5G Technology-Based Smart Power Distribution Station Simulation Design Specifications and Applications

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Abstract. The paper develops a 5G-based simulation design of a smart power distribution room. Through 5G's large-capacity, high-reliability connection technology, various operating data of the distribution network are collected in real time, so as to achieve a complete overview of the power environment and operating status of various power distribution rooms. Process data collection effectively improves the operation of safe equipment. At the same time, it provides massive basic inversion data for the interactive design of smart power distribution rooms, enhances the ability to control the power distribution room system and its equipment, and enhance the overall reliability of the power distribution room system.

Keywords: 5G technology, smart substation, simulation design, power distribution station simulation.

1. Introduction

This year, State Grid Zhejiang Electric Power creatively proposed to build a multi-integrated and highly resilient power grid in the form of the energy Internet. The energy Internet is the basis for multi-energy complementarity, efficient interaction, and green development. State Grid Zhejiang Electric Power will establish "three concepts" and construct A diversified, integrated, highly resilient power grid with massive resources being awakened, full interaction between source, grid and load, and improved safety and efficiency. This is the main position of the State Grid strategy in Zhejiang to build a leading international energy Internet company with Chinese characteristics basis. Promote the transformation of the power grid from "source with load" to "source-load interaction", from "redundancy to ensure safety" to "redundancy reduction to promote safety", from "power balance" to "power balance", and from "safety protection" The transformation of “efficiency reduction” into “double improvement of safety and efficiency” is the basis for the transformation of the Internet of Power to the Internet of Energy.

The power distribution room is an important part of ensuring the reliable operation of the power grid. The scale of the industry is also expanding. The scope of management and information management is becoming wider and wider. However, there are still huge limitations in its design. The typical feature is for the distribution network. The reliable operation of the power distribution room has huge redundancy in the capacity design of the power distribution room, causing great waste. The thesis applies 5G's Massive Internet of Things (mMTC) and High Reliability and Low Latency (uRLLC) technologies to achieve rapid transmission of massive data and background management systems. Among the core
applications of 5G, with low latency, large bandwidth and large IoT connections, URLLC and mMTC have natural massive data throughput capabilities, especially for the deployment of data collection nodes in power distribution rooms in multiple links, which are effective in processing data and reducing network pressure [1]. Is very important. But more importantly, real-time computing can deeply identify the model of scene data. With the support of 5G edge computing, you can slice on the network and develop a set of gateway equipment based on 5G transmission, which can effectively realize real-time data collection and transmission, and realize rapid interaction with the background.

2. Research on overall technology of smart power distribution room

2.1. Intelligent management integrated platform for smart power distribution room

The smart power distribution room relies on the ubiquitous power Internet of Things platform, based on the smart grid, and strictly implements the organization and management, standards and key technologies of the smart power distribution room. Through the real-time data of the electrical equipment and power environment of the power distribution room at the same time, use wireless private network or optical fibre network to transmit real-time data to the system platform to realize 24h online basic functions and advanced application services, which can provide managers with a comprehensive integrated platform for intelligent management of power distribution rooms. The platform is based on the Internet of Things platform, through the combination of software and hardware to upgrade the traditional power distribution room, and realize the informatization monitoring and control of the traditional power distribution room [2]. The platform mainly solves the problems of backward informatization of power distribution room operation and maintenance, chaotic and inefficient power distribution room management, large amount of operation and maintenance, high operation and maintenance costs, low inspection efficiency, poor management of safety hazards, and high security risks. Improve power quality and energy efficiency management by solving the above problems.

2.2. System Architecture of Smart Power Distribution Room

The traditional power distribution room upgrade is completed through the integration of software and hardware of the smart power distribution room system. Based on the Internet of Things platform, the organic integration of sensors and control systems is realized, and the information monitoring of the traditional power distribution room is realized, thereby realizing Upgrade and transformation of traditional power distribution room. The system is based on the Internet of Things platform, from the upstream monitoring centre to the downstream power distribution room monitoring sensors, and its architecture is mainly divided into four parts: perception layer, transmission layer, storage and application layer, and application management layer, as shown in Figure 1.
Figure 1. Smart power distribution room system architecture

The perception layer is the sensor placement layer of the power distribution room, used to collect the operating parameters, environmental parameters and electrical parameters of the power distribution room; the transmission layer safely and stably transmits the collected data to the storage and application layer; the storage and application layer realizes the collection Data storage and data processing functions; the application management layer analyses the collected data to realize the monitoring of the power distribution room. Through the four-layer structure of the smart power distribution room system, friendly interaction between information flow and business flow with power customers can be realized, and the quality of power supply and the level of operation and maintenance can be improved.

3. Functional design
The intelligentization of the power distribution room is based on the primary grid and equipment, with the intelligent system of the power distribution room as the core, and comprehensively utilizes multiple types of sensing and monitoring equipment to realize the collection and monitoring of key state quantities of the power distribution room [3]. The key status of the power distribution room is divided into six categories from the perspective of business applications: environment, security, video, equipment status, electrical operation parameters, and equipment IoT label management. The information collection of each state quantity mainly deploys corresponding monitoring sensors at key nodes of equipment and places, and the sensors collect and process corresponding state information digitally to realize real-time monitoring of information.
3.1. Environmental monitoring

The environmental monitoring host sends various environmental data to the monitoring centre in real time, as shown in Figure 2. After the monitoring centre obtains the data, it will immediately generate corresponding alarms in accordance with the established threshold conditions and alarm strategies, and send it to the relevant responsible users through the established channels such as voice, SMS, email, WeChat, etc., and follow the established abnormal handling measures. Control the opening or closing of equipment such as fans, water pumps, power control and control machines.

![Figure 2. Environmental parameter collection](image)

3.1.1. Purification and ventilation subsystem. The indoor and outdoor air exchange is carried out by starting the purification ventilation device, and the air inlet is connected with the purification ventilation device. The outdoor air is filtered through the laminated filter bag, and the purified air is sent into the room to form an indoor slightly positive air environment.

3.1.2. Temperature and humidity control subsystem. The temperature sensor is used to collect the relevant temperature information of each position in the room, and the feedback mechanism is established through the intelligent controller to automatically control the output and opening and closing of the fan, and adjust the air flow and convection intensity in real time to match the dynamic characteristics of the heat generation change of the heat source.

3.1.3. Waterproof immersion subsystem. For water level monitoring in power distribution rooms or cable trenches, the commonly used water immersion detectors are float type liquid level sensors, input water level sensors, and water immersion sensors. The working principle of the float type liquid level sensor is that when the liquid level reaches a present height, the reed switch in the liquid level switch will close and output an alarm signal.

3.1.4. Detoxification and oxygenation subsystem. The power distribution room needs to monitor SF6 and oxygen (O2) gas due to the leakage of SF6 switch cabinet. The partial discharge of the switchgear may locally damage the dielectric and cause an accident. In the process of partial discharge, ozone (O3) is generated. By monitoring the change of O3 concentration, the partial discharge of the switch cabinet can be indirectly detected.

3.1.5. Anti-smoke and fire system. At present, the most mature and widely used smoke detectors are ion-type smoke detection equipment. When the sensor detects smoke, it will send an alarm signal.

3.1.6. Noise and low frequency vibration monitoring. The noise and low-frequency vibration of the power distribution room mainly come from the transformer. Generally, only noise and low-frequency vibration sensors are installed in the transformer room to monitor the noise and low-frequency vibration of the transformer [4]. When the noise sensor and low-frequency vibration sensor detect that the transformer noise and low-frequency vibration exceed the established limits, sound insulation walls and
transformer foundation vibration damping devices should be used on the transformer room wall to effectively prevent noise or low-frequency vibration and prevent transformer noise and low-frequency vibration Disturb the people.

3.2. Data information management
Real-time data dictionary, real-time monitoring of measurement parameters and status information of field equipment. Historical data dictionary, realizing the query of historical data (data storage time can be configured by yourself). Load analysis, based on historical database records, can draw a trend graph of one or more parameters in a certain period of time. Fault analysis, each time a fault occurs, the system records fault information such as the time of the fault, the faulty substation, the cause of the fault, and the fault variable, so as to provide data for the user's fault analysis. Data dump is to process historical data when the system runs for a long time and the system data is stored in large quantities. Report function, users can customize the report format (daily report, monthly report, annual report) according to their needs, which can be embodied in a variety of forms such as tables and bar graphs, and can also be printed, archived and exported regularly.

3.3. Real-time data display

3.3.1. Local equipment display situation. Local equipment can display real-time data of environmental variables such as indoor and outdoor temperature, indoor and outdoor humidity, and the working status of field equipment such as transformer temperature and current.

3.3.2. Query the environmental variables of the underground power distribution room. Use a handheld device to query the environmental variables of an underground power distribution room, and return a short message present, as shown in Figure 3.

![Figure 3. Handheld device query and display various data screens](image)

3.3.3. The monitoring system queries the environmental variables of the underground power distribution room. Through the background screen of the monitoring system, various environmental variables and system working conditions of the monitored various power distribution rooms can be displayed in real time. Select a monitoring point and send a query command to obtain the current environmental variable data of the monitoring point and generate a graph, as shown in Figure 4.
3.4. Electrical energy quality monitoring

Monitoring electrical energy quality is a direct way to obtain electrical energy quality information. Although there are many testing instruments in this area, most of them can only be limited to testing continuity and stability indicators, while traditional testing based on effective values the technology is old and the testing time is too long. The effective value of the public test can no longer accurately describe the actual electrical energy quality problems. Therefore, it is necessary to develop new monitoring technologies that meet the following requirements.

1) Capable of capturing fast instantaneous interference waveforms. 2) It is necessary to measure the amplitude and phase of each harmonic to achieve a sufficiently high sampling rate to obtain detailed information of each harmonic. Among them, fast Fourier transform FFT and improved fast Fourier transform LFFT and PFFT can be used to quickly and effectively reduce the sampling rate. 3) It is necessary to establish an effective analysis and automatic identification system to reflect the characteristics of various electrical energy quality indicators and their changing laws over time.

The electrical energy quality monitoring system can achieve the following main functions: power quality data collection and processing; data query analysis and statistics; graphical display of power quality parameters; database management; power quality report generation function; upload electrical power to the superior electrical energy quality monitoring system Performance quality data functions, etc.

4. Human-machine interface

The machine interactive interface HMI is designed with Qt, including the main interface, system status interface, historical data interface, alarm information interface, etc. The main interface is mainly used to switch between the system status, historical data, and alarm information interfaces. It uses Qt's signal and slot mechanism to display different interfaces through the button trigger signal. At the same time, since there are 33 nodes in the system, one node corresponds to one site data, so a function drop-down menu is provided for site selection [5]. The system status interface is used to display the structure of the
system, voltage and power status curves, and to provide information security attack simulation and protection test panels. The historical data interface is used to query historical data, including data such as active power, reactive power, voltage, current, switch status, and time. This function is mainly realized by establishing a connection with MySQL, reading the data in the database and displaying it in the form of a table. The alarm information interface is associated with MySQL and anomaly detection module to obtain the generated alarm information. The anomaly detection module mainly detects anomalies in voltage, current, and system logs, including the identification and detection of attacks, and the judgment of voltage and current violations. Among them, intrusion detection is mainly for man-in-the-middle attacks based on ARP.

5. Gateway design and topology diagram based on 5G transmission

Apply 5G's Massive Internet of Things (mMTC) and High Reliability and Low Latency (uRLLC) technologies to realize rapid transmission of massive data and background management systems. Among the core applications of 5G, with low latency, large bandwidth and large IoT connections, uRLLC and mMTC have natural massive data throughput capabilities, especially for the deployment of data collection nodes in power distribution rooms in multiple links, which are effective in processing data and reducing network pressure. Is very important. But more importantly, real-time computing can deeply identify the model of scene data. With the support of 5G edge computing, you can slice on the network and develop a set of gateway equipment based on 5G transmission, which can effectively realize real-time data collection and transmission, and realize rapid interaction with the background.

A complete intelligent power distribution room system should be composed of three parts: the main station, transmission network and power distribution room unit, all of which are indispensable. At present, the main station is uniformly constructed by the Municipal Power Supply Bureau, and the transmission network is improved by the optical cables of the distribution network currently being covered, and the distribution room unit is the focus of this design. The construction of the power distribution room unit includes monitoring modules (including environmental monitoring, video monitoring, security alarms, equipment status monitoring), dynamic loop hosts, station-side processing units, NVR and switch communication equipment, etc., as shown in Figure 5.
6. Intelligent power distribution room station domain master protection algorithm design

The comparison table of the protection configuration of the power distribution station is shown in Table 1. It can be seen that the station domain protection cannot only realize the traditional protection function, but also quickly identify the bus fault, without the need for additional measuring equipment, and the economy is better. Compared with the substation, the protection configuration of the distribution station is relatively simple, and it is easier to realize the protection of the station area, thereby optimizing the protection performance.

| equipment          | Traditional protection                  | Site protection |
|--------------------|----------------------------------------|-----------------|
| Distribution transformer | Current quick break protection, Gas protection, Overcurrent protection | Current quick break protection, Gas protection, Overcurrent protection |
| 400V incoming line Feeder  | Current quick break protection, Overcurrent protection | Current quick break protection, Overcurrent protection |
| Busbar             | no                                     | Bus protection  |

The current differential can judge the fault location according to the parameters of the two ends of the component, remove the fault reliably and quickly, and protect the safety of the component. Therefore, for important equipment such as generators, transformers, high-voltage buses, and large motors, differential protection is used as the main protection [6]. These equipment have simple structure, convenient wiring, and easy access to electrical power at both ends. Since there are transformers in the station protection, take the transformer as an example to illustrate the differential protection. Figure 6 shows the simulation system diagram of the station protection.

![Figure 6. Station domain protection simulation system](image)

The transformer type is Y-Δ, and its two ends are bus 1 and bus 2. CB01-CB05 are 5 circuit breakers, of which CB03 and CB04 are connected to both ends of the transformer. The object of station protection is transformer T and bus 1 and bus 2. The division of protection scope is the focus of intelligent substation relay protection, which is directly related to protection reliability. The difference between station area protection and wide area protection is: the scope of protection is only the substation. The station protection divides the substation into two protection zones, CD1 and CD2. CD1 protection zone
is between CB02 and CB04, and its main protection objects are bus 1 and transformer; CD2 protection zone is between CB03 and CB05, and its main protection objects are transformer and bus 2. The main protection algorithm flow chart is formulated according to the protection scope, as shown in Figure 7.

![Flow chart of main protection algorithm](image)

**Figure 7.** Flow chart of main protection algorithm

In Figure 7, if a trip signal occurs in the CD1 area and the CD2 area at the same time, the fault point is located at the T transformer; if only the CD1 area has a trip signal, it means that bus 1 has failed; if only the CD2 area has a trip signal, it means that bus 2 has occurred malfunction. Since both the CD1 area and the CD2 area contain transformers, it is necessary to consider the impact of the inrush current on the protection. Traditional differential protection uses harmonic braking to prevent the relay protection system from malfunctioning. The calculation formula of the ratio differential protection current is:

$$I_{2A} = |\dot{i}_{2A} - \dot{i}_{2C} - a\dot{i}_{4a}|$$  \hspace{1cm} (1)

Among them, $\dot{i}_{2A}$ is the A-phase current at CB02, A; $\dot{i}_{2C}$ is the C-phase current at CB02, A; $\dot{i}_{4a}$ is the A-phase secondary current at CB04, A; a is the transformer ratio. The braking current calculation formula is:

$$I_{rA} = \frac{|\dot{i}_{2A} - \dot{i}_{2C} + a\dot{i}_{4a}|}{2}$$  \hspace{1cm} (2)

The ratio-based differential protection algorithm organically combines the substation protection modules and functional modules, which simplifies the repeated setting of protection modules distributed to the transformer, bus 1 and bus 2. The method can use the collected data to judge the fault location.
and send out an isolation signal to ensure the safety and stability of the system. However, since the protection area contains transformer T, the magnetizing inrush current in the transformer can easily cause the differential protection to malfunction. When a fault occurs inside the transformer, there are more harmonic components in the current, and the differential protection system will block the protection, so there is a certain delay in isolation. Therefore, the protection algorithm needs to be improved to slow down the delay. When the differential current is greater than the setting current, the iron core has begun to saturate at this time. The differential current at this time is the magnetizing current. Substituting the differential current into the magnetization curve, the initial magnetic flux $\varphi_{A0}$ can be obtained. After the iron core is saturated, the magnetic flux at any time can be obtained through integration:

$$\varphi_A = \int_{t_0}^{t} e_A dt + \varphi_{A0}$$  (3)

7. Performance testing and analysis

7.1. System operation test
In the normal operation of the system, the station control system 10 is selected as the monitoring object in the function button, and there is no alarm information after the operation is stable.

7.2. System Attack and Defence Test
The system attack and defines test is mainly based on ARP man-in-the-middle attack, detection and protection. The main functions of the ARP man-in-the-middle attack are as follows: the data interception attack device is inserted into the communication link between the station control system and the physical simulation object as an intermediate device to intercept the communication data between the two; system key parameter modification: the attack device pretends to be a station The control system sends the command of the modified control value of the system to the physical simulation object to make the physical system run in an abnormal state; the station control system deception: the attacking device pretends to be the physical simulation object and responds to the data request sent by the HMI. According to the intercepted data during the normal operation of the system, the attacking device forged the normal operation status data of the system and sent it to the station control system, creating an illusion of normal system operation. A man-in-the-middle attack based on ARP is used between the station control system 10 and the physical simulation object to tamper with the control data, and maliciously control the switch control of the physical object, which affects the operating state and scheduling of the system. The whole process is shown in Figure 8.
7.3. Simulation analysis of station master protection

In order to verify the feasibility of the above algorithm, take the station protection system in Figure 6 as an example to establish a simulation model. In Figure 6, the power supply takes the constant voltage model, the rated capacity of the transformer T is set to 55MVA, and the rated voltage is 154kV/22kV. Taking phase A as an example, the improved main protection algorithm is used for simulation and compared with the traditional method. Taking the CD1 protection area as an example, a fault condition inside the compressor is set for simulation. When the transformer is put into operation without load, the closing angle is zero, which will cause the transformer core to saturate. Assuming that the transformer has a single-phase grounding at 62.5ms, the traditional differential protection action in CD1 area is shown in Figure 9(a), and the improved differential protection action in this paper is shown in Figure 9(b).
Figure 9. No-load input transformer protection action

8. Conclusion
The intelligent power distribution room is a large-scale networked monitoring system integrating hardware, software, and network. It takes the power distribution room operation monitoring and management platform as the core to realize multi-level networking and cross-regional monitoring. The terminal system can be centrally monitored at the main station. Unified management to escort the intelligent distribution network. This article introduces a new type of intelligent power distribution room monitoring system. In this system, the comprehensive monitoring of the power distribution room is completed mainly from the aspects of environment, security, video, equipment status, electrical operation parameters, equipment Internet of Things tag management, etc., to improve the safety, reliability, and reliability of power distribution operation and maintenance. Intelligence, to realize the remote intelligent inspection of the power distribution room, and the Internet of Things label management of the operating equipment ledger, to meet the needs of comprehensive management and competitive business expansion.

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