Study Committee A3

Transmission and Distribution Equipment

Paper 10287_2022

Application of Digital Twin Technology in the Field of Substation Equipment Operation and Maintenance

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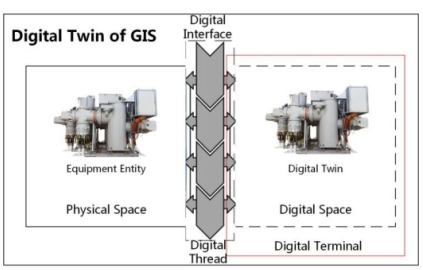
Motivation

- The equipment reliability in the power system directly affects the safety and stability of the operation of the power system. For a long time, due to the lack of effective state assessment methods, a large amount of operation, maintenance and overhaul work is required, resulting in unnecessary waste of resources.
- Digital twin refers to the full use of physical models, sensors, operating history and other data to integrate multi-disciplinary and multi-scale simulation processes. It serves as a mirror of physical products in the virtual space and reflects the entire life cycle process of corresponding physical products. In recent years, digital twin technology has gradually been promoted and applied in various industries, including the electrical industry.
- This paper carries out the research on digital twin modeling technology of substation equipment, proposes a standardized description method of equipment design, production, operation and maintenance data, and builds a 3D digital twin model of GIS equipment to realize the digital specification description of the full life cycle of the equipment. It also conducts research on the rapid simulation technology of the internal overheating state of the equipment to meet the actual needs of remote detection, diagnosis and operation and maintenance services for substation equipment.

Design of digital twin of GIS

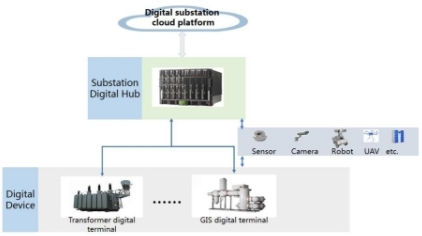
- The digital twin of power equipment is mainly composed of the device entity, the data exchange interface and the digital twin.
- The actual equipment information data is obtained from the equipment production, operation and management process, including basic equipment information, production design data, factory test data, operating environment data, online monitoring data and various sensor measurement data.



- The data exchange interface is a standardized information transmission channel, which can ensure timely and efficient data transmission at all time stages in the entire life cycle of the equipment operation.
- The digital twin obtains the externally collected data through the data exchange interface, stores the data in a structured manner, establishes a virtual model corresponding to the device, and can receive the simulation analysis request of the external system to drive the simulation system to simulate various operating conditions of the device. It can provide external simulation analysis result and update it in time according to the actual situation.

Digital twin system architecture

- Considering that the application of digital twins of substation equipment in substations has been functionally divided into three layers: Equipment layer, perception layer and application layer.
- Equipment layer: It includes the main equipment of production and operation and corresponding digital terminals, realizes the digital information storage of equipment, process information recording and edge operation of digital twins.
- Perception layer: It contains various sensing systems, equipped with cameras, robots and drones and other monitoring devices to realize the collection and transmission of equipment information. It is transmitted down to the digital terminal and transmitted up to the application layer.
- Application layer: It contains the data storage hub and monitoring management platform to realize the storage, extraction, analysis, display and application of all relevant information.



- The device layer digital terminal and the application layer function complement each other. The digital terminal provides functions such as edge computing and on-site rapid analysis for the application cloud, and the application cloud provides backup and computing power and functional supplements for the digital terminal.

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Digtial twin data classification

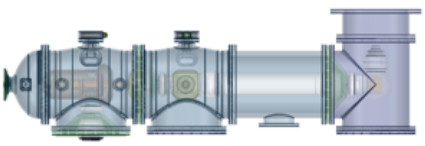
- Display information: Component size information, material information, production information, installation information, and maintenance information are stored in the database display information module. The digital twin model obtains the corresponding component information from the database and operates it in the software through interactive events such as clicking, moving and staying. Appeared on the top.
- Rendering effect information: The physical field data (electric field, magnetic field, temperature field and mechanics) representing the state of the device are stored in the database rendering information module in a specific format file, and the digital twin model is rendered to the corresponding part of the visual model by analyzing the data information of the file superior.
- Action information: The sensor data and position information data of the switch action are stored in the database action information module. The digital twin model is driven by the switch command to the database to obtain information, and the action is restored to the three-dimensional model.

Digtial twin data storage

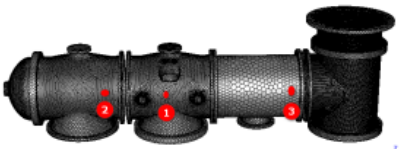
- The GIS equipment digital twin data storage management is mainly divided into physical model, collection module, data module and display module.
- The physical model is determined by the physical attributes of the equipment itself and the objective environment of installation and operation, and is not affected by the external operating environment. It is the basic mapping of physical equipment in the digital space. According to the design drawings of the GIS equipment and the information of the production raw materials, the basic three-dimensional data model of the equipment can be constructed, which can be GIM, BIM, 3DS and other model formats.
- The acquisition module is a channel for the digital system to acquire real-time data. The acquisition layer also has the functions of data format unification, data classification, and data labeling. The acquisition module receives the data of each sensor installed in the equipment, and uniformly converts the data into the same format. The data is labeled according to different sensor types, which are uncontrolled sensor data and controlled sensor data. The uncontrolled sensors collect GIS static data, such as voltage, current, and temperature. The controlled sensor collects the dynamic data of the GIS during the switching operation, such as the switching speed, the current of the opening and closing coil, and the mechanical characteristics.
- The data module stores various data generated during the equipment operation, and manages the data through real-time databases and historical databases, including a rapid simulation module, to realize real-time simulation of the electric field, magnetic field, and temperature field in the GIS. The data module includes a database and a simulation module. The database classifies and stores the data uploaded by the collection module according to equipment information data and GIS action characteristic data.The simulation module builds rapid simulation models of simulation fields with different parameters through processing methods such as machine learning and simulation model degradation.
- The display module realizes the external functions of the system through the support of the physical model, acquisition module, and data module. The display module realizes the external interaction of the system interface, including model display, data exchange, simulation calculation and state evaluation. The display module uses the equipment structure data of the model module and the status data of the data module to visualize the real-time status of the equipment.

Rapid simulation of digital twin

- This paper takes the temperature field of GIS equipment as an example to illustrate the realization of rapid simulation.
- According to the physical structure of the object under investigation, a three-dimensional model of the object is established. GIS heating faults usually occur at the busbar joints, and build a three-dimensional geometric model .



- For CFD simulation of the temperature field, the geometry needs to be cleaned and simplified to form a high-quality geometry that satisfies the CFD simulation.



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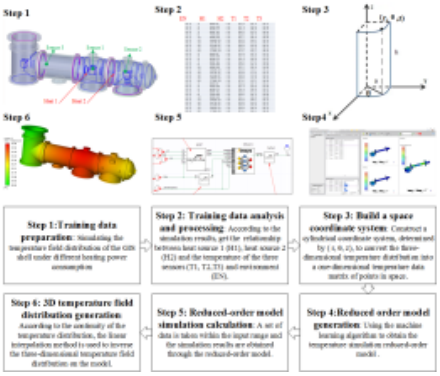
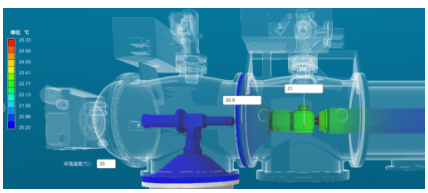
Rapid simulation of digital twin

- The Process of Rapaid Simulation of Temperature Field



- GIS equipment temperature reduction data preparation: The sampling points of training data are generated by DOE method, and the Central Composite Design (CCD) method is sampled. There are three variables, two heating elements and ambient temperature. Multiple simulation calculations are performed in the 3D simulation software to obtain the training data set, and save the results in a certain format and file structure. Among them, Points.bin provides node coordinates, Settings.json provides simulation condition information, and Doe.csv stores sampling point information. The training data adopts the static rom machine learning method to learn and train the three-dimensional simulation result data, and finally generate a temperature reduction model.
- A set of data is taken within the input range and the simulation results are obtained through the reduced-order model. The output result file is binary in .bin format, which contains the coordinate information (x, r, θ) of each feature point and the corresponding temperature information (x, y ,z). The output result is assigned to the established three-dimensional model. According to the continuity of the temperature distribution, the linear interpolation method is used to inverse the three-dimensional temperature field distribution on the mode.



- The accuracy verification of the digital twin of the GIS equipment temperature is mainly compared with the calculated value of the 3D simulation.The maximum and average values of the error distribution are compared with the set error range. If the error exceeds the set range, the set of data are added to the machine learning training set to retrain for a new reduced-order model, and perform verification again until the verification error is within the range.

State assessment based on digital twin

- According to the cause and manifestation of GIS equipment operation failure, the health evaluation of GIS equipment is divided into insulation state evaluation, conduction state evaluation, operation state evaluation and control state evaluation.
- Parameter evaluation: Obtaining real-time data of each direct parameter through the equipment digital twin model.
- Simulation evaluation: The real-time conductor voltage, current, and gas chamber temperature are input as boundary conditions into the GIS digital twin model for simulation analysis, and the temperature field distribution on the conductor and between the conductor and the gas chamber is calculated.
- Historical data evaluation: The real-time conductor voltage, current, and air chamber housing temperature are used as data sets, and the voltage, current, and air chamber housing temperature corresponding to historical faults and defects are converted to values under the same operating conditions for comparative analysis.

Summary

- With the development of digital technology, the digitalization of the power grid is an inevitable trend of development, which puts forward higher requirements for the management and evaluation of the full life cycle of substation equipment. Through the digital twin, the internal characteristics and operation mechanism of the equipment can be directly reflected, which is of great significance for equipment operators to deeply understand the equipment operation status. This paper studies the data modelling method, and applies the “digital twin” to the field of management, operation and maintenance of substation equipment, and proposes the application prospects and possible technical routes of the digital twin technology in the field of substation technology. It also points out the challenges faced by the digital twin technology in its application and provides a development direction for the digitization of electrical equipment.