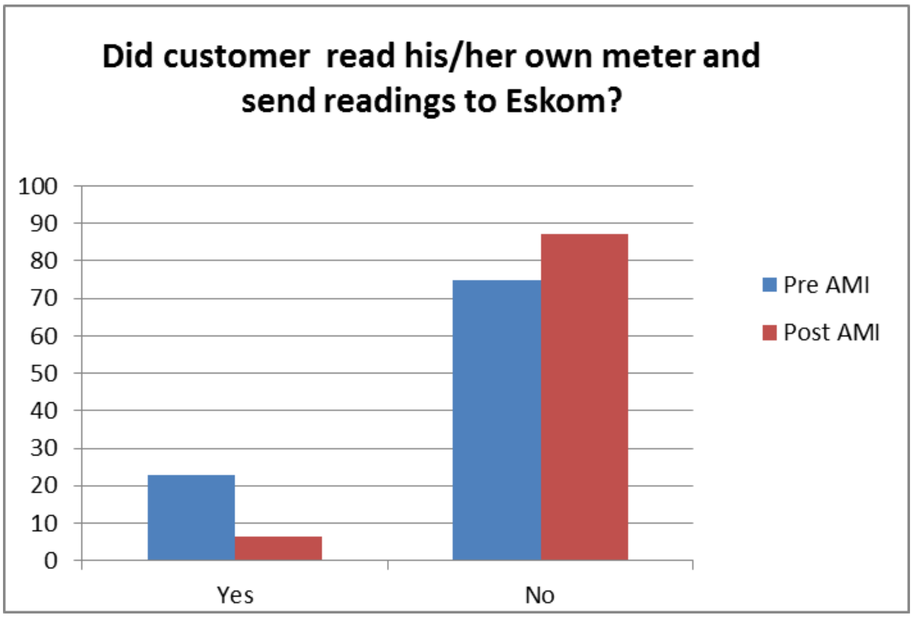


Figure 22: Percentage of customers that read their own meters

The objective of question 4.1 was to determine if the participants had known how often smart meters were read and whether these meters were read remotely through automated meter readings. There were 59.1% of the participants that were unsure how frequent their smart meters were being read. This highlighted the fact that AMI is a relatively new and maturing technology; and would require a more intense approach in customer education to ensure that the technology could be fully understand. The high figure of 59.1% could also have been attributed to the poor attendance of the residents during the customer engagement sessions marketing and introduction of the AMI solution.

Questions 3.4 and 4.3 determine the percentage of customers that queried their monthly bills through the Eskom Contact Centre or Customer Services office. The reponses revealed that prior to AMI, 21.5% of the participants stated they queried their bills and post AMI 8,9%

queried their bills. After the installation of AMI, less number of customers read their meters and sent readings to Eskom. This decrease can be attributed to more satisfaction with bills as the bills are now based on actual readings with no estimations in between. This is further supported by the results in Figure 23 where there is a clear increase in the number of satisfied customers.

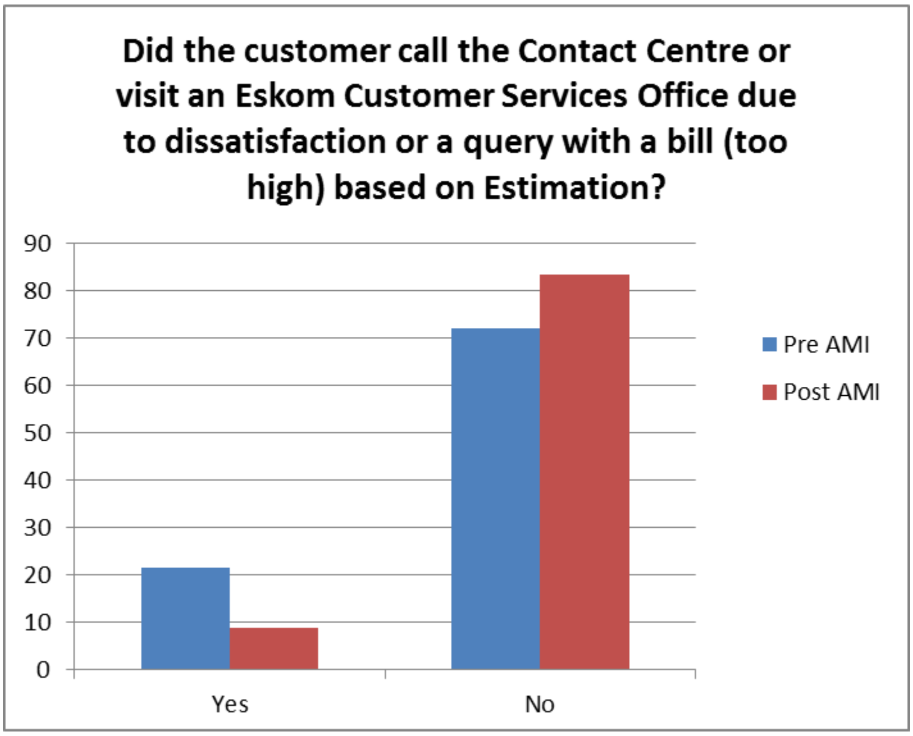


Figure 23: Percentage of customers that queried their bills

Effectiveness of the Customer Interface Unit (CIU)

A very important element of the AMI solution is the installation of Customer Interface Unit (CIU) also known as the in-home display unit through which each customer will be able to monitor and see the status of the electricity consumption of the household.

Figure 24 provides an indication of the effectiveness of the CIU in assisting customers manage their energy usage. More than half (58.2%) of the customers did not find the CIU helpful in managing energy. This is further supported in Figure 25 where close to half (48.1%) of the participants responded that the CIU was not user friendly and easy to operate. It was also found that a significant numbers of customers could not interpret the information provided on the CIU displays.

There were many customers that did not respond to Questions 4.5 and 4.6. This is due to that some of these customers had not received CIUs as when the survey was being conducted, the CIUs were still being distributed by an external contractor on behalf of Eskom. Furthermore, customers reported minimal instruction and education on the operation and functioning of the CIU. These customers also requested more training and information from the Eskom Contact Centre.

The survey also revealed that some of the customers disconnected the CIU from the power supply as they suspected that the CIU consumes "high" amounts of power which they would be paying for in their bills. However, the CIU consumes approximately 2 watts of power which is minimal and the end user should be informed thereof in future.

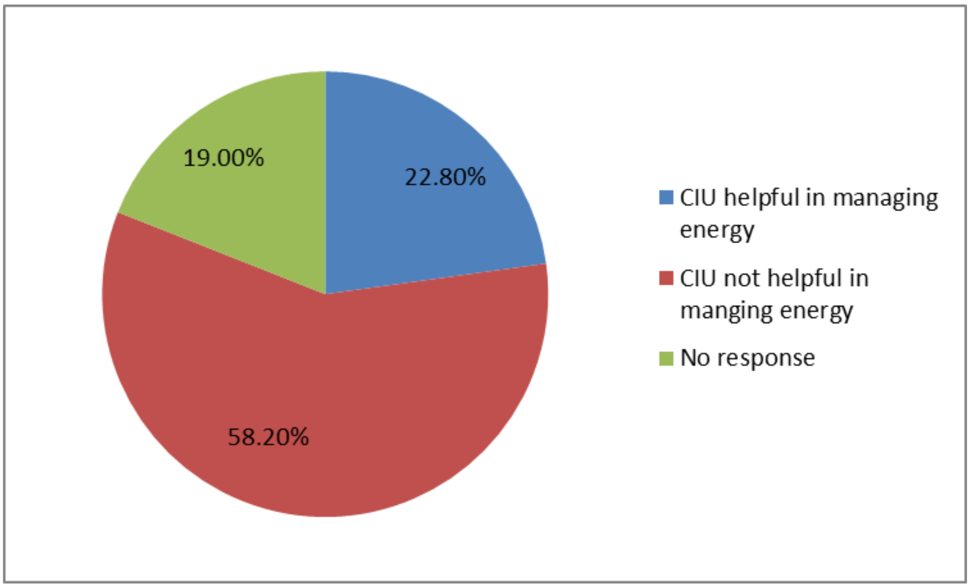


Figure 24: Percentage of customers that found the CIU to be helpful

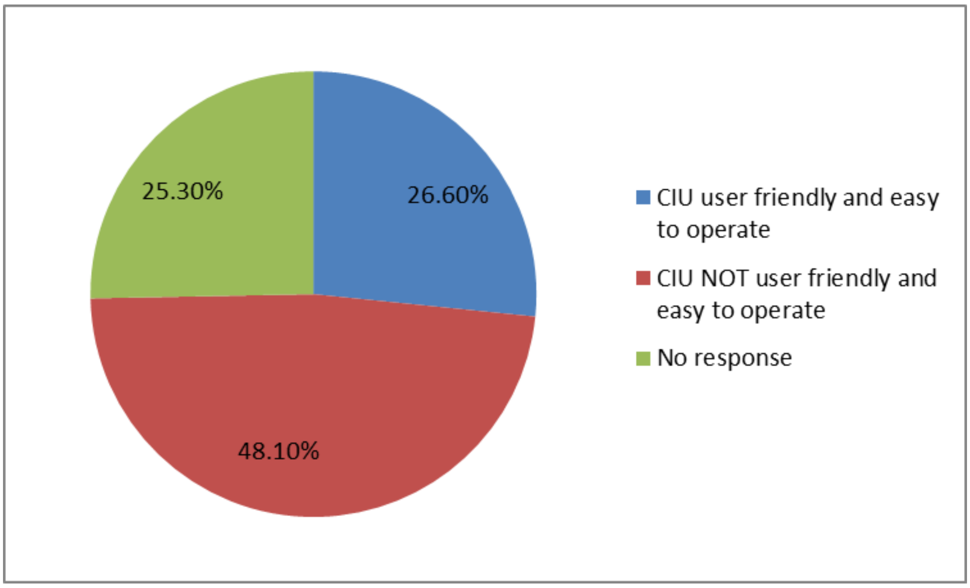


Figure 25: Percentage of customers that found CIU to be user friendly and easy to operate

Average monthly bill – before and after AMI was installed

Figure 26 indicated that prior to the installation of smart meters, 41.8% of participants were billed less than R500 per month and 40.5% were billed between R501-R1000 per month. After the installation of smart meters 44.3% report that they were billed at less than R500 per month while 24.1% were billed at R501-R1000 per month. This shows that the number of customers billed below R500 per month increased by 2.5% or that 2.5% of the customers realised a decrease in their monthly bill. Furthermore, 21.5% of the customers reported that they were billed over R1000 after the smart meters were installed. This presents a 13.9% increase in the percentage of customers billed over a R1000 per month after the installation of smart meters.

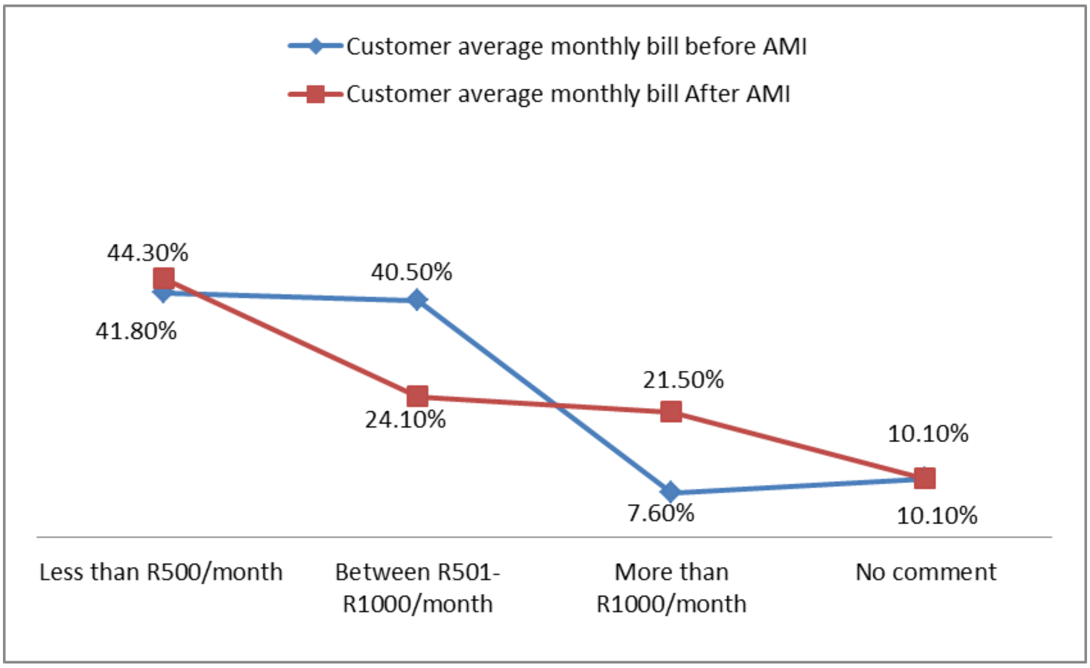


Figure 26: Analysis of average monthly bill

After the installation of the AMI smart meter only 12.7% (Figure 27) reported a decrease in their bill or consumption while a majority of 68.4% reported no decrease in their bill or consumption. This could have been attributed to the ineffectiveness of the CIU in influencing customer behaviour with regards to energy efficiency. Also, due to tariff increases during the duration of the survey, bills were often perceived by customers to be always high.

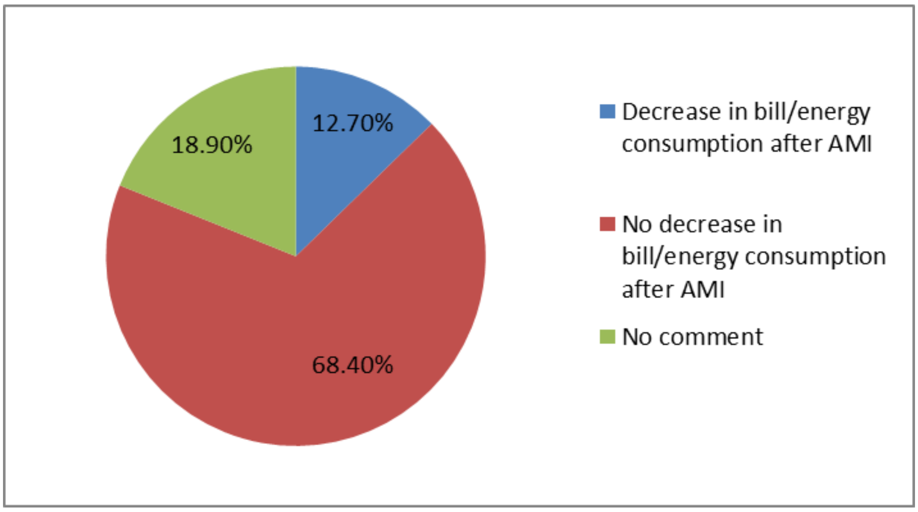


Figure 27: Decrease in bill or energy consumption post AMI installation

<u>Customer perception of conventional meter performance in comparison to that of a smart meter</u>

Figure 28 shows an increase in the number of satisfied and extremely satisfied customers. More than half of the customers reported that the Conventional Meter performs fairly but this number decreased by 10% for AMI Meters. This can be explained by the increased number of satisfied and extremely satisfied customers. A minority (less than 5%) of customers was most disappointed with AMI Meters.

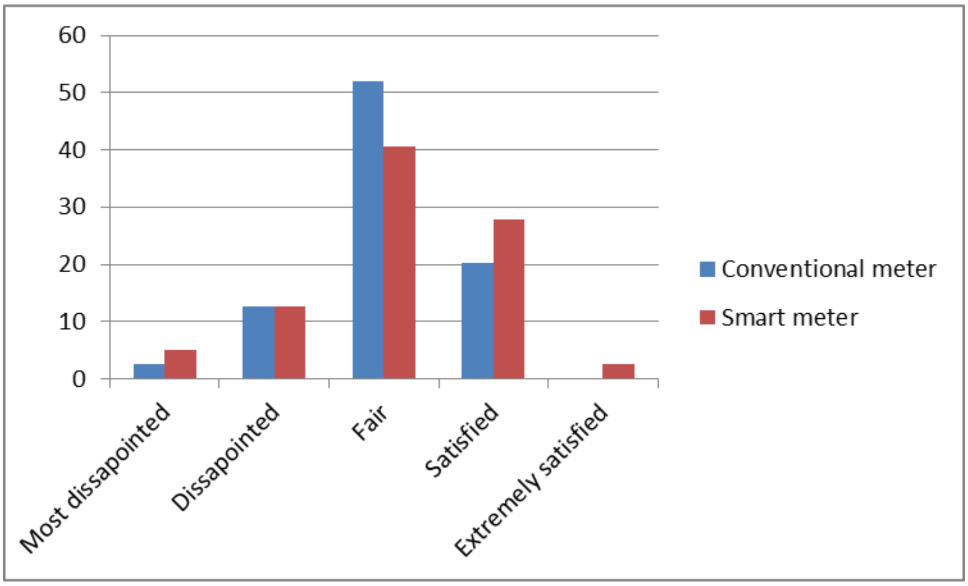


Figure 28: Comparative analysis of smart meter versus traditional conventional meter

Rating of customer service offered by Eskom before and after the installation of smart meters

During the rollout of the AMI programme there were increased interaction through information forums, distribution of information, fault investigations, etc. with customers. It was intended through Questions 3.5 and 4.9, to determine the level of service as perceived by customers during this period compared to service offered during the conventional meter era.

Figure 29 indicates an increased number of satisfied and extremely satisfied customers with the customer service offered by Eskom. Results in Figure 29 are consistent with the results in Figure 28, although there is a small increase in most disappointed customers; more than half of the customers are either satisfied or extremely satisfied. This shows that customers increasingly desire more interaction with the utility; thus AMI by design being a customer-centric technology should enable a more interactive customer-utility relationship.

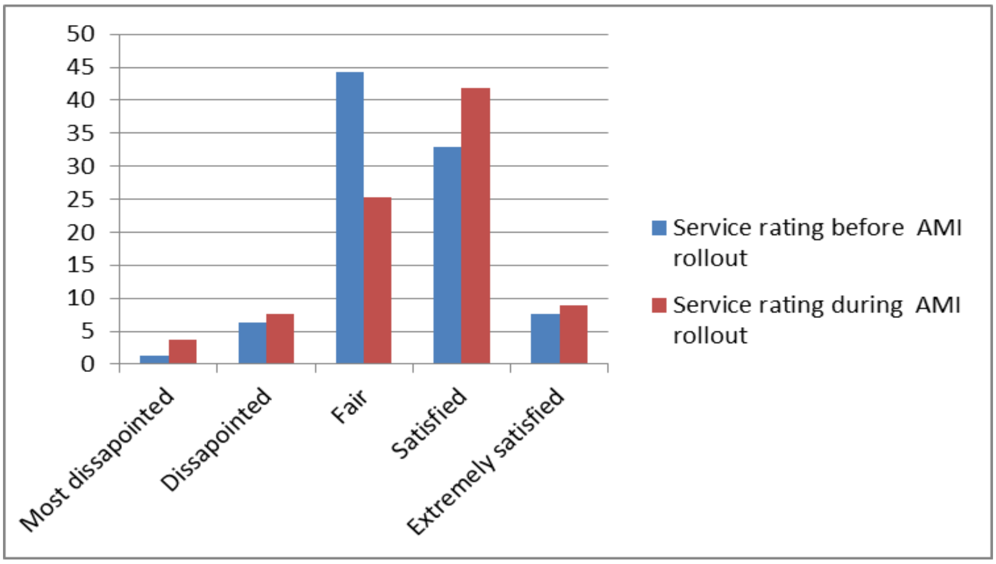


Figure 29: Analysis of customer services ratings by participants

6.3 QUANTITATIVE ANALYSIS: MEASUREMENT AND VERIFICATION STUDY TO ANALYSE AND DISCUSS THE PARTICIPANT'S ENERGY CONSUMPTION PATTERNS USING ESKOM'S CUSTOMER CARE AND BILLING SYSTEM

This section presents a quantitative analysis of the 79 participant's energy consumption patterns and their responses in the survey, using an extract populated with data for a period December 2009 to July 2013, downloaded from Eskom's CC&B system. The energy consumption data of the participants in the case study has been used to determine the savings in energy when the smart meter had been installed and compared to that of the traditional conventional meter.

Statisticians were consulted to advice on the most appropriate statistical technique for the case study. Various statistical techniques were considered and the "Box Plot" method [61] was selected. The "Box Plot" is a statistical graphical method used for identifying outliers in the dataset, comparing distributions and to display a summary of statistics for a set of data. The data extract for the 79 participants from the Eskom CC&B system, used for the quantitative analysis, was "data cleansed" for each month during year 2010 where the traditional conventional meter was still installed, and year 2012 where the traditional conventional meter was replaced with the AMI Meter.

6.3.1TOTAL ANNUAL CONSUMPTION FOR 2010 (CONVENTIONAL METER)

Figure 30 indicates the total consumption of the 79 participants of the survey for the period January 2010 to December 2010 recorded by the conventional meter.

Descriptive statistics - 2010

	# 1
count	757
mean	1 300.73
sample variance	1 952 171.86
sample standard deviation	1 397.20
minimum	0
maximum	11893
range	11893

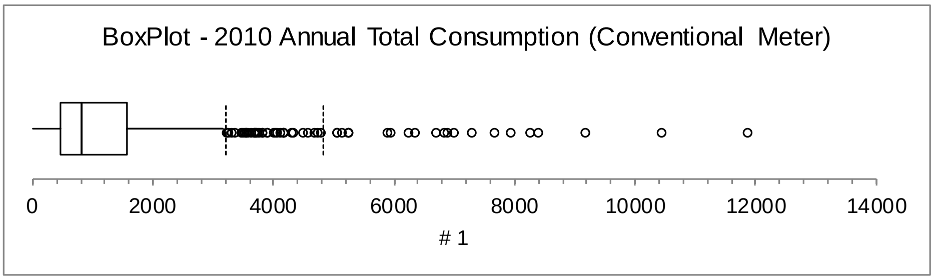


Figure 30: Annual total consumption (kWh) of participants recorded by the conventional meter in 2010

The Box Plot shows the observations for 2010 consumption. Observations that are outside the outer fence (second dotted line) are potential outliers or influential observations. However, due to the nature of the study, these observations were not removed. The reason for this is that the conventional meters were not read every month and readings had to be estimated for those particular months.

6.3.2 TOTAL ANNUAL CONSUMPTION FOR 2012 (AMI METER)

Figure 31 indicates the total consumption of the 79 participants of the survey for the period January 2012 to December 2012 recorded by the AMI meter.

Descriptive statistics - 2012

	# 1
count	780
mean	778.50
sample variance	967 458.48
sample standard deviation	983.59
minimum	12
maximum	15856
range	15844

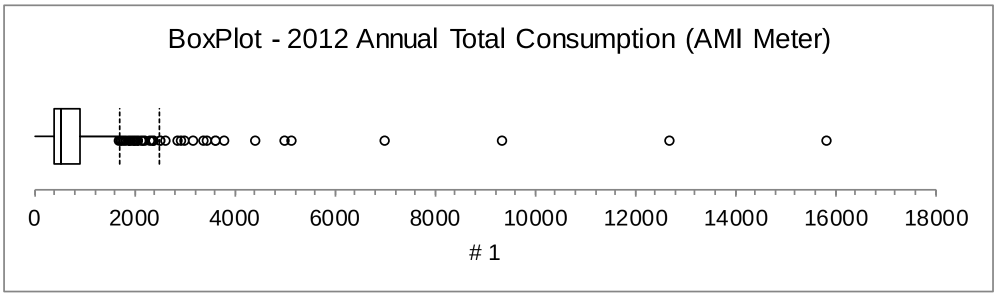


Figure 31: Annual total consumption (kWh) of the participants recorded by the AMI meter in 2012

The Box Plot above shows observations in the year 2012. To be consistent (for statistical purposes) with the conventional meter Box Plot, observations that are potential outliers or influential observations were not removed. The outer fence has decreased to just above 2 200. It can be observed that the readings are closer to each other compared to that of the observation 2010. The standard deviation has decreased which implies that the variation of readings for AMI meters is less than that of the conventional meters.

6.3.3 COMPARISON TREND: CONVENTIONAL METER (2010) AND AMI METER (2012)

Table 26 reflects the total monthly energy consumption profiles for all participants for both the conventional meter and the AMI smart meter for the periods 2010 and 2012 respectively. During 2011 the meter installations were being implemented and therefore the data was not analysed.

Table 26 is based on the sum of the energy consumptions for the 79 participant per month for periods 2010 and 2012. Based on the statistical Box Plot mean values for each month [APPENDIX A-3] during 2010 and 2012, the consumption trend over a 12 month period is shown in Figure 32.

Table 26: Total monthly energy consumptions for each month during 2010 and 2012

	Jan	Feb	Mar	Apr	May	Jun
CONVENTIONAL METER 2010	519.12	746.27	625.6	562.36	1091.17	1390
AMI METER 2012	669.28	780.63	515.68	649.52	612.67	750.32
	Jul	Aug	Sept	Oct	Nov	Dec
CONVENTIONAL METER 2010	1902.4	1928.5	835.75	905.82	2649.83	1144.3
AMI METER 2012	961.57	1101.46	662.52	491.67	579.54	561.63

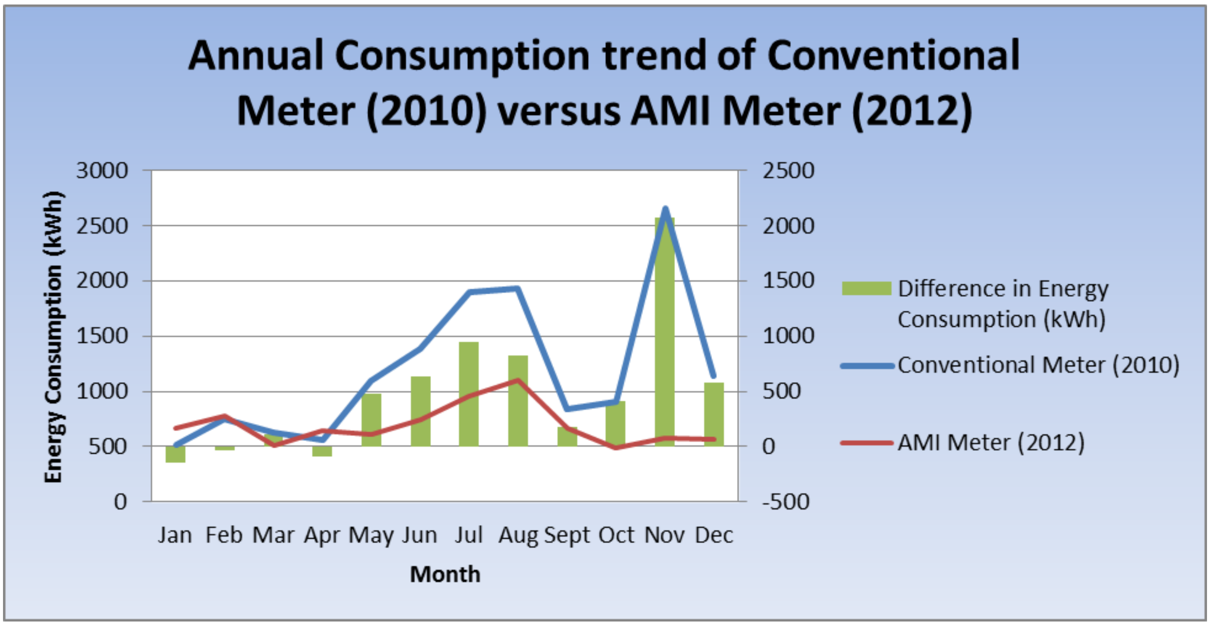


Figure 32: Comparison trend showing the total monthly energy profiles from the conventional meter during 2010 and AMI meter in 2012

Figure 32 indicates that the average energy consumption trend when the AMI meter was installed is much lower than that for the traditional conventional meter. Only 3 months (January, February and April) have recorded average consumption that was above. The graph shows a trend of data collection for the conventional meter compared to that of the AMI meter. The curve for the AMI meter as illustrated in the graph is more of a straight line and shows consistency in the trend pattern which can be attributed to the data interval reads of 30 minutes through automated meter readings. In the case for the conventional meter the graph shows a more inconsistent pattern mainly due to the meters being read manually and customers being hence estimated during the billing periods.

6.3.4 Hypothesis Testing for Case Study

In order to test if the consumer behaviour has changed after the installation of AMI Meters, a paired sample t-test [64] was used to test the following hypothesis:

H_0: Consumer energy consumption has not changed after installation of AMI, i.e. average consumption post-AMI is equal to the average consumption pre-AMI.

H_1: Consumer energy consumption has changed after installation of AMI, i.e. average consumption post-AMI is not equal to average consumption pre-AMI

This is equivalent to saying:
H_0 : $mean_{post\text{-}AMI}$ = $mean_{pre\text{-}AMI}$
H_1 : $mean_{post\text{-}AMI} \neq mean_{pre\text{-}AMI}$

Paired t-test was used as the same individuals were used before and after AMI Meters. This means that the samples remained the same.

As stated before, the power of the hypothesis test or the confidence level that the sample allows is 90%. This means that the null hypothesis will only be rejected if the significance value (also known as p-value) is less than 10%.

The test was conducted using R (a statistical software package) and the results are as follows:

```
Paired t-test

data:  CONVENTIONAL.METER and AMI.METER
t = 2.8158, df = 11, p-value = 0.01679
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
108.5305 885.5745
sample estimates:
mean of the differences
497.0525
```

The calculation above shows the difference between a conventional meter and AMI meter is 497.05kWh in average energy consumption. The positive difference confirms that the energy consumption for AMI meters is less than the energy consumption for conventional meters.

Conclusion: The null hypothesis is rejected as the significance value is less than 10%. Hence, it can be concluded that the consumer energy consumption has changed after installation of the AMI meters. It is worth noting that as the significance value is less than 0.05, the null hypothesis would be rejected under the 95% confidence level.

6.4 CONCLUSIONS

This section will highlight the findings for both the qualitative and quantitative analysis of the case study.

6.4.1 CONCLUSIONS – QUALITATIVE ANALYSIS FOR CASE STUDY

- ✓ The majority of the customers accepted the AMI technology positively; and to be more effective than the traditional conventional meter. However, many of the customers found the CIU to be ineffective for reasons stated in the discussion of results.
- ✓ Customer education on the operations and functioning of the CUI was insufficient. This is due to customers being provided only with an instruction manual without any training and explanation. It is therefore recommended that customer education needs to be more aggressive and continuous engagement with customers is required to monitor their understanding of the use of the CIU.
- ✓ The existing CIU display is difficult to interpret. It is recommended that a standardized display similar to the Power Alert graphics be incorporated into future CIU designs. Also the “cost of electricity” information should also be activated and displayed on the CIU.

- ✓ Thus in order for energy information provided by CIUs to be useful to customers it has to be presented in an easily understandable language. This also applies to labels used, buttons or switches that the customer uses to operate CIUs.
- ✓ The fact that a majority has not yet invested in energy efficient products such as solar water heaters, heat pumps, compact fluorescent lighting etc. raises questions about the effectiveness of the CIU in influencing customer behaviour.
- ✓ Encourage customers to participate in demand response programs that shift demand from peak to off peak times based on voluntary customer behaviour. Demand response programs use technology such as the CIU or in-home display that provide pricing, consumption, environmental and billing information to the customer; tariffs such as ToU; and customer education to manage demand. Demand response provides an opportunity to reduce overall energy consumption by increasing information to customers; and creates customer awareness that may lead to customer behaviour change.
- ✓ Customer convenience and comfort is extremely important, together with effective incentive schemes where cost rebates in the energy bills are provided to customers by the utility for energy consumption reduction and participation in demand response programmes. Energy efficient behaviour is only upheld if it has a visible and immediate effect on the electricity bill.
- ✓ Technical issues were experienced during the initial rollout of the project. These issues inconvenienced customers by randomly disconnecting their power supply and receiving erroneous bills. Therefore the customers’ experience and acceptance to the AMI solution was adversely affected. This may account for the negative perception of the service ratings received during the AMI rollouts.

6.4.2 CONCLUSIONS – QUANTITATIVE ANALYSIS FOR CASE STUDY

- ✓ Conventional meter analysis - the energy consumption profiles revealed large variances in usage over the 12 month period during 2010. This is uncharacteristic especially with a higher usage which appears in November 2010. The higher usage in the winter months (June, July and August) is reflected in the consumption pattern.
- ✓ AMI smart meter analysis – the energy consumption pattern is consistent for residential households. It is evident that the usage increases over the winter months of June to August and decrease over the summer months (September to May).
- ✓ The hypothesis test confirms that the consumer energy consumption in AMI meters is less than the consumer energy consumption in conventional meters. AMI meters aid consumers to be energy efficient as it is easier to track consumption through the CIU.

CHAPTER 7: CONCLUSIONS, RECOMMENDATIONS AND FUTURE WORK

7.1 CONCLUSIONS

The research study has resulted in the following key conclusions in support of the hypothesis - "the value proposition of implementing an AMI solution exists in an emerging economy and justifies the significant investment for such a solution":

- ✓ Market drivers determine the functional requirements for smart meters in each particular market. In most countries, both developed and emerging (such as South Africa), the drivers included regulation, legislation and/or specific government initiatives and interventions.

- ✓ The research has shown that lack of interoperability, standards and open protocols is a key challenge in most developed and emerging economies. The requirements for smart meter functionality vary significantly between countries based on their respective market drivers. This reduces the value proposition due to increased smart meter prices.

- ✓ AMI is still a maturing technology in both developed and emerging economies. Based on research by KEMA most U.S. utilities recognise that AMI technologies are maturing, but they cannot be characterised as being fully mature at this point. Large scale AMI deployment will result in the AMI technology evolving towards maturity, and to be priced at lower levels (due to economies of scale) to show a more positive cost-benefit analysis.

- ✓ Automated metering is a fundamental building block of a smart grid. In an emerging market environment, the challenges around effective business analysis and strategy development due to AMI deployment will place enormous demands on the information infrastructure of the power utility. Meter data volume growth and interoperability amongst new applications will be key characteristics of AMI towards a smart grid.

- ✓ Despite the many challenges experienced in an emerging economy such as South Africa, based on Eskom's pilot AMI deployment, there is a valid value proposition for AMI. The power utility has realised the following benefits which support the hypothesis:

    - Reduced meter reading costs, i.e. significantly reduced need to employ meter readers resulting in cost savings to the utility. The existing meter reader workforce could be re-deployment to increase the customer service efficiency.
    - Reduced meter reading errors, i.e. automated meter reading instead of manually capturing meter readings, eliminating human error when capturing.

    - Revenue protection through decreased electricity theft, i.e. smart meter flagged tamper detection alerts on the master station.

- ✓ The case study presented the hypothesis – “the implementation of an AMI solution would improve the end users’ perception around energy consumption, increasing efficiency and the value added from the AMI technology”, by concluding the following:

    - The majority of the customers accepted the AMI technology positively; and to be more effective than the traditional conventional meter. However, many of the customers found the CIU to be ineffective as the display was difficult to interpret and operate; and not user friendly.
    - Customer convenience and comfort was extremely important, together with effective incentive schemes.
    - The hypothesis test confirmed that the consumer energy consumption with AMI meters was less than the consumer energy consumption when conventional meters were used. The AMI solution did aid the consumers to be more energy efficient; it is expected that this is because it was easier to track consumption through the CIU once customers had familiarised themselves with the CIU over time. This was shown by the quantitative analysis of the case study results.
    - During the implementation of the initial AMI pilot project, issues came to light from customers being randomly disconnected or erroneously billed. Due to these technical factors, the customers’ experience and acceptance to the AMI solution might have been adversely affected.

7.2 RECOMMENDATIONS AND FUTURE WORK

The following recommendations are proposed out of the lessons learnt from the research study:

- ✓ The lack of interoperability, standards and open protocols should be addressed by the industry, to improve the value proposition of AMI.

- ✓ The information technology infrastructure associated with AMI should be capable of handling the large volume of data expected to be generated from smart meters.

- ✓ Customer education should be more aggressive and there should be continuous engagement with customers to monitor their understanding of the use of the CIU.

- ✓ A standardised display similar to the Power Alert graphics used on television should be incorporated into future CIU designs. The “cost of electricity” information should be displayed on the CIU.

- ✓ Utilities should provide customers with effective incentive schemes, such as cost rebates for energy consumption reduction and participation in demand response programmes.

It is proposed that further work be conducted in the AMI environment focusing on the following areas of possible research:

- ✓ Develop a predictive software model to simulate the impact of a particular customer having AMI hardware installed on his premises. At this point the aim should be to model the usage profile of a particular customer, given a low amount of data about them, i.e. working schedule and available appliances. The change in usage profile would then be predicted before and after the addition of AMI hardware.

- ✓ Aimed at validating the model developed for a single AMI customer, a case study should be undertaken to determine the change in usage profile for a particular customer. This would be done by making use of monitoring equipment, installed no less than a year before the AMI hardware would be installed. Once sufficient data over this period has been gathered about the usage of the customer, the AMI hardware would be installed and his usage would be continuously monitored for at least the same period of time, as before the AMI installation. If this is done on a statistically representative number of customers and the usage data before and after AMI implementation is compared, the predictive software model for a single customer could be validated and improved effectively.

- ✓ In order to determine the impact of an AMI implementation on a large group of customers and ultimately the whole country, a predictive software model should be developed that makes use of the validated model for a single customer. The model for large groups would take into account the economic conditions in a particular area, the interaction between customers and the impact of environmental factors over a long period of time.

7.3 CONTRIBUTIONS TO THE AREA OF AMI

The author, being a part of the Eskom's AMI pilot project, has highlighted the practical experiences and successes of AMI deployment in an emerging economy focusing on Eskom.

7.3.1 ESKOM'S AMI PILOT PROJECT

The contributions made to the area of AMI study, are highlighted below:

- ✓ Revenue collection – Eskom's business case on AMI is based on revenue collection. As part of Eskom's AMI deployment, 32 customers were found not be on the billing system, hence resulting in revenue loss to the business and economy. These defaulting customers were presented to the respective steering committee and regional working group meetings where solutions were presented to address the issue. A decision was taken by the committee for the defaulting customers to be remotely disconnected. As a result of the disconnection, customers signed up electricity supply agreements at the Eskom customer walk-in centres to ensure restoration of supply and large amounts of revenue for non-payment were collected from the defaulting customers.

- ✓ Bill queries – Many customers complained of "high bills" after the AMI solution was introduced. During this period, customers had to be made aware that the tariff had increased in April 2011 and that the smart meters had been installed just prior; colder than usual winter had also resulted in increased consumption; and the traditional conventional meters may have been inaccurate. As a result of the high volume of "high bill queries" the Eskom customer walk-in centres staff had to be trained on how to respond to these types of customer queries; and also developed a process to assist the staff to handle the queries.

- ✓ Estimations of customer bills – Due to the large number of meters being changed out in the field from the traditional conventional meters to the smart meters, this resulted in a backlog with regards to the meter changeout forms being captured onto CC&B. Hence, many customers were estimated during these months instead on being billed on actual readings. As a result, a job aid was compiled, on how to complete the meter changeout form for a smart meter. The staff at the Eskom customer walk-in centres were then trained on how to capture the meter changeout forms on CC&B which resulted in significant reduction in estimations of customer bills.

- ✓ Field audits – During the field installations of the meters, tampers and bypasses were identified at the meter point in the meter kiosks. There were also discrepancies on the data on the CC&B to that on the field e.g. existing meters were identified to have been swopped with the meter of the neighbour in many instances, the address of the customer on CC&B did not correspond to the customers' physical address in the field. As a result, these identified issues were highlighted and presented to the steering committee and regional committees. The necessary approvals were obtained from the business, and then initiated a project for the Revenue Protection department to conduct field audits to correct these highlighted issues. This exercise was extremely fruitful and assisted the various business value chains to resolve and correct field and system related issues.

- ✓ Business value chains – The existing business value chain processes were reviewed related to the respective areas impacted by AMI. These processes were then modified to include the AMI solution to improve business efficiency. Some of these processes include:

  - "Remote disconnection and reconnection" process where the smart meter may be remotely disconnected from the master station, hence preventing a technician from being dispatched to manually disconnect the meter.
  - "End device asset synchronisation" process to assist in automatically updating the master station when updated have been made on CC&B e.g. when a meter is serial number has been corrected on CC&B, the message will be sent to automatically update the master station with the corrected meter serial number instead of being manually captured.
  - "Meters not communicating" process to assist in identifying possible scenarios e.g. faulty meter, meter bypassed, and meter manually disconnected etc. Hence, this process aids the field services technicians in troubleshooting; and to investigate and perform the necessary corrective action to be taken accordingly when the meter is not communicating.

- "Performance job aid to create upload files, exceptions report and error logs". A performance job aid was compiled to assist the billing department in creating upload files for billing purposes; to create exceptions reports and error logs of meters' serial numbers that were not successfully billed during the meter read cycle.

7.3.2 PAPER PUBLICATIONS AND ARTICLES

In addition to the above mentioned contributions on Eskom's AMI Deployment project, the following discussion papers and article [APPENDIX B] were published.

- ✓ 17th International Symposium on High Voltage Engineering (ISH 2011) TITLE: "Towards a Smart Grid: A South African Perspective on the Enablement of Grid Intelligence to address Demand Response Challenges" The paper was submitted to and accepted by the technical committee for ISH. A poster presentation was delivered at the conference in Leibniz University in Hannover, Germany which was well received by academics attending the conference.

- ✓ 18th International Symposium on High Voltage Engineering (ISH 2013) TITLE: "Power Grid Intelligence: Utility Challenges on Advanced Metering Infrastructure Deployment and the Use of Meters as Smart Grid Sensors" The presentation was delivered to academics at ISH2013 which was also well received and interest shown in the area of study related to AMI.

- ✓ Metering International – Issue 1 (2013) publication
  TITLE: "Eskom's Advanced Metering International (AMI) Pilot Project – Key Challenges and Lessons Learnt". This article was published in Smart Energy and Metering International publication issue 1 in 2013. Here, the article was acknowledged by both industry and the academic environments.

REFERENCE LIST

[1] Eskom Annual Report 2011, http://financialresults.co.za/4C1723EC-90C8-4E11-9E71-27564FA50136/FinalDownload/DownloadId-A55833049DA2884282140041D42DA6B9/4C1723EC-90C8-4E11-9E71-27564FA50136/2011/eskom_ar2011/downloads/eskom-ar2011.pdf, Last Accessed, Feb 2014

[2] Ramila P, Rudnick H, Assessment of the Introduction of Smart Metering in a Developing Country, IEEE Paper, 2009

[3] Subramoney K.P, Madhoo H.V, AMI PMO Internal Stakeholder Communication, Eskom Report, version 4, Jan 2013

[4] Harvard Business Review, http://hbr.org/2006/03/customer-value-propositions-in-business-markets/ar/1, Last Accessed, Jan 2014

[5] Schneider Electric, http://www.schneider-electric.com/solutions/WW/en/sol/26048618-end-to-end-smart-metering-solutions, Last Accessed, Jan 2014

[6] The World Bank, http://data.worldbank.org/about/country-classifications, Last Accessed, Jan 2014

[7] http://en.wikipedia.org/wiki/Emerging_markets, Last Accessed, Jan 2014

[8] http://en.wikipedia.org/wiki/Developed_market, Last Accessed, Jan 2014

[9] Mak S.T, A Synergistic Approach to Implement Demand Response, Asset Management and Service Reliability Using Smart Metering, AMI and MDM Systems, IEEE Paper, 2009

[10] Mak S.T, A Synergistic Approach to Using AMR and Intelligent Electronic Devices to Determine Outages in a Distribution Network, IEEE Paper

[11] Chenthamarai S, Khota S, Advanced Metering Infrastructure for Smart Grid Applications, IEEE, 2012

[12] Xiao-min B, Jun-xia M, Ning-hui Z, Functional Analysis of Advanced Metering Infrastructure in Smart Grids, Proceedings of 2010 International Conference on Power System Technology, IEEE, 2010.

[13] Ray S, Presentation - San Diego Gas and Electric's Smart Meter Customer Experience, 2010

[14] Presentation, Pacific Gas & Electric's Smart Meter Program Overview, 2011

[15] Advanced Metering Infrastructure, Part 1: Business, Regulatory and Technical Considerations, Gartner Research Report no. G00151766, September 2007.

[16] Chartwell AMR Report 2007, 12th Edition, Chartwell Metering Series Research report, February 2005, Available at: www.chartwellinc.com

[17] Advanced Metering Infrastructure Market Potential, Energy Business Reports, Available at: www.energybusinessreports.com

[18] How California Attained a Leading Role in Establishing AMI Requirements and What jeopardizes Much of the State's Hard Work, Patti Harper-Slaboszewicz, Utilipoint International, December 2005, Available at: www.utilipoint.com

[19] Regulatory impact on AMR, Chartwell Metering Series Research report, February 2005, Available at: www.chartwellinc.com

[20] Frost & Sullivan Report, The Unites States Advanced Meter Infrastructure Market, N5F8-14, 2009

[21] Presentation, Smart Metering Lessons Learnt, AMEU Conference, Mohamed I, ITRON, Sept 2011.

[22] European research experience and needs on smart metering, Presentation by John Parsons, Project Coordinator, European Smart Metering Alliance (Available online at: http://62.121.14.21/Files/Exco%20File%20Library/Workshop%20Belg%C3%AFum%20October%202007/3%20J%20Parsons%20Bruges.pdf)

[23] Sinclair K, Presentation - Smart Metering, Actaris, 2008

[24] Directive 2006/32/EC of the European Parliament and of the Council of 5 April 2006 on energy end-use efficiency and energy service. (Available online at: http://www.esma-home.eu/userfiles/file/downloads/ESD_Directive.pdf)

[25] Smart Metering – the real energy benefits, Presentation by Dr Howard Porter, British Electrotechnical and Allied Manufacturers Association (BEAMA), International Energy Efficiency in Domestic Appliances and Lightning Conference 2006. (Available on-line at http://mail.mtprog.com/Presentations/Session_C/C3HowardPorter.pdf)

[26] Meeting the Energy Challenge – A White Paper on Energy, United Kingdom Department of Trade and Industry, May 2007. (Available online at www. dti.gov.uk). Smart Meters in Great Britain: The next steps? , Gill Owen and Judith Ward, Sustainability First, July 2007. (Available online at http://www.esma-home.eu/userfiles/file/downloads/Smart_Meters_%20in_GB_july2007.pdf)

[27] Smart Meters in Great Britain: The next steps? , Gill Owen and Judith Ward, Sustainability First, July 2007. (Available online at http://www.esma-home.eu/userfiles/file/downloads/Smart_Meters_%20in_GB_july2007.pdf)

[28] Electricity Smart Meter Functional Specification, SRSM Steering Group, Energy Retail Association, January 2007, Available at: www.energy-retail.org.uk

[29] White Paper on the Energy Policy of the Republic of South Africa, Department of Minerals and Energy, December 1998.

[30] The Electricity Pricing Policy of the South African Electricity Industry, Department of Minerals and Energy, Government Gazette Vol. 467, May 2004, Available at: www.gov.za

[31] Energy Security Master Plan – Liquid Fuels, Department of Minerals and Energy, Government Gazette Vol. 859, September 2007, Available at: www.gov.za

[32] Government Regulation Gazette, No. 8928, Regulation Paper, No. 31250, 18 July 2008, Pretoria

[33] Unique Mbane AMR System: AMR in action, Paper presented at African Utility Week, Cape Town, May 2006, Available at: http://www.spintelligent-events.com/auw2006/en/index.php

[34] Savings for Energy customers, Jocelyn Newmarch, Mail and Guardian online, 3 December 2007.

[35] The pilot testing and findings of the residential Time-Of-Use tariff (HomeFlex) project from an Eskom perspective, V Singh, M Dekenah, AMEU conference, Johannesburg, October 2006.

[36] Eskom pilots cellular geyser switching to cut power demand, Business Report, 2 August 2007, Available at: www.busrep.co.za

[37] Request for Proposal: HomeFlex Residential Time-Of-Use Project, Eskom Distribution, December 2005.

[38] Eskom Distribution Future Metering Strategy (Draft), ME Makwarela, October 2007.

[39] Eskom Distribution Specification for Domestic AMI Metering Equipment (Draft), HPD Groenewald, December 2007.

[40] KEMA analysis finds many utilities starting to develop AMI and utility-of-the-future strategies, Will McNamara, KEMA, Available at: www.kema.com, Last Accessed, Jan 2010

[41] IEE Report, Utility-Scale Smart Meter Deployments, Plans & Proposals, the Edison Foundation, Institute for Electric Efficiency, May 2012

[42] Presentation - India Smart Grid Forum, Smart Grid Vision & Roadmap for India (benchmarking with other countries) – Final Recommendations from ISGF, March 2013

[43] http://en.wikipedia.org/wiki/Smart_meter, Last Accessed, Dec 2013

[44] Application of San Diego Gas & Electric Company for Adoption of an Advanced Metering Infrastructure Deployment Scenario and Associated Cost Recovery and Rate Design, March 2005, Available at: www.energetics.com.

[45] Eskom Presentation – "AMI Programme Phase 1 Challenges, Lessons Learnt and Way Forward", Subramoney K.P, Madhoo H.V, Eskom AMI team, Nov 2012

[46] Mak S.T, Smart Meters Serving As Synchro-Sensors For Smart Distribution Grid Applications, IEEE, 2011

[47] Request for Proposal, Dx403, Advanced Metering Infrastructure Solution, March 2009.

[48] NRS049:2008, "Advanced Metering Infrastructure (AMI) Part 1 – Systems for residential and commercial customers," Version 1, ISBN: 978-0-626.

[49] Policy on Energy Efficiency and Demand Side Management for the South-African Electricity Industry, Draft 2, NERSA board, March 2004.

[50] Demand Response Enabling Technologies for Small-Medium Businesses, Technical report prepared in conjunction with the 2005 California Statewide Pricing Pilot, Lockheed Martin Aspen, April 2006. Available at: http://www.energetics.com/madri/pdfs/LMADRT_060506.pdf

[51] Assessment of Demand Response & Advanced Metering, U.S. Federal Energy Regulator Commission (FERC), August 2006. Available at: http://www.ferc.gov/legal/staff-reports/demand-response.pdf

[52] Advanced Metering for Energy Supply in Australia, Report by Energy Futures Australia for Total Environment Centre, July 2007, Available at: http://www.tec.org.au

[53] The Pilot Testing and Findings of the Residential Time-of-Use Tariff (HomeFlex) project from an Eskom perspective, V Singh, Eskom Distribution, June 2006.

[54] Position paper on Open Source communication protocols for the Eskom HomeFlex project, Rev 1.5, Venashree Vandayar, January 2006.

[55] An overview on AMR standardisation, Presentation by Gyözö Kmethy, President - DLMS User Association, European Utilities Intelligent Metering, Stockholm, April 2005, http://www.ucaiug.org/Openarchive/Shared%20Documents/Documents%20€-%20Standards%20(public)/AMR_Standardisation_Stockholm_V3_GK050414.pdf

[56] Micali V, Mhlongo M, Phaswana A, Statistics Consultants, Eskom's Research Testing and Development department, Statistical Inputs and Guidance - Case Study Analysis, 2013, 2014

[57] Clarke G, Cooke D, A Basic Course in Statistics, second edition, 1983, p32

[58] Elifson K, Runyon R, Haber A, Fundamentals of Social Statistics, third edition, 1998, p7

[59] Ary D, Jacobs L.C, & Razavieh A, Introduction to research in education, Fort Worth, TX: Harcourt Brace College Publishers, 1996

[60] Bartlett J, Kotrlik J, Higgins C, Organizational Research: Determining Appropriate Sample Size in Survey Research, Information Technology, Learning, and Performance Journal, Vol. 19, No. 1, Spring 2001

[61] Lane D.M, http://onlinestatbook.com/2/graphing_distributions/boxplots.html, Last Accessed, Jan 2014

[62] http://canmedia.mcgrawhill.ca/BAF1373A-2683-421D-9E95-B547A152113B/FinalDownload/DownloadId-9041F01F691BEB3A2096CA03C1DADA88/BAF1373A-2683-421D-9E95-B547A152113B/college/olcsupport/bowerman/2ce/Appendices/Technology%20Appendices%20Chapter%20Specific/Ch09_MegaStat.pdf, Last Accessed, Jan 2014

[63] Finos R, Gohn B, Smart Grid Enterprise Architecture, Pike Research, published Q4, 2011, p1,4

[64] http://www.r-bloggers.com/paired-students-t-test/, Last Accessed, Jan 2014

[65] Yelland C, Tshwane Metro metering contract branded "blatantly corrupt", EE-News, Issue 247, Dec 2013

[66] LSM Descriptions, South African Advertising Research Foundation, Jun 2011

[67] http://www.poweralert.co.za/, Eskom - Integrated Demand Management (IDM), Last Accessed, Jan 2014

APPENDICES

APPENDIX A-1: CASE STUDY - QUESTIONNAIRE

Eskom Distribution	CASE STUDY: AMI CUSTOMER PRE and POST EVALUATION FORM	Questionnaire No.

1. Biographical Information

Name of Customer	
Physical Address (Complex Name and Unit number)	
Contact Telephone no.	
Email address	
Customer Account No.	

2. Energy Provision Information

2.1 Major Home Appliances ☐ *Geyser* ☐ *Under-floor Heating* ☐ *Electric Stove* ☐ *Air Conditioner* ☐ *Swimming Pool Pump* ☐ *Fridge*

OTHER (High Consuming):

2.2 Has the customer installed any Energy Efficient products or solutions (e.g. Solar Water Heater, Heat Pump etc.)? If Yes, State the solution installed?

YES ☐ *NO* ☐

2.3 Did the customer change his behaviour patterns as a result of the Eskom Power Alerts on TV /Radio?

YES ☐ *NO* ☐

3. Pre - AMI Meter Installation Information (OLD METER)

3.1 Does the customer check his/her Eskom Bill to see if the bill is an "Actual Read" or an "Estimate"?

YES ☐ *NO* ☐

3.2 How often are you billed on an "Actual Read"?

Every month ☐ *Every 3 months* ☐ *More than 3 months* ☐ *Unsure* ☐

3.3 Did the customer read his/her own meter and phone/sms the meter readings to Eskom?

YES ☐ *NO* ☐

Eskom Distribution	CASE STUDY: AMI CUSTOMER PRE and POST EVALUATION FORM	Questionnaire No.

3.4 Did the customer call the Contact Centre or visit an Eskom Customer Services Office due to dissatisfaction or a query with a bill (too high) based on Estimation?

YES ☐ *NO* ☐

3.5 Please rate the service provided by Eskom? (Scale of 1- 5, where 1 is most disappointed and 5 extremely satisfied)

1	2	3	4	5
Most Disappointed	*Disappointed*	*Fair*	*Satisfied*	*Extremely Satisfied*

3.6 What was the customers' bill on average before the Smart Meter was installed?

Less than R500/month ☐ *Between R501 – R1000/month* ☐ *More than R1000/month* ☐

3.7 What was the customers overall feeling of the conventional meter?
(Scale of 1- 5, where 1 is most disappointed and 5 extremely satisfied)

1	2	3	4	5
Most Disappointed	*Disappointed*	*Fair*	*Satisfied*	*Extremely Satisfied*

4. Post - AMI Meter Installation Information (NEW METER)

4.1 How often was the customer's meter read?

Every month ☐ *Every 3 months* ☐ *More than 3 months* ☐ *Unsure* ☐

4.2 Did the customer read his/her own meter and phone/ sms the readings to Eskom?

YES ☐ *NO* ☐

4.3 Did the customer call the Contact Centre or visit an Eskom Customer Services Office due to dissatisfaction or a query with a bill (too high) based on Estimation?

YES ☐ *NO* ☐

4.4 What was the customer's bill on average after the Smart Meter was installed?

Less than R500/month ☐ Between R501 – R1000/month ☐ More than R1000/month ☐

Eskom Distribution	CASE STUDY: AMI CUSTOMER PRE and POST EVALUATION FORM	Questionnaire No.

4.5 Did the customer find the Customer Interface Unit (CIU) easy to operate and user friendly?

YES ☐ *NO* ☐

4.6 Is the CIU assisting the customer in managing his/her electricity consumption?

YES ☐ *NO* ☐

4.7 Has the customer noticed a decrease in the bill / consumption after installation of the AMI Solution?

YES ☐ *NO* ☐

4.8 What was the customers overall feeling of the new AMI solution (Smart meter and CIU)? (Scale of 1- 5, where 1 is most disappointed and 5 extremely satisfied)

1	2	3	4	5
Most Disappointed	*Disappointed*	*Fair*	*Satisfied*	*Extremely Satisfied*

4.9 Please rate the service provided by Eskom in regard to the installation of the AMI solution? (Scale of 1- 5, where 1 is most disappointed and 5 extremely satisfied)

1	2	3	4	5
Most Disappointed	*Disappointed*	*Fair*	*Satisfied*	*Extremely Satisfied*

General Comments

I hereby declare that the above information is true and correct as conveyed to me by the respondent.

Signature (customer)	Signature (interviewer) Date:

FOR OFFICE USE:

Meter Vendor	
Meter Serial No	

APPENDIX A-2: CASE STUDY - STATISTICAL ANALYSIS FOR SAMPLE SELECTION OF UNITS IN COMPLEXES

Table 1: Table for Determining Minimum Returned Sample Size for a Given Population Size for Continuous and Categorical Data

	Sample size					
	Continuous data (margin of error=.03)			Categorical data (margin of error=.05)		
Population size	alpha=.10 t=1.65	alpha=.05 t=1.96	alpha=.01 t=2.58	p=.50 t=1.65	p=.50 t=1.96	p=.50 t=2.58
100	46	55	68	74	80	87
200	59	75	102	116	132	154
300	65	85	123	143	169	207
400	69	92	137	162	196	250
500	72	96	147	176	218	286
600	73	100	155	187	235	316
700	75	102	161	196	249	341
800	76	104	166	203	260	363
900	76	105	170	209	270	382
1,000	77	106	173	213	278	399
1,500	79	110	183	230	306	461
2,000	83	112	189	239	323	499
4,000	83	119	198	254	351	570
6,000	83	119	209	259	362	598
8,000	83	119	209	262	367	613
10,000	83	119	209	264	370	623

NOTE: The margins of error used in the table were .03 for continuous data and .05 for categorical data. Researchers may use this table if the margin of error shown is appropriate for their study; however, the appropriate sample size must be calculated if these error rates are not appropriate. Table developed by Bartlett, Kotrlik, & Higgins.

SAMPLE SELECTION OF UNITS IN COMPLEX: RIVERSIDE MANOR

Random Sample for RIVERSIDE MANOR		Rounded off	Rounded off		Final Sample - Stand/Unit No's				removed duplications		smallest to highest
75.80339976	16.92736595	75	16		1		1	75	1		1
89.78475295	109.4477981	89	109		2		1	99	99		2
45.49882504	30.56276131	45	30		5		1	83	83		5
107.2123783	75.69029817	107	75		6		2	38	2		6
55.64470351	53.14981536	55	53		11		5	12	5		11
105.3927732	80.2309946	105	80		12		11	75	11		12
107.9841304	53.55232398	107	53		13		11	6	6		13
92.00686666	84.765038	92	84		14		12	14	12		14
90.76274911	11.52842799	90	11		15		12	56	56		15
49.68025758	103.1373943	49	103		18		13	1	13		18
22.74211859	71.42570269	22	71		19		14	90	14		19
88.11816767	85.61329997	88	85		21		15	14	15		21
32.53538621	72.6797998	32	72		22		18	91	18		22
67.60686056	80.93954283	67	80		24		19	28	19		24
49.51725822	54.78313547	49	54		25		21	102	21		25
5.344431898	12.04071169	5	12		32		22	71	22		32
108.9055757	9.635639515	108	9		33		24	103	24		33
14.44911039	90.57646413	14	90		35		32	72	32		35
48.1866512	42.89416181	48	42		38		32	59	59		38
106.0979949	7.154057436	106	7		39		33	53	33		39
42.57148961	89.26581622	42	89		40		35	84	35		40
21.66765343	102.5452742	21	102		42		38	50	38		42
102.5619068	16.39179662	102	16		43		39	108	39		43
79.32618183	40.55229347	79	40		44		40	40	40		44
90.36024049	25.23700674	90	25		45		42	89	42		45
40.90490432	40.9581286	40	40		46		43	69	43		46
13.25821711	1.585467086	13	1		48		44	83	44		48
35.5691702	84.20285653	35	84		49		45	30	45		49
79.63887448	15.66994232	79	15		53		46	61	46		53
1.083162938	75.18134098	1	75		54		48	42	48		54
57.74040956	79.41267129	57	79		55		49	103	49		55
44.13827937	83.88351085	44	83		56		49	54	54		56
38.91564684	50.38547929	38	50		57		55	53	55		57
33.6530961	53.13650929	33	53		58		56	80	80		58
74.43952757	80.97946104	74	80		59		57	79	57		59
65.40470595	53.31281472	65	53		60		58	83	58		60
24.5650502	103.7860652	24	103		62		60	72	60		62
2.952665792	38.19711905	2	38		65		65	53	65		65
32.0397351	59.78621784	32	59		67		67	80	67		67
60.22864467	72.85277871	60	72		69		69	106	69		69
15.62337107	14.34266182	15	14		71		71	66	71		71
85.70311594	96.7371746	85	96		74		74	80	74		74
12.87234107	14.51564074	12	14		75		75	16	75		75
58.5254677	83.86355174	58	83		77		77	23	77		77
94.77785577	31.76030763	94	31		79		79	40	79		79
1.602099673	99.28196051	1	99		80		79	15			80
46.43357646	61.50270089	46	61		83		85	96	85		83
77.91906491	23.66356395	77	23		85		88	85	88		85
43.42640461	69.68926054	43	69		88		89	109	89		88
56.09378338	80.2875454	56	80				90	11	90		89
11.01947081	75.76015503	11	75				90	25	25		90
1.55220191	83.15167699	1	83				92	84	92		92
94.8976104	62.13473922	94	62				94	31	94		94
71.1994995	66.57564013	71	66				94	62	62		99
39.50776696	108.7159642	39	108				102	16	102		102
69.02395703	106.008179	69	106				105	80	105		105
11.77791681	6.445509201	11	6				106	7	106		106
19.52870266	28.3406476	19	28				107	75	107		107
12.24695578	56.48963897	12	56				107	53	53		108
18.4176458	91.54448073	18	91				108	9	108		
				COUNT	49						

SAMPLE SELECTION OF UNITS IN COMPLEX: KALYPSO

Random Sample for Kalyso		Rounded off	Rounded off	Final Sample - Stand/Unit No's					removed duplications		smallest to highest
10.37281	41.78048	10	41	2			2	42	2		2
46.78381	15.05817	46	15	3			3	62	3		3
42.01633	3.35847	42	3	6			6	6	6		6
31.45585	59.95334	31	59	7			7	52	7		7
54.10981	62.18336	54	62	8			8	8	8		8
33.42265	59.57009	33	59	10			10	41	10		10
3.274239	62.9667	3	62	11			11	41	11		11
29.22584	68.67125	29	68	13			13	45	13		13
13.52306	45.30345	13	45	17			17	17	17		17
10.76028	21.04279	10	21	19			19	61	19		19
37.57735	26.2609	37	26	20			20	39	20		20
59.60588	67.13193	59	67	21			21	21	21		21
60.11338	20.30366	60	20	26			26	6	26		26
54.37724	11.55626	54	11	29			29	68	29		29
34.30076	31.30845	34	31	30			30	66	30		30
13.79681	17.58721	13	17	31			31	59	31		31
19.53294	61.97909	19	61	33			33	59	33		33
42.5891	19.06757	42	19	34			34	31	34		34
56.78835	13.41777	56	13	36			36	10	36		36
54.8721	6.822474	54	6	37			37	26	37		37
42.47749	3.149998	42	3	42			42	3	42		42
36.23386	10.11591	36	10	44			42	19			
34.26075	8.374432	34	8	46			42	3			
53.09482	8.151219	53	8	48			44	9	44		44
7.650044	52.71999	7	52	50			46	15	46		46
11.55837	41.14664	11	41	53			48	50	48		48
48.87906	50.29624	48	50	54			50	33	50		50
30.38191	66.05799	30	66	56			53	8	53		53
2.890988	42.31745	2	42	59			54	62	54		54
50.23728	33.42897	50	33	60			54	11			
44.90756	9.084078	44	9	61			56	13	56		56
26.89053	6.439222	26	6				59	67	59		59
21.40709	61.58953	21	61				60	20	60		60
20.51634	39.64943	20	39				61	61	61		61
64.0217	57.54643	64	57				64	57	64		64
			COUNT	31							

SAMPLE SELECTION OF UNITS IN COMPLEX: SHAMBALA

Random Sample for SHAMBALA		Rounded off	Rounded off	Final Sample - Stand/Unit No's				removed duplications		smallest to largest
16.87267678	9.324686	16	9	3		3	20	3		3
14.86379589	5.402295	14	5	4		4	22	4		4
7.276894436	8.808924	7	8	6		6	20	6		6
12.37348552	25.81689	12	25	7		7	8	7		7
4.717154454	22.90924	4	22	12		7	12	12		12
3.393414106	20.03439	3	20	25		12	25	25		14
18.52754295	22.22486	18	22	14		12	4			16
17.83629872	10.68123	17	10	16		14	5	14		17
6.227820673	20.47844	6	20	17		16	9	16		18
18.15903195	12.01489	18	12	18		17	10	17		22
7.678975799	12.70385	7	12	22		18	22	18		23
12.92281869	4.852199	12	4			18	12			25
23.41355632	5.863887	23	5			18	18			
18.07052828	18.38334	18	18			22	11	22		
22.31412702	11.43199	22	11			23	5	23		
			COUNT	11						

SAMPLE SELECTION OF UNITS IN COMPLEX: CASTLE ROCK

Random Sample for CASTLE ROCK		Rounded off	Rounded off	Final Sample - Stand/Unit No's			removed duplications	smallest to highest
9.111056856	17.95914	9	17	4	4	18	4	4
10.94979705	4.562273	10	4	5	5	11	5	5
24.90133366	16.05783	24	16	6	6	19	6	6
6.468153935	19.90011	6	19	7	7	9	7	7
9.197271645	14.28776	9	14	9	9	17	9	9
7.300546281	9.203375	7	9	10	9	14	14	10
5.773094882	11.41749	5	11	11	10	4	10	11
14.370159	15.51918	14	15	12	10	6		12
10.55534532	6.985443	10	6	13	12	19	12	13
4.611102634	18.893	4	18	14	13	4	13	14
13.34931486	4.243355	13	4	15	14	15	15	15
12.76183355	19.12647	12	19		15	11	11	18
15.20102542	11.19929	15	11		18	1	18	22
18.86706137	1.392926	18	1		22	12	22	24
22.17450484	12.40629	22	12		24	16	24	
			COUNT	11				

SAMPLE SELECTION OF UNITS IN COMPLEX: HILTON SANDS

HILTON SANDS

NOTE: Questionnaires were handed to Body Corporate Chairperson of Hilton Sands complex. However, these Questionnaires were not handed out to residents in the complex. Hence, no Questionnaires were returned and therefore excluded from the Case Study.

SAMPLE SELECTION OF UNITS IN COMPLEX: HAMPTON COURT

Random Sample for HAMPTON COURT		Rounded off	Rounded off	Final Sample - Stand/Unit No's				removed duplications		smallest to largest
3.587542344	9.888577	3	9	3		3	9	3		3
16.43321024	15.04779	16	15	11		3	11	11		6
5.682332835	15.67861	5	15	22		3	22	22		8
20.98303171	21.20917	20	21	15		5	15	15		9
9.069704276	8.005646	9	8	6		5	11			11
14.24399548	15.57546	14	15	9		6	23	6		14
6.883663442	23.72768	6	23	14		9	8	9		15
5.859279153	11.58028	5	11	16		11	14	14		16
26.73894467	23.27937	26	23	20		14	15			20
23.68642232	3.160649	23	3	23		16	15	16		22
23.30317087	8.201636	23	8	8		20	21	20		23
11.46839808	14.97955	11	14	24		23	3	23		24
3.906521805	11.55965	3	11			23	8	8		26
3.835901975	22.68029	3	22			24	10	24		
24.00698874	10.81457	24	10			26	23	26		
			COUNT	12						

SAMPLE SELECTION OF UNITS IN COMPLEX: BADGER PARK

Random Sample for Badger Park1		Rounded off	Rounded off	Final Sample - Stand/Unit No's				removed duplications		smallest to highest
28.67357402	17.352	28	17	2		2	34	2		2
25.29764702	11.45463	25	11	6		6	21	6		6
48.67543565	51.41633	48	51	9		15	14	15		9
33.05807672	11.83441	33	11	10		15	13	13		10
38.01535081	29.57942	38	29	13		17	25	17		13
48.14935759	39.42238	48	39	15		17	6			15
22.84469131	33.78027	22	33	17		17	51	51		17
32.07129124	21.28358	32	21	20		20	36	20		20
47.7711417	19.28043	47	19	21		20	31	31		21
30.30784021	10.64995	30	10	22		21	28	21		22
21.55751213	28.91171	21	28	25		22	33	22		25
20.47889645	36.83557	20	36	26		25	11	25		26
46.25205237	28.09769	46	28	28		26	22	26		28
31.13275552	10.23127	31	10	30		28	17	28		30
20.0384228	31.6386	20	31	31		30	10	30		31
48.26764733	9.130863	48	9	32		30	20			32
32.70632038	45.72597	32	45	33		31	10	10		33
17.17767876	25.54201	17	25	37		32	21	32		37
38.02624592	37.13907	38	37	38		32	45	45		38
17.73177282	6.760399	17	6	39		33	11	33		39
15.92941069	14.10993	15	14	43		38	29	38		43
2.643604846	34.90246	2	34	44		38	37	37		44
26.8042848	22.82134	26	22	45		43	2	43		45
43.87224952	2.095737	43	2			43	38			46
44.74230171	41.99673	44	41			44	41	44		47
17.6990875	51.60311	17	51			46	28	46		48
43.12515641	38.56478	43	38			47	19	47		51
30.63624989	20.50847	30	20			48	51	48		
15.33796197	13.86245	15	13			48	39	39		
6.677907651	21.30226	6	21			48	9	9		
			COUNT	23						

SAMPLE SELECTION OF UNITS IN COMPLEX: NAIVASHA MANOR

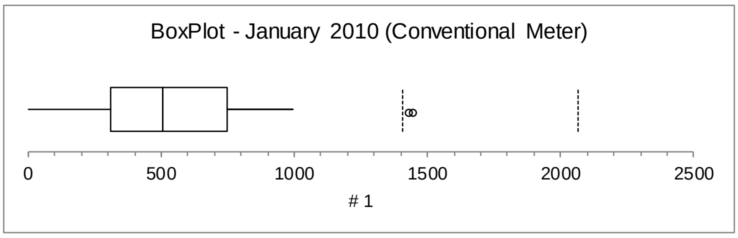
Random Sample for NAIVASHA MANOR		Rounded off	Rounded off	Final Sample - Stand/Unit No's				removed duplications		smallest to highest
2.419965209	23.21552	2	23	1		1	25	1		1
17.48780786	24.05734	17	24	2		2	23	2		2
22.10611286	32.92969	22	32	5		5	18	5		5
18.85113071	18.01907	18	18	6		6	18	6		6
1.38575396	25.65407	1	25	7		6	1			7
6.788262581	18.4351	6	18	8		6	19	19		8
7.758995331	26.7293	7	26	10		7	26	7		10
5.793115024	18.28373	5	18	12		8	30	8		12
6.934751427	1.096683	6	1	13		10	6	10		13
6.811700797	19.42927	6	19	14		12	17	12		14
21.20960112	6.20426	21	6	16		13	17	13		16
24.51243629	8.819575	24	8	17		14	16	14		17
12.87926878	17.73391	12	17	18		16	29	16		18
16.11764885	29.98721	16	29	19		17	24	17		19
25.74001282	5.130985	25	5	21		17	28	28		21
10.80108036	6.864437	10	6			18	18	18		22
13.62831507	17.96048	13	17			21	6	21		24
14.64299448	16.91845	14	16			22	32	22		25
17.04345836	28.05649	17	28			24	8	24		28
8.14865566	30.58391	8	30			25	5	25		
			COUNT	15						

APPENDIX A-3: CASE STUDY - STATISTICAL ANALYSIS MONTHLY CONSUMPTION DATA NORMALISATION

– JANUARY 2010 COMPARED TO JANUARY 2012 CONSUMPTION DATA ANALYSIS

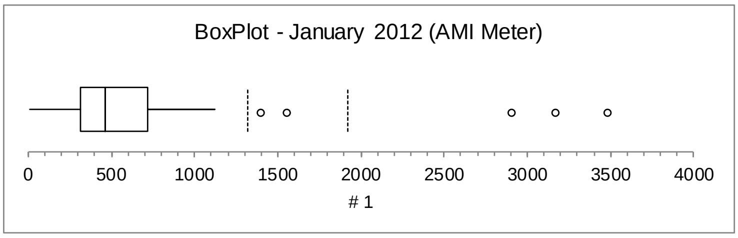
Descriptive statistics - Jan 2010

	# 1
count	42
mean	519.12
sample variance	120 109.67
sample standard deviation	346.57
minimum	0
maximum	1446
range	1446



Descriptive statistics - Jan 2012

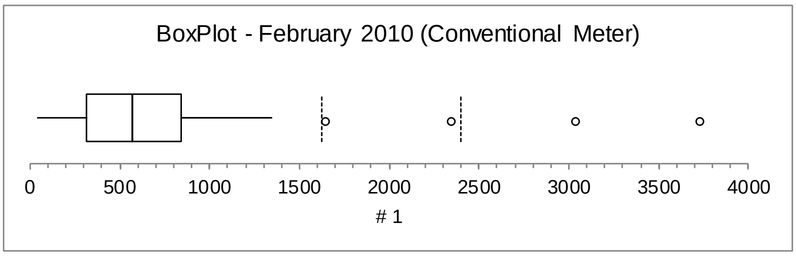
	# 1
count	61
mean	669.28
sample variance	438 232.34
sample standard deviation	661.99
minimum	12
maximum	3485
range	3473



– FEBRUARY 2010 COMPARED TO FEBRUARY 2012 CONSUMPTION DATA ANALYSIS

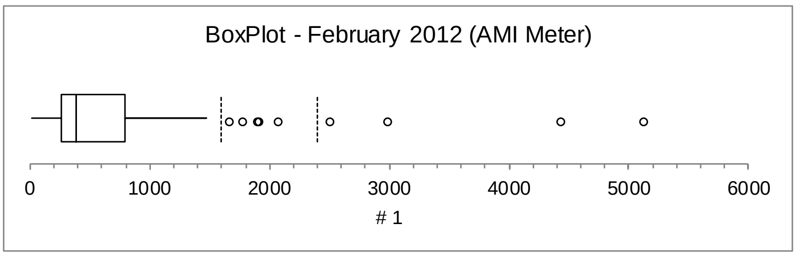
Descriptive statistics - Feb 2010

	# 1
count	48
mean	746.27
sample variance	511 357.31
sample standard deviation	715.09
minimum	45
maximum	3735
range	3690



Descriptive statistics - Feb 2012

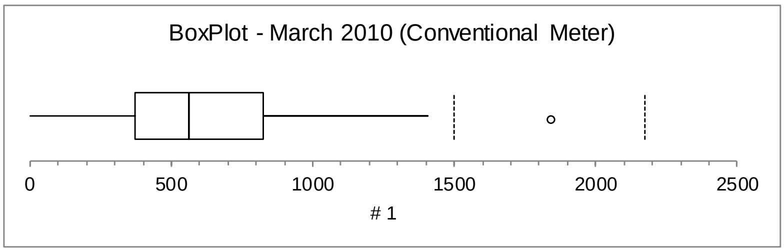
	# 1
count	64
mean	780.63
sample variance	916 802.24
sample standard deviation	957.50
minimum	16
maximum	5131
range	5115



– MARCH 2010 COMPARED TO MARCH 2012 CONSUMPTION DATA ANALYSIS

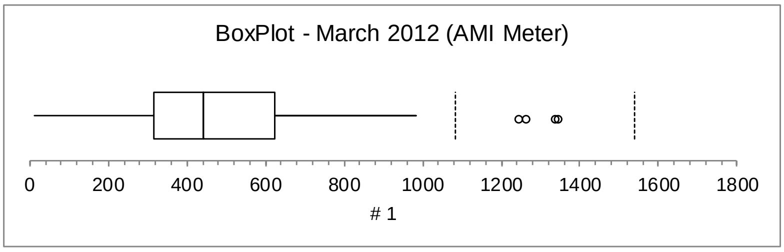
Descriptive statistics - Mar 2010

	# 1
count	43
mean	625.60
sample variance	150 526.34
sample standard deviation	387.98
minimum	0
maximum	1844
range	1844



Descriptive statistics - Mar 2012

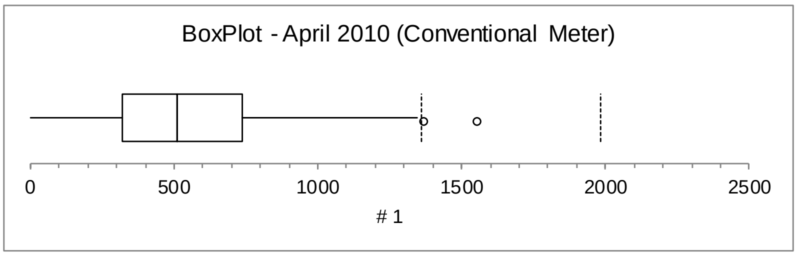
	# 1
count	62
mean	515.68
sample variance	88 850.81
sample standard deviation	298.08
minimum	12
maximum	1348
range	1336



– APRIL 2010 COMPARED TO APRIL 2012 CONSUMPTION DATA ANALYSIS

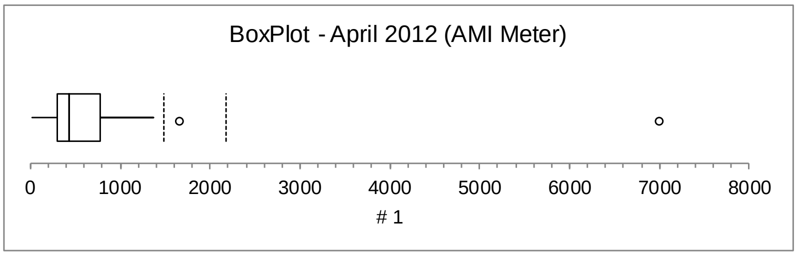
Descriptive statistics - Apr 2010

	# 1
count	45
mean	562.36
sample variance	145 110.42
sample standard deviation	380.93
minimum	0
maximum	1555
range	1555



Descriptive statistics - Apr 2012

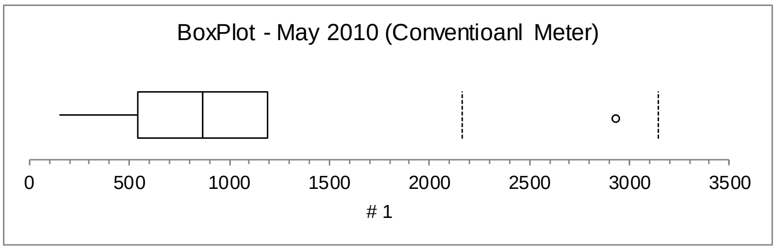
	# 1
count	69
mean	649.52
sample variance	714 528.81
sample standard deviation	845.30
minimum	19
maximum	6998
range	6979



– MAY 2010 COMPARED TO MAY 2012 CONSUMPTION DATA ANALYSIS

Descriptive statistics - May 2010

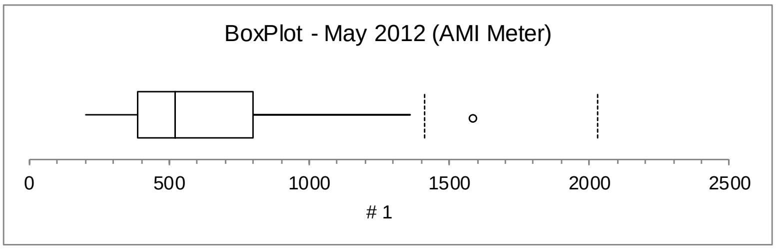
	# 1
count	6
mean	1 091.17
sample variance	981 164.97
sample standard deviation	990.54
minimum	151
maximum	2935
range	2784



BoxPlot - May 2010 (Conventioanl Meter)

Descriptive statistics - May 2012

	# 1
count	70
mean	612.67
sample variance	94 606.46
sample standard deviation	307.58
minimum	199
maximum	1586
range	1387

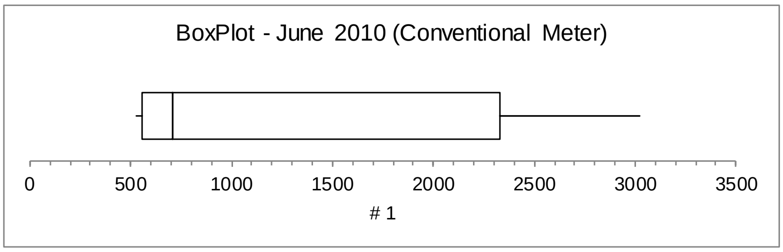


BoxPlot - May 2012 (AMI Meter)

– JUNE 2010 COMPARED TO JUNE 2012 CONSUMPTION DATA ANALYSIS

Descriptive statistics - Jun 2010

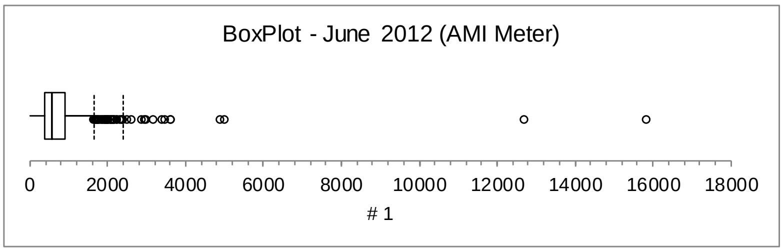
	# 1
count	6
mean	1 390.00
sample variance	1 440 945.60
sample standard deviation	1 200.39
minimum	527
maximum	3023
range	2496



BoxPlot - June 2010 (Conventional Meter)

Descriptive statistics

	# 1
count	989
mean	750.32
sample variance	662 963.79
sample standard deviation	814.23
minimum	16
maximum	15856
range	15840

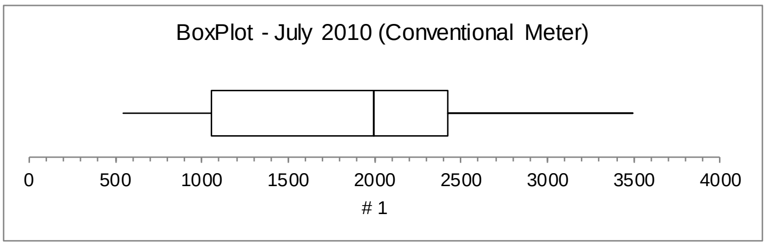


BoxPlot - June 2012 (AMI Meter)

– JULY 2010 COMPARED TO JULY 2012 CONSUMPTION DATA ANALYSIS

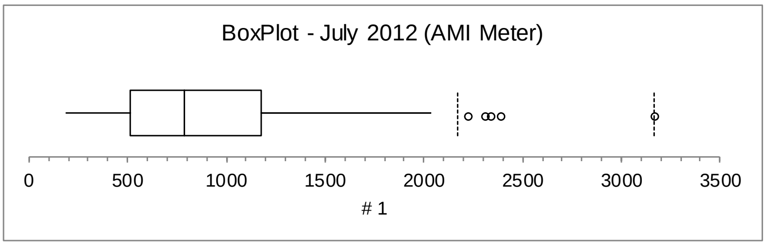
Descriptive statistics - Jul 2010

	# 1
count	5
mean	1 902.40
sample variance	1 344 725.30
sample standard deviation	1 159.62
minimum	543
maximum	3496
range	2953



Descriptive statistics - Jul 2012

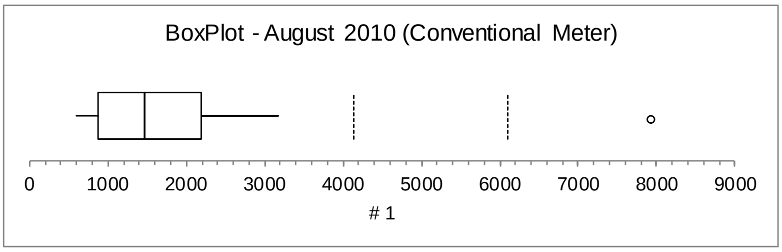
	# 1
count	68
mean	961.57
sample variance	374 705.08
sample standard deviation	612.13
minimum	185
maximum	3171
range	2986



– AUGUST 2010 COMPARED TO AUGUST 2012 CONSUMPTION DATA ANALYSIS

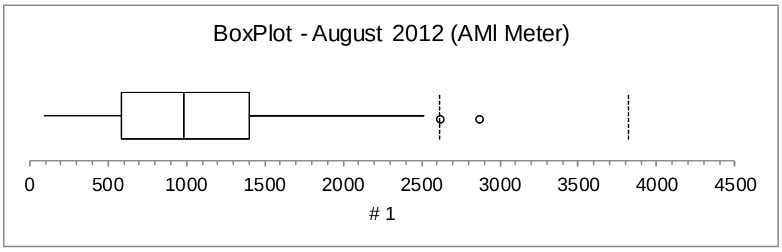
Descriptive statistics - Aug 2010

	# 1
count	16
mean	1 928.50
sample variance	3 214 399.47
sample standard deviation	1 792.87
minimum	591
maximum	7945
range	7354



Descriptive statistics - Aug 2012

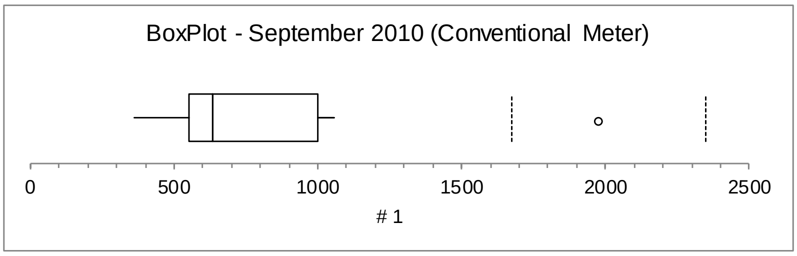
	# 1
count	72
mean	1 101.46
sample variance	393 690.45
sample standard deviation	627.45
minimum	90
maximum	2879
range	2789



– SEPTEMBER 2010 COMPARED TO SEPTEMBER 2012 CONSUMPTION DATA ANALYSIS

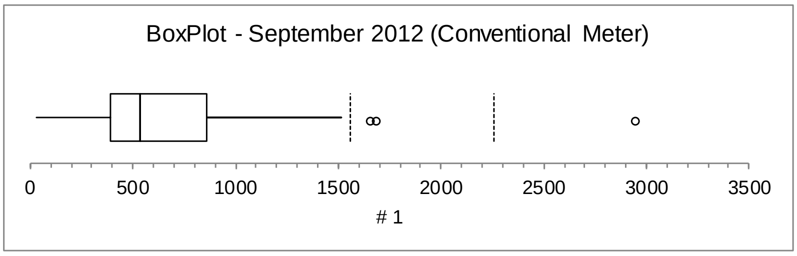
Descriptive statistics - Sept 2010

	# 1
count	8
mean	835.75
sample variance	268 525.36
sample standard deviation	518.19
minimum	363
maximum	1976
range	1613



Descriptive statistics - Sept 2012

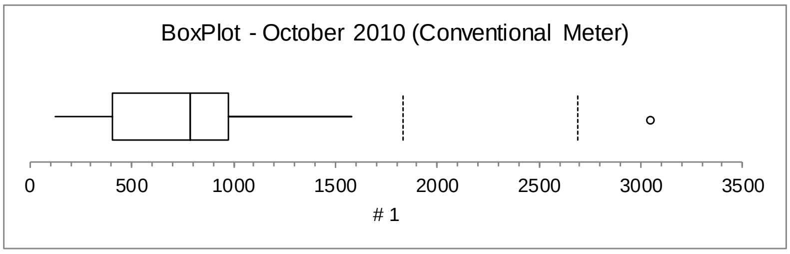
	# 1
count	75
mean	662.52
sample variance	197 110.60
sample standard deviation	443.97
minimum	29
maximum	2949
range	2920



– OCTOBER 2010 COMPARED TO OCTOBER 2012 CONSUMPTION DATA ANALYSIS

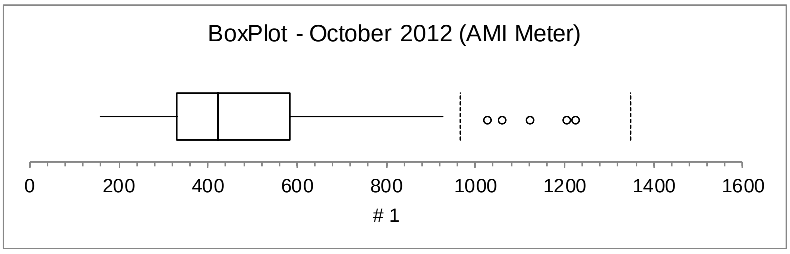
Descriptive statistics - Oct 2010

	# 1
count	11
mean	905.82
sample variance	675 351.96
sample standard deviation	821.80
minimum	121
maximum	3048
range	2927



Descriptive statistics - Oct 2012

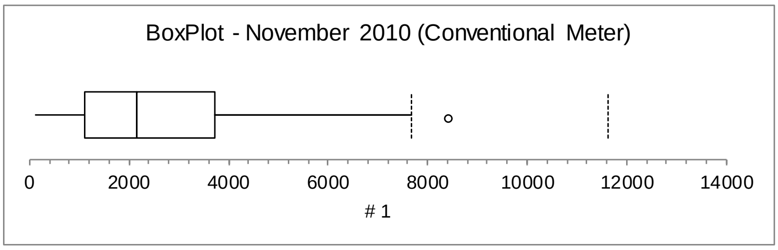
	# 1
count	75
mean	491.67
sample variance	58 638.23
sample standard deviation	242.15
minimum	158
maximum	1228
range	1070



– NOVEMBER 2010 COMPARED TO NOVEMBER 2012 CONSUMPTION DATA ANALYSIS

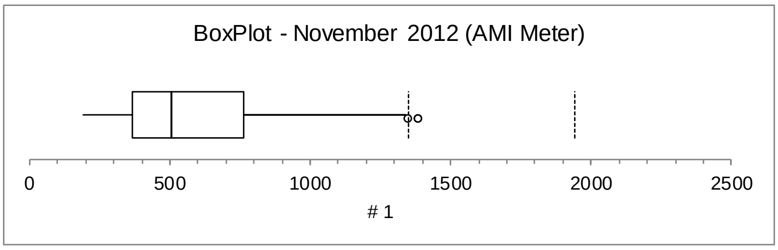
Descriptive statistics - Nov 2010

	# 1
count	48
mean	2 649.83
sample variance	4 335 426.40
sample standard deviation	2 082.17
minimum	131
maximum	8418
range	8287



Descriptive statistics - Nov 2012

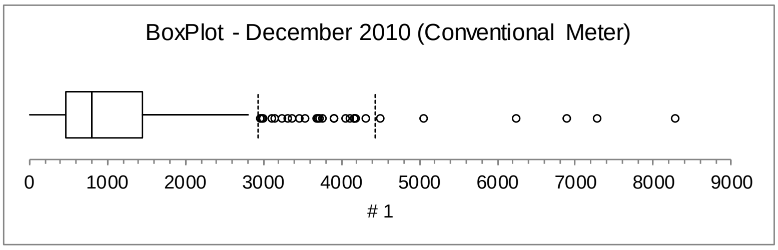
	# 1
count	76
mean	579.54
sample variance	84 673.72
sample standard deviation	290.99
minimum	190
maximum	1386
range	1196



– DECEMBER 2010 COMPARED TO DECEMBER 2012 CONSUMPTION DATA ANALYSIS

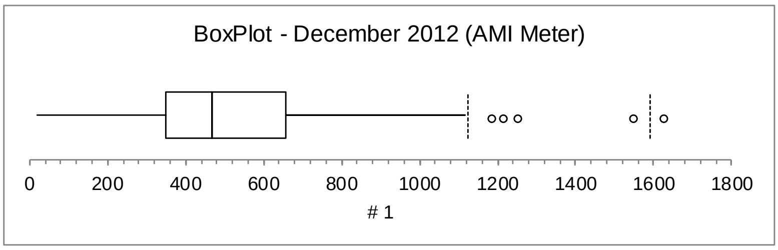
Descriptive statistics - Dec 2010

	# 1
count	473
mean	1 144.30
sample variance	1 103 714.15
sample standard deviation	1 050.58
minimum	0
maximum	8283
range	8283



Descriptive statistics - Dec 2012

	# 1
count	68
mean	561.63
sample variance	104 117.31
sample standard deviation	322.67
minimum	19
maximum	1628
range	1609



APPENDIX A-4: CASE STUDY - LIVING STANDARD MEASUREMENT (LSM) DEMOGRAPHICS

LSM 7 LOW (4.9%)

DEMOGRAPHICS

Female
25- 49
Matric and higher
Urban

R9 320 ave hh income per month

MEDIA

Wide range of commercial and community radio
TV: SABC 1,2,3, e.tv, DStv, Top TV, Community TV
All print
Accessed internet past 7 days
Cinema & Outdoor

GENERAL

Full access to services
Savings accounts
Increased ownership of durables plus DVD and motor vehicle
Participation in all activities

LSM 7 HIGH (5.3%)

DEMOGRAPHICS

Male
25-49
Matric and higher
Urban

R11 263 ave hh income per month

MEDIA

Wide range of commercial and community radio
TV: SABC 1,2,3, e.tv, M-Net, DStv, Top TV, Community TV
All print
Accessed internet past 7 days
Cinema & Outdoor

GENERAL

Full access to services, including cheque and savings accounts
Increased ownership of durables plus DVD and motor vehicle
Participation in all activities

LSM 8 LOW (4.3%)

DEMOGRAPHICS

Female
35+
Matric and higher
Urban

R13 210 ave hh income per month

MEDIA

Wide range of commercial and community radio
TV: SABC 1,2,3, e.tv, M-Net, DStv, Top TV, Community TV
All print
Accessed internet past 7 days
Cinema & Outdoor

GENERAL

Full access to services and bank accounts
Full ownership of durables, incl. PC
Increased participation in activities

LSM 8 HIGH (3.9%)

DEMOGRAPHICS
Male
35+
Matric and higher
Urban

R14 882 ave hh income per month

MEDIA
Wide range of commercial and community radio
TV: SABC 2,3, e.tv, M-Net, DStv, Top TV, Community TV
All print
Accessed internet past 7 days
Cinema & Outdoor

GENERAL
Full access to services and bank accounts
Full ownership of durables, incl. PC Increased participation in activities

LSM 9 LOW (4.6%)

DEMOGRAPHICS
Female
35+
Matric and higher
Urban

R17 988 ave hh income per month

MEDIA
Wide range of commercial and community radio
TV: SABC 2,3, e.tv, M-Net, DStv, Top TV, Community TV
Accessed internet past 7 days
All print
Cinema & Outdoor

GENERAL
Full access to services and bank accounts
Full ownership of durables
Increased participation in activities, excluding stokvel meetings

LSM 9 HIGH (4.6%)

DEMOGRAPHICS
Male
35+
Matric and higher
Urban

R21 328 ave hh income per month

MEDIA
Wide range of commercial radio
TV: SABC 2,3, e.tv, M-Net, DStv, Top TV, Community TV
Accessed internet past 7 days
All print
Cinema & Outdoor

GENERAL
Full access to services and bank accounts
Full ownership of durables
Increased participation in activities, excluding stokvel meetings

LSM 10 LOW (3.3%)

DEMOGRAPHICS
Male
35+
Matric and higher
Urban

R26 706 ave hh income per month

MEDIA
Wide range of commercial radio
TV: SABC 3, M-Net, DStv, Top TV, Community TV
All print
Accessed internet past 7 days
Cinema & Outdoor

GENERAL
Full access to services and bank accounts
Full ownership of durables
Increased participation in activities, excluding stokvel meetings

LSM 10 HIGH (3.1%)

DEMOGRAPHICS

Male
35+
Matric and higher
Urban

R32 521 ave hh income per month

MEDIA

Wide range of commercial radio
TV: M-Net, DStv, Community TV
All print
Accessed internet past 7 days
Cinema & Outdoor

GENERAL

Full access to services and bank accounts
Full ownership of durables
Increased participation in activities, excluding stokvel meetings

APPENDIX A-5: INTERNATIONAL SMART METERING DEPLOYMENTS

The table below presents a summary of international deployments for AMI focusing on USA [41], Europe [42], [43] and Asia Pacific countries [42], [43].

United States of America (USA)	**Smart meters installed** (as of May 2012)	**Planned smart meter deployment** (by December 2015)
	35.7 million	65 million Currently, 675 000 smart meters are being installed per month until 2015
Some of the Large Scale AMI Deployments by Major Utilities in the USA include:		
- Austin Energy	418 900	418 900
- Baltimore Gas & Electric	3 000	1 360 000
- Center Point	2 190 700	2 200 000
- Duke Energy	386 100	1 500 000
- Florida Power & Light Company	3 000 000	4 500 000
- Oncor (Texas)	2 534 000	3 400 000
- Salt River Project (Arizona)	792 500	935 000
- Pacific Gas & Electric	4 696 000	5 250 000
- San Diego Gas & Electric	1 364 000	1 400 000
- Southern California Edison	3 900 000	5 300 000
- Southern Company (Georgia)	3 998 000	4 617 000
- State Program (Pennsylvania)	1 409 000	6 000 000
- Xcel Energy	20 000	20 000
Canada	**Smart meters installed**	**Planned smart meter deployment**
Ontario – Hydro One	1.2 million (since 2006)	4.5 million
Europe	**Smart meters installed**	**Planned smart meter deployment**
United Kingdom	170 000 (as at 2010)	27 million. 100% smart meter rollout by 2020
Spain	26 million electricity customers of which,30% of all customers to have smart meters by 2010	13 million (ENDESA) by 2015 10 million (IBERDROLA) by 2015

Italy	40 million (since 2002)	ongoing
Germany	300 000 (as at 2010)	3.5 million (by 2018)
Netherlands	Delays due to Government uncertainty to deploy smart meters, since 2008	7 million smart meters rollout by 2013
Sweden	First country to install all 100% smart meters	First country to install all 100% smart meters
Asia Pacific	**Smart meters installed**	**Planned smart meter deployment**
China	33 million (as at 2010)	300 million (by 2015)
South Korea	Plan to install 5% of smart meters by 2020	100% smart meter rollout by 2030
Australia – Victoria	Smart meter rollout commenced in mid-2009	2.6 million smart meters by end of 2013
New Zealand	150 000 smart meters installed (since November 2005)	Further smart meter deployments have been stopped due to “lack of smartness”, by Parliament since 2009
India	Busy developing smart metering specification	100% smart meter rollout by 2022

APPENDIX B: PAPER PUBLICATIONS AND ARTICLES

Discussion Paper presented at the ISH 2011 Conference

TOWARDS A SMART GRID: A SOUTH AFRICAN PERSPECTIVE ON THE ENABLEMENT OF GRID INTELLIGENCE TO ADDRESS DEMAND RESPONSE CHALLENGES

H. Madhoo[1&2*], A. Khatri[1], K. Subramoney[1], N.Parus[1&2], W. Cronje[2]
[1]Eskom Holdings SOC Ltd, Johannesburg, South Africa
[2]The University of the Witwatersrand, Johannesburg, South Africa
*Email: hinesh.madhoo@eskom.co.za

Abstract: South Africa's power utility, Eskom, is currently considering implementing aspects of a Smart Grid. The primary reasons for the transition towards a Smart Grid is attributed to the challenges of capacity constraints on the power system, the demand response growth, outage management for the replacement of aging infrastructure and asset management. As such, several technologies, such as Smart Metering, Distributed Sensor Networks, and Distribution Substation Automation are being piloted and some key learning's have been noted. The purpose of this paper is to emphasise that both High Voltage Grid Intelligence as well as Low Voltage Grid Intelligence is required to effectively and efficiently implement a Smart Grid to deal with the utility's demand challenges.

1 INTRODUCTION

Electrical networks have been designed with the purpose of providing electricity to the end user. Supporting technologies are at present being developed to ensure that the system is no longer just a connection from generation to the consumer, but a more intelligent system, managed by data flow within the different processes.

A Smart Grid philosophy impacts the entire value chain of the utility. In order to manage the demand on the network, it becomes increasingly important to have a network which can provide real time information about its health and state.

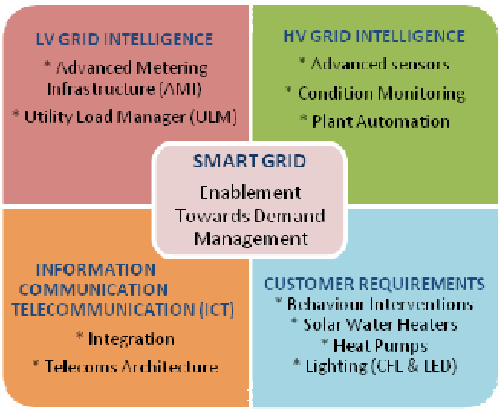


Figure 1: Holistic Approach to illustrate the different aspects of reducing demand on the network.

A holistic approach to achieving a Smart Grid would require consolidating Low Voltage (LV), High Voltage (HV), Information Communication and Telecommunication (ICT) and Customer requirements to enable the management of the demand challenges as depicted in Figure 1.

This paper focuses on the current initiatives within the LV and HV aspects towards a Smart Grid.

2 LOW VOLTAGE GRID INTELLIGENCE

Eskom's key focus areas are Advanced Metering Infrastructure (AMI), customer engagement and grid optimization. In order to achieve a holistic approach, Eskom has undertaken several demand response initiatives, as listed below:

- Demand Side Management (DSM) Program (Technologies such as solar water heating, CFL lighting, heat pumps, efficient showerheads, smart appliances, battery storage, etc.).
- Customer Power Conservation Program.
- Internal Energy Efficiency (Substations, network losses in buildings, thermal efficiencies, etc.).
- Advanced Metering Infrastructure and the Utility Load Manager.

DSM programs can support the broader objective of reducing demand and thus ensuring the base load is managed for long term sustainability. Peak demands are largely managed by AMI and peaking generation capacity. A key aspect often overlooked is that network performance can be improved with the data from the field devices.

The ability of a utility to predict and manage the complexity of the network will result in grid optimization, better management of its assets and reducing the probability of aging equipment failure. The intelligent utilization of electrical network data would enable the utility to drive specific demand response strategies based on network performance.

Demand response strategies thus need to be seen as an integrated approach from demand reduction, reducing technical and non technical losses to having a grid that is optimized across the entire value chain.

2.1 Advanced Metering Infrastructure

2.1.1 A South African Perspective

Many power utilities across the world have envisaged AMI to be the foundation of utilities transition towards a Smart Grid [12]. To assist in addressing the electricity challenges in South Africa, the national government passed "Regulation 773" mandating the use of smart systems and time-of-use (ToU) tariffs for customers consuming over 1000kWh per month, by 2012 [2][3]. To comply with the regulation, Eskom has embarked on an AMI rollout approximately 120 000 Eskom residential customers.

2.1.2 Primary Objectives for AMI

The key objectives for AMI implementation by South African power utilities are listed below:

- *Comply with National Regulation* - National regulation mandates the use of smart systems and ToU tariffs for customers consuming over 1000kWh per month by 2012.
- *Shift Load* - Shift load of medium to high (500kWh/month) residential consumers Living Standard Measurement (LSM) 7, 8, 9 through ToU tariff. The objective is to shift 65-87MW from the morning peak demand period and 65-82 MW from the evening period.
- *Change Customer Behaviour* - Incentivise the efficient use of electricity, power conservation through ToU tariff to promote lifestyle changes.
- *Limit Load* - Provide functionality to automatically & centrally limit and reduce customer demand in times of system constraints.
- *Maximize Operational Efficiencies* - Achieve improved billing accuracy through automated reading.

2.1.3 AMI Solution proposed by NRS049

The AMI deployment in South Africa is guided by a national standard NRS049. The standard was accepted by Industry and published by SABS in 2008. NRS standard are prepared by the Electricity Suppliers Liaison Committee (ESLC) and for use by South African electricity supply authorities, in collaboration with the South African Bureau of Standards (SABS).

Figure 2 below illustrates the NRS049 AMI architecture [5]:

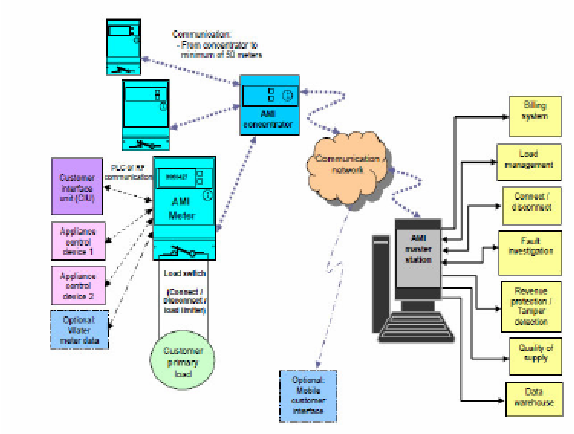


Figure 2: NRS AMI Architecture [5]

The AMI meters have a load switch to perform the capabilities of remote connect / disconnect and load limiting. The AMI meters communicate with a AMI data concentrator situated at the mini sub via power line carrier (PLC). The AMI data concentrator communicates via GPRS to the AMI master station which integrates to the utility's backend systems. The customers are handed a customer interface unit (CIU) providing real time energy consumption. The CIU communicates with the AMI meter via PLC or Radio Frequency (RF).

The timeframe for Eskom's AMI 10 000 (Phase 1) deployment is expected to be completed by 2012. Based on the lessons learnt, the remaining 110 000 (Phase 2) deployment is to follow thereafter over the next 3 to 5 years.

2.2 Utility Load Manager (ULM)

The ULM has been jointly developed by Eskom and a private industry partner as a residential technology to respond to the national challenges around load shedding in South Africa. The ULM is a load limiting system which can be used to limit the demand of residential customers during system constraints. The ULM will thus assist in minimising the potential of load shedding and managing electricity available to residential customers when national demand is too high.

The timeframe for Eskom's ULM pilot deployment of 27 000 units (20 000 Eskom sites and 7000 Metropolitan sites) is expected to be completed by mid 2011.

3 HIGH VOLTAGE GRID INTELLIGENCE

3.1 The Role of Telecoms and Control

Electrical networks are supported by an interconnected telecommunication infrastructure which has both Energy Management System (EMS) and Distribution Management System (DMS) functionality. This provides teleprotection, control and supervisory to the electrical network with Supervisory Control & Data Acquisition (SCADA).

Traditional SCADA systems provide simple methods to determine the state of the electrical network. Data acquisition is primarily used for status indications. This usually provides single bit or double bit indications for circuit breakers and disconnectors.

The active monitoring of data is done through event processing. This is a fundamental process to maintain the integrity of the electrical network. The rate of change of values from previous states provides the control room with information on the behaviour of the electrical grid. These monitoring algorithms ideally operate along certain set points for upper and lower limits. The devices that are controlled through present SCADA systems provide a vertically integrated operation where the intelligence is managed and controlled at the Master station. Essentially the core function of the SCADA system can be categorized as the following:

- Protection alarms (opening and closing of breakers due to fault currents).
- Protection alarms as indications of transformer health.
- Secondary plant monitoring (DC Alarms).
- Telecontrol systems for control of breakers (connection and disconnection of electrical network).

Although SCADA systems are not limited to these core functions, it has become common practice to focus remote management of the network through simple procedures. The complexity can be further advanced with the use of algorithms for automation functionalities.

The transition from the present network will largely depend on the deployment of an integrated communication platform. The platform would create the support required to exchange data in real time between plant devices, customers and intelligent software analysing the network.

3.2 Benefits of Evolving Technologies

The existing grid is a combination of legacy technologies and new innovative applications, which are used to control and manage the electrical network. The components of an electrical network can typically fall into the following:

- High Voltage (Power transformers).
- Medium Voltage (Power transformers).
- High and Medium Voltage Substations and Switchgear (Breakers, switches, isolators).
- Secondary Plant (IED, protection relays, control monitoring telecontrol, metering and communications).
- Power cables and overhead lines interconnecting substations and customers
- Low Voltage power transformers.
- Compensation equipment (Capacitive or inductive power devices for improving voltage, performance and power factor).

The table below captures details on some of the benefits of evolving technologies. These in essence, support grid optimization which would improve the reliability of the electrical network and thus mitigating the risks of load demands.

Table 1: Evolving Technologies [11]

Technology	Benefit	Key receivers
Variable frequency transformer	• Power transfer between non synchronized grids • Power transfer not interrupted when part of the grid experiences disturbances • No harmonics	Transmission
Phase shifting transformer	• Control active power flow	Transmission
Automatic capacitor switching	• Remotely configured for voltage support on network	Transmission and Distribution
Synchrophasor technology	• High sample rate to measuring electrical quantities • Validating the operational models. • Measurement of stability margins • System-wide disturbance monitoring (Phasor Measurement Unit, Wide Area Measurement)	System operator
Condition monitoring technology	• Advanced Sensors • Transformer monitoring • Circuit breaker monitoring • Hot spot monitoring • Overhead line monitoring	Transmission and Distribution
Distribution and substation automation	• Improve restoration times • Performance improvement • Asset management • Next Generation SCADA	Transmission and Distribution

Advanced metering	• Energy management • Demand response • Energy theft • Temper detection • Usage managements (appliances)	Business Value chain, DSM, Planning, revenue protection

4 GRID INTELLIGENCE THROUGH SENSOR DATA COLLECTION

The data from sensor networks can be any information that will empower a utility to make intelligent decisions for supporting the network. The purpose of using sensors on the network is to collect usable data which can provide an early warning system to ensure that the electrical network remains in a healthy and stable state.

Eskom is considering tools that are available (or needs to be developed) that would enhance the decision making process.

Current sensor initiatives within Eskom are aimed at real time monitoring of high voltage (Alternating and Direct Current) insulator leakage currents, spark gap operation detection and flashover fault detection. These sensors are intended to provide the Operational Managers with data on the state of various physical processes on the transmission lines. It further assists with fault finding and providing a better understanding of transmission line performance.

Eskom's sensor application program to optimise the network is discussed below.

Insulator leakage current monitoring

The presence of steady leakage currents on HV glass insulators are an indication of the severity of the pollution accumulation on it. The larger the leakage current magnitude, the higher is the pollution accumulation and the greater is the possibility of a flashover/spark over event. Having an understanding of the magnitude of the leakage current will allow the operational staff to determine mitigation measures such as washing and or replacement of the insulators. This information may prevent unnecessary line faults, damage to plant and outages.

Spark gap operation detection

HV lines are often equipped with spark gaps/arcing horns across insulators and surge arrestors. Eskom has a unique installation on the Apollo Cahora Bassa HVDC line, where the shield wire is insulated from the towers for PLC telecoms purposes. There are spark gaps installed across the shield wire insulator. It is important to understand where these spark over's occurs as continued operation affects line performance and may cause damage to other hardware. In some cases the fault distance locators are inaccurate and the fault location cannot be verified. Cost effective sensors are being deployed in strategic areas in order to signal the operation of the arcing horns or spark gaps in those areas.

Flashover detection

The HV transmission assets are subject to large magnitude over voltages due to switching operations, lightning, equipment failure and other induced surges. With reference to transmission lines, a cost effective flashover detector is being developed in order to more accurately locate the exact tower or line mid span segment where the flash over event occurred. For HVDC lines, the control system limits the voltage and current within 20 ms and generally there are no visible flash over burn marks indicating where the event occurred. The sensor will detect the flash over, time and date stamp the event, locally store the event and send an event signal to the control room. The exact location is required for line inspections and fault finding exercises. If the events occur outside the tolerable design criteria for the line, then an investigation will need to be undertaken to understand the cause and circumstances around the event. The findings can then be used to better engineer an improved solution and also improve the design practices of new lines.

Lattice Member Theft

The stealing of lattice members (steel support structures) off the lower end of the pylon on the Transmission and Distribution network has resulted in a risk to the Eskom network. The costs of the stolen lattice members are relatively low, however, this has led to the infrastructure becoming unstable, resulting in the affected areas collapsing over a period time and at any given moment, thus causing not only the general public risk but also the stability of the Eskom Transmission and Distribution Network in the area of the theft. To alleviate the problem, sensors are to be installed on the transmission towers which will communicate with the control room during the detection of the lattice member theft.

Low Hanging Conductor

The ultimate aim was to develop a sensor that can detect low-hanging conductors, together with a system that can relay the resulting alarm to the control room with GPS coordinates for effective deployment of field staff.

- The sensor is mounted on a pole, where it measures electric and magnetic field up to the 10^{th} harmonic (magnitude and phase).

The sensor is referred to as the EMFS (Electric and Magnetic Field Sensor).

- Included with the EMFS is a WNP (Wireless Node Prototype), which sends the measured electric and magnetic field values via radio link to a Gateway Wireless Node Prototype (GWNP), which is mains-powered and must be within about 100 m of the WNP.
- The combination of EMFS and WNP is called a RWNP (Remote Wireless Node Prototype). The RWNP is powered by batteries, which are charged via solar panels.
- The GWNP is connected to a GSMT (Remote GSM terminal), which then sends the measured information via GSM network to a remote database for access via a website.

Figure 3 below, illustrates the field trialled concept.

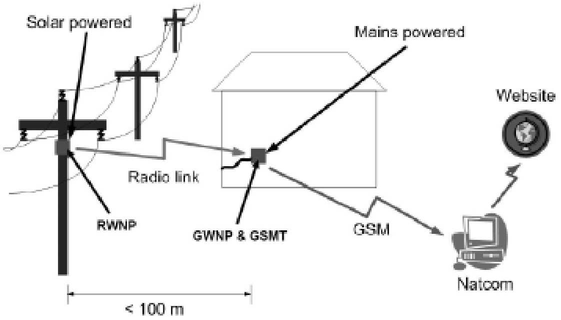


Figure 3: Low Hanging Conductor Solution

5 EMERGING ISSUES

Some key related emerging issues include the following:

- Cost of technology and deployment can result in huge capital investments. These need to be directly aligned to meeting business objectives.
- Present skills are highly specialised in specific areas of protection, telecontrol etc. Developing new skills becomes essential component in the success of designing, deploying and maintaining 'Smart Devices'.
- The present value chains are rigid in that they accommodate a specific methodology of operation. With an increase in grid automation the present value chains would need to be aligned to new processes and systems.
- Technologies need to be evaluated and field trialled to determine the actual benefit and not the promised benefit. The hype and excitement in smart technologies can shadow actual business objective.
- Business case development in choosing the appropriate technologies is crucial to support long term strategic intent.
- Data integration into current new systems would pose a significant challenge since interoperability becomes a huge issue.
- Further research needs to be conducted on applications that would enable data to become smart. Best methods to process this data to information for KPI management and long term sustainability is essential.

6 CONCLUSIONS

The following key conclusions have been noted:

- Enabling a Smart Grid requires several interventions. It becomes increasingly important that a holistic approach be considered for the optimization of the grid having an aging infrastructure.
- Grid optimization can be achieved by deploying distributed sensor networks, for data collection, asset management, predictive system response and for grid stability.
- Demand response technology solutions such as AMI provide the customer foundation of the utility's vision towards a Smarter Grid.
- Eskom is currently implementing distributed sensors on HV, MV and LV networks. The initial results from the sensor initiatives are demonstrating that these new data sources can have significant impact on managing the network.
- The intelligence of a Smart Grid can only be as good as the value of the useful information that can be gathered about its dynamic status. The data collected from these distributed sensor networks has to be careful integrated into the existing systems in order to convert it to useful information.

7 ACKNOWLEDGEMENTS

The authors would also like to thank Eskom for the support of this work and the Engineering Research Group at the University of Witwatersrand, Johannesburg through the TESP program.

8 REFERENCES

[1] Eskom Annual Report – 2008, http://www.eskom.co.za/annrepot08.html, last accessed: November 20, 2010

[2] Government Regulation Gazette, No. 8928, Regulation Paper, No. 31250, 18 July 2008, Pretoria

[3] The Electricity Pricing Policy of the South African Electricity Industry, Department of Minerals and Energy, Government Gazette Vol. 467, May 2004, url: www.gov.za, last accessed: January 23, 2011

[4] D. Gutschow, T. Nortje, H. Madhoo, "Smart Metering – Planning and Feasibility Scan," Eskom Report - RES/RR/07/29019, 2008

[5] NRS049-1:2010, "Advanced Metering Infrastructure (AMI) Part 1 – Systems for residential and commercial customers," Draft1, ISBN: 978-0-626

[6] H. Madhoo, P. Ijumba, L. Marwala, "Smart Grid Technology Scan," Eskom Report - RES/SC/10/31707, 2010

[7] Policy on Energy Efficiency and Demand Side Management for the South African Electricity Industry, Draft 2, NERSA board, March 2004

[8] Demand Response Enabling Technologies for Small-Medium Businesses, Technical report prepares in conjunction with the 2005 California Statewide Pricing Pilot, Lockheed Martin Aspen, April 2006. http://www.energetics.com/madri/pdfs/LMADRT_060506.pdf, last accessed: October 27, 2009

[9] Assessment of Demand Response & Advanced Metering, U.S. Federal Energy Regulator Commission (FERC), August 2006. http://www.ferc.gov/legal/staff-reports/demand-response.pdf, last accessed: April 18, 2010

[10] Advanced Metering for Energy Supply in Australia, Report by Energy Futures Australia for Total Environment Centre, July 2007. http://www.tec.org.au, last accessed: August 22, 2010

[11] A. Khatri, "Evolution of Future Electrical Networks in Eskom," 62nd AMEU Convention 2010, October 2010, pp. 113 – 118

[12] Smart Grid Cyber Security, EnergyBusinessReports.com, last accessed: August 10, 2010

Discussion paper presented at the ISH 2013 Conference

POWER GRID INTELLIGENCE: UTILITY CHALLENGES ON ADVANCED METERING INFRASTRUCTURE DEPLOYMENT AND THE USE OF METERS AS SMART GRID SENSORS

H. Madhoo[1&2*], W. Cronje[1], K. Subramoney[2]
[1]The University of the Witwatersrand, Johannesburg, South Africa
[2]Eskom Holdings SOC Ltd, Johannesburg, South Africa
*Email: hinesh.madhoo@eskom.co.za

Abstract: South Africa's power utility, Eskom Holdings SOC Ltd, is currently in the process of implementing smart metering solutions. One such initiative undertaken by the utility mandated by National Government has been the deployment of Advanced Metering Infrastructure (AMI) to its qualifying middle to high income residential customers, in a phased approach. AMI will also become the basis for building Grid Intelligence into the power network.

The paper focuses on two main aspects. Firstly, the lessons learnt and challenges faced by the utility on the deployment of AMI as part of the Grid Intelligence will be presented. The paper focuses on the utility's phase 1 deployment of AMI, which in accordance with the Regulation 773 [2], mandates the use of smart systems and time-of-use (TOU) tariffs for customers consuming over 1000kWh per month.

Secondly, the paper also discusses the use of AMI where the meter would act as a smart sensor to build Grid Intelligence in the power network. The data that is obtained from the installed smart meters could provide the ability to gain further intelligence such as Frequency Monitoring, Outage Monitoring, Power Quality Monitoring, Low Voltage Visualisation, Demand Response etc. via data mining, to achieve Grid Optimisation and move towards a practical Smart Grid.

1 INTRODUCTION

Eskom, South Africa's state-owned power utility, generates approximately 95% of the electricity used in South Africa and approximately 45% of the electricity used in Africa [1]. Eskom generates, transmits and distributes electricity to industrial, mining, commercial, agricultural and residential customers and redistributors.

In order to manage the power network, it becomes increasingly important to have a network which can provide real time information about its health and state. A holistic approach to achieving Grid Optimisation would require consolidating Low Voltage (LV), High Voltage (HV), Information, Communication and Telecommunication (ICT) and Customer requirements [8].

A key enabler towards the management of these challenges would be the deployment of Advanced Metering Infrastructure (AMI) and thereby move towards a Smart Grid.

In 2008, Eskom embarked on an AMI programme. The programme implementation was divided into Phases (Phase 1 and Phase 2) as a risk mitigation strategy.

The Phase 1 scope was a 10 000 meter pilot implementation with the key objective to develop internal capacity and experience on AMI technology and implementations. This phase also aimed to rollout and test the residential time-of-use (TOU) tariff - Homeflex.

2 THE AMI PROGRAMME

An extensive tender process for AMI solutions was initiated in March 2009, based on the South African industry standard for AMI, NRS049:2008 [4]. The standard was prepared by the Electricity Suppliers Liaison Committee (ESLC) for use by South African electricity supply authorities, in collaboration with the South African Bureau of Standards (SABS) [4].

The solutions were required to provide the following functionality, TOU metering, automated metering reading, non-technical loss detection, remote disconnect/reconnect, residential demand response (load limiting and appliance control) and low voltage (LV) network visualisation.

In September 2009, the tender process was concluded with the selection of two qualifying AMI solution providers for Phase 1. The scope of the solution providers were:

- Replacement of 5000 existing conventional meters, with 5000 smart meters.
- Installation of customer interface units (CIUs).
- Installation of data concentrators (DCs).
- Installation, setup and commissioning of the AMI Master Station or Head-end.

- Deployment of a Multi-vendor Integration Layer (MVIL) for integration between the Master Station and Eskom's billing system.

Phase 1 also required the following internal Eskom system developments:

- Deployment of the Multi-vendor Integration Layer (MVIL) for integration between Eskom's billing system and AMI Master Stations.
- Updates to the Eskom billing system to support automated meter reading (AMR), appliance control functionality and AMI meter types.

2.1 The AMI Solution

The phase 1 solution operates as follows:

The smart meter frequently updates the information displayed on the CIU using either power line communications (PLC) technology or radio frequency (RF) technology. The CIU provides the customer with the following useful information:

- Current usage or demand.
- Total usage and TOU register values.
- Current tariff rates.

PLC technology uses the power cables to communicate data and is sometimes referred to as "over power line" communications technology. RF is an "over the air" communications technology similar to the technology used in remotes for alarms and security gate motors.

Eskom's billing system updates the Master Station meter data and requests meters reads as per the normal meter read schedules through the MVIL interfaces with the master stations, using secure communications over the Internet.

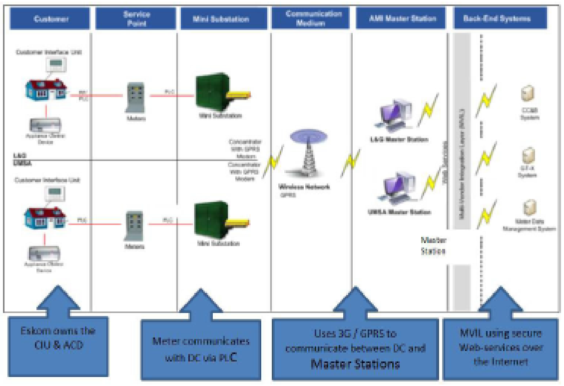


Figure 1: Eskom AMI Solution Architecture [6]

3 UTILITY BENEFITS AND CHALLENGES - AMI DEPLOYMENT

3.1 Utility Benefits on AMI Deployment

Although Phase 1 experienced several challenges, these challenges provided the team valuable learning and experience. The following benefits were realised:

- Created organisational appreciation for the challenges and complexity introduced by AMI.
- Reduction of non-technical losses
- Automated meter reading cost savings
- Reduction in Field Costs (Remote disconnect/reconnect)
- Provided significant lessons learnt and
- Developed AMI skills, knowledge and capacity
- Provided the opportunity to understand the operational requirements, test and refine additional AMI functionality e.g. tamper detection.

3.2 Utility Challenges on AMI Deployment

3.2.1 AMI Utility Challenges

The South African utility has experienced many challenges during the pilot deployment. Some of these key challenges are described below:

- *AMI Solution Challenges*:

  Several AMI solution performance issues were encountered, such as:
  - Meters disconnecting customers randomly.
  - Meters changing modes without cause.
  - Communication problems; between meter and CIU; meter and DC; DC and head-end.
  - CIU and meter display failures
  - Incorrect (extremely high) meter register values.
  - Meter recalls.
  - Inconsistency and mismatch of information displayed between CIU and Meter.

- *Customer Issues*:

  Historical and unresolved customer queries became the responsibility of the AMI programme. Some customers complained about increased bills as a result of AMI meters – however, after detailed investigations it was found that the complaints were due to:

- Customers not understanding their new bills.
- Historic customer queries.
- Replaced meters were of the very old mechanical type and may have slowed over time.
- The installation of the AMI meters also coincided with tariff increases therefore customers incorrectly attributed the increases to the new meters.

- *Field versus system Issues*:

  Data inconsistencies were uncovered, i.e. mismatches between field data and data captured in billing system. This data needed to be corrected through physical field audits before completing the meter change-out process.

- *Field Installation related issues*:

  - Transformer outages were required for the DC installations, prior to commencing with the meter installations. However, there were long lead times to obtain transformer outages, which resulted in meter installation delays. This issue was further exacerbated if the planned DC installation could not be completed during the allocated outage.
  - Maintenance – Eskom's current philosophy is not to install and maintain equipment beyond the meter. The installation of the CIU and ACD in the customer premise challenges this philosophy. The DC is also a new device that will have to be maintained by field staff.
  - Inaccurate low voltage (LV) – network diagrams resulted in stranded meter installations, that is, meters were not linked to data concentrators.
  - Customers were not available during normal working hours to install the CIUs. Appointments had to be arranged with customers for after-hour installations.
  - Limited space in existing transformer and meter kiosks, required additional kiosks to be installed.

- *Theft and Vandalism*:

  Theft and vandalism of several DCs were encountered. SIM cards were stolen from the plug-in modems on the DC.

- *Limitations on Specification and Standards*:

  The solution specification was based on the first version of national standard for Advanced Metering Infrastructure (AMI) - NRS049:2008 [4]. Being, version 1, the specification was still immature and untested. It was therefore expected that this specification would have to undergo revisions.

A summary of the key challenges experienced by the Utility (Phase 1) is depicted in the figure below: [7]

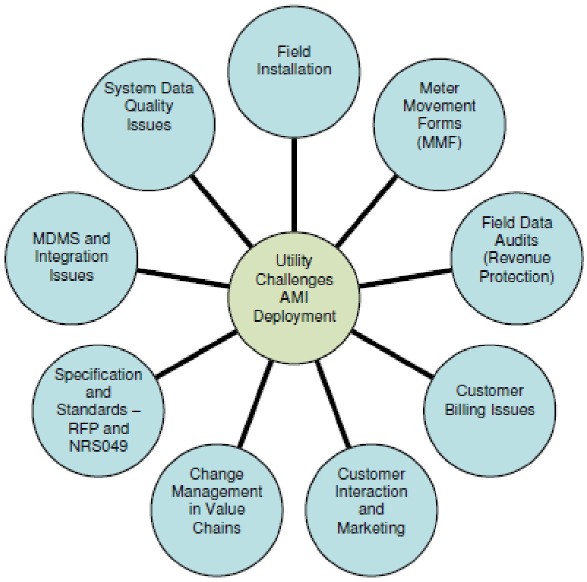


Figure 2: Utility Challenges – AMI Deployment.

3.2.2 AMI Lessons Learnt

The challenges mentioned above also resulted in several lessons being learnt. Some of the key lessons learnt are listed below:

- AMI implementations are complex and have significant impact to the entire electricity distribution value chain. Therefore, change management of the internal (field and customer service) and external (customers) stakeholders are critical. Further, the close integration between traditional separate information technology and operational technology departments is required. The programme must be prepared to play this integration role.

- It is critical that customer and metering field and system data is accurate prior to undertaking smart meter installations. Therefore, pre-installation field and system audits, data cleansing and resolution of technical field issues is critical. Existing business issues must be resolved first.

- The current national standard for Advanced Metering Infrastructure (AMI) NRS049:2008 [4], has some shortcomings and these need to be addressed. The specifications need to address the entire infrastructure value chain, especially, with respect to interoperability.

- The performance and reliability of the metering solution forms the foundation of the project and cannot be compromised. Therefore, strict compliance to functional, quality, performance, reliability, safety and security standards must be enforced. A comprehensive testing process is required to mitigate solution performance risks. The testing process will also develop internal skills and a better understanding of the different solutions functionality and performance capabilities.

- The AMI industry (technical and implementation) in South Africa is still developing and significant capacity development is required. It is critical that selected technology suppliers have a proven track record and have significant research and development and technical support capabilities, should technical failures occur.

AMI functionality should be gradually introduced; this allows the business to develop experience and confidence in the solution before introducing more complex functionality.

4 POWER GRID INTELLIGENCE THROUGH SMART METERS ACTING AS A SMART GRID SENSOR

Literature indicates that the Smart Grid application of smart meters require the efficient and effective collection of data, storage thereof and ease of access by applicable stakeholders [10]. The major benefit of this application is the ability to develop and implement control algorithms in order to optimise the energy delivery network, which directly services the customer. The information can be used for identifying overloaded transformers, which is an indication of the development of the geographical area associated to that particular feeder.

The purpose of using sensors on the network is to collect usable data which can provide an early warning detection system to ensure that the electrical network remains in a healthy and stable state.

Internationally, utilities have done significant work around power grid intelligence using the functionality of the smart meter to perform as a smart grid senor. Some of the intelligent aspects that may be realised from smart meters acting as sensor include the following, but not limited to; are depicted in the figure below:

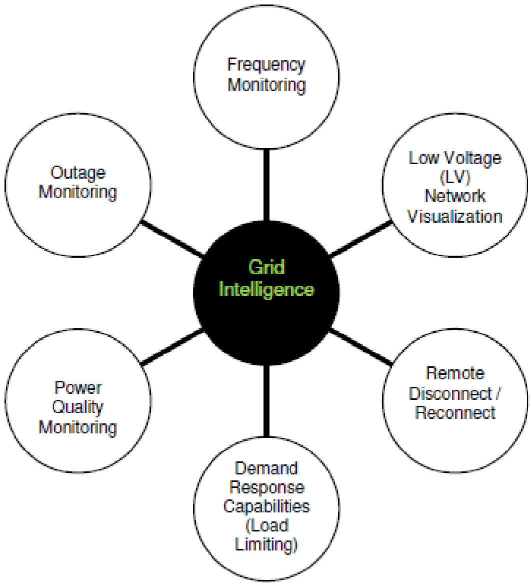


Figure 3: LV Grid Intelligence through maximising the capabilities of the smart meter to act a sensor on the power network.

Utilities deploying smart meters to act as sensors on the network to achieve LV intelligence could realise the following benefits mentioned in the table below:

Table 1: Grid Intelligence through Smart Meters acting a Smart Grid Sensor

Power Quality Monitoring	Power Quality will be determined by the profile data. The dips in voltage and current will be measured to assist with obtaining the power quality graph.
Voltage Regulation	The meter will record the voltage performance every 30 minutes. Voltage readings will be used to monitor the voltage dips on each phase.
Outage Reporting	AMI meters are able to recognise losses of power to the customers' premises. At the end of a set period, a manual reporting process will be defined to inform the Utility in retrospect of outages that

	have occurred on the meters.
Fault Reporting	AMI meters can be used for reporting of faults such as Auxiliary Device Fault and Isolated Fault. In the event that an auxiliary device fault is reported by a customer, a process will be defined to have the device replaced at a customer's premises. In the event of an isolated fault, a process will be defined to support customers who experience an isolated supply related interruption.
Remote Disconnect or Reconnect	In the event that a customer has defaulted to non-payment, the meter may be remotely disconnected or remotely reconnected when the customer has settled his account. This action will be executed on the Vendor Master Station.
Non-Technical Losses	Identify customers not on Eskom's billing system. Perform energy balancing at a mini-substation level by balancing energy delivered versus energy consumed at the meter level. Identify tampers and bypasses at the meters in the field i.e. removal of the meter terminal cover will flag as a tamper. Imbalance in currents will create alarms whereby a supply has been tapped prior to the meter (i.e. the customer consuming electricity illegally). This will assist the Utility in revenue collection and save other Utilities from spending money by conducting blanket audits.

Despite the efforts and contributions of achieving the power grid intelligence through a smart meter, many utilities have experienced challenges around capitalising from the data to perform advanced analytics to support operational and non-operational business intelligent decision making.

The South African Utility, through the AMI pilot deployment of smart meters, has managed to integrate AMI with normal business processes to enhance the business in the following aspects:

- Operational Efficiency – automated meter readings of 30 minute interval data from smart meters have provided accurate readings to customers. Customers would compare their bills with previous months' bills and would realise cost benefits by managing their consumption through educating themselves from the CIU display showing their instantaneous consumption during the peak and off peak periods.

- Network Planning, Load Forecasting and Load Research – the data from the smart meters was used by researchers in the organisation to perform load research studies, customer behaviour research on the impact of TOU tariff for the AMI pilot customer base. Network Planners envision AMI to empower energy savings by measuring, collecting and analysing energy usage. Network planners could use the data to perform load analysis on the network and load prediction for the suburbs where the smart meters were installed. This would assist network planners for feeder and transformer upgrades in the area.

- Remote Disconnection / Reconnection process – current business processes in Eskom were reviewed and modified accordingly to perform remote disconnections on the meters where customers defaulted in payment. When customers had settled their accounts, the smart meters would be remotely reconnected through an instruction from the master station.

- Tamper Detection – where smart meters were tampered with, an alarm would be flagged on the master station as well as reflected on the daily data readings files provided by the meter vendors which would then be for action by the business.

- Outage Management – outage notifications could be sent to the master station which could then flag other systems in the business such as SCADA, Outage Management System, Distribution Management System (DMS), and Energy Management System (EMS).

- Functional Requirement Specifications for AMI data – the AMI specification was designed for data to be integrated with other systems in Eskom such as Billing and other Metering systems. The data was made available in the Extensible Markup Language (XML) format and conformed to the Common Information Model (CIM).

- Shift in Customer Behaviour – The availability of near real time data on energy consumption and costs at a time where increases in tariff costs have been implemented, has made customers more aware of their of their energy usage and promoted energy efficiency. In future, customers will be able to log in to the web portal to access information on their energy consumption. This is similar to the availability of internet tools such as Google® Power Meter™ and that of other companies which use a web portal to supply home energy reports to allow neighbours to compare their energy consumption.

5 CONCLUSIONS

South Africa has embraced significant learning and practical experience gained from Phase 1 and has embarked on a detailed programme review process, which includes:

- Internalising the lessons learnt from Phase 1.
- Refining and enhancing the functional, technical, interoperability and performance requirements of the AMI solution.
- Strengthening the IT and telecommunications infrastructure. The communication network needs to be extremely reliable to transfer large amounts of information to the data concentrator and master station.
- Enhancing the field installation and business processes.
- Review and alignment of the current business processes to include the AMI requirements.
- Install the additional smart meters to act as sensors on the network to achieve LV intelligence.
- The measured data from the smart meters stored in the master station can be used for new customer billing strategies e.g. time of use tariff, critical peak day pricing, prepaid metering etc.
- Customer access to information about how one uses the electric energy imposes new requirements on how the metering data is stored, its format and accessibility [11].

6 ACKNOWLEDGEMENTS

The authors would like to thank Eskom for the support of this work and the Engineering Research Group at the University of Witwatersrand, Johannesburg through the TESP program.

7 REFERENCES

[1] Eskom Annual Report – 2008, http://www.eskom.co.za/annrepot08.html, last accessed: November 20, 2010

[2] Government Regulation Gazette, No. 8928, Regulation Paper, No. 31250, 18 July 2008, Pretoria

[3] The Electricity Pricing Policy of the South African Electricity Industry, Department of Minerals and Energy, Government Gazette Vol. 467, May 2004, url: www.gov.za, last accessed: January 23, 2011

[4] NRS049:2008, "Advanced Metering Infrastructure (AMI) Part 1 – Systems for residential and commercial customers," Version 1, ISBN: 978-0-626

[5] Presentation - AMI Programme Phase 1 Challenges / Lessons Learnt and Way Forward, Subramoney KP, Nov 2012

[6] Presentation - AMI PMO Internal Stakeholders Communication, Subramoney KP, Jan 2013

[7] Article - Metering International Issue 3 - Eskom's Advanced Metering Infrastructure (AMI) Pilot Project – Key Challenges and Lessons Learnt, Subramoney KP, Madhoo HV, 2013

[8] ISH2011 Paper – Towards a Smart Grid: A South African Perspective on the Enablement of Grid Intelligence to address Demand Response Challenges, Madhoo H, August 2011

[9] Advanced Metering for Energy Supply in Australia, Report by Energy Futures Australia for Total Environment Centre, July 2007. http://www.tec.org.au, last accessed: August 22, 2010

[10] Sioe T. Mak, "A Synergistic Approach to Implement Demand Response, Asset Management and Service Reliability Using Smart Metering, AMI and MDM Systems", IEEE, 2009

[11] Chenthamarai S, "Advanced Metering Infrastructure for Smart Grid Applications", IEEE, 2012

Article published in "Smart Energy & Metering International" – Issue 1, 2013

ESKOM'S ADVANCED METERING INFRASTRUCTURE (AMI) PILOT PROJECT – KEY CHALLENGES AND LESSONS LEARNT

By K.P. Subramoney and H. Madhoo, Eskom Holdings SOC Ltd, Johannesburg, South Africa

Eskom, South Africa's power utility, has embarked on an advanced metering infrastructure (AMI) programme targeting qualifying residential billed customers. The programme is a phased rollout of a smart metering solution and processes to approximately 120,000 customers. Phase 1 of the programme was a pilot rollout of 10,000 smart meters, which was aimed to test the technology and processes and pilot a residential time-of-use (TOU) tariff. This paper reviews the phase 1 results, key challenges and lessons learnt.

BACKGROUND

Eskom, South Africa's state-owned power utility, generates approximately 95% of the electricity used in South Africa and approximately 45% of the electricity used in Africa. Eskom generates, transmits and distributes electricity to industrial, mining, commercial, agricultural and residential customers and redistributors.

In 2008, Eskom embarked on an advanced metering infrastructure (AMI) programme. The programme implementation was divided into two phases as a risk mitigation strategy.

The phase 1 scope was a 10,000 pilot implementation with the key objective to develop internal capacity and experience on AMI technology and implementations. This phase also aimed to rollout and test the residential time-of-use (TOU) tariff, Homeflex.

PHASE 1 – AMI SOLUTION

An extensive tender process for AMI solutions was initiated in March 2009, based on the South African industry standard for AMI, NRS049:2008. The standard was prepared by the Electricity Suppliers Liaison Committee (ESLC) for use by South African electricity supply authorities, in collaboration with the South African Bureau of Standards (SABS).

The solutions were required to provide the following functionality: TOU metering, automated metering reading, non-technical loss detection, remote disconnect/reconnect, residential demand response (load limiting and appliance control) and low voltage (LV) network visualization.

In September 2009, the tender process was concluded with the selection of two AMI solution providers for phase 1. The scope of each of the the solution providers were:

- Replacement of 5,000 existing conventional meters with 5,000 smart meters
- Installation of customer interface units (CIUs)
- Installation of data concentrators (DCs)
- Installation, setup and commissioning of the AMI master station or head-end
- Deployment of a multi-vendor integration layer (MVIL) for integration between the master station and Eskom's billing system.

Phase 1 also required the following internal Eskom system developments:

- Deployment of the MVIL for integration between Eskom's billing system and AMI master stations
- Updates to the Eskom billing system to support automated meter reading (AMR), appliance control functionality and AMI meter types.

Figure 1 illustrates the phase 1 AMI solution components and supported functionality.

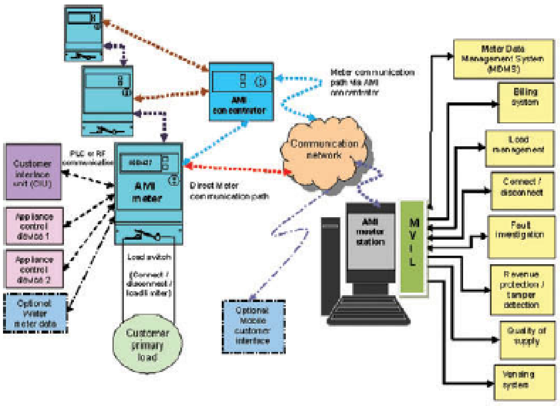


Figure 1 – Advanced metering infrastructure (AMI) components

The phase 1 solution operates as follows.

The smart meter frequently updates the information displayed on the CIU using either powerline communications (PLC) or radio frequency (RF) technology. The CIU provides the customer with useful information, such as:

- Instantaneous demand
- Total register accumulative usage and accumulative TOU register values (peak/off-peak)
- Current tariff period (peak/off-peak).

The meters communicate their usage and event information (such as tampers) to the data concentrators using PLC technology. The data concentrators upload this information to the master station on a daily basis or on demand, using a cellular data network.

Figure 2 – Field installation team

Meter readings were initially communicated from the master station to Eskom's billing system via a meter readings text file. Once the MVIL was deployed, it facilitated automated meter reading requests and meter data synchronization between the master stations and Eskom's billing system. The MVIL is implemented using secure web services, exchanging XML messages adapted from the Common Information Model (CIM) standard.

PHASE 1 STATUS AND ACHIEVEMENTS

Phase 1 meter installations began in the first quarter of 2011 and continued to the second quarter of 2012.

The installation statistics to date are:

Although the 10,000 planned phase 1 meter installations have not been completed, several benefits have been achieved:

- Automated meter reading of 3,232 residential customers
- Identified several customers that were not on the billing system
- Identified several metering and billing errors which required rectification
- Identified several incidents of non-technical losses
- Designed and deployed an open (non-proprietary) multi-vendor interface layer that can accommodate multiple AMI master stations
- Developed standardized meter and data concentrator installation specifications and practices
- Implemented remote customer supply disconnection and reconnection processes
- Converted 38 customers to the Homeflex TOU tariff – on a voluntary basis
- Learnt several invaluable lessons in various areas of AMI technology implementation
- Developed significant AMI skills and knowledge within the organization.

	Total
Data concentrators	127
Meters	3,232
Customer interface units (CIU)	1,106

Table 1 – Phase 1 installation statistics

PHASE 1 CHALLENGES AND LESSONS LEARNT

The following were some of the key phase 1 challenges:

- Delays were experienced due to a legal challenge of the AMI solution tender process.
- AMI solution performance issues were encountered, such as:
  - Meters disconnecting customers randomly
  - Meters changing modes without cause
  - Communication problems between meter and CIU, meter and DC, DC and head-end

  - CIU and meter display failures
  - Incorrect (extremely high) meter register values
  - Meter recalls
  - Inconsistency and mismatch of information displayed between CIU and meter.
- Historical and unresolved customer queries needed to be resolved.
- Some customers complained about increased bills as a result of AMI meters, although after detailed investigations it was found that the complaints were due to:
  - Customers not understanding their new bills
  - Historic customer queries
  - Replaced meters were of very old mechanical type and may slow down over time becoming inaccurate
  - The installation of the AMI meters also coincided with tariff increases, therefore customers incorrectly attributed the increases to the new meters.
- Data inconsistencies were uncovered, i.e. mismatches between field data and data captured in the billing system. This data needed to be corrected through physical field audits before completing the meter change-out process.
- Installation related issues:
  - The DC installations were required prior to commencing with the meter installations. The DC installations required transformer outages. However, there were long lead times to obtain transformer outages, which in some instances delayed meter installations. DC installations that could not be completed during the allocated outages further exacerbated meter installation delays.
  - Maintenance ÷ Eskom's current philosophy is not to install and maintain equipment beyond the meter. The installation of the CIU and ACD in the customer premise challenges this philosophy. The DC is also a new device that will have to be maintained by field staff.
  - Inaccurate LV network diagrams resulted in stranded meter installations, that is, meters were not linked to data concentrators.
  - Customers were not available during normal working hours to install the CIUs. Appointments had to be arranged with customers for after-hours installations
  - Limited space in existing transformer and meter kiosks required additional kiosks to be installed.
- Theft and vandalism of several DCs were encountered.
- The programme had executive support however, the same level of support was not experienced in the area offices due to:
  - Limited knowledge and internal communication about the AMI programme
  - AMI required significant area office support to assist with meter change-out capturing, customer forums, customer queries and training. However, this placed an additional burden on area offices that already had limited capacity.
  - The area offices were already supporting several other projects that were being implemented simultaneously in the area.
- Eskom's project personnel had limited experience with AMI implementations.
- The solution specification was based on the first version of national standard for AMI, NRS049:2008. Being version 1, the specification was still immature and untested. It was therefore expected that this specification would have to undergo revisions.

However, the challenges also resulted in several lessons being learnt, such as:

- AMI implementations are complex and have significant impact on the entire electricity distribution value chain. Therefore, change management of the internal (field and customer service) and external (customers) stakeholders is critical. Further, the close integration between traditional separate information technology and operational technology departments is required. The programme must be prepared to play this integration role.
- It is critical that customer and metering field and system data is accurate prior to undertaking smart meter installations. Therefore, pre-installation field and system audits, data cleansing and resolution of technical field issues is critical. Existing business issues must be resolved first.
- The current national standard for AMI, NRS049:2008, has some shortcomings and these need to be addressed. The specifications need to address the entire infrastructure value chain, especially with respect to interoperability.
- The performance and reliability of the metering solution form the foundation of the project and cannot be compromised. Therefore, strict compliance to functional, quality, performance, reliability, safety and security standards must be enforced. A comprehensive testing process is required to mitigate solution performance risks. The testing process will also develop internal skills and a better understanding of the different solutions' functionality and performance capabilities.
- The AMI industry (technical and implementation) in South Africa is still developing and significant capacity development is required. It is critical that selected technology suppliers have a proven track record and have significant research and development and technical support capabilities, should technical failures occur.
- AMI functionality should be gradually introduced, allowing the business to develop experience and confidence in the solution before introducing more complex functionality.

THE WAY FORWARD

Eskom has embraced the significant learning and practical experience gained from phase 1 and has embarked on a detailed programme review process, which includes:

- Internalising the lessons learnt from phase 1
- Revising AMI business and implementation plans
- Refining and enhancing the functional, technical, interoperability and performance requirements of the AMI solution
- Including the requirement for prepayment functionality
- Strengthening the IT and telecommunications infrastructure
- Developing additional resources to support the AMI solution
- Enhancing the field installation and business processes
- Review and alignment of the current business processes to AMI requirements.

The planned completion of the project review is June 2014. Thereafter Eskom will be in a more informed position to continue with its field rollout of AMI technology. MI

ABOUT THE AUTHORS
Kennedy Subramoney holds a Master of Science degree and is currently employed as a Senior Consultant by Eskom's Group Capital Division. He is the AMI Programme Manager and heads up the AMI Programme Management Office. He has also been an integral part of Eskom's deployment of its online vending solution.
kennedy.subramoney@eskom.co.za

Hinesh Madhoo is registered as a Professional Engineering Technologist and is currently employed as a Senior Engineer by Eskom's Research, Testing & Development Department. He is part of the AMI Programme Management Office focusing on the Operations and Processes Stream; and has been associated with research on smart grids, AMI and demand management.
hinesh.madhoo@eskom.co.za

www.eskom.co.za