The Application of IEC61850 Standard in the Online Monitoring System of the Smart Substation

Geng Baohong [1], Wang Zhiming [2], Ge Weichun [2], Wang Chenggang [2], Li Shuyang [2], Gao Qiang [1,3]
[1] Northeast Electric Power Research Institute, Shenyang, China
[2]Liaoning Electric Power Company Limited, China
[3] Shanghai Jiao Tong University, China

***Abstract*: This paper discussed the application of online monitoring system based on IEC61850 standard in the smart substation. Firstly, the functions and performance requirements of online monitoring system have been discussed, and the functional model and interface model of online monitoring based on IEC61850 have been established; Secondly, the application schema of online monitoring system has been designed for smart substation. Furthermore, according to the practical application in the pilot project, the validity of the models and the schema has been verified, and a summary of the application has been given.**

***Keywords:* IEC61850, Online Monitoring System, Smart Substation, Logical Node, ACSI**

I. INTRODUCTION

The IEC61850 standard is the main standard for smart substation. It has been successfully used in the communication of automation system in smart substation. The online monitoring system is an important component of the secondary system of the smart substations. It is the primary data source of the status visualization of primary equipments. Therefore, the online monitoring system must comply with the IEC61850 standard. However, the application of online monitoring was not widespread in the past, and was not fully integrated into the automation system, either. Therefore, many models used for online monitoring system are not given in the IEC61850 standard [4]. The application of the online monitoring system based on IEC61850 standard is immature. In order to achieve standardization of the online monitoring system in smart substation, firstly, the function and performance characteristics of the online monitoring system should be analyzed based on the modeling principles of IEC61850 standard [1][3]. Secondly, the necessary expansion and selection of the existing functional and service models in IEC61850 standard should be done. Finally, the actual online monitoring system schema based on these models should be designed to meet the requirements of the application in smart substation. The schema should be used in practical engineering of smart substation project. The validity of these models will be verified as the online monitoring system is successfully applied in real project. Then, the experience of this project using these models will provide the guidance for the follow-up projects.

II. IEC61850 MODELS

The goal of the IEC61850 standard is the interoperability between IEDs (intelligent electronic devices) from different manufacturers in the substation automation system. Various functions and performance requirements of the substation automation system have been analyzed, and functional models, as well as services for the interaction between the functional models have been defined in the standard. In IEC61850 standard, the basic unit of functional models is named logical node (LN). The logical node defines the minimum functional unit for data exchange. An IED is often combined with more than one logical node to realize the comprehensive automation capabilities. Fig.1 shows the modeling of a physical device. Compatible logical node classes and public data classes have been defined in Part 7 of IEC61850 standard documents. These standard function models can meet most application requirements of the automation system in smart substation [1][4] .

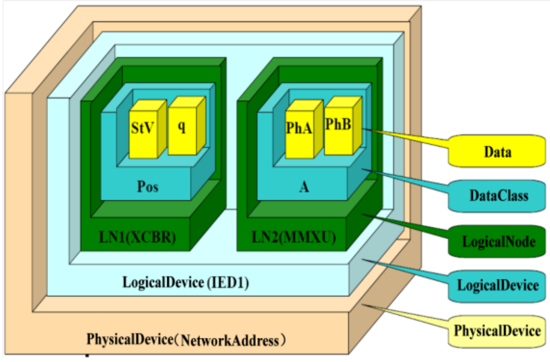

Fig. 1.A device model based on IEC61850

All compatible logical node classes used for the monitoring system are listed in TABLE I.

TABLE I

COMPATIBLE LOGICAL NODE CLASSES FOR MONITORING

Modelled in IEC61850-7-4 by LN	Comments
SIML	Insulation liquid such as oil
SIMG	Insulation gas such as SF6
SLTC	Drive supervision part of XCBR and XSWI
SOPM	Drive supervision part of XCBR and XSWI
SPTR	Supervision part of YPTR
SCBR	Supervision part of XCBR
SPDC	Supervision of partial discharge
STMP	Supervision of temperature

The IEC61850 standard is also able to adapt to a variety of communication performance requirements of a series of service interfaces. These interfaces are defined as abstract communication service interface (ACSI), which include the connection-oriented services such as the reporting service, the logging service, as well as the multicast non connection-oriented services such as GOOSE (Generic Object Oriented Substation Event) service and MSV (Multicast Sampled Value) service. [3]

In the application of the special project, the appropriate ACSI services should be selected to realize the exchange of data between different IEDs in the automation system according to the performance requirements and interaction logic of the special interfaces. Fig.2 demonstrates the structure of function models from the perspective of communication and the ACSIs models [3].

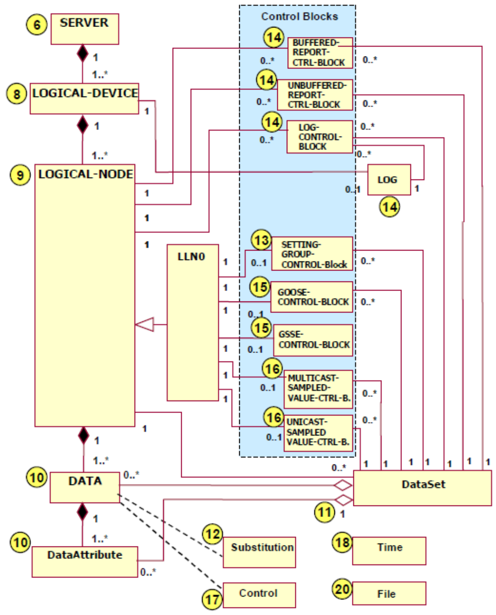

Fig. 2. Conceptual service model of the ACSI

In addition, in order to make the whole model system more integrated and consistent, a description language named SCL(Substation Configuration description Language) has been defined in Part 6 of the IEC61850 standard documents. The SCL is used to describe various models standardized in IEC61850 standard and the instantiation of these models in the special projects. The SCL can be used to describe the system modeling of a particular project or a particular IED device modeling. The conformance testing of modeling is described in Part 10 of the IEC61850 standard documents. The requirements and methods of the conformance testing are specified to ensure that different IEDs from different manufacturers can be modeled in strict accordance with the rules of IEC61850 standard, and achieve the true interoperability in the system[5][6] .

III. INTRODUCTION OF ONLINE MONITORING SYSTEM

In order to build the functional models and interface models of the online monitoring system based on the IEC61850 standard, analysis of the functionality and performance of the online monitoring system in the smart substations is necessary. The analysis should be based on the features of the online monitoring system. The main purpose of the application of the online monitoring system is to predict the failures of the primary equipments. These forecasts need consistent online monitoring of related parameters, and the usage of correct algorithm based on data measured. The data for measure and the algorithms to use are different for different types of devices. Online monitoring system usually is used to predict failures that generally have a longer period of development, as the system has enough time to forecast the fault, and the maintenance personnel have enough time to take the necessary test on site to identify and eliminate the fault. That is, the online monitoring system is based on the preventive mechanisms, and the relay protection system is based on the emergency response mechanism. Both the two systems aim to ensure the security and the stability of the grid.

To sum up, online monitoring system has the following characteristics:

1) Not a high real-time system;
2) Data to exchange is not large;
3) Need to get a lot of historical data in order to complete the trend analysis.

In fact, the online monitoring technology widely used is mostly served for the monitoring of the status of insulation of different primary equipments.

IV. ANALYSIS OF FUNCTION MODELS OF ONLINE MONITORING SYSTEM

In accordance with the principles of the IEC61850 standard, the function models of the online monitoring system should be selected from the existing monitoring models (compatible logical node classes with the prefix “S”) as possible and to extend these models to meet the specific requirement in online monitoring system. As previously mentioned, the models provided by IEC61850 cannot meet the needs of the practical application of online monitoring system. In order to extend these models, firstly, it’s necessary to analyze the functions related to the data exchange between the IEDs in the online monitoring system. As the introduction of the online monitoring system above, [1] these functions include:

4) monitoring data transmission
5) warning message transmission
6) historic data search
7) setting parameters download
8) time synchronization

According to the result of analysis, several types of data fields have been added to compatible logical node classes for monitoring:

1) sample interval setting
2) time stamp
3) setting data used for analysis
4) data to denote the result of analysis

And two logical node classes have been extended based on IEC61850 standard, they are:

1) SMOA-used to monitoring the insulation of MOA
2) SCAP-used to monitoring the insulation of Capacitive Equipment

V. ANALYSIS OF INTERFACE MODELS OF ONLINE MONITORING SYSTEM

A. Online monitoring system architecture

In order to identify the types of interfaces for online monitoring system, the architecture of the online monitoring system should be analyzed first. According to the previous analysis of the online monitoring system, and to consider the requirements of smart substation for online monitoring system architecture, the structure of the online monitoring system exists in two forms, the first one full support for the IEC61850 standard, shown in Fig.3, and the second one support the standard just in the network of substation layer, shown in Fig.4. All the interfaces of the online monitoring system are demonstrated in both figures.

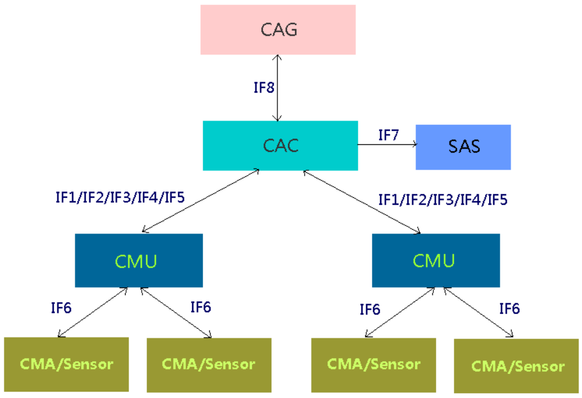

Fig. 3.Achitecture1 of online monitoring system

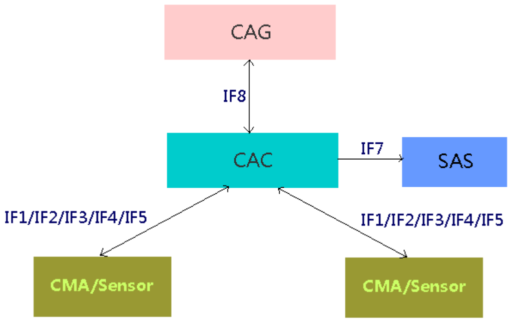

Fig.4. Achitecture2 of online monitoring system

In the figures:
1) CAG-state access gateway machine;
2) CAC-state access controller;
3) CMU-monitoring unit;
4) CMA-monitoring devices;
5) Sensor - sensors;
6) SAS-smart substation automation system.

CAG is the master system located in the province grid, which is responsible for receiving online monitoring data throughout the region. It stores and displays the data, management, and configuration of online monitoring device at all levels. The CAC is a station level device in the smart substation. It is mainly used for getting all online monitoring data within the smart substation, storing and presenting data, analyzing the fault based on these data, sending information to the CAG and downloading control commands and settings from CAG. The CMU is a device in bay level, which is used for converting the data from non-IEC61850 standard models to IEC61850 standard models, and communicating with the CAC based on IEC61850 standard. The CMA and Sensors are devices in process level. They are using for the status parameter data measurements, and communicating with the upper device. If the CMA/sensors support IEC61850 standard, the CMU can be canceled, and the online monitoring system will be simplified as a two-level system as shown in Fig.4. But most monitoring devices in the online monitoring system cannot support the IEC61850 standard directly currently. Therefore, the system structure shown in Fig.3 is widely used.

B. interface modeling of online monitoring system

Although the online monitoring system has two structures, the interfaces based on IEC61850 standard are exactly the same. Here we just discuss the modeling of the interfaces based on the IEC61850 standard. In the chapter III, functional analysis of the online monitoring system has been done, and various logical interfaces can be identified abstractly from these functions related to interactions. These interfaces (including non IEC61850 interfaces) and their comments are listed in TABLE II.

TABLE II

INTERFACES IN THE ONLINE MONITORING SYSTEM

Interface	Comments
IF1	datas transmission from CMU to CAC
IF2	warning messengers transmission from CMU to CAC
IF3	historical datas transmission from CMU to CAC
IF4	setting parameters download from CAC to CMU
IF5	time synchronization between CAC and CMU
IF6	Interface between CMU and CMA/Senser
IF7	Interface between CAC and SAS
IF8	Interface between CAC and CAG

In TABLE II, IF1 to IF5 and IF7 are the interfaces basis of IEC61850 standard. Before modeling these interfaces, the performance requirements and the interactive logic of each interface should be analyzed. Then, the suitable ACSI for each interface will be selected to realize the modeling.

As previously described, online monitoring system does not belong to the real-time systems. So most of its interfaces don't need high transfer speed. Most of data transferred in the online monitoring system is small in amount, and the bandwidth is less. But the partial discharge spectra data and the waveform data of the closing coil have large bytes to transfer. Therefore, these two types of data transmission need to consider the ACSI model with a large number of data transmissions. If the online monitoring system shares network bandwidth with other systems, the possibility of its cause network congestion should be evaluated. Here we can give an example to evaluate the influence of the raw data transmission of partial discharge monitoring on the network. The bytes of the data transferred in a period of time can be calculated by the equation as follow:

$$L=2*S*F*T$$

In this equation :

L- total bytes of raw data to transfer

S- number of sample points in one cycle(power frequency)

F-power frequency

T-total time of sampling

Assuming that S=1000 and T=1hour, then the L will be 720M bytes. It will take at least 1minute to transfer all these data by network with 100M bandwidth. Therefore, it's important to select appropriate transfer method to enhance the transmission performance.

In general, ACSI services based on the MMS protocol is enough for the data transmission requirements of the online monitoring system. According to the characteristics of various services provided by IEC61850 standard and the result of analysis above on the interfaces of the online monitoring system, ACSI for each interface has been selected shown in TABLE III [3].

TABLE III

SELECTED ACSI FOR INTERFACES

Interface	ACSI
IF1	URCB
IF2	LCB/File
IF3	RCB
IF4	SGCB
IF5	SNTP
IF7	RCB

In TABLE III:

1) RCB-Buffered Report Control Block;
2) URCB-Unbuffered Report Control Block;
3) LCB- Log Control Block;
4) File-File transmission;
5) SGCB-Setting Group Control Block;
6) SNTP-Simple Network Time Protocol;

VI. SCHEMA OF THE ONLINE MONITORING SYSTEM IN SMART SUBSTATION

As the function models and interface models of the online monitoring system have been built based on IEC61850 standard, and the structure of the system has been discussed clearly, the schema for a typical system can be designed here as the guidance for the implement of specific projects.

Considering that most monitoring devices cannot support IEC61850 standard currently, the structure of the online monitoring system should be a structure with 3 levels, which is shown in Fig.2. That is, CMU should be involved in the system. Then, a typical structure of the online monitoring system based on IEC61850 standard should be like that shown in Fig.5.

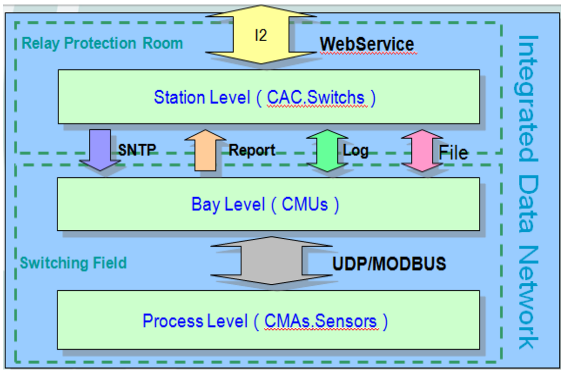

Fig.5 a typical structure of the online monitoring system based on IEC61850 standard

The IEDs(CAC and switchs) in the station level are located in the relay protection room, and other IEDs are located in the switching field. Communication between IEDs in station level and IEDs in bay level are basis of IEC61850 standard. Communication between IEDs in bay level and IEDs in process level may apply to MODBUS protocol basis of RS485 or UDP protocol basis of TCP/IP or any other protocols. In this structure, the CAC and the CMU are new devices involved to be compatible with the framework of smart substation. Therefore, functions of these two devices should be discussed here.

A. design of CAC

CAC is mainly responsible for the whole substation data collection, storage, analysis, display and alarm. It also supervises all the devices in the online monitoring system. Two key functions of CAC are the communication with CAG(remote master) based on webservice and the communication with CMU based on IEC61850 standard.

CAC's hardware can be a PC Server or an IPC or an Embedded Computer. All the functions are executed by the software of CAC. Fig.6 demosntrates the structure of CAC software.

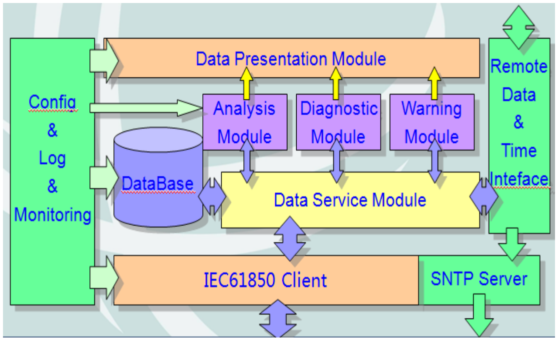

Fig.6 structure of the software of CAC

B. design of CMU

CMU is a new type of device specifically involved to support the IEC61850 standard. The major function of CUM is to covert data basis of non IEC61850 models measured by monitoring devices to data basis of IEC61850 models and to transmit data to CAC or to download commands from CAC to monitoring devices by using ACSIs discussed above. CMU is usually designed to cover the communication with monitoring devices in one bay such transformer bay or feed line bay.

CMU is usually located in the cabinet outdoor, it should be able to withstand the bad circum in the substation. So its hardware must be designed to ensure long-term stable in the switching field. And the software of CMU must have a flexible architecture to meet the access of devices with various types of communication protocols.Fig.7 demonstrates the structure of the software.

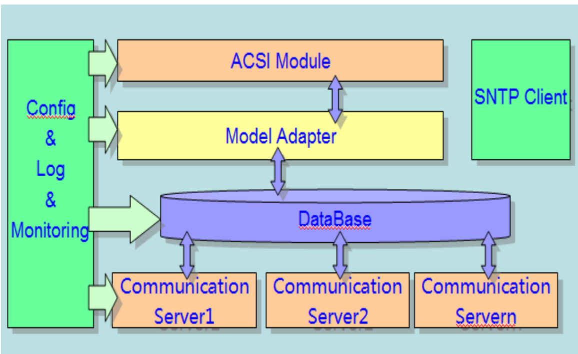

Fig.7 structure of the software of CMU

In Fig.7, the Communication Server module is used to realize clients that communicate with different monitoring devices by different protocols, that is, each type of protocol needs a particular Communication Server module; The Model Adapter module is the converter mentioned above to package data into the models of IEC61850 standard. The ACSI module is used to realize the server of IEC61850 standard and to exchange data and commands with CAC based on ACSIs.

VII. APPLICATION OF THE ONLINE MONITORING IN THE 500KV SMART SUBSTATION

The schema of online monitoring system designed above has been put into operation in a 500kV smart substation. The validity of the models has been verified.

The 500kV smart substation is a pilot substation of the state grid. The primary equipments, which are monitored by the online monitoring system, are including transformers, reactor, HGISs, GISs, and MOAs according to the design of the substation. Details of monitoring items and parameters are listed in TABLE IV:

TABLE IV

INTERFACES IN THE ONLINE MONITORING SYSTEM

Monitoring type	Monitoring parameters	The number of measuring points
DGA	H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, CO, CO_2, H_2O	2
PD	Amplitude, count, phase and type of partial discharge	2
Core Grounding Current	Grounding current	2
Oil Temperature	Temperature	4
Winding temprature	Temperature	4
Moisture and density of SF6	Humidity, temperature, pressure and density	224
Insulation of MOA	Leakage current, resistive current, surge times	63

The physical structure of the system are shown in Fig.8

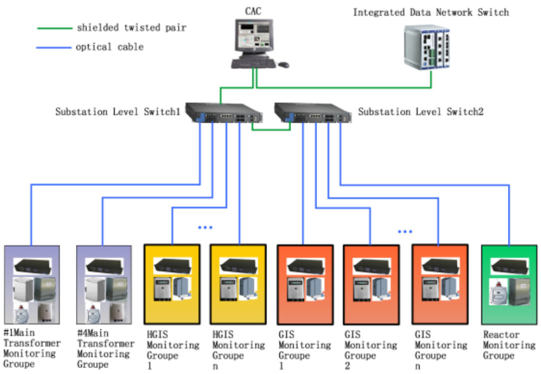

Fig.8 physical structure of the online monitoring system in the 500kVsmart substation

Here in Fig.8 the "Monitoring Groupe" consists of CMU and monitoring devices in a bay, and the "Integrated Data Network Switch" is used to communicating with the CAG. Two optical switches are used to set up the fiber Ethernet to support the MMS protocol and the amount of CMU is 34.

A application software has been developed for CAC apply to the structure in Fig.6 and Fig.9-11 shows the pages of the software.

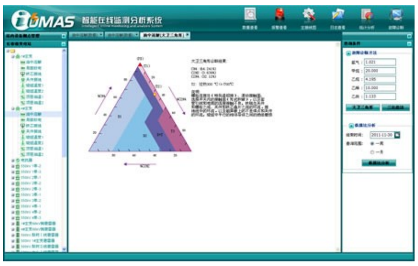

Fig.9 the interface showing the diagnosis result of dissolved gas in oil using the method Duval's triangle

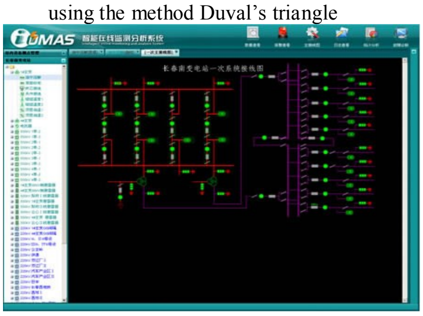

Fig.10 interface showing the status of the primary equipment being monitored

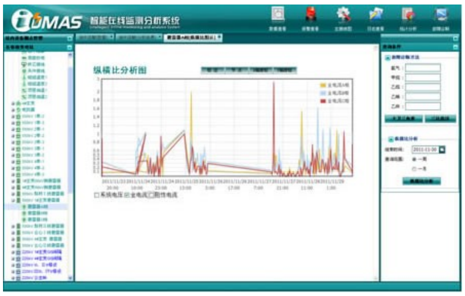

Fig.11 interface showing the diagnosis result of insulation parameters by comparison method

The SCD (Substation Configuration Description) document has been created to describe the configuration of the system, and the functions of the system have been tested both in lab and in site. The system has been running for about three months in the 500kV smart substation. Fig.12-15 are the pictures of CAC, CMU, and monitoring devices installed in the substation.

Fig.12 picture of the CAC and switches

Fig.13 picture of the CMU

Fig.14 pictures of the monitoring devices

VIII. Conclusion

In this paper, the function models and interface models of the online monitoring system have been built based on IEC61850 standard. Then, a typical schema of the online monitoring system has been designed. Finally, an actual system using these models and the schema has been constructed, which is running in a pilot 500kV Smart substation of State Grid. It will be the first online monitoring system in china that is full compliance with IEC61850 standard, and will guides the application of IEC61850 standard in the follow-up projects. In the future, the online monitoring system will be integrated into the substation automation system, the system structure will be different from which debated in this paper, so there are still many issues need to study on the application of online monitoring system in the Smart substation.

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