sgem
Smart Grids and Energy Markets

Analysis of needs and available solutions for second generation AMR support for Smart Grids

Markku Kauppinen, Vattenfall Verkko Oy

Markku Tuovinen, Empower Oy

Timo Nirhamo, Aidon Oy

Antti Mäkinen, Marko Pikkarainen, Pertti Pakonen, Pertti Järventausta, Tampere University of Technology

Contents

Preface

This report has been done as a part of the research work of the Smart Grids and Energy Market (SGEM) research programme. The report relates to the task 4.5 “Technical solutions for customer gateway and ICT systems” of the work-package WP4 “Active customer, customer interface and ICT”.

The report represents some examples of solutions currently used in few utilities as basis for further development. The text is partly based on already published papers, e.g. (Järventausta et. al) and (Trygg et. al.).. Late part of the report shows new use-case for the coming development.

1. Second generation AMR systems

1.1 Introduction

Since the time the first electricity energy meters were introduced in over hundred years ago, their basic function has remained more or less the same. The primary role of AMR (Automatic Meter Reading) systems is to provide real time energy consumption data to the utility, but the cost of retrofitting the existing energy metering system may not be justified if the meters are used merely for reading energy consumption data. The implementation of AMR systems will change the function of basic energy meter, which will become a smart terminal unit and gateway for multiple service providers and enable real time two-way communication between customers and utilities. From that viewpoint the AMR system can also be seen as an extension of SCADA and network management systems for controlling and monitoring the last parts of the network (i.e. the low voltage network) between medium voltage network and customer.

The open AMR market needs the whole new AMR platform. The future is in openness and interoperability, both horizontally and vertically. Horizontal dimension means possibility to build metering system by buying system parts from different vendors. This means less risk in compared to one supplier and possibility to select best fitting technology over the system life cycle. Vertical dimension emphasizes that total system functionality can be built from appropriate parts, each replaceable if needed. This is achieved by role based functionality with minimum overlapping and well defined, open interfaces.

The principal motivation for new AMR installations has usually been more accurate energy measurements for billing purposes, cost reduction and improved customer service. In addition to these, the possibilities of AMR include, for example, hourly based energy reporting, demand side management, disconnection and reconnection of electricity supply, determination of load profiles for network calculations, planning and secondary transformer condition monitoring, more accurate interruption statistics, broader basic level power quality monitoring, and the management of low voltage (LV) distribution network.

Measurement information from AMR system is traditionally serving the billing and customer service business processes. More accurate data for customer changes and other energy information details decrease the work required to conduct these processes due to more up to date measurement information. In some cases data available is hourly data and it is read automatically once a day. Load analysis and outage reporting can also benefit more detailed information. Remote switching of customer or part of loads is also available in some solutions. This control functionality can also be integrated for controlling for example street lights. Power quality data is also available in some cases in form of voltage levels and registrations of exceeding limits set in the AMR system. These are some examples of additional possibilities provided by current AMR solutions compared to manual measurement information gathering.

AMR offers two-way communication to the customer site, which makes it possible to enlarge on-line monitoring also to the low voltage network. This enables alarms on exceptional events, e.g. network faults and voltage violations, and here meters can also have some protective functions

adding the safety. The use and integration of AMR in network operation can be seen as an extension of SCADA and distribution automation to the low voltage level. So far automatic monitoring has been used mostly in 20 kV medium voltage networks.

Low voltage network management includes functions, for example, to indicate automatically if a fuse in the low voltage network has burnt or a conductor is broken, to locate the fault, to provide accurate interruption data, to monitor voltages at customer site in real-time, and provide power quality information for customer service.

Low voltage network is the key element in quality of supply to most of the end customers of DNO. Improving the quality of supply requires that network operation and planning and technical customer service would have access to low voltage network measurement information using their operational systems. This would decrease the amount of work done in these processes. Integrating advanced AMR solution with alarms and more accurate measurement information with additional measurement quantities to current operational information systems provides additional values to improve planning and operation and technical customer service business processes.

The Figure 1 presents a new way of network management using integration of AMR, DMS and QMS (i.e Quality Monitoring System) in network operation, asset management, customer service and other functions.

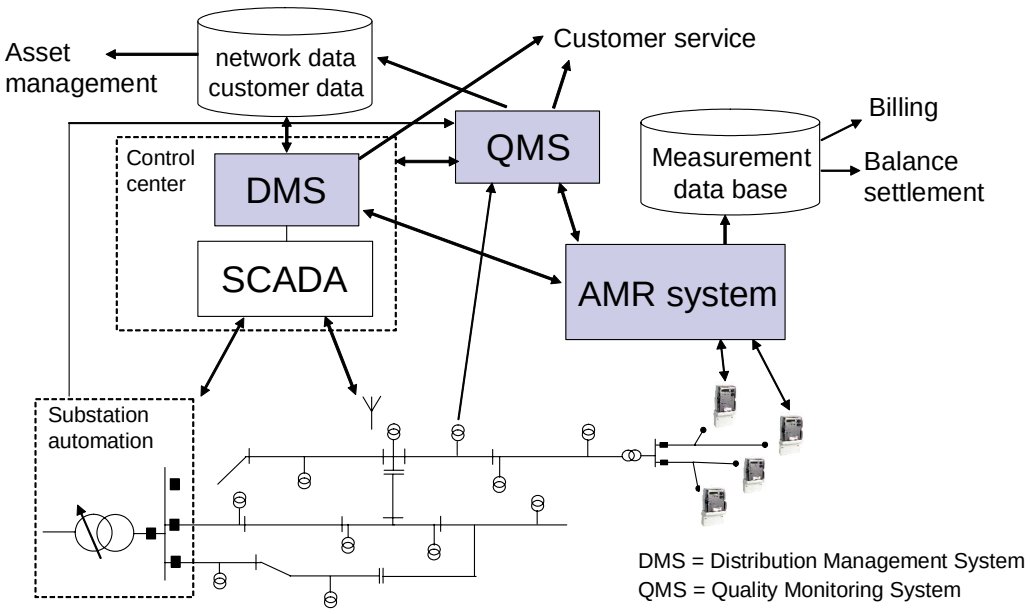

Figure 1. Integrated information systems for comprehensive network management.

1.2 Available solutions – Cases in Finland

In this chapter are described few existing AMR systems as base for coming research. Next subchapters are intent to show what functionality is already available in different utilities and some different solutions used in Finland today.

1.2.1 AMR-DMS Integration in Vattenfall Finland

In Vattenfall Verkko Oy full scale AMR roll-out project was launched in 2005 and completed in 2008. Total amount of installed meters in the project was approximately 340 000 pcs and total amount of all AMR meters is nowadays app. 395 000 pcs. Comprehensive usage of AMR metering enable many business development possibilities and during years 2008-2009 one major step utilizing AMR was to integrate AMR data collection system with Distribution Management System (DMS). This is called AMR-DMS integration. Primary functionality is shortly described in the following.

AMR-DMS integration is one of the development steps for the network fault management process. Main functionality can be divided to the next two parts, automatic alarms and status queries which are explained more detailed below in table 1.

- Alarms
  - Phase missing
  - Voltage level
  - Voltage unbalance
  - Neutral conductor fault
- Queries
  - Device responding - no alarms
  - Device responding - active alarms
  - Device not reached
  - Device unknown
  - Device switched off

VFV uses IskraEmeco Mx372xxx meters and in the current meter firmware available alarms are listed in table 1. Integration also enables status queries from DMS to the meters. A query can be sent to one meter or group of meters. Examples of these will follow later on in this chapter.

Table 1. Currently available alarms in Mx372xxx meters used by VFV.

Alarm	Note
Terminal cover open	Terminal cover open
Meter cover open	Meter cover open
Phase L1 missing	L1 voltage below 40 V
Phase L2 missing	L2 voltage below 40 V
Phase L3 missing	L3 voltage below 40 V
Phase L1 lower level	L1 voltage below settable level
Phase L1 upper level	L1 voltage over settable level
Phase L2 lower level	L2 voltage below settable level
Phase L2 upper level	L2 voltage over settable level
Phase L3 lower level	L3 voltage below settable level
Phase L3 upper level	L3 voltage over settable level
Asymmetrical voltage	Voltage asymmetry out of settable levels
System alarm power fail	Total power outage
Neutral 0 current at asymm. Load	Detects neutral faults using voltage asymmetry
System alarm installation	Meter installation not ready
Fatal fault	Internal watchdog

In the next pictures are shown some examples utilizing automatic meter alarms. In the Figure 2 is presented a situation where three meters have sent spontaneous alarms about neutral fault and how they are shown on the DMS screen. After receiving spontaneous alarms DMS query other meters in the same LV feeder.

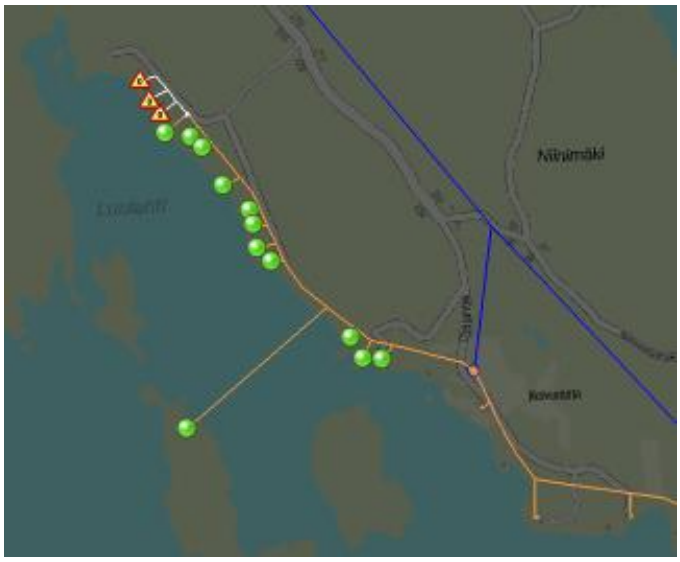

Figure 2. Three neutral fault alarms are shown by DMS.

In this case (shown in the Figure 2) DMS automatically generate a query to the other metering points in the same low voltage (LV) feeder to find out statuses of all the other meters. Therefore all meter in the same LV feeder are presented, not only faulted meters. This functionality offers quick snapshot to the control center operator from the faulted area.

One feature support finding low voltage faults under medium voltage (MV) fault. In the Figure 3 is shown a situation when MV fault is just occurred. Faulted line is presented with white color. In the Figure 4 is situation after MV fault is repaired, distribution restored and meters in the LV side are checked. System found that there are still four premises without electricity. This functionality support control center operators to optimize steering of work group in the field.

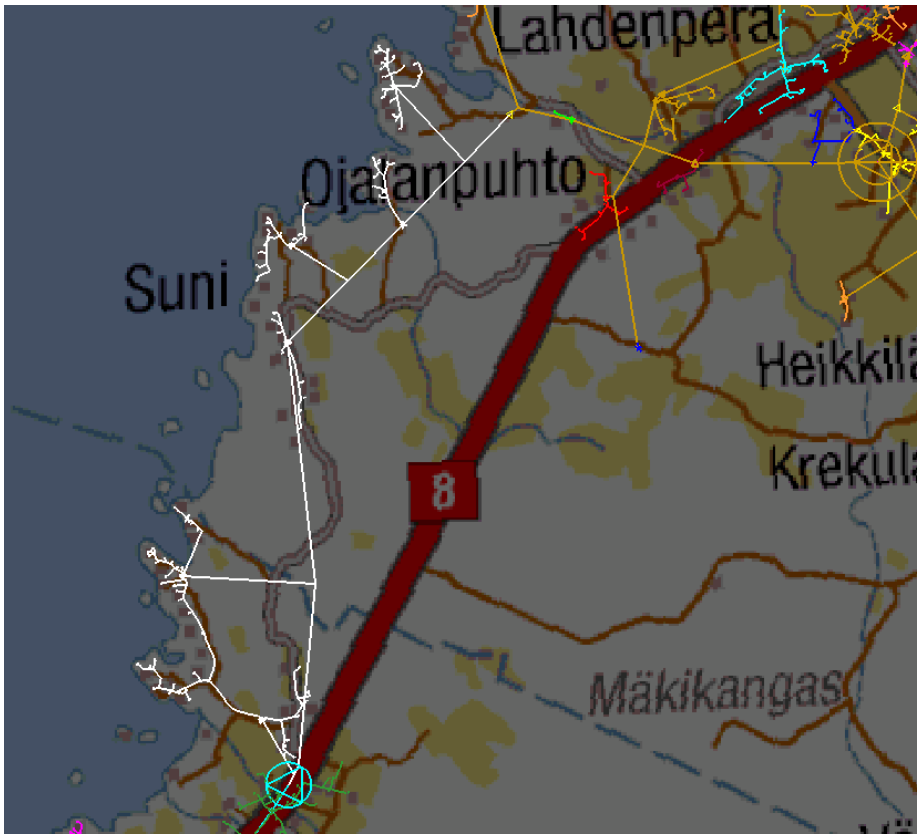

Figure 3. MV fault is just detected in DMS.

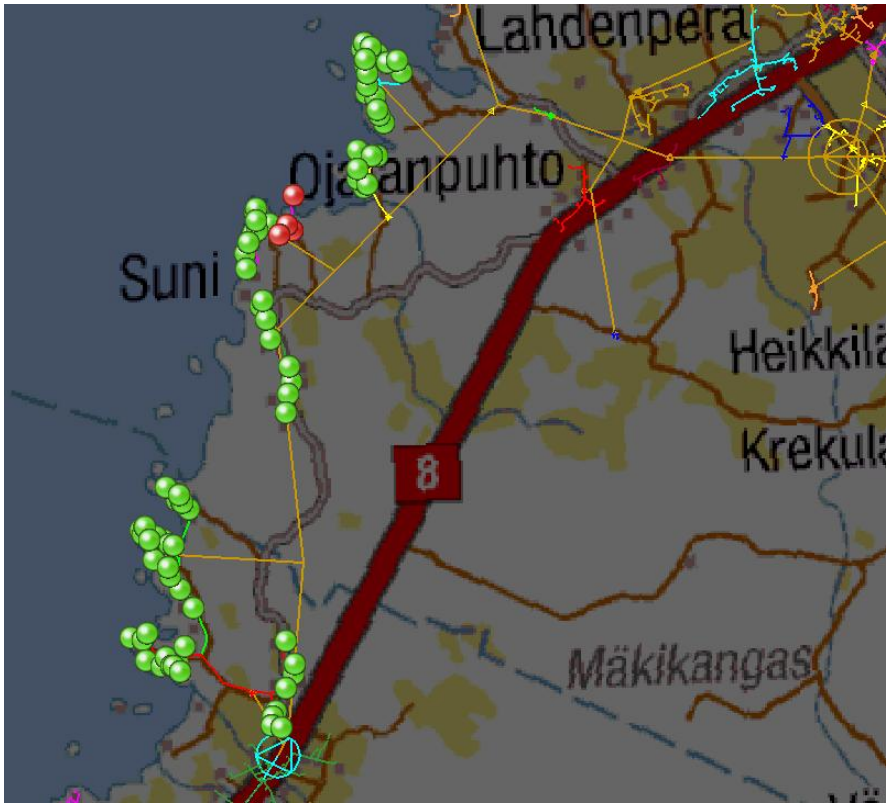

Figure 4. After MV fault is repaired remaining faults in LV network were found automatically by DMS.

Integration enables also to detect and locate broken conductor fault in the MV network. Figure 5 shows a situation where broken conductor in the MV feeder is detected and located between two secondary transformers. Location happens automatically based on the spontaneous meter alarms comparing LV network areas from where alarms are sent and from where not. After all alarms are received fault location can be pointed between two secondary transformers.

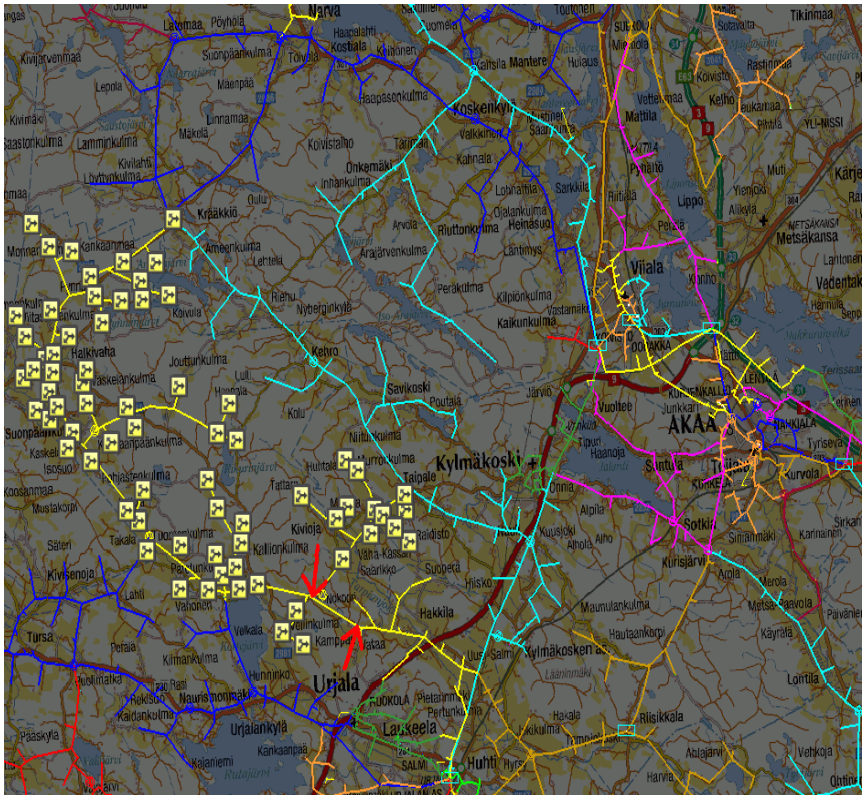

Figure 5. Broken conductor fault is located automatically.

1.2.2 “Piha” in Koillis-Satakunnan Sähkö

In Koillis-Satakunnan Sähkö Oy (i.e. Finnish distribution company) a development project were realised for developing a comprehensive technology solution of new functions of AMR and related information systems for low voltage network monitoring and management. The aim was to combine new-generation energy meters, data communication solutions and distribution management systems into an entity with an open architecture. The project consortium included different equipment and system vendors (i.e. ABB Oy, Aidon Oy, MX Electrix Oy, PowerQ Oy), the research organisation (i.e Tampere University of Technology) and the pilot distribution company.

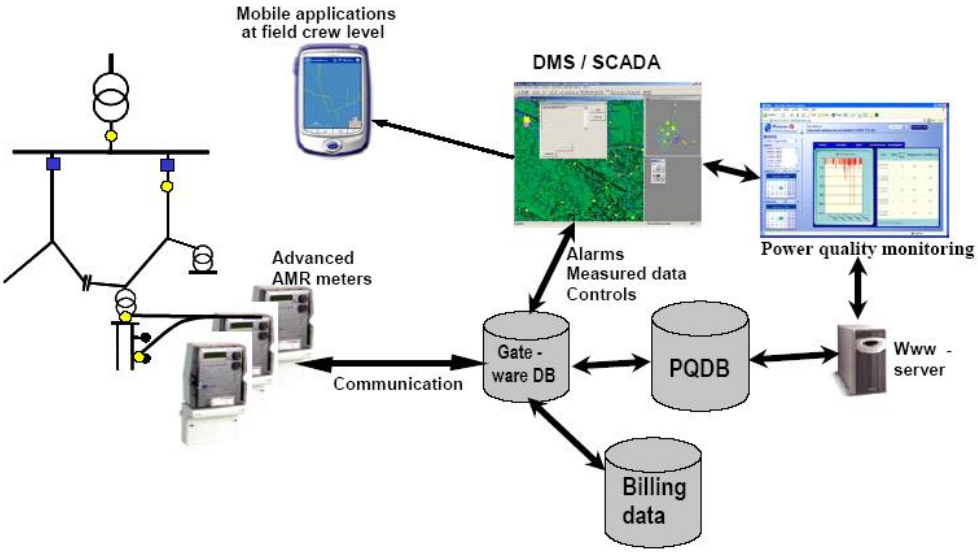

Figure 6 . The overall view of IT architecture in the pilot case

The pilot company has an advanced DMS for real time network analysis (i.e. load flow, fault currents), fault location, switching planning etc. However, low voltage network management has been totally in off-line mode since on-line information has been available only from primary substations and from some secondary substations along medium voltage feeders as presented in Figure 6 The integration of AMR makes it possible cost effectively to monitor low voltage network and analyze fault situations since AMR communication infrastructure can be used. Because network monitoring in SCADA/DMS requires that events from meters are received in near real-time manner an effective way to forward data from AMR is required. In the above mentioned development project OPC (originally OLE for Process Control) technology was selected for this purpose.

Aidon AMR system supports communication solutions which enables real time events to be sent spontaneously from AMR meter. Polling all the meters from reading system would be too slow. There are fast enough communication possibilities that are usable also in rural areas (e.g. GPRS) but taking into account the huge number of devices it must be carefully planned what kind of events will be sent from meters and how meters shall be configured. Without limitations and configuration options the number of events would exceed the capacity of practically any communication media.

An advanced AMR meter works as an intelligent monitoring device and utilizes the communication infrastructure to provide spontaneous event or alarm information to control center with vital information on low voltage network faults and voltage levels. The meter includes algorithms to inference the existence of a fault and type of the fault. Most interesting events have been: blown LV fuse, broken LV conductor (line or neutral), wrong phase sequence, broken MV conductor, power frequency over-voltages and power frequency under-voltages. In certain cases, e.g. when neutral conductor is broken, the advanced AMR meter even isolates automatically the customer

from the network. This requires a specific switching device which can be integrated into the advanced AMR meter.

The measurement data of the PQDB (i.e. Power Quality Database) can be studied using the Web–based application, PQNet system, in addition to DMS and network planning systems. The use of Web-based technology in PQ monitoring may be an internal or an outsourced service for distribution companies. Web-based PQ monitoring is an example of ASP (Application Service Provider) functions. Power quality data can also be offered to the customers (e.g. industrial customers) with their energy consumption and billing data through the Web.

1.2.3 Smart Management of Low Voltage Network with EmpowerAMM

Most of the Finnish DSO's have selected a service concept for the AMR delivery. This makes business environment more complicated than in the case of system delivery. All AMR related services require comprehensive integration of operational work and IT-systems of the DSO and service provider. This is challenging situation not only to the DSO and service provider but also to their subcontractors. The Task 4.5.2B concentrate to the development of co-operation methods in the AMR service environment and fault management processes are implemented as a demo solution. The project scope is described in Figure 7.

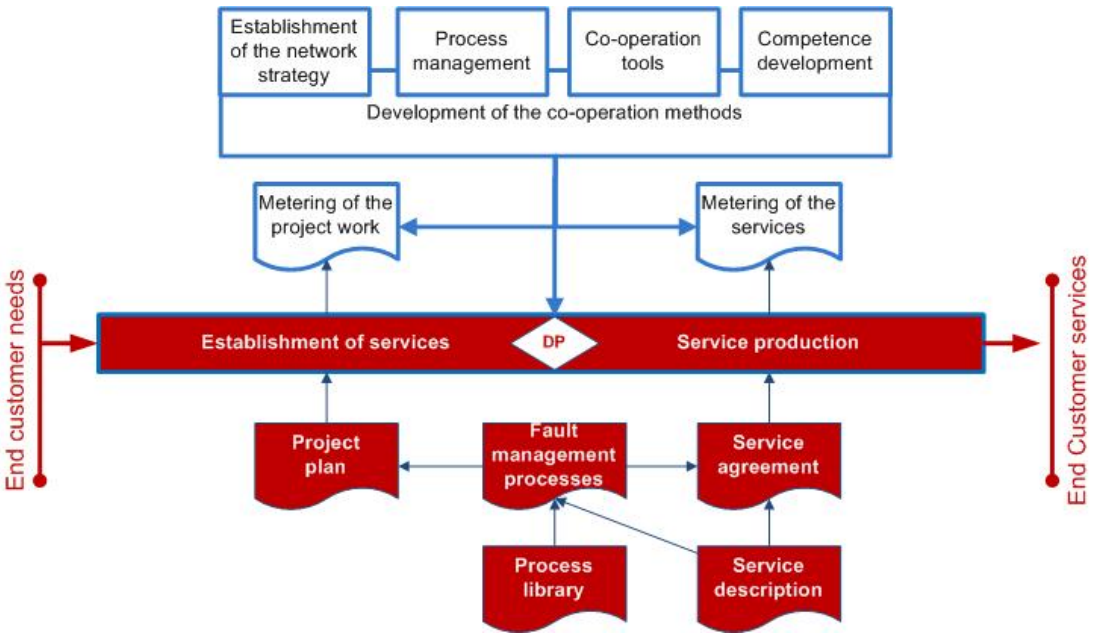

Figure 7. The project scope is for the Task 4.5.2B.

The tacit knowledge and long term experience in practical operation of a DSO gives the best background to further developments in management of low voltage networks. Empower Oy has carried out extensive process workshops to improve management of low voltage network processes shown in Figure 8.

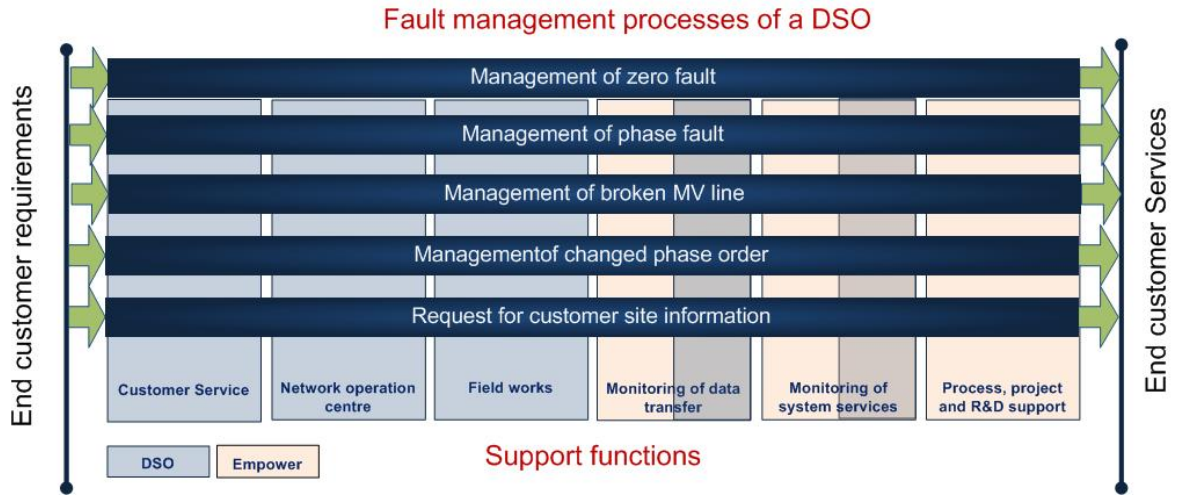

Figure 8. Fault management processes of a DSO.

The process workshops were based on the end customer needs and requirements – in this case reliable power delivery and also, in the case of disturbances, good customer service. The first step in the project was to build collaborative Intelligence by planning and implementing common, process oriented, methodology and tools for building integrated ICT infrastructures together with DSO, meter suppliers, ICT system suppliers and system integrators. The first phase has been carried out and required operational processes are now identified and described.

The management of zero fault is one example from the processes described in the process workshops. It is carried out with immediate disconnection of the customer site from LV network after the identification of the zero fault. The meter sends a zero fault alarm to the Empower's IT-service environment, which delivers it immediately to the DSO's Distribution management System (DMS). DSO delivers a SMS message to inform the customer about the fault and related repair time. DSO can also activate meter inquiries to study the status of the customer sites and to carry out fault location in more detail. After the fault repair the network operation centre connects the customer site to the LV network. Also customer is informed about the connection and fault related other information. DMS stores all disturbances to it's database to be utilized, for example, compiling network disturbance statistics or in constant compensation.

Next steps are especially the development of working methods but also specification of the service SLA levels together with the technology suppliers and plan and carry out required integration work between the service environment of Empower and DSO's IT-systems.

1.2.4 Echelon AMR meter - Widely used in Telvent's AMR service

In this chapter is shortly presented American Echelon's meter functionality. Presentation focus on Echelon model 83330 which is used Vattenfall Distribution Sweden. Telvent Co. is Spanish service provider especially for DSOs offering also AMR services. Telvent is the newest AMR service used by Vattenfall Distribution Sweden. In Finland Fortum is running AMR project to implement Telvent's service using Echelon meters.

Echelon 83330 is a poly-phase multi-utility meter. Communication is accomplished using Power Line Communication (PLC). Used communication reduces transferring distance but make it also possible in locations where operation is difficult with radio waves. However separate data concentrators are needed to gather information and deliver it forward. Data concentrator must be placed in power lines supplied by the same distribution transformer to ensure communication connection. (Kujala, 2009)

Data concentrators can use any IP capable network whether wired or wireless to deliver data forward. Using optical interference meter can be operated locally. Echelon 83330 is also equipped with M-bus connection. The meter can discover and query up to four M-Bus devices. Meter software can be upgraded remotely. Meter does not support DLMS protocol. Log book with circular memory buffer has capacity of 100 recorded events. After an occurred power quality event no events can be recorded for 1 second. Following quantities and power quality parameters can be measured and recorded into registers. (Kujala, 2009)

- Active and reactive power in both energy flow directions.
- Power quality parameters
    - Voltage dip / under voltage (RMS)
        - Records the number of events on any one phase. Threshold range can be set from 1% to 99% of nominal voltage. Duration of an event can be set from 0 to 15.555 seconds. This is the time that event must last continuously to be recorded as an event. Sampling is arranged in such way that one RMS sample is taken on every 200 ms..
    - Voltage swell / over voltage(RMS)
        - Limits and operation are similar as detecting voltage dips. The highest voltage during the most recent swell is recorded with a time stamp.
    - Over-current (RMS)
        - Records the number of events over 10 s on any one phase. Reference current is meter's maximum current (80 A) by default unless set otherwise.

The over-current analysis is designed to detect uses above reference level, not for recording instances of high amperage current surges.

  - Power outages
    - Records the duration, *power on* date and time, *power off* date and time of the last 10 long power outages. All short power outages are recorded. The voltage must be below the internal power outage level and last longer than set time. The internal power outage level is permanently set to approximately 74% (±5%) of the rated voltage (170 V). The range of power outage time threshold is 0 to 65.353 s. Outages shorter than defined time threshold but longer than 13 cycles are counted as a short power outage.
  - Phase loss
    - Records the number of phase loss occurred in any one phase with a time stamp. Voltage (RMS) drop on any one phase below set 61% (permanently set internal phase loss level, 140 V) for over 10 seconds.
  - Frequency
    - Except for the one to two seconds after power up, frequency is constantly monitored. Maximum and minimum values are registered with a time stamp.

- Tariffs
  - 4 tariffs with 10 possible tariff periods per day
  - 4-seasons per perpetual calendar, set by Day/Month
  - Perpetual holiday calendar for up to 15 holidays per year
  - Perpetual daylight savings changeover
  - 2 separate holiday day schedules and 3 separate day schedule per season.
- Load profiles
  - One load profile up to 16 channels.
  - Data logging intervals at 5, 15, 30, 60 minutes or 1 day.
  - Capacity: one measurement value per one hour up to 180 days or 2094 days at a 1-day interval.

In Vattenfall Sweden AMR-DMS integration is under planning but not implemented yet. Echelon's AMR service enables similar functionality than in Vattenfall Finland presented earlier in chapter 1.2.1. In Sweden three different AMR services are used but two older offers quite poor functionality for LV network monitoring. However the newest AMR service covers more than 75 % of all metering points and therefore implementation of AMR-DMS integration is seen beneficial in Sweden, too.

1.3 Gained benefits to utilize AMR in network management

Utilizing AMR offers better efficiency in fault situations and network management. Following is based on Aidon's experience and meter functionality. AMR support fault management, optimization of field work, customer service, network planning and monitoring of contractual issues.

With AMR meters faults can be perceived and identified immediately and located automatically which enable to guide field staff directly to the fault site. Based on AMR data control center have real time snapshot from faulted area at the field. This is essential for optimized allocation of needed work for fault repairing and distribution restoration. With reliable snapshot the scope of faults is in control which remarkably intensifies work of control center operators.

There is also possibility to prioritize the order of repairs e.g. important sites are handled first and the number of metering points that can be repaired on one occasion. When prioritizing work order essential is to know the location of the staff in the field. DMS systems are capable to utilize GPS information to show location of each field group. For example next benefits are obvious.

- Quick repair decreases the amount of work outside normal working hours
- Optimizing the number of staff working in the field
- The work can be carried out with fewer resources or, alternatively, faster
- The metering point is automatically disconnected in hazardous situations
- For instance, in case of a broken neutral wire, overvoltage can be extremely dangerous for humans, cause damages for devices, or ignite a fire
- Proactive work in network development
- Proactive network development based on collected data
    - Faults caused by aging network assets can be predicted
    - The strengthening of the network as electricity consumption grows can be predicted
    - Repairs and the purchase of new devices can be planned in advance
- Fault situations fewer, shorter, and less expensive
    - Proactive network development decreases the number of network faults
    - Proactive repairs can be aimed at preventing long-term or expensive fault situations
- Field staff working hours
    - Planned work can be carried out during normal working hours

IMPROVED CUSTOMER SERVICE AND HIGHER SATISFACTION

Being able to solve problem situations during the customer call is seen as a huge improvement in customer service. In the best case, the fault has been repaired before the customer has even noticed it. In cases of emergency, immediate automatic disconnection can help in preventing human and material damages. During network development work, PiHa also helps in fulfilling the customers' basic expectations of high quality electricity and uninterrupted supply better than before.

During customer contact, Aidon PiHa offers:

- Real-time access to phase voltage levels and phase currents. This data can be read from the metering device during the phone call, and it will tell immediately whether the situation is normal or not
- Real-time access to the registered network monitoring alarms, such as missing phases, broken neutral wire, overvoltage, under-voltage, or changed phase order. For instance, if DMS detects a blown fuse only at the metering point, the end customer can be advised to change the fuse
- Diagnosis history saved in the PiHa log
- A statistical presentation of voltage quality, that is, the situation on the previous week based on 10 minute averages, the average voltage level, as well as the highest and the lowest averages, time stamp included

MONITORING CONTRACTUAL USE OF ELECTRICITY

As many as three different current limits can be added to the metering point. The device measures, phase by phase, energy consumption and possible excess of current limits. This way, it is possible to monitor the situation and give a notification, if necessary.

The moment of excess and its duration will be registered and an alarm will be transmitted, if required, and electricity will be disconnected automatically. Limits, durations and functions can be remotely adjusted.

Current limits can be managed by DMS, which manages power shortages and the excess of dangerous current limits, and the customer information system, which again monitors the contractual use of electricity.

THE BENEFITS OF COMPREHENSIVE DIAGNOSIS FOR NETWORK MANAGEMENT

Fault management include the next functionality.

- measurements based on voltage levels, such as missing phases, broken neutral wire, broken medium voltage wire, overvoltage, undervoltage
- the metering point uses and produces energy; changed phase order
- sensors connected with status inputs (indication of an overheated transformer, for instance)
- measurements based on energy consumption (3 adjustable current and time limits)
- device faults
- automatic disconnection (overvoltage, undervoltage, broken neutral wire)
- each diagnosis will be logged, voltage level, current and timestamp included
- the collected data can be sent as an alarm immediately, after the configurable random delay, or alternatively saved only in the PiHa log.

1.4 PQ monitoring capabilities of Smart Meters

So far, voltage quality has usually been monitored temporarily at customer sites based on customer reclamations, not comprehensively and continuously from the entire distribution network. Power quality monitoring including continuous voltage quality monitoring in larger extent gives however important information for various operations of distribution company. The idea is to gather information from low voltage level and integrate it, for example, to network data bases and different planning and operation systems to increase knowledge with much larger amount of information.

More additional values to create profitability to AMR can be developed when the meter supports modular structure. Some of the functionalities can be developed inside the meter but some require additional parts. The power quality measurement is good example of the need for modular structure. Basic meter can detect faults and in some extent the voltage levels and outages but for voltages dips, flicker and other EN50160 measurements more powerful measurement capability is required. For this reason special quality modules can be integrated with the meter in selected locations e.g. one for each low voltage feeder is answer for large scale monitoring of power quality.

Today there are lots of different smart meters in markets. Those meters have various capabilities. In this chapter power quality monitoring capabilities of smart meters in the market are considered. Smart meters are split in four categories in this consideration to give information about the costs of smart meters in that group. Those categories are basic meters, meters for residential users, meters for high end users and special meters. The capabilities of different categories are based on brochures of smart meters and those are presented as a list. In addition the capabilities of each

group are combinations of all capabilities in smart meters that belong to each group. This means that the capabilities listed in each group may not be found in every meter belonging to that group.

Within Vattenfall Finland's (VFV) network, IskraEmeco MT372 meters measure $Urms$ values in every three phases. Alarms based on power frequency over-voltages and under-voltages are in use. The daily peak and minimum values of phase voltages are also measured and recorded. Voltage asymmetry is monitored by comparing measured voltages and the average volt-ages of all three phases. If the difference gets too high (limit value crosses), the meter sends an alarm signal. It is important to define two threshold levels to the meter correctly. It means when the voltage on one-phase rises, the upper threshold level must be set up high enough so that it is only exceeded in neutral faults and an alarm is sent. If the upper and lower threshold limit is exceeded at the same time, the system sends an alarm about asymmetrical voltage situation. These monitoring features are significant from power quality perspective. (Parkkinen, 2011)

The voltage quality performance of the VFV's distribution network is advanced. VFV has increased the amount of primary substations and the share of high impedance grounded networks. This has decreased the amount of voltage dips and flickering remarkably. As a consequence, voltage quality complaints are therefore relatively rare and customers are mainly satisfied to the quality they receive. Nevertheless, if a customer complaint is made related to quality issues, there is a systematic method how the quality is being improved within a reasonable period of time, effectively. VFV realizes also proactive voltage quality improvements by utilizing the continuous power quality measurements at the customer connection points. Based on the measurements, critical parts of the network from voltage quality perspective can be identified. This creates an opportunity for VFV to accomplish power quality improvements, even before a network customer recognizes voltage deviations and makes a complaint. This type of activity is very important from customer service as well as service quality point of view. (Parkkinen, 2011)

Within Vattenfall Sweden (VFS), there are three types of AMR meters installed. Only the latest, third generation is able to monitor voltage deviations in three phases like over/under voltages, voltage asymmetry, neutral faults, daily peak and minimum voltages etc. 70 % of meters installed are capable to do this, so the quality monitoring is not fully comprehensive in LV network at the moment. (Parkkinen, 2011)

The following presents functions of present smart meters based on survey of existing vendors.

Basic meters

- not much power quality monitoring capabilities except some meters can register power outages

Smart meter for residential users

- voltage level per phase (time interval is not very precisely defined)
- current per phase (time interval is not very precisely defined)
- power per phase (time interval is not very precisely defined)
- voltage unbalance
- daily peak and minimum voltage for each phase

- long and short outage detection with configurable time threshold (residential and small commercial energy consumers)
- voltage sag and swell detection with configurable voltage and duration thresholds (residential and small commercial energy consumers)
- THD event detection with analysis up to 10th harmonic to reveal unusual conditions (residential and small commercial energy consumers)

Smart meter for high end users

- phase current (instantaneous)
- phase voltage (instantaneous)
- V&I phase angles (instantaneous)
- active, reactive and distortion power (instantaneous)
- power factor (instantaneous)
- distortion power factor (instantaneous)
- frequency (instantaneous)
- monitoring and recording of voltage cuts, sags and swells with configurable voltage and duration thresholds and RMS coincident current
- outage log
- measurement of Total Harmonic distortion (THD) on voltages and currents
- harmonic analysis (even and odd)
- measurement of some harmonic voltages
- flicker measurement per phase
- voltage unbalance (measurement of negative and positive components of voltage)
- waveform capture capabilities (sampling frequency not well defined)
- neutral current measurement
- Programmable diagnostics for voltage imbalance, distortion, current imbalance, reversed polarity, high neutral current

Special meters

- equipped with high speed sampling frequency (for example 512 samples/cycle) and high resolution (for example 16 bit)
- lots of power quality monitoring capabilities for example: event out of limit log, waveform log, harmonic distortion analysis, AI reports - PQ analysis, fault analysis etc.
- these meters resembles more power quality analysers and are expensive

2 Needs of new functions of AMI based systems

In assessment of profitability and benefits of AMR in pure energy remote reading is not enough in many cases, especially in rural areas, where change readings are rare. Benefits are sought out from development of network operation and planning, demand side management (e.g. load control and dynamic tariffs), and customer service.

AMR –technology and modern computer system architecture enable the development of new functions. At the same time business environment and business models are being changed, which open new possibilities and requirements. Measurement information usage is one of the key elements in getting full benefit from AMR. Approach from main business processes of distribution network operator (DNO) can provide additional requirements for AMR compared to the current solutions in market. To be able to implement AMR system the whole meter chain from the customer site to the business systems has to be improved to assure the quality of the metered values. AMR implementation will change structure of information systems, too. Figure 9 presents a comprehensive approach for using AMI in LV network management.

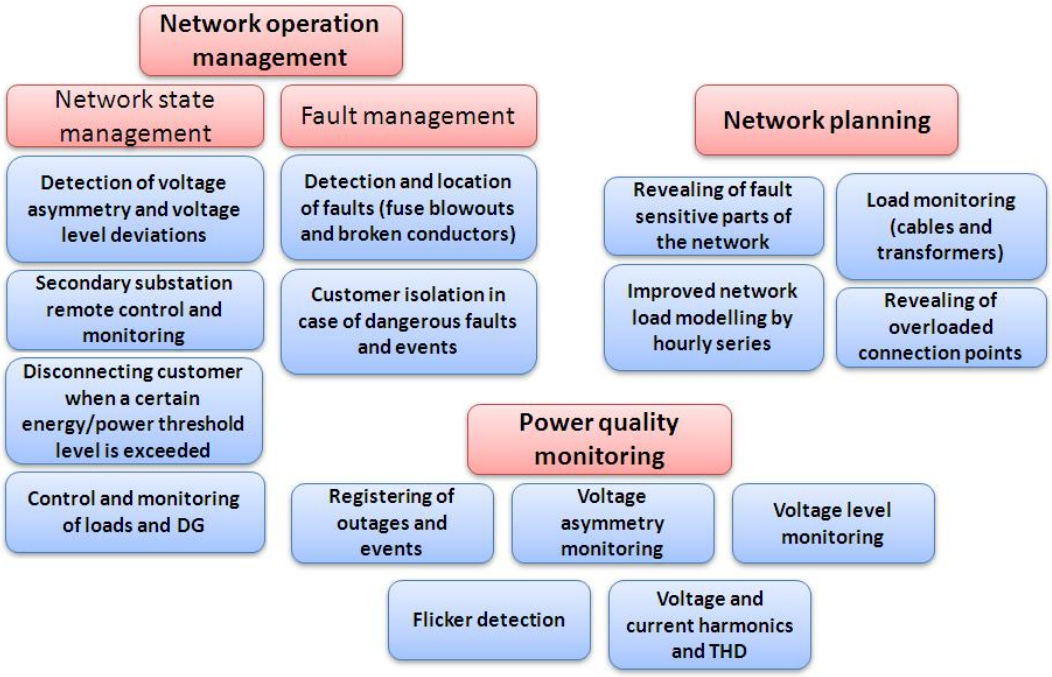

Fig. 9. Utilizing AMI in LV network management.

The possibilities of using AMR include, for example, real-time energy information, customer service, demand side management, disconnection and reconnection of electricity supply, determination of load profiles for network calculations, network planning and secondary transformer condition monitoring, more accurate interruption statistics, more sophisticated power quality monitoring facilities, and the management of low voltage distribution networks.

New functionality for AMI systems can be roughly divided into two time periods. They are short term and long term development. Short term development includes possibilities what can be realised with today's AMI generation where for example meter hardware set limitations for more advanced applications. In short term development study it is essential to see what have been already done and how.

Long term enhancement includes meter hardware evolution. Present AMR meters have for instance poor sampling and detection of asymmetrical situations can be based only to comparison of phase voltages. Even if the willingness is to increase intelligence of meters also better conclusion in the upper level IT systems is possible. This is one essential part of short term development and long term investigation will focus more in the metering equipment to specify needed hardware features for the next generation AMI.

At the moment network operation process can benefit especially from more efficient LV network fault management, as the detecting, locating, isolating and reporting of LV faults can be done almost in real-time manner.

Network planning will profit especially from more accurate network calculations, but AMI data can also provide many new tools (e.g. load monitoring and voltage quality analyses, and revealing of overloaded parts of the LV network) to support the planning and asset management processes. In the following text network planning and asset management issues using AMR data is discussed.

In the future smart meters could be used to control loads and DG comprehensively in the LV network. Appendixes 1 and 2 include some ideas on these issues.

In addition to traditional load control, advanced AMR meters equipped with an available programmable relay output can enable more advanced control functionalities. in advanced AMR meters certain power limits can be set and when the power consumption at the customer connection point exceeds the pre-programmed threshold value the meter can automatically control particular loads.

In advanced AMR systems the remote disconnection of a DG unit in case of maintenance or fault repairing work can be enabled with meters equipped with a disconnection unit. The disconnection can be done also automatically, which could be useful in a case of loss-of-mains, if disconnection units could be able to break fault currents.

The hourly series data obtained from advanced AMR meters can be used to improve load-modelling, thus giving more accurate results in LV network calculations. Instead of replacing the load curves directly with hourly series, AMR data should be used to refine the present customer classification and load curves. Advanced AMR meters also provide the hourly series of reactive

power to improve the results. In network calculations it is usually assumed that the power factor is constant. In the reality, the proportion of real and reactive power varies all the time.

With improved network calculations the peak demand, which is the most important planning criteria, at each point of the LV network can be estimated more accurately. In practice this means that the dimensioning of LV network components and fuse protection can be optimized. In addition, the losses can be evaluated more precisely

From the AMR data it is even possible to reveal overloaded customer connection points. Despite the occasional appearance, overloaded customer connection points can be troublesome for DNOs. The detection of these kinds of problems is hard and time consuming today, as it requires additional resources for separate metering and local studying of the LV network. Instead, this process could be done automatically by an application that compares measured currents gathered from AMR meters to the fuse size information of the customer information system (CIS).

The voltage quality obtained from advanced AMR meters enables proactive voltage quality management, as the possible voltage quality problems could be detected and repaired before the customer notices it. Potential voltage quality problems can be plotted beforehand, for instance, by combining voltage quality measurements to calculated short circuit current value. In addition, in a case of customer complain the AMR meter data can provide valuable information about the voltage quality history from the customer connection point to customer service.

3 Use-case for neutral-fault management

3.1 Basic use-case – ideal neutral fault management use-case

During a neutral fault situation, the impedance of the neutral circuit is increased by a conductor break or by a bad connection. Such neutral fault will cause voltages to float as higher or lower depending on the load balancing in the system. This type of fault condition causing any too high overvoltage may damage equipment connected to the supply and problems with safety protection occur. Risks both to humans and properties exist.

Even the current AMR system make possible to detect neutral faults there is need for further development. Present meters can usually detect neutral faults if a phase voltage rises up enough. There also neutral faults where phase voltages remain in between normal limits but can cause danger later on. Also such faults should likely be recognized. Reasonable rapidity of alarms is of course essential. One need is automatic switch off when a meter observes a dangerous situation.

In case of neutral fault customers are advised to turn main switch open to avoid even lethal risks. When any phase voltage increase high enough happens often damages to customer's property which must be compensated by utilities.

The main search question is that how neutral fault situation should be managed in the future in more advanced way. The plan is at first to establish ideal use-case for neutral fault management utilizing testing environment in the laboratory based on experience from formerly projects. Use-case will include the whole chain from a meter to DMS and also customer service and field groups.

After “ideal” method is determined it can be compared to present AMR systems to find out what is possible to do utilizing already installed meters and IT systems. The aim in task 4.5 is that ideal use case for neutral-fault is published by the end of February 2012.

3.2 Application enhancement with present metering equipment

Ideal use-case is independent of any equipment or manufacturer. For several utilities it is beneficial to complete also use-case study focused on the equipment used in a utility. Current generation of AMR meters has limitations to handle e.g. neutral faults and therefore it is interesting to search what is possible to do with different AMR meter types.

One of the most important features of present AMR meters is that their software is remotely programmable which enable adding new functionality or changes to the meter behaviour in different situations. In Vattenfall Finland one full scale meter software upgrade is completed. Upgrade was done to implement new features to handle more advanced way especially voltage asymmetrical situations. Anyway installed firmware limit possibilities and new features must be possible to realise with current meter hardware.

However essential is to find out how neutral fault management can be developed further using current meter hardware and what is possible to in IT system based on metered data analysis. Purpose is to determine how neutral fault management could be utilized more effectively before installation next AMR generation meters which should have lot more advanced metering features for different fault situation including neutral fault detection and protection functions.

References

Järventausta, P., Verho, P., Mäkinen, A., Kivikko, K., Kärenlampi, M., Chrons, T., Vehviläinen, S., Trygg, P. & Rinta-Opas, A. 2007. Using advanced AMR system in low voltage distribution network management. CIRED, 19th International Conference and Exhibition on Electricity Distribution, 21-24 May, 2007, Vienna, Austria 4 p.

Parkkinen Joni, Evaluating smart grid development for incentive regulation. Master Thesis, Tampere University of Technology, 2011, 117 p.

Trygg, P., Mäkinen, A., Verho, P., Järventausta, P. & Rinta-Opas, A., Providing additional value for AMR with integration to operational systems. Proceedings of the 8th Nordic Electricity Distribution and Asset Management Conference, NORDAC 2008, September 2008, Bergen, Norway

Kujala, M. 2009. Automated meter reading as part of network planning. Master's thesis. Tampere University of Technology, degree programme in electrical engineering.

Löf N., Pikkarainen M., Repo S., Järventausta P., Utilizing Smart Meters in LV Network Management. To be published in the proceedings of the 21th International Conference on Electricity Distribution, June 2011, Frankfurt, Germany

Information on smart meters of different vendors:

Echelon:

IEC_Polyphase_83332.pdf, [Online], Available: http://www.echelon.com/metering/datasheets/IEC_Polyphase_83332.pdf

IEC_CT_3_1.pdf, [Online], Available: http://www.echelon.com/metering/datasheets/IEC_CT-3_1.pdf

GE:

GE_SM_310.pdf, [Online], Available: http://www.gedigitalenergy.com/products/brochures/GE_SM310.pdf

GE_SM300.pdf, [Online], Available: http://www.gedigitalenergy.com/products/brochures/GE_SM300.pdf

GE_SM310.pdf, [Online], Available: http://www.gedigitalenergy.com/products/brochures/GE_SM310.pdf

KV2-family_GEA-12673.pdf, [Online], Available: http://www.gedigitalenergy.com/products/brochures/smartmetering/KV2-family_GEA-12673.pdf

GEa-13368, [Online], Available: http://www.geindustrial.com/publibrary/checkout/GEA-13368?TNR=Brochures|GEA-13368|PDF

Iskraemeco:

MT372_ang.pdf, [Online], Available:
http://www.iskraemeco.si/emecoweb/eng/products/bdf/MT372_ang.pdf

Itron:

F12686-4093_ACE4000_MK3-low-res.pdf, [Online], Available:
https://www.itron.com/PublishedContent/F13686-4093_ACE4000_MK3-low-res.pdf

F27104-PD4156_ACE8000_PowerGrid_v3-low-res.pdf, [Online], Available:
https://www.itron.com/PublishedContent/F27104-PD4156_ACE8000_PowerGrid_v3-low-res.pdf

Kamstrup:

file.pdf, [Online], Available: http://kamstrup.fi/media/12819/file.pdf

Landis+Gyr:

E120LiME_Fact_Sheet_EN_101.pdf, [Online], Available:
http://style.landisgyr.com/apps/products/data/pdf1/E120LiME_Fact_Sheet_EN_101.pdf
E120Lt_EN_TechData_v1101.pdf, [Online], Available:
http://style.landisgyr.com/apps/products/data/pdf1/E120Lt_EN_TechData_v1101.pdf

E120Gi_techData_EN_v100_screen1.pdf, [Online], Available:
http://style.landisgyr.com/apps/products/data/pdf1/E120Gi_TechData_EN_v100_screen1.pdf

SENSUS:

iCon APX data sheet _WEB.pdf, [Online], Available:
http://www.sensus.com/documents/10157/32589/iCON%20APX%20data%20sheet%20_WEB.pdf

Appendix 1

Ohjattavien releiden toimintojen kuvaukset ja niiden asettamia vaatimuksia (Löf 2011)

Toiminto	Toiminnon kuvaus	Vaatimukset AMR-mittareille	Vaatimukset ICT:lle	Muuta huomioitavaa
Etäohjattu kuormanohjaus	- Etäohjattava toiminto - Yksittäisten kuormien (esim. varaavan sähkölämmityksen) sähkönkulutuksen kannalta otolli-sempaan ajankohtaan	- Vapaa relelähtö kuormanohjausta varten	- Vähintään yhdensuuntainen tiedonsiirto etäohjauksia varten	- Toiminnolla on tarkoitus korvata vanhat VKO- & DLC-järjestelmät
Kuorman rajoitus/tehoraja ("ohjelmoitava sulake")	- Paikalliseen älyyn perustuva tai etäohjattava toiminto - Tietyn tehorajan ylittyessä ohjataan osa asiakkaan kuormasta, kuten sähkölämmityskuorma pois - Tapauksissa, jossa tietoisesti ylikuormitetaan liittymää raskaasti voitaisiin katkaista jopa koko liittymä	- Vapaa relelähtö kuormanohjausta varten - Tehonrajoitusominaisuus - "Ohjelmoitava sulake" edellyttää suojaustoimintojen integroimista mittariin	- Kahdensuuntainen tiedonsiirto, joka mahdollistaa: • hälytykset • etäohjaukset ja -asettelut • mittareiden parametrien ja kytkimen tilan tarkistus etänä • Lokien etäluenta	
Taajuusriippuva kuormanohjaus	- Paikalliseen älyyn perustuva toiminto - Mahdollistaa tiettyjen kuormien hyödyntämisen häiriöreservinä, kuten varaavaan sähkölämmityksen, sähköauton latauksen, jne.	- Vapaa relelähtö kuormanohjausta varten => mikäli mittarissa on myös katkaisulaite, on mittarissa oltava vähintään kaksi relelähtöä - Kyettävä mittaamaan taajuutta	- Ei ICT vaatimuksia	

Appendix 2

Katkaisulaitteen toimintojen kuvaukset ja niiden asettamia vaatimuksia (Löf 2011)

Toiminto	Toiminnon kuvaus	Vaatimukset AMR-mittareille ja katkaisulaitteelle	Vaatimukset ICT:lle	Muuta huomioitavaa
Sähköntoimituksen keskeytys/ takaisinkytkentä	- Etäohjattava toiminto - Sähköntoimituksen katkaisu etänä: • maksamattomien laskujen vuoksi • myyntisopimuksen päättymisen vuoksi - Sähköntoimituksen takaisinkytkentä etänä uuden myyntisopimuksen astuessa voimaan	- Relelähtö katkaisulaitetta varten - (Katkaisulaite lukittuu automaattisesti auki asentoon) - (Lukituksen vapautus etätoimintona)	- Vähintään yhdensuuntainen tiedonsiirto etäohjauksia varten	
Energiaraja	- Paikalliseen älyyn perustuva toiminto - Katkaisu tapahtuu automaattisesti tietyn energiarajan ylittyessä - ”Prepaid-sähköliittymät”	- Relelähtö katkaisulaitetta varten - Loki/rekisteri tapahtumille - (Katkaisulaite lukittuu automaattisesti auki asentoon) - (Lukituksen vapautus etätoimintona)	- Kahdensuuntainen tiedonsiirto, joka mahdollistaa: • hälytykset • etäohjaukset ja -asettelut • mittareiden parametrien ja kytkimen tilan tarkistus etänä • Lokien etäluenta	- Reaaliaikaiset energiankulutustiedot pitää olla asiakkaan saatavilla (esim. internetistä, puhelimitse, tekstiviestitse, energianäytöstä, tms.)
Asiakkaan erottaminen sähköverkosta sähköturvallisuuden vaarantuessa	- Paikalliseen älyyn perustuva toiminto - Katkaisu tapahtuu automaattisesti: • nollaviasta • yli- & alijännitteistä • väärästä kiertosuunnasta	- Kyettävä havaitsemaan luotettavasti nollaviat, väärän kiertosuunnan sekä yli- ja alijännitteet - Relelähtö katkaisulaitetta varten - Loki/rekisteri tapahtumille - Katkaisulaite lukittuu automaattisesti auki asentoon - (Lukituksen vapautus etätoimintona)	- Kahdensuuntainen tiedonsiirto, joka mahdollistaa: • hälytykset • etäohjaukset ja -asettelut • mittareiden parametrien ja kytkimen tilan tarkistus etänä • Lokien etäluenta	- Erottaminen tulisi tapahtua mahdollisimman nopeasti, kun vikatyyppi on varmistunut erityisesti nollavian tapauksessa (epäilyttävä/varma 0-vika)
Pientuotannon verkkoon syötön esto	- Paikalliseen älyyn perustuva toiminto - Pientuotantoyksikkö erotetaan automaattisesti, jos asiakkaalla ei ole sopimusta verkonhaltijan kanssa pientuotannon verkkoon liittämiseksi	- Relelähtö katkaisulaitetta varten - Loki/rekisteri tapahtumille - Pätö- ja loisteho-mittaukset molempiin suuntiin - Katkaisulaite lukittuu automaattisesti auki asentoon - (Lukituksen vapautus etätoimintona)	- Kahdensuuntainen tiedonsiirto, joka mahdollistaa: • hälytykset • etäohjaukset ja -asettelut • mittareiden parametrien ja kytkimen tilan tarkistus etänä • Lokien etäluenta	- Toiminto ei ole käytössä asiakkailla, joilla on tehty sopimus tehon syöttämiseksi verkkoon