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

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

1 INTRODUCTION

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

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

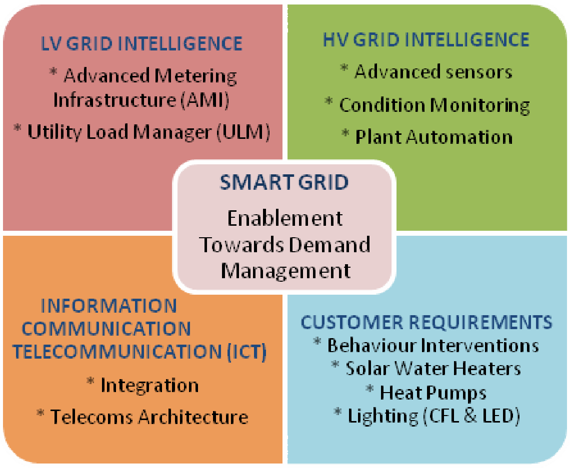

Figure 1: Holistic Approach to illustrate the different aspects of reducing demand on the network.

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

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

2 LOW VOLTAGE GRID INTELLIGENCE

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

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

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

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

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

2.1 Advanced Metering Infrastructure

2.1.1 A South African Perspective

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

2.1.2 Primary Objectives for AMI

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

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

2.1.3 AMI Solution proposed by NRS049

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

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

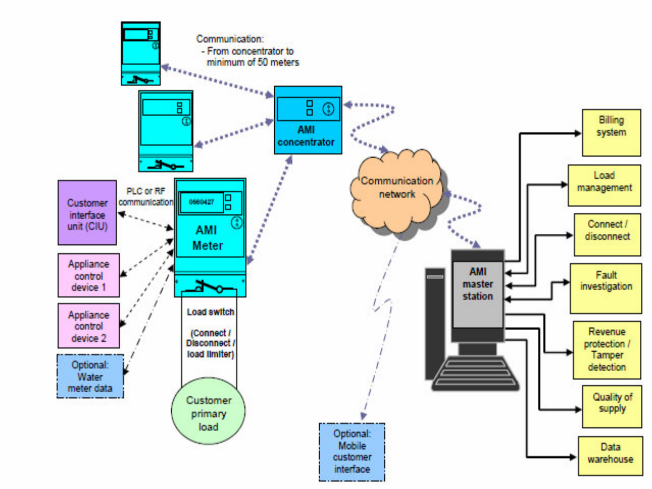

Figure 2: NRS AMI Architecture [5]

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

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

2.2 Utility Load Manager (ULM)

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

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

3 HIGH VOLTAGE GRID INTELLIGENCE

3.1 The Role of Telecoms and Control

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

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

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

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

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

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

3.2 Benefits of Evolving Technologies

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

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

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

Table 1: Evolving Technologies [11]

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

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

4 GRID INTELLIGENCE THROUGH SENSOR DATA COLLECTION

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

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

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

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

Insulator leakage current monitoring

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

Spark gap operation detection

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

Flashover detection

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

Lattice Member Theft

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

Low Hanging Conductor

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

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

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

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

Figure 3 below, illustrates the field trialled concept.

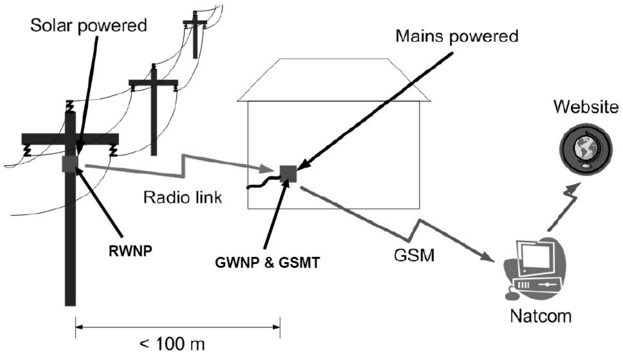

Figure 3: Low Hanging Conductor Solution

5 EMERGING ISSUES

Some key related emerging issues include the following:

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

6 CONCLUSIONS

The following key conclusions have been noted:

- Enabling a Smart Grid requires several interventions. It becomes increasingly important that a holistic approach be considered for the optimization of the grid having an aging infrastructure.

- Grid optimization can be achieved by deploying distributed sensor networks, for data collection, asset management, predictive system response and for grid stability.

- Demand response technology solutions such as AMI provide the customer foundation of the utility's vision towards a Smarter Grid.

- Eskom is currently implementing distributed sensors on HV, MV and LV networks. The initial results from the sensor initiatives are demonstrating that these new data sources can have significant impact on managing the network.

- The intelligence of a Smart Grid can only be as good as the value of the useful information that can be gathered about its dynamic status. The data collected from these distributed sensor networks has to be careful integrated into the existing systems in order to convert it to useful information.

7 ACKNOWLEDGEMENTS

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