Possibilities of demand side management with Smart Meters

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ABSTRACT

There are problems with congestion during peak electricity demand periods for today's grid infrastructure. As the demand has been sharply increasing day by day, the power reserve, as it is designed today, may be gradually phased out. Demand side management (DSM) can then be necessary to keep balance between the demand and the supply. By using Smart Meters (SMs), the Distribution System Operator (DSO) can manage the demand side during peak load crisis and decrease the risk of blackouts. The SM may allow the DSO to switch loads in an area using a customer's prioritize list, while excluding emergency service providers and critical customers from switching. Moreover, switching multiple SMs at a time might have impact on the Power Quality (PQ) of the grid. This paper presents results from field test on multiple SMs switching and investigated the impact of SMs switching on the PQ of the electricity grid.

INTRODUCTION

The Smart Meter (SM) provides benefits of the smart grid to customers by empowering them to get knowledge about and means to reduce their energy use and monthly bill. The SMs constitutes gateways to increase energy efficiency and integrate renewable energy sources, while supporting a new generation of intelligent appliances and plug-in electric vehicles that will benefit customers. In the history of metering technology, smart metering represents the third stage in a chain of developments spanning more than hundred years [1].

In the first stage, traditional electromechanical meters which were developed in the late Nineteenth century have a spinning disc and a mechanical counter display. The replacement of electromechanical meters with solid-state electronic meters resulted in the second stage in the meter evolution, making it possible to measure energy using highly integrated components. Once meter data is available in electronic form, it becomes feasible to add communications to the meter, allowing the meter to use automatic meter reading (AMR) to access data remotely via the communication link. This helps eliminate estimated bills and the need for a meter reader to visit customer's home. Smart metering, the third stage in the meter evolution, broadens the scope of AMR beyond just meter readings with additional features enabled by two-way data communication.

A smart metering solution generally delivers a range of applications using an infrastructure comprising networked meters, communication networks and data collection and management systems. SMs or advanced metering infrastructure (AMI), can take real-time or near-real-time measurements, provide outage notification and power quality (PQ) monitoring, and support in-home energy applications. It allows data exchange between the SM and the central system (CS) of Distribution System Operator (DSO), while also allowing customers to have timely and easily accessible information about their usage.

The SMs are undergoing an increasing deployment all over the world and have been introduced in several regions. The European Commission has included ten common minimum functional requirements for electricity smart metering systems in Recommendation 2012/148/EU [2]**.** These functionalities include the essential elements that a smart metering system should have to benefit all stakeholders - the customer, the metering and the DSO. The minimum Functionalities refer enabling smart metering in a secured and safe environment, commercial aspects of supply/demand and the integration of distributed generation.

Among the ten common minimum functional requirements, one functionality requirement is that the SM should allow remote ON/OFF control of the supply and/or flow or power limitation. This functionality relates to both the demand side and the supply side. There was a consensus on the provision of this functionality. It provides additional protection for the consumer at allowing for grades in the limitations. It can speeds up processes such as when customers are moving home, the old supply can be disconnected and the new supply can be enabled quickly and simply. It can also be used for handling technical grid emergencies such as demand side management (DSM).

DSM means that the electricity demand is adapted to the electricity production and the available electricity in the grid and it both refers to reducing electricity demand and avoiding load peaks during congestion in the grid. The DSO can implement the DSM in different ways like direct and indirect control. The benefit for a DSO to control the energy use is to be better able to handle congestion situations and decrease the risk of blackouts. The DSO can use the remote switching technique of the SM for direct control of the demand in emergency situation. Switching multiple customers at a time might have some impact on the PQ of the grid. This paper present results from filed test on multiple SM switching. The test result is analyzed to investigate the impact of multiple SMs switching on the grid's PQ based on the standards used in Sweden for PQ analysis [3, 4].

GLOBAL SMART METER ROLLOUT

The DSOs worldwide are deploying SMs to provide customers better visibility into their electricity consumption. Moreover, the SM enables demand response to reduce peak load, to manage voltage to reduce energy consumption, and to provide customers new offerings like time-of-use billing. The global SM rollout is discussed in this chapter to show the possibility of using SM for DSM.

A. Smart Meters in Europe:

Smart metering rollout is progressing well in Europe according to [5 -8]. Over the past years, almost all European countries have performed cost benefit analyses of smart metering and the majority of the cases have resulted in a recommendation to go ahead with a rollout. The Electricity Directive in the Third Energy Package, Directive 2009/72/EC1, triggered the installation of SMs for at least “80% of customers by 2020, subject to a cost-benefit assessment on long-term cost and benefits to the market and the individual customers or which form of intelligent metering is economically reasonable and cost effective and which timeframe is feasible for their distribution”.

In Europe, Italy and Sweden are the first countries to complete a near full rollout of the SMs [5, 6], while several European countries prepare the take-off. During 2001 to 2008, Italy installed around 36 million SMs. In the years 2003 to 2009, Sweden completed a full roll-out, installing 5.2 million SMs for a total investment of around € 1.5 billion. The smart metering coverage of Finland is close to hundred percent. Malta has also installed SMs for customers, which has covered almost 100 percent of total metering point. In Denmark, the DSOs have rolled-out SMs for about 60% of customers by the end of 2013 without any legal decision, which is however expected to be taken shortly. In Germany no decision has been taken yet for a full roll-out. Belgium has decided not to install SMs based on a negative cost-benefit analysis; the same is the case in the Czech Republic.

Other countries in Europe such as Spain, Austria, Ireland, the Netherlands, France and Estonia are going ahead with the process and have already mandated the SM roll-out with a specified timetable. There are different deadlines in each country from 2017 to 2020. For example, France will install 35 million meters by 2017, the UK will install 56 million by 2019, and Spain will install 28 million by 2018.

The Swedish Parliament approved monthly reading of all electricity meters from 1 July 2009, supported by the findings of the Swedish Energy Agency that more frequent meter reading would generate economic net benefit. Since July 2009 monthly meter reading is required for smaller customers with a fuse of less than 63 A and hourly metering should be performed for larger customers. From 1st October 2012 a new regulation was introduced, that allowed the customers to require hourly metering of their electricity consumption, if they had an hourly energy contract with their retailer.

B. Smart Meters in America:

According to [9-10], North America has the world’s highest penetration of SMs, exceeding 50 percent. A number of states, including California, Texas, Florida and Pennsylvania have approved utility plans for massive SM deployments, while others such as Virginia have turned down major project proposals. As of April 30, 2014 16.18 million SMs have been installed in US, which has covered around 12% of US customers [13]. In Canada, the provinces of Ontario and British Columbia have introduced mandatory requirements for smart electricity meters for all customers.

C. Smart Meters in Asia:

In Asia, East Asia is in the earliest phase of the roll-out of SM. Large-scale rollouts of SM to residential customers recently begun in Japan and South Korea. Japan already has the world’s most advanced grid monitoring systems [10] and several of the leading DSOs have announced plans for SM deployments over the next ten years. South Korea has adopted a national plan for the construction of a smart grid by 2020. China has begun deploying a new generation of more advanced electricity meters, which are prepared for two-way communication. China is on track to reach near hundred percent penetrations of SM by 2015 [10].

D. Smart Meters in Middle East:

The deployment of SMs in the Middle East is still in its early stages. Jordan, Lebanon, Syria, Iraq, Yemen, and even Oman and Bahrain in the Gulf, have yet to start the introduction of SMs. Utilities in Saudi Arabia, Qatar and Dubai, are still in the pilot phase. The rest of the countries are actively deploying the technology. But only one utility in the UAE, Abu Dhabi’s ADWEA, has fully completed the phase-one rollout of SMs for electricity and water [12].

DEMAND SIDE MANAGEMENT

Demand Side Management (DSM) was introduced by Electric Power Research Institute (EPRI) as a concept that consists series of activities which government and DSOs perform to increase social welfare and decrease the needed investment in electricity industry in 1980s [14]. Increased peak load demand and ageing grid infrastructure are examples of drivers for DSM. The distribution grid generally holds overcapacity to handle peak demand situations, and is constructed to handle maximum peak demand. The power reserve consists of both backup power that can be started on short notice and agreements on reduced consumption.

According to [22], todays designed power reserve will be gradually phased out. The implementation of the smart grid and DSM are expected to provide flexibility that will contribute to reducing the need for a power reserve. A main issue that is discussed now-a-days regarding the grid infrastructure is the problem with congestion during peak electricity demand periods. The key to make demand side management more effective and the grid smarter is to fully and dynamically integrate consumer's loads, and information about their usage into the operation of the grid. The SMs can help in achieving this target by providing hourly electricity consumption data.

In [13], it is explained that there are two ways of controlling the customer energy use: direct and indirect. Direct control of the energy use means that a contract is made with customers where the customer allows direct control over the power output. The controlling party could be for instance, the DSO or the electricity supplier. The benefit for a DSO to control the electricity use is to be better able to handle congestion situations and decrease the risk of blackouts. Indirect control means giving incentives to the customers based on different types of contracts that will motivate the customers to adapt their electricity use. In this case, no certainty of the customer reaction is given but with experience the supplier and grid owner could predict the reactions. The smart metering system can be used for direct control of demand side in the grid based on contract with the customers. DSM from the substation level includes all customers under that substation. But DSM by using SM switching technique may help the DSO to exclude emergency service providers and the critical customers from power outage while decreasing the risk of blackout due to high load demand. The impact of the SMs switching on the PQ of the grid is discussed in the following Chapters.

TEST ON SMART METER SWITCHING

This paper includes results from field tests on multiple SMs switching. The test plan, measurement method for PQ related parameters used in this work are discussed in this chapter. This work conducted field tests on multiple SMs switching in two residential areas with twelve and thirty-seven customers respectively. The fuse ratings of the customers are between 16A and 50A with a three phase connection.

A. Test plan

The investigated smart metering system is built with remotely accessible breakers in the SMs. The DSOs can switch the breaker of the SM of any customer remotely when it is needed. Some DSOs in Sweden are currently applying this technique for customers typically one by one when customers are changing addresses, or when contracts are terminated, or have defaulted on their payments. For switching any SM, the DSO sends a signal to the breaker of the specific SM from the CS. The switching signal first travels from the CS to the MCU by using GPRS and the MCU deliver the signal to the specific SMs by using Zigbee radio.

This project performed the field test during the planned outage for the preventive maintenance work of the DSO. The DSO first switched OFF the SMs of the selected customers remotely and then disconnected the power supply from the substation. After the intended maintenance work, the DSO reconnected the power supply from the substation and finally reconnected the breaker of the SMs remotely. This work used Power Quality Meters (PQMs) at the substation level and also at some selected customers level to measure and record the PQ data. Figure 1 shows a test scenario of remote SM switching.

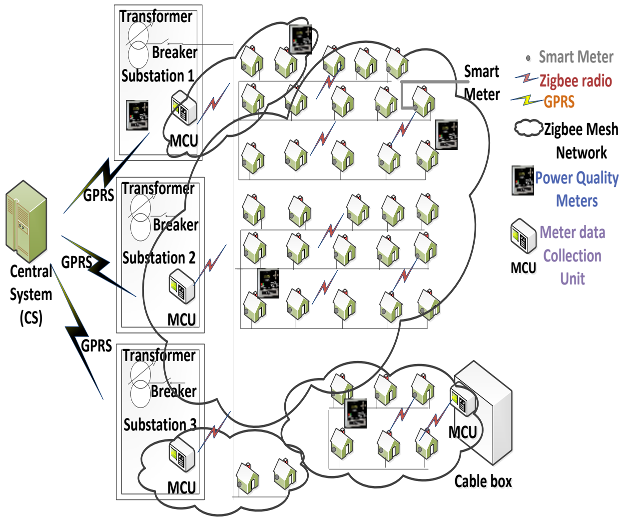

Figure 1Test Scenario of remote SM switching

This work performed risk analysis of the test before conducting the field tests on real customers [15]. Figure 2 shows the steps followed during the test.

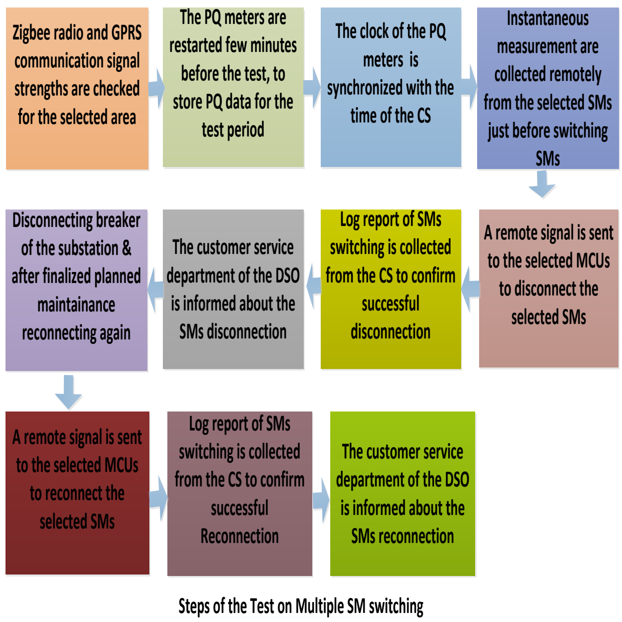

Figure 2 Steps followed during the test on multiple SMs switching

B. Measurement method

The test results presented in this paper are from portable PQMs that are used for temporary and short-term PQ monitoring at the customer site and also at the substation. The PQMs stayed at the test location for an hour during the test period and captured a sample of measurements. The PQ measurements carried out in accordance with Class A of IEC 61000-4-30 [4]. Flagging was used according to the standard to prevent double counting. The phase to neutral voltage was measured to evaluate the voltage quality.

The following disturbances were covered in the analysis: supply voltage variations, flicker, voltage unbalance, total harmonic distortion, voltage sag, voltage swell, power frequency and transient.

This work selected five locations for PQ measurement during each test to investigate the impact of SM switching on the PQ. Four PQMs monitored the PQ at a random selection of connection points of four customers for relevant sample throughout the selected area. One PQM monitored the PQ at the substation in the same area. The PQMs measured different parameters e.g., RMS voltage, current, power, frequency and harmonics. The maximum and minimum values of different parameters were monitored in addition to parameter averages over a certain period. The time windows used in the PQMs for the measurements are shown in Table 1.

Table 1 Time window used for different parameters

Parameters	Time Window
Phase to neutral voltages	1 sec
Three Phase currents	1 sec
Real, reactive and apparent power of three phases	1 sec
Power factor	1 sec
Frequency	10 sec
Short term flicker, P_{st}	10 min
Voltage Unbalance (%)	1 min
Individual harmonics and THD(%) of Voltages and currents	1 sec

The PQM used in this work, allows the user to select a triggering method. The triggering *method* used for different events e.g., voltage sag or swell, supply voltage variation and interruption are in accordance with Class A of IEC 61000-4-30. There is no standardized method for the detection of transients, neither transient overvoltage nor transient overcurrent [16]. The limit used for triggering transient events during the first test was +/-50% of nominal value. There was no transient event recorded during the first test. Based on that, the triggering limit for transient event was lowered to +/-25% during the second test to investigate even small transient effect during multiple SMs switching. The PQMs can record waveform for triggered events e.g., the PQM recorded waveform for transient events for a period of 0.2 sec at 12.8 kHz sampling frequency. The waveform of a transient event is recorded for ten cycles; two cycles before the event triggered and eight cycles after the event triggered. The PQMs recorded RMS value of different parameters for the test period with one second interval. The reference voltage used to relate the size of voltage-quality disturbances to, is in accordance with EN 50160 [3]. The reference voltage is equal to the nominal voltage, in this case 230 V phase-to-neutral.

RESULTS AND ANALYSIS

The test results on multiple SMs switching are presented and analyzed in this section. This work focused on the events related to the multiple SMs switching only. Four PQMs were temporarily installed at four randomly selected customer's site during each test and those customers are numbered as C1, C2, C3 and C4 in the analysis. The PQMs of the customer's site and the substation are denoted as Cxy and Sx respectively, where x represent the test number and y represent the customer number.

A. Voltage-Quality Variations

The regulation for voltage-quality like EN 50160 gives a number of conditions that the voltage characteristics have to fulfil for the voltage quality to be of sufficient [3]. In the regulation, some limits are given for the voltage-quality variations such as unbalance, Harmonics and voltage fluctuations [17, 18].

Table 2 Maximum value and limit of different parameters

PQM	*Unbalance (%)*		*Flicker, P_{st}*		*THD (%)*	
	Max	*Limit*	*Max*	*Limit*	*Max*	*Limit*
C11	0.38	2	0.27	1	1.16	8
C12	0.35	2	0.16	1	1.17	8
C13	0.37	2	0.18	1	1.17	8
C14	0.59	2	0.62	1	1.29	8
S1	0.34	2	0.11	1	1.26	8
C21	0.43	2	0.13	1	1.32	8
C22	0.43	2	0.15	1	1.32	8
C23	0.44	2	0.16	1	1.30	8
C24	0.43	2	0.09	1	1.32	8
S2	0.39	2	0.08	1	1.28	8

Table 2 shows the maximum values of unbalance, flicker P_{st} and Total Harmonic Distortion factors (THDs) recorded in the PQMs during SMs switching and also the limits used as standard. The result shows that the maximum values of the parameters are well below the limits for each parameter. The PQMs recorded one-sec window values of the RMS voltages for the test period to investigate slow voltage variation. The study shows that all one-sec values of the RMS voltages are within the limit, between 90% and 110% of the reference voltage for all voltage level.

B. Power-Quality Events

The triggering method is required for voltage quality events. The characteristic of an event can be determined by using triggering method when an event is detected [19]. The voltage quality is regulated based on defined limits for voltage quality events such as voltage sag, voltage swells and rapid voltage changes [4].

The voltage sag or swell is defined as an event during which the one cycle rms voltage suddenly drops below 90% or goes above 110% of the nominal voltage, followed by a return to a value higher than 90% or below 110% of nominal value, in a time varying from 10 ms to 60 s [20]. The PQMs did not record any voltage sag or swell event during SM switching.

A rapid voltage change is defined as a change in rms voltage per second faster than 5% of the reference voltage [21]. The switching of multiple SMs was performed during the two tests without any rapid voltage change occurrence at the customer site as well as at the substation level.

The EN 50160 standard states that the range of frequency variation for interconnected supply system should be +/- 1% of nominal value, 50Hz for 95% of the time. The power frequency was between 49.94Hz to 50.01Hz during SMs switching.

Two PQMs at the customer site recorded two transient events during SMs reconnection of the second test when the limit used as +/-25% of nominal value for transient event trigger. Transient current surge was observed during reconnection of the SM only for a short period of around 0.15 ms. The calculation of rms voltage during transient surge current shows that the rms voltage of the effected phase was distorted by around 2 V or less.

CONCLUSIONS

The PQMs at the substation level did not record any PQ event while two PQMs at the customer site recorded only two transient events during SMs reconnection of the second test. The duration of the transients surge current was around 0.15ms and the change in RMS voltage due to the transient surge current was around 2V. Each SM in the investigated system takes around 6 sec to complete the switching process. On an average, 40 SMs communicates with one MCU and the MCUs execute disconnection or reconnection of SM one by one. This technique of MCU may help to keep the grid stable due to the process of gradual increment or decrement of loads in the grid instead of creating a sudden big change of load in the grid which may lead to blackout. The DSOs may use the SM switching technique in future for DSM during peak load crisis to decrease the risk of blackout. Switching small number of customers did not show any big impact on the PQ. But switching a large number of customers at a time using SMs, might have impact on the PQ at customer site. More research is, however, needed to fully investigate the impact of multiple SM switching.

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