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Research on the Standard System and Key Technologies of Digital Substation Technology

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Abstract. This paper proposes a digital substation standard system to enhance management efficiency. It introduces a model for comprehensive digital information perception and Bayesian algorithms for monitoring. Wireless sensor identification collects subsystem data, analyzed by decision tree clustering. Key meta-data scheduling and fusion methods integrate digital information across the substation. Digital twin technology enables dynamic data fusion and sharing, optimizing substation management.

Keywords. Digital twin; Digital fusion; Mining; Bayesian approach; Substation management

1. Introduction

With the rapid development of the national economy and urban modernization level, the demand for electricity is increasing, the type and number of power grid transmission and transformation equipment is also growing, and the safe operation of the power grid and transmission and transformation equipment has also put forward higher requirements [1]. The stable operation of power transmission and transformation equipment is the basis of power supply, is the guarantee of the safe operation of the power grid. However, the current operation status of transmission and substation equipment is still unstable, and there is a large gap between operation and maintenance personnel and a relative shortage of operation and maintenance resources [2]. This makes it difficult for the staff to monitor the operation status of transmission and substation equipment in real time, and it is impossible to predict the next operation status of transmission and substation equipment [3]. As a result, power safety accidents caused by abnormalities in transmission and transformation equipment occur from time to time.

At present, the operation condition detection method of power transmission and transformation equipment is mainly based on the staff's working experience and ratio analysis, waveform analysis and other methods of judgment [4]. However, with the

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continuous innovation of power transmission and transformation equipment technology, product models increased, the traditional method is difficult to cope with the equipment quantitative, differentiated and refined operational status monitoring needs, resulting in lagging operational status monitoring and verification, equipment maintenance backwardness and so on, thus affecting the safe operation of power transmission and transformation equipment [5]. In addition, the traditional method neglects the application of historical condition data, cannot explore the potential connection between the historical data, and cannot utilize the historical data to infer the operation status to guide the maintenance work [6].

Digital substation technology as an emerging digital technology, based on the data extracted and uploaded by the sensor, the use of three-dimensional modeling of the relationship between the data, the transmission and substation equipment and the virtual digital space to establish a close link between the construction of real-time visualization of the digital twin simulation model, and based on this to achieve real-time intelligent perception, prevention of accidents, and other effects [7]. Digital substation equipment is an indispensable part of the digital power grid, through the promotion of operation and inspection and control of the digital and intelligent, laying the cornerstone of the development of grid digital intelligence [8].

2. Status quo of digital power transformation standardization organization at home and abroad

ISO (International Standards Organization) and IEC (International Electrotechnical Commission) jointly promote standardization in the power field around the world to provide norms and guidance for the development of the power industry. They have set up a number of professional technical committees in this field to meet the standardized needs of power system management, power electronics equipment, power transformers, etc. Among them, the IEC / TC57 (Power systems management and associated information exchange, Power System Management and Related Information Exchange) Technical Committee focuses on the standardization of power system management and related information exchange. The committee has formulated a series of international standards to provide an important basis for the planning, design, operation and maintenance of the power system. The IEC / TC22 (Power electronic systems and equipment, Power Electronics Systems and Equipment) Technical Committee is committed to the standardization of power electronics systems and equipment. Power electronics technology is playing an increasingly important role in modern power systems, and the committee's focus is on the design, manufacturing, testing and operation of power electronics equipment. The IEC / TC14 (Power transformers, Power Transformer) Technical Committee focuses on the standardization work in the field of power transformer. Power transformers are the core equipment in the power system, and the committee focuses on the technical requirements, test methods, operation and maintenance and other aspects of transformer standards. However, in terms of digital transformation technology, the establishment of international standards is relatively few. This does not mean that the importance of digital substation technology is low, on the contrary, it reflects the rapid development and technical complexity of this field. Digital substation technology involves many key technologies, such as the Internet of Things, big data, cloud computing, artificial intelligence, etc. These technologies have been widely used in every link of the power system.

The current status of the domestic power standardization organization includes several technical committees, which are responsible for the formulation and revision of standards in different fields. The National Technical Committee for Standardization of Power Grid Operation and Control (SAC / TC 446) mainly involves power system modeling, simulation, large power grid protection, etc., has issued 43 national standards and 127 industry standards, and the future will focus on the intelligent and digital power grid development. The National Technical Committee for Standardization of Power System Management and Information Exchange (SAC / TC 82) is responsible for substation, distribution network and data security standards, and has issued 5 national standards and 31 industry standards, focusing on guiding smart substation technology. The National Technical Committee on Standardization of High-Voltage Test Technology and Insulation Coordination (SAC / TC 163) focuses on high-voltage test and insulation standards, and has issued 107 industry standards to support the digital application of electric energy metering and equipment monitoring. The Technical Committee of Standardization Transformer in the Power Industry (DL / TC 02) involves the technical standards of transformers and related equipment. It has issued 66 industry standards and 41 group standards, and issued 25 new standards, focusing on smart grid and Internet of Things technologies. The Technical Committee for Standardization of High voltage Switchgear and DC Power Supply (DL / TC 06) has formulated standards for high voltage switchgear and DC power supply, and has issued 44 industry standards, involving digital power supply equipment. The Standardization Technical Committee of Power Industry Relay Protection (DL / TC 15) focuses on relay protection and stability control, and has issued 112 industry standards and 41 group standards, covering the protection and operation and maintenance devices of smart substations. The Technical Committee of Standardization of 3 D Design of China Electric Power Council (CEC / TC 18) is responsible for the 3 D design standards of power transmission and transformation engineering, and has issued 9 group standards, involving 3 D design modeling and software platform specifications. These committees have promoted the digital and intelligent transformation of their power systems and substations through their standardization work.

3. Methodology

3.1. Framework design of digital substation technology standard system

Digital power transformation technology is the core of the construction of digital power grid and new power system, which requires the establishment of a standard system with strong system, high compatibility and good inheritance. This standard system should reflect the integrity and hierarchy, avoid duplication, and ensure the comprehensive coverage and effective connection of technical standards. At the same time, the system should inherit the existing standards, moderately integrate and upgrade, pay attention to the needs of new technologies, and maintain openness and compatibility, so as to adapt to the development of intelligent terminals, the Internet of Things and other emerging technologies. In addition, the standard system should also be practical. By summarizing the practical engineering experience, the scientific and reasonable standard planning and dynamic adjustment plan should be formulated to support the actual demand of the digital construction of the power grid.

In the study of digital substation technology standard system, it is necessary to follow the idea of moderate advance, inheriting the tradition, opening up the future and comprehensive coverage. The standard system should maintain the moderate advancement of technical content, avoid too advanced or lagging, so as to implement smoothly and encourage technological innovation. At the same time, it should integrate the traditional physical power grid standards and digital technology requirements to form a structured framework. The future goal is to guide technology development, develop long-term standard planning, and form new standards when the technology matures. The standard system should have comprehensive coverage, including digital and traditional physical standards, to ensure its comprehensive guidance and effective application in substation technology.

In the core stage of digital power grid and new power system construction, the evolution of digital transformation technology is particularly critical. Based on the unique nature of the current power grid operation, we have carried out a detailed hierarchical division design of each professional branch of the digital substation technology. In this process, we strictly follow the classification criteria of "overall coverage, overall improvement", to ensure that every detail is fully considered. After in-depth analysis and discussion, we have successfully constructed the standard system framework of digital transformation technology, which covers 5 directions of general technology, physical system, business system, platform support and digital twin, and divided 18 subheadings in detail, as shown in Figure 1. This framework not only fully covers the core elements of digital transformation technology, but also ensures the coordination and unity of various parts, which lays a solid foundation for the continuous progress and development of digital transformation technology.

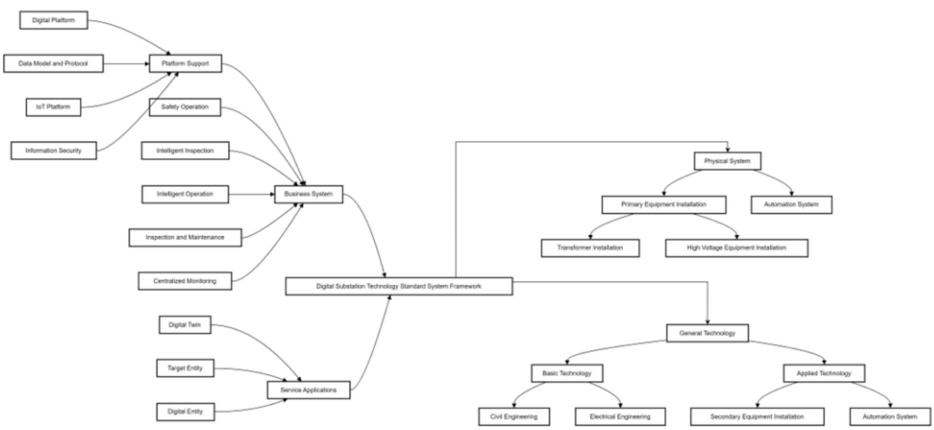

Figure 1. Digital substation technology standard system diagram

3.2. *Analysis of Digital Twin Technology for Transformer Management*

In the digital twin substation system, massive data processing and complex algorithm model training rely on its powerful arithmetic power, and the increasing data volume puts forward higher requirements on the real-time computing ability of the system. The whole life cycle data storage and management of the environment and equipment in the substation is an important support for the digital twin substation system [10]. There are a large number of structured and unstructured data in the digital twin substation system, throughout the operation, maintenance, failure, failure, decommissioning and other aspects of the whole life cycle, operation monitoring data can provide complete data support for data analysis and display, while providing rich sample information for data mining, which can deepen the potential information on the system's operating mechanism of the cognition to realize the digital twin of the The potential information can deepen the knowledge of the system operation mechanism and realize the surreal attributes of the digital twin.

The imbalance in the proportion of negative samples in substation historical operation data makes it difficult for data-driven deep learning model-based prediction results to reach the desired target. Introducing a priori knowledge to enhance the robustness and generalization of deep learning models is a common method to solve the data imbalance in power systems. Substations have accumulated a large number of mechanism models and logic rules in long-term production practice, and the combination of mechanism knowledge, expert system and data-driven deep learning method can reduce the requirements of deep learning model training on the number and quality of samples and enhance the adaptive ability of the model, and at the same time, the deep learning method can also be updated, corrected and supplemented to the physical model, so as to achieve the purpose of fusion and mutual reinforcement.

The constrained continuous value attribute feature decomposition method is adopted to realize the fusion processing of the digital information of all elements of the substation, and the digital information storage structure model of all elements of the substation is obtained. Utilizing the laser point cloud panoramic scanning technology, combined with the high performance and strong compatibility of the 3D engine, the digital twin management of all elements of the substation, digital twin management of the 3D scene reconstruction process is shown in Figure 2.

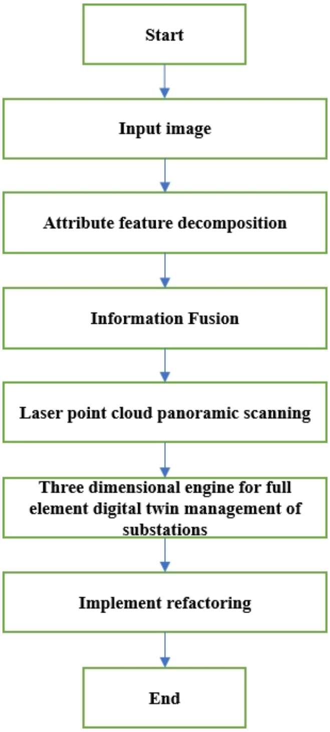

Figure 2. 3D scene reconstruction for digital twin management

Substation operation and maintenance personnel can use the application layer function of the substation digital twin system to process all kinds of operation data, accurately perceive the operation status of equipment, efficiently manage and utilize the operation data of the whole life cycle of equipment, and provide scientific and effective decision-making solutions for the operation and maintenance of substation systems.

To construct a group transmission control protocol for substation all-element digital information, and to obtain the standard deviation of substation all-element digital information transmission σ_j, No. Analyzing digital information on all elements of a substation x Records, No y The feature volume of clustered attribute value samples is obtained by using data cleaning technology to obtain the feature component of digital information of the whole element of substationSmais $(r_x(y), \sigma_y)$, i.e

$$v_{ij} = \frac{x_{ij} - \min(x_{ij}) \text{Smais}\,(r_x(y), \sigma_y)}{\max(x_{ij}) - \min(x_{ij})} \tag{1}$$

In the formula, the x_{ij} for the information gain of each attribute, the $i = 1,2, \cdots n$, $j = 1,2, \cdots m$; $\max x_{ij}$ represents the maximum value of information gain. $\min x_{ij}$ represents the minimum value of information gain.

By using the data cleaning technique to clean incomplete data, wrong data and duplicate data, the complete information distribution structure of the total elemental figures of the substation is obtained as follows.

$$CV = V_m \left| r_i - \sigma_j \right| x_{ij} \mathrm{d}\left[\sigma_j\right] \tag{2}$$

Among them, the degree of integration of digital information of all elements of the substation is CV; V_m represents the value of the degree of data cleansing.r_i represents the initial value of the substation's full element number.σ_j Represents the ideal value for digital cleaning of all elements of a substation.

Standard deviation analysis was used to obtain the similarity variance for the detection of full-factor digital information in substations as, the$f$erA$A_i[j]$Calculation No i Records, No j The distribution set of full elemental digital information of the substation with attributes,the similarity probability density is obtained as.

$$d_i = m \cdot \text{fer } A_i[j] \times \sum_{j=1}^{m} A_i[j] \cdot CA \tag{3}$$

Accessing and forming structured time-series data with business information, the twin components of digital information mining for the whole elements of substation are obtained through multidimensional sensing as.

$$\lambda_{\max} = d_i \sum_{i=1}^{m} \frac{Ap_i}{p_{i,AHP}} \tag{4}$$

By calculating the precise spatial coordinates and positions, analyzing the digital information components of the whole elements of the substation, the fuzzy information fusion constructed random number expression for the digital information of the whole elements of the substation is obtained as follows.

$$\varphi_n = \lambda_{\max}\left(x_{1,n} \cdot x_2\right) \times 2^i \tag{5}$$

Through the three-dimensional simulation of the twin substation, to realize the "one-stop" access to the station assets, operational status, to obtain the detection of statistical components as follows.

$$F(\sigma_i) = \varphi_n w_i \sum_{j=1}^{n} \left(\sigma_i + x_{ij}\right)^2 \tag{6}$$

In the formula, thew_iTime-consuming for transformer information management.

Calculate the subset of packet features of substation all-element digital information, and establish the delay control parameter model of substation all-element digital information mining.

3.3. Substation digital information fusion and feature optimization detection

Use digital substations to comprehensively monitor physical substations, use mathematical algorithms such as Bayesian method and D-S evidence method to obtain probabilistic decisions in the digital monitoring process of all elements of the substation, and achieve information fusion of all elements of digital information in the substation.

The correlation distribution function for the full elemental digital information of the substation is given by.

$$C(x) = \frac{mF(\sigma_i) - \lambda_{\max}}{m[x]} \tag{7}$$

Combining video surveillance, robot inspection, VR, AR and other technologies, adaptive optimization is used to achieve feature optimization and analytical control of the all-element digital information of the substation. The obtained all-element digital analytical component of the substation is:

$$\mu_i = C(x) \sum_{i=1}^{c} \mu_{ik} \tag{8}$$

In the formula, the μ_i Represents the substation-wide numerical resolution factor.

Extracting the envelope characterization quantities of substation all-element all-state digital information management data, and obtaining the reliability components of substation all-element digital monitoring outputs.

$$x_n^2 = \mu_i x_{n,G} + \Delta x_i \tag{9}$$

Calculate the subset of feature attributes for substation all-element digital information mining,and get the threshold function for substation all-element digital information detection satisfies.

$$X^{(2)} = \left\{ x_1^{(2)}, x_2^{(2)}, \cdots, x_n^{(2)} \right\} \tag{10}$$

The fuzzy information fusion results of digital information mining for the whole elements of the output substation are.

$$\overline{X^{(2)}} = \{1,2,3, \cdots, x\} \tag{11}$$

The set of association rules for the full elemental digital information of a substation is.

$$X^{(3)} = \left\{ x_1^{(3)}, x_2^{(3)}, \cdots, x_8^{(3)} \right\} \tag{12}$$

Based on the acquired subset of samples for the detection of digital twins for all elements of a substation, the $\overline{X^{(3)}} = \{5,10\}$, introduce alarm information and effectively combine it with scada remote signaling and telemetry information to achieve comprehensive display and unified management of primary and secondary equipment status information and asset information in the station.

3.4. *Experimental analysis*

Matlab and SPSS statistical analysis software are used to conduct substation information management and feature analysis covering the whole station, and set the contribution degree and twin correlation dimension of relevant constraint variables.

4. Results and discussion

Carrying out the whole element digital information management of substation, we get the test results of the difference level of digital information fusion, as shown in Table 1.

Table 1. Transformer management information fusion results under digital twin

transformer management constraint variables	the fusion threshold	the fitting error	regression test values	level of variability
device status information	8.42	0.078	101.07	0.0801
asset information	8.03	0.074	96.40	0.0771
remote monitoring and management	1.76	0.016	21.11	0.0099
telemetry information	8.10	0.075	97.20	0.0779
mounting alarm messages	7.63	0.070	91.60	0.0729
people management	7.32	0.068	87.87	0.0695
video surveillance	7.46	0.069	89.47	0.0710
Inspection	7.54	0.070	90.53	0.0719
Reliability	7.21	0.067	86.53	0.0683
synergistic	7.39	0.068	88.67	0.0702
Transformer system characterization	7.61	0.070	91.33	0.0726
The personnel factor	7.19	0.066	86.27	0.0681

Analyzing the above test results, it can be seen that adopting the method of this paper for substation information management with full station coverage can make the differentiation distribution smaller, with a mean value distribution of 0.072, which meets the reliability requirements.

5. Conclusion

This paper puts forward the construction of digital substation technology standard system and demand analysis, this paper introduces digital twin technology, establishes the substation all-element all-state digital information comprehensive perception model. Using multi-dimensional, panoramic grid virtual and real fusion analysis method, combined with quantitative regression statistical analysis method, to realize the data fusion and regression analysis of the substation real space digital twin, to realize the parallel mining and fusion clustering of the substation all-element digital information. Through the experimental analysis, it can be seen that the method of this paper can be directly applied to the operation and inspection operation with less error in the detection and management of the digital information of all elements of the substation.

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