Research on key technology of 3D digitization for secondary system of power grid based on model application analysis

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Abstract. In order to solve the problems of long development time, poor expansibility and small application scope in the digital design of secondary system of intelligent substation at present, this paper puts forward the 3D assembly techniques based on the expanded model by analyzing the integration of secondary model files of intelligent substation. In the design process of this method, the relationship between primary equipment and secondary equipment, the mapping between logical circuit and real circuit are fully considered. By using standard family library techniques, file analysis techniques and automatic mapping techniques, the coupling between physical model and logical relationship is realized. Taking the actual 220kV intelligent substation as the pilot, the three-dimensional model in secondary system simulation analysis, online monitoring and the application of fault diagnosis shows that the techniques can effectively improve the efficiency of three-dimensional design and maintenance of secondary system.

1. Introduction

Three dimensional digital design of power grid is an integrated innovation of modeling technology, information technology and network technology, which is conducive to the optimization of design, construction and installation, production and operation, and is conducive to improving the intrinsic safety level of power grid engineering in the whole life cycle. It is an important technical support for the construction of smart grid. Three dimensional technology can realize the full information simulation of power grid, with the characteristics of digitization and visualization, which can effectively improve the management level of engineering construction and operation inspection, and lay the foundation for the construction of digital power grid [1-3].

In China, digital design of power transformation projects based on three-dimensional information technology has entered the promotion stage, and relevant departments of State Grid Corporation of China have successively issued the specification for digital design transfer of power grid projects [4, 5]. However, the three-dimensional design specification for substation secondary system has not yet been established. At present, some scholars have carried out relevant work on the three-dimensional design of substation secondary system. Reference [6] proposed a three-dimensional visualization information interaction technology of substation based on common information model (CIM). This technology can solve the problems of non intuitive display of equipment information and difficult interaction in the...
traditional way, but the traditional collision method is still used in the construction of three-dimensional scene, which is not adaptable to the secondary system. Reference [7] proposed a three-dimensional design method based on substation terminal block diagram, cable inventory and other information. This method needs to collect a large number of original data, and the modeling process is time-consuming, labor-consuming and inefficient. Reference [8] proposed a design scheme of secondary specialty cooperating with other specialties. Although the scheme can fully consider the three-dimensional design of secondary system, it has high requirements for the compatibility of design software and the coordination of various departments, which is not conducive to the actual implementation. Literature [9] adopts the 3D design method of virtual reality technology, but this method is not conducive to the expansion and maintenance of the built model. Once the substation structure changes, all the related designs need to be modified, which brings difficulties to the maintenance and update of the system. Literature [10-11] focuses on the application of 3D model in the intelligent operation and inspection of the secondary system, but it is not conducive to the rapid and effective establishment of 3D model Without specific elaboration, it can not provide effective modeling methods for designers.

In view of the shortcomings of the above research content, this paper takes several key model files of the secondary system of intelligent substation as the starting point. Through the application integration analysis of the secondary model files, the relationship between the model file and the 3D design is studied. The 3D assembly technology based on the extended model, including the standard library technology, the file analysis technology and the automatic drawing technology, is proposed. The technology can realize the high-efficiency integration of the three-dimensional model of the secondary system in substation, the coupling between the physical model and the logic, which lays the foundation for the advanced application of 3D model in the secondary system, such as simulation analysis, online monitoring and fault diagnosis.

2. Overall thinking of 3D digital design for secondary system

The establishment of three-dimensional digital design model of intelligent substation aims at the practical application scene of secondary specialty, so as to provide more direct and efficient means for operation and maintenance personnel in the aspects of simulation analysis, online monitoring and fault diagnosis. At present, the establishment of information interaction model of intelligent substation is based on IEC61850 standard, which is applicable to intelligent electronic equipment (IEE) of intelligent substation The interaction language and information interaction mode of equipment (IED) equipment are specified in detail [12]. The normal operation and maintenance of the secondary system of intelligent substation are based on the secondary system model file. The key models include the substation configuration description (SCD) file and the system specification file Description (SSD) and grid information model (GIM).

In this paper, three-dimensional digital design is constructed and applied based on the above three core model files, as shown in Figure 1: (1) firstly, the application analysis of three types of model files of intelligent substation is carried out, and the internal relationship mechanism of three-dimensional digital design of secondary equipment is constructed. Among them, SCD model file provides logical connection information for the communication between secondary equipment 3D models; SSD model file provides hierarchical attribute information for the association between primary and secondary equipment 3D models; GIM model file provides document information for the handover and application of secondary system 3D models. (2) Thirdly, based on the above model files, through the study of the secondary equipment 3D model standard family library technology, file analysis technology and automatic mapping technology, so as to complete the secondary equipment 3D external visualization model. (3) After completing the three-dimensional digital design of the secondary system, the advanced application of the three-dimensional model of the secondary system in the actual operation and maintenance is completed by studying the interface technology between the three-dimensional model of the secondary system and the operation information, online monitoring and diagnosis technology.
3. **Application analysis of key model files in secondary system**

3.1 **Application analysis of SCD file**

The SCD model file of Smart Substation is based on IEC61850 specification and is written in XML language. It specifies the information sharing and interoperability between IEDs in Smart Substation. Based on the method introduced in reference, the SCD file is analyzed to obtain the communication relationship among IEDs in substation, including ied model information, subnet allocation information and virtual circuit information. The file contains five elements: header, substation, IED, communication and datatype templates [13]. At the same time, according to IEC61850 standard, SCD file establishes three kinds of information service models: MMS (Manufacturing Message Specification), goose (general substation oriented time object) and SV (sampling value). The goose information contains the interactive information between IED and intelligent terminal, and the SV information contains the sampling value between IED and merging unit.

By analyzing the node information of goose control block, inputs and SV control block in ln0 under different ied nodes, the virtual circuit information about goose / SV of the IED device can be obtained, as shown in Figure 2, including the failure trip information between protection devices, the voltage and current sampling information of protection devices, the trip information of protection devices, etc.

SCD model file can provide logical relationship description for information transmission between 3D models of secondary system. IEC 61850 engineering relay protection application model provides optical fiber physical connection relationship between ied device ports. By obtaining logical loop relationship between ied devices and matching with actual optical fiber, virtual real association mapping of secondary system in 3D model can be realized.
3.2 Analysis of SSD file application

The SSD file of Smart Substation describes the structure of the primary system and the associated logical nodes, which provides an effective basis for the device attributes and connection relationship. At the same time, the primary and secondary device relationship of the system is described in detail, and the system can be graphically realized through the configuration tool. Reference [14] describes the SSD file structure, which mainly includes the following object models: substation, voltage level, transformer, bay, equipment, Subequipment, function, connectivity node, terminal, Logical node (Inode), etc.

SSD file describes the model of primary equipment and secondary device in substation, establishes the hierarchy structure of "power grid, station / voltage level, interval, equipment / component, attribute", and sets parameters for primary equipment of power grid. SSD files follow the requirements of gb/t4728 to establish primary equipment elements of power grid. In engineering, we should adopt the modeling method based on Bay (interval), that is, organize equipment or function into a series of intervals according to their relationship or function relationship.

After the primary device interval modeling is completed, the primary and secondary association is carried out, and the Inclass, iedname and other attributes of Inode are assigned. The primary and secondary device association is established according to the following rules:

1. The functions and information in the secondary equipment are associated with the primary equipment through the logical node, and the lphd configuration of the protection equipment logical node is associated with the corresponding primary equipment;
2. All the four remote data associated with the primary equipment are associated with the corresponding primary equipment object through the logical node;
3. All the protection action information and setting information associated with the primary equipment are associated with the corresponding primary equipment object through the logical node;
4. All the process layer information associated with the primary device is associated with the object of the corresponding primary device through the logical node;

Through the above process, the association of two-dimensional graphics between primary equipment and secondary equipment is realized, as shown in Figure 3. The graphic display of the primary and secondary equipment is realized by using the integration of graphics and modeling technology, as shown in Figure 4.

Therefore, in the construction of 3D model of secondary equipment, in order to make the assembly process as simple as possible, this paper uses the integration of graphics and modeling technology to
associate the 3D model of secondary equipment in the construction process of visual components of primary equipment, so as to ensure the consistency of 2D module and 3D module state of equipment.

3.3 Application analysis of GIM file

Power grid GIM technology is mainly used in the design and construction of power transmission and transformation engineering [15]. This paper expands the content of secondary system according to the GIM specification of State Grid, including protection devices, intelligent terminals, merging units, measurement and control devices, switches, stability devices, recorders and other secondary equipment of various manufacturers, as well as related secondary auxiliary components. For example,
"geometric fineness of protection device model", "engineering information of protection device" and "attribute fineness of protection device" are specified for secondary protection device, as shown in Table 1.

| Attribute | Data Type | unit | Example | General model | Productct model |
|-----------|-----------|------|---------|---------------|-----------------|
| Project name | Character type | - | | ✓ | ✓ |
| Power grid project identification system code | Character type | - | Software automatic generation | ✓ | ✓ |
| Dispatching code | Character type | - | | | |
| Real ID | Character type | - | | | |
| Attachment No. | Character type | - | Software automatic generation | ✓ | ✓ |
| Project number | Character type | - | | ✓ | ✓ |

Fig. 5. Handover model composition of GIM

The established 3D model of substation secondary system is handed over according to the GIM standard format of State Grid, as shown in Figure 5. The models include digital elevation model (MOD), engineering model (CBM), physical model (DEV) and composite model (PHM).

Through the transfer of standard GIM model, we can achieve: (1) data normalization check. Including 3D model integrity check, GIM format normative check, 3D model and design drawings consistency check. (2) Model visual editing. The established three-dimensional model is visualized to display the three-dimensional model of the secondary system, and the wrong part of the model can be modified. (3) Model change process control. Through the normative review and consistency verification of the model, the model is archived and managed. When there are changes on site, the warehousing model is modified in time and marked to ensure the consistency between the warehousing model and the site.
4. Key technology of 3D model assembly for secondary system
In order to improve the efficiency and quality of the 3D design of the secondary system and ensure the integrity of the 3D model design, as shown in Figure 6, this paper develops the standard family library and material library of the secondary system in an object-oriented way, expands the 3D information of the secondary model file, and studies the model file identification and analysis technology, automatic screen assembly and editing technology, so as to realize the automatic installation of the 3D model of the secondary system match.

Fig. 6. 3D modeling process of secondary system

4.1 3D component family library and material library technology
In this paper, the three-dimensional modeling of the secondary system is carried out by using Autodesk Revit software [16]. The general model family library is established, including the secondary panel cabinet and secondary accessory component family library. The secondary accessory components include: pressure plate, button, indicator light, air switch, terminal strip, handle, optical fiber and distribution frame. The basic attribute information of all secondary Bay cabinets and secondary equipment accessory components includes name, type, basic shape and size scaled according to standard scale. The family library also includes different states of components.

In order to create the 3D model quickly and accurately, this paper establishes the material library of packaged secondary equipment according to different manufacturers and different types of secondary equipment. The material library contains three-dimensional models of different manufacturers and models of secondary equipment. The three-dimensional model contains the manufacturer information, model information, protection type information, device plug-in information and three-dimensional space information of secondary equipment, as shown in Table 2. The 3D model of the secondary equipment in the material library is shown in Figure 7.

In order to ensure that the three-dimensional information of the protective device in the material library has good reusability, the three-dimensional model of the secondary equipment in the material library is updated regularly according to the verified equipment list issued by the State Grid, so as to ensure that the equipment in the material library is consistent with the actual application scene.
Table 2. Equipment and material library information

| No | Name                                           | Type            | Manufacturer   |
|----|------------------------------------------------|-----------------|----------------|
| 1  | 220kV line protection                          | RCS-931ADMM     | Nanrui         |
| 2  | Main transformer measurement and control device| CSC-282         | Beijing Sifang |
| 3  | Ethernet switch                                | 2D-PCS-9882BD   | Beijing Sifang |

Fig. 7. Merge unit model in material library

4.2 Three dimensional information expansion of secondary equipment model

Because the secondary model file of Smart Substation does not contain relevant three-dimensional information at this stage, based on the SSD file of substation, this paper expands it, improves the three-dimensional attribute information of secondary equipment, provides model support for the construction of three-dimensional model, and ensures the consistency of two-dimensional information and three-dimensional information of secondary equipment of substation.

According to the hierarchical structure of primary and secondary equipment described in SSD file, this paper establishes the attribute information of secondary room, cabinet and unit, as shown in Table 3, forming a complete hierarchical structure of "power grid. station / voltage level. Room. Bay. Cabinet. device / element and attribute".

In terms of three-dimensional spatial information, the specific location of the secondary cabinet in the small room adopts the spatial coordinate system (x, y, z). The secondary device and auxiliary components are described in terms of coordinates (F level, u level, L level), in which F is the level arranged from front to back, u is the level arranged from top to bottom, and l is the level arranged from left to right, so as to complete the attribute addition of the spatial location information of cabinets, devices and components, as shown in Figure 8.
Table 3. Secondary system object information

| No | Object     | Attribute information extension                        |
|----|------------|--------------------------------------------------------|
| 1  | room       | name, describe (des), Voltage level (vol)              |
| 2  | cabinet    | name, describe (des), Voltage level (vol), bay, position (pos) |
| 3  | device     | name, describe (des), type, cabinet, position (pos)    |
| 4  | Unit       | name, describe (des), type, class, cabinet, position (pos) |

4.3 Model analysis and automatic screen assembly technology

In this paper, the parsing method based on document object model (DOM) is used to parse the extended SSD file [13]. In this method, the entire SCL file is read into the memory at one time, and the configuration file information is transformed into the object node tree, so as to extract the attribute and position information of the secondary cell, secondary cabinet, secondary device and components. By analyzing the SCD model file of intelligent substation, the logical connection relationship between secondary equipment and the connection address between optical fiber and cable are obtained.

Fig. 8. Extended SSD model file

Fig. 9. 3D modeling process based on extended SSD file

According to the basic rules of electrical secondary design, the number in the system logic data has the unique principle in the same level directory. Through the model analysis results, according to the module family in the mapped standard modular family library, the secondary equipment family model in the system design is extracted. By using the logical relationship of cabinet box, cable and optical fiber in the model file, as well as the numbered attribute information of cabinet, component, equipment and wiring, it is constructed from the outer cabinet to the internal device and terminal strip equipment, calls the matching module family, analyzes its location layout, automatically generates the
three-dimensional model of the secondary system, and finally generates the GIM file of the three-dimensional model of the substation secondary system. The overall process is shown in Figure 9.

5. Application cases

The three-dimensional model assembly technology of secondary system proposed in this paper has been applied in the 220 kV Qiushan substation of Hebei Province. As a key construction project of three types and two networks of Hebei electric power company, it has achieved good results, which proves the feasibility and effectiveness of the method.

(1) In this paper, the 3D modeling of intelligent substation secondary system is carried out by using Autodesk Revit software, and the device attributes are assigned by std-r to form a universal modular family library of standard cabinet box, device equipment, terminal strip, components, cable and optical fiber, and the effect rendering is carried out, which lays the foundation for the establishment of 3D model of the pilot station. The general model family library of substation secondary system can be loaded repeatedly in any model project. As the resource accumulation of three-dimensional model of substation secondary system, it realizes the reuse of three-dimensional model resources, reduces the workload of modeling and improves the efficiency of modeling.

(2) The SSD model file of 220kV Qiushan station is expanded with three-dimensional information. Through the actual measurement of the position of each voltage level chamber and panel cabinet in Qiushan station, the position information of each panel cabinet is determined, and the relative position of each secondary device and accessory component is determined to complete the addition of three-dimensional information. The SCD model file of 220kV Qiushan station is analyzed to determine the position information of each panel cabinet. The logical information of each IED device in process layer and bay layer is connected to construct the mapping between virtual circuit and real circuit of the whole station.

(3) According to the analysis of the three-dimensional attributes of the secondary equipment in the established extended SSD file and the equipment connection relationship in the SCD file, combined with the associated information of the standard equipment material library and the standard modular family library, the model integration design is carried out to realize the instantiation of the secondary three-dimensional model cabinet in the engineering design stage of Qiushan station, as shown in Figure 10.

(4) The 3D model of Qiushan station is applied to 3D panoramic visualization. The visualization data support includes extended SSD model file, standard SVG graphics file, standard GIM file, online monitoring real-time monitoring data. The 3D engine display technology can visually display the 3D panorama of the substation by parsing the standard GIM file; it can integrate with the online monitoring system platform through TCP protocol and interface access technology to interact and display with the 3D engine when the fault information is detected, so as to realize the panoramic perception and fault location in the 3D scene, as shown in Figure 11-13.

Fig. 10. 3D model of secondary panel cabinet and central control cabinet in Qiushan station
Fig. 11. 3D online monitoring of secondary system

Fig. 12. fault location of 3D model

Fig. 13. 3D model fault alarm

The 220kV Qiushan substation adopts the three-dimensional modeling method proposed in this paper to realize the rapid establishment of the three-dimensional model of the secondary system. Because the establishment of the three-dimensional model is based on the model file of the secondary system, the consistency of the three-dimensional model and the two-dimensional model is ensured, and the consistency of the three-dimensional online monitoring information and the actual operation information of the substation is ensured, and the secondary system simulation of the intelligent substation is realized. The effective application of analysis, online monitoring and fault diagnosis in the three-dimensional scene can provide more friendly and intuitive experience for the staff and greatly improve the operation and maintenance efficiency of the secondary system.

6. Conclusion
This paper introduces a three-dimensional assembly technology for secondary system of intelligent substation. Firstly, the current situation of 3D modeling of secondary system is analyzed, and the shortcomings of existing assembly technology are pointed out. In view of these shortcomings, a 3D model assembly technology based on substation secondary system model file is proposed. In the design process, the relationship between primary equipment and secondary equipment, and the mapping between logical circuit and real circuit are fully considered. Through the use of standard
family library technology, file analysis technology and automatic mapping technology, the coupling between 3D model object and logical relationship is realized to ensure the reliability. Finally, the effectiveness of the technology is verified by a pilot case. Through this technology, it can not only improve the development efficiency of the current three-dimensional model of substation, but also the key technology has strong popularization, which can greatly reduce the use cost, and lay the foundation for the future application to other new generation of intelligent substation. At the same time, under the background of energy Internet construction, it plays a significant demonstration role in improving the 3D digital design of substation secondary system and promoting the application of 3D visualization technology.

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