DEVELOPMENT OF SMART DISTRIBUTION MANAGEMENT SYSTEM FOR PREDICTIVE OPERATION OF POWER DISTRIBUTION SYSTEMS

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ABSTRACT

In this paper, the development of Korean Smart Distribution Management System (KSDMS) for real-time predictive operation in distribution systems is introduced. The summary is divided into two parts. One is the system architecture that is consist of the device level for the real-time data acquisition and the server level for the data related to the voltage, current, faults, power quality and load profiles of the network are gathered using a standardized communication method based on IEC 61850. We developed the smart Feeder Intelligent Electronic Device (FIED) communicated using IEC 61850 protocol. The other is a real-time security analysis programs for smart distribution systems, designed to provide the distribution operator with accurate real-time situational information and predictive operation. We designed the database which can be used commonly for all security analysis programs of KSDMS.

INTRODUCTION

In the circumstance of smart grid, the use of renewable energy resources (wind power and solar) and customer information will be steadily increased. Technologies to operate and control the distribution systems are especially important because they are directly influenced by new facilities and information.

In recent years, many reports relating to smart distribution management systems have been published [1-7]. Mamo et al. explained the concept and necessity of smart distribution applications and suggested the need for fast simulation and modeling [1]. Sebastian et al. proposed distribution state estimation and situational awareness [2]. King approached smart grids with respect to the data model [3]. Fan compared the management tools of conventional distribution systems with those of smart grid systems [4]. See et al. presented the need for real-time analysis of distribution systems, insisting on periodical data measurements of various distribution networks [5]. Suter and Werner introduced the concept of an Energy Management System (EMS) and described the role of the control center for smart distribution systems [6]. Mamo et al. compared conventional distribution automation with smart distribution management and proposed distribution state estimation, voltage var control, and network reconfiguration as the solution for smart distribution control [7].

Overall, the studies above identify important common elements for smart distribution management system. First, operators of smart distribution systems should have fast and accurate access to the current network situation. This requires periodic and fast simulation of the distribution network security, as well as collecting variety of real-time information for each network component. Second, changes in the topology of the distribution system and the role of the distribution control center must be considered. In a smart distribution grid, the grid topology is not only radial; looped and meshed networks will also be introduced under normal operation conditions. Therefore, the role of the control center can no longer be that of merely indicating faults in the distribution network. The concept of the control center must change for EMSs.

In this paper, we summarize the development of system architecture and application software for the Korean Smart Distribution Management System (KSDMS). A high-level concept for solution-based processes of KSDMS is extracted and low-level designs are also accomplished by using each functional component.

CONVENTIONAL DISTRIBUTION SYSTEMS

Distribution Automation Systems (DAS) are responsible for the control and management of conventional distribution systems in Korea. DAS aims to solve the problems caused by unanticipated faults in distribution systems.

Configuration of a distribution systems

The range of distribution systems in Korea covers the circuit breaker of substation to distribution transformers. It is composed of distribution feeders and related equipment; protective devices, automated and manual switches, and distribution transformers (pole/pad type).

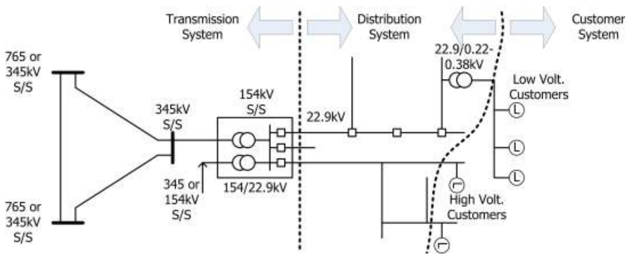

Fig. 1. Topology of a conventional distribution system.

A conventional distribution topology is shown in Fig. 1. As shown in Fig. 1, the facilities in the distribution substation (154/22.9kV) are not included in the distribution system. Therefore, to control and manage the distribution system, distribution operators only use protective devices, automatic switches and distribution transformer taps in distribution feeders.

Conventional distribution automation system

Development of the Korean Distribution Automation System (KDAS) begun in 1993, and KDAS has been operating since 1998. Until now, KDAS has been installed in all 190 branch offices, and around 35% of total 127,000 line switches have been automated. Several types of communication media such as optical fiber (68%), telephone wires (15%), trunked radio systems (TRS, 8%), mobile data (8%) and CBMA (1%) are used for KDAS.
The major functions of KDAS are to monitor distribution feeders, clear the faults, and restore unfaulted sections. Faults events are automatically detected and cleared by protective devices. After clearing the fault, the unfaulted section loads are restored by handling automated switches. Switch control is accomplished via remote operation by control center operators or by the maintenance crews who are dispatched.

Challenges for operating distribution systems

In the DAS, a few real-time measured data is gathered and the time synchronization of the data is not up to the expectation. The operators of DAS did not recognize the exact system condition (voltage and current) but he can expect that because the other power sources except for the power from transmission system are not existed and the system topology is always radial. However, his intuition cannot use any more because the output of renewable energy resources is frequently changed according to the environmental factors and the closed loop topology is introduced in the distribution system.
Therefore, the smart distribution operation system that provides the accurate current system conditions and the predictive measure for the abnormal conditions is needed.

KSDMS ARCHITECTURE

The KSDMS project was started in 2009 for obtaining the advanced distribution operation in smart grid circumstance of Korea. The object of KSDMS is to provide the accurate real-time situation information and predictive operation. The KSDMS is composed with two parts. One is the system architecture that is consist of the device level for the real-time data acquisition and the sever level for the data processing and middleware. In the KSDMS, numerous data related to the voltage, current, faults, power quality and load profiles of the network are gathered using a standardized communication method based on IEC 61850.

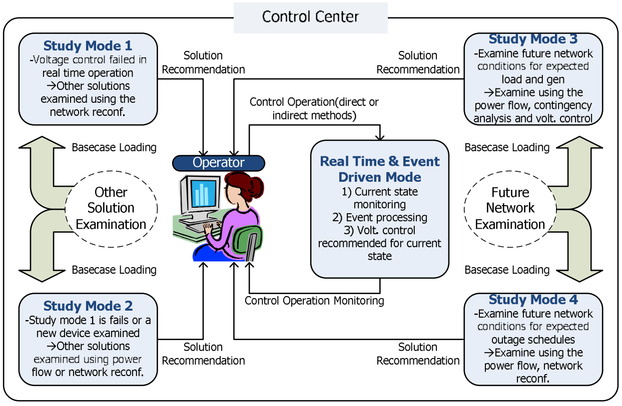

Fig. 2. Solution extraction procedures for KSDMS.

We developed the smart Feeder Intelligent Electronic Device (FIED) and Advanced Metering Infrastructure (AMI) gateway communicated using IEC 61850 protocol. The other is the application software that is to provide the accurate real-time situation information and predictive operation.
The solution extraction strategies are shown in Fig. 2. As shown in Fig. 2. An operator supervises the operated network by using a real-time measured data and the results of the application software. If a problem (i.e. voltage violation, line overloading, etc) is predicted, the operator sends a command to the remote controlled devices via Human Machine Interface (HMI).
As shown in Fig. 2, solution extraction procedures of KSDMS are shaped as EMS. The operators of KSDMS can recognize problems and anticipate potential risks for the entire distribution network for each branch office using various application solutions. In the rest of this section, we will introduce the system architectures for the solution extraction procedures.

Server system architecture

Fig. 3 shows the composition of the KSDMS servers and the interconnections among the components through middleware. Data from field devices such as FIED and Feeder Remote Terminal Unit (FRTU) are connected and exchanged with the server via Data Communication Processing (DCP).
Other system components include HMI, engineering

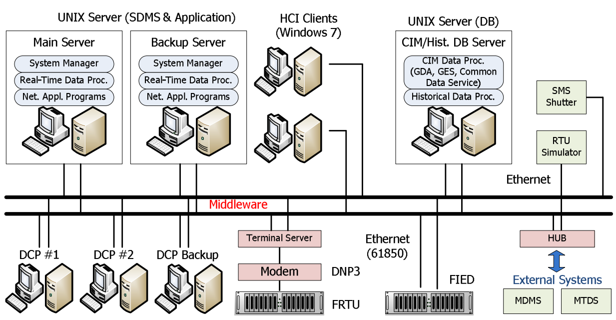

Fig. 3. Server system architecture.

stations for DB, and schematic editing, the application server and DBMS server are also connected to each component via middleware. The characteristics of our server architecture are summarized as follows.

1) The UNIX is selected for the Operating System (OS) of the servers for considering the stability of the system.
2) The multiple backup is employed for the DCP server.
3) The application software and operational database is in the main server.
4) Due to an economic point of view in distribution network, we allow the SPF (single point failure) of server architecture, i.e., historical DB server, terminal server, etc.

For exchanging CIM data with external systems, the server uses Generic Data Access (GDA) for request/reply oriented service for access of complex data structures and Generic Eventing and Subscription (GES) for a general purpose capabilities to publish and subscribe to events and alarms defined in IEC 61970/61968.

Data communication processing

The main component in the data communication processing of KSDMS is the DCP. It processes data from field devices using IEC61850 as well as DNP3 protocol. It analyzes the data frames from field devices and converts these events to measurement and control data. Using Simple Network Management Protocol (SNMP), the DCP also provides the capabilities of configuring and monitoring the communication networks and devices. It can also manage time synchronization between field devices using Simple Network Time Protocol (SNTP). It uses redundancy control to achieve high availability. Fig. 4 shows the system architecture of the DCP.
IEC 61850 is considered as the protocol for field communication. To satisfy the requirement of a communication network for using IEC 61850, three design factors such as network management, automatic communication link transfer and architecture of communication stack are considered for the communication network and devices.

Feeder intelligent electronic devices

Fig. 5 shows a prototype of the IEC 61850 based FIED in the KSDMS. To implement the IEC 61850 protocol for distribution devices, we define logical nodes for devices such as recloser, automated switch, multi-way circuit breaker, etc. Some logical nodes are reused in FIED whereas some such as cold load pick up, fault indicator and power quality must be created or redefined. In addition, IEC 61850 services are also modified and redesigned to apply to FIED.
To real-time data exchange with AMI, AMI Gateway is developed. AMI gateway is used for real-time data exchange with data concentrating unit in AMI system and for providing IEC 61850 services to KSDMS server.

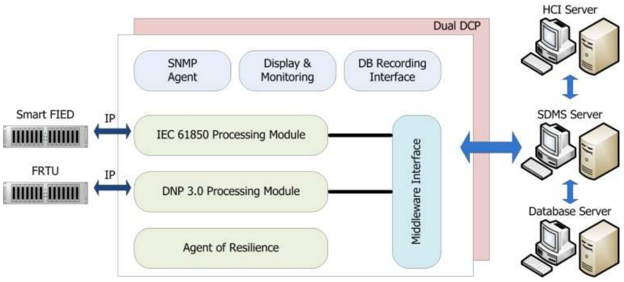

Fig. 4. System architecture of the DCP.

Fig. 5. Smart FIED of KSDMS.

KSDMS APPLICATION SOFTWARE

In this section, we present the design of the application programs in KSDMS. The KSDMS application solutions are divided into three categories, which are shown in Table 1.

Table 1. Categories of application solutions for KSDMS

No	Type	Execution /Periodic /Execution Time	Object	Appl.
1	Event Driven Mode	Automatic /Irregular /≤ few sec	Fault clearing, restoration	NP1), PC2), SR3)
2	Real Time Mode	Automatic /Periodic /≤ few minute	Recognition of current network conditions, control recommendation	NCP4), DSE5), RPF6), ND7), LM8), VVC9)
3	Study Mode	Manual /Irregular /≤ few minute	Examination of future network conditions	SPF10), ONR11), GF12)

*Note that 1)NP: network protection, 2)PC: protective coordination, 3)SR: service restoration, 4)NCP: network connectivity processing, 5)DSE: distribution state estimation, 6)RPF: real-time power flow, 7)ND: network diagnosis, 8)LM: load management, 9)VVC: voltage var control, 10)SPF: study power flow, 11)ONR: optimal network reconfiguration, 12)GF: generation forecasting

The objects of each mode are as follows.
1) Event driven mode treats the fault in the distribution network and service restoration for the unfaulted sections.
2) Real-time mode provides the periodic solutions of network condition and voltage control for operators.

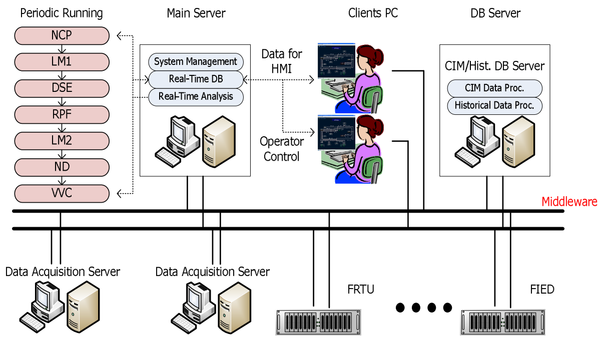

Fig. 6. Composition of KSDMS real-time applications.

3) If a solution in real-time mode is not satisfied, operators examine the case in study mode. They can examine the case using other application (SPF, ONR), after which the network conditions (analog/digital status and devices) can be modified.

The composition of KSDMS real-time applications is shown in Fig. 6. As shown in Fig. 6, the real-time measured data is periodically gathered from FRTU/FIED to data acquisition server. The data transfer to the real- time database in the main server and operators' HMI and the real-time applications are also periodically accomplished in the main server. Through the various real-time application solutions, the operators can recognize the accurate current conditions and problems. And also the operators anticipate potential risks of the entire distribution network and he can handle the device control setting.
The KSDMS is designed to cover a distribution branch office in Korea and one branch office has typically 200 distribution feeders. The size of topological characteristic matrix (Y matrix, H matrix, Jacobean matrix) can be larger than the whole transmission system. Therefore, we introduced the Network Connectivity Processor (NCP). The NCP creates the electrical node (bus) using the physical node and switch status and forms the electrical islands. The acquisition of the real-time load data for the whole distribution system did not possible even if the metering devices of customer are dispersed. For the state estimation, it is essential that the real-time injection data for whole distribution system. The Load Management (LM1) is for load data calculation using real-time measured data of a few devices. The output of the LM1 is for the pseudo input of state estimator. The Distribution State Estimator (DSE) of KSDMS is used for the detection and replacement of measured data. To consider the unbalance nature of distribution system, we use the three phase H-matrix and estimate the tap position for each phase. The unbalanced three phases Real-Time Power Flow (RPF) is developed and it use the output of the three phases unbalanced state estimation. The results of RPF are used for the generation of individual Load Patterns (LM2). The Voltage Var Controller (VVC) is accomplished to remove the voltage violations and to minimize the loss. The linear and non-linear optimization techniques are used in VVC. We design hierarchical and non-hierarchical database for KSDMS applications. For relations between each table, we use the Linked List Model [8]. Each table is composed of 3 links. One identifies each record of the table with a consecutive integer. Another contains the data of each record, which consist of names and properties. The third contains links with other tables, which are divided into head, sibling and indirect indices.

CONCLUSIONS

In this paper, we summarize the system architecture and application software of the KSDMS. The major difference between KSDMS and conventional DAS is that the real-time synchronized data can be measured in KSDMS and it can be used for the periodic diagnosis of various application programs. For this, system architecture is designed to similar with a small EMS. For the architectural designs of KSDMS, we propose a communication system using the IEC 61850 protocol, feeder IEDs, and CIM-based middleware and server systems. We propose various application programs for the periodic diagnosis of a network. The proposed architecture and application software of the prototype KSDMS will be tested by using an actual distribution system of Je-Ju island of Korea.

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