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Published in:
Proceedings of 25th International Conference on Electricity Distribution, CIRED 2019

Publication date:
2019

Document Version
Publisher's PDF, also known as Version of record

ENABLING SMART GRID FEATURES BY ENHANCED UTILIZATION OF ACTUAL ADVANCED METERING INFRASTRUCTURE

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ABSTRACT

The behaviour of Low Voltage (LV) grids is undergoing a transition from a load leaded passive role to a more active one [1], arising technical challenges such as sudden voltage dips and swells, bidirectional power flows, etc. Besides, these events are not automatically reported at the Distribution System Operator (DSO) control center, and mitigation actions (in case of abnormal conditions or outages) take relatively long time and a lot of manpower [2]. However, the undergoing deployment of Advanced Metering Infrastructures (AMI) in Europe appears promising for addressing these operational challenges. Nevertheless, the actual performance of the existing AMI is given by an architecture mainly designed for billing purposes, where the potential of the systems is not fully exploited. This paper aims to provide, an overview of the actual architecture, performance and utilization of the AMI. Additionally, alternative approaches on the utilization of actual AMI are discussed, in the frame of the ongoing research project PSO-RemoteGrid, in concordance with the needs reported by DSOs in Europe. Practical aspects such as the required system architecture supporting the implementation of smart grid functionalities are also discussed. This paper aims to increase the awareness of smart grid actors on existing capabilities and unused potential of current AMI.

INTRODUCTION

In the last years, the penetration of Renewable Energy Sources (RES) has increased considerably in Europe along with the electrification level; which now includes among others heat pumps and electric vehicles. Thus arising new technical problems like reduction of voltage quality, inadequate protections scheme; as well as the need of grid reinforcements [3]. On the other hand, despite of all these changes, the common practices of the DSO have not adapted; still depending on consumer complaints to detect the issues. In fact, even though Smart Meters (SMs) present high rates of deployment in several European countries like Spain, where the deployment is already 100 % [4], they are only used for billing purposes; dismissing the possibility of using that available information.
AMI is the basic building block for the Smart Grid development in distribution systems; whose main purpose is to enable a bidirectional communication between customer and control center. It is composed of two main subsystems, namely the communication infrastructure and the SMs. The latest are capable of measuring and calculating electrical parameters of different nature i.e. voltage and current phasor measurements, four-quadrant active and reactive power and energy, or different power quality metrics as Total Harmonic Distortion (THD) and voltage unbalance detection among others [5]. Additionally, SMs are capable of sending that information to a central data management system using different telecommunication protocols and technologies. Therefore, they can be used to detect faults and send outage or restoration notifications allowing the utilities to increase the grid reliability [6]. Despite their monitoring capabilities, they are currently only used for billing purposes; reporting only energy readings and some flags belonging to the device status logger. Moreover, the communication infrastructures supporting the link between the points of measurement and the DSOs control center are configured in reading cycles which are not designed to support LV grids operational features [7].
This paper proposes an enhanced AMI utilization scheme which provides operational services to DSOs. Namely, Smart Metering data monitoring and simplified system operator data access procedures. The main system architecture is presented where functions of main systems and sub-systems are discussed.

ADVANCED METERING INFRASTRUCTURE

In this section, the system architecture, typical used communication network technologies, main SMs features and the actual performance and utilization of the AMI are introduced.

Architecture

The typical AMI architecture is depicted in Figure 1. The data from the SMs is collected via data concentrators or collectors by using multiple communication technologies, for, e.g. wireless (LTE, 3g/4g, RF mesh based) or wireline (Fiber, PLC, Broadband). Then the data packets are stored and aggregated by the data concentrators and then forwarded via another communication link to the Head End Systems (HES) which performs Metering Data Management (MDM) in order to interface it with other entities, as for instance, the DSO control center [8]. However, the current AMI is developed and mainly used for billing of customer power consumption with a meter reading at long update rates i.e. 6 hours once or twice a day.

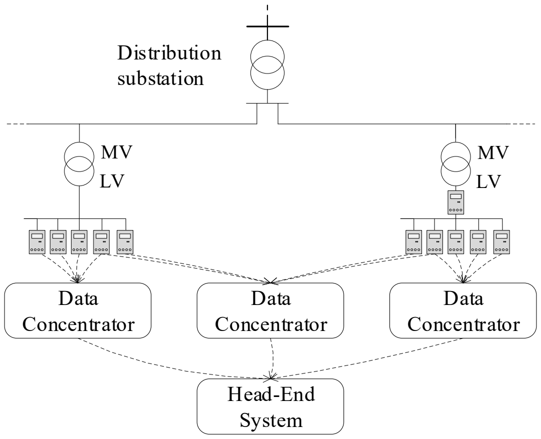

Figure 1: Typical AMI system architecture.

Main Communication Network Technologies

Communication networks represent two-way data flow between different AMI components as specified in Figure 1. There exist many realizations of the heterogeneous (multilayered) communication technologies, for example, the three widely used technologies between SMs and data concentrators in Europe are, Narrowband PLC, Wireless point-to-point (p2p) and RF Mesh-based [9]. On the other hand, Fiber and Wireless point to point support communication between data concentrators and HES.

Table 1: Examples of Communication Technologies for AMI in Europe

Standard	Communication Technology	Bandwidth/Data rates
GSM/GPRS/2G	Wireless p2p	Up to 270 kbps
UMTS /3G	Wireless p2p	5.75–22 Mbps
LTE/4G	Wireless p2p	86–500Mbps
PLAN	PLC	200bit/s–2.4 kbps
Meters &More	PLC	4.8–57.6kbps
PRIME	PLC	21.4–128.6kbps
1901.2	PLC	Approx. 80 kbps
G.9902	PLC	Approx. 80 kbps
Kamstrup RF	RF Mesh	Approx. 4 kbps
MeshNet3	RF Mesh	9.6 kbps

Hence the primary constraint in the slow data collection arises because of the low bandwidth communication between SM and data concentrator. Table 1 presents a comparison of widely used communication technologies for AMI applications regarding bandwidth/data rate. From the comparison, the data rates are also affected by communication standards even though they are using the same technologies. Communication technology standards, in particular, define rules or conventions for the information exchange between devices (here: SMs and data concentrators) in a network. Most of the AMI networks use RF meshed or PLC based standard coupled with 3G/4G technologies for sparsely populated SM nodes. Although 3G/4G technologies have very high bandwidth, it would be costly for the DSOs to cover all SMs with those technologies.

Smart Metering Data

Smart Meters are the essence of modern AMI systems. In three-phase four-wires LV grids, these devices measure the three phase-to-neutral voltage phasors as well as the current phasors at the three phases. Based on the measurements the SM calculate additional parameters of interest. The ypical information provided by this devices is summarized below based on [5]:

- Four-quadrant active and reactive energy.
- Four-quadrant active and reactive power averaged over a predetermined averaging period. Also maximum and minim power values are recorded in the given period.
- Voltage and current phasors: average, maximum and minimum values during the averaging period. The system can be configured to provide measurements in specific instants i.e. instantaneous values.
- Average voltage and current THD.
- Power quality data: typically most of the values recorded by the power quality logger are counters of specific events. For instance, out-of-range voltage frequency, under and over voltage variations exceeding different thresholds, voltage unbalanced between phases, power interruptions, etc.

ENHANCED AMI UTILIZATION

Daily tasks performed by DSOs require more than ever a closer look into the LV grid state while the potential of modern AMI is not fully exploited at the moment. Therefore, this section introduces advanced AMI system utilization schemes based on the main items addressed in the Danish project PSO-RemoteGRID [8][10]. Firstly, a web Geographical Information System (GIS) based data visualization system aiming to making smart metering data available to the system operators is presented. This platform allows monitoring electrical parameters measured, calculated and recorded by SMs. However, approaching a near real-time monitoring of data is subjected to the communication network bandwidth. As part of the project investigated items, details about the actual reading cycle and scheduling of SMs are presented.

Monitoring System

Based on the testimony of one Danish DSO it is known that the SMs data is made accessible by following a manual procedure (except the billing process which is automated). The operator identifies the relevant meter ID and sends a demand for the parameter of interest to get a response in a procedure that takes in average 45 to 60 seconds. From this user story it seems evident that such a manual interaction is not efficient, especially making use of a modern system as the AMI.
The proposed solution is an automated monitoring system that uses the GIS map as a basis to visualize smart metering

data. Figure 2 shows the system architecture from a medium size DSO in Denmark. A web based solution is chosen which uses a database containing the GIS map and topological grid information to create the main user interface where the SM data is placed. The goal is to achieve a visual experience helping to locate easier the parameters under consideration. For instance, an event of alarm pushed through the communication network reporting overvoltage in a specific node of the system could be easily located and identified by the system operator.

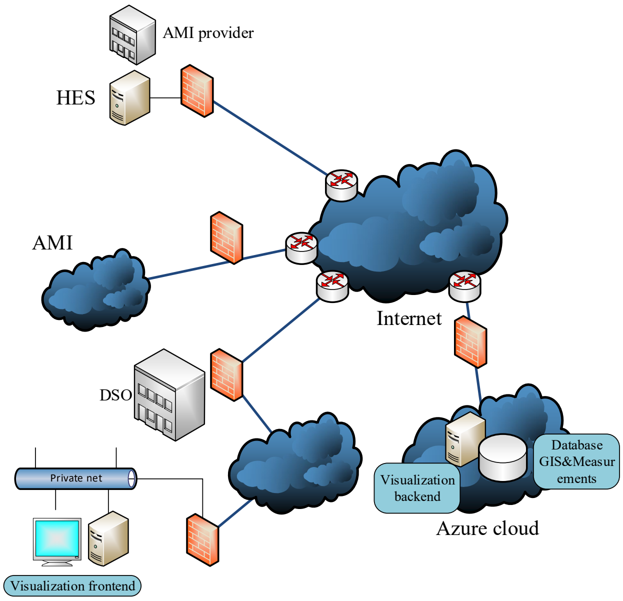

Figure 2: Visualization system interface within existing DSO and AMI provider system architecture.

Figure 3 depicts a prototype of the web based system user interface when an off-line simulation was run. Different colours are used depending on the visualization needs and preferences of the final user. In the simulation, the colouring was configured to represent different voltage levels. Therefore, the SMs which still did not report any value are considered as inactive and coloured in blue. On the other hand, the traces collected from the SM were filtered depending on the actual voltage level. Voltages within ± 5% of the nominal value are represented in green color, voltages within ± 5% to ± 10% are shown in yellow and red color is used for the measurements exceeding that limit. The system can be configured so additional information is obtained by the operator if accessing areas of interest. For example, load profiles generated by the SMs could be made available for different customers just by a mouse click.
Although this tool is still under development, this is a clear example of an enhanced utilization of the AMI data which main benefits can be listed below:

- Simplified and automated procedure to access SM data.
- User-friendly interface providing relevant information by means of visual interaction.
- Flexible configuration of data visualization including visualization format and selection of relevant parameters.

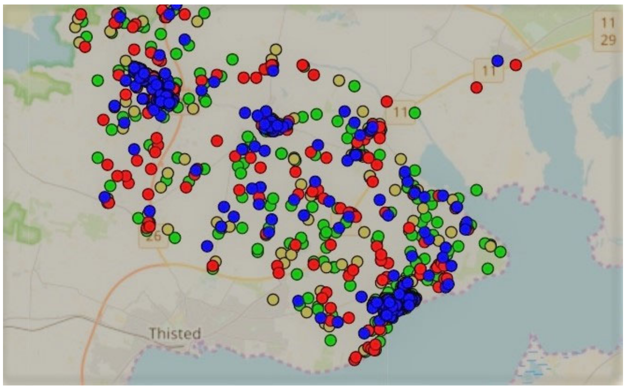

Figure 3: Simulation screenshot from prototype of advanced AMI monitoring system [10].

The main challenge of this approach lies on the limits shown by the communication network capacity. Approaching a near real-time monitoring of the entire grid implies overloading the network due to the increased amount of data. This is especially relevant recalling the design criteria of actual AMI systems which mainly respond to that of an automated billing process.

Data Collection

To support near real-time monitoring using the existing AMI infrastructure, it is paramount that data from SMs should be collected with small-time granularity. The communication technology used for the study is RF mesh-based systems executing pulling of SM data with multi-hop strategies. RF Mesh infrastructure transmits data over long distances by splitting the range into a series of short hops, utilizing SM mesh nodes as routers in each hop. Figure 4 shows the reading cycles for such systems.

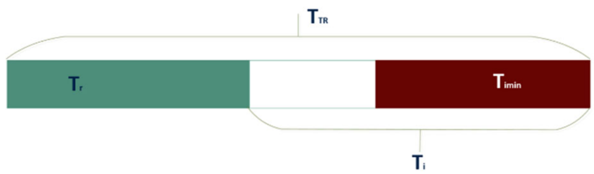

Figure 4: AMI Reading Cycle

The concentrator repeats the pulling of data from all meters periodically with a period of $\mathbf{T_{TR}}$. The data concentrator pulls its current view on the SM measurements from all the SMs in the range which results in with reading time $\mathbf{T_r}$. The Idle time $\mathbf{T_i}$ is the remaining time from the fixed total allocated reading time of $\mathbf{T_{TR} = T_i + T_r}$. The idle time has some lower threshold value $\mathbf{T_{imin}}$ where going below this would affect services executed at an idle time for eg. (potential firmware updates). As shown in Figure 5 the remaining idle time can potentially be used for scheduling selected relevant SMs ($\boldsymbol{R}$) as long as $\mathbf{T_R < T_i}$. This minimizes the reading cycle of the **R** SMs.

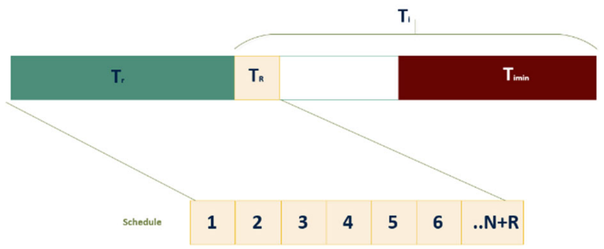

Figure 5: Scheduling of SMs

Several strategies are being investigated for adapting the data collection process in the project [11][12][13]. For example, one way of minimizing the reading cycle is by optimizing the scheduling of SMs reading by the data concentrator, where Schedule is the order of reading SMs within the periodic pull access. The schedule defines when and how often SM information is accessed. Part of the idle time described earlier could be used to obtain relevant SMs with small-time granularity with a reading cycle (see $\mathbf{T_R}$ Figure 5). Further information about the study can be found in [12][13].

REAL TIME HARDWARE IN THE LOOP SETUP

The designed systems are evaluated using the Smart Energy Systems Laboratory [14] facilities, placed at the Energy Technology department from Aalborg University, with a system architecture as the one depicted in Figure 6.

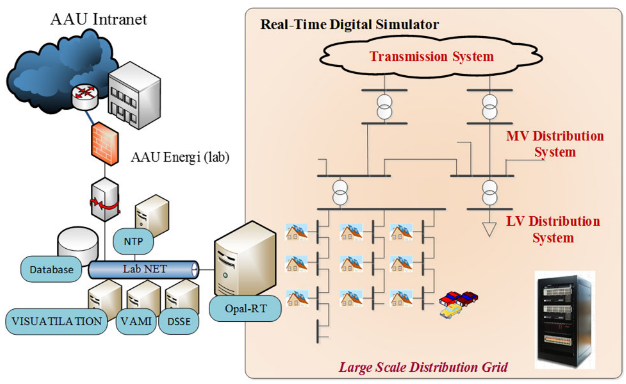

Figure 6: Laboratory setup system architecture deployed for RemoteGRID project activities.

Equipped with its own net, the laboratory facilities allow emulating the behaviour of the main systems and subsystems. The grid model is implemented by using a real-time simulator (OPAL-RT) while the AMI is emulated using a generalized application called Virtual Advanced Metering Infrastructure (VAMI). The environment allows testing of additional features outperforming the monitoring solution. For instance, Distribution System State Estimation for LV grids is one of the research areas in RemoteGRID project.

CONCLUSION

The successful development and implementation of Smart Grid solutions require to exploit the potential of AMI systems. Although its communication infrastructure is mainly designed for billing purposes the AMI provides a large amount of relevant information about the LV grid operational state. However, nowadays, the procedures to access smart metering data are inefficient and need to be updated according to the DSOs operational needs. The first step could be to develop a visualization solution to monitor the information in a user friendly manner which at the same time would simplify procedures while optimizing time. On the other hand, handling the large amount of data produced by thousands of SMs is challenged by the bandwidth of actual used communication technologies. However, this paper shows that the scheduling of data access can be configured to improve the system performance and to enable additional features. PSO-RemoteGRID project focuses on enhancing the utilization of AMI towards a smarter and more efficient operation of the LV grids.

Acknowledgments

This work is financially supported by the Danish project RemoteGRID which is a ForsKEL program under Energinet.dk with grant agreement no. 2016-1-12399.

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