Smart grid network: managing, controlling, and monitoring a smart grid network for improved utility operational performance and revenue securitization

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Abstract*—*The introduction of smart grid solutions to municipalities with outdated, prepayment-metering technologies is the clear future of utilities distribution. At present, utilities are being pilfered from distribution sources by means of bypassing and even tampering with meters. With a smart grid network, however, an Advanced Meter Infrastructure based Asset Management System is able to not only account for every KWh of energy passing through each smart meter, resolving the pilfering issue, but also optimize the distribution of energy, shaving load peaks and identify unbalanced load between multiple phases. The ability to forecast an overloaded transformer also allows for preemptive replacement, both saving money and avoiding a potential outages. The issue of implementation errors is addressed by the provision of an end-to-end, turnkey solution, ensuring that all logistics are handled in an efficient manner. The relatively large initial investment of a smart meter solution, compared to that of an outdated prepayment system, is minuscule to the savings that will be realized in the short and long term, with multiple financing strategies in place to make sure that no sum of money will stand in the way of an energy-savvy tomorrow.

Index Terms*—*Loss Control, Revenue Protection, Revenue Enhancement, Smart Grid, Smart meter

I. Introduction

The aim of this paper is to propose principles of core requirements for the implementation of a full end-to-end turnkey, smart Grid solution based on Advanced Metering Infrastructure (AMI). The paper takes into account the overall challenges municipalities/distribution utility companies are confronting these days, suggesting implementation of a comprehensive solution utilizing smart grid applications.

Smart metering, an integral part of a modern distribution grid, is essential for assuring the viability of municipality operation.

An advanced, multi-layer, anti-fraud protection system provides real time tampering prevention and control on both the meter level and the grid level, delivering full transparency of losses in the grid. Such a system provides a dramatic reduction in lost revenues and a boost to revenue collection, driving towards an improvement in the balance of revenues, compared with expenditure to the energy supplier (Eskom).

Despite the small size of municipalities relative to national utilities, municipalities as distribution companies for electricity and water should have full access to the services available to large-scale utilities.

The adoption of a smart grid platform makes possible the implementation of all current and potential future requirements of a modern grid network, including real time anti-theft revenue protection, smart prepayment and vending, asset management, demand side management, outage management, GIS, workforce automation, customer service portals, project implementation, etc.

This paper will include discussions of solutions and capabilities of best practice, such as multi-faceted approaches to ensure end-to-end loss control/revenue protection and revenue enhancements within the smart meter ecosystem.

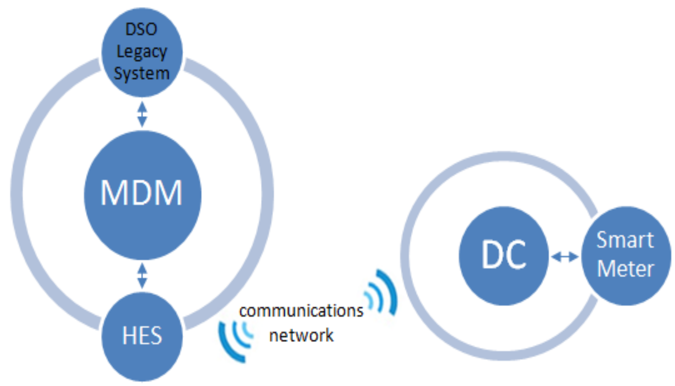

Fig. 1 Core Smart Metering Ecosystem

II. SMART REVENUE PROTECTION

A. Energy Losses:

The foundation of any smart metering solution is the implementation of an exception alert and alarm system, including the MDM, smart meters, keypads and related interconnected sub-systems (e.g. Vending Management System). The “security-net-intelligence” service will, among other things:

- Identify early malicious activity
- Proactively notify the MDM operator/administrator and field service operators

The advanced smart metering system reduces collection losses by identifying meter and grid tampering. Additionally, the hardware and software continuously calculate energy losses and monitor un-normative consumption profiles.

The PLC data concentrator meters the output of the LV transformer, comparing total power consumption with users’ individual power consumption in the same root. These analyses enable system operators to identify tampering and excess line losses within network roots.

Fig. 2 Energy Loss Analysis

III. Addressing Lessons Learned

Specific attention should be paid to critical challenges of smart metering projects implemented elsewhere to reduce commercial losses of power distribution companies.

B: Smart Meters vs. Simple Metering

Despite the high cost of implementing smart meters relative to that of simple prepayment meters, utilities the world over are adopting smart meters to replace existing simple pre-paid meters. Simple prepayment meters are a potential solution for improving poor revenue collection but provide no protection against electricity theft involving meter bypassing or tampering. Utilities claim that smart meters are more secure and resistant to tampering than pre-paid meters. An advanced metering system with associated meter data management, along with the use of Advanced Metering Infrastructure (AMI), is considered a “future proof” investment and regarded as a key factor for smart grid development to meet the power sector needs of tomorrow.

C: Challenges of STS Vending

Challenges have been observed regarding illegal vending of STS tokens. When a suitably “smart” metering system downloads the STS tokens into the meter, the system should receive a confirmation through the two-way communication that the token has been successfully loaded, subsequently reading the credit balance in the meter. This validates the transaction and ensures the meter has accepted the exact value. With every increase of the KWh balance, the system should automatically verify with the billing and vending system that the increase has been backed up by a legal transaction. The system should log all meter activity so that it can maintain records of each individual who loaded the credit, type of transaction (automatic/manual), information of the user, the time of the transaction, and the transaction amount. All this information should be stored in the database and be available for managers to verify.

III. Two-Way Real Time Solutions

Provisions for reliable and cost-efficient bidirectional communication with smart meter assets is essential for real-time monitoring and control. A smart meter with a modular communications system enables hot-swappable field replacement of the communications module; this enables, without dismantling of the meter, plug-and-play flexibility of any communications, such as PLC, GPRS or LAN. It provides freedom of choice to the municipality to incorporate new, ever improving communications technologies and a variety of communication modules in each zone.

Reliable communication with every meter is necessary to perform real-time loss analysis, remote disconnection, address customers’ problems, report alarms/events (e.g. meter tampering or power outages), synchronize clocks to various time zones, remotely upgrade firmware, and fully view consumption without sending a field team to the site.

The ideal smart meter architecture incorporates reliable Power Line Communications (PLC), avoiding the incurring of service charges from a 3rd party telecommunications provider (SIM cards), is plug-and-play, and is low cost to maintain.

IV. Project Performance Indicators

To ease monitoring and evaluation of project performance indicators, baselines should be established and agreed upon with the vendor. A project objective should also include the level of the collection rates. After the completion of the Project, the parties should conduct a study, through a joint technical Committee, to determine the success of the Project. This study should include an economic component as well as a financial model for the purpose of evaluating the profitability of the project. The results would be useful for evaluating long-term prospects of Project replication and drawing lessons to improve deliverable service.

V. Project Financing

Since many municipalities face a prohibitive financial scenario, imposing significant challenges to the development of infrastructure projects, support of Private Sector Partners may be needed to implement smart grid programs.

VI. Implementation

Implementation risks of the system should be properly addressed. Many projects have failed not because of the products themselves but rather faulty implementation. An end-to-end, turnkey solution provider with full responsibility of the project’s entire scope, including integration with the municipality’s back-office systems, provides a seamless service to design/plan, integrate and deploy the system with the needed flexibility and timely responses to any customization requirements.

Efficiency of installation can be streamlined using low-cost, smart, hand-held devices. Electronically entering these devices with GIS location enables full transparency of the grid. Such devices also enable workforce automation by monitoring and reporting the number of meters installed per time period. If a quality or performance issue occurs, the system can also provide an audit trail.

VII. Efficient Consumer Engagement

A well-designed and implemented customer engagement plan is also necessary for acceptance of the technology and deterring of tampering attempts.

Since electricity and water services are critical systems, requiring 24/7 reliability, increased visibility to the customer both makes life easier and provides much faster responses to their needs.

A self-service customer portal would provide the consumer with access to consumption/cost/tariff data, messages from the utility, and outage information. With the use of automated email/SMS notifications of low prepayment credit and outage information, customer satisfaction would be improved and operating costs reduced.

VIII. Smart Grid network

A. Asset Management

An AMI based Asset Management System (AMS) lowers operating costs, helps to prevent outages, and minimizes unexpected capital investments – all in a single system. An AMS should feature an open architecture, web browser-based platform, a dynamic, interactive user interface, and GIS capability.

With a comprehensive set of tools, the municipality can access:

- Asset View
    - Cost-effective, deep visibility into the distribution network (list of meters connected to each respective transformer and at what phase)
    - Municipalities can choose to prioritize locations in the network rather than disperse evenly to all locations – an approach that yields significant cost savings without sacrificing high value
- Power Factor & Voltage Monitoring
    - Displays actual measurements of system asset loading, voltage and power factor parameters
    - Values can be used for monitoring voltage/power factor violations (above and below nominal values), load balancing, adjusting of load between phases, system planning, new services, and design support
- Transformer View
    - Overloaded transformers are recognized by aggregating and analyzing meter-by-meter AMI load data at each distribution, prioritizing them for early replacement and failure prevention
    - Early identification and proactive replacement of at-risk transformers can save a municipality in massive failure costs. Also, by identifying at-risk transformers with high load growth, replacement transformers can be better sized.

B. Outage Management

An AMI based Outage Management System (“OMS”) provides automated notification of outages for faster restoration time, assists in the diagnosis and analysis of the probable outage causes, automatically notifies affected consumers, and provides validation of the electrical infrastructure status for the safety of maintenance crews.

Furthermore, ensuring that services the municipality provides to its citizens proceed in a timely manner is of fundamental importance to all stakeholders. The OMS assists in ensuring that minimum service levels are met through accelerated, automated measuring and reporting to management, government authorities, and the public.

During the absence of external power, the OMS can leverage the smart meters’ internal batteries to send a “last gasp” outage alert, via remote communications, to the OMS. The smart meters will remotely send all the load profile channels for the two minutes prior to the outage in order to analyze and diagnose the probable cause of outage (e.g. loss of phase, overload, or drop in frequency). This will provide important real-time data in order to rapidly detect potential power outages of transformer, feeders and substations, scoping the sizes and locations of the events and pinpointing affected service points; for both predictive and post-incident analysis, OMS can also identify likely upstream incident locations.

With the availability of an OMS, savings will manifest themselves in the form of a substantial increase in real-time data availability, visibility of affected areas, fewer staff resources needed to manage an increasing outage workload, internal and external standards compliance, automated customer notification, and a decrease in customer calls and ROI in a short timeframe.

C. Demand Side Management:

The AMI should support intelligent elements in the grid to gather and analyze information in real-time in order to determine whether the grid is at risk by certain high demand points (domestic consumer, industrial consumer, city). The system should support load control devices, installed in consumer premises, to limit the use of auxiliary customer equipment (hot water heaters, air conditioners, swimming pool pump, etc.) during peak energy periods.

The MDMS should support under-frequency monitoring for rapid response to peak demand. The MDMS should also have the option to disconnect and connect customers upon settable values in frequency. The Demand Side Management System

(DSMS) should offer load management for all MV and LV consumers, performing peak levelling, peak shaving and load management.

D. Phase detection and auto discovery

As mentioned earlier, in a standard grid network of simple prepayment meters, there is no way to determine the amount of power flowing through each meter, and therefore no method to detect any degree of power loss due to tampering across the grid as a whole, let alone across each of three phases. Here, we introduce a technology, Auto Discovery and Phase Detection, utilizing the aforementioned three-phase system to increase, by threefold, the resolution by which tampering and bypassing of traditional prepaid meters can be detected. This technology concurrently enhances the dependability of the electrical grid, encourages consumers to pay their fair share, and increases the chances of energy thieves being caught tampering with or bypassing the grid.

The ability of the Data Collection Unit (DCU) and Smart Meter modems to communicate with each other is enabled by plug-and-play "Dynamic" Power Line Communication (PLC). Alternative meter communication technologies such as Radio Frequency (RF) are subject to interference, whilst GPRS requires the use of expensive SIM cards and data transfer costs. Dynamic PLC enables automatic application of features such as Auto Discovery and Phase Detection without any additional implementation cost. Also, since data is being streamed not through the air but rather though the existing electrical cable, Dynamic PLC helps to ensure that all information is being transmitted safely and efficiently.

E. Phase Detection

Energy Loss per Each Transformer Phase

This Advanced Meter Infrastructure is composed of a number of different elements working together in unison. In this technology, Data Collection Units (DCUs), with inbuilt Current Transformer (CT) Master Meters, and Smart Meters communicate to the MDMS, providing an accurate accounting of each ampere of current flowing through the distribution transformer and consumer endpoints. In real time, this system can not only report the total current flowing through each of the Smart Meters but also the current flowing through the distribution transformer and meters in each of the three phases (i.e. Phase A, Phase B, and Phase C).

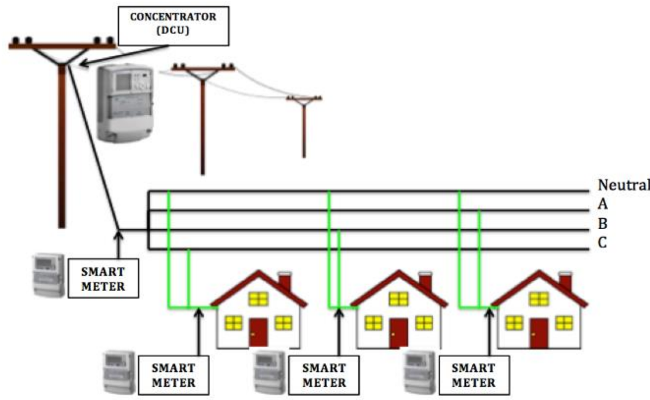

Figure 3: Simple Depiction of Smart Grid Solution Set-Up

With this breakthrough in the introduction of Phase Detection, the loss in electricity can be pinpointed to the exact phase (A, B, or C). Since the phases of each power line conducting energy to the residences is measured and analyzed, the chances of detecting the exact person/residence stealing electricity triples.

Analysis of Unbalance across the Grid

Another component of this technology addresses unbalance in Demand Responses of the three different phases. Without the ability to monitor the amount of electricity being conducted through each phase, there are often overloads of single phases, leading to damage of transformers and in turn dangerous situations and costly repairs. With this new Demand Response feature, the currents of each phase are plotted in real time, displaying if there is an unbalance across any of the phases. Should an unbalance past a given degree be detected, the power to that phase is temporarily shut off (except to critical consumers such as emergency services, etc.). A maintenance crew must simply reroute a fraction of the power lines to different phases, ensuring that the load is more evenly balanced. Shown below is a hypothetical depiction of such a reading. For a given current threshold, this technology would instantly detect the excessive current of Phase A and temporarily shut off supply to Phase A until the proper measures are taken to balance the uneven loads.

To combat adverse situations in the field, this technology sends immediate notifications in the case of events such as critical transformer overload or meter bypassing/tampering to the area's project manager as well as alerts of personal electricity overuse to individual customers in residential areas. This ability to proactively address these types of issues saves time and money for both energy distributors and consumers.

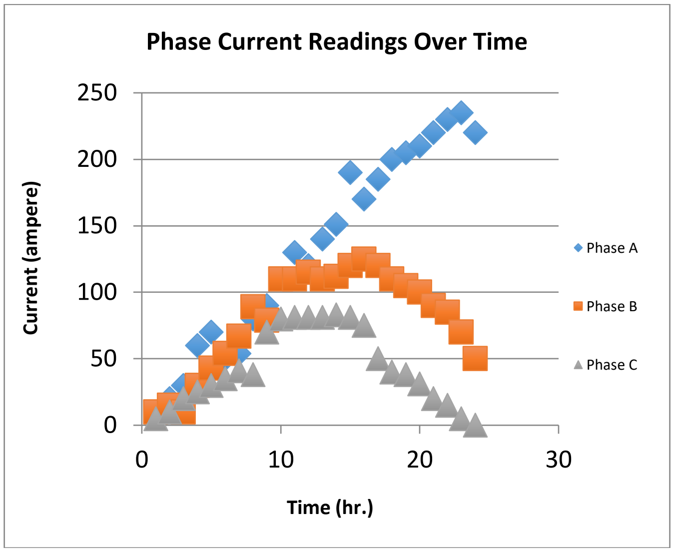

Figure 4: Hypothetical Real-Time Current Reading

F. *Auto Discovery*

The term "Auto Discovery" encompasses both Auto Registration and Auto Detection of Smart Meters, which work together to integrate all DCUs and Smart Meters on a grid, increasing transparency across the grid and allowing for capabilities such as "plug-and-play".

Auto Registration of Meters

Here we introduce the implementation of an Auto Registration feature for Smart Meters within the energy grid. As soon as a Smart Meter is integrated into the smart grid, the MDMS software recognizes the Smart Meter, automatically registering and placing it under the jurisdiction of the respective DCU. This technology also ensures that each Smart Meter is assigned under its correct transformer and DCU, both eliminating any potential assignment mistakes and contributing to a complete and integrated network map.

Auto Detection of Meters

In addition to Auto Registration of Smart Meters to each respective DCU, Auto Detection of Smart Meters allows all devices to recognize an incoming Smart Meter as soon as it is registered. This Smart Grid solution contributes to ensuring that all electricity conducted across all phases is further accounted for, as well as allowing for increased ease and deployment of this Smart Grid solution.

The benefits of implementing a smart energy grid solution capable of Phase Detection and Auto Discovery solve the main issues facing standard electrical grids. Unbalance analysis, a feature of phase detection, allows for the prevention of transformer overload, an extremely costly incident. Energy loss detection, again falling under the umbrella of phase detection, suppresses the phenomenon of electricity theft, an enormous practical issue. Auto Discovery, and Auto Registration in particular, makes the deployment of Smart Meters into the grid much more efficient, cutting down on time of installation, number of technicians required, and possible network inaccuracies. Phase Detection and Auto Discovery together, an elegant fix to such a glaring issue, sets a precedent for the future of energy grid solutions.

IX. Conclusion

The introduction of smart grid technologies focused on reducing energy theft is a very effective tool to optimize the use of existing infrastructure in the electricity sector.

In the example below, commercial losses were reduced from 57% to 12% within two weeks of installing the system.

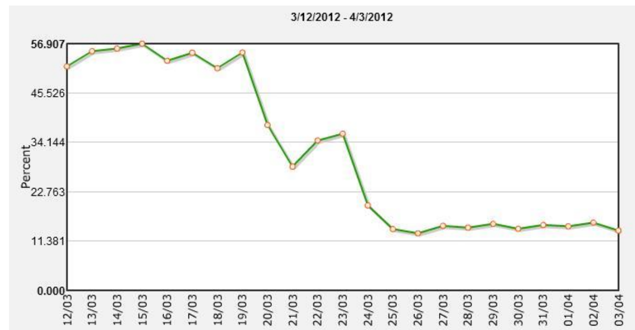

Fig. 3 Loss Reduction

However, careful planning and development must be administered to ensure that the Project proceeds smoothly.

To help evaluate distribution efficiency projects for improving service delivery and reducing losses, consider the following points:

Is the system built to control essential elements such as:

(i) Remote crediting of meters;
(ii) Remote switching between credit and pre-payment;
(iii) Sending of immediate online tariff changes;
(iv) Providing emergency credit;
(v) Trickling flow or limiting load when credit runs out
(vi) Providing user-friendly friendly pre-notification of disconnections

- When the meter has no power and the terminal cover is opened, will the meter detect and record the event/disconnect immediately when power resumes?
- Do the meters have a super-cap in addition to a battery to expand the lifetime of the meter to minimum of 25 years?
- Can load limitation be customized for each individual consumer or groups of consumers separately, i.e. select customers at automatic disconnection above 60 amps?
- Does the system cover all the requirements of a modern utility, including support for demand side management, GIS asset mapping, business intelligence, transformer load management, outage management, voltage/reactive power management, meter installation automation, etc.?

These questions are all of vital importance to consider prior to installation of a Smart Grid solution. If, however, the answer to each of these questions is a resounding "yes", the implementation of this solution will propel the system into the future of utility distribution.

X. About the Author, Power-C Metering Africa (PCMA)

PCMA is inspired to change Africa's outlook on municipality utilities management, the way electricity and water are consumed and managed, the collection of money for the services delivered to improve the infrastructure, the lives of the consumers and service delivery. PCMA as a technology partner does this through smart metering, smart grid solutions and revenue management, with applications based on an open system architecture. PCMA recognizes that revenue collection is a key to the success for any municipality and is proud of the contribution in overcoming these major obstacles.

PCMA is a leader in harnessing scientific know-how in smart grid related applications, with innovative solutions reflecting a high level of understanding customer needs. The Company received extensive recognition as a preeminent smart grid solution vendor providing systems with a high level of innovation, systems performance, functionality, communications reliability, ease of use, as well as significant value for money.

Fundamental to success is the combination of a unique technology and in providing complete system solutions to enable municipalities to significantly increase network visibility, optimize efficiency, and substantially improve the management and control of their networks. It also enhances revenues of municipalities who suffer from widespread underpayment and/or fraud, and a tangible lack of control. It enables municipalities to make optimal use of their infrastructure and equipment, to respond to peak demand periods, and to plan, design and implement effective growth and infrastructure replacement and upgrades. PCMA offers a solution to municipalities not just for their current needs, but for the next fifty years ahead (Electric Vehicle, Renewable Energy, Micro-grids/Off grid solutions, Demand Side Management, Distributed management, Storage management and more).

Founded in 2008, PCMA is based in Johannesburg, and is supported by a team dedicated to success through unceasing product innovation and customer satisfaction. The superior technology is used by leading utilities in more than 12 countries within different environments and installations. The data from these installations show that the investment payback period for the utility is very short.

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