Design of Intelligent Partial Discharge Inspection System for Distribution Equipment Based on Internet of Things

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Abstract. With the rapid development of information communication, the Internet of Things and other technologies, the distribution network has evolved from a single power network to intelligent information integration. Due to the characteristics of large-scale distribution network equipment, scattered deployment, and complicated operating environment, the operation and maintenance work has problems such as low working efficiency and severely insufficient measurement coverage. Based on this, this paper adopts the system architecture of cloud, pipe, edge, and end to design an intelligent inspection system for partial discharge of power distribution equipment. The system is mainly based on intelligent sensing and supplemented by mobile detection. It integrates advanced technologies such as intelligent sensing, big data analysis, wireless communication into all aspects of distribution network inspection, so as to realize intelligent sensing, data fusion analysis and fault alarms of distribution network, guide defect elimination work in time, and provides technical support for status maintenance and safe operation of distribution network equipment.

1. Introduction
The distribution network is at the end of the power system, and its operating state affects the user experience directly [1], which is a key link related to the "quality service" of the grid company. For a long time, the construction of China's distribution network has been promoted continuously. With the rapid development of information and communication technology, intelligent sensing technology, and Internet of Things technology, the distribution network has evolved from a single power network to intelligent information integration. However, due to the characteristics of many types of distribution equipment, large volume [2], scattered deployment, and complicated operating environment. It still faces the problems of lack of power distribution equipment condition detection technology, low efficiency of operation inspection personnel, and serious shortage of measurement coverage [3].

The detection of power distribution equipment is mainly based on live detection, which has achieved good results in recent years. However, with the rapid development of distribution networks and the comprehensive promotion of live detection, existing problems have become increasingly prominent.
First, live detection relies on manual inspection methods, which has low efficiency and high personnel requirements. The current configuration of transportation inspection personnel is difficult to meet the needs of large-scale and high-frequency live detection of power distribution equipment; Secondly, the distribution of power distribution equipment is scattered, and most of them are on-pole or in-box equipment, which cannot be covered by traditional live detection instruments; Third, because the measurement data is huge and the format is not standardized, the workload of post-processing is large, and it is difficult for data sharing to form data islands. Online monitoring can solve some problems because of its high degree of automation. However, for the volume of power distribution equipment, there are problems such as high one-time investment costs, complex installation, and difficulty in later adjustment and maintenance.

In recent years, with the rise of Internet of things technology and the promotion of ubiquitous power Internet of things, a lot of research work has been carried out on the application of Internet of things in distribution network in China. The paper [1] proposes the distribution Internet of things system based on comprehensive perception and software definition. The paper [4] proposes the overall structure of the power Internet of things. According to the actual needs of distribution network inspection work, State Grid Corporation combined with the Internet of things system architecture, carries out the distribution network mobile operation application, reducing the management cost and improving the work efficiency effectively. However, in general, the current research tends to the top-level design, and the mobile operation application is mainly based on the physical ID. There are some problems such as inconsistent standards, repeated development, and nonstandard process, which limit the expansion of mobile inspection in the distribution network.

Partial discharge detection is an important method for judging the insulation status of electrical equipment [5]. This article uses partial discharge live detection as the starting point, based on existing research; it adopts the Internet of things, intelligent sensing, wireless communication and other technologies. The architecture and functions of each level are analyzed, and an intelligent inspection technology system for distribution equipment based on the Internet of things is constructed. It can obtain partial discharge data of power distribution equipment quickly, analyze the operating status of the equipment accurately, and reduce the workload of inspection personnel greatly, and provide comprehensive technical support for operation and maintenance of distribution equipment.

2. System architecture design

Internet of things is a highly integrated and comprehensive application of wireless communication technology, intelligent sensing technology, container technology, etc. It uses a large number of nodes deployed in the measured area to perceive and collect the status information of the monitored objects cooperatively, and through multi-source parameter fusion and feature analysis of the information, it judges the operating status of the monitored objects, enabling more equipment to achieve wide coverage, low-cost, intelligent access to meet the needs of real-time, accuracy and comprehensive information acquisition. According to the system architecture of Internet of things, the architecture of the intelligent partial inspection system for partial discharge of power distribution equipment is divided into four parts: cloud, channel, edge, and terminal, as shown in Figure 1.

The terminal is the state sensing unit of the intelligent inspection system, which uses different types of sensors to collect the abnormal signals from the partial discharge of the distribution equipment, providing the data basis for the evaluation of the insulation state of the distribution equipment. The intelligent sensors for detecting partial discharge include ultra-high frequency (UHF), high-frequency current transformer (HFCT), transient earth voltage (TEV) and acoustic emission (AE), etc. diversified detection technologies can detect partial discharge signals more comprehensively. The sensors are installed in magnetic suction or caliper mode, which does not affect the normal operation of the equipment, and have the characteristics of plug and play and convenient installation.

The edge is located near the edge of the network. It is a distributed open platform that integrates core capabilities of network, computing, storage, and applications. It provides edge intelligent services nearby to meet the key needs of agile connection of distribution network, real-time business, and local
intelligent diagnosis. In order to achieve the requirements of intelligent inspection of equipment on the pole or in the box of the distribution network, the system uses two types of edge devices: intelligent gateway and inspection terminal. The intelligent gateway can realize intelligent unmanned inspection, collect the data which collected by the intelligent sensor automatically and upload it to the cloud, without the need for inspectors to arrive at the site for operation. However, some power distribution equipment is located in the area without network coverage, the intelligent gateway cannot upload data to the cloud, and some pole or box equipment installation space is limited, so the intelligent gateway can’t be deployed. The system can solve the above problems effectively by using inspection terminal. When inspectors arrive at the scene, they collect sensor data through the inspection terminal or collect data stored in the intelligent gateway directly, which not only solves the problem of data uploading, but also simplifies the inspection staff’s workflow and improves the coverage of inspections.

![Figure 1. The architecture of partial discharge intelligent inspection system](image)

The channel is the network management and control, which is the data transmission channel between the terminal and the cloud. The management layer of the intelligent inspection system includes the communication network between the terminal and the side, and the communication network between the side and the cloud. The terminal-side communication network is a communication network between the sensor and the intelligent gateway or inspection terminal. It has the characteristics of flexible networking and low power consumption. The cloud-side communication network is a communication network between the cloud platform and the intelligent gateway or inspection terminal, which has the characteristics of high reliability and low delay.

The cloud is the cloud platform, which integrates storage, processing, analysis, display, diagnosis and other functions to realize the centralized management, display, analysis and application of test data, and ensure the safety and standardization of test data management; at the same time, it evaluates the operation status of diagnostic equipment through a variety of advanced applications, provides auxiliary decision suggestions, and guides the status maintenance of distribution equipment.

Through the deployment of partial discharge intelligent inspection system for distribution equipment, advanced technologies such as intelligent sensor, big data analysis, wireless communication are
integrated into each link of distribution network inspection, so as to realize intelligent perception, data fusion analysis and fault alarm of distribution network, guide defect elimination work in time, and provide technical support for condition maintenance and safe operation of distribution network equipment.

3. System function design

3.1. The terminal layer

The functional module diagram of the intelligent sensor is shown in Figure 2. According to the functional requirements, the intelligent sensor is divided into perception module, conditioning module, micro processing module, communication module and energy supply module. The perception module is used to collect the partial discharge signal from the equipment. The conditioning module is used to amplify, filter and convert the weak PD signal into digital signal with appropriate level, waveform and frequency. Micro processing module is used to coordinate other modules to complete system functions. The power supply module uses lithium battery to provide power for each module, so that the sensor does not need external power supply. The communication module is used for two-way communication of data, which can send data to the outside and receive instructions from the outside.

![Figure 2. The function module diagram of intelligent sensor](image)

The technical specifications of the intelligent sensor should meet are as follows:

| Parameter                  | UHF   | HFCT | AE   | TEV   |
|----------------------------|-------|------|------|-------|
| Frequency Range(MHz)       | 300~1500 | 0.5~50 | —    | 3~100 |
| Center frequency(kHz)     | —     | —    | 40   | —     |
| Measurement range(dB)      | 0~70  | 0~80 | -7~68| 0~60  |
| Measurement error(dB)      | ±1    | ±1   | —    | ±1    |
| Resolution(dB)             | 1     | 1    | 1    | —     |
| Average effective height(mm)| ≥8   | —    | —    | —     |
| Battery life(year)          | ≥8    | ≥8   | ≥8   | ≥8    |

3.2. The edge layer

The edge layer device serves as the channel connecting the terminal layer and the cloud layer. In addition to the collection and transmission of data, it also needs to have a lightweight cloud computing function to extend the primary computing capabilities of the cloud to the edge. Strategy control and fault diagnosis, reduce response delay, improve control flexibility, and realize localized risk processing and fault diagnosis of perceived data.
(1) Data collection function

Both the intelligent gateway and the inspection terminal can directly establish wireless network connection with the intelligent sensor to collect the data collected by the intelligent sensor. Considering the efficiency of data collection and the integrity of data, the inspection terminal and the intelligent gateway should establish a transmission channel, which can collect the historical data stored in the intelligent gateway in batches and shorten the time of data collection.

(2) Intelligent linkage function

The intelligent linkage function refers to that the edge layer equipment analyzes the collected data, forms the linkage strategy according to the analysis results, and controls the state of the intelligent sensor, such as the sensor acquisition frequency and acquisition gain, etc. Taking ultrasonic sensor (AE) as an example, the linkage strategy is as follows:

a) Acquisition frequency

In order to reduce the power consumption of intelligent sensor and meet the inspection requirements, the acquisition frequency of sensor is generally set to once a day. When the edge layer equipment judges that the collected data is abnormal, the acquisition frequency of the sensor is increased to collect more abnormal data for accurate analysis and trend tracking.

b) Acquisition gain

Due to the wide range of ultrasonic signal generated by partial discharge, when fixed gain multiple is used for measurement, the measurement accuracy of small signal is low, and the measurement waveform of large signal will be distorted, so the ultrasonic sensor will design multi-stage amplification circuit to make it have multiple gain multiples. However, if the signals with different gain multiples are collected at the same time, the power consumption of the sensor will be increased. Therefore, the gain of the sensor can be adjusted by using the edge layer device to improve the measurement accuracy of the sensor on the premise of ensuring low power consumption. The flow chart of adjusting the gain of ultrasonic intelligent sensor is as follows:

![Diagram](image_url)

Figure 3. Acquisition gain adjustment process
First, collect the ultrasonic amplitude spectrum data at a default gain of 100 times; then, determine whether the amplitude of the ultrasonic amplitude spectrum data exceeds 90% of the maximum range at a gain of 100 times. If it exceeds, adjust the gain of the sensor to 10 times. If it is not exceeded, the gain is not adjusted; finally, if the gain is adjusted, the ultrasonic amplitude spectrum data at 10 times the gain is collected to determine whether the amplitude of the ultrasonic amplitude map data exceeds 90% of the maximum range at 10 times the gain. If it is exceeded, adjust the gain of the sensor to 1; if it is not exceeded, do not adjust the gain.

c) Atlas type

The power consumption of amplitude spectrum acquisition is low, and the amplitude spectrum can judge whether the data is abnormal by threshold comparison method, so the ultrasonic sensor only collects the amplitude spectrum when sensing the ultrasonic partial discharge signal. When the edge layer equipment judges that the amplitude spectrum data is abnormal, adjust the spectrum collection type of the sensor, and collect the amplitude spectrum, waveform spectrum, phase spectrum and flight spectrum data at the same time, so as to provide a variety of data basis for the diagnosis of the partial discharge signal type of the cloud master station, and improve the accuracy of the partial discharge type identification.

(3) Fault diagnosis function

Limited by hardware resources, only simple threshold diagnosis is carried out in the edge layer. The diagnosis methods include differential threshold diagnosis, time series threshold diagnosis and horizontal contrast threshold diagnosis. Differential threshold diagnosis is to compare the detected value with the threshold value to judge the severity of defects; Time series threshold diagnosis arranges the data of the same equipment and the same measuring point into series according to the sequence of their occurrence time, analyzes the historical trend, and judges the severity of defects based on catastrophe theory; Horizontal contrast threshold diagnosis is to judge the severity of defects by comparing the detection data of the same kind of equipment, the same time and the same measuring point, and taking the average level of the same index of the same kind of equipment as the benchmark. By using the fault diagnosis function of the edge layer equipment, the inspectors can obtain the fault information of the equipment at the detection site, improve the real-time fault diagnosis, and provide the judgment basis for the inspectors.

(4) Control agent function

The control agent function refers to that the edge layer device transmits the control instructions of the cloud layer to the sensor, which enables the cloud to complete the remote control of the intelligent sensor. The remote control includes updating the sensor configuration information, remote reset, remote debugging and remote upgrading. When there is no communication between intelligent gateway and cloud platform, patrol terminal can be used to transmit control instructions to intelligent gateway or intelligent sensor.

3.3. The channel layer

The channel layer network architecture is shown in Figure 4. The terminal-to-terminal communication network belongs to the scope of local area network and adopts Lora wireless communication mode for data transmission; the cloud side communication network belongs to the scope of wide area network and adopts 4G private network or public network wireless communication mode and Ethernet wired communication mode for data transmission; the intelligent gateway and patrol inspection terminal use blue teeth for communication.
3.4. The cloud layer

The cloud layer refers to the cloud-based main station platform, which consists of servers and client workstations, and uses container technology and artificial intelligence technology to implement unified management of information, analysis and display of inspection data, and inspection task management functions in the form of micro-services. The cloud layer architecture is divided into three parts: the Infrastructure-as-a-service layer (IaaS), the Platform-as-a-service layer (PaaS), and the Software-as-a-service layer (SaaS), as shown in Figure 5. The IaaS layer mainly includes computer servers, communication equipment, and storage devices. It provides users with IT infrastructure services such as computing, storage, or network capabilities as needed. The PaaS layer provides a platform for developing and operating application software to provide operating environment support for applications. The SaaS layer provides a variety of micro-services for different needs through the internet to achieve application service.
In summary, based on the system architecture of cloud, channel, edge and terminal, the monitoring data, intelligent patrol inspection data, equipment account and other information are used as data sources to evaluate the operation status of the equipment through a variety of advanced applications such as map diagnosis, visual display, status exception alarm, etc., to provide auxiliary decision-making suggestions and guide the status maintenance of power equipment. Through the unified management of intelligent detection, data storage, data analysis and application, the work efficiency can be improved effectively to ensure the safe operation of the equipment.

4. Application scenario analysis

4.1. Intelligent perception
By installing intelligent sensors such as UHF, AE, HFCT, and TEV on the power distribution equipment, the electromagnetic signals and acoustic signals generated by its internal partial discharge are monitored three-dimensionally. To achieve a more comprehensive, objective, and true reflection of the operating status of the equipment under test. Through the threshold and map diagnosis of the collected data, the health level of the equipment is evaluated, and the maintenance mode is changed from "post-event response" to "pre-event prevention".

4.2. Intelligent Inspection
By deploying an intelligent gateway to automatically collect and upload data collected by intelligent sensors, unmanned inspection is implemented to alleviate the problem of insufficient staffing of live detection. For areas without network coverage, inspection personnel can use the inspection terminal to collect data stored in the intelligent gateway to solve the problem that data cannot be uploaded. For scenarios where an intelligent gateway cannot be deployed, inspection personnel can use the inspection terminal to directly collect data stored in smart sensors, simplifying the inspection personnel’s workflow and improving the coverage of inspection operations. Mainly based on the intelligent perception of the gateway, supplemented by the mobile detection of the terminal, to realize the intelligent inspection of power distribution equipment, and promote unmanned operation and maintenance in the field of power distribution.

4.3. Panoramic display
Through centralized display of detection data, three-dimensional display of equipment models, and abnormal alarm display, users can grasp the equipment status and operation from a macro perspective, so that the equipment can "talk" and the station can "think". Facilitate the rapid location and processing of fault causes, guide the development of targeted status inspections, and improve the ability of management departments to intelligently sense and comprehensively analyze the status of power grid equipment.

4.4. Aiding Decisions
The inspection terminal has a lightweight cloud computing function. When inspectors hold the inspection terminal to perform inspections, they can check the abnormal situation of the local discharge data on the spot, assist the inspectors in emergency treatment of failures, and prevent the expansion of the fault range. After the partial discharge data is uploaded to the cloud platform, the cloud platform uses deep learning and multi-dimensional data fusion algorithm to analyze the partial discharge data accurately, improves the diagnostic accuracy and diagnostic efficiency comprehensively, provides effective basis for formulating maintenance strategy, and realizes the transformation from traditional artificial operation and maintenance mode to intelligent operation and maintenance mode.

5. Conclusion
Based on the system architecture of cloud, channel, edge and terminal, this paper designs an intelligent inspection system for partial discharge of power distribution equipment. The system is mainly based on
intelligent perception and supplemented by mobile detection. It has the characteristics of flexible deployment, simple operation, and extensive coverage. Upload the detection data through the intelligent gateway or inspection terminal to realize the centralized management, display, analysis and application of partial discharge data, and ensure the security and standardization of the detection data management; Evaluate the operating status of equipment through a variety of advanced applications, and provide aiding decisions recommendations for guiding the maintenance of power equipment; through the integration of Internet of things technology and condition monitoring technology, the rapid acquisition of data is realized, the workload of inspection personnel is reduced greatly, the production efficiency and management level of operation and maintenance of distribution equipment are improved, and all-round technical support is provided for operation and maintenance of distribution equipment.

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