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Research Article

Design of a Real-Time Wireless Sensing Monitoring System Based on Acoustic Emission Power GIS Equipment

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In this paper, real-time monitoring of acoustic emission power GIS equipment is studied and analyzed, and a real-time wireless sensing monitoring system is designed. The overall design of the wireless sensing monitoring system for acoustic emission power GIS equipment is as follows: the model of the system is constructed, the design of the system module function is proposed, the platform of the system is built, the hardware and software solutions are configured, the operating system is optimized, the graphics and data are input into the GIS distribution network system, the editing function is optimized, the fast positioning function of the equipment is improved, and the automatic generation of the system diagram is improved. By using ZigBee technology to establish a wireless sensor network and realize wireless transmission of monitoring signals, it can avoid many disadvantages, such as cumbersome cable laying, troublesome changes, inconvenient expansion, and daily maintenance in wired transmission, and save various resources and reduce monitoring costs, which is well worth promoting in the system. In this paper, for the actual situation of GIS equipment, combined with the characteristics of the wireless sensor network structure and the design needs of the monitoring system (the overall design of the monitoring system, OFS maximum response amplitude of 19.9 mV, to be reached 40 dB), the signal will be uploaded to the high-speed collection system, and the efficiency is increased by more than 10%. The feasibility test of the monitoring system, the test results, and the related data show that the UHF sensor can accurately collect the UHF signal, the wireless network formed by ZigBee can reliably transmit the signal, the monitoring interface is correctly displayed, and the whole monitoring system operates stably and meets the requirements of the initial design.

1. Introduction

With the development of society and economy, as well as the progress of science and technology, the safety of electric power systems is closely related to social stability, and the normal operation of electric power equipment is necessary to ensure the normal operation of the electric power systems. As important component equipment of substations, transformers and GIS will lead to the paralysis of power systems once the failure occurs, which will lead to serious loss; therefore, it becomes especially important to ensure the normal operation of transformers and GIS. Electrical equipment mainly consists of conductors, magnetic conductive materials, insulating materials, and operating mechanisms, and the failure of electrical equipment can be divided into three categories: mechanical failure, conductor failure, and insulation failure [1]; insulation failure in the electrical equipment failure in the proportion of the larger, so the insulation status of electrical equipment monitoring and regular maintenance, can avoid part of the insulation failure, to avoid causing greater losses. Therefore, monitoring the insulation status of electrical equipment and carrying out regular maintenance can prevent some of the insulation failures from occurring and cause more losses [2]. Reliability overhaul focuses on the overall operating status of the power system. The overhaul process is more complicated. Regular overhaul can no longer guarantee the normal operation of power equipment. Condition overhaul is currently the focus of electrical equipment overhaul. The maintenance of substation electrical equipment can be divided into regular maintenance, condition maintenance, and reliability maintenance. Periodic maintenance is the maintenance of electrical equipment according to a fixed interval of time, and the method is suitable for the situation where the number of electrical equipment is small; state maintenance is a comprehensive evaluation of the actual operating state of electrical equipment, according to its comprehensive evaluation to determine its maintenance plan; reliability maintenance is focused on the overall operating state of the power system, and its maintenance process is more complex [3]. Regular maintenance can no longer guarantee the normal operation of electrical equipment; condition maintenance is the current focus of electrical equipment maintenance, online monitoring, and evaluation of the operating status of electrical equipment, according to its evaluation results to take corresponding measures that can greatly reduce the investment of resources.

As partial discharge occurs inside the GIS cable terminal, the ordinary infrared temperature measurement and ground loop current test cannot be found to detect these partial discharge phenomena. Therefore, to ensure the safe and stable operation of power equipment, the accurate detection of partial discharge phenomena is particularly important, not only to be able to detect the presence or absence of partial discharge phenomena but more importantly also to be able to monitor the development of partial discharge; only then can we take reasonable means of maintenance [4]. What is more important is to be able to monitor the development of partial discharge. Only in this way can we take reasonable maintenance measures. This can effectively improve the large-scale power outages of the power grid and make full use of electric energy. This will enable the grid to be effectively improved for large-scale power outages and make full use of the power. This paper establishes a wireless sensor network by using ZigBee 8 technology to realize wireless transmission of signals, which can avoid many disadvantages, such as cumbersome laying, troublesome changes, inconvenient expansion, and daily maintenance in wired transmission, and save various resources and reduce monitoring costs, which is well worth implementing in the system. The overall design of the system is based on the structural characteristics of the GIS equipment, the technical characteristics of the wireless network and the monitoring requirements of the power supply company, and the topology of the wireless sensor network of the monitoring system is determined to be a star network. After processing by the PC, the local discharge is displayed in front of the operator in the form of graphics and data to realize real-time monitoring of GIS equipment in the substation.

The wireless sensor network holds the current international attention and is a multidisciplinary frontier hot research field; the ZigBee technology is applied to the local in-line monitoring of GIS equipment in the power system, improves the level of automation, intelligence, and digitalization of substations, and reduces personnel monitoring costs and comprehensive wiring costs, in line with the requirements of strong smart grid construction. On this basis, run the basic applications of distribution network production and dispatching, unify business specifications, improve the modern management level and production efficiency of regional distribution networks, and solve the practical tasks of distribution network management, mainly involving the spatial GIS information display and some spatial analysis functions, integration of production management data and distribution network verification. Carry out spatial visualization, spatial analysis, and spatiotemporal analysis to provide a scientific basis for the development of power generation management, integrate multidimensional information, such as power supply network information and equipment usage information, integrate and develop modules for managing power equipment and operation management, and provide modern production management tools.

2. Current Status of Research

In terms of the current research status of partial discharge signal detection, the methods for partial discharge detection inside gas-insulated electrical appliances are divided into two categories: electrical and nonelectrical detection methods, among which nonelectrical detection methods are divided into two categories: nonchemical detection methods and chemical detection methods [5]. The chemical detection method mainly uses the composition of SF_6 gas to complete the detection of partial discharge, because the partial discharge phenomenon inside the gas-insulated appliance will be diluted by the large amount of SF_6, and at the same time, the overheating fault inside the device will also decompose part of the SF_6 gas and produce decomposition products with similar composition, thus largely affecting the partial discharge detection results [6]. The chemical detection method can only generally reflect the partial discharge situation inside the electrical equipment; if you want to accurately understand the real discharge situation, you need to use more complex and sophisticated instruments to carry out off-line detection and analysis [7]. At present, the commonly used detection methods are the pulse current method, ultrasonic method, and ultra-high-frequency method; the detection frequency of the pulse current method is usually within 10 MHz, which can achieve accurate measurement of the local discharge signal. Therefore, this detection method is not suitable for the detection of partial discharge signals of substation equipment.

To solve the problem of real-time monitoring of high-voltage transmission lines, literature [8] designed a wireless sensor network-based online monitoring system for high-voltage transmission lines, which realizes the collection, transmission, and processing of various environmental parameters of transmission lines through ZigBee technology, to monitor the operation status of high-voltage transmission lines in real time. In the literature [9], a transformer partial discharge online monitoring system was designed for transformer partial discharge to provide a guarantee for the safe operation of power transformers. Literature [10] designed a transformer temperature monitoring system based on a wireless sensing network, using platinum resistors to collect the temperature data and ZigBee wireless communication module for data transmission, which is important for real-time monitoring of transformer oil and winding temperature. Literature [11] used a wireless sensing network for temperature monitoring of substation equipment, with detailed design of monitoring nodes and gateway nodes, and literature [12] innovatively designed a UHF temperature monitoring subsystem and substation monitoring subsystem using IoT technology, modern communication technology, and information processing technology to realize the design of the substation sensing monitoring system based on power IoT. To effectively monitor the temperature condition of power equipment, literature [13] put infrared thermal imaging technology to monitor the temperature of power equipment, which circumvents the disadvantages of other types of sensor monitoring.

The early fault monitoring signal of the equipment is very weak, and there is strong electromagnetic interference at the equipment operation site, and the existence of problems such as a low signal-to-noise ratio at the monitoring site brings some difficulties to the condition monitoring. Some of the existing monitoring systems can only reflect the development trend of equipment failure but cannot provide the type of equipment failure and the severity of the failure [14]. The software and hardware have different degrees of defects and instability, which can easily cause false alarms and missed alarms. The current specification does not have corresponding technical requirements and indicators, making condition monitoring lack scientific standards. The current monitoring and diagnostic system have difficulties in continuous real-time monitoring and cannot predict sudden failures accurately and timely. Therefore, the original single small-scale monitoring system can no longer meet the requirements of a smart grid for advanced asset management. Moreover, with the rapid growth of the scale of the electricity information collection business, the stored monitoring data also shows an exponential growth trend, and how to better realize the online monitoring of power equipment status is a topic well worth studying.

3. Acoustic Emission Power GIS Equipment Real-Time Wireless Sensing Monitoring System Design

3.1. Real-Time Monitoring Analysis of Acoustic Emission Power GIS Equipment. As important equipment of power systems, acoustic emission power GIS equipment undertakes the tasks of voltage conversion, power distribution, and transmission. Therefore, the prevention and avoidance of power transformer faults are of great importance to the stable operation of the power system. However, transformer fault monitoring is a very complex issue; the capacity of the transformer, the voltage level, the performance of the insulation, the working environment, and even different manufacturers all have an impact on the monitoring results [15]. Carry out spatial visualization, spatial analysis, and spatiotemporal analysis to provide a scientific basis for the development of power generation management, integrate multidimensional information, such as power supply network information and equipment usage information, integrate and develop management modules for power equipment and operation management, and provide modern production management tools. According to the process of fault occurrence and development, transformer faults can be divided into gradual faults and sudden faults, and according to statistical data, the largest proportion of transformer faults is gradual faults. Gradual failure mainly refers to the transformer in operation, due to insulation aging, quality defects, moisture, and other factors that make insulation performance decline and eventually lead to transformer insulation failure. This type of fault can be detected in advance by online monitoring means to avoid more serious accidents.

In the power equipment insulation structure, the local field strength is more concentrated; the appearance of local defects will lead to partial discharge, partial discharge as an electrical discharge in the insulation medium, although it does not affect the insulation properties of the medium but foreshadows the insulation aging of the equipment, which also makes the insulation aging eventually develop into the most important reason for insulation breakdown. The transformer partial discharge process is accompanied by electrical impulses, electromagnetic radiation, ultrasonic waves, and other phenomena; the amount of partial discharge and changes in discharge patterns can reflect many faults; timely and effective monitoring of partial discharge and accurate detection of the type and location of partial discharge of the transformer and targeted maintenance measures are done to avoid more serious sudden failure of the transformer. Gradual failure mainly refers to the transformer in operation. Due to factors such as insulation aging, quality defects, moisture, and other factors, the insulation performance of the transformer is reduced, which ultimately leads to the insulation failure of the transformer. In general, the low-voltage line loss is about 10%; if part of the station area is relatively high, the theoretical line loss is also high, indicating that the power supply line has problems; the existing line can be simulated and optimized, if the optimization plan is feasible before the actual transformation; sometimes, it is necessary to relocate the distribution substation; to find the best solution, you can also simulate the displacement to calculate the theoretical line loss if the plan is feasible; then, the actual transformation can be carried out. The line loss calculation formula and explanation are as follows:

$$\Delta A_{\mathrm{xt}} = N I_{\mathrm{pj}}^2 K^2 R_{\mathrm{dc}} t. \tag{1}$$

Calculate before the low-voltage line from the end to the first, the branch line to the mainline (that is, to take the load incremental way (more convenient)), and divide into several calculation line segments; the line segment is divided into the following principles: the transmitted load is the choice of a line number, and the length of the line segment is the same for the same line segment, otherwise another calculation line segment. At this point, the R_{dc} calculation formula is

$$R_{\mathrm{dc}} = \frac{\sum_{i=1}^{n} N_1 S_I^2}{N\left(\sum_{i=1}^{m} A_1\right)^3}. \tag{2}$$

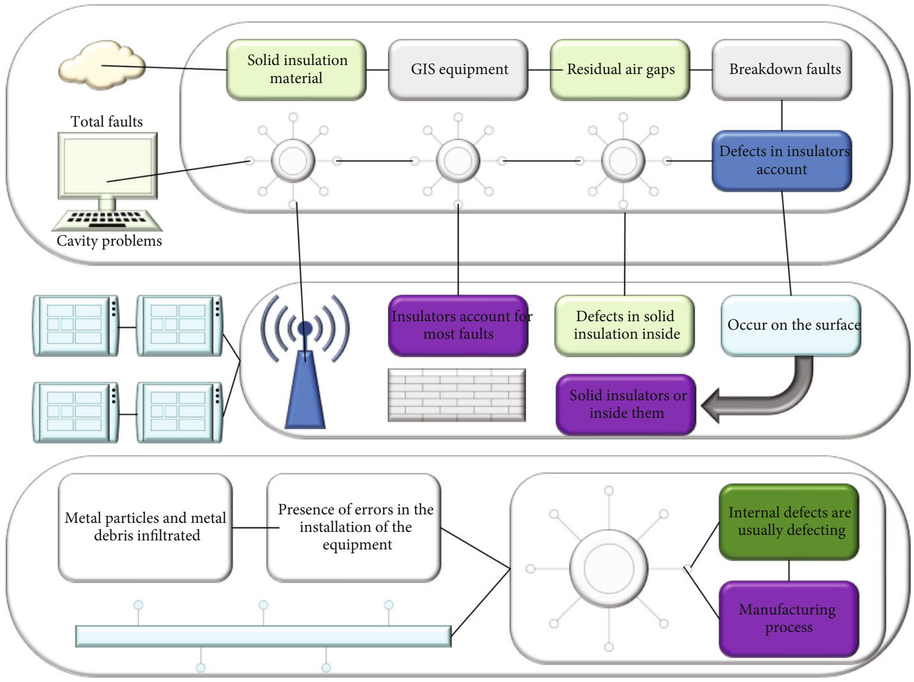

Figure 1: Acoustic emission wireless sensing real-time monitoring architecture.

In today's information-based society, a wide variety of sensors are used in different industries, are used to accurately obtain the required information, such as monitoring the working state of equipment, monitoring the functions of the human body, and observing the vast universe, and are applied to a variety of scientific research, covering almost every scientific and technological projects, such as sensors in social development, economic development, and the importance of self-evidence; various countries are also very focused on this aspect of research so that sensor technology has advanced by leaps and bounds. Sensors can be divided into many kinds according to their functions: gravity sensors, laser sensors, biosensors, photosensitive sensors, vision sensors, displacement sensors, and so on. In the monitoring system developed in the thesis, to collect the propagated UHF local discharge signal, the corresponding UHF sensor must be used [16]. UHF sensors use coupled antennas to sense the pulsed electromagnetic wave signal generated by the local discharge inside the GIS equipment in the UHF frequency band. Sometimes, it is necessary to migrate the distribution transformer. To find the best solution, the theoretical line loss can also be calculated by simulating the displacement. If the solution is feasible, the actual transformation can be carried out. The sensors are divided into two types, built-in and external, according to the different installation locations.

The built-in sensor, as the name suggests, is installed inside the GIS equipment. The built-in sensor has high sensing efficiency and strong anti-interference ability and can efficiently collect the UHF local amplification signal generated by GIS, but it requires more sensors, and one must be installed at every distance, which is costly and adds more sealing points. The design and installation of the sensor are synchronized with the GIS equipment body, which is installed at the factory and is not suitable for the already operating GIS equipment.

$$i(t) = I_0 e^{-(t+t_0)^2 \times 2\sigma^2}. \tag{3}$$

It mainly refers to the defects of solid insulation materials inside GIS equipment, such as residual air gaps. Breakdown faults caused by defects in insulators account for 10% of total faults, and faults caused by cavity problems in early insulators account for most faults, so defects in solid insulation inside GIS equipment often occur on the surface of solid insulators or inside them. Internal defects are usually formed in the manufacturing process but not detected; they are often small, such as some infiltrating metal particles and metal debris and internal air gaps; due to the presence of errors in the installation of the equipment, the movement of the conductor may also give a certain degree of impact, as shown in Figure 1.

The wavelet analysis method is a time-domain localized analysis method with fixed window size (i.e., window area), but its shape can be changed, and both the time and frequency windows can be changed, i.e., with higher frequency resolution and lower time resolution in the low-frequency part and with higher time resolution and lower frequency resolution in the high-frequency part. Wavelet transform is a function of a basis wavelet that is shifted and then made the inner product with the signal to be analyzed at different scales.

$$WT_x(a,\tau) = \frac{1}{\sqrt{a}}\int_{-\infty}^{+\infty} X(w)\varphi^*\left(\frac{t+b}{a}\right)dt. \tag{4}$$

The equivalent frequency domain is expressed as

$$WT_x(a, \tau) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} X(w)\varphi^*(aw)e^{-jwt}dw. \quad (5)$$

Then, the signal can be recovered by wavelet transform, i.e.,

$$x(t) = \frac{1}{\sqrt{c}} \int_{0}^{+\infty} a^2 \int_{-\infty}^{+\infty} X(w)\varphi^*(aw)e^{-jwt}dadb. \quad (6)$$

The wavelet transform differs from the time-domain window of the short-time Fourier transform because only the position of the window on the phase plane time axis is affected, but it can affect not only the shape of the window but also the position of the window on the frequency axis. It is because the wavelet transform makes the sampling steps adjustable in the time domain for different frequencies that the wavelet transform has better properties compared to the Fourier transform [17].

The ZigBee protocol is divided into two modules, one is the physical layer (PHY) and MAC layer specifications defined by IEEE 802.15.4, and the other is the network layer (NWK), security layer, and application layer (APL) specifications proposed by the ZigBee Alliance. The ZigBee protocol stack collects the protocols of each of these layers, functionally implements them, and provides some APIs for users to call. The protocol stack adopts the idea of layering, each layer has different functions, and data is only transmitted between adjacent layers, which has many advantages; for example, if a part of the network protocol changes, it is enough to modify several layers related to it, instead of changing all layers. The coordinator is indispensable in wireless sensor networks; regardless of which topology the network uses, the coordinator is a must and must be unique. The coordinator is mainly responsible for establishing and maintaining the wireless network and allocating the computing power and larger storage space for its point joint network, so the golden expert function that is a must is all required for the coordinator to be indispensable from the structure and mesh topology. To join the network, the router is indispensable in the tree topology and mesh topology. There is no need to forward data, so there are no requirements for computing power and storage space, and full-function or semifunction equipment is used at will. Its main method includes forwarding data, because the router has a certain address space, and also being a parent node to accept child nodes plus to achieve multihop transmission of data. Expand the coverage radius and communication distance of the wireless sensor network. Since the router must forward data, it also must use full-featured equipment. The terminal node is mainly responsible for collecting and sending data and only passively accepts the parent node to join the network, without itself as the parent node and without forwarding data, so it does not require computing power and storage space and freely uses full-featured devices or semi-featured devices. The main purpose of building the network topology is to expand the coverage radius and communication distance of wireless sensor networks, as shown in Figure 2.

When the partial discharge amount reaches or exceeds this standard, the starting voltage value of partial discharge will take the effective value of the applied voltage, and when the partial discharge amount is lower than this standard, the extinguishing voltage value of partial discharge will take the highest value of the applied voltage.

$$M_{\lambda b}(\lambda, T) = C_1 \lambda^5 \exp\left(\frac{C_2}{\lambda T + 1}\right). \quad (7)$$

After the signal is transmitted to the material surface, it is received by the acoustic emission sensor attached to the surface and converted into an electrical signal; then, after signal amplification and other signal processing, the signal can be recorded and displayed by the instrumentation; find the characteristic parameters that can better characterize the material damage, and use certain data processing. Finally, the material damage is evaluated and interpreted according to certain evaluation criteria.

3.2. Real-Time Wireless Sensing Monitoring System Design. Ultrasonic sensors can convert the ultrasonic signal generated by the local discharge source into an electrical signal, which consists of a piezoelectric chip that can both transmit and receive ultrasonic waves. The spectrum of ultrasonic waves generated by different discharge types varies, and the ultrasonic signal inside the device is often small in amplitude, so the ultrasonic sensor is used for partial discharge detection; its operating frequency and sensitivity are important indicators of whether the sensor is good or bad. The partial discharge-generated ultrasonic signal value is concentrated in about 30 kHz, the ultrasonic sensor resonant frequency is also positioned at 30 kHz, and the bandwidth frequency is 10-200 kHz, so the choice is the PAC manufacturing D9241A-type sensor (sensitivity of -65 dBm and configured with a coupling agent); before using the sensor for detection, the coupling agent will be applied to the sensor head, to increase the chip and the device shell fit and reduce signal attenuation and external interference [18]. A sensor is shown in Figure 3; the connection cable used is the BNC-N-type RF coaxial shielded cable; the type of cable attenuation is small; high shielding performance, the applicable frequency band, stable performance, and the advantages are obvious.

The signal reception and processing module contain three acquisition systems. First, the signal acquisition unit of the industrial frequency signal can be obtained from the ordinary 220 V power supply, and through signal conditioning output, a certain amplitude of the periodic signal can provide the detection system with the synchronous reference phase and synchronous industrial frequency voltage over-zero point to achieve accurate phase calibration of the local discharge signal. Second, the ultra-high-speed synchronous acquisition system, according to the sampling bandwidth of the UHF sensor, uses an acquisition system with a maximum sampling frequency of 2 GS/s. The data storage form adopts the segmented acquisition method, that is, the UHF

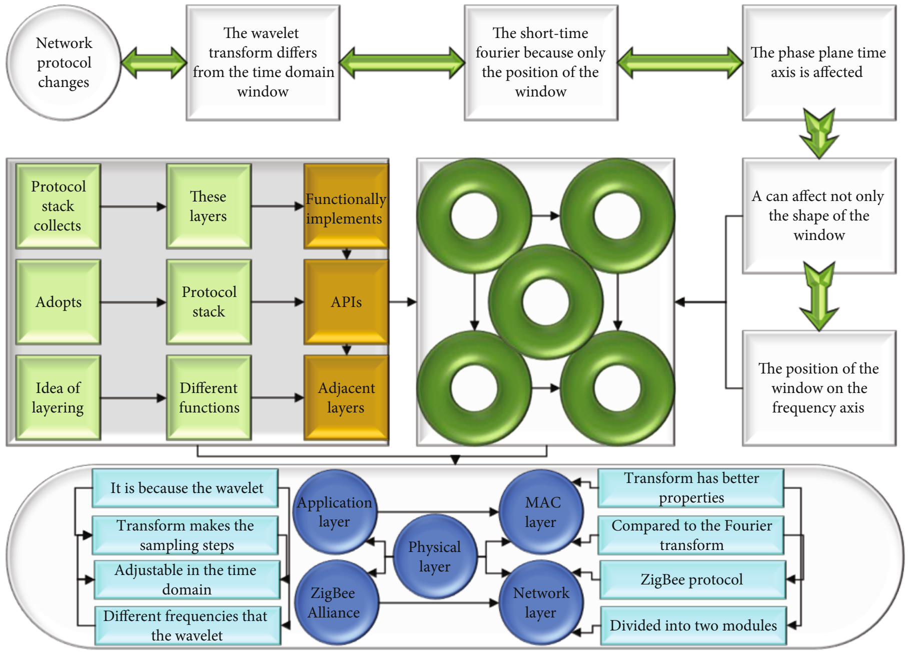

Figure 2: Protocol coincidence structure diagram.

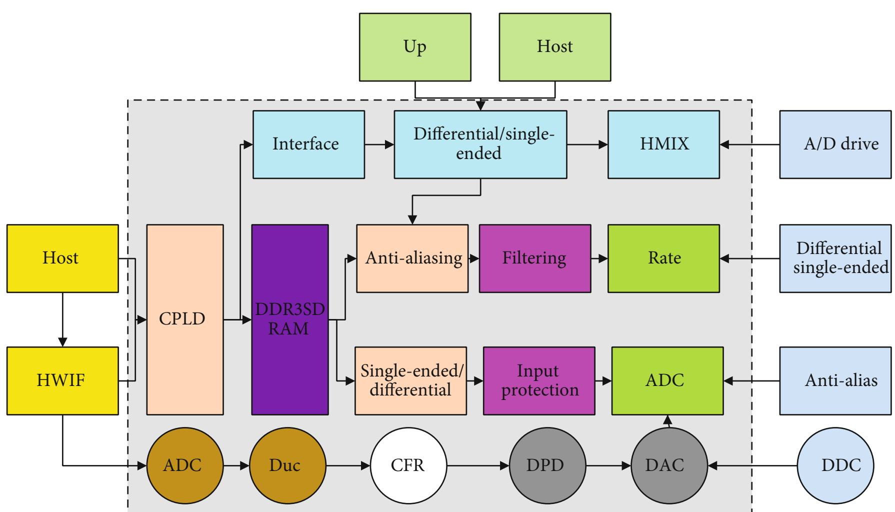

Figure 3: Test host schematic.

pulse signal coupled to the sensor itself as a trigger source to store the signal in segments, and then read out these UHF signals continuously through queuing technology. This approach reduces the storage space required by the acquisition system and enables continuous acquisition of the local discharge signals by using MS/s level sampling boards for reading data [19]. Third, the synchronous low-speed acquisition system is mainly used for the acquisition of synchronous voltage signals and ultrasonic local discharge signals at a maximum sampling rate of 2.5 MS/s. In addition, this system is also used as a synchronous system for the high-speed acquisition system to realize the synchronous acquisition of UHF signals and the phase calibration.

The function of the charged detection system for GIS partial discharge is to detect the UHF and ultrasonic local discharge signals inside the GIS equipment and display the signal waveforms in the system interface to provide a basis for analysis and diagnosis. Combined with the hardware design in the previous section, the software for system control and data acquisition and analysis is built on the LabVIEW virtual instrument platform, which mainly contains the parts of data acquisition control and data archiving storage, and historical data retrieval, as shown in Figure 4. The maximum sampling rate is 2.5 MS/s. In addition, the system is also used as a synchronization system for high-speed acquisition systems to realize the synchronous acquisition of UHF signals and achieve phase calibration.

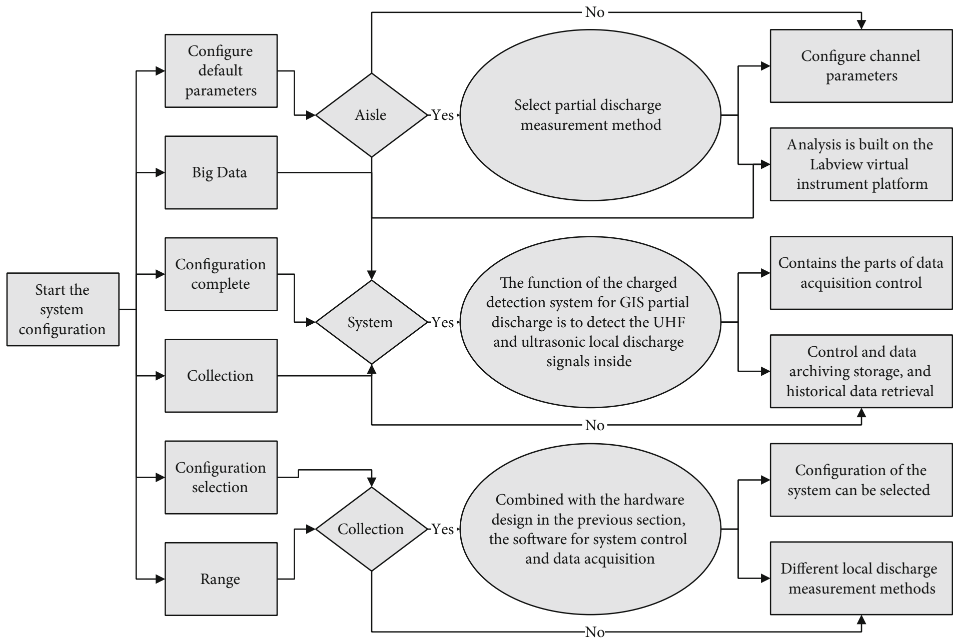

Figure 4: Flowchart of testing system configuration.

According to the actual situation on-site, the configuration of the system can be selected. According to the type of sensor used, different local discharge measurement methods can be selected, such as ultrasonic measurement, UHF measurement, and combined acoustic and electrical measurement. According to the measurement method selected by the user, the system can automatically correspond to the corresponding acquisition channel, while the user can select the parameters of the acquisition channel and the range of the detection data in the human-computer interaction interface. After the initial processing of the acquired data, the acquired local discharge waveform, the synchronous signal waveform, and the calculated local discharge pattern will be displayed on the interactive interface.

If partial discharge exists inside the power equipment, the coordinates of the partial discharge point are calculated by solving the hyperbolic equation using the time difference of the arrival of the acoustic signal to different sensors. The acoustic-acoustic localization method takes the first arriving acoustic signal as the reference and measures the time difference of the arrival of the same acoustic signal to each sensor to complete the localization of the partial discharge point [20]. The acoustic-acoustic positioning method is widely used for its simple principle, strong anti-interference ability, low design cost, and no need for a power outage. However, there are some unsatisfactory aspects of the acoustic localization method, such as the accuracy of the time delay estimation, the sensor position error, and the complex propagation of the acoustic signal inside the power equipment, which can cause some influence on the localization of the partial discharge point.

In the whole GIS local discharge UHF signal detection system, the role of the detector circuit is crucial. Due to the presence of high-frequency interference signals, the extraction of local discharge pulse signals requires a detector circuit to filter out the high-frequency portion of the signal. Its merit has a direct impact on the accuracy of detection. The logarithmic detector generally includes the matching circuit, logarithmic amplification, detector and buffer output, and other parts, of which the core part is the logarithmic amplification and detector. This detection system should be at least in the range of 0.3 GHz-1.5 GHz, which belongs to the ultrahigh frequency, and the detection process is to detect the envelope of the ultra-high-frequency signal, which is generally within 10 MHz, so the processing requirements for this wide dynamic range signal are much higher, and the general linear amplifier does not have the ability to process this signal [21]. Therefore, the processing requirements for such wide dynamic range signals are much higher, and general linear amplifiers are not capable of processing such signals, and the resolution must be ensured in the subsequent analog-to-digital conversion process. The best example of this is the logarithmic amplifier, whose most obvious feature is the variable gain.

Comparing demodulated logarithmic amplifiers, baseband logarithmic amplifiers, and basic logarithmic amplifiers, the basic logarithmic amplifier has excellent DC accuracy and a very wide dynamic range of up to 180 dB, but its AC performance is poor; the baseband logarithmic amplifier overcomes the former's poor AC performance and can respond quickly to rapidly changing inputs; the demodulated logarithmic amplifier has the nature of segmented linear approximation. The detector circuit in this system is a wideband detector, and the signal is demodulated using the contact detector technique. The detector and amplification will also be performed simultaneously in the modified system.

4. Analysis of Results

4.1. Real-Time Monitoring of Performance Results. The traditional monitoring means is to arrange several infrared cameras in the location to be monitored, as well as wiring in the substation to meet the data transmission requirements of the cameras, but because the wiring is cumbersome and the substation itself has a complex electromagnetic environment, wired data transmission will be affected to a certain extent, so the wireless transmission method is chosen; the infrared camera will be connected to a wireless router. Therefore, the wireless transmission method is chosen, and the infrared thermal imaging camera is connected to a wireless router to ensure that the back-end monitoring center is in the same LAN with it so that data transmission can be carried out conveniently, which greatly improves the security, remoteness, and real time of the infrared thermal imaging monitoring system for power equipment. The data collected by the front-end thermal imaging acquisition system is transmitted wirelessly to the back-end data processing and display module, and the monitoring client installed with the infrared thermal imaging online monitoring system software can realize the control function of the front-end thermal imaging acquisition system, and any computer in the same LAN can observe the front-end thermal images and data in real time and realize the alarm processing, recording, query, statistics, and detection data curve output of the monitored equipment data in each area through the online monitoring system software. The online monitoring system software can realize various functions such as alarm processing, recording, query, statistics, and output of testing data curves for the monitored equipment data in each area.

Real-time monitoring of the appearance and working status of transformers, the high-voltage circuit breakers and other important operating power equipment, and the surrounding environment in substations to ensure their normal operation always follows the principle of reliability in system design and hardware selection to ensure that the system can reliably play its maximum role; the operation of the infrared thermal imaging monitoring system is simple and easy to grasp, and the background monitoring personnel can be flexibly used and maintained, giving full play to all aspects of the function; flexible configuration of the condition monitoring system according to the requirements of the monitoring environment facilitates future system expansion; innovative use of wireless transmission for the transmission of monitoring data greatly abandons the disadvantages of wired transmission. The system can be flexibly configured according to the requirements of the monitoring environment so that the system can be expanded in the future; the innovative use of the wireless transmission method for monitoring data transmission greatly abandons the drawbacks of wired transmission, and it is easier to meet the actual requirements of the substation environment, as shown in Figure 5.

The radius of the mandrel has a small effect on the sensitivity of the fiber-optic ultrasonic sensor. This is because as the radius of the mandrel increases, the equivalent stiffness factor of the sensor increases, but so does its overall mass. The simultaneous change of the two will offset the effect on the center frequency of the sensor. In addition, the larger the mandrel radius, the better the modulation of the sensing fiber length by the mandrel deformation. However, the

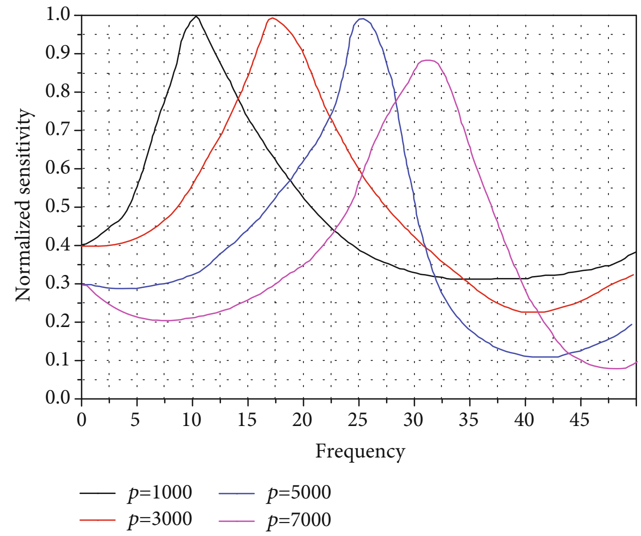

Figure 5: Effect of sensor sensitivity.

increase in the sensor equivalent stiffness coefficient reduces the radial deformation of the mandrel, and the combined effect on the sensing fiber length is smaller, so the effect of the mandrel radius on the sensor sensitivity is not significant.

In the design of GIS fiber-optic ultrasound sensors, it is advisable to choose a mandrel with a large Poisson's ratio and a small elastic modulus and density to obtain a higher sensitivity in the high-frequency band, and the center frequency can be regulated by optimizing the height of the mandrel. However, if the selected mandrel has a small modulus of elasticity, although a high peak sensitivity can be obtained, its center frequency is often low, and the prepared fiber-optic ultrasonic sensor is not necessarily suitable for GIS partial discharge detection considering the size constraint. To obtain high sensitivity in the frequency band around 40 kHz, the matching relationship between mandrel material and size needs to be considered in the actual design of fiber-optic ultrasonic sensors.

This detection system requires at least the device bandwidth within the range of 0.3 GHz-1.5 GHz, which belongs to the ultrahigh frequency. In the detection process, the envelope of the ultra-high-frequency signal is detected, generally within 10 MHz. When the voltage is increased to $U = 49.8$ kV, the responses of the GIS fiber-optic ultrasound sensor and PZT sensor are shown in Figure 6, respectively. It can be seen that in five working frequency cycles, under the same ultrasonic signal excitation, the maximum response amplitude of OFS is 19.9 mV, which is five times the background noise ($U = 0$ kV). And the PZT response amplitude is comparable to the background noise, which cannot discriminate the local discharge signal.

The reasons for the above signal characteristics are as follows. With the gradual increase of the applied I.F. voltage, the linear metal particles are subjected to small vibration by the electric field force, and the former can detect the small vibration signal of the linear metal particles due to the higher sensitivity of the fiber-optic ultrasonic sensor than the PZT

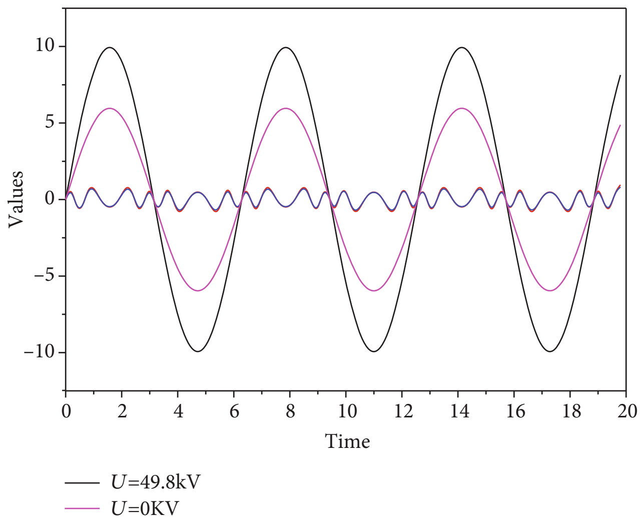

FIGURE 6: Sensor response.

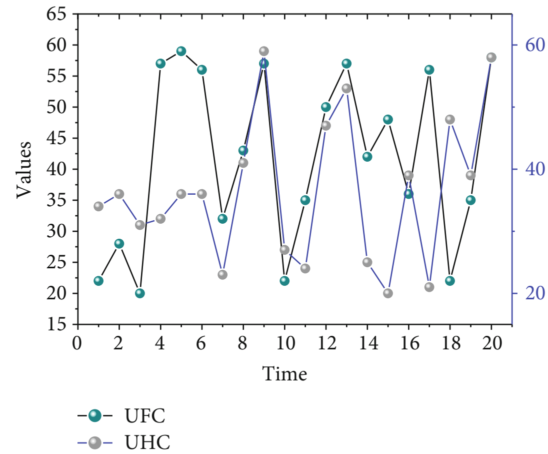

FIGURE 7: UHF amplifier gain effect.

sensor. When the frequency voltage increases further and reaches the starting voltage of the linear metal particles, the particles jump back and forth rapidly between the guide rod and the cavity wall and generate discharge when colliding. Due to the large collision signal, the fiber-optic ultrasonic sensor and PZT sensor can detect the large value signal at the same time, while the UHF sensor also detects the discharge signal. However, because the discharge current is very small, the partial discharge meter and high-frequency current sensor are unable to detect the discharge signal.

4.2. Real-Time Monitoring System Performance Results. To ensure the smooth operation of the sensor, it is also necessary to reduce the adverse effects of external factors, and one of the most important methods is to change the detection frequency. At the same time, to improve the sensitivity of the detection system, in addition to setting the frequency of UFC in a range (0.3 GHz~1 GHz), it is necessary to make sure that the UHF sensor equipped in the system is a UHF microstrip sensor and make use of its portable and compact characteristics to continuously amplify the collected UHF signal, and when it reaches 40 dB, the signal will be transmitted to the high-speed collection system. However, there are safety hazards in this process, so to reduce the hazards and increase the limiting function, the limiting circuit will be carefully investigated, especially the strong interference signals such as switching signals that need to be paid special attention to. The gain effect of the UHF amplifier involved in this system is shown in Figure 7.

HFCT internal core material can have a large impact on the frequency band of the module and even affect its frequency band range to some extent. The analysis of the common materials around will lead to many experimental conclusions and ideas to choose the most suitable material for the internal core. Ni-Zn ferrite is more stable and has the best response in response to the experimental analysis of the core frequency, and it has a high-frequency band. In this experiment, the NiZn ring with inner and outer diameters and lengths of about 100 mm was selected to do measurement practice using its characteristics, and it will be found from the experimental results to be highly sensitive as HFCT. The current measurement range is from 0 to 10 A, and the frequency band measurement range is from 1 to 40 MHz, and the response is good.

The UHF wave frequency and range were combined in the previous test, and the frequency band range was also considered in the AE sensor test. After debugging, it is possible to systematically process the collected signals of multiple types, frequencies, and speeds and to use 8 or more paths efficiently, quickly, and conveniently for signal upload at the same time. The maximum value of the frequency is set to 2.5 M/s during the collection process to suit the performance of the sensor. The system can be used to collect ultrasound signals and industrial frequency signals simultaneously in a segmented or continuous manner, as well as to determine the location of the local discharge source and have a strong function for phase calculation.

To analyze the GIS localization signal by the combined acoustic-electric method, the first step is to use UHF technology to roughly locate the localization source and receive both the high-frequency current and the AE signals. By comparing and processing the obtained data, we can effectively screen out the possible interference data in the GIS site, to improve the accuracy of localization of the local discharge source and the accuracy of defect-type discrimination. Therefore, when the system starts the analysis and processing operation, several UHF sensors should be equipped near the insulators of GIS equipment, and the appropriate number of AE sensors should be equipped on the outside of GIS equipment, and the HFCT module should be installed on the ground wire at the back of the cable. Finally, with the help of the local discharge analysis and processing equipment and high-speed oscilloscope equipment, the local discharge signals around the sensors are collected and sorted out to ensure the smooth operation of the local discharge source location and to accurately identify the defect type and insulation degree, as shown in Figure 8.

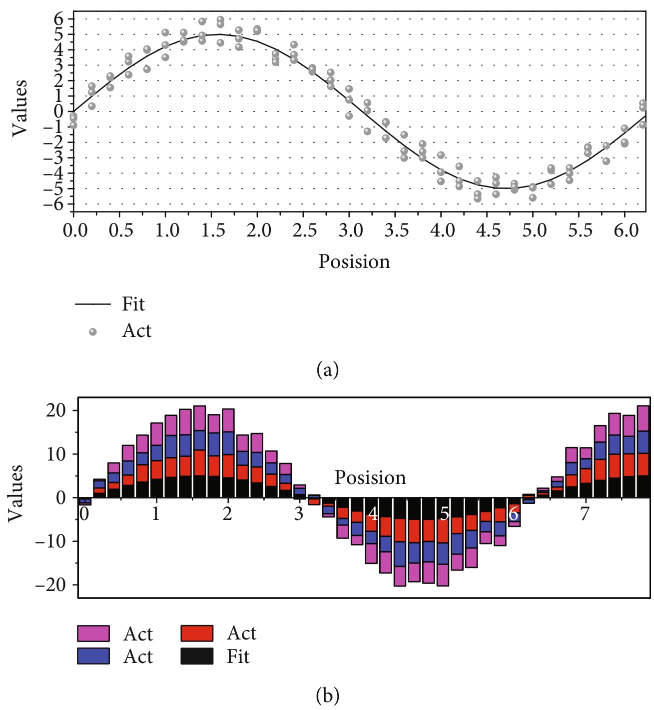

Figure 8: Phase detection results.

According to the UHF detection results, the signal amplitude of the UHF PRPS and PRPD patterns is very high, and the discharge phase is wide; both have typical characteristics of suspended potential discharge. From the ultrasonic detection, the RMS and peak values of the continuous spectrum grow very large compared with the background, and the correlation between 50 Hz and 100 Hz is obvious, and the 100 Hz correlation is much larger than the 50 Hz correlation, and the phase spectrum shows obvious two clusters, which has the typical characteristics of suspended potential discharge. According to the combined acoustic and electrical signal mapping, the ultrasonic signal and the UHF signal have a one-to-one correspondence in the working frequency cycle. The abnormal signal still exists during the live detection and retesting of the phase gas chamber, and the sound and electricity are combined to locate, and the abnormal discharge position is inside the casing riser (transition tank). According to the above analysis, combined with the typical discharge characteristics of various types of defects and the structure and installation characteristics of the HGIS, the internal defects of the gas chamber are judged to have suspended potential discharge defects, accompanied by metal particle discharge, according to the different characteristics of the test data and the graphs, to determine the nature of the defects and establish the effectiveness of the joint acoustic-electric diagnosis. After collecting data and graphical information on equipment anomalies, the purpose of applying the combined acoustic-electric detection means in partial discharge charged inspection to practical operation is achieved through the analysis of detection means, and experience is accumulated for future partial discharge charged inspection work. Based on theoretical analysis of the causes of equipment abnormalities, further accurate verification is done in combination with the disintegration of equipment, emphasizing the feasibility and sustainability of combined acoustic and electrical detection.

5. Conclusion

According to the requirements of online monitoring of GIS equipment in acoustic emission stores, the overall design of the GIS local monitoring system based on ZigBee technology is divided into three aspects, data acquisition, data transmission, and data processing. And the hardware design and software design in the three modules are introduced separately. The hardware design includes choosing CC2530 as the ZigBee chip and GZ-GISSEN-01 digital UHF local area discharge sensor as the sensor and designing their related circuits, such as the power supply circuit, serial communication circuit, and sensor circuit. The software design includes the design of the terminal node and coordinator node. And the typical patterns are obtained by using the UHF method and ultrasonic method for detection, and the characteristics of each typical pattern are summarized. And various interference signals were studied to obtain several interference signal profiles, and the type of interference signal was determined by comparing the profile characteristics during the background noise test, and the corresponding shielding measures were used to shield the interference source and improve the accuracy of detection. Three examples of partial discharge charged detection of field equipment were selected, and the abovementioned GIS partial discharge charged detection system was used for testing, and the testing process and processing scheme of partial discharge were analyzed, and the partial discharge source was identified and accurately located, and the application in practical operation was summarized to provide a reference basis for future electrical detection work.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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