Research on Substation Comprehensive Information Automation System Based on Smart Grid

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Abstract. In order to cope with the needs of large-scale substation intelligent transformation in China during the "13th Five-Year Plan" period and the corresponding intelligent transformation of traditional substation condition monitoring systems, this article takes 500 kV traditional substations as an example. Analysis of standards, software and hardware of station control layer and bay layer, diagnostic methods, etc., gives the realization method of upgrading, and points out the next research direction. This transformation can lay a good foundation for the informationization, automation and interaction of the smart grid.

1. Introduction
The substation integrated automation system is a comprehensive automation device that integrates protection, measurement, control, signal remote transmission and other functions, uses microcomputers and network technologies, and fully utilizes digital communication technology to realize data sharing for secondary equipment in power systems. Comprehensive, computerized structure, operation monitoring screen, intelligent operation management and so on. At present, the layered distributed substation integrated automation system based on Lonworks bus technology has been widely used. Based on this, an in-depth study on the characteristics of dispatch automation system and distribution automation system is proposed, and a penetration mode of regional smart grid deployment automation system based on IEC61968 message integration technology is proposed, using graphical interaction mode based on SVG and CIMXML based on IEC6190 standard The model exchange method solves the problem of graph-model integration, and uses the cross-system message transmission method based on IEC61968 message integration technology to realize the problem of substation data collection and reverse data remote control [1].

2. Information physical fusion analysis of substation automation system

2.1. Information Physics Fusion Framework of Substation System Based on IEC61850 Standard
With the development of information technology and the construction of smart grid, the substation automation system already has the architecture of the information physical fusion system. The simplified model of the actual substation automation system is shown in Figure 1. The IEC61850...
standard establishes the Unified stipulations, the physical layer elements considered under this stipulation are voltage transmission lines, busbars, circuit breakers and main transformers on both sides.

Figure 1. Simplified model of substation automation system

The information layer is divided into station control layer, bay layer and process layer. As a communication bus, the process bus plays the role of sending and receiving digital signals between the process layer and the bay layer, and establishes a communication bridge between the protection unit, the merging unit and the circuit breaker. As a connecting element between the physical layer and the information layer, the circuit breaker acts as a control terminal and is a specific coupling point between the physical layer and the information layer. The information layer components under the IEC61850 standard are mainly process bus, merge unit and physical component protection unit. The protection unit is divided into transmission line protection unit, transformer protection unit and bus protection unit.

The substation layer is the management core of the integrated automation system, including. Host computer and man-machine workstation, data processing and communication device, GPS synchronization system, etc. It provides a good man-machine interface for information analysis and processing, database management, anomaly detection and alarm, complete the conversion of communication protocols, and achieve communication with the bay layer and remote dispatch centre. The number of nodes in the substation layer is small, but the amount of data transmission is large, with information on monitoring, protection, electricity measurement and other safety automatic devices.

2.2. Hierarchical structure
The condition monitoring system of the original traditional substation is mainly composed of a monitoring and acquisition device, a communication front-end system, and an industrial computer in the station. Some use multiple communication protocols, and some use a controller area network (CAN) as a unified communication method, which lacks a unified technology. Standards, products of different manufacturers are incompatible with each other, a monitoring type set of systems, there are multiple front-end systems for one device, status data resources cannot be shared, devices cannot be controlled uniformly, and they cannot adapt to the development trend of smart grids. Through the transformation, the primary equipment status monitoring, information modelling standardization, and the communication protocol DL / T860 standardization were implemented at the entire station. Figure 2 is the hierarchical distributed system architecture of the transformed substation equipment status monitoring system (in the dotted frame), which is divided into station control layer, bay layer and process layer. Increase the application of intelligent diagnosis according to the needs, and at the same
time realize the unified communication control of the lower layer devices and the communication interface to the upper-level master station system (transformer CAG).

![Figure 2. Substation equipment status monitoring system architecture after transformation](image)

The station control layer is provided with a station-side monitoring unit status access controller, with the substation as the monitoring object, to realize the operation control of the entire online monitoring system and the collection, storage and forwarding of the status data of all substation equipment. The bay layer is a comprehensive monitoring unit. The comprehensive monitoring unit takes the monitored equipment as the object and realizes the functions of data collection, processing, and communication agency of all monitoring units of the monitored equipment. The process layer is a monitoring unit of various professional and technical directions that takes the monitoring project as the object, and realizes the functions of automatic collection, measurement and digitalization of the status information of the substation equipment. The transformed substation will not have a self-contained monitoring project, eliminating the need to install multiple sets of front-end systems with different functions in one equipment. The substation uses the CAC to associate the integrated monitoring units of each device. The same device uses the integrated monitoring unit to associate the different monitoring units together. From top to bottom, the structure clearly forms a unified online monitoring system for the substation [2].

3. Smart grid deployment automation system penetration mode technology

3.1. Main network graph and model integration synchronization mechanism

The integration of the main network graphics is divided into two types according to the main network system support and retrieval type, the main network system that supports remote retrieval and the main network system that does not support remote retrieval. For the main network system that supports remote access, the graphic information in the main network system can be freely accessed through the remote access interface to realize the virtual import of the main network power transmission and transformation system graphics. The graphic information that can be read by this method includes the transmission and transformation graphs in various main grid systems such as plant and station diagrams, contact diagrams and tidal current diagrams. The associated model information in the
retrieved graphics is the model information of the remote main network system and does not depend on the system local database.

According to the recommendation of CCAPI, the interactive mode of graphics centre should be adopted in the dispatch automation system. In the graphic-centric interaction mode, there is a loosely coupled relationship between visualization and data storage, and it is easy to support the diversity of each object representation; it is easy to support the background data in the chart; it is easy to integrate the graph into the chart; You can easily use the SVG browser. This method is mainly aimed at dispatching automation system and SCADA. The flow of graphic interoperation is shown in Figure 3.

For the main network system that does not support remote access, the SVG graphic file exported from the main network transmission and transformation system can be generated in the application system according to the IEC61970 standard. If the main system transmission and transformation system model information has been imported into the application system, the graph can be associated with the main network transmission and transformation system model imported by the application system through the model keyword. According to the CIM RDF model described in the IEC 61970 501 standard, a power system model can be converted and exported into an XML document, as shown in Figure 4. This document is called CIM XML document. The CIM RDF mode provides the resource description format used by CIM XML documents. The final CIM XML model exchange document can be parsed, and the information in it will be imported into an external system [3].
3.2. Information Physics Interface Matrix

The failure range of the physical layer corresponds to the product of the probability of the corresponding independent information elements. The occurrence probability of each state sequence of the information layer can be calculated according to the conditional probability formula. The matrix form is the information physical interface matrix mentioned in this paper. Probability characterization of propagation includes driving events such as information layer delay, interruption, misalignment, and component failure in information physical systems, with a view to characterizing the interaction mechanism between existing power equipment and information systems. The specific expression is:

$$CCPM = \begin{bmatrix}
p_{1,1} & p_{1,2} & \cdots & p_{1,n} \\
p_{2,1} & p_{2,2} & \cdots & p_{2,n} \\
\vdots & \vdots & \ddots & \vdots \\
p_{m,1} & p_{m,2} & \cdots & p_{m,n}
\end{bmatrix}$$

(1)

Among them, \(p_{i,j}\) is the probability that a specific fault scenario \(j\) occurs during the fault clearing process of the \(i\)th physical component; \(m\) is the number of physical components; \(n\) is the number of fault scenarios. Each scene corresponds to the 0-1 sequence of related information elements, and also corresponds to different physical fault ranges. As shown in Figure 1, there are 33 elements corresponding to the interface matrix, and its 1 state sequence is "1000000000110000000011000000000000". See the fault clearing analysis in Section 3 for specific scenarios. The sum of the elements of each row in the interface matrix is 1.

3.3. Comprehensive automatic monitoring

The five-proof system can prevent maloperation in the substation, ensure the safe operation of the substation, and prevent human misuse of equipment. Any normal trip operation must go through the simulation preview and logical judgment of the five-proof system, which can greatly prevent and reduce the occurrence of power grid accidents. Among them, the mandatory five-proof blocking: by adding a lock to the primary device and implementing the forced blocking of its operation, only the
operations performed in the correct order after the simulation in this system can unlock the operation, so as to achieve the purpose of five-proof. The auxiliary tool of the host computer can realize the maintenance of the system graphics under the cooperation of the software, realize the functions of lock code test, lock unlock test, equipment code collection, etc., and can configure the system parameters according to the usage [4].

3.4. Video surveillance
The video monitoring system consists of an infrared network camera, a hard disk video recorder, a transmission line, a switch and a monitor. Real-time video surveillance of important key parts is realized through network cameras located in key areas inside and outside the 35 kV substation. The number of installations is 28, and the monitoring locations are as follows: 8 at the outer wall of the 35 kV substation; 2 at the interior of the capacitor; 2 at the exterior of the capacitor; 2 at the exterior of the power distribution; 14 at the interior of the distribution; the system structure is shown in Figure 5. It can realize the recording and real-time viewing of the video information of the operation status of the equipment and the surrounding environment. Through the analysis of the collected information, the countermeasures are formulated in a timely manner.

3.5. Communication service of condition monitoring system
The communication function is upgraded to receive the DL / T 860 standard information uploaded by the integrated monitoring unit, centralize the data of all online monitoring units in the whole substation, and issue control commands to the monitoring unit. The main communication services include alarm, spectrogram call, periodic upload of spectrogram data, and different sampling periods are set according to the real-time requirements. For example, the local discharge unit usually sends the measurement value every 5 minutes, and the oil chromatography unit is set to be sent daily. One-time measurement value; the spectrum information adopts the waveform file in the wave-recording format, and is transmitted between the CAC and the monitoring unit using services such as Get File Attribute Values, Get File, etc., and is transmitted to the CAG in the form of a binary stream, and stored as a Blob field type, such as judgment If a partial discharge occurs, it can be summoned in CAG, and the spectrum generated by the monitoring unit can be sent [5].

There are 2 types of interface methods for CAC. 1. Use Web Service and XML technology according to the I2 interface specification with the upper-level system to push and receive instructions to the provincial monitoring centre of the network. I2 interface functions include I2 interface configuration management tools and templates, transmission information types, access to CAG configuration, self-starting at power-on, manual shutdown, logging, database settings, communication with the master station, and support for master station control command functions. It can be transmitted at regular intervals within the specified transmission time interval and supports resuming
of breakpoints. For the problem of large data volume, the segmented technology is adopted for transmission. 2. Interact with other business systems to realize data and function through the enterprise service bus. Register the online status, measurement value, alarm information and other data of the substation real-time monitoring with the Web Service package to the enterprise service bus for other systems to call, and also call the services of other application systems [6].

4. Data collection

4.1. State quantity collection
State quantities mainly include: circuit breaker state, disconnector (knife gate) state, transformer tap state, and substation primary equipment alarm signal at present, most of these signals are input into the system using photoelectric isolation, which can also be obtained through communication. The protection action signal is obtained through the serial port (RS-232 or RS484) or computer local area network through communication. Model the reliability of information layer components as a two-state model, similar to the normal and abnormal operation of physical component equipment, set the information component status to binary values 0 and 1, where 0 indicates that the component is in normal operation and 1 indicates the component in an abnormal working state (fault, communication delay blocking, and malfunction), the process changes as shown in Figure 6. In the figure, \( \lambda \) is the failure rate of a single component, and \( \mu \) is the repair rate of a single component. The specific data is given in Table 1.

| Element          | Mean time between failures / a | \( \lambda / \text{a}^{-1} \) | Average repair time / h | \( \mu / \text{a}^{-1} \) |
|------------------|-------------------------------|-------------------------------|------------------------|------------------------|
| Merge unit       | 140                           | 0.00667                       | 7.99998                | 1094.002               |
| Breaker          | 100                           | 0.01                          | 7.99998                | 1094.002               |
| Protection unit  | 40                            | 0.02                          | 7.99998                | 1094.002               |
| Process bus      | 100                           | 0.01                          | 7.99998                | 1094.002               |

Then the occurrence probability \( p \) of the single element in the normal working state and the occurrence probability \( p' \) in the abnormal working state of the information layer are respectively:

\[
p = \frac{\mu}{\lambda + \mu}
\] (2)
Due to electromagnetic interference under high-voltage environment, information communication will have a certain delay. GOOSE data packets may be discarded due to this delay. The probability \( \eta \) is used to measure the delay transmission process of the process bus. The probability of occurrence in abnormal working state \( p' \) are:

\[
p = \frac{\mu}{\lambda + \mu} (1 - \eta)
\]

\[
p' = 1 - p
\]

Among them, \( \eta = 0.3\% \). Calculate the occurrence probability of each information element in the normal working state and the occurrence probability in the abnormal working state independently. The results are shown in Table 2. It can be seen from Table 2 that the probability that the process bus is in a normal working state is lower than other components due to factor (4).

| Element           | \( p \)         | \( p' \)         |
|------------------|-----------------|-----------------|
| Protection unit  | 0.999981734     | 0.000018264     |
| Merge unit       | 0.999993912     | 0.000006088     |
| breaker          | 0.999990868     | 0.000009132     |
| Process bus      | 0.996990894     | 0.003009104     |

4.2. Analog quantity acquisition

Typical analogy quantities collected by conventional substations mainly include: bus voltage, line voltage, current size and power value of each section. Feeder current, voltage and power values, phase, frequency, etc. In addition, there is the collection of non-electricity such as transformer oil temperature and substation room temperature. The precision of analogy quantity acquisition should be able to meet the needs of SCADA system.

4.3. Pulse volume

The pulse quantity is mainly the output pulse of the pulse watt-hour meter, and it can also be connected to the system by photoelectric isolation. The counter counts the number of pulses internally to achieve electrical energy measurement.

4.4. Event recording and fault recording distance measurement

The event sequence record shall include the protection action sequence record and the switch trip record. The resolution of its SOE is generally between 1-10 ms, so as to meet the requirements of different voltage levels for SOE. The substation fault recorder can be implemented in two ways as required. One is to centrally configure a dedicated fault recorder and communicate with the monitoring system. The other is the decentralized type, that is, the computer protection device doubles as the record and the ranging calculation, and then the digitized waveform and ranging results are sent to the monitoring system for storage and analysis by the monitoring system.

5. Conclusion

The overall structure of the distributed substation integrated automation system mainly depends on the choice of communication system, and the overall performance of the system is also largely determined.
by the quality of the communication system. Practice has proved that the communication rate, communication distance, anti-interference ability, number of supported nodes and fault tolerance of the Lonworks bus can all meet the requirements of the reliable operation of the automation system, and its advantages of distribution, openness and scalability make the comprehensive automation of substations is simple and easy to operate from design, installation and commissioning to normal production operation and maintenance. It saves costs and improves the reliability of the operation of substation integrated automation systems, so it has been widely used. In the future practice of substation integrated automation engineering, Lonworks fieldbus has a broad application space, and will greatly promote the development of substation integrated automation technology.

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