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Sustainable Smart Substation Design for Use in Future Power Grids

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The substation is a core component of the energy conversion and operation control of a power grid. The construction of smart substations is one of the key links for implementing a strong smart grid strategy. To undertake informatization, automation, and interaction of the strong smart grid strategy, this paper identifies the problems and shortcomings currently occurring in the application of substation technologies by comprehensively considering the status of substation technologies and the development requirements of future power grids. The key technologies required for a smart substation i.e., state monitoring, data acquisition, protection control, the information network and the construction technology are discussed, and the design and construction scheme of online monitoring, substation-area protection, integrated information network and modular construction technology are put forward. In addition, the results brought by the application of new technologies are analyzed based on actual engineering.

Keywords: substation design; environmentally friendly; state monitoring; substation-area protection; integrated information network

1. INTRODUCTION

The power grid features flexible running modes, large flow changes, and complex operational controls with increasing scales, access of large-scale wind power generation and photovoltaic power generation, and the application of multi-type flexible AC/DC equipment. As a result, there is an increasing work load for data analysis and processing at the master station end of the power grid [1]. The substation, as the core node of energy conversion and operational control, should be developed with an accelerated intelligentization process in order to play a role in smart analysis and decision-making. In the meantime, a more efficient, energy-saving and environmentally friendly substation is required to meet the social requirements of these aspects [2].

Currently, elements of conventional substations are mainly protected, which is inadequate for handling complex faults. Different communication protocols are adopted between devices and functional subsystems are independently configured, so the information sharing level is low. As repeat devices and samplings are adopted, long-time system joint adjustments are required and a lot of operation and maintenance work has to be carried out. Due to the above shortcomings, the conventional substations cannot meet the development mode transformation requirements of a modern power grid [3]. Breakthroughs related to digitization, networking, integration and intelligentization of substations will be integrated with the rapid development of information and communication technologies, the establishment of IEC 61850 standards and the application of electronic instrument transformers [4].

In this paper, the problems and shortcomings of current substation technologies applied in the engineering field are analyzed from technical developments in the substation field. Key technologies are discussed from five aspects; state monitoring, data acquisition, protection control, the business platform and the information network.

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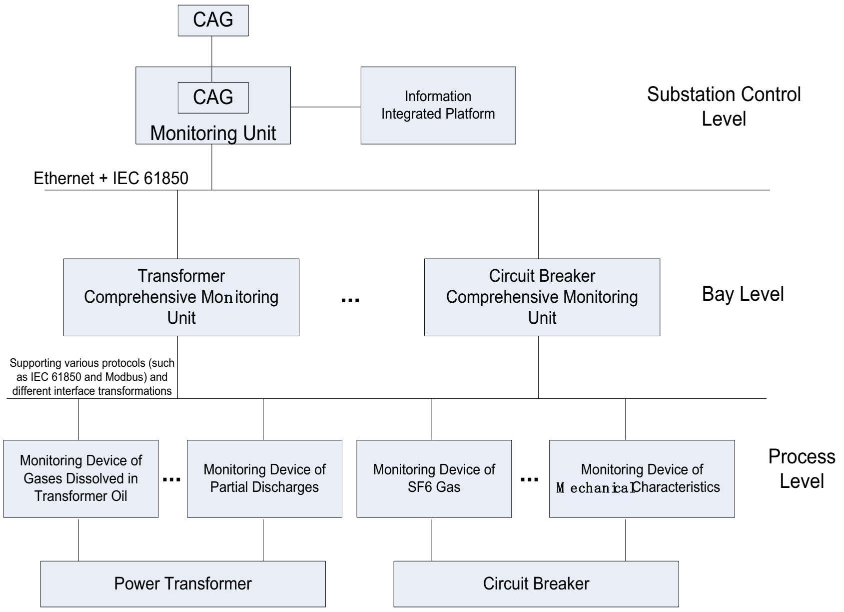

Figure 1 Architecture of on-line monitoring system of smart substations.

2. STATE MONITORING OF SMART DEVICES

The concept of a "smart device" is introduced with the intelligentization development trend of substations [5]. In terms of physical form and logical function, a smart device can be considered as "primary equipment + smart components". Currently, smart components are mainly used as smart interfaces for the primary equipment. They are connected to the primary equipment with conventional electric cables and to relays, measurement and control devices and other secondary equipment with optic cables. They transmit the primary equipment's state information to the uplink through GOOSE messages and receive GOOSE downlink switching-closing control commands for protection, measurement and control. For smart devices, they are no longer divided into primary equipment and secondary equipment. Some functions of the devices at the process level and those at the bay level of the conventional substation are integrated. In addition, the operational state of a smart device can be judged on-line by means of real-time monitoring and device life-cycle prediction, realizing device self-diagnosis and supporting real-time device control and state monitoring.

On-line monitoring of the smart device is mainly to realize the following three objectives: built-in sensing in order to ensure that key device data is reliably collected; standard data integration based on smart component technology and the IEC 61850 standard in order to provide normalized data support for data saving and analysis; and visualization of device state data by modeling analysis of the device state. The on-line monitoring system of the smart device is developed with bus-based distributed and layered architecture. Similar to the overall communication structure of the substation, this system consists of three levels, i.e., the process level, bay level and substation control level, as shown in Fig. 1.

The process level consists of on-line monitoring sensing elements and the IED of the primary equipment (such as the transformer), which collects state data of substation devices and converts analog signals of the primary equipment to digital signals. At the bay level, the corresponding integrated monitoring unit is set based on the type of primary equipment to realize standard communication with devices at the substation control level, processing of monitoring data, threshold comparison, monitoring, warning and other functions. At the substation control level, a substation end monitoring unit is provided to realize data acquisition and operational control of the entire on-line monitoring system.

3. SUBSTATION-AREA PROTECTION

For the conventional substation, the low-frequency load shedding device, overload shedding device, standby power supply auto-switching device, and bus differential protection device, among others are all configured independently. Furthermore, electric cables are used for connections to instrument transformers and various types of devices are involved, so the wiring is complex. In terms of conventional backup protection, stage-based distance protection or over-current protection is provided. Action selectivity between the uplink protection and the downlink protection has to be guaranteed within strict time limits. Under a complex operating mode, the action time-limit of backup protection may last for several seconds and such problems as large-range fault clearing and complex co-ordination may rise [6]. The action speed is slow if selectivity is guaranteed by setting the value and time co-ordination. In addition, each of the elements is required to be provided with various backup protection mechanisms, resulting in a complex structure of protection systems and high value of investment in equipment.

The application of digitalized information acquisition and networked communication transmission makes it possible to realize centralized substation-area protection with network acquisition and network tripping based on substation

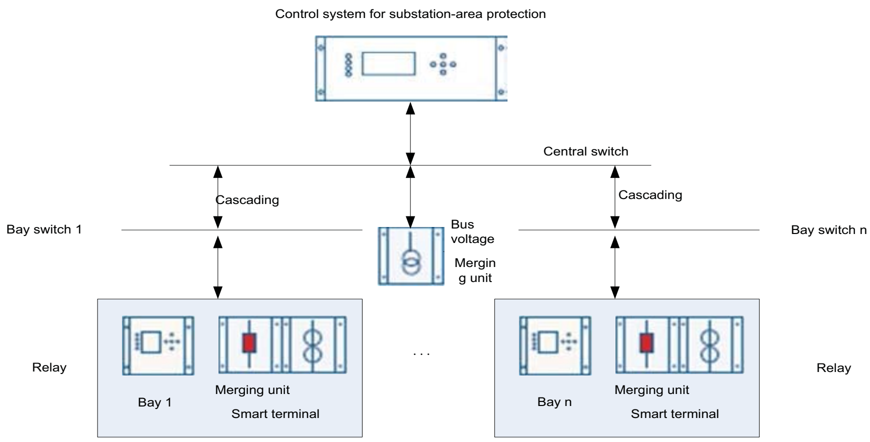

Figure 2 Network acquisition and transmission scheme of substation-area protection.

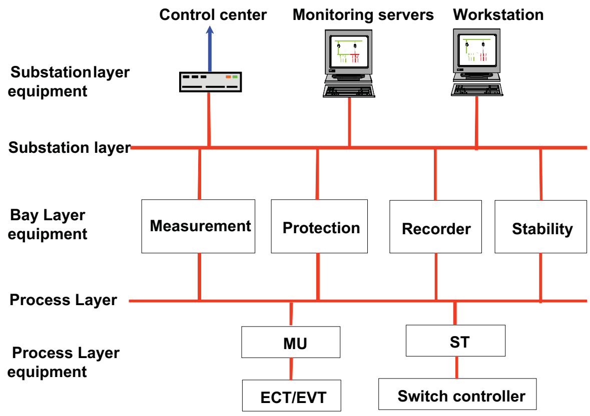

Figure 3 Structure of three layers, two networks.

information. Substation backup protection, breaker failure protection, LV bus protection, low-frequency and low-voltage load shedding, standby power supply auto-switching and overload shedding are highly integrated for the substation-area protection by taking full advantage of the standardized information sharing of the smart substation. The objects of substation-area protection involve all elements and lines in the substation. Backup protection, redundancy protection, control and other similar elements in the substation are realized by the network acquisition and network tripping mode with centralized voltage and current information, device action and state information, and other information, of each element and line in the substation [7].

As shown in Fig. 2, the substation-area protection system is technically based on the digitalized acquisition and networked transmission of information at the process level.The integration of backup protection, breaker failure protection, LV bus protection, low-frequency and low-voltage load shedding, standby power supply auto-switching, overload shedding and other functions are optimized by a centralized acquisition of current, voltage and other information from each line and element of the substation [8]. The substation-area protection control devices follow the reliability principle focusing on mis-operation prevention. Tripping and control commands act on the smart terminal over a GOOSE network. Functional configurations of the substation-area protection are shown in Table 1 below.

4. INTEGRATED INFORMATION NETWORK

The in-station information network is a special data communication network providing such functional services as protection, measurement, control, metering, PMU and fault recording. According to different types of applications, the in-station network information includes GOOSE, SV, MMS and time-adjusting information. At present, the information network in the substation is set as per the structure of three layers, two networks, as shown in Fig. 3 [9–12].

The secondary system for primary equipment is established based on micro-electronics; computer technologies and new sensors enabling intelligent operation of primary equipment; digital technical applications being extended from the secondary system to the primary system; digital interfaces between the protection control command and the operating mechanism of primary equipment being provided via an optical network; and a combination of the process level bus and the bay level bus of the smart substation being possible. Therefore, the existing three layers, two networks structure of the substation will be gradually changed into an integrated high-speed communication network.

According to the development of flow control technology and new integrated equipment, it is known from the analysis of network transmission flow that the communication network structure of three layers, one network, with a common network

Table 1 Functional configurations of substation-area protection.

Functional property	Functional module	Description
Redundancy protection	Line protection, main transformer protection, bus protection, segment protection	Redundancy of single protection for devices with a capacity of 110 kV and below
	Rapid fault locating	Based on multi-point information; cooperated with local protection to accelerate fault clearing
Optimized backup	110 kV breaker failure protection	Breaker failure protection function
	10 kV breaker failure protection	Simple bus protection based on GOOSE messages
Safe and stable control	Low-cycle and low-voltage load shedding	Integrated with low-cycle and low-voltage load shedding; optimized load shedding strategy
	Substation-area standby power supply auto-switching	Comprehensive standby power supply auto-switching under different voltage classes in substation
	Overload shedding of main transformer	Overload shedding and load sharing of main transformer
Wide area protection sub-station	Wide area protection sub-control station	Information acquisition, processing and transmission (to uplink) within the substation; wide area information verification and execution

transmission of MMS, SV and GOOSE information and the establishment of an integrated network for the whole station are realized in the substation (110 kV or below). Therein, the network topological structure is a single-star structure; shared-port transmission of GOOSE, SV and MMS is adopted for access devices and the method of network acquisition and network tripping is adopted for substation area protection so that the number of network switches is significantly reduced. The structure of three layers, one network is shown in Fig. 4.

5. CONSTRUCTION CASE

The Chongqing Dashi 220 kV substation project is located in the periphery at the south side of the planned Hechuan Comprehensive Industrial Park in Menjing Village, Dashi Town, Hechuan District, Chongqing. The construction of this substation aims to solve load growth issues in the Hechuan North industrial development zone, the Weituo chemical industrial park, the Dashi comprehensive industrial park and Flower Beach International City in Siju Township, among others, and to provide power supply for the 110 kV Wuzun, Siju, Shaxi and Xiaoanxi substations planned during the 12th five-year plan in order to reinforce the structure of Hechuan's 220 kV grid and to improve the reliability of power supply in the Hechuan District. The design sketch of Dashi substation is shown in Fig. 5.

For the selection and layout optimization of primary equipment, integrated smart breakers (including CT) and gas insulation tubes will be adopted so that the longitudinal dimension of the power distribution device will be reduced by 45.5 m. If the pneumatic switchgear cabinet is arranged in the container room, the building area will also be reduced by 520 m^2. The plane layout of the 2200 kV, 110 kV and reactive areas will be optimized so that the floor area will be reduced by 7280 m^2, occupying 34%. Table 2 shows the comparison of the original design scheme and the intelligentization solution.

6. CONCLUSIONS

This paper deals with the development trend of intelligent technologies for substations of future grids from 3 aspects below:

First, using the model of equipment, sensor and intelligent component, the online monitoring of the operation status of equipment is realized.

Second, each substation is equipped with 1 set of substation domain protection devices, which realizes the integration of redundant protection and substation domain control.

Third, an integrated information network is adopted to realize information sharing and network transmission.

The configuration state and intelligentization level of the current substations in our country are described via the case study of the intelligentization solution of Chongqing Dashi 220kV substation in this paper. The effect analysis of the intelligentization of substations is also discussed with relevant data.

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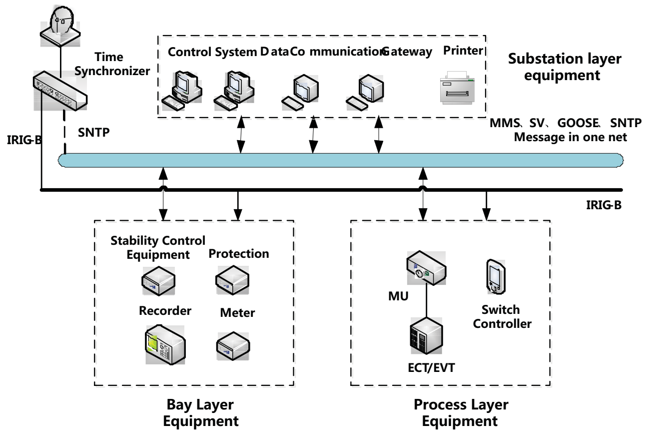

Figure 4 Structure of three layers, one network.

Figure 5 Design sketch of chongqing dashi 220kV substation.

Table 2 Comparison of design scheme of chongqing dashi 220 kV substation.

Item	Original scheme	Intelligentization solution
Main electrical wiring	Duplicate-busbar	Integrated breakers for 220 kV line; disconnectors at the outgoing line side cancelled; for 110 kV line, single bus and 3 segments to be used to replace the duplicate-busbar
Selection of electrical equipment	Conventional AIS equipment	Pneumatic switchgear cabinet to be adopted for 10 kV line; integrated reactive equipment to be adopted for reactive line
	Conventional secondary equipment	Local protection and multi-function measurement and control to be lowered to prefabricated cabins
Floor area	21360 m^2	Floor area after optimization: 14080 m^2; reduced by: 7280 m^2, occupying 34%
Building area	841 m^2	Building area after optimization: 321 m^2; reduced by: 520 m^2, occupying 62%
Secondary cabinet	108	Prefabricated secondary combination device to be adopted; number of secondary cabinets after optimization: 88; reduced by: 20, occupying 19%
Construction period	1 year	Technology of construction of standard delivery to be adopted with efficiency increased by 40% and construction period reduced to 7 months.

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