Research and Application of Intelligent Learning System for Power Grid All-Element Simulation Based on Microservice

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Abstract. This paper introduces a development method of a micro-service-based power grid full-element simulation smart learning system. It explains in detail how to make full use of the microservice technology to develop services for the power system simulation training platform to solve the collaborative problems of different scopes, different characteristics, and different types of simulation calculations. The method can effectively use the computer resources of the training system, avoid the waste of resources of the training system on the simulation computing platform, and reduce the investment in hardware equipment. Finally, this article verifies the feasibility of the development method proposed in the article through a practical case.

1. Introduction
Microservices are an architecture and organization method for developing software, consisting of small independent services that communicate through predefined APIs. Using the microservice architecture, the application is built into many independent components, and each application process is run as a service. These services use lightweight APIs to communicate through predefined interfaces. These services are built around business functions, and each service performs a function. Because they run independently, they can be updated, deployed, and expanded for each service to meet the requirements for specific functions of the application.

Power grid all-element simulation is a brand-new power grid simulation based on cloud technology. It uses micro-service technology to build a simulation learning platform. The simulation scope includes not only the wide-area regulation system at the provincial and prefecture level, but also local regulation at the county and distribution level. The simulation object includes not only the primary equipment of the power system, but also the secondary equipment, station-side information, large-screen dispatching information and other equipment. On this basis, three-dimensional simulation
technology is applied to display the three-dimensional real-world simulation of field equipment and personnel operations, which truly achieves the simulation of all elements of the power grid.

Based on this all-element simulation, combined with xAPI-based learning behavior collection technology and adaptive learning technology, an "Internet +" multi-professional comprehensive simulation smart learning system is formed. Through this system, remote self-study, counseling, and training are carried out to provide technical support for the State Grid Corporation of China's occupational energy level evaluation for dispatching, monitoring, substation operation and maintenance, and substation maintenance.

2. System architecture design

The training system adopts hierarchical, component-based and service-oriented architecture ideas, and uses micro-service technology to establish a multi-functional hierarchical platform architecture. The open technical architecture of the simulation platform is proposed as shown in Figure 1.

![Figure 1](image_url)

**Figure 1** The overall architecture of a micro-service-based power grid full-element simulation smart learning system

The overall structure of the system is divided into four layers, namely: infrastructure layer, basic service layer, simulation application layer, and GUI layer. Utilizing the good openness and flexibility of microservice technology can better meet the needs of the continuous development of system integration and applications; hierarchical functional design can effectively organize hardware resources, data and software functional modules, and apply. Provide an ideal environment for development and operation; public application support and management functions developed for system and application operation and maintenance requirements can provide comprehensive support for the operation and management of application systems.

The infrastructure layer mainly includes hardware facilities and basic software supporting simulation calculations. The hardware includes other hardware facilities such as computer simulation host/network storage/high-speed Ethernet/display equipment. The basic software includes Docker software distribution deployment system and Swarm simulation cluster management system. Docker realizes the containerization of simulation applications, which is easy to deploy and expand. Swarm implements cluster management of simulation applications, abstracting several application containers into a whole for unified management. Docker and Swarm together form the software foundation of the system's microservices.

The basic service layer is composed of data and model management software and platform management software, and provides data and model storage access functions for the simulation learning system. It can provide multiple types of data including real-time historical data, permissions,
screen and platform management data, power grid models, and primary and secondary equipment models of substations.

On the basis of the service layer, the application layer has developed substation simulation, converter station simulation, provincial power grid simulation, provincial monitoring system simulation, provincial information substation simulation, county distribution network simulation, feeder automation simulation, and station-side information simulation. Various simulation algorithms and related applications, as well as training and learning applications such as substation operation and maintenance, skill drills, training management, and examination assessment, have realized the core functions of the networked and gamified substation inspection and training system.

The GUI layer is composed of B/S visual human-machine interface, which is designed with the surface MVC architecture model to reduce the degree of correlation between application functions and human-computer interaction. It mainly includes functions such as visual modeling, power grid simulation monitoring, substation virtual reality visual display, and large-screen dispatching display.

3. All-element simulation platform design

The system architecture of the power grid all-element simulation platform is shown in Figure 2. It mainly includes multi-level power grid simulation, monitoring simulation, station-side information simulation, automation simulation interface and feeder automation simulation.

![Figure 2: Full-element simulation platform architecture](image)

3.1. Provincial grid simulation

The provincial power grid simulation uses the monitoring object of a provincial power grid simulation system to correctly simulate the operation of the power grid under normal, abnormal, and faulty states through the power system simulation calculation program to realize the simulation of the provincial power grid. In addition to the detailed simulation of the power grid equipment in the region, all external power grids that have a greater impact on the simulated power grid are also retained, and parts of the external power grid that have a relatively small impact use dynamic equivalent models. The construction of the provincial power grid simulation power grid as the basic grid framework, power points and load points, external power grids, tie lines, protection and automatic devices as simulation objects to achieve integrated real-time simulation based on physical mechanisms.

The simulation model includes power supply model, load model and network model. Power supply models include classic generator set models, general prime mover models, general speed control systems, and boiler models that typically include once-through boilers and drum boilers. Load models include voltage and frequency function models, equivalent R-L-C circuit models and asynchronous motor models. Different types of load models can be combined into more complex models according
to actual conditions. The network model includes bus model, line model, transformer model, reactor model, capacitor model, switch model, network topology model, fault model and other provincial power grid models that may be involved.

3.2. County and distribution network simulation

County and distribution network simulation is the foundation of the integrated simulation training system for county-level power grid control and distribution. It provides power grid operation monitoring data for simulation, provides correct response to faults and abnormal events, and provides correct power flow transfer feedback for operation. The distribution network simulation system fully considers the power supply characteristics of the distribution network, constructs a representative distribution network, and realizes the integrated simulation of the county and distribution network. Distribution network simulation includes typical county distribution network substations, equipment and various typical power supply methods. The county distribution network simulation distribution network is based on the regional power grid to build a 10kV network. The transmission grid and the distribution network are actually an inseparable whole, so the power flow of the transmission and distribution network is analyzed and calculated from a global perspective.

County distribution network simulation includes distribution network topology, normal and fault flow calculations, load and output adjustments, etc. The power system simulation calculation program correctly simulates the operation of the grid under normal, abnormal, and fault conditions, and can realize various normal distribution networks. Simulation of operation mode, typical accidents and distribution dispatching functions to realize the simulation of ground distribution and dispatching power grid. The operation mode can be adjusted, various faults can be set, analog switch or automatic device refusal, operator's misoperation, protection and automatic device behavior, etc.

3.3. Province, region and county monitoring system simulation

Province and region monitoring system simulation establish the control center monitoring system D5000 simulation. The monitoring system includes dispatchers and supervisors SCADA systems. They are the working platforms for operators to conduct daily monitoring and operation processing. The monitoring system simulation mainly simulates the functions of the monitoring system, GUI and operation process provide students with a virtual working environment.

County and distribution monitoring system simulation simulates the distribution dispatch automation monitoring system, simulates the dispatch automation system and the dispatch room environment, issues dispatch orders, uses the dispatch automation system, and can perform operation monitoring, operation and accident handling on the simulated power grid through the system. The interface design style and operation control mode of the simulation system are the same as the actual dispatching and monitoring system.

The monitoring system simulation software adopts dynamic human-machine interface technology, dynamic icon technology, dynamic menu technology, middleware technology and program automation technology based on human-machine interface server, and has developed a general monitoring simulation basic function library and monitoring system simulation template. Support the simultaneous realization of multiple monitoring system man-machine interface simulations on a set of simulation system, rapid development of monitoring interfaces of different styles, different types, and complete functions, which greatly improves the versatility and flexibility of the simulation interface, and simulates each A style of monitoring system interface.

3.4. Station information simulation

Station-side information simulation includes three types: substation, converter station, and distribution station. Station-side information simulation establishes a detailed equipment mechanism simulation model for primary and secondary equipment on the station side, and realizes detailed simulation based on the operation mechanism of primary and secondary equipment, can simulate various typical faults and abnormalities of primary and secondary equipment, and realize primary and secondary equipment
control With operation, abnormal and accident handling functions, and on this basis, the station side exchanges information.

The simulation objects include the mechanism simulation model of power distribution primary equipment, the mechanism simulation model of power distribution secondary equipment and the simulation of station-side monitoring information. Among them, the station-side monitoring information simulation includes the interactive behavior of the primary and secondary equipment and secondary signals of the distribution network, as well as various prompt information such as accident information, abnormal information, over-limit information, displacement information, and notification information.

3.5. Automation simulation interface
The automation simulation interface is an interface used to communicate with the monitoring system, which is almost a collection server, and communicates in accordance with the standard 104 protocol. The simulation information sub-station of the simulation system sends a message to the front server through this interface, and the remote signal and telemetry data after the front server parses the message is transferred to the SCADA system of the monitoring system. The simulation system can also analyze the remote control and remote adjustment commands sent by the monitoring system through the interface, realize the four-remote communication between the simulated power grid and the real master station equipment, and provide a training environment for dispatching, monitoring and automation.

3.6. Feeder automation simulation
Feeder automation simulation includes centralized feeder automation and voltage feeder automation simulation. Among them, the centralized feeder automation function is realized by the cooperation of the power distribution master station, communication system, and terminal equipment. The power distribution master station collects the information of all power distribution terminal equipment through the communication system. The power distribution master station determines the fault location through network topology analysis, and issues remote commands to control the power distribution switch, and finally realizes "fault location -> fault isolation. Restore power to the faulty area" to restore power. Voltage-type feeder automation mainly adopts the joint action of recloser and sectioner, and cooperates with the front switch on the power side. In the case of loss of voltage, it is determined whether the feeder has lost voltage + time limit + head-end switch recloser, based on the preset Logic coordination to achieve fault diagnosis, location, isolation and restoration of power supply in non-faulty areas, and jointly complete the voltage-type local control function. Voltage type switch means that the switch will automatically trip when the feeder line loses voltage, and the switch will be closed with delay when the feeder line comes in. The head switch, section switch and boundary switch on the line use the protection cooperation of the upper and lower switches to minimize the number of power outages in non-fault areas and the number of substation trips in the fault handling process, and to complete the automatic location and isolation of multi-branch distribution network faults. The feeder automation simulation function simulates the process of fault location, isolation and restoration of the distribution network based on the functional realization mechanism of the distribution terminal and the distribution master station.

4. Smart learning system design
4.1. Learning behavior collection and storage
This system adopts the unified standard xAPI to realize the collection and analysis of the learning behavior data of substation transportation inspection. The new generation of xAPI (Experience API) is a technical specification used to store and access learning experiences, which can support tracking more detailed online learning behaviors. xAPI allows the decoupling of learning content from the platform, can record and provide learners with their own learning experience and metadata, and allows
any permitted participant to store and retrieve scalable learning records, learner information and learning experience files. And its process has nothing to do with the platform. The main components of the learning behavior collection and storage model based on xAPI are: authentication, activity agent, activity sentence, learning recording system, etc. The learning behavior collection and storage model is shown in Figure 3.

![Figure 3 Learning behavior model based on xAPI](image)

The specific technical solutions of this system are as follows:

1) Establish relevant operation models in the simulation training system of substation inspection

Related operation models in the substation inspection simulation training system include: operation object type, operation object name, operation action type, operation result and operation result description and other attributes. The type of operation object is defined according to the type of two-dimensional operation interface and three-dimensional equipment model in the substation transportation inspection simulation training system. The name of the operation object is defined on the basis of the above operation object type, plus the ID number of each device model. Through the type of the operating object and the name of the operating object, the objects operated by the trainees can be located accurately and in detail in the power simulation training system. The operation action type is to define the action that the student performs on the operation object. Different types of operation objects correspond to different operation action types. Through the operation action type, the relevant actions of the students in the power simulation training system can be collected. The operation result is to define the status returned by the students after a certain operation action is performed on the operation object. The status returned by different types of operation actions is different. The operation result description is to define the reason for the abnormal operation result status, or other return values when the operation result status is normal.

2) Create the data structure related to the above operation model
The data structure related to the operation model in the substation inspection simulation training system is created based on the xAPI specification and JSON format, and is used to store the relevant operation behaviors and learning experiences of the trainees in the substation inspection simulation training system.

The data structure described here contains all the attributes of the trainee's operation behavior in the power simulation training system, mainly including training course ID, operation type, operator, operation occurrence time, operation action, operation object, operation result, etc.

3) Create intermediate program, message bus and message data format

Because the substation inspection simulation training system and the learning record library are independent modules, the learning behavior of substation inspection cannot be directly reported to the learning record library, so an intermediate program is created to collect the operation behavior in the substation inspection simulation training system, and call the data encapsulation method of xAPI to encapsulate the collected operation behavior data, and send it to the learning record library corresponding to the target address through the HTTP protocol.

4.2. Smart learning function design

Smart learning technology is a technology that analyzes and predicts learners' learning interest, knowledge level, learning style, and learning progress by collecting behavioral data in the learning process to provide personalized learning services. The core technologies that constitute adaptive learning include smart learning system models such as adaptive learning engines, domain models, user models, and teaching models. The domain model describes the structure of domain knowledge, including concepts and connections between concepts, and describes the connection between domain knowledge and corresponding learning content. The user model is an abstract description of the characteristic information of users (i.e., students), including knowledge structure, learning goals, background experience, cognitive style, learning preferences, academic performance, current ability and other information. The teaching model defines the rules for accessing various parts of the domain model based on the information in the user model. The adaptive learning engine analyzes learners' learning requests or learning behaviors in real time, selects, assembles and presents personalized learning content for learners based on information in other models, and updates and maintains user models based on user learning behaviors and learning effects.

This system models IEEE PAPI and CELTS-11 specifications based on the general user model based on the current learning/training situation, learning/training situation, learning resources, and student status of current substation transportation inspection employees, power industry enterprise training, and targeted Modification, improvement and refinement, design and propose a user model modeling standard that meets the characteristics of substation inspection and training.

Based on the theory of adaptive learning technology, this system comprehensively considers the relevant characteristics of the user model, including learning style, cognitive level, and learning history, and develops a personalized learning content recommendation technology suitable for the learning characteristics of employees in the power industry. Among them, learning style characteristics include elements such as style perception, information input, cognitive level includes elements such as knowledge concept familiarity, knowledge concept understanding level, knowledge system relationship, and learning history include learning pace and learning repetition. From the implementation level, personalized recommendation technology has two aspects: personalized recommendation content presentation and personalized recommendation content navigation.

5. Conclusions

The traditional integrated control simulation training system lacks integrity, authenticity and pertinence in the training process, and the training also lacks networked, intelligent learning methods, and visual simulation methods, which affect the training effect. The micro-service-based power grid full element simulation smart learning system addresses the above problems and proposes a networked smart grid control training room construction solution. Based on the "Internet + training" simulation
smart learning platform architecture and core technology, it is developed and operated in the cloud the new type of power grid control training software meets the requirements for the transformation of the power grid from "intelligent control" to "lean control and active dispatch". After the project was actually put into operation in the Gansu Electric Power Company, it made up for the previous simulation defects, stimulated the enthusiasm of the students to experience, shortened the learning cycle, and played a role far beyond the traditional simulation training methods.

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