Study of metering systems for smart grids

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Chapter 1

Metering Systems

In this chapter it is presented the state of the art regarding metering systems in the electrical energy field. These systems are divided in metering systems, Advanced Metering Infrastructure (AMI), Energy Management Systems (EMSs) and Energy Information Systems (EIS).

1.1 Smart Meters

1.1.1 Definition

Smart Grids improves the functionality and concept of traditional electrical grids by obtaining the grid component's data using Information and Communication Technology (ICT). Such grids benefit the reliability and the efficiency of the system with the usage of the acquired data, [1].

Although the smart meters does not have an effective definition, those devices are composed by an electronic box and a communication link, [2]. A smart meter is responsible for measuring the energy-related parameters and the user consumption with a given time interval. All those measurements are then transmitted upon a communication network to the utility or to other player with rhe responsibility of using the meter data. The information obtained from the data is shared with consumer -side devices, to inform the end-users on their related costs and energy usage, [3].

Evolution of Electricity Meters

Before 1970, a main part of the electricity metering was done by electromechanical meters (Figure 2.1). These meters are connected to the load and the rotation speed of the aluminum disk is proportional to the active power. In addition to active energy meters, there are also reactive energy and maximum demand metering, [4].

Figure 1.1: Huyu Electric DD282 single-phase KWH electromechanical meter, [5].

Figure 1.2: VISIONTEK 37TM Three Phase Electronic Energy Meter, [6].

To accomplish the lack of accuracy and of configurability of electromechanical devices, [7] , the electronic meters (Figure 2.2) has been introduced with the advance of measuring the general electrical parameters. After 1970, the automatic meter reading feature was included to electronic meters and a unidirectional communication approach was implemented to send data with a possible short time delay , [4].

1.1.2 Smart Meters in Smart Grid

Smart meters implement a bidirectional communication on top of AMR. They are inherent to smart grid systems. Figure 3 illustrates a smart meter who is responsible for the intelligent control and the reliable integration of distributed generation points having the loads dispersed over either a uniform or non-uniform distribution network, [8].

Figure 1.3: SGM 1100 Residential IEC Smart Energy Meter

The typical grid and a need to have Smart Grids

Similarly to the evolution of electricity meters, the utility grid has evolved from a centralized production and control perspective to a distributed one. The conventional electrical grid is a network with a transmission link connecting power producers and end-user consumers. The control and distribution of electrical power is made in a centralized way. With the increase of power demand, increase of complexity and having more and more decentralized power generation, a migration to the smart grid framework is required, [8].

Smart Grid frame work

Nowadays, generation and energy production includes distributed and dispersed energy generation sources, making easier the task of integration of this Distributed Renewable Energy Sources (DRES) with increased grid penetration and possible energy storage. Furthermore, reduction of transmission losses, a hierarchical control for grid security and identifying the possible optimized capacity expansion along with enhanced management of loading characteristics of the demand side are the basic framework of the above-mentioned grid, [8].

1.1.3 Features of Smart Meters

A smart metering system combines several controlling devices, a extensive number of sensors for measuring the parameters and devices responsible for the transferring of the data and the commands. The detection of unauthorized consumption due to electrical energy theft and the improvement of the energy in the distribution are other advantages of smart meters. These devices acts as a gateway by having a communication interface protocol to the database stored by the utility company, [8].

The design of an ideal smart grid has to focus on prediction, adaptability and reliability points. Moreover, it requires to cover the demand adjustment, the load handling, flexibility and sustainability and it should incorporate advanced services. In advance, an end to end control capability has to be ensured as well as finding the optimal cost and asses, increase the quality of energy and quality of service. Another features of smart grids are the automatic restoration ans self-healing, being all the previously presented features of the smart grids highly dependent of the role of the smart meters, [1].

Smart-meter types are also distinguished based on features like data-storage, communication type and connection with the energy supplier. The data storage capability allows data to be stored in the meter, being transferred after a few days or weeks to the Meter Data Management System (MDMS) of the utility. Compensations for some power quality deficiencies can be also considered; therefore the future meters should be also capable of register certain basic power quality characteristics. In advance, the design of rate and tariffs of electricity providers determine the requirements such as the period of meter intervals or the temporal resolution (commonly ranging from 15 min to 1 h). During those intervals, the production and consumption of active and reactive power is mandatory to be separately measured, [3].

1.1.4 Accuracy of Measured Data

Missing or erroneous data may determine substantial costs. Therefore, data must be reliable and accurate. The IEC 61036 standard define the accuracy requirements of billing meters. In advance, this standard lists the quantities such as the reference currents and voltages, influences of the harmonic distortion and other test limits, [9; 10].

1.1.5 2009/72/EC Directive

Framed in the European Union (EU) vision on having common rules for the internal market of electricity, there is a need of promote the energy efficiency, the sharing of information and the use of intelligent metering systems. , [11]. Resulting from the third Energy Package, Directive 2009/72/EC of 13 July 2009, the outcome of the European Commission (EC) is to establish a Task Force for smart grids, focus on promoting the development of a common EU smart grid vision, being the work of this tf the identification of key issues that requires to be solved.

Three Expert Groups (EGs) and a steering committee are the structure of this task force. The steering committee belongs to a high level that integrates regulatory bodies, Transmission Systems Operators (TSOs), Distribution System Operators (DSOs), Distribution Network Operators (DNOs), and consumer and technology suppliers. In addiction, this steering committee supports the achievement of the 2020 targets (accomplish 20% reduction in greenhouse gas emission; achieve 20% of EU energy production from renewable energy sources; obtain 20% enhancement in energy efficiency, [12]). The three expert groups are the subsequent, [11]:

- EG1. The features and functionalities of smart grids and smart meters (evaluating the recent state of the art, analysing the services and the smart grid components, and defining the strategy for standards);
- EG2. Define regulatory recommendations or directives for the safety, handling and protection of the data in the smart grid (required to design a standardized data model and ensuring cyber security);
- EG3. Defining the roles and responsibilities of players involved in the development of smart grids, like as DSOs/DNOs and define the role of standards.

The following articles from 2009/72/EC directive illustrates this need, [13].

> Art^{o} 3.11: *Promote Energy Efficiency*
> *"In order to promote energy efficiency, Member States or, where a Member State has so provided, the regulatory authority shall strongly recommend that electricity undertakings optimise the use of electricity, for example by providing energy management services, developing innovative pricing formulas, or introducing intelligent metering systems or smart grids, where appropriate".*

> Art^{o} 3.12: *Sharing of Information*
> *"Member States shall ensure the provision of single points of contact to provide consumers with all necessary information concerning their rights, current legislation and the means of dispute settlement available to them in the event of a dispute. Such contact points may be part of general consumer information points".*

> ANNEX 1.2: *intelligent metering systems*
> *"Member States shall ensure the implementation of intelligent metering systems that shall assist the active participation of consumers in the electricity supply market. The implementation of those metering systems may be subject to an economic assessment of all the long-term costs and benefits to the market and the individual consumer or which form of intelligent metering is economically reasonable and cost-effective and which timeframe is feasible for their distribution".*

1.2 Advanced Metering Infrastructure

The integration of different sub-systems is inherent to achieve an intelligent grid. The substantial establishment and functionality of all sub-systems is of fundamental importance in overall SG operation, where the output of each layer serves as the input of the layer. Advanced Metering Infrastructure (AMI) is a configured infrastructure incorporating a set of technologies to obtain the measurements of a large area, [1].

1.2.1 Infrastructure

The infrastructure is dependent on having smart meters connected to a higher level using different communication networks, that are dependent on the corresponding level of the infrastructure hierarchy (as example, wide-area networks (WAN), neighborhood area networks (NANs) and home (local) area networks (HANs)). It includes also Meter Data Management Systems (MDMS) and operational gateways and systems that aims to integrate the collected data into software application platforms and interfaces, [1; 3].

At AMI level, devices within the premises of a measure target (e.g. a house) transfer data with each other and with the utility network using the smart meters. At higher level, the Home Area Networks (HAN) exchanges the data with the utility provider, [1].

1.2.2 Features of AMI

With Advanced Metering Infrastructure (AMI) technology and by having the access to the information displaying both the price and consumptions, the customer can promote the reduction on energy consumption on the situation of having higher prices. The result for consumers is to reduce their electricity bills and for retailers is the increase in ofter of different electricity prices, [2].

A main characteristic of AMI is the bidirectional communication. Besides the remote metering as presented before, other advances are the transmission of commands or prices between utility and the smart meter or load handling devices, [1]. On the management side, the AMI allows the service provider (utility) to employ systems that collect and analyze logged data to optimize operations, energy costs and consumer service. Also, an immediate feedback on consumer outages and power quality can be provided and grid automation may be also supported, [3].

1.2.3 Data Aggregating / Data Communication

Smart meters exchanges the data with the end-user and with the service provider at the consumer level. The Home Area Network (HAN) automatically collects data from metering devices. Neighborhood Area Networks (NANs) are used for meter data collection. These data are transferred to a central database and used for various purposes, [3].

A HAN network allows connecting smart meters to handle the operation of electrical devices and implementing energy management features by using devices like as programmable communicating thermostats and other load-control devices, such as in-home displays, Plug-in Electric Vehicles (PEVs), and distributed power-generation devices. Besides that, a smart interface to the market may be offered as well as support security monitoring, [3]. The requirements of the communication bandwidth in HAN's vary from 10 to 100 Kbps for each device, [1].

Data Management

A database system performing editing, estimation and validation on the AMI data is used in order to guarantee that the data the information is accurate and complete. This task is made by a Meter Data Management System (MDMS). It is also endowed with analytical tools and functions that enable the cooperation for other information systems (like operational gateways), [3]. MDMSs are better explained in the following sections.

1.3 Energy Management Systems

Being the Energy Management Systems (EMS) a combination of switches, sensors, controls and algorithms, it is basically proposed to enhance the building energy performance recurring to saving energy and/or promoting the reduction of peak demand,[3; 4; 8]. In addiction, it is designed for automated Demand-Response (DR) functions, [3].

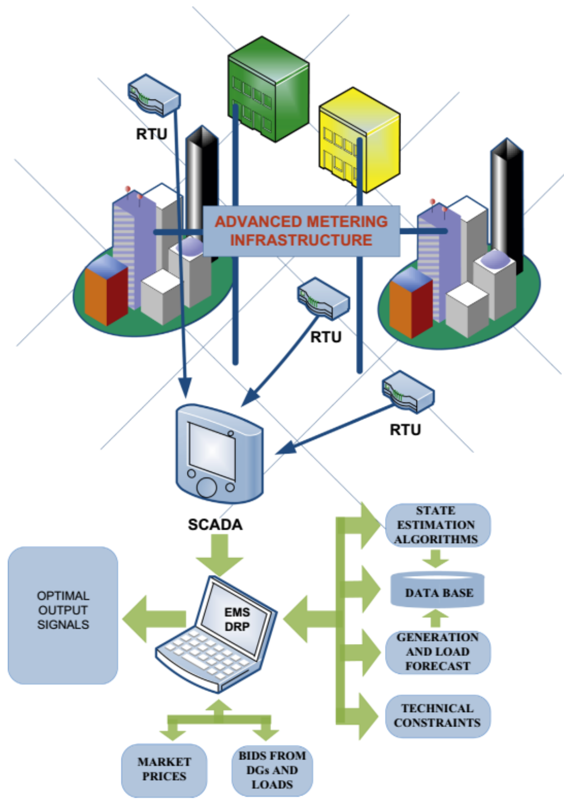

Figure 1.4: Integration of a EMS system in AMI. Adapted from [3].

1.3.1 EMS Features and Requirements

One major advantage of EMS is the ability to help in analyzing, monitoring and controlling different systems, playing an important role in reducing the overall peak demand. This is made by with series of sensors, switches, controls and algorithms, [8; 3].

As requirements, the possibility of monitoring individual loads and appliances is necessary for load control strategies, as well as validation of control response, development and updating of load models. If the measurements are required by control loops or checked on-line, a time resolution around 1 min is usually needed and extensive delays are undesirable, [3].

1.3.2 EMS in Railways

On the railway environments, with the increase in traction of regenerative braking and the increase of energy generation from renewable sources, there is a need for optimized management of energy flows within the network. This efficient management of all energy sources is enabled according to the actual demand. The development of an automatic control of voltage distribution within the network is required for the increase in efficiency and the stability of the railway system, [14].

Shift2Rail (S2R)

Accordingly to the Multiple-Annual Action Plan of Shift2Rail, [15], a detailed supervision of the energy consumption on railway systems is required for the analysis and management of energy efficiency.

Smart Metering Demonstrator

In the framework of the Shift2Rail (S2R) Innovation Programme 3 (IP3) "Cost efficient and reliable infrastructure" it is proposed to develop a Smart Metering Demonstrator (SMD) that reach a detailed monitoring and supervision of various energy flows on the premises of all of the Railway System.

The support of all energy management strategy is to build, on top of n extensive knowledge of energy flows, the dynamics of every consumers and generators. The SMD is required to validate a standard metering architecture that is coordinating on-board and ground measurements, providing the energy data analysis (in a Big Data type of Operational Data Management (ODM) platform).

The purpose of this demonstrator is to exploit measured data and the data analysis results, using developed User Applications (UA) and a Railway dedicated Distributed Energy Resource Management System (RDERMS).

1.4 Energy Information Systems

In AMI architecture, an appropriate data collection, storage and making it available to end user is required. This is achieved with information systems and also other advances has the ability of helping to identify errors and making decisions, [8].

Energy information systems (EIS) has the possibility to operate as the gateways between utility and existing EMS, [8]. Smart energy information systems (SEIS) goes further, and being based on Information and Communication Technology (ICT), allows the players in the energy sector to exchange information across organizational boundaries, [16].

Also, the advantages of EIS are the following, [3; 16]:

- Offer notification capabilities for end users, if endowed with automated response capabilities;
- Monitoring and recording real time energy consumption information for the analysis of building operations, billing validation and reporting, allowing alerts concerning DR events to be received or supply notification and analysis features;
- Grant automatic answers to utility-requested events or support towards the detection of errors, by analysing the effects of operational changes made in the response to an event and to make decisions;
- Endorse the environmental sustainability in the energy system, resulting in the reduction of the cost all players in the energy value chain.

1.5 Cost-benefit Analysis of Smart Metering Systems

The benefits of smart meters could be listed as following, [2; 17]:

- The availability of new tariff products that can change the pattern and level of electricity production and consumption;
- The support for features that enables the enhancement of the cost efficiency and cost savings in the distribution and in retail business (specifically if peak shaving is the key promoter of smart meter development); support for the enhancement over service performance
- The increase on system security;
- If peak shaving is the main driver for smart meter deployment, the expected cost savings derived from generation and network investments deferral should be quantified first;

On the field of the costs, they can also be listed as the following ones, [2; 17];

- The cost of purchase and the installation of the meters;
- The cost of upgrading the billing and operational management of the systems that are responsible for the processing and store of more detailed usage data;
- The cost of increase on new capital and operation and management (O&M);
- The cost of usage of equipments and systems on smart metering.

As conclusions of [17], the costs and benefits of implementation a smart meter system should be weighed against the costs and benefits associated with other demand management alternative. Also, some benefits could not be quantified, being this a complicated process that depends on many factors, [2].

1.6 Synthesis

This chapter follow the structure proposed by [3]. There are several approaches to cover this thematic, however the structure followed allows to have a better view of the main component of a smart system - the smart meter - before went to the tudy of the overall system.

Since there is an important background on smart meters, the electromechanical energy readers and later on automatic metering readers, it was followed a study on this background towards presenting the smart meter. Finally, a rough view on the regulations applied on energy meters are presented.

The whole architecture - or infrastructure - was then presented, having in mind the proposal of [3] on a good structure to present this thematic. In this section was discarded the presentation of the communication technologies that support this infrastructure, since these technologies will better presented in chapter 3.

However, this architecture is open and does not follow a strict regulation, specially i terms of definitions or keywords. This means that several approaches could be presented to cover this "infrastructure". Nevertheless, that does not mean that a bad coverage of this infrastructure could be present by other authors. Also, since this architecture has been emerging from the central infrastructure of the utility grid, where all the management is made a grid operator, several coverages of this topic may follow a not well defined definition of smart grid/smart metering system.

As it was presented in the beginning and following the ideas of several authors that cover this thematic, there is no exact definition of smart meters, smart grid, smart monitoring infrastructure, etc. It was made an assumption for smart metering systems, whee those systems may act as s system where each node has a bi-directional mean of communication. Therefore, a distinction is made between the "old" metering devices - where the utility grid/supervisor only have access to the metering data - and the new smart metering devices that has a bi-directional communication, receive information/commands from the utility grid/supervisor of the smart grid/etc. and, some kind of decision making could be done by those devices (as an example, promote energy efficiency by enabling/disabling devices that could operate in off-peak hours, such as heating devices, freezing devices, etc).

A brief effort was made to present the future directions of this study on railway systems. This complex environment could be considered as a possible smart grid and an advanced metering and monitoring infrastructure inherent to this environment. Therefore, a study on the Energy Management Systems for railways was made as a starting point to the future work.

On the following chapter, the communications will be covered to fulfill the gap left by the coverage of this metering infrastructure chapter.

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