Development of an Intelligent Station HMI in IEC 61850 Based Substation

Seong-Jeong Rim†, Sheng-Wu Zeng* and Seung-Jae Lee**

Abstract – Because the existing Human-Machine Interface (HMI) for the conventional substation cannot dynamically indicate the configuration information of the Substation Automation System (SAS). In this paper, an intelligent station HMI is proposed for IEC 61850 based substation. The program of the proposed HMI not only can automatically generate the layout of single line diagram, but can also indicate the communication network and functions of IEDs by reading SCL files. It greatly helps monitor the operation status, communication network and each IED dynamically, such as failure detection in SAS. Furthermore, this paper presents the possibility of developing new software for SAS with the full use of IEC 61850-6. Once the software is complete, there is no need to change it when the substation is upgraded or when it is migrated to other IEC 61850 based substations, which is a cost-effective solution.

Keywords: Substation Automation, IEC 61850, Substation Configuration Language (SCL)

1. Introduction

Since first being published in 2004, the IEC 61850 standard, "Communication networks and systems in substations", has an increasingly significant impact on the development of substation automation system (SAS) [1-3]. In the past three years, there are already more than 300 substations around the world that have been upgraded or newly built with this new standard. More and more countries are also planning to migrate to this standard [4].

In the conventional substation, because there is no integrated configuration information for the whole substation, the station diagram in the Human-Machine Interface (HMI) is usually drawn by humans (usually the developer). The developer can only gather and analyze the dispersed information and draw the station diagram manually. Although some software providers also provide a station diagram editor for convenience, the station diagram is specific to that station. Because the diagrams are usually different between substations, once the HMI has been developed, it can only be used in the specified substation. It is neither flexible nor convenient, and usually causes mistakes because the programmers are usually not familiar with substations [5].

In the IEC 61850 standard, a Substation Configuration description Language (SCL) is proposed to describe all the configuration information of the substation [6-7]. This is the first time the configuration information of a substation is centralized in a standard format. The standard configuration file thus provides the possibility to develop an intelligent HMI that can be developed once and used in all IEC 61850 compatible substations.

In this paper, the development of an intelligent station HMI in IEC 61850 based substations is presented. Using an SCL file in the station unit, the proposed HMI can display the layout of the station diagram, the communication network and the functions of the substation automatically. Using MMS protocol, it can also dynamically monitor the operation status, the communication network and each IED without any human intervention. The proposed HMI shows the possibility of developing generic station automation software. Moreover, this HMI is also very suitable for failure detection in SAS.

This paper comprises five parts. In Part 2, the structure of IEC 61850 based substation and HMI function are simply introduced. Part 3 depicts the Substation Configuration Language (SCL) and engineering process using SCL. In part 4, the implementation of a new intelligent station HMI is proposed and developed. And finally, it reaches a conclusion in Part 5.

2. Station Hmi in Iec 61850 Based Substation

2.1 Structure of IEC 61850 Based Substation

Substation Automation System (SAS) is used for controlling, protecting and monitoring substations. From a logical

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point of view, SAS comprises three levels [8]:

- The station level with the Gateway to Control Center, Substation HMI and Engineering tools.
- The bay level with all the control and protection units.
- The process level with more or less intelligent process interfaces to the switchgear.

In substation, the station bus is usually used to connect the station level with the bay level; the process bus is used to connect the bay level with the process level. Using station bus and process bus, the final system architecture is shown in Fig. 1. This allows for seamless data access within the substation.

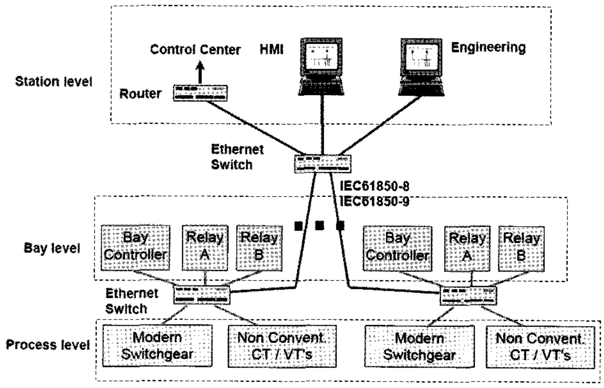

Fig. 1. Structure of IEC 61850 based SAS

2.2 HMI Function

In order to meet the requirements of system supervision and control, the HMI in the station unit should contain all the current status information of the substation. The developed HMI contains the following components:

- Single line diagram, which stands for the electrical primary power system, contains all the electrical equipments and the architecture of the system.
- Communication system, which stands for the communication system in the SAS. In this part, IEDs in the same communication network are connected. Each IED is located with its primary equipment. The operation status of the communication network and IEDs are presented using different colors.
- Functions, which contains the detailed information of IEDs from different vendors.

3. Engineering Using Scl

The main purpose of IEC 61850-6 is to allow the interoperable exchange of device descriptions and system configuration between system configuration tools and IED configuration tools, which are probably provided by different vendors. For this purpose, IEC 61850-6 specified a Substation Configuration description Language (SCL).

3.1 Introduction of SCL

The SCL is based on Extensible Markup Language (XML). Its syntax is well defined as a W3C XML schema. The SCL in its full scope describes the following models:

- A model of the substation at single line level.
- A model of the logical communication connections between all used IEDs.
- A functional model of the SA functionality by means of logical nodes, logical devices, and the data flow between them.

Furthermore, the connections between these models can be described using SCL by means of the allocation of logical nodes to the primary power equipment and to the IEDs.

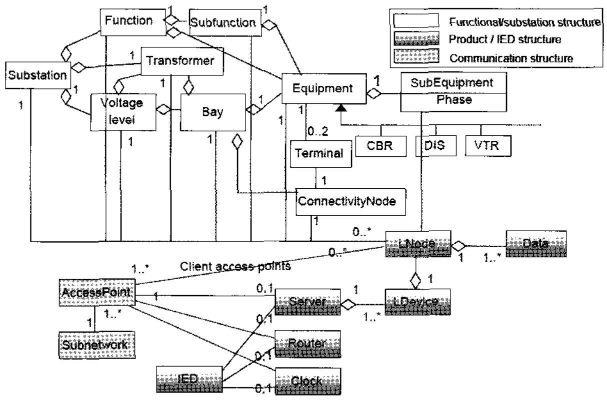

Fig. 2. SCL object model

The overview of those models and the connections between them by using Unified Modeling Language (UML) notation is given in Fig 2.

3.2 Engineering Process with SCL

SCL specifies a hierarchy of configuration files to distinguish the data exchange between different tools [9-10]. The various SCL files include:

- System Specification Description (SSD) file contains one or more substation sections and data type templates sections, which describes the single line diagram and the logical nodes allocated to the diagram.
- IED Capability Description (ICD) file contains an IED section which describes the capability of IED.
- Substation Configuration Description (SCD) file is generated from the SSD file and the ICD file using System Configuration Tools. It contains a substation description section, a communication configuration description section, all IEDs and a data type template section.
- Configured IED Description (CID) file is generated from the SCD file using IED Configuration Tools. This file can be downloaded by an IED and used to configure that IED.

The key technology in the engineering process is the System Configurator and IED Configurator. One proposed engineering process is shown in Fig. 3.

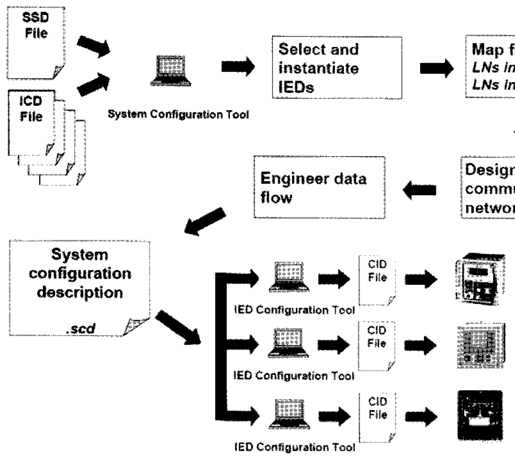

Fig. 3. Engineering process with SCL

1. System Configuration Tool gets all the system related information from the SSD file and product related information from the ICD files.
2. System configuration engineers select and instantiate IEDs, map function LNs in the SSD file to LNs in IEDs, design communication network and the data flow.
3. System Configuration Tool creates the SCD file from input SSD and ICD files.
4. A vendor-specific IED Configuration Tool receives the SCD file and creates a CID file.
5. The created CID files is downloaded by an IED and used to configure that IED.

3.3 Parsing of Elements in SCL

As mentioned in 3.1, SCL is an XML based language. Therefore, SCL files can be parsed using various kinds of XML parsers. After being parsed, the SCL text file can be transformed into a data structure suitable for later processing [11-13]. In this paper, the Simple API for an XML (SAX) parsing model is used [14].

The SCD file contains 5 main sections: header, substation, communication network, IEDs and datatype template.

The substation section contains the model of substation, which describes the primary system structure as shown in Fig 2.

- Substation, identifies a whole substation.
- VoltageLevel, an electrically connected substation part which has the same voltage level.
- Bay, a substation part within the same VoltageLevel.
- Equipment, a primary device within the Substation, for example circuit breaker, disconnector, voltage transformer etc.
- ConnectivityNode, an electrical connectivity node object of Bay which can connect different Equipment. It normally belongs to Bay.
- Terminal, an electrical connection point of Equipment. A Terminal can be connected to a ConnectivityNode. It normally belongs to Equipment.

The single line diagram of a substation shows the electrical connections between these primary devices. The ConnectivityNode models these connections in the Bay level. In this model, the Equipment and Bay are connected using ConnectivityNode and Terminal.

The communication network section describes the communication model in the substation.

- Subnetwork, a connecting node for direct (link layer) communication between access points.
- Access point, a communication access point of the logical device(s) of an IED to a subnetwork.

The IED section contains a model of configured logical device on an IED.

- The IED section contains a model of configured logical device on an IED.
- IED, a substation automation device performing SA functions by means of logical nodes (LNs). It normally communicates with other IEDs in the SA system via a communication network.
- Server, a communication entity within an IED. It allows access to the data of the logical devices and logical nodes contained in the server via the communication network and its only access point.
- LDevice, a logical device that is contained in a Server of an IED.
- LNode, a logical node implementation contained in an LDevice of an IED.
- DO, the DATA contained in the LNode.

4. Implementation of the New Hmi

As mentioned in 3.3, we can get all the substation configuration information by parsing an SCD file. Regarding the main contents of an SCD file, the HMI has three main parts: Substation, Communication and Function.

Compared to the conventional HMI, this new HMI has many obvious advantages:

- SCD file only: It can be used in any IEC 61850 based substation as long as the SCD file of the substation is available. Also, this is the first time the primary system topology in SCD files is fully used.
- Cost-effective: Once developed, it can be used in any IEC 61850 compatible substation. Even if the substation is upgraded, there is no need to change the HMI. This therefore greatly decreases the cost.
- Reliable: Compared to the conventional drawing-manually method, it can greatly decrease human errors and

thus avoid mistakes.

- User Friendly: The HMI is designed and implemented in a user friendly way. It is very easy to operate.
- Novel: This substation HMI is generated automatically.
- Based on this, further development of the automatic station HMI and intelligent IED failure detection software is allowed.

This HMI is developed using C++, Qt GUI library, which brings additional advantages:

- Fast: the project uses SAX XML parsing model, which is much faster than DOM parsing model especially when the SCD file becomes bigger.
- Easy to extend: The project is object oriented, which makes it very easy to extend.
- Cross platform: The program is developed using the Qt GUI library, which is a cross platform C++ library. The project can be compiled on Windows, UNIX, Linux and Mac OS.
- Easy to internationalize: Using the very powerful and handy internationalize tool - Qt Linguist. The HMI can be translated into other languages without any programming knowledge.

4.1 Single Line Diagram

The substation section in the SCD file describes the single line diagram by means of ConnectivityNode and Terminal.

Each device in the substation section has one or two Terminal. Two Equipments which have the same Terminal are considered to be connected at this Terminal. Using this information, the program can generate the layout of a single line diagram automatically, as shown in Fig. 4.

The diagram is generated using only an SCD file. If the SCD file changes, the diagram will change according to the new SCD file.

The diagram is always kept at the center of the window when the size of the window changes. If the window space is not large enough for the single line diagram, a scroll bar (vertical or horizontal) is generated automatically. This is important because the scale of the substation is unknown. It also provides facilities to IED failure detection, because the screen of the IED failure detection device is usually small [15].

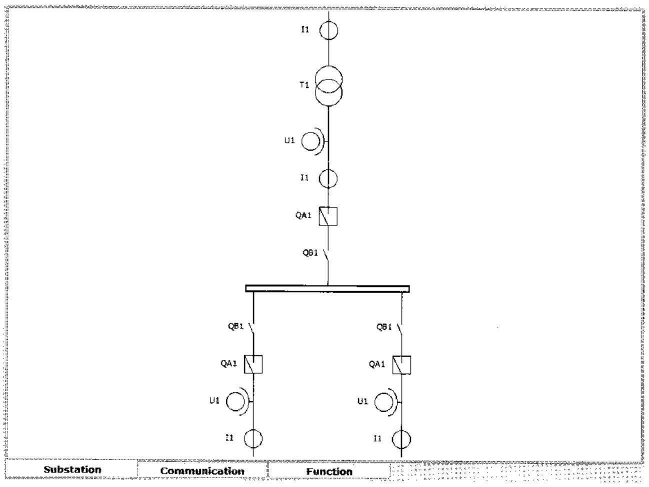

Fig. 4. Single line diagram layout

4.2 Communication

The communication section in the SCD file describes the data flow between IEDs in the system. In the communication network in the substation, each IED is connected to one or more subnetworks to commit a substation automation function. E.g. the bus protection function is implemented by several IEDs in one subnetwork.

The naming of an IED consists of a higher-level designation and its functional designation. e.g. D1Q1QA1 stands for an IED which controls a circuit breaker QA1 of Bay Q1 in VoltageLevel D1. This naming rule is used for the location of IEDs to single line diagrams.

In the communication section in an SCD file, each IED has an Access point. IEDs which have the same Access points within the same Subnetwork are considered to be connected in that Subnetwork.

Using the Access point and name of the IED in the communication section, the layout of the communication network can be generated automatically.

Moreover, using a light-weight communication program, the HMI can check the status of IEDs in the substation using MMS messages. The dataflow between HMI and the communication program is shown in Fig. 5.

The communication program uses the MMS Virtual Lite (MVL) application framework provided by MMS-EASE Lite library. It acts as a series of clients and each IED in the substation acts as a server. Every 1000ms the communication component checks the status of each IED by sending request to each of them in parallel. Then, depending on the response, the status is written in the shared memory area, where the "normal"/"failed" status of the IED is represented with "1"/"0", respectively.

The "Communication" part of the presented HMI will read

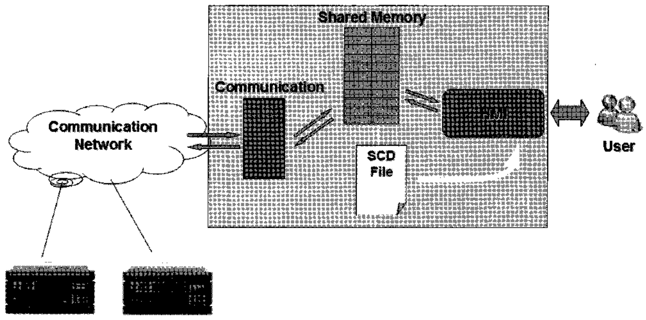

Fig. 5. Data flow of HMI with communication to IED

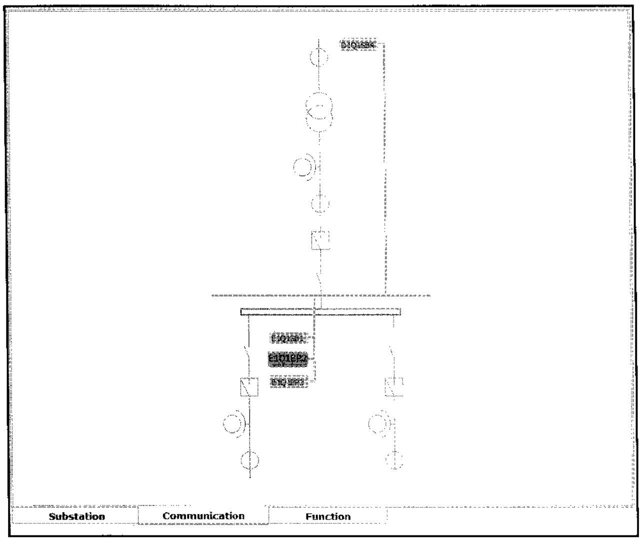

Fig. 6. Communication layout

the shared memory area and be refreshed every 1000ms. After that, the IED is displayed with red/green colors depending on the IED's real time working status. Fig. 6 shows a failure in IED E1Q1BP2 has been detected. This IED is located in VoltageLevel E1, Bay Q1.

4.3 Function

The IED sections in the SCD file describe the IEDs by means of logical nodes.

Click the IED, the detailed information will be shown in the tree on the top right corner. Click the item on the tree, the detailed information of the item will be shown in the table on the bottom right corner, as shown in Fig. 7.

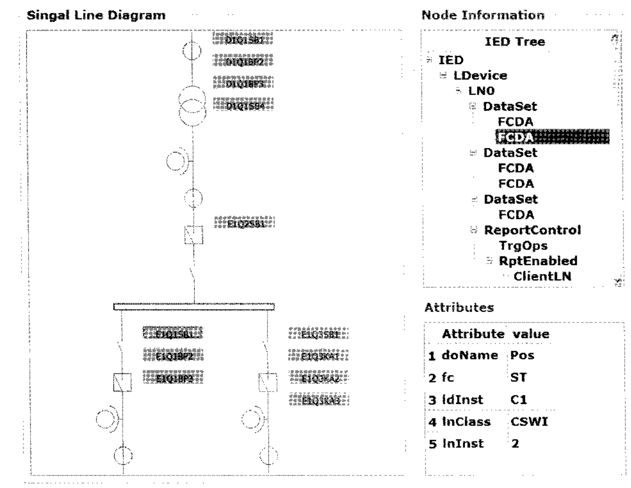

Fig. 7. Function layout

5. Conclusion

The development of an intelligent station HMI in IEC 61850 based substations is presented in this paper. Provided with the SCD file of the substation, this HMI can generate the layout of the single line diagram, the communication network and IEDs automatically. Combined with a light-weight communication program using MMS message, the new HMI can also detect the working status of communication networks and IEDs in real time.

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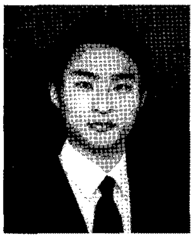

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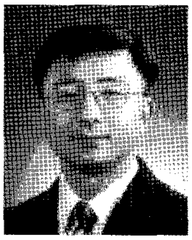

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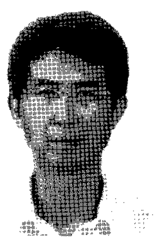

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