DEVELOPMENT OF IEC 61850 BASED FEEDER IEDS FOR SELF-HEALING OPERATION IN DISTRIBUTION NETWORK

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ABSTRACT
Recently, in the context of smart grid, the usage of the IEC61850 communication standard gets broader and broader. Though IEC61850 has been used as communication standard for substation automation, the scope that it is applied becomes wider and wider into area of distributed energy resources including storages, communication between substation and control center, feeder automation and EV charging for smart consumers. In the flow of this IEC61850, KEPCO are carrying out the development of Smart Distribution Management System, and as a part of this R&D project, IEC61850 based Feeder IEDs of distribution switchgear is being developed. In this paper, IEC61850 based data model, software & hardware architecture of Feeder IEDs are presented. In addition, protection coordination and service restoration scheme by using peer to peer communication among FIEDs are also presented for self healing operation of distribution network.

Keywords
Smart DMS (Distribution Management System), IEC 61850, Feeder IEDs (Intelligent Electronic Devices), Distribution Automation

INTRODUCTION
Smart grid became a buzz word as one of major trends a decade in energy field for last 5 years. EU set the target of smart grid as 20:20:20 by 2020, i.e. reduction of GHG emission in 20% below 1990 levels, 20% of energy consumption from renewable sources, 20% reduction in primary energy use by 2020. Korea understands smart grid as green growth platform that can converge the relation g industry including power, communication, construction, auto and energy industry for optimal operation of T&D network intelligently for energy efficiency and GHG reduction.

In the flow of smart grid, IEC 61850 becomes core communication protocol for open accessible, interoperable and future proof environment in power automation. Though IEC61850 started as international standard for communication of substation automation, the scope of IEC61850 applied become wider and wider into area of distributed energy resources including storages, communication between substation and control center, feeder automation and EV charging for smart consumers. That’s why object oriented data model, high speed data exchange, support of peer to peer communication, interoperability, the support of simple engineering [1].

In recent years, some papers have been published relating to application of IEC61850 in distribution automation. Mohagheghi et.al also proposed the modelling of distribution automation system components using IEC61850 [2]. Palak et.al presents the simulation study for distribution automation systems (DAS) with DERs based on IEC61850 [3]. V. Valeriy et.al presented the distributed fault location, isolation and supply restoration in distribution networks [4].

KEPCO Research Institute is carrying out the development of Smart Distribution Management System (SDMS), and as a part of this project, IEC61850 based Feeder IEDs of distribution switchgear is being developed [5]. In this paper, IEC61850 based data model, software & hardware architecture of Feeder IEDs are presented. In addition, protection coordination and service restoration scheme by using peer to peer communication among FIEDs are also presented for self healing operation of distribution network.

SYSTEM ARCHITECTURE OF IEC61850-BASED FEEDER IEDS

Overview
Figure 1 shows the system configuration of Smart DMS (SDMS). Field data from switch and breaker along the distribution lines and distributed generation data also be sent through Feeder IED (Intelligent Electronic devices). Meter data can be sent through AMI gateway to SDMS Server. These devices use IEC61850 as well as DNP3 for data communication. Using these collected data SDMS application carried out the functionality including real time network analysis, distribution network operation and optimization, DER (Distributed Energy Resources) management & control and self healing. This configuration will be extended to energy storage device, electric vehicle and home and building energy management system. In the long run, SDMS will expand its function to virtual power plant including demand response resources.

IEC61850 communication protocol is used in data acquisition from Feeder IEDs and meter data from AMI Gateway station.
IEC 61850 protocols have major advantages over legacy protocols such as DNP3. It is listed as following:

1) It is more easily extendable.
2) The data (LNs, data objects and attributes) are more self-descriptive.
3) It is more flexible in parameter setting control and gives the user the degree of freedom to define, change and edit the parameters.
4) The user can access the complete information hierarchy of all objects by obtaining the directory.
5) User can select data more flexibly for reporting, enabling/disabling the comm. Control objects and changing report/log behaviours
6) Complete description of device configuration is available in XML format
7) It provides vendor independent engineering tools
8) It is open for future service systems

IEC 61850 Data Models for Feeder IEDs

In this section, IEC 61850 data models for the Feeder automation are presented. Logical Devices are divided and modelled into 4 groups including protection, sensing, control, measurements. And suitable logical nodes are selected in each group. 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.

<table>
<thead>
<tr>
<th>LN Name</th>
<th>Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTUV</td>
<td>Low voltage, voltage loss,</td>
</tr>
<tr>
<td>PTOV</td>
<td>Overvoltage, Live line, swell</td>
</tr>
<tr>
<td>PIOC</td>
<td>Instantaneous Trip (High current)</td>
</tr>
<tr>
<td>PTOC</td>
<td>Overcurrent Prot. (Fast/delay)</td>
</tr>
<tr>
<td>PTRC</td>
<td>Trip</td>
</tr>
<tr>
<td>PTUF</td>
<td>Under Frequency</td>
</tr>
<tr>
<td>RDIR</td>
<td>Direction of power flow</td>
</tr>
<tr>
<td>RREC</td>
<td>Reclosing</td>
</tr>
<tr>
<td>RDRE</td>
<td>waveform</td>
</tr>
<tr>
<td>RSYNC</td>
<td>Phase Synchronization</td>
</tr>
<tr>
<td>RBRF</td>
<td>Failure of Trip</td>
</tr>
<tr>
<td>MMXU</td>
<td>Measurement (Src/Load/Fault current, True RMS Mag, Of Sag, swell, interruption)</td>
</tr>
<tr>
<td>MSTA</td>
<td>Average Load Current Max Current of Day</td>
</tr>
<tr>
<td>MMTR</td>
<td>kWh</td>
</tr>
<tr>
<td>MSQI</td>
<td>Unbalance</td>
</tr>
<tr>
<td>MHAI</td>
<td>THD</td>
</tr>
<tr>
<td>XSWI</td>
<td>Open/Close of Switchgear</td>
</tr>
<tr>
<td>XCBR</td>
<td>Open/Close of Breaker</td>
</tr>
<tr>
<td>CSWI</td>
<td>Control of Switch/Breaker</td>
</tr>
<tr>
<td>ZBAT</td>
<td>Battery status</td>
</tr>
<tr>
<td>GGIO</td>
<td>Door Open, Lock/Unlock TD, internal Temperature</td>
</tr>
<tr>
<td>GGIO</td>
<td>Fault Indicator (Instant. Permanent)</td>
</tr>
</tbody>
</table>

IEC61950 Service Utilization Schemes

In this section, the strategies of the IEC 61850 service utilization for the provision of the Feeder measurement and status data to the SDMS are proposed. In this paper, 9 types of services are proposed to be used in the Feeder IEDs, among 10 types of services defined in the IEC 61850 Communication services. Sampled Value service is not used. And GOOSE service is used for exchange the event messages (such as detecting fault current) for protection coordination. The definitions and the utilization schemes are described in detail in Table 2.
H/W architecture of Feeder IEDs

An IEC 61850 based Feeder IED for SDMS is developed. Feeder IEDs can be divided into 4 parts such as MCU (Main Control Unit), AIU (Analog Input Unit), PSU (Power Supply Unit), and HMI (Human Machine Interface) Unit. Main control Unit has 2 processors of Main processor and DSP (Digital Signal Processor). Main processor handles the functions of input/output data processing, event monitoring & analysis, communication. DSP take the parts of floating point calculation, real time waveform conversion, data measurement and protection. Figure 3 shows the block diagram of Feeder IEDs.

![Feeder IED Block diagram](image)

**Figure 3 Feeder IED Block diagram**

<table>
<thead>
<tr>
<th>Service model</th>
<th>Definition</th>
<th>Utilization scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic exchange</td>
<td>Issued for reading and writing data.</td>
<td>To be applied to read distribution feeder data and write the parameters</td>
</tr>
<tr>
<td>Data set</td>
<td>Allows grouping various data.</td>
<td>To be used for grouping the similar data set with same priorities, periods, etc.</td>
</tr>
<tr>
<td>Substitution</td>
<td>Replaces the process values such as DI, DO and AI by the pre-defined or pre-specified values.</td>
<td>To be used when some problems occur in the acquisition of data from the feeder IED</td>
</tr>
<tr>
<td>Setting group</td>
<td>Defines how to switch from one set of setting values to another, and how to edit values of each setting items.</td>
<td>To be used for the client to manage the configuration of the Feeder IEDs</td>
</tr>
<tr>
<td>Report</td>
<td>Generates reports to the client. Reports are divided into two categories: buffered reports and unbuffered reports.</td>
<td>To be used for the SGS to send the feeder data to the client, in the form of buffered or unbuffered report.</td>
</tr>
<tr>
<td>GOOSE</td>
<td>Provides fast and reliable system-wide distribution of data; peer-to-peer exchange of IED binary status information.</td>
<td>To be used for exchange the event message for protection coordination</td>
</tr>
<tr>
<td>Sampled value</td>
<td>Provides fast and reliable transmission of the sampled values of the process data.</td>
<td>Not to be used</td>
</tr>
<tr>
<td>Control</td>
<td>Provides the clients with the function to control the devices in the servers.</td>
<td>To be used for control of remote controlled switches and recloser.</td>
</tr>
<tr>
<td>Time synchronization</td>
<td>Provides the function of the time synchronization for the IEC 61850 systems.</td>
<td>To be applied to synchronize the time information of the Feeder IEDs with S-DMS Server.</td>
</tr>
<tr>
<td>File transfer</td>
<td>Supports the exchange of huge data blocks in the form of files.</td>
<td>To be applied to send the waveform in case of fault and in-rush.</td>
</tr>
</tbody>
</table>

Table 2 IEC 61850 Service utilization strategies

Figure 4 shows a prototype of the Feeder IED. All 4 types of Feeder IEDs are developed for automated switch, recloser, multi way circuit switch/multiway, distribution feeder data to the DMS Server in the form of files.

![Feeder Intelligent Electronic Device (IED)](image)

**Figure 4 Feeder Intelligent Electronic Device (IED)**

PROTECTION COORDINATION

In this section, the scheme and algorithm of protection coordination and fault isolation in feeder IEDs are presented briefly. This scheme and algorithms are applied to distribution network with distributed generation.

When reclosers detect the fault and its direction, it starts trip-ready timer and multicasts the fault detection events (PFF: Protection Forward Fault/PRF: Protection Reverse Fault) to reclosers in neighbourhood. When the reclosers receive fault event data from other reclosers, it decides whether or not it has to reset its trip_ready timer with the following logical equation 1. If (SELF_PFF and Loads ide_PFF) or (SELF_PRF and Sourceside_PRF) == true, reset Trip_Ready. If recloser did not feel the fault current, it did not take any action. If trip_ready timer is not reset, it is going to trip in specified period.

To be applied to send distribution feeder data and write the parameters

To be applied to control remote controlled switches and recloser.

To be applied to synchronize the time information of the Feeder IEDs with S-DMS Server.

To be applied to send the waveform in case of fault and in-rush.
After recloser (or other breaker) goes open, switch goes to the process of fault isolation. When switches feels the fault and no voltage, it starts sw_ready timer and mutuates the fault detection events (SFF:Switch Forward Fault/ SRF:Switch Reverse Fault) to switch/reclosers in neighborhood using GOOSE message. When the switch receives fault event data from other switches/reclosers, it decides whether or not it has to reset its sw_ready timer with the following logical equation 1. If (SELF_SFF and Loadside_SFF) or (SELF_SRF and Sourceside_SRF) == true, reset sw_ready. If switch did not feel the fault current, it did not take any action. If sw_ready timer is not reset, it is going to open in specified period in no voltage condition. After switching (to open), it sends the commands of OPEN to load side switch(es) (DTO: Direct Transfer OPEN). The switch(es) which receive DTO Command from its/their source side switches, it/they switches to OPEN if it/they are not OPEN.

CONCLUSION

In this paper, the IEC 61850 based Feeder IEDs are presented as a part of the R&D project of “Development of Smart Distribution Management System (SDMS)” which is being carried out by KEPCO Research Institute since 2009. The system architecture of IEC61850 based feeder IEDs is depicted briefly with data communication processing in Smart Distribution Management System. IEC 61850 data models and service utilization strategies of feeder IEDs are also presented. In addition, hardware architecture and prototype of feeder IEDs are showed. Lastly, protection coordination scheme and fault isolation using peer to peer communication briefly introduced. Conformance and functional test are being conducting now.

As a future plan, after functional test and integrated test with SDMS and other components in laboratory, prototype of feeder IEDs are modified and get some advancements in protection coordination and fault isolation algorithm. In the third quarter of the year, field test with these feeder IEDs are planned for self-healing operation.

REFERENCES


