



Design and Application of a Full-Service Simulation System for Dispatching Automation

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Abstract. Currently, the simulation adaptation capability of dispatching automation systems for new-type power systems is significantly insufficient. With the high proportion of renewable energy integration, the power grid's ability to resist disturbances continues to weaken, making the traditional power control simulation mode inadequate for supporting the refined simulation scenarios required for dispatcher training. To address these issues, this paper constructs a full-service simulation system for dispatching automation based on digital twin technology. It focuses on core technologies such as simulation snapshot generation, closed-loop verification of full-service simulation for power grid dispatch and operation, and data mining and evaluation of grid simulation operation data. Ultimately, it achieves closed-loop simulation verification for all power grid dispatch and operation services and the analysis and evaluation of dispatching strategies. This system has been practically applied and verified in the context of remote practical training for State Grid Zhejiang Electric Power Dispatching Automation, successfully resolving industry pain points such as limited offline training scenarios and prominent conflicts between work and training. Its simulation fidelity and application effectiveness have been fully validated through practical scenarios.

Keywords: Digital Twin, Dispatching Automation, Full-Service Simulation System, Power Grid Training

1 Introduction

As the core technical equipment for power system dispatch and operation, dispatching automation systems integrate computer technology, communication technology, automatic control technology, and power system analysis technology[1-2]. They realize the real-time monitoring of grid operation status, data acquisition, analysis and decision-making, automatic control, and integrated information management. The core objective is to ensure the safe, stable, high-quality, reliable, economical, and efficient operation of the power system, adapting to the development needs of modern power systems such as new energy integration and increasing grid complexity.

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In recent years, the large-scale integration of new energy sources has significantly increased the complexity and uncertainty of the power grid, with more frequent interactions between different levels, placing higher demands on dispatching automation systems[3-5]. These systems not only need to possess high-precision, high-fidelity simulation capabilities but also must meet diverse scenario requirements such as remote dispatcher training, cross-regional practical operation, and online assessment. Traditional simulation systems suffer from issues like limited functionality, disconnection from actual production systems, and insufficient coverage of training scenarios, making it difficult to support the development of dispatching services and talent cultivation under the new-type power system.

Based on this, this paper utilizes digital twin technology to achieve[6-8], for the first time, a 1:1 full-dimensional simulation of the production dispatching automation system, constructing a virtualized full-service simulation system for the power grid. This system can not only monitor the real-time operation status of the power grid and simulate various operating scenarios to improve dispatch accuracy and safety but also support remote training applications relying on a secure network architecture, providing dual technical support for the optimization of dispatching services and talent cultivation.

2 Construction of the Full-Service Simulation System for Dispatching Automation

2.1 Overall System Architecture

This system is constructed based on digital twin technology, with the core objective of achieving a full-element twin of core systems such as the electricity spot market technical support system, the D5000 system, and the new-generation dispatching control system, without impacting the stable operation of the primary station system. The simulation system includes all application nodes and databases such as SCADA, FES, historical database, and OPS. Its application programs, graphics, models, configuration data, and underlying operating system are entirely consistent with the production primary station system, supporting the independent operation of multiple sets of sub-module twin simulation test systems.

The system adopts a hierarchical architecture, divided from bottom to top into the infrastructure layer, hyper-converged architecture layer, resource delivery layer, and operation and maintenance management layer, as shown in Fig. 1:

The Infrastructure Layer utilizes localized standard X86 hardware equipment, ensuring the system's self-reliance and controllability.

The Hyper-converged Architecture Layer provides a mature and stable industrial-grade virtualization environment, supporting parallel simulation for multiple systems.

The Resource Delivery Layer constructs twin simulation test domains for multiple primary station systems, compatible with various types of domestic secure operating systems and domestic secure databases.

The Operation and Maintenance Management Layer realizes resource monitoring and operation management through an integrated portal. It includes functional entry points such as the management portal, virtual machine portal, and audit portal, supports multi-language adaptation, and can display the global utilization rate, occupied proportion, and allocation status of resources such as CPU, memory, and storage in real-time

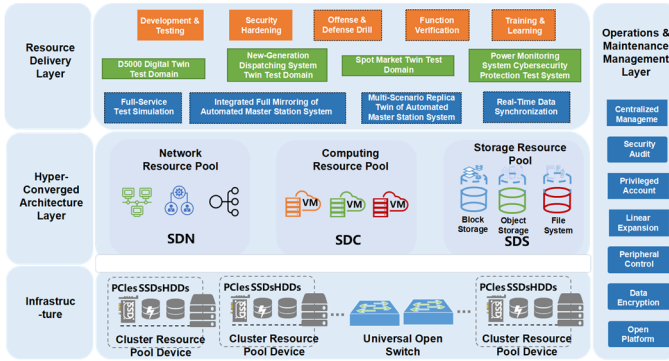


Fig. 1. The Overall Architecture of of the Full-Service Simulation System for Dispatching Automation

2.2 System Network Architecture

To ensure the security of the production primary station system and the independence of the simulation system, a secure and controllable network architecture has been designed for this system (as shown in Fig. 2). The core design points are as follows:

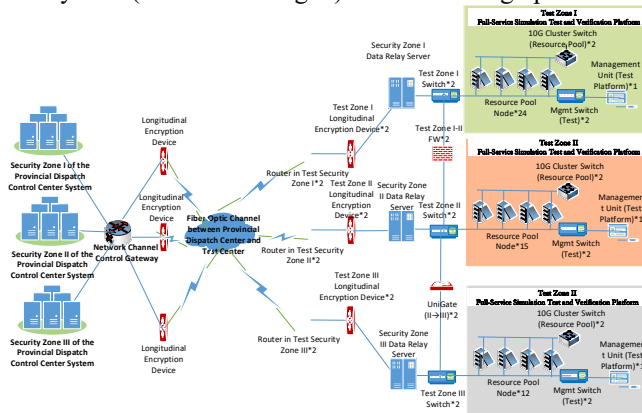


Fig. 2. Network Architecture of the Full-Service Simulation System for Dispatching Automation

Network Isolation and Access Control: Network control equipment manages the connectivity status between the primary station system and the test environment. A firewall is added on the production primary station side, configured with NAT map-

ping. This ensures that access from the test environment does not directly correlate with the actual IP addresses of the security zones, preventing network location exposure.

Encrypted Data Transmission: Longitudinal encryption devices are deployed at the network boundaries between the simulation system and the production primary station system, achieving end-to-end encryption for data transmission.

Data Synchronization Mechanism: Network connectivity with the primary station system is established solely through a single data synchronization relay server. Both initial data images and incremental data updates are first synchronized to this relay server before being distributed to other equipment in the test environment, avoiding direct access to the primary station system.

Remote Access Support: The system supports access to the training environment via internal LAN web login. Leveraging dedicated channels of the dispatching data network, it securely interconnects with the internal networks of power supply companies in multiple regions such as Ningbo, Shaoxing, and Huzhou, providing the network foundation for cross-regional remote training and practical operations.

3 Functional Optimization of the Full-Service Simulation System for Dispatching Automation

With the rapid development of new energy sources in the novel power system, the uncertainty of grid operation has increased significantly, and the interconnections and interactions between different grid levels have become more frequent. Existing power grid simulation analysis software can hardly adapt to practical application needs. In this context, it is imperative to research key technologies such as generating time-series power flow simulation snapshots for the power grid, closed-loop verification of full-service simulation for grid dispatch and operation, and data mining and evaluation of grid simulation operations. This aims to enhance the authenticity and accuracy of the training system's simulation analysis, improve the reliability and stability of online decision-making application control software, and ultimately achieve closed-loop simulation verification for all grid dispatch and operation services and the analysis and evaluation of dispatching strategies. Therefore, after completing the platform environment setup and network architecture construction of the full-service simulation system for dispatching automation, the research team concurrently carried out functional optimization work on the simulation system.

3.1 Rapid Generation of Power Grid Time-Series Power Flow Simulation Snapshots

Time-series power flow simulation snapshots are the core parameters and computational basis for various applications within the simulation system. This paper researches technologies from three aspects: generating time-series power flow under extreme matrix model changes due to node splitting and aggregation, multi-temporal

flexible dynamic simulation based on real-time measurements and state estimation snapshots, and simulation of grid mode adjustments and fault handling.

Based on the correlation analysis of multi-temporal grid topology characteristics, a multi-area snapshot optimization grouping strategy is proposed, achieving rapid generation and dynamic updating of simulation snapshots. This technology has been practically applied in the training system of the Zhejiang Power Grid Dispatching Automation Simulation Test Center. It can quickly construct multi-area, multi-condition grid simulation scenarios according to training needs, providing dispatchers with an operational environment for practical training that is consistent with the actual production system, effectively enhancing the authenticity and relevance of training.

3.2 Closed-Loop Verification of Full-Service Power Grid Simulation

Addressing the lack of a simulation strategy verification environment for core grid services, research was conducted on building full-service simulation scenarios for dispatch and operation. Through the precise simulation of core elements such as grid physical characteristics, operational states, dispatch task requirements, dispatch commands, and execution results, the system can quickly generate disturbance events suitable for business strategy verification, enabling the rapid construction and operational deduction of closed-loop verification scenarios.

In the remote practical training application at the State Grid Zhejiang Training Center, this function realized a full-process closed-loop simulation of "dispatch command issuance - equipment operation response - operational status feedback - strategy optimization and adjustment": trainers issue dispatch operation tasks through the system, trainees remotely operate simulation models to execute commands, the system provides real-time feedback on changes in grid operational status, simultaneously verifying the standardization and rationality of the operation process, forming a complete training closed loop.

3.3 Data Mining and Analytical Evaluation of Grid Simulation Operations

To fully leverage the value of system data and support training effectiveness optimization and dispatch capability improvement, this paper constructs a full-process technical system of "data collection - correlation analysis - intelligent evaluation - strategy iteration":

Starting with mining association rules for data related to primary and secondary equipment during grid faults, a dispatch intelligent agent based on deep reinforcement learning is constructed.

The rationality of the agent's strategy is verified through fault replay tests, forming a method for checking and evaluating grid fault replay strategies.

The dispatch intelligent agent achieves example learning and quantitative evaluation of dispatch operation behaviors.

Relying on this technology, the Zhejiang Power Grid Dispatching Automation Simulation Test Center has developed a training resource library comprising 5 stand-

ard courses and 20 micro-courses, and has conducted 4 sessions of "New Technology, New Equipment, New Process" training. By mining and analyzing trainee operational data, it can accurately identify operational weaknesses, providing data support for developing personalized training plans, while also enabling dynamic optimization and iteration of training courses.

4 Application of the Full-Service Simulation System for Dispatching Automation

As a key technical support platform in the field of dispatching for the novel power system, this system's overall technical level has reached international leadership. It has achieved in-depth application in multiple scenarios such as dispatching automation testing and evaluation, remote training, and network security protection, yielding significant practical results.

4.1 The Innovativeness of the Application

Pioneered the Digital Twin Full-Service Simulation Mode for Dispatch Production Systems: Achieves precise replication of the entire dispatch business process, with 100% consistency between simulation scenarios and the production system, providing a high-fidelity environment for technical verification and training.

Constructed Integrated Simulation Capability for Full Scenarios: Achieves integrated support covering all environments, applying all elements, and verifying all versions, filling the gaps of traditional simulation systems in areas like remote collaboration and cross-regional application.

Innovated the Application Launch Verification Management Process: Combined with rapid twinning technology, reduces the deployment verification cycle for new services and functions by nearly 50%, while ensuring deployment security, as shown in Fig. 3.

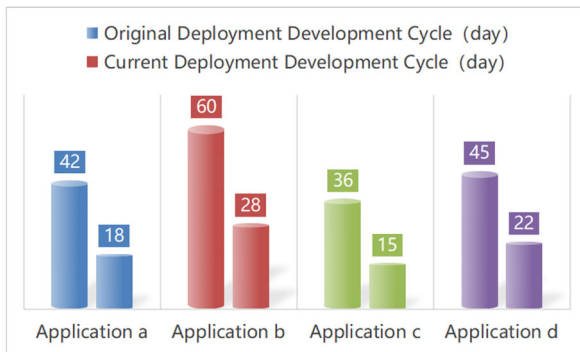


Fig. 3. The Variation in Development Cycles for Different Application Functions

Built an Integrated Platform for Industry-Academia-Research-Application: Fosters deep integration of technological achievements and industry needs through a joint

team talent cultivation mechanism, forming a virtuous cycle of "R&D - Application - Iteration".

4.2 Typical Application Scenarios

In Dispatcher Training: The remote practical training platform built upon this system has successfully achieved cross-regional interactive training. For instance, during a remote training session between State Grid Zhejiang Training Center and State Grid Ningbo Company on November 24, 2022, trainers remotely demonstrated typical application scenarios of the new-generation dispatching technical support system, while Ningbo Company experts shared achievements from their pilot construction of the regional dispatching control system(as shown in Fig. 4). Trainees remotely logged into the system from computer rooms with internal network access, performed routine operations and skill practice on equipment models, and underwent online assessments post-training, realizing synchronized "training-practice-assessment".



Fig. 4. A Remote Training Based on the a Full-Service Simulation System for Dispatching Automation

To date, through the system it has covered provincial, municipal, and county-level dispatch units, conducted 4 specialized training sessions involving over 300 participants. The training satisfaction rate for the dispatch automation specialty has significantly increased, by nearly 20% as shown in Fig. 5.

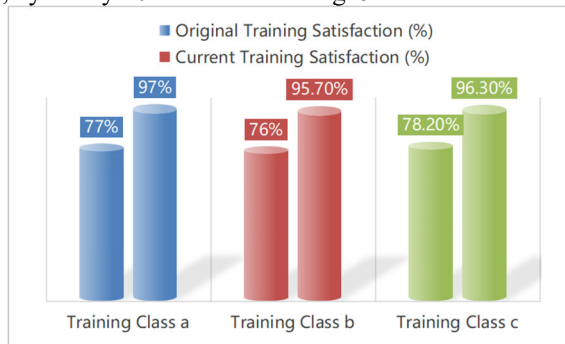


Fig. 5. The Change of Training Satisfaction Rate for the Dispatch Automation Specialty

In Dispatching Automation Product Testing: Leveraging the 1:1 simulation capability, it enables full lifecycle performance verification for various dispatching automation products. It has completed pre-deployment testing for multiple system upgrades and transformations, identifying and resolving over 30 potential issues, ensuring the stable operation of production systems.

In Network Security Protection: A cyber security range integrating sandbox push-pull, attack and defense penetration, personnel training, and experimental R&D was constructed. Multiple rounds of security attack and defense drills have been conducted, significantly enhancing the security protection level of power monitoring systems.

4.3 Application Value

Security Assurance: Through precise simulation and attack-defense exercises, reduces the incidence rate of network security risks in power monitoring systems by over 60%, building a strong technical defense line for the safe and stable operation of the power grid.

Cost Control: Compared to traditional offline training and physical test environment construction, this system reduces resource consumption such as venue leasing and equipment deployment. To date, it has saved millions of RMB in training and testing costs.

Technical Empowerment: Provides an efficient experimental environment for frontier research topics related to the novel power system, accelerating the development process of key technologies and supporting the construction of the "Digitalization-led Provincial Demonstration Zone for Novel Power Systems".

Industrial Support: Promotes the standardization of dispatching system inspection and product service standardization, supports the incubation of innovation projects in the dispatch specialty, and contributes to the achievement of the "Dual Carbon" goals and the long-term sustainable development of the dispatching field.

5 Summary

This paper constructed a full-service simulation system for dispatching automation based on digital twin technology. By 1:1 replicating the core applications and data of the production dispatching automation system, and adopting a hierarchical platform architecture and a secure and controllable network architecture, it achieved the virtualized simulation of multiple dispatching-related systems without interfering with the stable operation of the primary station system. By optimizing the three core functions—rapid generation of power grid time-series power flow simulation snapshots, full-service simulation closed-loop verification, and operational data mining and analytical evaluation—the system significantly enhanced the simulation's authenticity, reliability, and intelligence level.

The system pioneered the digital twin full-service simulation mode, achieving integrated simulation capabilities covering all environments, all elements, and all ver-

sions. It has been deeply applied in multiple scenarios within State Grid Zhejiang, including remote practical training for dispatching automation, product testing, and network security protection. Its overall technical level has reached international leadership. The system not only provides efficient technical support for the construction of the novel power system but also establishes a full-chain service system of "simulation - training - evaluation - optimization". It effectively solves problems such as geographical limitations of offline training and prominent work-study conflicts, laying an important foundation for the high-quality development of power grid dispatching services and the cultivation of professional talent. In the future, efforts will focus on further expanding the coverage of simulation scenarios, deepening the integration and application of artificial intelligence technologies, and continuously enhancing the system's intelligence and practicality.

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