Development of a Conceptual Reference Model for Micro Energy Grid

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Abstract

In this paper, we present a conceptual reference model necessary for further study on interoperability between logical nodes for a variety of services in a micro energy grid that enables realizing efficient energy generation, consumption, and distribution by optimally utilizing different energy resources like gas, heat, as well as electricity. Referring to the conceptual reference models presented in the NIST standardization framework for the Smart Grid, we define key features and major applications required for the micro energy grid, and design an application-level reference model for each of them.

Keywords: Micro Energy Grid, Conceptual Reference Model, Smart Grid, MEG, Domain Model, Micro Grid

1. Introduction

Due to increasing shortage of the fossil fuel and the impelling pressures from environmental protection, new generation sources of high efficiency such as fuel cell, micro gas turbine, and heat pump, as well as Renewable Energy Sources (RESs) such as wind and solar power, are becoming the most important Distributed Energy Resources (DERs) nowadays. As the Smart Grid are getting into real implementation phase from conceptual reference modeling, the need for more effective and efficient smaller smart grid is emerging that has decentralized generation and storage facilities placed physically near the customer premises.

Micro Energy Grid (MEG) is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. MEG can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode. It also considers heat and gas as well as electricity, as one of the target energy resources that should be managed to improve energy utilization on micro grids. Traditional smart grid technologies have been developed to improve the energy efficiency mainly focusing on electricity. However, the importance of other energy resources like heat and gas might be relatively higher according to the characteristics of the target domain for MEG business. In addition, there co-exist different energy resources in most business domains like commercial building or industrial complex. Thus, different energy resources are needed to be considered in a combined way to improve energy efficiency on targeted MEGs.

To accelerating the deployment of MEG, it is required to build and verify practical business models which enable optimized energy generation, delivery, and consumption by monitoring and analyzing the whole process of energy life cycle. For this, it is important to ensure interoperability between various types of devices, systems and services on micro grids. A formalized reference model for MEG can be employed as an interoperability guide to lead a MEG project successfully. Thus, we made a study on a conceptual reference model for MEG. Its goal is to identify functional entities and define logical interfaces among them for use in a variety of MEG applications. After identifying key features from the concepts of MEG, we develop a conceptual reference model including the domain model and functional architecture for MEG. We also design application-level reference models that define functional elements and their associations for identified high-priority applications. The designed reference models help MEG service providers to be aware of interoperability issues on their MEG projects and settle the issues with other participants easily.
2. Related Works

The smart grid requires a hundred of standardizations, specifications, and requirements to ensure its interoperability. NIST chose 8 priority areas that should be mainly considered in the smart grid, and decided to focus on them in developing interoperability standards necessary for the Smart Grid. NIST also divided the Smart Grid into several domains such as customer, market, service provider, operation, bulk generation, transmission, and distribution [1]. On the basis of the NIST framework including a smart grid conceptual reference model, IEEE P2030 presents the Smart Grid Interoperability Reference Model (SGIRM) to give interoperable design and implementation that facilitates data exchange between Smart Grid elements. The P2030 SGIRM is a conceptual representation of the Smart Grid architecture from three different perspectives such as power systems, communications, and information technology platforms. It presents a set of diagrams that contain smart grid entities and their relationships in order to offer standards-based architectural models for the integration of power systems with communications and information technology platform. The P2030 SGIRM also performs a role as a platform for smart grid applications [2].

3. Design of a Conceptual Reference Model for MEG

MEG is to enhance the local reliability and flexibility of traditional electric power systems, which may consist of distributed energy resources (DERs), loads, measurement and protection devices, and management systems. It is a sort of a small electric power system being able to operate physically islanded or interconnected with utility grids. MEG also embraces different energy resources like heat and gas as well as electricity. Considering these key features of MEG compared to the Smart Grid, we design a conceptual reference model for MEG. Although the designed model is based on the NIST 7 domain model, there exists the difference between them. One big difference is that the designed MEG domain model does not include bulk generation and transmission domain because the domains lie beyond the scope of MEG defined as a group of interconnected DERs and loads within clearly defined boundaries. Instead, we newly add the DER domain that provides the functionality of energy generation for the MEG on the behalf of the bulk generation domain of the Smart Grid. With the newly defined 6 domain model including Market, Operation, Service Providers, Distribution, DER, and Customer domain, we design a MEG conceptual reference model.

![Conceptual Reference Model for MEG](image)

**Figure 1.** Conceptual Reference Model for MEG

The reference model shows domain actors and their communication paths via information network within a domain or across domains. Figure 1 shows that the reference architecture for MEG consists of information network, domain actor, and communication path.
4. Design of Application Level Conceptual Reference Models for MEG

To develop the Smart Grid standardization framework, NIST focuses on 6 key applications to prioritize its work to achieve interoperability of smart grid devices and systems [1]. Among the applications chosen for the Smart Grid, we focus on 2 key applications which are considered ones closely associated with MEG: advanced metering and distributed micro energy grid management. These applications are modeled by using functional elements depicted in the conceptual reference model for MEG. To clarify functionalities and operations of each MEG application referring to their requirements and service scenarios discussed in [3], we identify the domain actors and logical communication interfaces among them, and describe application-level conceptual reference models for each application as follows.

4.1. Advanced Metering

The influence of market-driven pricing and electricity deregulation has led utilities to look for a means to match consumption with generation. Advanced Metering is a core application to keep balancing energy demand and supply by enabling two way communications with smart meters. AMI systems are capable of measuring, collecting and analyzing energy usage, allowing commands to be sent toward the home for multiple purposes, including pricing information, demand response actions and so on. Basically, AMI systems consist of smart meters, metering systems, and Meter Data Management Systems (MDMSSs). MEG aims at enhancing energy efficiency through proper utilization of different energy resources and energy saving control. This can be achieved by gathering meter data from a large number of measuring points on multiple paths considering the characteristics of individual energy resources. This means that the measuring target range is needed to extend from customer sites like home, building, and factory to individual customer devices or DERs. The DERs can be placed inside a customer site or outside. To build a diverse range of metering infrastructure for MEG, we present a reference model of advanced metering as depicted in Figure 2.

![Conceptual Reference Model for Advanced Metering](image)

**Figure 2. Conceptual Reference Model for Advanced Metering**

In this model, we consider two different aspects of energy metering at the same time. From a utility provider perspective, energy use of individual households could be measured through logical communication paths AM1 and AM3 via private utility networks. Metering information from DER or Distribution domain could be gathered through AM2, AM4, AM5, and AM9. The Sensors and Measurement Devices could directly send meter data to the Distribution SCADA or via the DER Gateway/EMS. On the other hand, Retail energy providers could access to customer sites via the Energy Services Interface due to the security concerns on meter data communication in the Internet, and collect meter data from Meter and DER Gateway/EMS through AM5, AM6, and AM13. Customer
EMS could get meter data through AM7 and relay them to the retail energy provider through AM8 and AM5.

### 4.2. Distributed Micro Energy Grid Management

MEG is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that act as a single controllable entity. MEG safety and reliability must be ensured by deploying a variety of protection, control, and measurement devices. These grid assets offer some crucial information necessary for grid operators to schedule their DERs’ operations. On the basis of the information, precise measurement on energy consumption and production enables sharing surplus energy among neighborhood MEGs and supplying it to the macro grid. With the capability of two-way energy flow control, surplus energy from small distributed generators could be aggregated into energy large enough to supply it to customers. All of these requirements and functionalities are considered in designing a reference model for micro energy grid management shown in Figure 3.

The main purpose of MEG management is to protect and control its grid assets and networks. For this purpose, a utility provider collects information from Sensors and Measurement Devices through logical communication paths DM2 and DM7 via Distribution SCADA, and issues control messages to Protection and Control Devices through DM2 and D9. Utility providers also adjust energy production of their own DERs, keeping monitoring the state information of the DERs through DM11, DM12, DM13, and DM14 via DER Gateway/EMS. Considering energy price information from energy market and grid reliability, Micro Grid EMS determines an appropriate grid connection type, and requests Grid-Tie Switch to set appropriate connection modes through DM8. Third party providers as an aggregator check the state information of customer DERs through secure channel DM3 via ESI, and properly manage operation schedules of the DERs in order to meet contract conditions on energy aggregation and supply with energy market.

![Figure 3. Conceptual Reference Model for Distributed Micro Energy Grid Management](image)

### 5. Conclusion

MEG is a sort of a small electric power system being able to operate physically islanded or interconnected with the Smart Grid. It considers not only electricity but also heat and gas as one of the target energy resources that should be managed to improve energy utilization. Regarding these key features compared to the Smart Grid, we designed a conceptual reference model including the domain model and functional elements for MEG. Among the key applications for the Smart Grid, we chose advanced metering and distributed energy grid management as core applications for MEG. The chosen core applications were modeled including domain actors and logical communication interfaces among
them. The designed conceptual reference models can help MEG designers locate interoperability problems on their MEG projects and solve the problems.

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7. References