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Postprint of Integration Testing Method for Smart Grid Dispatching and Control System Based on Simulated Substation

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Abstract

Before a new substation is integrated into the smart grid dispatch control system, dispatch master station commissioning must be carried out to ensure that operational information within the substation is accurately forwarded to the dispatch master station, thereby guaranteeing the reliability of fundamental data for the grid dispatch control system. This paper proposes a system integration debugging method for dispatch master stations based on a simulated substation, which utilizes the simulated substation to emulate real-time data and operational information of various equipment types within the substation, and communicates with the dispatch master station to achieve closed-loop control of information exchange between the substation and dispatch master station, thereby enabling integrated debugging of the correctness of database configuration, model establishment, and graphical screen associations in the dispatch master station system. Engineering practice demonstrates that this method can ensure the correctness of dispatch master station commissioning, improve debugging efficiency, and achieve improvement and innovation over traditional debugging methods.

Full Text

Preamble

Integrated Debugging Method for Smart Grid Dispatching and Control System Based on Simulated Substation

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Abstract

Before a newly constructed substation is integrated into the smart grid dispatching and control system, debugging of the dispatching master station must be conducted to ensure that operational information from the substation is accurately forwarded to the master station and to guarantee the reliability of the system's fundamental data. This paper proposes an integrated debugging method for the dispatching master station based on a simulated substation. The method employs a simulated substation to emulate real-time data and operational information from various types of power equipment, establishing communication with the dispatching master station to achieve closed-loop information interaction between the substation and master station. This enables integrated debugging of the master station's database configuration, model establishment, and graphical interface associations. Engineering practice demonstrates that this method ensures the correctness of master station debugging, improves debugging efficiency, and represents an improvement and innovation over traditional debugging approaches.

Keywords: Simulated substation, smart grid, dispatching and control system, debugging, IEC 61850

1 Introduction

Smart grid dispatching and control systems implement integrated configuration for both grid dispatching and substation monitoring, combining grid dispatching, monitoring centers, and operational stations to jointly manage the power grid [1]. Under this integrated management model, both grid dispatching and substation monitoring are handled by the dispatching and control center, with substation operation gradually transitioning to an “unmanned 值守, remote centralized monitoring” model. Furthermore, smart grid dispatching and control systems feature advanced application functions such as sequential control, event recall, data identification, and intelligent alarming, which effectively reduce the workload of dispatching operators and enhance the intelligence level of grid operation, ensuring safe and stable grid operation [2-3].

The real-time database of the dispatching master station stores vast amounts of information—including network models, equipment parameters, real-time data acquisition, and calculation results from all connected stations—in a structured manner in memory, meeting the high-speed access requirements of various applications for large volumes of real-time data. This database serves as the foundation for advanced applications in smart grid dispatching and control systems [4]. Consequently, the correctness of the dispatching master station's database configuration, model establishment, and graphical interface associations is crucial to the safe and stable operation of the dispatching automation system, making research into rapid and accurate debugging methods for the master station database of significant practical value.

Currently, before a newly built substation is integrated into the smart grid dis-

patching and control system, debugging of the dispatching master station' s real-time database can only commence after the substation' s local monitoring system has been debugged and the dispatching data network channel is ready. Substation acceptance personnel operate equipment locally according to the control information sequence table issued by the dispatching center, while the dispatching master station receives and displays action signals forwarded by the telecontrol device. Master station staff communicate with substation acceptance personnel via telephone to determine changed signal points based on the "0" or "1" status changes, and verify whether the signal description corresponds correctly to the triggered signal at the substation through alarm information and indicator flashing. This process confirms the correctness of the master station' s database configuration, model establishment, and graphical associations [5-6]. For a 500 kV smart substation, nearly ten thousand control information points must be processed, and debugging must be completed for multiple dispatching master stations (typically involving grid dispatch, provincial dispatch, and local dispatch). This results in heavy debugging tasks, low efficiency, long durations, and requires coordination among many parties, making fault detection and troubleshooting difficult during the debugging process. Moreover, some advanced application functions cannot be properly debugged using traditional methods, preventing their application and promotion in actual engineering projects.

To ensure the correctness of the dispatching master station database before a new substation is integrated into the smart grid dispatching and control system, improve debugging efficiency, and achieve improvements and innovations over traditional debugging methods, this paper proposes an integrated debugging method for smart grid dispatching and control systems based on a simulated substation. This method uses a simulated substation to emulate real-time data and operational information from various types of substation equipment and communicates with the dispatching master station to achieve closed-loop control of information interaction between the substation and master station. It enables integrated debugging of the master station' s database configuration, model establishment, and graphical associations, and has been applied in engineering practice.

2 Simulated Substation

2.1 Simulated Substation System Structure

The simulated substation is designed with application function testing and integrated debugging as its core objectives. Based on real-time database virtual device simulation software, it performs equivalent simulation of substation secondary equipment to emulate real-time data and operational information from various types of substation equipment. This enables testing and integrated debugging of application functions for upper-layer devices (including substation monitoring backends and dispatching master stations) and ensures correct response to commands issued by these upper-layer devices. The simulated substation system structure is shown in [Figure 1: see original paper], adopting

a hierarchical distributed design principle with five layers from bottom to top: hardware system, operating system, middleware layer, unified management platform, and application layer.

The main functions of each layer are as follows:

- (1) **Hardware System:** The physical devices that constitute the simulated substation, comprising entity components with computing, control, storage, input, and output functions.
- (2) **Operating System:** Manages the hardware, software, and data resources of the simulated substation system, controls program execution, provides a human-machine interface, and offers necessary services and corresponding interfaces for the development of other functional software.
- (3) **Middleware Layer:** Provides a new architecture for multi-level distributed heterogeneous systems, enabling the simulated substation test system to benefit from application component technologies such as heterogeneous system support and interoperability.
- (4) **Unified Management Platform:** Includes a database management platform and a network communication management platform, which facilitate capacity operations on the database and implement inter-process communication through event publishing and subscription mechanisms.
- (5) **Application Layer:** Comprises a database configuration tool, simulation control platform, and IEC 61850 Manufacturing Message Specification (MMS) server.

The database configuration tool can directly import the Substation Configuration Description (SCD) file to establish substation equipment operation acquisition point information in the real-time database and customize test services. The simulation control platform consists of a human-machine interface, task control center, command processing center, and process management center. The human-machine interface displays substation operation information, device status, test task progress, operation records, and simulation messages. The task control center accepts manual or automatic test tasks, forms a control command queue, and sends it to the command processing center. Upon receiving control commands, the command processing center starts and stops corresponding virtual devices. The process management center monitors messages, operation records, and simulation test records and stores them automatically. The IEC 61850 MMS server simulates various devices within the substation, mapping them to MMS for real-time exchange of data and information with monitoring backends and telecontrol devices, thereby achieving interoperability between devices from different manufacturers in a network environment [7-8].

2.2 Simulated Substation System Structural Characteristics

- (1) **Service-Oriented Architecture (SOA) Adoption:** As shown in [Figure 2: see original paper], application software functions are designed modularly and can be flexibly configured to different nodes of the system according to user requirements, building an application-oriented, safe, reliable, resource-sharing, and easily expandable support system.
- (2) **Middleware Technology Adoption:** Middleware shields the complexity of the underlying operating system, eliminating the need for repetitive work when porting programs across different system software, thus providing high portability.
- (3) **IEC 61850 Standardized Communication Protocol Adoption:** The IEC 61850 standard introduces MMS into the smart substation automation field, clearly defining how MMS exchanges real-time data and monitoring information at the application layer, providing technical support for information sharing and interoperability.

3 Integrated Debugging Method Based on Simulated Substation

3.1 Integrated Debugging System

The dispatching master station integrated debugging system based on a simulated substation includes the simulated substation, telecontrol device, dispatching data network, dispatching master station, monitoring backend, information comparison system, and connection networks between various devices. The debugging system architecture is shown in [Figure 3: see original paper].

The simulated substation emulates real-time data and operational information from various types of substation equipment and transmits this information to the telecontrol device and substation monitoring backend via the IEC 61850 communication protocol. The dispatching master station establishes communication with the telecontrol device through the dispatching data network, obtains the real-time data and operational information forwarded by the telecontrol device via the IEC 104 protocol, issues dispatching commands, and performs integrated debugging. The information comparison system establishes connections with both the dispatching master station and the substation monitoring backend, performs real-time comparison and analysis of messages between the two, automatically monitors the correspondence between substation information and master station information, and implements closed-loop management of information verification to ensure the accuracy and reliability of debugging results.

3.2 Integrated Debugging Strategy

The integrated debugging strategy employs the simulated substation to emulate real-time data and operational information from various types of substation equipment. Through IEC 61850 communication protocol, this information is transmitted to the telecontrol device and substation monitoring backend. The dispatching master station communicates with the telecontrol device via the dispatching data network, acquires the forwarded information through the IEC 104 protocol, issues dispatching commands, and conducts integrated debugging. The information comparison system connects to both the dispatching master station and substation monitoring backend, performs real-time message comparison and analysis, automatically monitors the correspondence between substation and master station information, and achieves closed-loop management of information verification to ensure debugging accuracy and reliability.

3.3 Integrated Debugging Content

The integrated debugging of the dispatching master station database using the simulated substation includes the following verification items:

- (1) **Tele-indication Function Verification:** The simulated substation emulates status outputs from various types of substation equipment to verify whether alarm screens, indicator lights, and display screens on the dispatching master station are consistent with the simulated actions.
- (2) **Tele-measurement Function Verification:** The simulated substation applies tele-measurement values to voltage and current circuits to verify whether various tele-measurements on the dispatching master station are consistent with the applied values. By setting limit values for certain tele-measurements and changing these values at the simulated substation, the system checks whether the dispatching master station correctly records limit violations.
- (3) **Tele-control Function Verification:** The simulated substation automatically responds to the dispatching master station's tele-control selection and preset commands, sends back verification information, executes remote commands, and transmits the status of controlled objects upon successful operation.
- (4) **Protection-Related Function Verification:** The simulated substation emulates protection action scenarios to verify whether the dispatching master station correctly receives related tele-indication signals, protection measurements, and protection action information. It also checks whether the dispatching master station automatically pushes alarm screens when protection actions occur at the simulated substation.
- (5) **Query and Record Function Verification:** The simulated substation emulates various events to verify whether the content output by the substation matches the alarm content in the dispatching master station

database. Queryable content on the dispatching master station includes tele-indication changes, tele-measurement limit violations, Sequence of Events (SOE), and equipment/node status. The master station can select time ranges, event types, and alarm types in historical event and alarm processing to query and verify whether the database completely displays the requested information.

- (6) **Time Response and Clock Synchronization Monitoring:** The simulated substation emulates changes in substation equipment tele-measurement data, tele-indication status changes, and responses to master station commands to verify whether the response time of analog and status quantities and tele-control execution time on the dispatching master station meet requirements. It also checks whether the clock synchronization monitoring system maintains synchronized status.
- (7) **Data Identification:** The dispatching master station can analyze the accuracy of measurement values and status quantities to identify bad data. By having the simulated substation transmit a measurement value set outside its reasonable range, the system checks whether the dispatching master station can correctly identify the anomaly. It also verifies whether the master station can correctly identify when a measurement value experiences abnormal jumps.
- (8) **Intelligent Alarm and Fault Analysis Functions:** When the simulated substation emulates substation equipment operation faults, the dispatching master station can record alarm information during accident conditions and generate fault analysis reports through either active transmission from the simulated substation or data 召唤 from the master station. The reports include steady-state, dynamic, and transient data during accidents, integrate and analyze this data, and store the results. The system checks whether the alarm analysis results are consistent with the simulated fault types.

4 Engineering Application

To verify the feasibility of the proposed integrated debugging method for dispatching master stations based on simulated substations, engineering personnel conducted a pilot application during the debugging and testing process of a 500 kV smart substation' s integration into the smart grid dispatching and control system.

4.1 Integrated Debugging

The integrated debugging of the NARI D5000 dispatching master station was performed using the simulated substation, as shown in [Figure 4: see original paper]. After completing parameter configuration on the simulated substation interface, the SCD file was imported into the simulated substation system to establish substation secondary equipment acquisition point information in the

real-time database. By importing the control information point table, the system could perform automatic or manual simulation of tele-indication changes, apply tele-measurement values at the substation, respond to tele-control operations from the dispatching master station, and customize debugging services for the master station, as shown in [Figure 5: see original paper].

4.2 Point Table Comparison

Before debugging, the acceptance sequence was established based on business requirements and agreement with the field site regarding the acceptance interval order and signal sequence within intervals. Using point numbers as unique identifiers and acceptance order as the basis, the correctness of transmitted information was verified one by one. The standard point table was imported into the acceptance system and parsed to generate a standard format. Using point numbers as unique identifiers, the D5000 database was automatically compared with the standard point table, and comparison records and modification suggestions were exported to ensure that Chinese names, alarm levels, and other information were correct, as shown in [Figure 6: see original paper].

4.3 Graphical Model Verification

Graphical model relationships were verified through topology checking, using the relationship between equipment and signals in the diagrams to determine the accuracy of associations between graphical models and signals. As shown in [Figure 7: see original paper], graphical file keyids with incorrect associations could be summarized and displayed on the simulated substation interface, facilitating location and modification by automation maintenance personnel.

4.4 Real-Time Monitoring

Both the simulated substation and dispatching master station possess message parsing, display, and monitoring functions to monitor system operation status in real-time and assist in problem location. They also monitor the channel status of multiple channels simultaneously, as shown in [Figure 8: see original paper].

4.5 Effect Comparison

A comparison of effects between the traditional debugging method and the simulated substation integrated debugging method is presented in the table below.

[TABLE:N]

5 Conclusion

This paper proposes an integrated debugging method for smart grid dispatching and control systems based on simulated substations, enabling rapid and accurate debugging of dispatching master station database configuration, model es-

establishment, and graphical interface associations. The method is characterized by:

- (1) The simulated substation focuses on application function testing and integrated debugging. Through equivalent simulation of substation equipment, it emulates real-time data and operational information from various types of substation equipment and transmits this information to the dispatching master station, achieving integrated debugging of the master station.
- (2) The simulated substation communicates with the dispatching master station in real-time through telecontrol devices. This debugging method implements closed-loop management of monitoring information acceptance and debugging, automatically monitoring the correspondence between substation information and master station information to ensure debugging accuracy and guarantee the reliability of fundamental data in the power dispatching automation system.
- (3) The method enables real-time monitoring of communication messages, fault location, automatic verification of correct correspondence between substation output and master station response, automatic point table comparison, recording of verification processes, saving of modification records, and generation of debugging reports.

The integrated debugging method for dispatching master stations based on simulated substations was piloted in the debugging and acceptance work of a 500 kV smart substation's integration into the smart grid dispatching and control system. Engineering practice demonstrates that this method ensures the accuracy and efficiency of dispatching master station debugging, accelerates the integration progress of new substations into the dispatching control system, and achieves improvement and innovation over traditional debugging and acceptance modes. Since tele-control operations are closed-loop processes initiated by the dispatching master station, it is recommended that actual transmission tests still be conducted to ensure the safety and standardization of dispatching master station tele-control operations.

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