High Level Requirements for Smart Meters that Will Enable the Efficient Deployment of Electric Vehicles

Evangelos Karfopoulos, Erietta Zountouridou, Stavros Papathanassiou, and Nikos Hatziargyriou

National Technical University of Athens, School of Electrical and Computer Engineering, Hroon Polytechneioy 9, 15773 Zografou, Athens Greece
ekarfopoulos@gmail.com, eriettaz@power.ece.ntua.gr, st@power.ece.ntua.gr, nh@power.ece.ntua.gr

Abstract. In case the electrification of transportation, i.e. electric vehicles (EV), occurs in an uncontrollable way, electric grids may come up with various potential problems, in terms of overloaded lines, increased losses, voltage quality issues, generation adequacy etc. There is a need for a middleware between EV and grid, on the top of which the different involved parties (DNO, ESCOs and aggregators) will be able to implement their EV control and management concept. Smart meters are the key technology that will enable the efficient adaptation of EV in the electric grids. However, the lack of common requirements on functionality and open interfaces fractionalize their massive implementation and increase their cost. This paper presents the high level requirements for future smart meters that will enable the efficient EV deployment.

Keywords: electric vehicles (EV), smart meters, interoperability.

1 Introduction

The massive adaptation of electric vehicles (EV) in an uncontrolled way may create a negative impact on the operation of electricity grids (overloaded lines and transformers, voltage drops, increased network losses, generation adequacy and frequency regulation, higher energy market prices etc.), necessitating new investment in the distribution, transmission and generation system [1],[2]. In order to overcome such difficulties, a middleware between the EV and the electric grid should be implemented, on the top of which the different energy/grid parties (DNO, ESCOs and aggregators) will be able to deploy their EV control and management concept. Smart meters can be effectively implemented as the middleware that will enable the control of EV.

Smart meters offer to the responsible energy/grid parties real time monitoring of the energy transaction between the EV and the grid. This energy exchange is bidirectional: grid to vehicle when EV are charging their batteries and vehicle to grid (V2G) when the EV support the grid, behaving as distributed generators [3],[4]. Smart meters allow the control of energy flow, in terms of amount and direction, in a direct or indirect way. With the direct control, the party controlling the EV defines the

N. Hatziargyriou et al. (Eds.): E-Energy 2010, LNICST 54, pp. 73–81, 2011.

set- points of the batteries and this order is transmitted to the EV battery management system through the smart meter. With the indirect control, the responsible party gives incentives through tariffication (dynamic prices, multiple tariff zones etc) to the EV owners who finally take the decisions.

Utility metering is undergoing a revolution as long established mechanical and electromechanical meters are replaced by electronic meters. This has the potential to bring hundreds of millions of new meters into use across Europe. Smart metering technology has shown general evidence of product evolution. However, the great technological diversity should not generate new obstacles. The lack of adequate common requirements on functionality and open interfaces (interoperability) fractionalizes the market and increases costs both for smart meters and for the applications and services that use metered data. Section 2 presents the high level requirements for smart meters that will enable the efficient control of EV.

2 High Level Requirements for Smart Meters

The high level requirements, which should be adopted by smart meters for the efficient deployment of EV in the electric grid, are described in this section. Each one is presented and analyzed in detail below.

2.1 Interoperability and Public Communication Standards

Large, integrated, complex metering systems require different layers of interoperability, from a plug or wireless connection to compatible processes and procedures for participating in distributed business transactions. Very simple functionality—such as the physical equipment layer and software for encoding and transmitting data—might be confined to the lowest layers. Communication protocols and applications reside on higher levels with the top levels reserved for business functionality. As functions and capabilities increase in complexity and sophistication, more layers are required to interoperate to achieve the desired results. Each layer typically depends upon—and is enabled by—the layers below it. Establishing interoperability at one layer can enable flexibility at other layers.

Compatibility and interoperability must be ensured so that the functions of the meters can be effectively used by various parties without any unnecessary technical ramifications. From the end users' scope, it is important to have the freedom to contract with different energy supplier companies (ESCOs), without the need to change the metering infrastructure, and take services from different market parties. For energy retailers competing for final customers, the key issues regarding interoperability is that the smart meter fitted at the property can be adopted by any new energy retailer and connected seamlessly with the new energy retailer's billing system. This would imply that energy retailers will have to find common approaches and agree a minimum level of functionalities related to final customer feedback that all energy retailers provide or risk implementing incompatible schemes with consequent high costs of final customer switching.

The issue of interoperability can be identified more as an issue of standards rather than technology. Standards are critical to enabling interoperable systems and components [5]. Mature, robust standards are the foundation of mass markets for millions of components i.e. smart meters. Standards enable innovation where components may be constructed by a multitude of companies. They also enable consistency in systems management and maintenance over the life cycles of the components. Such standards enable diverse systems and their components to work together and to securely exchange meaningful, actionable information.

There are a number of different physical communication media and associated protocols. It is possible that no single approach will meet all requirements, for instance, wireless based systems may fail to work in circumstances where heavy screening to the signals is required. Thus it is likely that a number of different options will be required even within a single smart metering system. Smart meters will introduce new functions such as local and wide area communications between the meters, local displays, other utility meters and the remote data collector. Smart meters may also introduce new data items, data flows and new business processes, such as dynamic tariffs and multi utility data flows. Smart metering systems will also interface with customers, smart homes applications and smart grids. The meters, display devices, communications and other devices will be produced by many manufacturers to be used by many utilities working under a wide range of market conditions. There will be multiple software applications from those embedded on the meters through to the back office. All of these components must work together correctly and reliably in parallel and series as appropriate. To achieve this, it is essential to develop a comprehensive interoperable environment for smart meters. Thus, it is important to use common standards approach as to facilitate connection to the meters.

There is a danger that the development of incompatible national schemes will lock final customers into their existing energy retailer or restrict market access to local companies that have the necessary knowledge to operate the schemes. The costs for new entrant companies will be lower if they could replicate a common approach in different countries. Such a common approach would have a number of benefits. By avoiding the need for each member state and national metering stakeholder to investigate and develop their own approach, less regulatory, industry and government cost would be required. Meter and associated equipment would be manufactured in larger volumes resulting in lower costs. Larger markets would also encourage more innovation from hardware and software developers. A common approach would also support European Commission objectives for free market in services.

2.2 Communication Architecture

A conceptual model of the communication architecture of smart metering is presented in figure 1. Two layers of smart meter communication can be identified, one with the upstream network and another with the end-user. In the upstream network, the parties that require communication with the smart meters are the energy suppliers, the distribution network operator and the service companies (i.e metering service companies). Bidirectional information flow and data exchange between the upstream network and the smart meter is mandatory, whereas it is optional for the local communication between smart meter and the customers. In the latter case, the decision depends on the cost of the required communication infrastructure which should be evaluated depending on the added value of the customers' feedback.

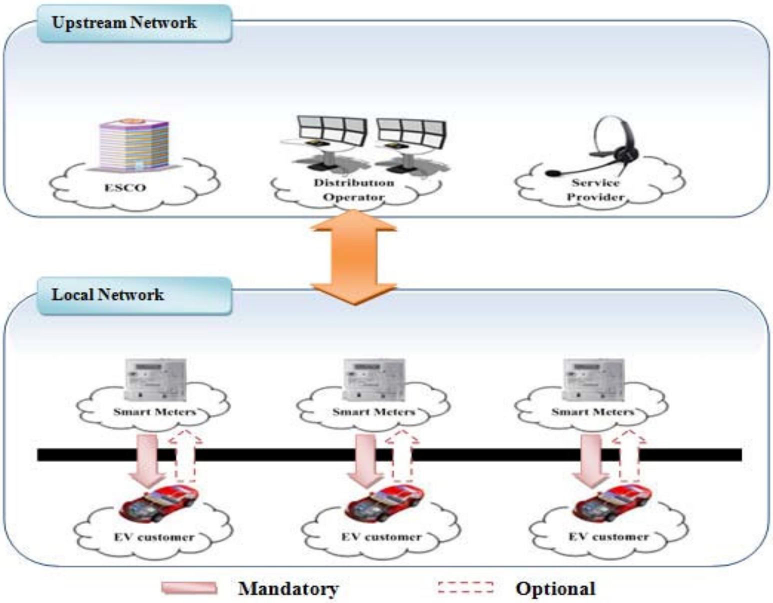

Fig. 1. Conceptual model of the communication architecture

Data exchange between smart meters and the upstream network enables various tasks like readings, connection and disconnection, tariff programming, alarms management, clock synchronization and/or firmware update, which can be done remotely.

Smart meters provide useful information to distribution network operators providing increased levels of monitoring of the distribution system. This information can be further evaluated to manage networks more efficiently, minimizing the risk of congestions and reducing the network technical or non-technical losses. Furthermore, the real-time information enables faster identification of the location of a fault and restoration time, as with smart meters the DSO automatically knows where the power is out and can dispatch crews to restore it without having to wait for customer notification.

Smart meters allow the energy supplier a better knowledge of the consumption pattern of individual customers, giving the opportunity to target them with different price options. Remote collection of meter data reduces the cost of data collection and billing inaccuracies, while the energy supplier is capable of remotely interrupting and reconnecting the customer supply. Smart meters might also be used to reduce the curtail final customer load (load management) when network or generation capacity is approached, reducing the cost of energy supply and improving efficiency.

Smart meters provide consumers historical and present information about energy consumption, power quality and the different tariff schemes. Thus customers are able to manage their energy consumption more efficiently resulting in savings on energy bills. Such information is important for the owner of an electric vehicle, since he should have knowledge of the state of charge of the batteries, the estimated time of battery charging and the remaining time of charging.

Energy and other utilities are supplied using independent distribution networks. In most cases, metering of energy as electricity, gas and heat, as well as water, is based on individual, independent meters. The principle of multi-utility smart metering is to combine all utility measurements into one device or system. In many circumstances, a smart metering system for more than one utility, for example electricity and gas, could be more effective in influencing energy savings as well as optimizing the metering installation costs and maintenance. There are a number of different models for multi-utility metering; the system can be operated by a single energy retailer offering multi-utility services, metering services can be provided by an external independent data acquisition company, or a single utility can offer access to their smart metering system to other utilities. Generally, multi-utility metering offer a significant opportunity for reduction of operational reading costs, especially with regard to shared communications systems and customer displays. Instead of many subsystems only one reliable system is used.

The design of the communication architecture should ensure the communication performance requirements in terms of availability, reliability and speed of response. For some services communication availability and response time are much more critical than high data transfer rates and the impact of these on the final customer experience should be considered at the design stage. For example, dynamic tariffs and demand response might need instantaneous communication in order to deal with an imminent peak demand rather than settlement and billing. Reliability is very important as far as the billing process is concerned. Most modern meters store metered values for several weeks or months (depending on memory specified) thus reducing the risk of billing data loss due to WAN reliability issues.

Security of the communication is another major issue that should be addressed. Smart meter systems are vulnerable to hacking attempts as they are widely accessible for extended periods and control large financial values. The security of the system must be managed appropriately to ensure that only approved parties can access the meter data and that final customers and others cannot access data within the meter that they are not approved to view. As the computing power of home computers can be expected to rise considerably over the lifetime of the smart metering system, the meters should be able to remotely accept improved security algorithms during their service lives.

2.3 Service Lifecycle Management

Service lifecycle management deals with the administration of functionalities and services during their entire lifecycle. Service lifecycle management (SLM) is a holistic approach which helps service organizations better understand the revenue potential by looking at service opportunities proactively as a lifecycle rather than a single event or series of discrete events. Almost all the different types of smart meters provide customers the same functionalities. What will drive the purchase decision of the customer besides price is the service.

The service lifecycle management should enable the deployment of new services, the update of existing services, the starting and stopping of services and the configuration and parameterization of running services. A sophisticated lifecycle management has the potential to increase the availability of enterprise systems as it extends the possibilities of changing grid operation processes without considerably influencing the efficiency of the entire system.

2.4 Eventing Support and Alarm Handling System

Either in the local network or in the grid, the events that can be generated are numerous even during normal operation. Some of these events can provide an overview of the current status of the network while others can indicate unexpected problems. The event reports may not be only electrical but functional as well. The list below presents examples of event reporting:

- Confirming successful initialization of the smart meter installed in the field
- Confirming data linkages between a smart meter identification number, serial number and customer account
- Confirming that the meter management data has successfully received notification of any changes to customer account information
- Confirming that the metering service operator has successfully made changes to customer account information
- Confirming the successful collection and transmission of meter data or logging all unsuccessful attempts to collect and transmit meter data, identifying the cause, and indicating the status of the unsuccessful attempt(s)
- Confirming whether the meter reads acquired within the daily read period are in compliance with the time accuracy levels
- Confirming time synchronization
- Addressing the functionality of the smart meter communication link
- Identifying suspected instances of tampering, interference and unauthorized access
- Identifying any other instances that impact or could potentially impact the smart meter's ability to collect and transmit meter reads to the responsible parties.

Apart from the eventing support, smart meters should be equipped with an alerting system in case critical events are generated. Critical events are defined to include any operational issue that could adversely impact the collection and transmission of meter information during any daily read period.

- ✓ Smart meter operational failure
- ✓ Issues related to the storage capacity
- ✓ Communication links failures
- ✓ Network failures
- ✓ Loss of power and restoration of power
- ✓ Unauthorized access

Filtering (to select the messages that are of real interest), local processing and evaluation are additional mechanisms that can enhance the performance and scalability of the eventing support. In a critical situation, messages have to be treated with high priority. Furthermore, the smart meter should get only the necessary decision, critical information and not get overwhelmed with all alerting data from the network. Therefore, support for the exchange of emergency data and a common alerting protocol have to be in place.

2.5 Ability to Combine Different Business Cases and Participate in Different Market Services

The power market environment is quite complicated since there are several different market sectors where a market player can participate. The fact that electric vehicles can behave either as distributed generators or as controllable loads complicates the situation even more since they are able to directly sale energy or provide ancillary services. Smart meters are the mean to the market participation. Thus, they should enable the participation of EVs in different business cases, such as those described in SmartHouse/SmartGrid project [6] and the selection should be made according to the price offered by the responsible parties (aggregator, ESCO).

Smart meters should enable the market participation of electric vehicles as either individual units or aggregated sets [7]. In the latter case a commercial aggregator should exercise the task of jointly coordinating the energy use of electric vehicles that have contracted with them. The joint management of a collection of electric vehicles can be done in two ways. The aggregator might directly control several electric vehicles, however this would require the end-users to allow direct access to the control of the vehicles. Another way is that an aggregator can only provide incentives to the participating vehicles, so that they will behave in the desired way with a high probability, but not with certainty. The second option leaves the power of control to the end-user.

The aggregated sets of electric vehicles can provide real-time imbalance reduction of a retail portfolio by utilizing the real time flexibility of the end customers. An actor that is responsible for a balanced energy volume position is called Balance Responsible Party (BRP). The BRP is obliged to make a plan by forecasting the production and consumption of the responsible grid area (control area) and notify this plan to the TSO. The risk of this predictability may cause deviations from this plan and consequently generate imbalance costs due to the use of reserve and emergency capacity. In order to manage imbalance risk, market participants undertake balancing activities before gate closure occurs in the power exchanges, as well as in the settlement period itself. In the latter case, the key idea is the utilization of real-time flexibility of their dynamic approach, behaving either as flexible distributed generators or as responsive loads/storages. Market parties aggregate these flexible distributed generation and responsive loads in a virtual power plant (VPP).

Another business case is the distribution system congestion management. Non- coordinated control of a large fleet of electric vehicles may lead to a sharp rise in needed capacity on lines and transformers. By coordination of these devices they can be allocated time slots for operation, that are spread over time ensuring the stability of the grid. The distribution network operator detects overflow situations based on the congestion management system and relies on customer site response programs to tackle this. The end user (electric vehicle owner) should be able to deliver flexibility services to the network operator. Therefore, in case that a substation controller measures the load flow and is critical, it creates a market signal that encourages the electric vehicles to react accordingly by adjusting their operating point based on the prices.

Variable tariff-based load and generation shifting is the business case where a variable profile is given to the customer one day before the day of delivery by a retailer. The profile is considered fixed after transmission to the customer, so the customer can rely on it and send feedback of their automatically planned/predicted load/generation profile. It would be possible that in exchange for an additional financial incentive, customers might be willing to accept adaptations of the price profile during the day of delivery reflecting changes in the retailer's portfolio that come up during the day and also to reduce imbalance in his portfolio. Another option could be a "maximum average cost per kWh" guarantee given by the retailer, protecting the customer from an increase in his energy cost by errors in the automated management systems or by his personal behavior.

Distribution grid cell islanding in case of upstream system events is another important business case. The key idea of this business case is to allow the operation of a grid cell in island mode in case of upstream system disturbances in a market environment. This business cases considers that the islanding procedure is performed automatically. The scenario has two main steps: the first step takes place before the event that may occur and the second step is the steady islanded operation. During the first step the customers declare their availability and forecast the consumption as well the available power and energy in the next hours. A load shedding schedule should be created according to the criticality of the consumers, as well as the amount of money they are willing to pay during the island mode. In the first minutes after the event the DSO allows operation according to the criticality. If there is enough power within the islanded part, no load shedding will take place. When balance and stability has been ensured, the Aggregator decides how to manage the energy within the network.

3 Conclusions

Smart meters are the key technology that allows the actors involved to control the bi- directional energy flow between EV and grid. The massive implementation of smart meters presupposes the definition of common requirements. This paper presented a discussion on common high level requirements for smart meters, that will allow the controlled deployment to mitigate potential negative impacts of a massive EV penetration to the grid.

Smart meters are the middleware that enables market participation of EVs. Smart meters allow either direct control of the EV by defining set-points for the exchange of power between batteries and the grid or indirect control by providing the EV battery management system with price signals, depending on the type of market they participate.

Interoperability and high communication standards are the two major forces that will boost the massive implementation of smart meters. The common architecture defines all interactions between smart meters and the different entities or devices in the overall electric grid.

Acknowledgment

The authors would like to acknowledge the support received EU for the research project "Merge".

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