The construction system and application of distribution network digital gateway integrated with electrical topology

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ABSTRACT

With the digital transformation of distribution network, it is a trend to use digital twins to simulate the status and operation of distribution network system. However, the current distribution network digital twin system is inclined to model three-dimensional display and data superposition, lacks the characteristics of power business, and is difficult to grow synchronously with the dynamic evolution of the power system. At the same time, the twin construction for massive distribution network objects consumes a lot of labor and time costs[1]. Therefore, this paper introduces the grid topology and electrical state calculation model based on graph calculation, integrates the electrical topology to realize the rapid construction and automatic layout of distribution network data twins, and carries out distribution network business applications such as distribution network panoramic state monitoring, power supply range analysis, etc. based on the distribution network twins scene.

Keywords: Distribution network system, digital twin, topology

1. INTRODUCTION

The rapid construction and linkage analysis of digital twins for distribution network involves digital technologies such as power topology model, digital twins, etc. In terms of power grid topology construction technology, State Grid Jiangsu Company has built a regional power grid topology map covering 1000kV-400V full voltage level to provide data and graphics services for development, safety supervision, marketing, materials and other disciplines; State Grid Intelligent Research Institute has put forward a grid native map model with electrical topology as the core, providing a solution for the automatic construction of provincial "grid one map"; In terms of power grid digital twinning technology, State Grid Corporation of China has carried out parametric 3D modeling of transmission lines and 3D modeling of substations[2] to realize the functions of visual display of equipment status, spatial measurement and analysis of transmission lines, substations and underground cables; The capital construction department of the company has carried out special research on 3D model standardization, 3D design review technology, and developed GIM standards[3] for power transmission and transformation construction. On the basis of the existing achievements, this paper has carried out the research and application of the distribution network digital twin construction system integrating electrical topology.

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Seventh International Conference on Mechatronics and Intelligent Robotics (ICMIR 2023), edited by Srikanta Patnaik, Tao Shen, Proc. of SPIE Vol. 12779, 127790M · doi: 10.1117/12.2688682

2. OVERALL ARCHITECTURE

According to the company's relevant system standards, sort out the existing data structure and data sources of the new distribution network, consider the different access methods of multi-source heterogeneous data, and take the micro-service concept as the guide to form the overall architecture of the distribution network digital twin construction system integrating the electrical topology, which is divided into the overall architecture resource layer, service layer, system layer, and application layer. The resource layer obtains the resource data related to the distribution network based on the power grid data center and the power grid measurement center. According to different types of data, different data acquisition methods are adopted. After data extraction and conversion, the data is stored in the data collection center composed of file system, graph database[4], relational database and timing database. The service layer is based on the micro service architecture[5] and provides data resource security sharing services and system-related services. Data resource security sharing services include data aggregation, data fusion, data modeling, etc; Topology services include generation and loading of power grid topology, and digital twin services include 3D model library, twin construction and mapping services. The system layer provides system management functions and visual interface related components based on data resource security sharing services and system services. Develop a prototype system based on VUE to realize the separation of front and rear ends. It provides functions such as data association, distribution network topology, model base management, automatic construction of distribution network scenarios, and rapid layout. System management provides basic operation and maintenance such as system log management, user management, authority management, role management, etc. The application layer combines the construction requirements of the distribution network digital twin scene, and based on the services provided by the prototype system, carries out the pilot application research of the distribution network panoramic status monitoring, power supply analysis and other typical business scenarios. The Overall architecture is shown in Figure 1.

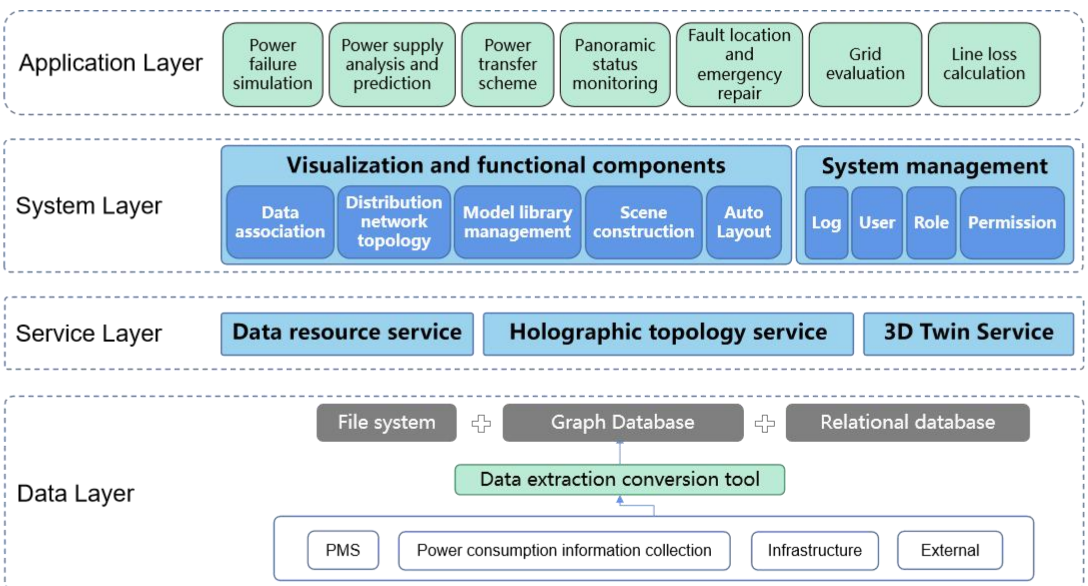

Figure 1. Overall architecture.

3. TECHNICAL ARCHITECTURE

The system takes micro-services as the core, develops a new type of distribution network data resource technology architecture based on multi-source heterogeneity, builds a micro-service system based on SpringCloud, establishes a certification and authentication center, a general configuration center, and a service registration center, and provides functions such as load balancing, routing, diversion, authentication, registration, discovery, configuration, and monitoring. Service calls are uniformly distributed through gateway services, and then routed to various micro-services.The Technical architecture is shown in Figure 2.

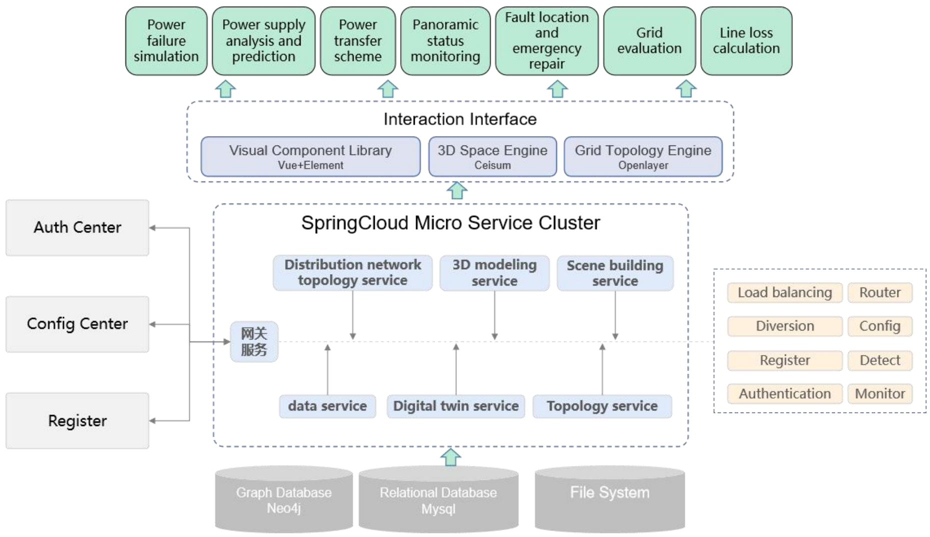

Figure 2. Technical architecture.

Based on the concept of micro-service, carry out the research on the technical route and development and selection of the rapid construction service prototype system of the distribution network digital twins integrated with the electrical topology, and propose the technical route of the rapid construction service of the distribution network twins applicable to multiple scenarios. Carry out development and selection research on the basic components involved in the system development, test and verify the mainstream basic components from the dimensions of function, performance and applicability, and optimize the development framework of the rapid construction service prototype system of the distribution network digital twins integrated with electrical topology[6]. Carry out technical route and development component selection from framework research and development. Some technical routes are shown in Table 1:

Table 1. Technical routes.

Name	Component/Tool	Technology Roadmap
Platform Research framework	Basic architecture	B/S Framework
	Back-end development	java/sprint cloud
	Front-end development	vue/vscode
	Web container and proxy	tomcat/nginx
	Microservice	Nacos
	Service operation environment	Docker/K8S
	Geographic information engine	2D:openlayer
	3D engine	Cesium/WebGL
Data Service	Graph Database	neo4j
	Relationship Database	mysql
	Unstructured data	fs/hdfs
	Data extraction conversion tool	python/Java
	Power system model	java
	Digital twin model	3dmax/blender/cesium

4. CORE FUNCTIONS

Research and develop the rapid construction service prototype system of distribution network digital twins integrating electrical topology, mainly including data association, distribution network topology, twin model management, automatic scene construction, rapid scene layout and other modules.

In terms of data, based on data sources such as Data Mid-Platform[7], business center, and measurement center, sort out multi-source heterogeneous data related to distribution network, develop data collection and aggregation tools, and provide data aggregation services. According to the topology model designed by the system, the topology data is parsed and converted into the required structure, and stored in the graph database. The resource asset data related to the account is extracted and stored in the relational database. Power consumption measurement, power flow measurement, environmental measurement and other data are stored in the time series database, and power failure, emergency repair and other record information are stored in the relational database. Offline map files, other involved distribution network model data, images and other unstructured data are stored in the file system.

In the aspect of distribution network topology construction, the distribution network topology model is built based on the graph database, and the topological graph data in PMS and GIS systems are studied and analyzed to realize the storage, automatic conversion and dynamic loading of topology. With the equipment as the core, add terminal, account and view frame nodes, and add version control nodes to realize multi-temporal[8] version control. The relationship between equipment nodes is divided into electrical topology, physical topology, connection relationship and subordinate relationship to meet the requirements of the global topology of the equipment, and finally form a unified topology model of the distribution network covering multi-dimensional information such as network topology, equipment account, power information, geographical location, time scale, and other typical elements such as nodes, edges, attributes, etc., as shown in Figure 3.

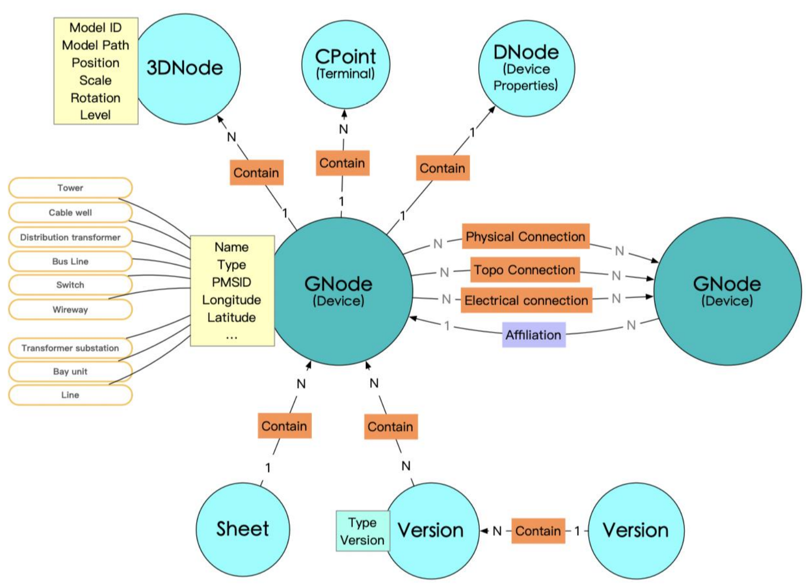

Figure 3. Graph Data Model.

In the aspect of twinning scene construction, data twinning model library is established for distribution network equipment to realize bidirectional binding and support the automatic construction and rapid layout of distribution network digital twinning scene. Distribution network mainly involves

Relying on the digital twins of equipment and facilities and distribution network topology, form the automatic mapping and construction of digital resources to twins, and integrate GIS, environment and other data. Topology analysis based on graphics and SVG data and mapping oriented to data twins are carried out to realize the placement and automatic stacking of twins, as well as the line connection between twins, and a quasi-realistic distribution network operation scenario is realized by combining a small amount of manual correction.

5. POWER FAILURE SIMULATION

Based on the distribution network digital twin scene, the layout of topological path class scenes in the two-dimensional and three-dimensional space is realized. Based on the topology breadth search, depth search, connectivity analysis and other technologies, the simulation drill of distribution network power outage integrating electrical topology is implemented[9], and the inference and analysis of power outage range impact, switching power analysis, power point tracing and so on are realized.

The outage range analysis[10] is simulated when the operation mode needs to be changed to make the operation of the power grid more safe and stable. The outage range analysis function counts the outage impact range and returns the affected device set. There are many methods to calculate the outage range, but its core is to divide the power grid into several electrically connected subnetworks, and the subnetworks that do not contain power points are the outage areas. It is necessary to study the use of input conditions such as switch status and stop conditions, as well as the treatment of sub-graphs without power points. Through various logic judgments, the use of input conditions such as switch status and stop conditions is realized, and the power failure influence range that meets the conditions is returned.

The outage scope analysis shows the impact of the fault node on the entire power grid equipment, that is, once the equipment fails, how to change the working status of other equipment. Take the faulty equipment as the starting node, set the search depth or other stop search conditions, and conduct conditional breadth first search with the starting node as the center, and return all the found node sets and the node sets that meet the specific conditions.

Power failure scope analysis service input and output, with specific meaning listed in Table 2.

Table 2. Analyze the equipment nodes affected by a power failure.

function	**Analyze the equipment nodes affected by a power failure**	
performance index	The average time of each W node is not more than 20ms, and the analysis time is not more than 10W nodes, within 200ms	
Input	MapID	Identify the type of map
	ObjectId	Start device
	VoltageLevel	Voltage level limit: used when the search result has voltage level range limit, corresponding to the code value of the voltage level code table. Indicates the result between the selected starting voltage level and the set voltage level.
	SwitchConditions	The interrupt status of some interrupt devices is passed in for simulation analysis. Multiple string types can be specified. The parameters are separated by commas and multiple items are separated by vertical bars.
	SourceConditons	Power point condition, which is used to further specify the power point (only if it meets the power point identification and this condition is considered as power supply), string, which can specify multiple parameters, with semicolons separating between parameters and vertical lines separating between multiple parameters
	VersionNo	Identify version or base version
Output	Result	The result return code identifies whether success or failure reason
	ObjectCounts	Return the total number of device nodes affected by power failure
	ObjectIds	Set of device nodes for analysis results

According to the version identification, analyze the downstream of all the topologically connected devices of the starting point of the input parameter, stop at the downstream that meets the stop conditions, and return the downstream devices obtained from the analysis. The specific processing logic is as follows: ① Perform the electrical analysis of the level 1 breadth topology with the starting point of the input parameter; ② From the results obtained from the breadth analysis of the first layer, the equipment in the results shall be subject to extensive and in-depth diffusion analysis in turn; ③ Diffusion analysis shows that the switch status of the switch equipment is judged according to the switch conditions value first. If it is closed, the analysis of this branch will continue. If it is open, the analysis of this branch will stop; ④ If the Source Conditions is not empty, the analyzed equipment will judge whether it meets the set value. If it meets the set value, it will be the power point, and the diffusion analysis will be ended; ⑤ If the voltage level of step-down transformer is higher than the input equipment, the transformer can be determined as the power point and the diffusion analysis is ended. For the branch without power point, it is considered as the range that may be affected by the initial equipment power failure. The branch without power point result is returned, and whether the power point is found or the error reason code is analyzed in the Result.

6. EQUIPMENT STATUS CHANGE ELECTRIFICATION ANALYSIS

Based on changes in switch status, equipment listing, and other information, identify the scope of impact and update the equipment electrification status. This algorithm is based on conditional controlled graph traversal search, which requires studying the logic that affects various information changes and updating device electrification status information for different logics. In research and development, various logical controls are used to cover the impact of changes in all information on the power grid, and to achieve full state change analysis of equipment electrification.

The main task is to synchronize and update data on some special information. Changes in this information will affect the electrification status of devices in the surrounding topology network. Setting the switch status of input devices to open or closed requires analyzing whether the affected devices are electrified or not, and identifying the new electrification status on the devices.

Equipment status change, live analysis, input and output parameters, with specific meanings listed in Table 3..

Table 3. Switch state change electrification analysis algorithm parameters.

function	**Equipment status change electrification analysis**	
performance index	On average, each W node should not exceed 20ms, and the analysis should not exceed 10W nodes within 200ms	
Input	MapID	Identify on which graph to analyze
	ObjectId	Starting device
	VersionNo	Identify version or base version
	IValue	Submitted value (switch status value or listing information value)
	InType	0, meter switch status, 1 meter listing
Output	Result	The result return code identifies whether it was successful or the reason for the failureIdentify the t

According to version no in the topology network of the base or version: ① If InType is 0, the submitted device is a disconnected type device, and its submitted value is the switch state value. Update the KGZT attribute value of the device Object Id, and based on the submitted switch state value, if it is closed): Search for devices directly connected to the Object Id device topology to determine if any of them are live. If device a is live, identify the Object Id device as live, And identify its upstream as device a, conduct electrical breadth analysis on the non charged device side, and identify the device as live and its topology parent device as upstream. If there is no live device in the topology device directly connected to the Object Id, then identify the Object Id as not live; If it is disconnected: determine whether the Object Id is charged. If it is charged, identify the Object Id as not charged. Search for devices directly connected to the Object Id device topology, take the direction of non upstream devices for electrical breadth analysis, and identify the device as not charged and clear its upstream identification. ② If InType is 1, the listing information of the submitted device is equivalent to an electrical failure of the device. The IValue value is updated to the listing attribute of the Object Id to determine whether the Object Id is charged. If it is charged, the Object Id is marked as not charged. Search for devices directly connected to the Object Id device topology, take the direction of non upstream devices for electrical breadth analysis, and the analyzed device identification is marked as not charged and clear its upstream identification.

ACKNOWLEDGMENTS

This work was supported by State Grid Corporation of China’s Science and Technology Project (5108-202218280A-2-396-XG) which is 'Research on rapid construction and linkage analysis technology of distribution network facilities digital twins integrated with electrical topology'.

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