Research on High Voltage Online Monitoring System for Dielectric Loss of Capacitive Equipment in Substation

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Abstract. The paper introduces the principle of on-line monitoring of the dielectric loss factor of capacitive equipment and the composition of the monitoring system. It explains the software-based mathematical analysis method and harmonic analysis method, and uses DSP for digital filtering. At the same time, the paper establishes an intelligent auxiliary monitoring terminal in the substation, uses the equipment ADP+ equipment protocol library to dynamically connect to various auxiliary monitoring equipment, uses signal frequency conversion sampling, alarm recording and other acquisition strategies to extract key equipment operation information, and hierarchically redundant storage data. Improve the real-time monitoring level of operating equipment and reduce the cost of operation and maintenance.

Keywords: Dielectric loss, online monitoring system, harmonic analysis, digital filter, Fourier transform.

1. Introduction
The safe operation of high-voltage electrical equipment is an important factor that affects the safety, stability, and economic operation of the power system. An accident in high-voltage electrical equipment will not only cause damage to the equipment itself, but also cause many losses. In order to monitor the insulation status of capacitive equipment, it is necessary to extract the ground current signal at the end of the equipment. In order not to change the original wiring method of the tested primary equipment, the ground wire of the tested equipment is widely used with active or passive through-core current transformers. Or the final screen is directly connected to the monitoring capacitor to extract the leakage current of the high-voltage power equipment insulation, but the through-core current transformer is susceptible to temperature, input current and load changes, making the angle difference and the ratio difference unstable; the monitoring capacitance method is due to capacitance After being broken down, it is easy to cause the final screen to open. Therefore, the dielectric loss measurement method widely uses digital measurement technology, and then adopts the corresponding filtering algorithm for the sampled value [1]. This article first introduces the composition of the capacitive equipment online monitoring and fault diagnosis system, and makes a more detailed analysis and comparison of existing dielectric loss monitoring methods. At the same time, it analyses the reasons for the unsatisfactory operation of the online monitoring system that has been put into operation. Related suggestions.
2. Capacitive equipment monitoring content and system composition

2.1. Monitoring content
The dielectric loss tangent value $\tan \beta$ is the dielectric loss factor, which is a characteristic quantity that reflects the degree of dielectric loss of the insulation. It depends on the characteristics of the material and has nothing to do with the size, size and shape of the material. Therefore, $\tan \beta$ can be used as a parameter to reflect the insulation status of the equipment. Measuring dielectric loss can discover hidden accidents in time and improve the safety and effectiveness of the system. In addition, the current I flowing through the medium and the capacitance of the medium can also reflect the insulation status of the equipment [2]. Therefore, $\tan \beta, I, C$ is usually used as the main monitoring content of capacitive equipment.

2.2. System integration method
System integration involves multiple data resources: data access of various auxiliary monitoring equipment, video monitoring systems, account docking of various equipment, unified user authentication systems, expert analysis systems, etc. How to integrate many resources to form a unified whole and provide a unified service is one of the main difficulties in the research. After the system is integrated, how to extract and analyse data for so much information to provide users with effective information and convenient applications is the key to platform construction. The classification of online monitoring and auxiliary equipment is shown in Table 1.

Table 1. Classification table of online monitoring and auxiliary equipment

| classification                   | List                                                                 |
|----------------------------------|----------------------------------------------------------------------|
| Equipment online monitoring      | GIS gas density, oil chromatography, lightning arrester leakage current, arc suppression coil, capacitive equipment, partial discharge and other online monitoring equipment |
| Public equipment monitoring      | DC system, battery, DC grounding monitoring, AC system               |
| Power quality monitoring         | Power quality monitoring, voltage monitoring                         |
| Environmental Security Monitoring| Video monitoring, ambient temperature, humidity, perimeter prevention, access control, water pump, fire and theft prevention, air conditioning, SF6 monitoring |

The overall idea of unified integration is to use OGSA grid technology to effectively integrate various resources to form a unified whole, use hierarchical storage and hierarchical application strategies to classify and summarize many data, and provide differentiated services for various personnel and roles. Convenient application [3].

2.2.1. System composition. The monitoring system generally includes the following basic units: a) Signal transmission unit. The sensor detects the characteristic quantity reflecting the state of the equipment under test, converts it into a suitable electrical signal and transmits it to the subsequent unit. It has the function of observing and reading the monitoring signal. b) Signal processing unit. The signal sent by the sensor is pre-processed, the signal amplitude is adjusted to a suitable level, and interference is suppressed to improve the signal-to-noise ratio. c) Data acquisition unit. The signal sent by the sensor is pre-processed, interference is suppressed, and the analogy-to-digital (A/D) conversion and acquisition record are performed. d) Information transmission unit. The data obtained by the data acquisition unit is transmitted to the subsequent unit. e) Data processing unit. Process the transmitted signal. Such as suppressing interference, extracting characteristic values, etc., to provide effective data...
for diagnosis. f) Diagnostic unit. Analyse and compare the data, historical data, criteria, procedures and operating experience of the data processing unit. Judge the status of the equipment and the location of the fault in order to take maintenance measures [4]. The entire monitoring system can be summarized into three subsystems, namely the monitored equipment and sensors in the field, the signal pre-processing and data acquisition subsystem, and the signal processing and diagnosis system.

2.2.2. Multi-point homogeneous distributed service architecture. The system integration adopts the OGSA grid system concept, uses SOA to abstract many involved resources into services, and uses Web Service unified interface and data exchange format to form a comprehensive system application through the combination and interaction between services. Each service is independent, layered deployment, and completely loosely coupled, and can be upgraded and maintained independently without affecting the application of other functions. Register services through service management and dynamically configure business logic through Call Flow, a service invocation process, to form various applications. The multi-point homogeneous distributed service architecture guarantees uninterrupted application services and guarantees the continuity and stability of real-time monitoring: when the monitoring system or network fails, the intelligent terminals coordinate with each other and automatically select an intelligent terminal to take the lead Station function, receiving the alarm information of each station, the main station system automatically switches to a certain intelligent terminal, providing users with normal operation monitoring applications [5]. The distributed service architecture is shown in Figure 1.

![Figure 1. Distributed service architecture](image_url)

2.2.3. Data hierarchical redundant storage. To ensure data security, all data are redundantly stored in the intelligent terminal and master station system. At the same time, taking into account the effective use of system resources, all data is collected, compressed, and synchronized. Data storage is stored in real-time tables, 24h tables, and historical tables. Different information (alarms, status, monitoring data) is collected according to classification, and different collection strategies are adopted. Alarm information, status information, monitoring data, and statistical information are stored and summarized in categories. Each site saves the collected data independently, the status information and alarm data are summarized in the auxiliary monitoring system in real time, and the historical data and statistical information are regularly synchronized with the provincial auxiliary monitoring system. The auxiliary monitoring system can trace the collected data of the substation [6]. The intelligent terminal and auxiliary monitoring system of each substation can operate independently, and the failure of either end will not affect the use of other nodes. as shown in picture 2.
3. Establishment of dielectric loss monitoring model of wavelet transform and adaptive online filtering

In order to better solve the influence of frequency fluctuations on the actual system and effectively extract the fundamental signal, an online filtering model of digital low-pass filter based on wavelet transform and adaptive neural network is established. Through adaptive neural network real-time training of wavelet decomposition parameters, the difference between the actual input signal and the desired signal decomposition coefficient tends to zero, achieving the effect of spectrum leakage caused by odd harmonic signals, white noise, frequency changes, and switching power supply pollution to the power grid Inhibition of interference signals. The filtering model is shown in Figure 3.

\[
2 \sum_{i=0}^{m} e_i^2 = \min
\]

In Figure 3, \( x(k) \) is the input signal and \( d(k) \) is the desired signal. The objective function \( 2 \sum_{i=0}^{m} e_i^2 \) is established to minimize it, and the adaptive filter matrix is trained to use 

\[
[x(k) - d(k)] \rightarrow 0
\]

to obtain the wavelet decomposition coefficient \( F_i(k), F_i(k), ..., F_{m-1}(k) \). In the training process, the adaptive filter matrix adopts a diagonal matrix and a normalized LMS algorithm, namely

\[
e_i(m) = d_i(m) - \omega_i^e(m) \mu_i(m)
\]
\[ \omega_i(m+1) = \omega_i(m+1) + \frac{2a \mu_i(m)}{\gamma + N_i^2(m)} \]  

(2)

The correlation function method uses auto-correlation function and cross-correlation function to calculate the dielectric loss angle. The principle of the algorithm is briefly described as follows. Suppose the current signal and voltage signal are as follows:

\[ i(t) = A \sin(\omega t + \varphi_i) \]

\[ \mu(t) = B \sin(\omega t + \varphi_\mu) \]  

(3)

Let \( R_u(0), R_c(0), R_u(0) \) be the autocorrelation function of the voltage signal, the autocorrelation function of the current signal, and the cross-correlation function of the voltage signal and the current signal, respectively. The dielectric loss angle is:

\[ \delta = \frac{\pi}{2} - \left( \varphi_i - \varphi_\mu \right) = \frac{\pi}{2} - \arccos \left( \frac{R_u(0)}{\sqrt{R_u(0) R_c(0)}} \right) \]  

(4)

The correlation function method can better solve the problem of spectrum leakage when FFT is sampled in a non-full period, but it has higher requirements for the pre-band pass filter. Some scholars use the parabolic interpolation formula to construct the interpolation function to calculate the correlation function. Simulations have proved that this method can reduce the error of discrete integration. Aiming at the problem that the correlation function method produces large errors during non-periodic sampling, a method of obtaining a full-period signal based on the same direction zero crossing and sampling linear interpolation to correct the integration interval is proposed, which reduces the dielectric loss measurement error caused by non-periodic sampling [7].

4. Analysis of experimental results

In order to verify the accuracy of the front-end device measurement of the designed online monitoring system, the system was simulated under laboratory conditions. The experimental circuit is shown in Figure 4. In the experiment, the power supply was taken from 220V mains, and the single-phase experiment was carried out. The leakage current of the capacitive test sample is connected to the measurement circuit of the lower computer through the current sensor output. After adding a resistor in series with the voltage of the test sample, it is connected to the other input terminal of the measurement circuit of the lower computer through the voltage sensor output. The dielectric loss factor of the capacitive sample measured by the bridge method is 0.6065\%.
Figure 4. Measurement simulation experiment circuit

It can be seen from the experimental results that when the power grid frequency fluctuates, the measurement results change little and are relatively stable, indicating that the measurement results are less affected by frequency fluctuations. In the range of 49.4Hz-50.5Hz, the change of dielectric loss factor is less than 0.0318%, and the relative error is less than 5.25%, which has little effect on the measurement results of dielectric loss factor.

5. Conclusions
This article introduces the principle of online monitoring of dielectric loss factor and the composition of the system. The big data analysis method is used to realize real-time digital filtering, and multiple cosine window interpolation algorithms are used to modify the FFT transform. The factors that affect the measurement results are analysed, and some solutions are proposed to improve the accuracy of online measurement results.

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