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Research Report

Investigation into the impact of wind power generation on Demand Side Management (DSM) practices

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Declaration

I declare that this research project is my own, unaided work, except where otherwise acknowledged. It is being submitted for the degree of Master of Science in Engineering (Electrical) at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

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Signed this 9th day of October 2014

Abstract

The construction of a number of wind farms in South Africa will lay the foundation for the country to embrace the generation of greener energy into the National Grid. Despite the benefits derived from introducing wind power generation into the grid, this source encompasses adverse effects which need to be managed. These adverse effects include the intermittency and lack of predictability of wind. In power systems with a high penetration of wind energy, these effects can severely affect the power system's security and reliability in the event of significant rapid ramp rates. Recently, many utilities around the world have been exploring the use of Demand Side Management (DSM) and Demand Response (DR) initiatives and programmes to support and manage the intermittency of wind power generation.

This report outlines the programmes and benefits of DSM/DR and provides a critical analysis of the challenges facing South Africa with implementing these initiatives. Introducing these programmes necessitates the employment of a number of Smart Grid technologies including Advanced Metering Infrastructure (AMI), next generation telecommunications technologies, smart meters, enterprise system integration and dynamic pricing. These tools and techniques are discussed and their challenges described within the context of South Africa's current state of the power system. The current practices for DSM/DR in South Africa have been evaluated in this report. Despite, the success of many DSM/DR initiatives in the commercial, industrial and agricultural sectors, it is found that much work is still required in the residential sectors as the current DSM initiatives are not adequate for managing wind power generation. A detailed analysis and recommendations for South Africa's DR program is then presented based on industry best practices and experiences from other utilities who are currently exploring DSM/DR in the residential sector using Smart Grid technologies.

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Abbreviations

3G	Third Generation
ACD	Appliance Control Device
ADM	Add Drop Multiplexor
ALFS	MV90 meter data repository
AMI	Advanced Metering Infrastructure
AMR	Automated Meter Reading
APN	Access Point Name
ARRA	American Recovery and Reinvestment Act
BPLC	Broadband over Power Line Carrier
CC&B	Consumer Care & Billing
CFL	Compact Fluorescent Lamp
CIP	Critical Infrastructure Protection
CIU	Consumer Interface Unit
CIM	Common Information Model
COSEM	Companion Specification for Energy Metering
DLMS	Device Language Message Specification
DMP	Demand Market Participation
DR	Demand Response
DREAM	Demand Responsive Electrical Appliance Manager
DSL	Digital Subscriber Line
DSM	Demand Side Management
ECS	Energy Conservation Scheme
EDGE	Enhanced Data Rates for GSM Evolution
EEI	Energy Efficiency Index
EGM	Energy Growth Management
EIA	Electronic Industries Association
ESCO	Energy Service Companies
EU	European Union
FERC	Federal Energy Regulatory Commission
FPI	Fault Path Indicator
FTTH	Fibre to the Home
GoS	Grade of Service
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
GW	Gigawatt
ICASA	Independent Communications Authority of South Africa
ICT	Information and communications technology
IDM	Integrated Demand Management

IEC	International Electrotechnical Commission
IPP	Independent Power Producer
IPTV	Internet Protocol Television
ISM	Industrial, Scientific and Medical radio bands
KPI	Key Performance Indexes
LED	Light Emitting Diode
LPU	Large Power Users
LTE	Long Term Evolution
MV90	Multi-Vendor 90 metering data acquisition system
MVIL	Multi-Vendor Integration Layer
NERC	North American Electric Reliability Corporation
NERSA	National Energy Regulator of South Africa
NRS	National Rationalisation of Standards body
PCP	Power Conservation Programme
PDH	Plesiochronous Digital Hierarchy
PoP	Point of Presence
POTS	Plain Old Telephony Services
PTT	Push to Talk
QoS	Quality of Service
RPP	Renewable Power Plants
REFIT	Renewable Energy Feed In Tariff
RTU	Remote Terminal Unit
SAGC	South African Grid Code
SDH	Synchronous Digital Hierarchy
SCADA	Supervisory Control and Data Acquisition
SIM	Subscriber Identity Module
SLA	Service Level Agreements
SO	System Operator
STS	Standardized Transfer Specification
TOU	Time of Use
UK	United Kingdom
UHF	Ultra High Frequency
UML	Unified Modelling Language
US	United States
V2G	Vehicle 2 Grid
VHF	Very High Frequency
VoIP	Voice of Internet Protocol
WAMS	Wide Access Monitoring Systems
WiMAX	Worldwide Interoperability for Microwave Access
XML	Extensive Markup Language

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1. Introduction

Due to the shortage of coal, increasing costs of fossil fuels and environmental pollution, power utilities around the world are seeking alternative solutions and introducing measures to assist environmental protection, combat global pollution and increase security and reliability of supply on the power system [4]. These solutions incorporate the use of renewable energy sources embedded into a power system's generation, transmission and distribution network. Eskom, South Africa's state owned power utility has 27 operational power stations which supplies more than 40 GW into the National Grid. In the past, the state-owned utility was in a position to sustain South Africa's demand until recently, when the country's electricity demand exceeded supply resulting in load shedding contingencies being implemented country wide since 2007 [12].

South Africa's Department of Energy has instituted the Renewable Energy Feed-In Tariff (REFIT) programme for the purpose of allowing Independent Power Producers (IPP) to construct, operate and maintain wind farms amongst other renewable sources in South Africa and supply energy into the National Grid. As a result, these wind farms are now in construction phase and soon to be commissioned on to the Distribution and Transmission Networks.

The use of wind power generation presents a number prevailing adverse effects which need to be considered by the system operator. These effects include the intermittent nature and variability of wind, lack of predictability and forecasting errors which can severely compromise the security and reliability of a power system with a high penetration of wind power generation. Historically, the conventional method of managing system security and reliability was through the use of capacity reserves using coal-fired and gas operated generators. This method does not contribute towards the reduction of the countries carbon foot print and requires additional reserves which are not always available in South Africa.

Around the world, utilities are now exploring the use of Demand Side Management (DSM) and Demand Response (DR) initiatives to manage the intermittency of wind power generation.

This report describes the concepts of DSM and DR and presents an outline of the benefits and challenges which exist. In addition, current DSM and DR practices around the world and in South Africa are discussed. In order to successfully deploy DSM and DR programmes with the intent of managing the intermittency of wind necessitates the implementation of Smart Grid enabling technologies to support these programmes. A review of the Smart Grid technologies including Advanced Metering Infrastructure (AM), next generation telecommunications, smart metering, enterprise system integration and dynamic pricing is presented. The impact of wind power generation on South Africa's current DSM practices is outlined with an analysis of the current prevailing challenges and suggested remedial actions which need to be implemented during small-scale pilot projects. These remedial actions are all presented in the context of South Africa's power system with reference to best practiced methods experienced the world over.

2. Background

A number of power-utilities around the world in conjunction with energy regulators and state governments have commenced implementing carbon reduction mechanisms and programmes to reduce their countries carbon footprint and promote the use of renewable energy sources as opposed to conventional methods of generating electricity.

Over the past 10 years, European governments have developed policies to encourage the development of renewable energy systems including wind farms [14]. The 2001 / 77 / EC European Commission Directive has set a target of 22 % gross energy production using renewable energy sources by 2010. As a result, wind power generation in Portugal will be increased by 8000 MW by 2020 [1].

The European Commission has set a target of 20% of its generating capacity to be sourced from renewable energies by 2020 [6]. Portugal has a target of 31% by 2020 [6]. It is estimated that Portugal can reduce their peak consumption in 2020 by 17.4% based on the energy reduction measures that have been implemented in the country [6].

China has committed to reducing carbon emissions by 40-45% below its levels produced in 2005 by 2020 [4]. China has included the use of wind energy in order meet this target.

Wind energy has been identified as a major contributor to facilitate utilities in meeting their prescribed targets and goals. The installed capacity of wind power the world over reached 194 GW in 2010 [17]. In the European Union, Germany has the highest installed capacity of wind power exceeding 25 GW [17]. This is followed by Spain with 19 GW, and then France and Italy [17].

South Africa has a proposed roadmap which indicates 27 % of gross energy production to be generated from renewable sources by 2030. It is envisaged that wind energy production will constitute 30% of this target. This roadmap further incorporates a high roll out of solar water heaters (SWH), promotes an increase in employment and stabilization of greenhouse gas emissions generated from the electricity sector [12].

In order to alleviate the electricity deficit in South Africa, Eskom has embarked on a capacity expansion programme which promises to increase the generation capacity by an additional 10 GW [12]. This is achieved mostly through the construction of new coal-fired power stations (Medupi and Kusile) and the returning to service of mothballed power stations [12]. In recent years, the use of renewable energy has been observed as an opportunity to encourage a more secure, labour intensive, economically viable and sustainable society [12]. South Africa's meteorological conditions suggest significant levels of renewable energy potential. Consequently, a 10 000 GWh of energy and has been targeted for renewable energy and 3.2 GW has been determined to be generated through renewable sources [32]. This will be achieved through the Department of Energy's Renewable Energy Independent Power Producer Programme and the Renewable Energy Feed in Tariff programme allowing investors of renewable energy sources to generate electricity and wholesale the electricity back to Eskom for a prescribed fee defined in their power purchase agreements. These programmes have attracted a number of foreign investors into South Africa. This programme will transpire through a number of phases allowing Independent Power Producers (IPP) to bid during each phase for the finance, construction, operation and maintenance of Renewable Power Plants (RPP) in South Africa [32]. Currently phase 1 bids are in construction phase with the first wind farm and solar park expected to be in commercial operation during the first quarter of 2014. Successful preferred bidders for the third phase will be concluded in 2014 [32]. Eskom also aims to construct a 100 MW concentrated solar plant and a 100 MW wind farm [12].

Wind is a natural resource which can be a viable source of energy to a power system providing green energy into the grid [4]. However, the implementation of wind power generation into a power system brings forth a number of challenges which utilities need to carefully consider and control in order to ensure grid reliability and stability. These challenges are largely attributed to the integration of renewable energy systems into power grids and managing the intermittent behaviour of these renewable sources as in the case with wind energy [4].

In cases where an electricity grid encompasses a large scale penetration of wind power generation, it becomes crucial to ensure that adequate methods are employed to compensate for the variability and unpredictability of wind. Furthermore, the risk on the power system increases as wind power variations transpire during peak times [1]. Reduction of wind in power grids with large scale wind energy penetration can introduce severe consequences on the security, integrity and reliability of the power system predominantly where no additional resources are available to respond to significant ramp rates [1]. This becomes more severe in the winter months where demand is higher. In addition, the scenario depicting a high availability of wind power when demand is low requires consideration. In such cases, maximum wind power should be harnessed on to the grid whilst decreasing the utilization of conventional generators. An additional factor contributing to wind variations is seasonal changes which often befall in short time scales [6]. There is large probability of low wind power in the summer months (hot days without wind) and with the increase use of air conditioners, demand during the summer months is constantly on the rise [6]. However, many countries with substantial wind power generation have experienced tremendous positive/negative ramp rates in wind output in hourly time scales. These extreme ramp rates can compromise the security of the power system [1]. In a 100 MW wind farm, ramp rates between 4% - 7% of the installed capacity in second intervals can be experienced [8]. Ramp rates between 10% - 14% can be experienced in minute intervals for the same installed capacity [8]. Daily and monthly variations and the frequency of these variations require careful consideration when determining capacity reserves in a power system with a high penetration of wind power generation.

The characteristics and nature of wind limits the possibility of always meeting peak loads with renewable sources [1]. The output wind power of an electrical system is attributed to the availability of wind which falls outside the dominion and control of the system operator (SO) [1]. The availability of wind is governed and determined by prevailing meteorological conditions which can be forecasted to a reasonable degree of accuracy with current technologies [1]. The intermittency of wind power requires the system operator (SO) to put measures in place to effectively manage the quality and security of supply and balance between supply and demand in the power system [1].

A number of solutions are being explored around the world to counteract and respond to the intermittent nature of wind. These include:

1. Providing additional supply energy using conventional generators at the expense of increasing operating costs and harmful emissions of gases [1]. These Power plants are used for operational and capacity reserves [1].
2. Using energy storage technologies [1]. These technologies assist in minimizing system constraints during peak times, provide an opportunity to harness additional wind power energy when demand is low and provide grid support and stability during drastic negative ramp rates experienced on the network [4]. Pumped hydro storage systems and compressed air energy storage mechanisms are potential technologies for combating variable wind power generation [4]. This technology has matured over recent years and an increase in its use has been seen particularly in the United States [11]. Since 2009, 537 MW owing to energy storage systems have been added to the US power system [11].
3. Grid integration into other power systems including the use of Independent Power Producers (IPPs). This option has recently being largely explored all over Africa.
4. Geographical distribution of wind farms to manage the intermittency of wind power [1]. This will increase predictability and decrease variability [7].
5. Utilizing complimentary renewable energy systems e.g. Photovoltaic and Concentrated Solar.
6. Curtailment of wind power generation to minimize the risk on the power system during peak times by limiting the penetration of wind energy. This however does not benefit Independent Power Producers (IPPs) and based on the power purchase agreements between the utility and IPPs, power utilities may be required to remunerate IPPs when such curtailment conditions are employed under these conditions [18].
7. Reduce forecast horizons from a day ahead to a few hours ahead in order to reduce the energy required to match demand with supply due to prediction errors [7]. The South African Grid Code (SAGC) requirements for renewable power plants (RPPs) do not specify the accuracy of the forecast data [18]. Hence, providing the System Operator with hourly data can reduce the risk on the power system.
8. Improving forecasting techniques can assist the System Operator in making more informed decisions regarding the power system's capacity reserves.
9. Using Demand Side Management (DSM) and Demand Response (DR).
10. Implementing various Smart Grid enabling systems which can support DSM and DR.

The focus of this report is to outline current DSM and DR practices throughout the world and investigate the impact embedded wind power generation has on current practices. In addition, the associated Smart Grid enabling technologies which can be explored to supplement DSM and DR in managing the intermittency of wind is discussed.

3. Demand Side Management

The provisioning of capacity reserves and managing wind intermittency is an on-going predicament throughout the world with various countries researching new techniques and tools which can facilitate the management and security of the power system when integrating renewable sources into their national grid [4]. In order to provide supply to an uncontrolled demand, power utilities around the world are required to ensure that sufficient capacity reserves are provisioned to provide generation security [5]. Conventional generators are typically used to provide the additional capacity during peak times and when the power system is severely constrained. According to [5], when analysing the peak and off peak loads averaged annually on the UK electrical system, the utilization of the generation capacity is below 55% [5]. Providing suitable generation capacity reserves using traditional methods is a costly exercise especially in power grids with a low utilization factor thus affecting the network investment. A more efficient technique is considered in many power utilities by load shifting demand from peak to off peak times resulting in an increase in utilization of the generation system and capitalizing on network investment [5]. A number of tools and techniques for load shifting are currently being researched and implemented in countries with a high penetration of wind energy.

One of the key enablers of managing the intermittency of wind is through the use of demand side management (DSM) and demand response (DR) tools. Load shifting can be achieved by implementing a variety of techniques centred on DSM and DR.

DSM can be characterized as a set of techniques which can be used to reduce the load on the demand side during peak times. According to the EIA, DSM refers to the planning, implementation and monitoring of utility activities designed to motivate consumers to modify patterns of energy usage and load shifting demand [1]. DSM can further facilitate utilities with embedded renewable energy generation by decreasing demand to match available supply rather than increasing supply to match the current demand. This is achieved by varying the load using DSM to match the available supply [1]. The use of DSM and DR is an option which needs to be considered and explored as a cost-effective method to adjust and control consumption in response to wind intermittency. Applications of DSM can be used to provide system support and can be seen as an alternative form of operating reserve for power systems.

DSM aims to redistribute the load over a given period of time and does not necessarily reduce the overall energy consumption [5]. Furthermore, DSM can indirectly educate the consumer in managing electrical consumption more efficiently which can contribute to a reduction of electricity consumption.

There is a need for flexible capacity to stabilize and balance the power system. A number of generators operating at partial load degrade the efficiency of the power system, despite achieving the flexibility [8]. DSM/DR provides a technique which can be observed as an alternative capacity reserve [8]. The rewards of DSM/DR are greater when integrated with systems with inflexible generation capacity.

The suite of interrelated programmes of DSM and DR are aimed at providing consumers a greater role in the value chain of energy trading. These programmes are designed to allow consumers to shift their demands during peak times in real time, reduce their overall energy consumption and educate consumers on practicing energy efficiency/conservation.

In Portugal, according to [1], business as usual was measured against the application of various DSM programmes for the industrial, domestic and tertiary sectors and aggregated according to different loads. According to their research, in the domestic sector, technologies with high power consumption included lighting, air-conditioners and washing machines. Furthermore, efficient washing machines were not cost-effective. In the tertiary sector, high power consuming loads included air-conditioning systems and lighting. Reduction of 13 % of peak load was observed when using DSM initiatives. The cost of these initiatives was less than the production of cost using renewable energy sources. Furthermore, spikes at peak load can be further managed with DR techniques by controlling the load. DR techniques can assist in abrupt variations by adjusting load in near real-time. According to [9], wind power production is more severe during the winter days as load is generally higher and according to their research, in summer days, the load is directly proportional to the temperature and the wind power production is inversely proportional to the temperature [9].

3.1 Drivers of DSM

Currently, apart from the cost of electricity, there have been limited inducements for consumers particularly in the domestic sector to become responsive and manage their energy consumption effectively by changing their consumption patterns.

The concept of DSM and DR is not new. Utilities, energy regulators, state governments and municipalities have been practicing these programmes for a number of years (prior to the implementation of widespread wind power generation) in order to derive additional benefits from its institution. These additional benefits include:

1. To improve the efficiency and utilization of a power system.
2. Deregulation of the electricity industry and energy trading has provided the consumer with many alternatives/options making the consumer a key component in the value chain of the power system [5].
3. DSM has not achieved significant penetration in the domestic electricity market.
4. Defer costs for network expansion and infrastructure development [5].
5. Development and usage of Information and communication technology (ICT) in power systems has provided additional fuel to deploy DSM.
6. Climate change challenges and environmental protection.
7. There is an opportunity for DSM to provide an alternative form of reserve as opposed to investing in conventional generators to provide security, reliability and assisting in outage management of the power system [5].
8. Increase distribution generation in the distribution network [5].
9. DSM can improve the security of supply on the power system with high penetration of wind generation by increasing the amount of wind power harnessed from wind

farms. The deployment of DSM will supplement the management of wind intermittency. Consequently, fewer generators will be required for spinning reserves and operational use [5]. The dual benefit derived from this approach will be the reduction of fuel costs and carbon emissions footprint.

10. If short term power reserves are acquired using conventional methods, electricity prices will rise [8]. DSM can prevent this from transpiring.
11. Utilities in California have used DSM programmes over the past 30 years in order to keep their per capita energy consumption constant [1].
12. Significant price increases during peak periods is the stimuli for an increase in penetration in DSM.
13. DSM can indirectly educate the consumer in managing their overall energy consumption and provide consumers with a greater role in the value chain of energy trading.

3.2 Current DSM Practices around the world

DSM has been in existence for a number of years and has been successfully deployed in countries around the world. The following programmes are some of the current practices being employed the world over.

1. A large portion of the domestic sector in Portugal has started replacing inefficient refrigerators and freezers with equipment with a higher class (A+ / A++) as per the Energy Efficiency Index (EEI).
2. The domestic sectors in many countries have replaced Incandescent light with Compact Fluorescent Lamps (CFL) [1].
3. Fluorescent T8 bulbs with magnetic ballasts replaced with T5 bulbs with electronic ballasts [1].
4. Inefficient air conditioners replaced with high efficiency Class A heat Pumps [1].
5. Public lights and traffic lights replaced with LED's [1].
6. Replacement of conventional motors with high efficiency motors in the commercial and industrial sectors [1].
7. Night-time heating with load switching has been implemented in the UK with special tariffs associated with night time heating. The use of night time heating provides a balanced load for the entire day. However, domestic consumers are now exploring the uses of gas heaters.
8. Direct Load Control (Domestic) – these programmes provide direct control to swimming pool pumps, air-conditioners and geysers for short duration intervals using a communications device which is responsible for executing controls sent from the utilities control centre.
9. Load Limiters are used to limit the amount of power consumed by each consumer. The limits can be adjusted depending on the stress and power conditions on the power system [7].
10. Many industrial consumers (e.g. Refinery's, steel companies, and mining industries) typically subscribe to commercial / industrial programmes aimed at allowing their loads to be interrupted for short durations when the power system is under severe

strain. These interruptions are not performed on a daily basis and can assist the utility to reduce demand by interrupting heavy loads and remunerating the consumer with reduced tariffs thus compensating them for the inconvenience [5]. Commercial consumers subscribe to these programmes as well allowing their heating systems, building air conditioning systems and lighting to be controlled [2].

11. Large industrial consumers often participate in frequency regulation programmes. Frequency regulation programmes involve the monitoring of the frequency of the power grid and maintain the frequency at the nominal value (50Hz in South Africa). A depression in system frequency often occurs when generator outages occur. Frequency regulation is then achieved by instituting load reduction programmes and controlling large industrial consumer loads (e.g. Smelters) [5]. The Belgium transmission system operator (Elia) has contractual agreements with industrial consumers to temporary permit the interruption of large power components in order to ensure grid security [7].
12. Recent advancement in technology has opened avenues for manufacturers to investigate the possibility of fabricating smart appliances which integrate frequency regulation mechanisms that monitor the state of the power system frequency and operate accordingly [5].
13. Time of use Tariff (TOU) is a widely practiced initiative in Europe and the US whereby utilities afford consumers the opportunity to consumer their daily energy consumption during off-peak times at reduced rates. These rates are generally higher during peak periods [5].

3.3 The 6 Levers of DSM

According to Mckinsey, DSM encompasses 6 dominant pillars which need to be considered when implementing DSM programmes in a utility. These levers are depicted in Figure 1.

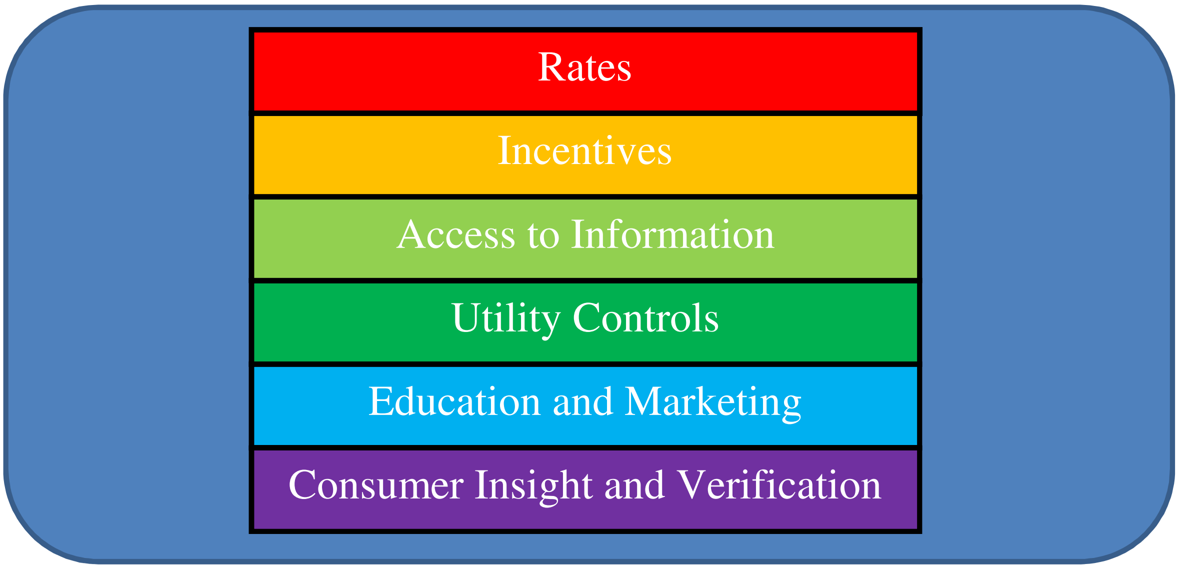

Figure 1: The 6 levers of DSM as described by Mckinsey [10].

The levers described in Figure 1 outline the foundation of DSM. These are explained as follows:

1. Rates: Utilities are required to negotiate and carefully tailor their tariffs designs in order to reap the benefits expected from DSM [10].
2. Incentives: Utilities should consider compensating the consumer for being energy efficient and participating in DSM programmes. Further rebate and compensation can be given to consumers who participate in pilot programmes in order to create awareness, educate consumers and allow them the opportunity to adopt new energy usage profiles [10].
3. Access to information: Consumers respond more favourably with managing their energy usage when they have access to real-time information. Utilities are expected to open up a communications channel with the consumer [10].
4. Utility Controls: The next generation Smart Grid will enable utilities to use direct load control programmes and automation tools to control demand during peak periods. The use of Smart Grid technologies will enable consumers to manage their demand profiles according to real time information received from utilities. Using these technologies will enable utilities to automate demand response programmes and offer the energy capacity of the grid to the energy trading market as a resource [10].
5. Education and marketing: To promote and educate consumers on the benefits of DSM and DR [10].
6. Consumer insight and verification: To measure DSM benefits, program results need to be verified [10]. The Smart grid promises the verification of DSM program results. It should be noted that measurement and verification of DSM programmes in isolation is still at its infancy stages with many utilities around the world experimenting new and improved techniques of quantifying the benefits derived from disaggregated DSM programmes.

Utilities are encouraged to adopt these levers in their DSM strategies in order to derive the benefits promised by DSM.

4. Demand Response (DR)

With large scale wind integration, DSM may not be sufficient. In such cases, Demand Response techniques and technologies are required to provide near real-time consumption reduction [1]. The rationale behind DR is to provide the consumer with the opportunity to reduce his consumption if the service / equipment he is using, is costing less than what he is paying for the electricity during peak times. The economic benefit for the System Operator is to provide incentives to the consumer and remunerate the consumer for reducing power consumption as opposed to paying additional operating costs to match the available demand by providing additional energy using conventional methods [1]. DR has traditionally been used to improve the efficiency and optimize the power system [7]. The Federal Energy Regulatory Commission (FERC) estimates that demand response programmes can cut US peak demand by up to 20 percent within 10 years.

4.1 Drivers of Demand Response

A number of shortfalls exist with DSM programmes which necessitate the need in exploring DR programmes. These factors have contributed towards the rising widespread investment in DR programmes and have been the driving force pressurizing utilities to explore these avenues. These are discussed below.

1. Even though wind power is a suitable alternative form of generation as opposed to a coal-fired power plant, the security of a power system with a high penetration of wind generation can be compromised due to the intermittent nature of this source. Assuring the security of the power system necessitates the exploration of alternative methodologies. This has been one of the driving motivational tools to infiltrate the power system with the institution of demand response techniques enabling demand-side actions [8]. DR can provide real-time variation in load which is a requirement in order to mitigate the variability effects of wind.

2. Over the past few years, there has been an increase in the use of air-conditioning systems in the corporate and domestic sectors resulting in an upsurge in demand of electricity. DR can facilitate managing this growth in demand.

3. To a certain extent, by deploying DR and DSM at peak times, it can assist in relieving transformer loading and overheating and alleviate the load on cables and overhead lines thus prolonging the lifespan of costly HV plant equipment.

4. Under rare occurrences, the power system often experiences shortages of excessive amounts of energy. DR can be instigated in these scenarios to alleviate the strain on the network near real-time. As opposed to investing in costly generation capacity to cater for these rare occurrences, DR can be deployed on consumers who are willing to reduce their demand and be remunerated by the power utility [5]. Hence, DR can improve the efficiency of the transmission network when coping with unplanned outages. A possible solution is for the system to operate at a lower generation capacity and a higher utilization factor with remedial DR and DSM measures in place in the event of an unplanned outage or overloading on the network [5]. This solution of load curtailment provides lower costs to operate the network with less congestion. According to [5], this philosophy is based on corrective measures deployed whilst operating the network as opposed to operating the network using preventative measures with conventional capacity reserves.

5. With DR, there is an opportunity for consumers to manage their electricity consumption in response to signals (prices or load contracts).

4.2 Demand Response Developments and Practices

Many utilities have been running pilot projects and investing significantly towards the research and development of DR. Some of the current practices around the world in the field of DR are detailed below. These include:

Around the world, systems are being tested which semi-autonomously responds to instructions received from the SO to decrease/increase demand when required. These systems can be used for DR programmes.

Scandinavian and UK markets have been managing short-term energy trading based on supply predictions. These markets offer incentives and trade for both load reduction and increases at a designated time [8]. This concept is termed bidding on short term markets. These markets have targeted the following loads [8]:

a. Domestic refrigeration
b. Industrial or commercial refrigeration
c. Large scale water pumping
d. Electrical heating systems
e. Heat pump with heat storage

According to [8], there is very little information available on the technical characteristics relating to different loads, as much of the technology is yet to be developed. Utilities in Belgium have attempted to analyse the technical characteristics of different loads which can assist in time shifting during generation peaks and when wind generation is low. Each appliance applicable for use on DR programmes is analysed according to their power demand in Belgium and load profiles are created using average yearly consumption [8]. A limited number of appliances are then evaluated according to their power demands and their control properties (e.g. frequency regulation) in an attempt to quantify the cumulative energy savings which is available for DR [8].

According to [8], two major groups of high energy consuming appliances in the domestic centre exist:

a. Appliances operating for short periods (e.g. dishwasher, washing machine, tumble dryer). These loads can be used during generation peaks.
b. Appliances that operate in standby mode and activate when required (e.g. refrigeration systems, air conditioners, heating systems). These loads can be used for time shifting based on the availability of wind power generation.

In the United States, 8% of consumers have already commenced participation in a demand response programmes.

A number of DR programmes are practiced around the world predominantly in the US and in Europe. These programmes include:

a. Direct Load Control: Remotely cycles of a consumer's electrical supply after receiving participation consent from the consumer. This is often used in conjunction with DSM load limiting programmes.

b. Interruptible load: This program is typically used in a commercial/industrial environment. This has been a program that has been deployed in South Africa over recent years. Load is curtailed during peak periods. Supply to the consumer is typically remotely switched off after notification is given. Incentives are usually given to a consumer for their participation which is governed by a contractual agreement between Eskom and the consumer.

c. Emergency Demand Response: This program serves as an emergency contingency when load reduction is required near real-time. This event may typically arise during a high responsive negative ramp rate of wind energy. Incentives will need to be provided to consumers who subscribe to this event.

d. Demand bidding and buyback: This program allows the system operator to offer load reductions at a price and identify how much load the consumer will be willing to forego for the price offered. With demand bidding, consumers have the option of enrolling on programmes which offer incentives if loads are sacrificed during peak times and when wind production is low. This provides an opportunity to load shift and increase the utilization on the power system. Demand bidding programmes provides the consumer with choices in managing their daily consumption. Equipment such as heat thermostats/air conditioners and swimming pool pump controllers can be programmed to change their settings and switch off when required. The consumer receives signals on when to reduce or relinquish their energy consumption based on the state of the power system and can opt whether or not they wish to participate in that particular event. Participating in events implies a reduction in their tariffs. The converse situation also applies. If wind production is high, incentives can be given to consumers to utilize the available energy at a reduced tariff. This allows consumers to manage the load profile and utilize their energy requirements during periods of high wind power generation.

e. Real – Time pricing: this pricing model fluctuates hourly or more often in order to indicate changes in the energy trading market. These changes can be in response to a loss of renewable sources.

f. TOU Pricing: A rate given to consumers which varies by the time period.

g. Critical Peak Pricing with Control: This is pricing model which is designed to encourage energy efficiency and conservation by inflicting a higher rate for energy consumption during peak periods to the energy trading market. This is implemented in conjunction with direct load control.

h. Peak time rebate: This program allows consumers to earn a rebate by reducing energy from a baseline during a specified number of hours on critical peak days.

5. Current DSM practices in South Africa

Eskom have established an Integrated Demand Management (IDM) division to ensure the security of short term supply. This is accomplished through the institution of various programmes aimed at promoting energy efficiency and conservation to all consumers, supporting behavioural change and the move to more energy efficient technologies. IDM achieves this by implementing DSM and DR initiatives.

For residential consumers, Eskom provides guidance and advice to the general public of South Africa on how to conserve energy and become energy efficient. This is done through advertising, providing monthly feedback via social media networks on becoming energy efficient, radio and television talks, feedback to the general public on the state of the power system etc. Eskom's DSM/DR programme has been focused on load shifting and actively managing and reducing electricity demand profiles in the domestic sector. At present, public education and awareness on energy efficiency is a major contributor to the DSM/DR programme [12]. This programme is aimed to achieve a target of 10% reduction in power demand and a savings of 8000 MW by 2026 [12]. This programme includes the free replacement of incandescent lights with CFL, providing rebates to consumers wishing to replace the use of electric geysers with solar water heaters, mass-rollout of geyser blankets and efficient shower-heads and offering incentives to replace electric stoves with gas-operated stoves.

Currently, in the Domestic Sector, Eskom meters are read manually, estimated or automatically through the use of GSM services and more recently using GPRS. A number of meters within Eskom are legacy mechanical meters without remote communication capabilities. In these cases, no form of DSM/DR is achievable [29].

Eskom's current stance with regards to the commercial and industrial sectors is different to that of their residential sector predominantly attributed to the fact that the commercial and industrial sectors contribute to a large portion of Eskom's revenue and are considered Large Power Users (LPU) [29]. All metering points in this sector use TOU tariffs which include Nightsave, Miniflex, Transflex and Megaflex.

Eskom have also instituted various funding models to provide rebates to commercial, industrial and agricultural consumers who wish to conserve and become more energy efficient.

These models are described as follows:

1. Performance Contracting Model (> 5MW): This program is intended for the commercial and industrial sector. This program allows large power users to work with project developers to submit a proposal to Eskom for a performance contract to reduce their energy consumption over a 3 year period [34]. The project developer will be responsible for all upfront payment required to implement energy efficient solutions and reduce the large power user's energy consumption. Over a 3 year period, Eskom will measure and verify the consumer's energy consumption and will provide a rebate on their energy savings [34].

2. ESCo Model (>1 MW): Eskom affords Energy Service Companies (ESCo) accredited with Eskom to identify large power users (>200 kW) who are willing to participate in reducing their electricity consumption in their respective businesses. As a result, a 3 way partnership is formed between Eskom, the relevant ESCo and the consumer. Upon approval of the application, Eskom will fund up to 100% of the financial savings promised.

3. Standard Offer Rebate (> 50kW): This model is intended for the commercial, agricultural and industrial sectors. It has been designed to provide financial incentives to consumers willing to reduce electricity consumption by installing Eskom approved technologies. This includes amongst others: energy efficient lighting systems (CFL) and LED down-lighters for building lighting systems; installing variable speed drives to control HVAC units and replacing aluminium and steel pipes with copper pipes for heating and cooling systems; using industrial heat pumps and solar water geysers; implementing small scale renewable energy solutions etc. [33]. Payment is usually made in 3 year cycles following a measurement and verification exercise in order to ensure the sustainability of the savings [33].

4. Standard Product Model (1 – 250kW): This program is aimed at enabling consumers to replace common inefficient technologies with energy efficiency equivalents such as energy efficient lighting systems, energy and water efficient shower-heads, heat pumps etc. [32].

The government of South Africa in collaboration with Eskom have implemented the Power Conservation Programme (PCP) aimed at providing a DSM solution to counteract the energy constraints experienced in South Africa [32]. The Energy Conservation Scheme (ECS) which forms part of PCP compels large power consumers to curtail their energy consumption by 10% of their nominal consumption profile [32]. The consumers will be responsible for applying measures to reduce their current consumption below the new baseline. The consumer will be charged excessive tariffs should they exceed the baseline. The scheme allows agreements to be setup between LPU's and afford consumers using excessive energy to purchase energy from those that are using less than their current energy allocations.

To supplement DSM, Eskom have initiated various DR programmes for the commercial and industrial sectors including municipalities. These programmes include:

1. Demand Response hardwired peak: This programme is aimed at allowing industrial and commercial consumers (including municipalities) to setup upfront contracts with Eskom for reducing their energy consumption during the peak periods in the winter season [32]. Eskom in turn will measure their consumption and pay for each MWh that is reduced by consumers [32].

2. Demand Response Rewards Programme: Eskom remunerates the commercial and industrial sectors for reducing electrical loads at very short notice (10 minute and 30 minute intervals) [32]. In addition, each time a consumer's load is reduced at the request of Eskom, they will receive an additional capacity payment for successfully subscribing to the event [32].

3. Demand Market Participation (DMP): Eskom utilizes an application called a virtual power station which schedules and dispatches DR events. Commercial and Industrial sectors receive incentives for responding to control signals sent from the control centre for consumers to reduce their demand (minimum of 20 MW) within 10 seconds up to 10 minutes [32]. This programme assists Eskom in managing sudden variations in frequency.

4. Standby Generator Compensation Programme: Eskom provides incentives to commercial and industrial consumers who wish to utilize their own backup/standby generator (> 1 MW) for 2 hours a day when requested to do. Consumers will be able to subscribe to a maximum of 100 events per year.

6. Challenges facing Demand Side Management and Demand Response

Despite the benefits available from instituting DSM/DR, a number of prevailing challenges exist which need to be administered when deploying various programmes. The challenges which are currently being faced by many power utilities around the world are discussed below.

One of the challenges of DSM is controlling load controlled devices in order to reduce energy consumption. During periods of low wind power generation, load controlled devices are switched off to decrease the energy consumed on the network. When these devices are eventually switched back on when wind generation is high, the energy consumed of such loads is greater than the amount of load curtailed during the energy reduction process [5]. According to [5], designing controlled loads to operate with maximum efficiency and utilization especially during start-up operation is a key technical challenge which is currently being pursuit by many vendors [5].

The ability to effectively manage fluctuations in electricity prices and billing to consumers based on their responses and subscriptions to various DR events. Management of pricing from a technical and commercial aspect is a key challenge. The billing system should have the facility to manage these fluctuations and the utilities processes should be refined and in some cases modified to accommodate this form of dynamic pricing.

There is a challenge to manage the change in energy usage as more consumers respond to price fluctuations and utilize their energy during off-peak periods and when required according to the signals received.

The internet and broadband communications will play a vital component for energy trading between the utilities and the consumer. There is a lack of skills and infrastructure in the ICT, metering and telecommunications systems to accommodate the deployment of DSM/DR on a national scale. There have been initiatives and proposed paradigms such as GridWise and Intelligrid which aim to converge electrical and communications system into an enhanced energy trading communications and management architecture [8].

There is a challenge to justify the costs required to install the infrastructure required for DSM/DR. These costs need to be weighed against the benefits originating from its institution. A business case needs to be developed to attempt to determine the costs and the benefits of widespread DSM/DR implementation. A lack of understanding of DSM and DR applications is a key factor which requires considerable attention. Furthermore, quantifying costs and benefits of disaggregated technologies/applications associated with DSM is a complex task and a challenge at hand.

According to Meiqi and Liangzhong, technical, economic and environmental factors need to be assessed with current and future DSM/DR applications.

System complexity is increased when implementing DSM/DR and management of its applications is paramount for its success. Utilities are advised to continue piloting and investing in research and development of DSM/DR in order to acquire confidence in the different methodologies available.

There is a lack of incentives for consumers to change their consumption patterns and compromise there convenience for efficiency.

Loads such as cooling appliances require sufficient operational time thus making load shifting a challenge [8]. In addition, inactive loads such as washing machines and tumble dryers can be activated when supply is high. However, these loads can only operate for a specified time.

Around the world, various techniques and paradigms are being developed in order to ascertain the most optimal architecture required to alleviate these challenges. A number of these challenges are addressed in the next generation Smart Grid architecture. In addition, the full benefits of DSM/DR are only realized once utilities have commenced widespread rollout of their associated programmes. A pre-requisite to this implementation is to institute a number of Smart Grid enabled technologies to support DSM/DR applications.

7. Smart Grids

A Smart Grid is an intelligent network built on existing electrical utility infrastructure incorporating self-healing capabilities with the objective of providing visibility, automatic control and advance decision making processes in the power system [16]. It is an interconnected system constituting information and communication technologies which are used to support the power system panning from the generation facilities to the end-user [13].

Utilities are currently investigating various technologies and devising a strategy which describes the new Smart-Grid paradigm envisioned for their countries electrical infrastructure [16]. A Smart grid is a way to maximise the output of the power system while reducing energy consumption. In this way, the power system is utilized effectively and economically [11].

Next generation of smart technologies will supplement DSM/DR in allowing consumers to make smarter and more informed decisions on their energy consumption and educate them on energy efficiency [10].

In the past, availability of recent technologies limited the growth of DSM and DR making these programmes (including measurement and verification) a time consuming and expensive endeavour [10]. With the idea of Smart Grids in mind, a greater infiltration of DSM and DR programmes is expected [10].

The role and benefits of the Smart Grid in the context of DSM/DR and assisting in the effects of wind power generation includes:

1. Networks will be able to cope with full duplex traffic allowing utilities to communicate in near real time to consumers [10]. A full duplex network will permit the transmission of TOU tariffs and control signals to consumers providing them the capability of responding and participating in various DR and DSM programmes on a real time basis. This is expected to cause a paradigm shift in consumer behaviours [10].

2. The Smart Grid will enable consumers to manage their usage more efficiently and make more informed decisions on various energy service offerings [13]. In addition, the Smart Grid will improve system reliability and stability and permit a more seamless integration of renewable energy generation sources [13].

3. The Smart Grid will provide real-time communication and interaction with loads, distribution, transmission and generation systems, integration of distributed generation included renewable sources and energy storage [13].

4. The installation of smart meters will enable utilities to download and analyse data in intervals of 15 minutes if required. Access to information and transmitting information to consumers on a real time basis will now be possible. This is in accordance with Figure 1 as outlined by Mckinsey [10].

5. To lower the costs of services and to strengthen system security and reliability [13].

6. Smart grid enabled systems and processes which provide energy consumption information have proven to reduce energy consumption by 18% according to the results received from various pilots [10].

7. Reduction in green-house gases through the use of renewable energy sources [16].

8. The Smart Grid recognizes the need for Asset Management and condition based monitoring systems to support operations and maintenance of power system mission critical plant [16].

9. Through Eskom's planned electrification programmes which are currently being rolled out, there has been an increase in consumers in the energy market and a great need to improve system efficiency [13]. This increase has resulted in a growth for demand in energy during peak times [16]. The next generation Smart Grid can assist utilities with coping with peak loads and managing system efficiency.

10. The planning and development of the Smart Grid network will influence the need to amend government legislations, policies and regulations to support the integration of IPP's and renewable generation into the national grid [16].

Some of the components comprising a Smart Grid include automated meters, consumer 'smart' appliances, wireless broadband communications, high speed communications backbone, standardized operating protocols etc. [13].

Utilities are expected to accelerate the pace of testing various Smart Grid enabling technologies. To fully conceptualize and embrace a Smart Grid or a Smart Grid enabled network, utilities are required to test and ascertain which technologies will be most effective in their respective environments. In this way, working knowledge and challenges will be gained through these pilots. Acquiring first-hand experience in best practices needed to overcome these technological and commercial challenges is a key enabler when implementing the next generation Smart Grid. Furthermore, utilities will be required to increase their management capabilities with consumers, as consumers will now be participating in various programmes affecting their monthly utility bills [10]. Furthermore, full service and system support to consumers will be required to manage these complex DSM/DR programmes. The consumer in a Smart Grid becomes a resource which adds value to the system [13]. The architecture comprises smart appliances, smart operations, smart planning, smart pricing and smart policies.

According to [35], there exist 3 versions of the Smart Grid. Figure 2 indicates the different versions of the Smart Grid and the corresponding focus topics for each version.

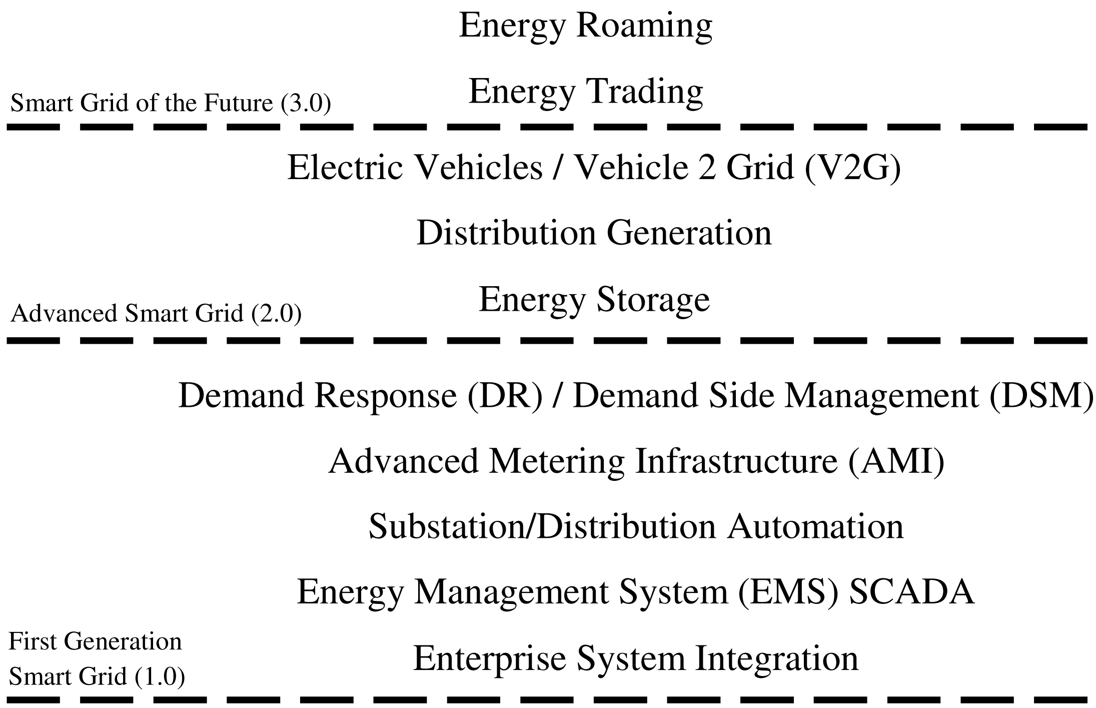

Figure 2: Proposed description of various versions of a Smart Grid.

7.1 Smart Grid Developments and Practices

A number of techniques and applications centred on DSM/DR and its associated Smart Grid enabling technologies are currently being researched and implemented in countries with a high penetration of wind energy.

In the UK, the Demand for wind research and development project was introduced in order to investigate the use of DSM for addressing the variability of wind. This research included:

1. The development of a technology to perform automatic, semi – automatic and advisory load controls in households [2].
2. Monitor household energy [2].
3. Communicate usage data and control signals between the control centre and residential consumers [2].
4. Measure the change in consumer energy usage patterns when utilizing DSM and comparing direct and indirect DSM measures [2].
5. To replace the method of using fossil fuels to heat water by using renewable energy sources [2].
6. Develop a system that uses household modems and web technology to communicate directly to the control centre. Electricity usage is constantly monitored and control signals are sent to automatically control loads (e.g. geysers). Furthermore, users are

requested to switch off unnecessary loads during peak times. The website has public access allowing users access to their demand data. In addition, this site encompasses discussion forums for users to interact and communicate with neighbours and exchange tips for improving efficiency and conservation of energy [2]. The equipment to be installed varies according to the DSM program consumers wish to adopt depending on whether they wish to use the monitoring, semi-automatic, automatic or advisory DR program. The purpose of this system is to create a demand for wind generation and allow consumers to use a larger load when a surplus for wind is available. Any excess of wind energy can be sold at reduced tariffs to promote and utilize renewable energy sources [2].

A key objective of the project in the UK is to monitor and understand the power consumption profile in the domestic sectors. Consumers have the option of providing the system with available loads for that day in a semi-automatic system. In addition, consumers can provide information into the system to explain their demand profile. The aim of the system is to change consumer behaviour patterns and provide consumers with the opportunity to respond to electricity price fluctuations.

US Utilities have committed to investing in the procurement of 40 million smart meters over the next 5 years [10]. The US government has demonstrated its support by sanctioning acts and regulations directed towards encouraging the development of electricity delivery and Smart Grids [11]. A large portion of these funds originate from the American Recovery and Reinvestment Act of 2009 (ARRA). Some of the main objectives are to upgrade the power system to enable consumer choices, create jobs, energy exporting and generate clean and secure energy from renewable sources [11]. Utilities and businesses have joined forces to pilot programmes which can facilitate the inception of a Smart Grid using research grants reaching up to 8 billion dollars [11]. These include state and local governments which have implemented policies driving the innovation and improvement in technology of the US power system [11]. Approximately 25 states have implemented policies and regulations promoting a Smart Grid system.

The city of Tallahassee in Florida has spent 8.8 million dollars to implement a Smart Grid based DR program that allows users to remotely cycle off their air-conditioners.

The Turkish electricity market is undergoing rapid growth and large capacity increases are expected from renewable energy sources. A projected target of 30% of demand to be supplied by wind and solar is anticipated by 2023 [20]. In light of this, Turkey has made the development of a Smart Grid a priority and will be investing $5 billion on Smart Grid technologies in order to meet their targets [20]. More than 1 million prepayment smart meters have already been installed in Turkey [15].

Recent reports have also shown that a number of countries in Asia are investing significantly in the development of the Smart Grid. China projects that their installed base of smart meters will reach $377 million by 2020 resulting in a penetration level of 74% [21].

In Ontario, 4.3 million smart meters have been installed with a 1000 homes having a complete integrated smart-grid solution. The intention behind this investment was to reduce peak demand, improve energy efficiency and increase visibility and control. This solution incorporates: a utility management system capable of managing demand by load shaping; a consumer portal accessible over a web interface, mobile application or tablet allowing consumers to conveniently manage energy usage; the core network infrastructure communicating to smart meters using broadband power line carrier (BPLC) and digital area radio and a home energy manager that the consumer uses to communicate with the control centre on DR applications.

Utilization of smart meters has grown exponentially in countries such as the UK, Germany, Spain, China, Australia, New Zealand, India and other developing countries [15].

The California Energy Commission is currently making efforts to improve the use of DR in the state of California. This is being achieved by deploying advanced metering infrastructure, investing a suitable communications system and deploying DR-enabled thermostats in the residential sector [36]. Homes in California use the autonomous demand responsive electrical appliance manager (DREAM) to automatically respond to price signals thus negating the home-owner from being forced to respond to utility messages on a daily basis [36]. The system comprises a user interface, the control unit and a number of wireless sensors and actuators for temperature, motion etc. The user interface provides consumers with the current price of electricity, information on their current energy consumption and a platform to learn how the system operates [36]. The system is responsible for reducing electricity loads during peak hours and maintains the user's thermal comfort with minimum energy usage and cost using methods of learning consumer's behaviour and computing a set of decision making algorithms [36].

In South Africa, Eskom's current smart metering strategy does incorporate the accommodation of DR programmes including Time of Use Tariffs (TOU) with load limiting capabilities and remote disconnection [21].

Another concept envisaged in the next generation Smart Grid as indicated in Figure 2 is Vehicle 2 Grid (V2G). V2G is a method of selling demand response back to the utility using electric vehicles. This will provide a method of responding to the negative variations of wind power generation and allow consumers to feed energy from electric vehicles back into the grid [35]. The challenges which exist with this form of capacity reserve include; smart charging – a process to prevent accidental peaks in demand and a method of drawing energy from these vehicles in a manner which does not hinder the consumers battery lifespan and provides sufficient energy when the consumer requires the vehicle [16]. South Africa has not deployed charging stations or electric vehicles at present; however, Eskom's research and development department is currently investigating the impacts of Electric Vehicles on the network in South Africa.

At present, South Africa does not have a high penetration of wind energy generation. However, going forward with the institution of the REFIT programme, this is expected to change. The management of the intermittency of wind energy in South Africa's electrical system will require the addressing of a number of technical and practical challenges. Amongst others, these include DR programmes; the power system's pricing model; integration of various enterprise systems (e.g. billing and asset management systems); the ICT infrastructure and management of Advanced Metering Infrastructure (AMI).

7.2 Advanced Metering Infrastructure (AMI) and Automated Meter Reading (AMR)

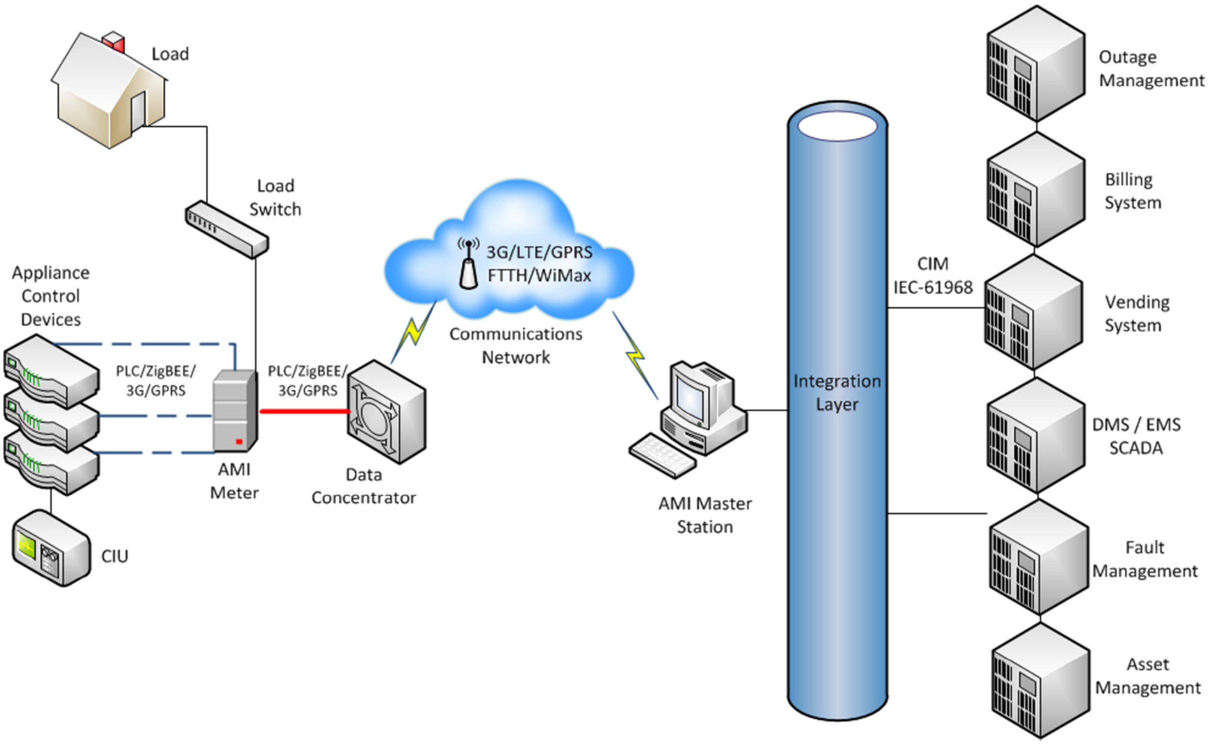

Figure 3: Typical architecture of an Advanced Metering Infrastructure system.

One of the prominent Smart Grid technologies that support DSM/DR applications is advanced metering infrastructure (AMI) with smart meters. As depicted in Figure 3, this includes a master station, a full duplex communications network, smart meters, data concentrators, a load switch, appliance control devices (ACD) and a consumer interface unit (CIU). The CIU normally resides at the consumer's premises and communicates with consumer's meter and displays information from the meter. The CIU also acts as the consumer interface back to the utility allowing them to respond to pricing signals and subscribe to various DSM/DR events.

The AMI master station has the capabilities of vending, billing, load management, connect/disconnect, fault investigation, revenue protection/tamper detection, quality of supply and acts as a data repository. The system is associated with the transmission and reception of data from remote meters to enterprise systems operated by a utility.

According to the NRS specification for AMI's in residential and commercial sectors, the following primary functions are prescribed for an AMI:

1. Class 1 meters are required operating in credit and pre-payment fashions [19].
2. Implementation of TOU to be supported [19].
3. Local/Remote disconnect functions required [19].
4. Remote meter configuration change [19].
5. Real time clock synchronized with the AMI master station [19].
6. Control and control override of appliances [19].
7. Facility of local/remote communications [19].
8. Load limiting [19].
9. Meters shall have the facility to register with the master station after being commissioned and periodically verify the status of the system with the master station [19].

At present, standards used for communications between smart meters and the AMI master station includes the Companion Specification for Energy Metering (COSEM) and Device Language Message Specification (DLMS). Both standards have been adopted by the IEC and defined in IEC 62056. DLMS entails the concept for abstract modelling of communication entities. COSEM identifies the rules and standard for data transfer with energy meters. DLMS/COSEM provides the object model of the functionality of meters, encompasses a messaging system that interprets the model and converts the data into a series of data bytes. In addition, it provides a method of transporting the data from the meter to the data concentrator and ultimately to the AMI master station [31].

It should be noted that having a network encompassing a large installed base of smart meters does not constitute a Smart Grid [22]. A number of enterprise systems including resource management, outage management, asset management, consumer management are required to be integrated harmoniously in order to fully rationalise the benefits of a Smart Grid. Furthermore, specific needs of the industry should be considered and a strategy with a roadmap towards the end-state should be clearly defined prior to commencing the journey towards a Smart Grid [22]. This becomes more critical when mission critical services are involved.

In order to enable the transfer of information to various stakeholders within the utility, it is necessary for the AMI master station to integrate into the utilities enterprise systems [23]. This can be achieved using an adaptive interface that uses a common information model (CIM) described in IEC-61968 primarily structured in Extensive Markup Language (XML) [24].

As mentioned, inter-application integration is paramount for the exchange of real-time information used in the enterprise network. Systems which use adaptive interfaces for supporting CIM will prevent the replacement of existing applications and systems and secure current investments. It is thus advised that all utility enterprise systems support this interface.

Should this not be the case, plans need to introduced where possible and feasible to develop an adaptive layer on the relevant enterprise system to support this interface.

The IEC 61968-1 standard requires the domain model of each enterprise system interface to be defined in Unified Modelling Language (UML) and that XML be the data format for document interchange [24]. Having a common architecture will enable various systems to inter-communicate and facilitate data exchange between various business functions. These business functions include: sales, network operations and support, distribution management system, fault management, records and asset management, consumer services, operational planning, maintenance and construction etc. Data acquired from smart meters can then be fed into these business functions.

The economic benefit of employing this Smart Grid technology includes early outage detection, efficiency load management, improved device management, credit management and tamper detection thus avoiding loss of revenue and providing revenue protection.

The complete solution for smart metering should accommodate a web-interface which provides consumers with their metering data, historical trends, usage profiles, costs, provide a forum allowing consumers to exchange ideas and information on energy efficiency and DSM and provide a portal for utilities to communicate and update consumers on a real-time basis.

Currently, AMI systems and smart meters that have been deployed in the South African power system are capable of providing the following minimum facilities [23]:

1. Event reporting with time to the AMI master station.
2. Local/remote appliances connect/disconnect.
3. Remote meter/data concentrator configuration change.
4. Control a minimum of two appliance devices.
5. Load limiting.
6. TOU Tariffs configurable through messages from the AMI master station.
7. Sending commands remotely to meters to operate a number of ACD's.
8. The ability to remotely curtail demand and provide load control during system emergencies.

In South Africa, Eskom recently completed phase 1 of its AMI implementation with two suppliers which included the installation of more than 3000 smart meters on the network [16]. The intent of this project was to improve Eskom's experience with smart metering and AMI's and meet the objectives outlined for phase 1 [25]. These objectives include:

1. Testing the implementation of DR programmes.
2. Promoting consumer behaviour change by offering incentives. These incentives were in the form of providing real-time energy usage information and supporting TOU tariffs allowing consumers the opportunity to understand their demand profiles and focus on load shifting towards off-peak times.
3. Improve efficiency and consumer service.
4. To understand consumer requirements.

5. To experience the challenges which exist with the implementation of AMI's in order to derive a standardized solution going forward in preparation for a widespread roll out and introduce remedial actions to facilitate these challenges.

The implementation of the AMI in the Eskom network required integration into the utilities existing Consumer Care & Billing system (CC &B). The AMI master station and CC & B required interface adaptors for integration in order to facilitate data transfer across multi-vendor operating systems. This resulted in the development of a Multi-Vendor Integration Layer (MVIL) using CIM which allowed the integration of both vendors AMI back-end systems into the enterprise network [25]. In addition, a consumer web-based portal was developed that accessed CC&B and provided consumers with energy usage information [25].

Eskom has experienced much success from Phase 1 of the AMI project. Their reports indicate that a number of benefits and challenges were experienced during this pilot. These include:

1. Consumers that were initially not on the billing system were added as a result of the meter installations [25].
2. Errors found on the billing system were rectified [25].
3. Meter tampering and illegal meter bypassing were identified [25].
4. Detailed specifications and installation procedures on smart meters were documented as a result of the experience gained during the implementation. This laid the foundation for developing the skills in smart metering for Eskom [25].
5. Communication problems and ICT issues were experienced [25].
6. Consumers demonstrated a lack of knowledge of the new system [25].
7. Developing remote disconnect work flow processes [25].
8. Inaccurate drawings resulted in incorrect installations and stranded meters communicating to the wrong data concentrator [25].
9. Theft and vandalism [25].
10. Human resource capabilities to assist with data capturing, procurement, consumer queries, project management and training and support were key factors that challenged the project [25].

It should be noted that Eskom's AMI pilot did not include the pre-payment sector. The pre-payment system has a number of prevailing challenges for use with AMI primarily due to the manner in which tokens operate in a pre-payment meter and the incompatibility of the billing system to support pre-payment meters.

On the prepayment system, meters in South Africa use standardized transfer specification (STS) tokens developed in 1993 by Eskom and now managed internationally by the STS Association [30]. STS is a messaging system responsible for carrying information from a vendor's point of sale and a pre-paid meter in a secure fashion [30]. The use of STS in South

Africa addresses a number of concerns surrounding prepaid metering systems. STS benefits include:

1. Enhanced security with the prevention of generating fraudulent tokens, tampering of existing tokens, re-use of existing tokens etc. These are achieved through advanced encryption techniques and secure management [30].
2. STS allows the generation of tokens for a specific meter that it is intended for.
3. STS is designed as an open system specification allowing utilities to utilize multiple vending systems with multiple STS compliant meters thus ensuring interoperability [30].

The standard specifies the method of encoding information from the vending station to the prepaid meter. It constitutes a 20 digit number issued upon purchase of electricity from a local vendor. Upon entering the number into the prepaid system, the specified amount of electricity will be released for use on the STS prepaid meter. The billing system requires development to support the required Tokens and TOU.

Furthermore, to successfully rollout AMI on a national scale, it is imperative that the telecommunications network is able to support the requirements needed for an AMI.

7.3 Telecommunications Requirements

In order to support Smart Grid enabling technologies, high up-front capital is required for network expansion and providing a telecommunications network that is capable of supporting full duplex traffic allowing near real time communications to consumers. A full duplex network will permit high speed data transfer of control signals, messages and events between consumers participating in DR programmes and the utility.

Eskom profoundly rely on their own privately owned Telecommunications service provider, Eskom Telecommunications to supply, install, commission and maintain the telecommunications systems for operational and information technology and services. These technologies and services are primarily used for the following:

1. Transfer SCADA data to the control centre.
2. Provide operational voice and data services for communication between operators on site and the work management centres and control centres [28].
3. Deliver high speed information transfer for teleprotection [28].
4. Plain old telephony services (POTS) at all Eskom sites [28].
5. Network management of all equipment.
6. Metering using GSM/GPRS technology.
7. Remote engineering access [28].
8. Distribution automation.
9. Teleconferencing and video conferencing facilities.
10. Wide Access Monitoring Systems (WAMS).

A variety of telecommunications systems and services are used to deliver the aforementioned functions in Eskom. These predominantly include the use of a complex circuit switched system compromising an extensive SDH and PDH network using a number of multiplexors and ADM's [28]. Information is reliably transported using microwave radio and a vast network of fibre optic cables. In addition, a significant install base of analogue and digital narrowband area radio networks operating under UHF and VHF licenses are used for SCADA and operational voice services.

Eskom also exploit the services of 3rd party ICT vendors to provide wireless data services for transporting SCADA, remote engineering and metering data to their respective management enterprise systems. These vendors provide a point of presence (PoP), secure connectivity via a private APN for wireless services, SIM Cards and GSM/GPRS/3G capable communications devices. Consequently, Eskom has an extensive network deployed country-wide which utilize GPRS/3G services for use with RTU's, FPIs, reclosers, meters etc.

For the AMI system, there are a number of technologies available which can be considered. Depending on the bandwidth available and cost, these technologies can be surveyed in order to ascertain the optimal solution. Typical architectures of an AMI system as depicting in Figure 3 indicate three possible scenarios requiring telecommunications and/or ICT infrastructure. These are between the data concentrator and the AMI master station, between the data concentrator and the smart meter and between the smart meter and the CIU and/or ACD [29]. It should be noted that the communications technology between the meter and the ACD and the communications technology between the meter and the data concentrator or the data concentrator and the AMI master station do not need to be the same. Due to the fact that some of the desired communication technology options are only available in certain areas, the choice of having a mixture of technologies in the final solution is preferred.

To fully conceptualize a smart metering system, telecommunications will also be required at stand-alone meters and meters residing at substation level. Eskom is currently migrating to GPRS on all stand-alone meters and meters residing at substation level. However, with the idea of substation automation in mind, the possibility of integrating the metering system at the substation SCADA system is being explored [29]. In addition, with the availability of broadband infrastructure in a substation as a requirement for substation automation, the capability of remotely accessing metering data via this infrastructure is currently under investigation [29].

For the Smart Grid, utilities are requested to test a number of these technologies during their small-scale pilot implementations of AMI. A variety of these technologies and services are detailed below.

7.3.1 Power Line Carrier

Power line carrier (PLC) and Broadband Power Line Carrier (BPLC) can be used for high-speed internet access using existing residential homes electrical infrastructure [16]. The technology is based on DSL which exploits un-used transmission capabilities on the wires and using signalling frequencies other than the power frequency. This is largely employed between the meter and the data concentrator unit (DCU).

7.3.2 Fibre to the Home

Going forward, with the inception of Fibre to the Home (FTTH), additional bandwidth may be available from 3rd party vendors who are operating supplying services to homes including VoIP, ipTV and internet services etc. However, this introduces a number of challenges and risks which need to be carefully considered before this option is recognized. These include: stability of 3rd party vendors and possibility of liquidation, service level agreements, availability of communications, costs, security etc. In addition, each concentrator communicates with a number of smart meters. This will be rather challenging to implement as there may not be availability of fibre cores between all devices required to communicate to a concentrator.

7.3.3 GPRS/EDGE/3G

At present, mobile service providers have achieved a large coverage for wireless data communications using GPRS, EDGE and/or 3G. Latency and throughput on GPRS/EDGE/3G can be variable as the network operates on a best-effort grade of service (GoS). The GoS depends on available base stations in a cell, the number of simultaneous data users currently connected and registered on a base station, available bandwidth etc. Consequently, this makes mobile communications inadequate for mission-critical real-time services. However, for purposes of DR applications and providing bi-directional communications between the utility and the consumer/data concentrator, GPRS/EDGE/3G is adequate.

7.3.4 Long Term Evolution (LTE)

The institution of Long Term Evolution (LTE) networks in South Africa will promise the availability of additional bandwidth soon in major metropolitan areas with a number of LTE communications devices already available by 3rd party vendors. LTE will provide an increase in capacity and speed and reducing latency when compared to its predecessors and provides a packet switched Ethernet interface which is supported in many emerging smart meters and new LTE communications devices.

7.3.5 ZigBEE

ZigBEE is a suite of communication protocols typically used in home area networks using lower powered digital radios [37]. ZigBEE operates over a meshed network allowing data to traverse over long distances by the passing information to intermediate devices. ZigBEE is adequate for use on an AMI system typically between data concentrators and smart meters and/or between the smart meters and the consumer’s CIU/ACD. ZigBEE devices typically promise a secure network using complex encryption techniques and operate with a long battery life [37]. ZigBEE operates in the 2.4 GHz band along with Wi-Fi and Bluetooth. Some of the applications where ZigBEE has been deployed successfully around the world include: residential electrical metering systems, home and building automation systems and industrial monitoring and control systems [37]. ZigBEE is an open standard managed by the ZigBEE Alliance, compiles with the IEEE standards for wireless networks, requires no ICASA license fee for use in South Africa and ZigBEE compatible devices can be added/removed on a mesh network with relative ease [37]. This technology should be considered by utilities for use with AMI's.

7.3.6 WiMAX

The use of wireless communications such as World-Wide interoperability for Microwave Access (WiMax) and wireless devices using the ISM radio frequency band which support high data rates is another medium which has recently been adopted in many AMI solutions.

Issues that need to be addressed when evaluating the optimum telecommunications medium and associated technology include:

1. Determining the speed and the maximum no. of meters that can be used per data concentration unit (DCU). This will assist in evaluating the bandwidth requirements needed.

2. Quality of the links/services required for the AMI system, packet error rates and bit error rates available for different communications mediums, signal strength coverage for wireless networks, bandwidth availability, bandwidth requirements and the different Quality of Service (QoS) regimes available for different systems.

3. The scalability, affordability, company reputation, service level agreements with the service provider with end to end guarantees, possibility of differentiating between different classes and quality of services are all factors which need to be deliberated when deducing the supplier.

In South Africa, Eskom is currently investigating the use of 3rd party networks as the only feasible option [29]. The remote digital radios on Eskom's area radio network use the Push to Talk (PTT) half duplex philosophy thus allowing only one outstation to communicate at a time to the base repeater. Due to the large amounts of smart meters envisaged on the network, area radio at this stage cannot support a wide-spread rollout of smart meters making it only adequate for SCADA and operational voice [29]. Consequently, technologies such as LTE, 3G/GPRS, WiMAX and ZigBEE radio-based networks at concentrator and meter level are under consideration [29].

7.4 Ancillary Services

In power systems with embedded wind power generation, it is often possible for wind power plants to provide system support to the network and provide a form of ancillary service to the system operator. Ancillary services include the services that support the provisioning of energy to ensure power system reliability and security. Careful consideration of the power system economics and engineering must be considered in the design.

To support the scheduling of energy, the system operator requires ancillary services which include frequency support, voltage support and system restoration. Ancillary services markets are usually tied to the energy markets and thus have a dynamic pricing structure.

FERC defines ancillary services in the following categories:

1. Scheduling, system control and dispatch usually provided by the transmission system operator.
2. Reactive supply and voltage control which is usually supplied as a cost-based service and can be provided by wind power plant systems.
3. Regulation and frequency responsive services. Regulation is usually dynamically priced and used to assist in frequency control.
4. Energy imbalance service.
5. Operating reserve – synchronized reserve service (spinning reserve)
6. Operating reserve – supplemental reserve service (non-spinning reserve)

In North America, NERC defines and governs the reliability requirements. These requirements include the provisioning of atleast 50% of spinning reserve immediately available for synchronization and supply to the grid. Spinning and non-spinning reserve constitutes the utilities contingency reserves. Some regions have requirements to have 2nd contingencies. These contingencies need to be available within economic dispatch interval which is typically 5 minutes.

Under most conditions, spinning reserves are costly as generators are required to forfeit energy sales in order to respond to contingencies. Further costs are attributed towards additional maintenance and fuel costs of the generators.

Embedded wind power generation would undoubtedly affect the ancillary services requirements. These are required to be dynamic as demand resource can actively contribute towards the capacity reserves. In addition, the predicted wind power would impact the amount of variability on the power system. Hence, markets need to now plan ahead in order to ascertain what the ancillary service requirements will be based on the predicted conditions on an hourly basis.

Research has shown that renewable technology will be participating in certain ancillary service markets. Through the inception of embedded wind power generation, the need to recognize additional ancillary services including frequency response, voltage and reactive power support should be considered.

7.5 Dynamic Pricing

The consumer needs feedback on how much energy they have saved when they participate in events and how much they could have saved if they participated. It is rather challenging for the CIU of the smart meter to integrate pricing with energy consumption and provide real-time dynamic pricing updates. In addition, should this be achieved, its accuracy when compared to the electricity bill generated from the utilities billing system requires careful consideration. A more efficient method of providing such real time information is to provide consumers with a web-accessed information portal which access the utilities billing system. This access to information is one of the supporting pillars based around DSM/DR [10].

The consumer needs to be compensated for being energy efficient and participating in DR programmes. Furthermore, rebates and incentives should be given to consumers who partake in pilot programmes. A duel benefit is derived from this approach as the learning experience is extended to the consumer creating awareness, and an opportunity for consumers to adopt energy efficient behaviour profiles [8].

Over recent years, South Africa experienced electricity price increases on a yearly basis. Escalating prices is now the reality for many consumers in South Africa. The realization of the increase in electricity prices can be the incentive required to accelerate the adoption and promotion of consumer behaviour change by instituting dynamic pricing thus enabling the consumer to have control over his energy consumption and electricity bill.

8. Impact of wind generation on current DSM Practices and recommendations

In South Africa, despite not having a large install base of renewable sources at present, through the Department of Energy's REBID programme, we can expect a significant rise in the use of wind power generation within the next few years. Eskom have done much work on their current DSM and DR programmes predominantly within their industrial, commercial and agricultural sectors, however, the use of DR programmes in the residential sector is yet to be seen. At present, through their IDM programme, they have been reaching out to the residential sector by creating awareness and promoting energy efficiency and conservation predominantly through advertising and providing energy tips. In addition, Eskom have embarked on an energy conservation campaign in the residential sector by replacing common inefficient energy equipment with their corresponding energy equivalents such as lighting systems, water efficient shower-heads, geysers blankets etc. They have also committed to providing rebates (percentage of the total cost) for installing solar powered geysers in residential homes. The state government is further assisting by installing solar geysers on all new build houses funded by the government.

The introduction of wind power generation still introduces the issue of intermittency of wind and the effects it has on the power system. This effect will require near real-time variation in the load and the residential sector forms a key component in managing this intermittency as opposed to utilizing conventional capacity reserves. Hence, current DSM/DR practices will need further enhancement predominantly in the residential sector. Current DSM practices in the residential sector will reduce energy consumption and promote energy efficiency/conservation, however, this savings will eventually saturate and a more real-time behavioural change in consumers demand profile is required to combat the intermittency of wind power generation. This will need to be achieved by revisiting the strategy for deploying DR within the residential sectors in order to ensure sustainable quality, security and reliability of supply. The benefits derived from this approach can be observed from utilities around the world who have introduced this initiative on their network as discussed in sections 4.1 and 4.2.

The strategy for DSM/DR in the commercial, industrial and agricultural sectors should continue as planned as these have been proven to be efficient, beneficial and are comparable to international best practiced approaches.

The deployment of DR in the residential sectors introduces a number of prevailing challenges and the current infrastructure within the residential sector cannot accommodate DR programmes. Eskom, as per their strategy, will need to consider the use of smart grid technologies to facilitate this task. As discussed a number of technologies exists which can supplement DR. These include AMI's, installation of next generation telecommunications infrastructure to support AMI's, dynamic pricing and automation and integration of utility enterprise systems.

The deployment of AMI cannot follow a 'big bang approach' and it is important to continue with research and development through small-scale pilot projects in order to acquire the experience and understanding of the underlying technology and the prevailing challenges which need to be ironed out from a technical and commercial aspect. It is also important to implement and evaluate various DR programmes during these pilot projects to ascertain its benefits and examine consumer behavioural change in order to better understand the consumers demand profile.

Eskom is currently compiling there business requirements and developing the strategy with regards to measurements and metering within all aspects of the business including Distribution, Transmission & Generation. These requirements include: TOU, AMR, energy management within the consumers home, improvement in revenue collection, integration of Quality of Supply information, the capability to remotely change metering technologies from conventional tariffs to pre-payment, support for multiple communications mediums and load limiting with remote connect/disconnect capabilities [29]. Eskom's core end state vision is for their metering system is to encompass AMI Smart meters embedded primarily with remote communication capabilities handling both credit and pre-payment technologies and perform Quality of Supply measurements [29].

Eskom's plan for the future on the domestic sector is to install smart meters with load control capabilities, emergency load limiting DR programmes, remote disconnection, outage detection, web service functionality and support dynamic pricing [29]. In addition, they envision future smart meters for the pre-payment sector to accommodate remote automatic Token entries [29].

It is imperative that Eskom proceed in the direction of their strategy by introducing small scale pilot projects involving the implementation of AMI, testing of existing and emerging technology and implementing DR programmes and brings the consumer into the value chain.

As experienced by many utilities around the world, the implementation of the next generation Smart Grid presents a number of prevailing challenges. These challenges within the South African context are discussed below.

8.1 Analysis of the challenges of implementing Smart Grid technologies for DR

This section details the challenges and possible solutions which utilities including Eskom will experience and need to consider when implementing Smart Grid technologies. It is critical that these issues are recognized and resolved during the small-scale implementation of pilot projects in order to secure a sustainable roll-out of the associated technology and harvest the benefits promised. Some of these issues and possible solutions are detailed herewith.

Extensive support and consumer service will be needed to manage complex DR programmes/applications.

The AMI system needs to accommodate all consumer sectors including pre-payment metering. In South Africa, large portions of the domestic sector employ the use of the pre-payment electricity system. Many challenges exist when considering smart-metering on pre-payments systems. Utilities including Eskom are required to investigate these issues and develop a strategy going forward with regards to pre-payment systems.

Utilities are to decide on whether or not pre-payment accounting will be achieved locally or centrally on the back-end system depending on whether transactions that will occur in currency or energy units. At present, the STS Association in collaboration with the IEC is currently enhancing the existing STS specification to include: currency credits and energy credits, transfer of tariff information and the use of bi-directional communications systems in order to support the transfer of STS credits using communication protocols such as DLMS [30]. This will address the issues surrounding dynamic pricing in the pre-payment systems.

In South Africa, Eskom's CC & B Billing systems need to be enhanced to support TOU and other DR related programmes for the pre-payment metering system. Furthermore, the customer web interface portal will need to be integrated into Eskom's billing system for all consumer sectors.

The impact on business operations by instituting a full-scale roll out of smart meters and AMI's needs significant consideration. Issues which need to be considered from a commercial perspective include business operations, impacts on value chains, systems and stakeholders [12]. These need to be identified and a work-process flow with adapted processes and procedures need to be defined.

Theft and vandalism which is often faced in a number of high risk areas is a key factor which needs to be assessed. In South Africa, this is an on-going issue facing Eskom in all disciplines. In phase 1 of Eskom AMI project, Eskom have added additional secure kiosks for the data concentrator in order to prevent further incidents of theft and vandalism [25]. Eskom's current metering strategy does include automated tamper detection and identification as one of their business requirements [15]. Eskom have also successfully implemented split metering solutions in high risk areas. The split metering solution is a system that separates the customer interface unit from the measurement and control unit. The customer interface unit is installed in a location which is easily accessible to the public whilst the secure measurement and control unit is installed in an accessible enclosed area. This solution assists in meter tampering and bypassing for illegal connections. Lastly, the use of AMI's with wireless technologies requires the use of SIM cards on all communications devices using 3G/GPRS/LTE technology. Eskom have experienced significant theft and fraudulent behaviour on SIM cards used on communications devices for metering and SCADA. Investigations are currently underway in Eskom for the use of SIM chip devices which have the SIM card microprocessor mounted on the printed circuit board making it inaccessible to lawbreakers. South Africa's leading mobile operators MTN and Vodacom have made SIM Chip devices available for vendors.

Regulations and existing government policies need to be amended in order to support DR programmes in the domestic sectors.

Control signals, data formats and protocols utilized on all Smart Grid enabling devices need to be internationally recognized and standardized and not proprietary [25]. At present, there is a lack of interoperability and open standards. The European standards organization working groups and technical committees mandated by the European Commission are reviewing and developing standards with the intent of harmonizing and standardizing the integration between systems in order to ensure an inter-operable Smart Grid architecture [17]. In the near future, we can expect a mapping between the Common Information Model message profiles defined in IEC 61968 and DLMS/COSEM (IEC 62056) message profiles thus allowing smooth integration of AMI master stations and the integration layer linked to utilities enterprise systems [27]. It is also envisaged that a translation between IEC 62056 and the IEC 61850 suite standards used for substation automation system will exist [27].

There is a great need for consumer education. Consumers will demonstrate resilience to the new technology due to a lack of knowledge and understanding of the system.

Creating awareness and including the consumer in the value chain during the infancy stages of the project can speed up adoption and acceptance of the new technology and prevent concerns and uncertainties arising in the deployment phase. This has been experienced by utilities in Texas and California.

The type of communications media for the full duplex network is not specified in the NRS specification for AMI's for use in South Africa [19]. As discussed, many solutions exist for the telecommunications technology for AMI's and due to the rapid growth in technologies and services in the past 10 years, it is envisioned that the complete AMI system will comprise a number of technologies and services throughout its implementation. Eskom is currently adopting this philosophy of keeping the telecommunications technology and service of the AMI dynamic and separate from the metering devices whilst continuing to investigate emerging technologies [29]. This is attributed to the fact that technologies keep evolving and often some technologies are succeeded by even newer technologies without having the opportunity to mature well enough in the market [15]. It is then a requirement for all metering devices to seamlessly connect to any external communications device.

The integration layer as depicted in Figure 3 will be responsible for the acquisition of all data from the AMI master stations, consolidating the required information and distributing this information to the relevant business functions via their respective enterprise systems. These functions include outage management, asset management, Distribution Management Systems (DMS), Energy Management Systems (EMS) etc. Eskom is adopting the strategy of unifying a common backend system to facilitate this task. This system shall support the integration of multi-vendor AMI systems be capable of synchronizing with enterprise level systems for data transfer [29]. Amongst others, these enterprise systems include work and asset management (MAXIMO), DMS (ABB NM), EMS (TEMSE), outage management system (VAT), customer information system (GTX), metering system (MV90 and EMDAS), billing system (CC & B) and geographical information system (SmallWorld).

At present, there is a lack of smart appliances infiltrated in South Africa's domestic sector to facilitate home automation systems. The small scale pilot project should factor this into account and a survey needs to be conducted to investigate areas with a large penetration of smart appliances in order to evaluate the benefits of home automation for the utility.

Eskom is required to consider real-time pricing arrangements with consumers from the domestic sector and utilize dynamic pricing schemes during the pilot phase of testing smart grid technologies. This will provide an understanding on consumer adoptions and responses to pricing signals, consumer demand profiles and consumer behavioural change in response to dynamic pricing. Dynamic pricing schemes for the domestic sector need to be implemented on the billing system.

Another important challenge facing South Africa is there exists a vast number of municipalities which purchase energy from Eskom and through their own electrical infrastructure, distribute this energy to the residential sector. This complicates the system and methods need to be instantiated and tested in order to achieve interoperability between enterprise systems existing at Eskom and the municipality. This will allow Eskom to send control and pricing signals to municipalities who can then forward this information to residential homes. This will require municipality participation and investment in comparable smart grid technologies to facilitate the widespread implementation of DR programmes across South Africa.

AMI cyber-security factors with regards to authentication, authorization, audit trails, secure communications, role-based engineering, configuration and firmware updates are aspects which require careful consideration. In South Africa, the NERC CIP suites of standards are adopted for use in Eskom.

Defining and setting up an agreement with the consumer needs to be evaluated during the pilot phase of the implementation. This needs to be clearly defined with consumer acceptance prior to the rollout. Consumer input during the small-scale roll-out is suggested.

Managing and validating metering data is essential prior to rolling out Smart Meters. Phase 1 of the AMI rollout in Eskom proved that one of the critical challenges experienced during the implementation revolved around data inconsistencies on the meter data management system.

System audits need to be conducted prior to the rollout and the authenticity of all drawings needs to be verified during installations to prevent stranded meters and ensuring the accuracy of the consumer network database [25].

Network planning and roll-out strategy, billing for revenue collection, credit management, inspection, maintenance and repair philosophies need to be prepared.

Outages are required during installations of data concentrators. Additional outages will be required with data concentrators which could not be commissioned initially due to issues experienced with equipment. Consumer notification and acceptance is required and Key Performance Indexes (KPI) will be affected during this time. Installation of smart meters requires approval from home-owners and this can only be accomplished at their convenience. This can possibly delay rollouts and installations of CIU's, data concentrators and smart meters.

Asset Management of all installed smart meters, data concentrators and ACD's along with inventory count, monitoring of assets and operations and maintenance philosophies of all assets need to be conducted during the small-scale implementation. This will assist in identifying and resolving possible challenges with the enterprise system prior to a national rollout.

Setting up contractual agreements with suppliers of Smart Grid technology equipment (e.g. AMI, smart meters, data concentrators etc.) need to be carefully prepared including maintenance and support contracts if required, service level agreements (SLA), repairs, installation guidelines and standards, equipment warranties and performance levels.

Post monitoring of connectivity to all smart devices between the control centre and the consumers premises and measuring of performance of all equipment within the AMI domain should be mandatory. Utilities are advised to implement automatic monitoring and reporting systems which can facilitate this process due to the large number of equipment envisioned for commissioning.

Project management of installations, outages, human resources, procurement of all equipment, technical support, finance management, training and development are some of the key factors which need to be adequately managed throughout this process.

When developing the Smart Grid strategy, careful consideration needs to be given on the type of DR program applicable for the power system. Appropriate statistical and load research techniques need to be applied when evaluating which DR program and application to implement on the network. This requires quantification (measurement and verification) on the amount of load reduction which can be achieved on different DR programmes. A number of methods exist which can be employed to calculate the required baselines and load reductions possible in different DR programmes. This should be investigated during the implementation of AMI's on a small scale. The utility is requested to invest in research and development for the measurement and verification of disaggregated DR programmes. These programmes need to be measured against the cost-effectiveness, application potential and consumption reduction.

This enables the utility to monitor consumer behaviour and experiment with a number of DR applications in order to evaluate the optimum cost-effective solution offering the most reduction. Furthermore, this research will pave the way forward on the choice of DR program to be used in conjunction with AMI's for the large-scale rollout of the technology.

Initially, this approach might seem costly and time consuming as opposed to choosing a DR program based on best practiced approaches chosen by other ISO's and utilities. However, not all utilities share the same experience and encompass the same demand behaviour. Meteorological conditions and the economic circumstances of a country are key factors which can affect consumer behaviour patterns and energy consumptions. Hence, each utility is required to invest significantly in understanding their consumer's energy trading requirements. For example, the use of air-conditioning system's in South Africa is moderate when compared to countries situated near the equator which experience higher temperatures in the summer months. In addition, choosing a DR program without understanding the consumers energy requirements can lead to utilities paying incentives in excess of consumer responses and/or no load reduction being recorded during a DR event which can lead to consumers not-participating in future events.

The results from the small scale pilot implementation of AMI's and different DR programmes should then be weighed against the practical and financial feasibility of implementing them in order to ascertain the optimum solution for the power system.

9. Conclusion

With the large integration of wind energy sources in the power system, utilities are expected to accelerate the pace of testing various smart grid technologies in order to support DSM and DR initiatives. These initiatives will assist in managing the intermittency of wind power generation.

This report outlines the concepts of DSM and DR with reference to a number of industry best practiced approaches and based on experiences from utilities around the world. The Smart Grid enabling technologies which are needed to supplement DR and DSM are described including AMI's, emerging telecommunications technologies, dynamic pricing and utility enterprise system integration. A review of various Smart Grid experiences around the world is then presented and discussed within the context of South Africa's current power system infrastructure. This report further provides a detailed analysis of the impacts of current DSM/DR practices on wind power generation and the challenges that need to be mitigated in order to successfully roll out various DSM/DR programmes. Remedial actions are then provided within the context of Eskom's current DSM/DR programmes.

This analysis showed that whilst the agricultural, commercial and industrial sectors have a sustainable programme, much work is required on the domestic sector. In addition, the current DSM initiatives in the domestic sector will not be adequate to manage the intermittency of wind power generation. It is essential for DR programmes to be implemented in the domestic sector to facilitate DSM. However, the current infrastructure does not support a widespread implementation of DR in South Africa. In addition, a number of commercial and technical challenges are prevalent and outlined in the analysis. These include the inability of the billing system to accommodate pre-payment metering, no support for currency on STS tokens for pre-payment and limited support on meters available at this stage to support the next generation of tokens, lack of existing telecommunications infrastructure and AMI etc. Furthermore, much of South Africa's residential sectors are supplied from local municipality's electrical infrastructure. This complicates the deployment of DR in residential homes and municipalities and Eskom are required to develop a strategy going forward with regards to integrating enterprise applications for sending control and pricing signals and for managing AMI throughout the country.

It is vital for Eskom to commence research and development of DR techniques and tools within the residential sector. Acquiring first-hand experience in best practices needed to overcome these technological and commercial challenges is a key enabler when implementing smart-grid technologies.

A cost-effective solution would be for Eskom to deploy AMI on a smaller scale which includes a large portion of the DR applications and programmes that is desired on the final network as outlined in there smart grid strategy and roadmap. This will enable Eskom to test various DR programmes, observer consumer behavioural change, identify and resolve key technical and commercial challenges and laying the foundation of enabling full home automation systems which support the next generation Smart Grid.

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Appendix A

A1. Introduction

This paper was presented at the 2013 Protection, Automation & Control (PAC) World Africa Conference hosted in South Africa by the author. This paper was written during the research phase of this project and as a result, abstracts from this paper have been taken from this research report both which have been compiled by the author. As such, no copyright infringements have been violated. Both documents remain the sole work of the author and the intellectual property of the University of the Witwatersrand, Johannesburg.

A2. Research Paper

Proceedings of the 2013 Protection, Automation and Control (PAC) World Africa Conference, Cape Town, South Africa, July 2013.

The role of smart grid technologies on demand response in a power system with embedded wind power generation

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Abstract

Around the world, energy regulators and power utilities have set medium and long term targets to meet gross electricity production aided by the employment of a number of renewable energy sources such as wind energy. These targets are in response to climate change, reduction of emissions produced by conventional electricity generation methods and increasing prices of oil and fossil fuels.

Due to its intermittent nature, wind energy has adverse effects with limited predictability which can compromise the security and reliability of a power system with a high penetration of embedded wind power generation. These effects include the availability of wind, accommodation of its variability and managing capacity reserves, managing costs and regulating the balance between supply and demand. These effects can be managed through the use of real-time Demand Response applications. This paper presents the challenges which have been faced by other utilities on a global scale to combat the adverse effects of wind energy by using Demand Response. A number of smart grid enabling technologies in the automation and control plant discipline which are currently being tested and implemented in other countries are described and these applications and their challenges in the South African context are outlined. The objective of this paper is to aid utilities when developing their business plans and strategies for the next generation smart-grid framework

Keywords: DSM, Demand Response, ICT, Smart Grids, AMI, metering

1 Introduction

In South Africa, the state of the power system and the balance between supply and demand is tight, thus further emphasizing the need to invest in cleaner energy to meet South Africa's future demand. The inception of independent power producers (IPPs) generating cleaner energy to support the existing power system coupled with Eskom's intent on building wind farms will lay the foundation for South Africa to embrace wind energy technologies and contribute towards the reduction of emissions on a global scale.

The output wind power of the electrical system is governed and determined by prevailing meteorological conditions which falls outside the dominion and control of the system operator. Reduction of wind in power grids with large scale wind energy penetration can introduce severe consequences on the security, reliability and integrity of the power system predominantly where no additional resources are available to respond to significant ramp rates [1]. Many countries encompassing a substantial install base of integrated wind power generation have experienced extreme positive/negative ramp rates. Ramp rates between 4% - 7% of the installed capacity can be experienced in a second and rates between 10% to 14% can be experienced in minute intervals for the same installed capacity [2].

The intermittency of wind energy can be managed by a number of resources including grid integration, energy storage technologies, complimentary renewable energy systems, improved forecasting techniques and conventional spinning reserves.

One of the key enablers of managing the intermittency of wind in a power system is through the institution of smart grid technologies and programmes. These include Demand Side Management (DSM) and Demand Response (DR) programmes. These programmes and techniques can facilitate the reduction of load on the demand side during peak times and can be used by utilities to decrease demand to match available supply as opposed to the conventional method of increasing supply to meet current demand by operating spinning reserves.

DSM and DR programmes are being explored and implemented by many utilities around the world including South Africa. However, the intermittency of wind require near real-time variation in the load in order to not compromise the security of supply to the grid. In this case, it is important to introduce DR initiatives and there supporting smart grid technologies to supplement DSM and manage the power-system.

In the next few years in South Africa, the building and integration of large-scale wind farms on the transmission and distribution networks is inevitable. This outcome necessitates the investigation of South Africa's current DSM and DR practices in order to determine the most optimized approach in managing the power system. It is fundamental that this approach incorporates the correct implementation of smart grid technologies such as advanced metering infrastructure (AMI) coupled with various demand response technologies. These technologies need to be aligned with the countries smart-grid strategy going forward and should contain the appropriate means to compensate the effects of wind variability.

2 Demand Side Management / Demand Response

To provide supply to an uncontrolled demand, power utilities around the world are required to ensure that sufficient capacity reserves and ancillary services are provisioned in order to provide generation security especially in cases where integrated renewable energy systems exist. Additional reserves can be provided through the use of DSM and DR.

Over the past few years, Eskom's DSM program has been primarily focused on load shifting and actively managing and reducing electricity demand profiles [3]. Public education and awareness on energy efficiency is a major contributor to the DSM program. This program is aimed to achieve a target of 10% reduction in power demand and a savings of 8000 MW by 2026 [3]. Part of Eskom's DSM program includes the replacement of incandescent lights with CFL, providing rebates to customers wishing to replace the use of electric geysers with solar water heaters, mass-rollout of geyser blankets and efficient shower heads, incentives to replace electric stoves with gas-operated stoves and endorsing the use of smart metering devices.

DSM can further acts as a remedial balancing action to manage the unpredictability and variability of wind power. Applications of DSM can provide additional system stability and support and can be seen as an alternative ancillary service.

a) Benefits of DSM

- Increase the utilization factor of generation network and capitalize on network investment. The conventional method of having a number of spinning reserves operating at partial load degrades the efficiency of the power system [4].
- Provides flexible capacity to stabilize and balance the power system.
- DSM can indirectly educate the consumer in managing their overall energy consumption and provide consumers a greater role in the value chain of energy trading.
- Climate challenge and environmental protection.

b) Challenges of DSM/DR

DR can assist abrupt variations by adjusting load in near real time. However, in order to fully conceptualize and benefit from the load reduction that can be achieved, a number of prevailing challenges need to be carefully considered. These primarily include:

- There is a lack of ICT and metering infrastructure required to deploy DSM/DR on a national scale.
- The ability of the billing system to efficiently manage dynamic pricing with fluctuations and billing to customers based on their responses is very limited.
- There is a challenge to justify the upfront capital investment required to install technologies for DR. These costs need to be weighed against the benefits derived from its correct institution.
- Quantifying costs and benefits derived from disaggregated smart grid technologies/applications associated with DR.
- Lack of skills and confidence in different smart grid -enabling technologies which support DSM/DR. Utilities are encouraged to continue piloting and investing in research and development as the system complexity increases considerably when

implementing DSM/DR applications and management of these applications is paramount for its success.

- There is a lack of incentives for consumers to change their consumption/behaviour patterns and compromise their convenience for efficiency.
- Loads which require sufficient operational and start-up time make load-shifting a challenge [2].
- Inactive loads can operate when supply is high, however, these can only operate over a specified period of time.

3 Current Smart Grid Enabling Technologies

A number of techniques and tools centred on demand response are currently being researched and implemented in countries with a high penetration of wind energy.

The Federal Energy Regulating Commission (FERC) estimates that DR programmes can alleviate US peak demand by up to 20% within 10 years.

In Portugal, investigations and tests were conducted against various DR programmes using the industrial, domestic and tertiary sectors. Reduction of 13% of peak load was observed when instituting these programmes [1]. Their research estimated that peak load reduction of 17.4% can be achieved by 2020 by continuing to apply DR programmes with smart grid technologies [1].

In the United Kingdom, the "Demand for Wind" research project was introduced to investigate the use of DR programmes in order to address the variability of wind energy in a power system. The scope of the research included the development of smart grid enabled technology to perform a number of functions including: diverse forms of controls in the residential environment; monitor household energy, communication of usage data and control signals between the control centre and the household; measuring consumer energy usage patterns using DSM/DR programmes; develop a small scale home automation system with embedded web technology enabling direct communication to consumers through web-forums [6]. The key objectives of this project was to promote renewable energy sources by creating a demand for wind energy, prevent wind curtailment, enable consumers to use a larger load when surplus of wind energy was available and change customer behaviour patterns by allowing consumers the flexibility of responding to electricity price fluctuations by managing the energy usage accordingly [6].

The Belgium transmission system operator, Elia has contractual agreements with industrial customers to temporary permit the interruption of large power components in order to ensure grid security [7]. New England's ISO ancillary services market project enables utilities to bid DR capacity into the energy markets which is perceived as capacity reserves [8].

Scandinavian and UK markets manage short-term energy trading based on supply forecasts and predictions. These incentives are offered to consumers for both load reduction when wind energy is low and for increases in load when wind energy is high [2]. In these markets, much research has been done in analysing the technical properties of different loads in the domestic sector which can assist in time shifting and during generation peaks [2]. Two major groups of high energy consuming appliances in the domestic centre exist: appliance operating for short periods which are typically used for during generation peaks and appliances that operate as and when required [2].

Utilities in the United States have committed to investing in over 40 million smart meters over the next 5 years [8]. The U.S. government has demonstrated its support with a number of acts, regulations and policies being introduced which are directed towards the development of the next generation smart grid. A substantial portion of the funding of this smart grid development is sourced from the American Recovery and Reinvestment Act of 2009 (ARRA) [11]. One of the main objectives is to upgrade the power system to enable consumer choices, create jobs and generate clean and secure energy from renewable sources. Nine states are estimated to have over 50% penetration of advanced meters [13]. FERC's latest annual assessment indicated that the potential demand response resource contribution from all DR programmes is nearly 72 GW which is nearly double the generation capacity available in South Africa [13].

The city of Tallahassee in Florida has spent 8.8 million dollars to implement a smart grid based DR program that allows users to remotely cycle off their air-conditioners.

The Turkish electricity market is undergoing rapid growth and large capacity increases are expected from renewable energy sources. A projected target of 30% of demand to be supplied by wind and solar is anticipated by 2023 [13]. In light of this, Turkey has made the development of a smart grid a priority and will be investing $5 billion on smart grid technologies in order to meet their targets [13].

Recent reports have also shown that a number of countries in Asia are investing significantly in the development of the smart grid. China projects that their installed base of smart meters in China will reach $377 million by 2020 resulting in a penetration level of 74% [15].

In Ontario, 4.3 million smart meters have been installed with a 1000 homes having a complete integrated smart-grid solution. The intention behind this investment was to reduce peak demand, improve energy efficiency and increase visibility and control. This solution incorporates: a utility management system capable of managing demand by load shaping; a consumer portal accessible over a web interface, mobile application or tablet allowing consumers to conveniently manage energy usage; the core network infrastructure communicating to smart meters using broadband power line carrier (BPLC) and digital area radio; a home energy manager that the consumer uses to communicate with the control centre on DR applications.

Eskom's current smart metering strategy does incorporate the accommodation of DR programmes including Time of Use Tariffs (TOU) with load limiting capabilities and remote disconnection [11].

4 Role of Smart Grid Technologies

Utilities are currently investigating various smart grid enabling technologies and developing strategies which describes the new smart-grid paradigm envisioned for their countries electrical infrastructure [9]. This is being done with the idea of improving the efficiency and utilization of the power system.

The next generation of smart grid technologies will support DR programmes and applications in allowing consumers to make smarter and informed decisions on energy efficiency and conservation. In many parts of the world, deregulation of the electricity industry and energy trading has provided the consumer with many choices thus making the consumer a key component in the value chain of the power system.

The management of the intermittency of wind energy in South Africa's electrical system requires a number of technical and practical challenges which need to be addressed. Amongst others, these include demand response programmes, the power system's pricing model, the advanced metering infrastructure and the ICT infrastructure.

a) Advanced Metering Infrastructure

One of the prominent smart grid technologies that support DR applications is advanced metering infrastructure (AMI) with smart meters. This includes a master station, a full duplex communications network, smart meters, data concentrators, a load switch, appliance control devices (ACD) and a customer interface unit (CIU). The type of communications media for the full duplex network is not specified in the NRS specification for AMI's for use in South Africa.

Currently, AMI systems and smart meters that have been deployed in the South African power system are capable of providing the following minimum facilities:

- Event reporting with time to the AMI master station.
- Local/remote appliance connect/disconnect.
- Meter/data concentrator configuration change
- Control a minimum of two appliance devices
- Load limiting
- TOU Tariffs configurable through messages from the AMI master station
- Sending commands to meters to remotely operate a number of ACD's.
- The ability to remotely curtail demand and provide load control during system emergencies.

It should be noted that a smart meter is not a smart grid [14]. A number of enterprise systems including resource management, outage management, asset management, customer service constitute a smart grid. Specific needs of the industry should be considered and a strategy with a roadmap towards the end-state should be clearly defined prior to commencing the journey towards a smart-grid [14]. This becomes more critical when mission critical services are involved.

In order to enable the transfer of information to various stakeholders within the utility, it is necessary for the AMI master station to integrate into the utilities enterprise systems. This can be achieved using an adaptive interface that uses a common information model (CIM) described in IEC-61968 primarily structured in extensive markup language (XML).

Inter-application integration is paramount for the exchange of real-time information used in the corporate network. Systems which use adaptive interface supporting CIM will prevent replacement of existing applications and systems and secure the current investment.

IEC 61968 that the domain model of each enterprise system interface be defined in Unified Modelling Language (UML) and that XML be the data format for document interchange. Having a common architecture will enable various systems to inter-communicate and facilitate data exchange between a variety of business functions. These business functions include: sales, network operations and support, distribution management system, fault management, records and asset management, customer services, operational planning, maintenance and construction etc. Data acquired from smart meters can then be fed into these business functions.

The economic benefit of employing this smart-grid technology includes: outage detection, load management, device management, credit management and tamper detection thus avoiding loss of revenue and providing revenue protection.

The complete solution for smart metering should accommodate a web-interface which provides customers with their metering data, historical trends, usage profiles, costs, a forum allowing consumers to exchange ideas and information on energy efficiency and demand side management and provide a portal for utilities to communicate and update consumers on a real-time basis.

Eskom has recently completed phase 1 of its AMI implementation with two suppliers which included the installation of more than 3000 smart meters on the network [16]. The intent of this project was to improve Eskom's experience with smart metering and AMI's and meet the objectives outlined for phase 1 [16]. This includes the implementation of DR programmes; promoting customer behaviour change by offering incentives (real-time energy usage information and supporting TOU tariff/Load Shifting); improve efficiency and customer service and understand the requirements and challenges which exist with the implementation of AMI's in order to derive a standardized solution going forward.

This required integration into the utilities existing Customer Care & Billing system. The AMI master station and CC & B required interface adaptors for integration and data transfer. This resulted in the development of a multi-vendor integration layer (MVIL) using CIM which allowed the integration of both vendors AMI back-end systems into the enterprise network [16]. In addition, a consumer web-based portal was developed that accessed CC&B and provided consumers with energy usage information [16].

Eskom has experienced much success from Phase 1 of the AMI project. Their reports indicate that a number of benefits were derived from this pilot. These include:

- Customers which were initially not on the billing system were added as a result of the meter installation [16].
- Errors found on the billing system were rectified [16].
- Meter tampering and illegal meter bypassing were identified [16].
- Detailed specifications and installation procedures on smart meters were documented as a result of the experience gained during the implementation. This laid the foundation for developing the skills in smart metering for Eskom [16].

b) Demand Response Programmes

Using DR programmes and technologies will enable utilities to provide automated DR programmes and offer the energy capacity of the grid to the energy trading market as a resource [8].

The economic benefit for the system operator is to provide incentives to the consumer and remunerate the consumer for reducing energy consumption as opposed to paying additional operating costs to match the available demand by employing the use of spinning reserves.

The DR applications that can assist load reduction by providing incentives during times when wind energy is low include:

- Direct Load Control: remotely cycles of a customer's electrical supply after receiving participation consent from the consumer. This is often used during load limiting programmes. Load limiting can assist in load reduction, however, a consumer is forced to use a pre-specified amount of energy or supply will be disconnected.
- Interruptible load: this program is typically used in a commercial/industrial environment. This has been a program that has been deployed in South Africa over recent years. Load is curtailed during peak periods. Supply to the consumer is typically remotely switched off after notification is given. Incentives are usually given to a consumer for their participation which is governed by a contractual agreement between Eskom and the consumer.
- Emergency demand response: this program serves as an emergency contingency when load reduction is required near real-time. This event may typically arise during a high responsive negative ramp rate of wind energy. Incentives will need to be provided to consumers who subscribe to this event.
- Demand bidding and buyback: This program allows the system operator to offer load reductions at a price and identify how much load the consumer will be willing to forego for the price offered. With demand bidding, consumers have the option of enrolling on programmes which offer incentives if loads are sacrificed during peak

times and when wind production is low. This provides an opportunity to load shift and increase the utilization on the power system.

- Time of Use Tariff: this is a pricing model that is designed to encourage energy efficiency and conservation by inflicting a high price for energy during peak periods.
- Real – time pricing: this pricing model fluctuates hourly or more often in order to indicate changes in the energy trading market. These changes can be in response to a loss of renewable sources.

When developing the smart grid strategy, careful consideration needs to be given on the type of DR program applicable for the power system. Appropriate statistical and load research techniques need to be applied when evaluating which DR program and application to implement on the network. This requires quantification (measurement and verification) on the amount of load reduction which can be achieved on different DR programmes. A number of methods exist which can be employed to calculate the required baselines and load reductions possible in different DR programmes. This should be investigated during the implementation of AMI's on a small scale. This enables the utility to monitor consumer behaviour and experiment with a number of DR applications in order to evaluate the optimum cost-effective solution offering the most reduction. Furthermore, this research will pave the way forward on the choice of DR program to be used in conjunction with AMI's for the large-scale rollout of the technology.

Initially, this approach might seem costly and time consuming as opposed to choosing a DR program based on best practiced approaches chosen by other ISO's and utilities. However, not all utilities share the same experience and encompass the same demand behaviour. Meteorological conditions and the economic circumstances of a country are key factors which can affect consumer behaviour patterns and energy consumptions. Hence, each utility is required to invest significantly in understanding their consumer's energy trading requirements. For example, the use of air-conditioning system's in South Africa is moderate when compared to countries situated near the equator which experience higher temperatures in the summer months. In addition, choosing a DR program without understanding the consumers energy requirements can lead to utilities paying incentives in excess of customer responses and/or no load reduction being recorded during a DR event which can lead to consumers not-participating in future events.

During this pilot, baselines are required to be continuously adjusted based on historical load-usage data and factoring the availability of wind energy during that time. This will allow the utility to create weather based consumer models of various DR programmes based on the sample data recruited from participants of the pilot project and weather data retrieved from the wind farm controller system.

This result should then be weighed against the practical and financial feasibility of implementing different DR programmes in order to ascertain the optimum solution for the power system.

c) Challenges facing smart grid enabling technologies

- Lack of infiltration of smart appliances to facilitate home automation systems.
- Extensive support and customer service will be needed to manage complex DR programmes/applications. Customer queries need to be resolved and many customers will demonstrate resilience to the new technology due to a lack of knowledge and understanding of the system.
- The AMI system needs to accommodate all customer sectors including pre-payment metering. This particularly applies to the billing system. Many challenges require consideration when considering smart-metering on pre-payments systems. Utilities are required to investigate these issues and develop a strategy going forward with regards to pre-payment systems. Some of the issues include: the flexibility of having the billing system communicate with the pre-payment meters, pre-payment accounting to be achieved locally or centrally on the back-end system depending on whether transactions that will occur in currency or energy units, backward compatibility with existing token technologies, support for TOUT and other complex demand response applications etc. [18].
- The impact on the business by instituting a full-scale roll out of smart meters and AMI's needs consideration. Issues which need to be considered include business operations, impacts on value chains, systems and stakeholders [12]. These need to be identified and a work-process flow with adapted processes and procedures need to be outlined.
- Defining and setting up an agreement with a customer. This needs to be clearly defined with customer acceptance prior to the rollout. Consumer input during the small-scale roll-out is suggested
- Managing and validating metering data. Phase 1 of the AMI rollout in Eskom showed that one of the critical challenges facing the implementation revolved around data inconsistencies on the meter data management system. Systems audits need to be conducted prior to the rollout and the authenticity of all drawings needs to be verified during installations to prevent stranded meters and ensuring the accuracy of the customer network database.
- Network planning and roll-out strategy, billing for revenue collection, credit management, inspection, maintenance and repair philosophies need to be prepared.
- Outages are required during installation of data concentrators. Issues surrounding data concentrators will require additional outages. Customer notification and acceptance is required and key performance indexes will be affected during this time.
- Installation of smart meters requires approval from home-owners and this can only accomplished at their convenience. This can possibly delay rollouts and installations of CIU's, data concentrators and smart meters.

- Inventory count, monitoring of assets, project managing installations, monitoring of connectivity, resolving issues with suppliers, metering solution performance issues,
- Theft and vandalism which is often faced in a number of high risk areas. Eskom have added additional secure kiosks for the data concentrator in order to prevent further incidents of theft and vandalism.
- Regulations and existing government policies need to be amended in order to support DR programmes in the domestic sectors.
- Control signals, data formats and protocols need to be internationally standardized and not proprietary. There is a lack of interoperability and open standards. The European standards organization working groups and technical committees mandated by the European Commission are reviewing and developing standards with the intent of harmonizing and standardizing in order to cater for the interoperability in the smart grid architecture [17]. In the near future, we can expect a mapping between the Common Information Model message profiles defined in IEC 61968 and DLMS/COSEM (IEC 62056) message profiles thus allowing smooth integration of AMI master stations and the integration layer linked to utilities enterprise systems [17]. It is also envisaged that a translation between IEC 62056 and the IEC 61850 suite standards used for substation automation system will exist [17].
- There is a great need for consumer education. Creating awareness and including the consumer in the value chain during the infancy stages of the project can speed up adoption and acceptance of the new technology and prevent concerns and uncertainties arising in the deployment phase. This has been observed by utilities in Texas and California.

d) Ancillary Services

Under most conditions, spinning reserves are costly as generators are required to forfeit energy sales in order to respond to contingencies. Further costs are attributed towards additional maintenance and fuel costs of the generators.

Embedded wind power generation would undoubtedly affect the ancillary services requirements. These are required to be dynamic as demand resource can actively contribute towards the capacity reserves. In addition, the predicted wind power would impact the amount of variability on the power system. Hence, markets need to now plan ahead in order to ascertain what the ancillary service requirements will be based on the predicted conditions on an hourly basis.

Research has shown that renewable technology will be participating in certain ancillary service markets. Through the inception of embedded wind power generation, there is a need to recognize additional ancillary services including frequency response, voltage and reactive power support.

e) Dynamic Pricing

Customer needs feedback on how much energy they have saved when they participate in events and how much they could have saved if they participated. It is rather challenging for the CIU of the smart meter to integrate pricing with energy consumption and provide real-time dynamic pricing updates. In addition, should this be achieved, its accuracy when compared to the electricity bill generated from the utilities billing system requires careful consideration. A more efficient method of providing such real time information is to provide customers with a web-accessed information portal which access the utilities billing system. This access to information is one of the supporting pillars based around DSM/DR [8].

The consumer needs to be compensated for being energy efficient and participating in DR programmes. Furthermore, rebates and incentives should be given to consumers who partake in pilot programmes. A duel benefit is derived from this approach as the learning experience is extended to the consumer creating awareness, and an opportunity for consumers to adopt energy efficient behaviour profiles [8].

Recently, South Africa experienced electricity price increases on a yearly basis. Escalating prices is now the reality for many consumers in South Africa. The realization of the increase in electricity prices can be the incentive required to accelerate the adoption and promotion of customer behaviour change by instituting dynamic pricing thus enabling the consumer to have control over his energy consumption and electricity bill.

f) ICT Infrastructure

In order to support these smart grid technologies, high up-front capital is required for network expansion and providing a network that is capable of supporting full duplex traffic allowing near real time communications to customers. A full duplex network will permit the transmission of signals, messages and events between customers participating in DR programmes and the utility. In addition, there are a number of technologies available which need to be considered for the AMI. In addition, depending on bandwidth available and cost, a number of technologies can be used. For example, the communications technology between the meter and the ACD and the communications technology between the meter and the data concentrator or the data concentrator and the AMI master station do not need to be the same. Utilities are requested to test a number of these mediums during their small-scale implementation. These technologies are detailed below.

- Broadband over power line carrier (BPLC) can be used for high-speed internet access using existing residential electrical infrastructure. The technology is based on DSL which exploits un-used transmission capabilities on the wires and using signalling frequencies other than the power frequency. This is largely employed between the meter and the data concentrator unit.
- Going forward, with the inception of fibre to the home (FTTH), additional bandwidth may be available from 3rd party vendors who are operating VoIP, ipTV and internet services. However, this introduces a number of challenges and risks which need to be carefully considered before this option is recognized. These include: stability of 3rd

party vendors and possibility of liquidation, service level agreements and availability of communications, costs, security etc. In addition, each concentrator communicates with a number of smart meters. This will be rather challenging to implement as there may not be availability of fibre between all devices required to communicate to a concentrate.

- At present, mobile service providers have achieved a large coverage for data communications using GPRS and 3G. Latency and throughput on GPRS can be variable as the network operates on a best-effort grade of service depending on the number of simultaneous data users on a service in making it inadequate for real-time services. However, for purposes of demand response applications and providing bi-directional communications between the utility and the customer/data concentrator, GPRS/3G is adequate. With the institution of LTE networks in South Africa, additional bandwidth will soon be available in major metropolitan areas with a number of LTE communications devices already available by 3rd party vendors. LTE will provide an increase in capacity and speed and reduce latency when compared to its predecessors and provides a packet switched Ethernet interface which is supported in many emerging smart meters.
- The use of wireless communications such as World-Wide interoperability for Microwave Access (WiMax) and wireless devices using the ISM radio frequency band which support high data rates is another medium which has recently been adopted in many AMI solutions.

Issues that need to be addressed when determining the optimum telecommunications medium include: determining the speed and the maximum no. of meters that can be used per data concentration unit (DCU), quality of the links, packet error rates and bit error rates, signal strength, availability, meter data management and web-based services, integration of customer interface portal with the billing system, scalability, affordability, reputable service level agreement with telecommunications service provider with end to end guarantees, possibility of differentiating between different classes and quality of services etc.

5 Conclusion

With the large integration of wind energy sources in the power system, utilities are expected to accelerate the pace of testing various smart grid technologies. Acquiring first-hand experience in best practices needed to overcome these technological and commercial challenges is a key enabler when implementing smart-grid technologies that can support Demand Response.

A cost-effective solution would be for utilities to deploy AMI on a smaller scale which includes a large portion of the DR applications and programmes that is desired on the final network as outlined in there smart grid strategy and roadmap.

This paper presents the role DSM and DR plays in a power system and outlines a number of benefits and challenges associated with these programmes. The current smart-grid enabling technologies which are being employed around the world in order to manage the intermittency of wind energy is presented and the role of these technologies is discussed with particular reference to ancillary services, the ICT infrastructure, advanced metering infrastructure and the challenges accompanying these technologies.

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