UTILIZING SMART METERS IN LV NETWORK MANAGEMENT

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ABSTRACT

The role of the low voltage (LV) network in electricity distribution is changing. Traditionally distribution network management and automation have been focused on the medium voltage (MV) side whereas the LV side has got remarkably less attention. The purpose of this paper is to discuss how the functionalities of smart meters can be utilized to improve LV network management from the viewpoint of LV network operation, planning and asset management, in particular. The paper focus especially on advanced automatic meter reading (AMR) meters, but other smart meters, such as secondary substation monitoring devices, has also been taken into account. As a result of this paper, an overall framework of the utilizing of smart meters comprehensively in LV network management is presented.

INTRODUCTION

Electricity distribution systems in Europe are slowly evolving into a direction that increases the importance of the LV network in electricity distribution. In Smart Grids the role of the LV network will be significant due e.g. to small scale distributed generation (DG), the charging of electric vehicles (EVs) and advanced metering infrastructure (AMI).

In recent years the advancements in the grid and automation technologies of the LV network have brought many alternative choices to improve the performance of the LV side. Novel LV network structures, such as the 1 kV LV distribution system [1], the LVDC distribution system [1] and the concept microgrid, have been introduced, but so far none of them has manage to replace traditional LV structures in a large scale. However, as a significant part of the distribution networks are about to reach the end of their life-time in the near future, and at the same time the penetration of heat pumps, DG and EV has been predicted to increase, these alternative structures need to be considered in revenue strategies. For the same reasons more automation is needed to ensure the safe operation of the LV network, and also to obtain more accurate data about present LV networks. In the near future the automation intensity level in the LV network is increasing substantially due to AMI, in particular.

ADVANCED METERING INFRASTRUCTURE

In the visions of Smart Grids it has been recognized that AMI will play an essential role in the realization of the distribution system of the future. AMI is often referred to a trendy phrase "smart metering", even though the meaning is not exactly the same. Smart metering is actually concerned with residential smart meters and metering systems related to them, whereas AMI is associated to a metering infrastructure that provides information in almost real-time manner from every strategic point across the distribution network, not only from customer premises. Another definition of AMI could be that it refers to a system that measures, collects and analyzes energy usage and other measurements, and interacts with smart meters through various communication media.

From the viewpoint of the LV network AMI covers all smart meters installed at customer connection points and MV/LV secondary substations. The first major steps towards comprehensive AMI have already been taken, especially, by the virtue of the present proliferation and development of advanced AMR technology. Remote readable energy meter is being developed to be intelligent equipment including in addition to traditional energy metering also various new advanced functions based on local intelligence and remote control [2].

USING AMI IN LV NETWORK MANAGEMENT

Distribution network management systems, such as distribution management system (DMS), SCADA, geographical network information system (NIS/GIS), have been developed to serve the MV network mostly. Nevertheless, recent studies and activities [2, 3, 4, 5, 6, 7] have proved that by integrating MV/LV substation monitoring devices and advanced AMR meters to present network management systems, these smart meters can be utilized in network management. Figure 1 illustrates how advanced AMR meters, for example, can be comprehensively used in network management.

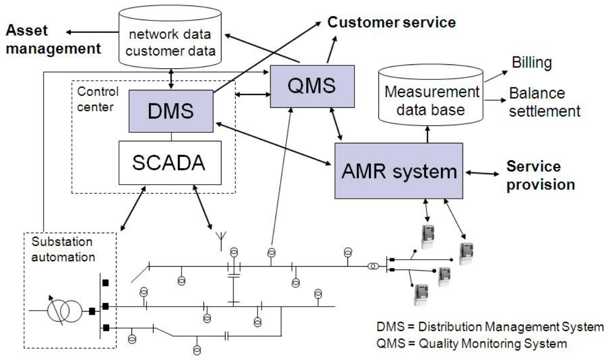

Fig. 1. Using AMR system in network management [2]

It is a common practice in Finland to have network data available at NIS also from the LV network. Control center information systems are also highly integrated, and therefore e.g. network and customer data are also available at DMS.

This paper discusses how AMI data can comprehensively be utilized in LV network management. The aim is to provide a state-of-the-art of useful smart meter functionalities that can benefit network operation, planning and asset management. Figure 2 presents a comprehensive approach for using AMI in LV network management discussed in later chapters.

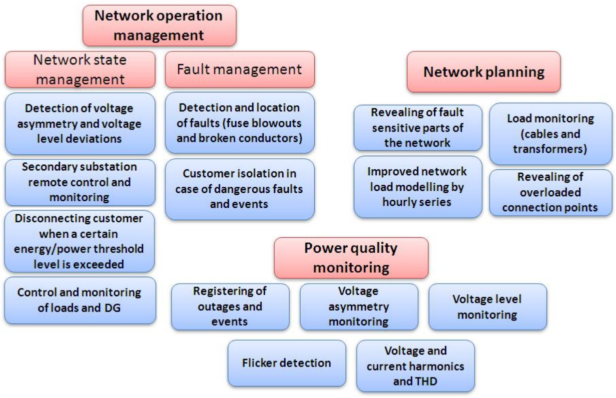

Fig. 2. Utilizing AMI in LV network management.

In some Finnish distribution companies comprehensive integrated information system entity for LV network management based on the installation of advanced AMR meters has been realized, described in [3] and in [4]. The latter introduces the installation of advanced AMR meters to all 350 000 customers of Vattenfall Distribution Oy in Finland where the system is in real operation.

LV network operation

Network operation requires information about the state of the distribution network all the time. Traditionally, the real-time information has been available from the MV network only. Two-way communication between distribution network company (i.e. DNO) and customer site make it possible to enlarge online monitoring and control to the LV network. The use and integration of AMI to DMS can be seen as an extension of distribution automation and SCADA to the low voltage level. [3]

Fault management

So far LV network faults have not been detected until a customer makes a call to the control center that he/she is without electricity. Advanced AMR meters and modern secondary substation monitoring devices can both detect missing phase voltages and other voltage abnormalities, and then send automatically alarms about faults to the DMS system. The missing phase voltage information makes it possible to reveal fuse blowouts and broken phase conductors that can cause an outage to customers.

Secondary substation monitoring devices, however, cannot detect the fuse blowouts located in LV distribution cabinets or broken LV conductors behind the fuses. Instead, as the advanced AMR meters can cover every customer premise, only a few faults remain outside the advanced AMR system, that informs the control center about faults in the LV network. Alarms cannot be sent when all phase voltages (e.g. 3-phases in Nordic Countries) are missing simultaneously, because the communication network could then jam in case of MV faults, as those are seen as an outage on the LV side. For the same reason meters that are connected to one phase only cannot send alarms about missing phase voltage at all. Nevertheless, advanced DMS can detect some of these faults with queries that can be sent to the meters. Queries can be extremely useful when a MV line has been repaired and re-energized after a major disturbance. With queries the control center can detect the broken LV lines and send the field crew to repair the LV side before they leave the faulted area.

Another important benefit is improved electrical safety as advanced AMR meters can detect voltage abnormalities (e.g. voltage asymmetry, under- and overvoltages) and based on the voltage asymmetry information it can detect a broken neutral conductor. An advanced AMR meter equipped with a specific disconnection unit can then isolate the customer automatically from the LV network in the case of a dangerous event. Customer isolation is important especially when a neutral conductor is broken in the LV network, because in that case hazardous voltages can occur, which can damage electric devices and cause a fire. In the worst case the metal covers of electrical devices become live and therefore dangerous to people around them.

Advanced AMR meters also gather valuable information about interruptions, such as fault type, the beginning and ending time of fault. The interruption information can be gathered automatically, which can make the interruption reporting regarding LV faults more fluent and accurate. So far LV interruption reporting has been done manually and the interruption durations have been rough estimations, as there has not been reliable information about the beginning times of interruptions. Moreover, the determination of possible compensations, which are paid to customers in long interruptions, can be automated using AMR data. [3]

Network state management

Network state management is defined here as remote and automatic actions that are used to achieve the most optimal use of the network. Today the control activities done in the LV network are performed mostly to balance the peak demand of the power system by controlling particular loads (e.g. electric space heating on/off) of a customer on request or the basis of a pre-defined schedule. In addition to traditional load control, advanced AMR meters equipped with an available programmable relay output can enable more advanced control functionalities.

AMI can enable various load controlling functionalities performed automatically or remotely. If the measurements are obtained from residential smart meters only, the control center could receive an alarm about distribution transformer overloading, and preplanned changes in the LV network state might be performed. When the measurements are available from the secondary substation the customer loads could be controlled automatically with an intelligent device from the secondary substation and an alarm is sent to the control center only, if the automatic control fails. The latter functionality can be extremely important in the future, if the charging of electric vehicles becomes more common, as it can be utilizied in smart charging.

At the customer level automatic load control is necessary. In fact 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 addition to above mentioned control functionalities, 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.

Asset management and LV network planning

The LV network may not have been as critical part of the distribution network from the reliability point of view as the MV network has, but its importance from the viewpoint of network assets is evident. The LV network is the most extensive and expensive part of the distribution network. For instance, in Finland the LV network comprises over 60 % of the length of the distribution network and approximately half of the total value of the distribution networks is committed in LV networks (including MV/LV substations) [8]. Moreover, the most of the network losses in electricity distribution are occurred in LV networks and in secondary substations that are feeding them.

Traditionally, the evaluation of the state of the LV network has been based on network calculation, the computed value of short circuit current and possible power quality reclamations. The AMI system provides accurately measured data, which can be used to improve the accuracy of network calculations, and enables new tools for power quality and load analyses.

Improved network calculations in LV network planning

The initial information for network calculations (i.e. power flow and fault current calculations) is obtained from the network database (e.g. network topology and component properties) and from the customer database (e.g. load curves). One of the most challenging issues regarding the network calculations of the LV network is the fact that the smaller the amount of customers examined in statistical network calculations the more inaccurate are the results.

The hourly series data obtained from advanced AMR meters can be used to improve load modeling, 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 [9]. 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.

Novel network analyzing tools based on AMI data

In reference [7] novel analyzing tools for supporting network planning and asset management based on AMR data were examined. These tools enable to analyze the loading of network components (e.g. transformer, cables) or even to make direct conclusions about the network state, such as the criticality of network renewal.

Traditionally LV networks have been designed in such a way that overloading can be avoided and some capacity margin is left for the future load increment. However, the consumption habits of customers can change temporarily or permanently. Customers can invest in electricity based heating or cooling systems in an area where such systems have been uncommon before, which can remarkably increase the peak demand in the LV network. From the AMI data, the increased peak demand can be indicated, and possible network reinforcements in the LV network (e.g. replacing the transformer or cables with bigger ones) can be done in time. Respectively, the same information may be used to securely postpone network investments when peak demand has decreased (e.g. electrical heating has been replaced with other energy sources).

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).

Advanced AMR meters also provide outage information that can be utilized to reveal fault sensitive parts of the LV network. Thus renewal activities could be allocated more effectively.

Voltage quality management in the LV network

Traditionally the voltage quality in the LV network is evaluated mostly based on the computational voltage drop, the calculated value of short-circuit current, and to some case-specific measurements that have been performed when a customer has complained about bad voltage quality. The first two values of the above indicators are not necessarily the best possible ones for voltage quality problems.

Advanced AMR meters have created an opportunity to expand the voltage quality monitoring to cover every customer premise. Depending on the meter configuration these meters can monitor some basic power quality quantities, such as voltage level in each phase and voltage asymmetry. Meters also gather voltage information that can be used to provide an educated indication about the flicker, which is one of the most common reasons for the voltage quality complaints today. In advanced AMR meters there is also a possibility to set certain limits to these quantities, and when a set threshold level is exceeded, the meter can send an alarm about bad voltage quality.

In addition to advanced AMR meters, there are also other smart meters capable for voltage quality monitoring, such as secondary substation monitoring devices. These devices can monitor a few voltage quality quantities that advanced AMR meters cannot (e.g. voltage harmonics), record disturbance events and in general are more accurate. The less critical data related to voltage quality can be stored in a power quality database and an alarm is sent about the most critical nonconformities in voltage quality [5]. Furthermore, for the most critical customers specific voltage quality monitoring devices can be used. These devices are typically fixed installed. The devices can measure, for example, flicker, voltage dips and total harmonic distortion and can also send an alarm when necessary.

Even though advanced AMR meters do not necessarily include as versatile voltage quality measurements as above mentioned sophisticated smart meters, the coverage of these meters makes a comprehensive voltage quality monitoring possible. Voltage quality monitoring at the MV/LV substation level might give a good overall picture of voltage quality, but it does not provide any information about the voltage quality in customer premises where the standard EN 50160 states that the voltage quality should be measured. Moreover, the devices with more versatile voltage quality features have not proven to be installed in every customer premise, because of economic reasons and the fact that the AMR meter is installed there anyway.

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 calculational 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.

CONCLUSIONS

In this paper, the utilization of smart meters in LV network management was discussed. Possibilities to use AMI in network operation, planning and asset management have been analyzed. 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. 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. In the future smart meters could be used to control loads and DG comprehensively in the LV network.

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