Software Functional Requirements and Architectures of Microgrid Energy Management System

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Abstract

Distribution management system or microgrid energy management system plays an important role in monitoring, operation and control of electrical distribution systems by utilizing IT infrastructure. Nowadays, the rapid increase of the distributed resources makes the conventional management system have some additional functionality for the reliable operation due to intermittent renewables and the efficient operation on the economical purpose. In this paper, the brief standard software functional requirements of microgrid energy management system are provided through survey of the recent commercial products of the major vendors, and furthermore the architectures of microgrid energy management system are provided in comparison with major suppliers' microgrid energy management system. The summary of investigation will be able to make the developers and researchers focus on the specific functionality in the real world.

Keywords : Distribution management system, microgrid energy management system, renewables, application software program, software functional requirements

I. INTRODUCTION

Many distribution power companies make an effort to operate their power apparatus, e.g., sectionalizer, recloser, circuit breaker, transformer, etc., for stable power supply together with IT-based distribution management system (DMS) [1][2]. Meanwhile, the distributed energy resources (DER) are installed increasingly to save the operational energy costs and avoid CO_2 emission under the regulation or for the social welfare. In particular, of the fast-growing renewables e.g., wind power or photovoltaic, make the distribution power company or the owner of DER have difficulty in balancing power supplies and demands efficiently as well as maintaining the power quality, i.e., voltage or frequency under a certain limitation. To cope with this problem, electrical storage system is used for compensation of the intermittency and the profit maximization [3][4].

DER are simply interconnected with the traditional power system line in the earlier stage. However, the more DER are installed in the distribution system, which can constitute a small scale power grid in conjunction with its multiple groups of loads and it is called microgrid, the more needs about the efficient and economical operation of DER within microgrid there exist [5]. Microgrid has two operation modes. One is on-grid mode where microgrid is operated in parallel with the main grid, and the other is off-grid mode where it is isolated independently [6]. The main operational objective of on-grid mode is to minimize the operational costs with the tariffs which is imposed on the customer or the owner of microgrid at point of common coupling. The main operational objective of off-grid mode is to maintain the frequency or voltage within a certain limited value while keeping the balance between supply and demand.

The extensive researches examined the energy management of microgrid [7]-[10]. There are two approaches to energy management of microgrid; the centralized energy management and the decentralized energy management. The centralized energy management of microgrid is similar to energy management of the main grid in respect of the energy management process, and the decentralized energy management is mainly based on the multi-agent technology. Recently, the commercialized energy management systems are mainly based on the centralized energy management [11].

Typically, the centralized energy management has three level of control hierarchy; the primary control, the secondary control, and the tertiary control. The primary control means the local control where the inverter or the synchronous generator is controlled by control target value or by its own control strategy autonomously in milliseconds. The secondary control means the management system level of frequency regulation or the voltage regulation by using droop characteristics in seconds for the parallel operation of multiple generators. The tertiary control means the economic dispatch of distributed resources in minutes including the generation scheduling before a couple of days or before twenty-four hours. The electrical load forecast as well as renewables forecast such as photovoltaic and wind power generation which is essentially based on weather forecast should be performed in advance of the generation scheduling. Fig. 1 shows the typical functional process of energy management. These applications of energy management system will be built based on the substantial software platform which consists of database system, communication system, and primitive data processing process system, or the embedded hardware system.

Nowadays lots of microgrid projects have been performed for test and validation, where a variety of emerging technologies are implemented [5][11]-[13]. However, almost all of them cover only the operational strategy or the special algorithm for their own specific purpose. The specific methodology of each application will

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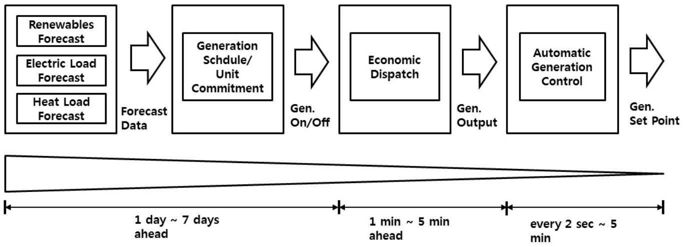

Fig. 1. The typical functional process of energy management.

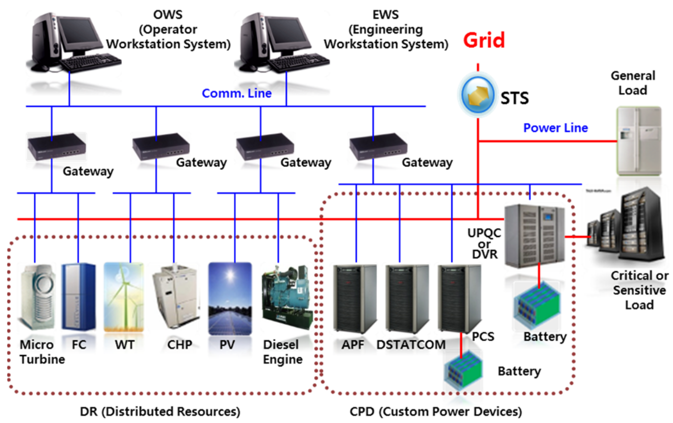

Fig. 2. Typical configuration of microgrid.

not be focused in this paper, but the typical functionalities of software applications in microgrid energy management system (MGEMS) as well as its architectures on which software applications are built, will be focused on and reviewed through the investigation of the researches and the commercial microgrid products, which helps to build the baseline system and to design the integrated software system in detail.

II. ENERGY MANAGEMENT IN DISTRIBUTION SYSTEM

A. Distribution Management System (DMS)

Aging infrastructure in the distribution system especially in the North America makes the utility introduce the commercial advanced distribution management system [14], whose main functionalities can be categorized as follows:

1) Typical functions
- Dynamic topology processing
- Fault Detection, Isolation & Restoratin
- Distribution automation
- Outage analysis
- Geographical schematic distribution feeder single line displays (SLD)

2) Advanced functions
- Volt/VAR control
- Line loss reductions
- Switching order suggestion
- Closed loop
- Protection coordination
- AMR/AMI
- Interface to work order management system (WOS)

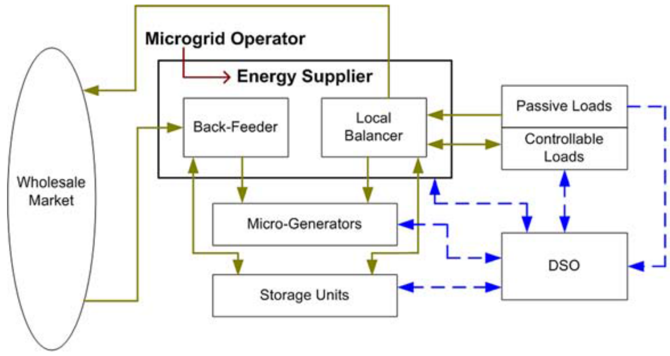

Fig. 3. The liberalized market model.

- Interface to customer information system (CIS)
- Messaging system to field crews
- Information system for power system assets

In addition to the above functions, applictions of microgrid, e.g., generation applications to handle the operation of DER including renewables and electrical storage system and power demands can be implemented as a subsystem or a subfunction of DMS. but it is a recent trend to build the separate generation management system to DMS while it is interfaced with DMS for data exchange.

B. Microgrid Energy Management System (MGEMS)

Microgrid consists of the DER, power electronic devices and power apparatus, communication system, and management system as shown in Fig. 2. In the respect of the owners of DER, market model for microgrids can be classified into monopoly model, liberalized market model, and prosumer consortium model [15]. The market model is very important to determine the functionalities and architecture of MGEMS. For example, since MGEMS can deal with one microgrid of multimicrogrid simply as a distributed resource in the aggregate amount, the centralized energy management is more appropriate for the monopoly model and prosumer consortium model. However, MGEMS can be a subsystem or subfunction of DMS for monopoly model, but it is not true for prosumer consortium model. Furthermore, the required load demand can be supplied by the excessive generation of DER or by purchasing more electricity from grid even for prosumer consortium model where the owner of microgrid has both DER and loads. Another option is that the required load demand can be curtailed by suppressing the controllable loads. For this reason, the generation and demand response are dealt with separately in general. Almost all of commercial products of the major vendors' MGEMS , e.g., ABB, Alstom, GE, Schneider, and Siemens, are being developed for the liberalized market model in Fig. 3, where a variety of solutions about demand response are supplied. Finally, we categorize the functionalities in MGEMS into three main functions in this paper by taking into consideration that it is difficult to determine the solution of the mixed generation scheduling and demand response and that it is difficult for software application to complete the required actions without high-performance hardware, e.g., storage inverter or static transfer switch.

1) Generation Scheduling Functions

Generation scheduling functions of MGEMS are similar to those of the wide area generation energy management system, i.e., the simplified generation energy management system in the assumption that all of generated energies supply all of power demands with no consideration of the network topology. The formulation of the following solution has to include the minimum number of states or status which is selected by intensive investigation on the network changes, e.g., interlocked operation by automatic transfer switch of multiple generators. In addition, more than one point of common coupling (PCC) may be challenges of researches and developments in perspective of both microgrid owner and distribution system operator (DSO), e.g., there are difficulties in the determination of the flows at multiple PCCs to maximize the profits for microgrid owner or the awareness of looped operation through multiple PCCs in microgrid for DSO. Moreover, prioritization has to be dealt with in applications, e.g., operator's manual override state/status, smart inverter's time based schedule, remote commands from DSO, etc.

- Renewables forecast : photovoltaic or wind
- Electrical or thermal load forecast
- Optimal generation scheduling : operating reserve and minimum operation time for a long lifetime
- Economic dispatch : operation cost minimization including environmental costs or profit maximization
- Automatic generation control : frequency control
- Automatic voltage control : reactive power control
- Automatic energy storage system control

2) Demand Management Functions

In comparison with generation energy management system, microgrid energy management system should include the functionalities about demand type distributed resources as follows [16]. Almost of all functions are designed on normal conditions, except load shedding on emergency condition, which has to be integrated with the restoration process by sequence process list after transition to normal condition. Demand management functions are developed independently of generation scheduling functions until now. The integration of generation scheduling and demand management will be challenges because both results inevitably affect each other, e.g., the reduction in demands by demand management will cause the reduction in generation at that time, which is not the result of generation scheduling.

- Load shedding : capacity program
- Load shedding : emergency interruptible program
- Ancillary service markets
- Load shifting
- Load into supply market
- Information system for power system assets

3) Power Devices Dependent Functions

Scan period for telemetered value is typically a few minutes and the shortest scan period can be a few seconds in some special case. For uninterrupted operation when the fault in the main grid occurs, the very fast separation between the main grid and microgrid and then the continuous energy supply with energy storage system is required, which can be completed only with software energy management system. In a certain condition, the sustainable operation is prohibited due to interconnection rules. Microgrid energy management system should include the functionalities about power devices as follows.

- Anti-islanding : anti-islanding protection
- Automatic reconnection
- Load shedding : based on special purpose hardware
- Blackstart
- Renewables output limitation control : dependent on load level or load factor of wind energy

III. ARCHITECTURES OF MGEMS

Major EMS/DMS suppliers will provide applications modules to help microgrid operation. The microgrid market is growing rapidly, but there is no typical form of MGEMS. Even major suppliers develop and provide MGEMS based on their own different architectures, respectively. According to hardware architectures, we categorize some recent commercial MGEMS into three architectures in this paper: EMS/DMS platform based architecture, embedded system based architecture, and service oriented architecture.

A. EMS/DMS Platform Based Architecture

Platform based architecture will be appropriate when MGEMS market will be growing in similar form of the wide area energy management system. In this case, microgrid will be constructed with larger scale manned or unmanned center, and one central energy management system can handle all of multiple child microgrid even in multimicrogrid.

1) Alstom Grid

Alstom Grid has its *e-terra* platform and lots of appropriate *e-terra*s based on its base platform in the generation/transmission power system. For MGEMS, *e-terra*renewableplan is provided for forecast and planning, and *e-terra*disgen is provided for operation of distributed resources. In addition, *e-terra*DRBiznet is provided for demand response.

2) Siemens

Siemens has Spectrum Power platform (formerly known as Telegyr) and lots of appropriate Spectrum PowerCCs based on its base platform in the generation/transmission power system. Spectrum Power 7 MGMS (Microgrid Management System) as a MGEMS is provided, where the special functions such as generation and load management, forecast application, and optimization applications are implemented [17]. In optimization applications, the commercial optimization solvers, e.g., IBM ILOG CPLEX and Gurobi are used.

B. Embedded System Based Architecture

Embedded system based architecture will be appropriate with the limited budget. In this case, microgrid is anticipated to be constructed with small scale unmanned center. Central energy management system plays a role on only remote integrated monitoring or only simple optimization with suboptimal solution received by child microgrid in multimicrogrid, i.e., distributed computing.

1) ABB

ABB has the extensive Network Manager's system for

EMS/DMS. However, he has the different simple system for MGEMS. The industrial PC called MGC series as a local controller is provided and software web solution called M+ Operations as a central manager is provided [18][19]. Its solution is almost same as SCADA except the simple scheduler of the distributed resources.

2) GE Digital Energy

GE Digital Energy has XA/21 solution for EMS and PowerOn platform for DMS. However, he has a little bit simple different system for MGEMS. The industrial PC called U90 plus as a local controller or a central controller is provided. The concept of U90 plus has the hierarchical characteristic [20]. Compared with ABB MGC series, U90 series provide the fluent generation optimization solutions and HMI Display in it. Similar to ABB, software web solution called EnerVista as a central manager is provided.

C. Service Oriented Architecture

Service oriented architecture is similar to EMS/DMS platform based architecture in except that hardware infrastructure will not be implemented in the field, but in the cloud system. In this case, microgrid is anticipated to be constructed even with no unmanned center. It may not be appropriate in the time-critical case, where local hardware controllers are essential.

1) Schneider

Schneider has its ADMS (Advanced Distribution Management System, formerly known as Telvent) for EMS/DMS. However, he has the different simple system for MGEMS. The software web solution based its unique cloud-based StruxureWave platform as a central manager is provided. Its solution is almost same as SCADA except the simple scheduler of the distributed resources.

IV. CONCLUSION

The standard software functional requirements and architectures of MGEMS are provided in this paper through survey of the researches and the recent commercial products of the major vendors. The determination of the target market is important in advance of development of the entire efficient MGEMS. Nowadays microgrid market is growing fast, but the typical architectures and configuration of hardware system as well as software system have not yet been established.

Many suppliers in the world have developed the site-specific energy management system, which has to be modified massively in different sites or which has the simple dashboard showing only the metered value and trend data. Even major suppliers of conventional EMS/DMS provide the different types of MGEMS due to the immature market environments. The standard software requirement and architectures of MGEMS are investigated and summarized in this paper, which helps the extended researches and the efficient development of MGEMS in the real world.

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