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

Yun Guo*, Minhu Xu, Hang Zhang, Rui Zhang, Kexin Zhang and Yang Zhou

State Grid Heilongjiang Electric Power Co., Ltd. Electric Power Research Institute, Harbin 150040, China

*Corresponding author email: yunguo2020@sgcc.com.cn

Abstract. In view of the remote collection of voltage and current in the online monitoring system for dielectric loss of high-voltage capacitive equipment in substations, it will lead to the problem of difficult to guarantee collection synchronization and large data transmission. The paper cleverly borrows AC 220V voltage as the reference phase, current and voltage monitoring terminal Calculate the phase relationship between the current, voltage and the reference phase of the capacitive device, and send it to the master station as an intermediate result. The master station calculates the dielectric loss of the capacitive device and forms a demand report. This method avoids the problem that the current and voltage acquisition is difficult to synchronize, and can greatly reduce the system cost and the amount of transmitted data. Because the terminals are calculated separately, the real-time performance of the monitoring system is improved.

Keywords: High voltage equipment, dielectric loss, reference phase, online monitoring.

1. Introduction

With the advancement of advanced sensor technology, computer technology and optical fibbers communication technology, the development of modern power industry has got rid of the limitations of previous technical conditions, relying on the non-stop online monitoring of the insulation of high voltage equipment to replace the traditional offline monitoring that is out of the actual operating environment In this way, it has greatly promoted the application and popularization of synchronous online monitoring and diagnosis. Various dielectrics or insulating materials under voltage have energy loss. The dielectric loss will cause the insulation temperature to rise and accelerate the aging of the insulating material. Therefore, the size of the dielectric loss is an important indicator to measure the insulation level of capacitive electrical equipment. Because high-voltage capacitive equipment is not concentrated in the substation, but scattered in different voltage levels [1]. Generally, only current can be collected at high-voltage capacitive equipment, while the grid voltage can only be collected by a voltage collection terminal after installing a PT near the transformer. This results in the collection of capacitive equipment voltage and current in different places. When monitoring the dielectric loss of high-voltage capacitive equipment, synchronous acquisition of voltage and current signals is required, so the synchronization of acquisition becomes the key.
2. The principle of dielectric loss factor measurement

2.1. Measuring principle of zero-crossing comparison

The zero-crossing comparison method is also called the phase-detection method, which converts the measured zero-crossing point time difference of two sine waves into a phase difference according to the sine wave frequency to obtain the phase $\varphi(x)$ of two sine waves of the same frequency. In the above process, the accuracy of the angular frequency $\omega$ or period $T_s$ of the high-voltage power supply is critical to the accuracy of $\varphi(x)$ calculation [2]. The software design of this measurement method is simple and clear, and it is highly dependent on the hardware design. The single-chip system is required to achieve the same cycle $T_s$ measurement while completing the reading of the count value $N_c$ to avoid the introduction of measurement results due to the frequency drift of the high-voltage power supply. Big error. The block diagram of the measurement principle of the zero-crossing comparison method is shown in Figure 1. It is known that $U''_x, I'_x$ is the effective value of the sampling voltage and current of the test sample, $K_1, K_2$ is a constant, and the capacitance $C_x$ of the test sample is:

$$C_x = \frac{I_x \sin \varphi_x}{\omega U} = \frac{K_1 I'_x \sin \varphi_x}{K_2 \omega U'}$$  \hspace{1cm} (1)

Where:

$$\varphi_x = \omega \left( N, T_s / 2 \right) = \frac{2\pi N T_s \left( \text{rad} \right)}{2T_s} = \frac{360 N T_s \left( \circ \right)}{2T_s}$$  \hspace{1cm} (2)

![Figure 1. Block diagram of measurement principle of zero-crossing comparison method](image)

The principle of zero-crossing comparison method is shown in Figure 2. First, the sensor in the sampling circuit is used to capture the zero-crossing points of the current and voltage signals, and then the collected signals are converted into square wave pulse signals through certain logic. The phase
difference of the voltage and current signals can be characterized by the pulse width, and finally the square wave is measured. Width and convert to get the dielectric loss of the tested sample [3]. The key of the zero-crossing comparison method is how to accurately capture the zero-crossing points of the voltage and current signals, and then realize the high-precision conversion from the AC signal to the square wave signal.

2.2. Absolute measurement principle
When the insulation deterioration of the high-voltage bushing occurs, its fault characteristics are increased on the one hand; on the other hand, it is manifested as a short circuit of one or more layered capacitors, leading to an increase in \( C \). This method extracts the voltage vector \( U \) of the high-voltage bus and the voltage vector \( U_1 \) of the voltage divider capacitor at the end of the casing, and calculates the angle \( \tan \theta \) of the two. Since \( C_i \geq C \) is approximately \( \tan \delta \geq \tan \theta \), the value of dielectric loss factor \( \tan \delta \) can be indirectly calculated by measuring \( \tan \theta \), namely:

\[
\tan \theta = \frac{\omega C_CR}{C_i + C} = \frac{\omega CR}{1 + C_i/C_i} \approx \frac{\omega CR}{C_i} = \tan \delta
\]  

(3)

Where \( \delta = 90^\circ - \phi_x \).

3. On-line monitoring system design of equipment dielectric loss

3.1. Overall design
The system is designed as a modular hierarchical structure. The first layer is the collection terminal layer, which is composed of multiple capacitive device current collection terminals and one grid voltage collection terminal to complete data collection, intermediate data generation, processing and upload; The second layer is the central station layer, which is composed of central computers, which completes data processing and generates final data, charts and logs for management personnel’s reference; the system parameters can be configured; the final result is released; the third layer is the client Layer, composed of client computers, exchanges data with the power customer service management platform through protocols, which is convenient for maintenance personnel to monitor. The main research here is the terminal layer and the central computer layer, and only the first layer is designed [4].

3.2. Capacitive device current collection
The current collection terminal is designed to simultaneously collect the current of the nearby A, B, and C compatible devices and the voltage of the 220V AC power supply in the substation. The electrical connection diagram of the current collection terminal is shown in Figure 3. The current collection terminal is designed with Arm high-speed single-chip microcomputer, 6-channel synchronous 16-bit A/D converter and wireless transmission module. CT adopts zero magnetic flux current transformer with phase delay and extremely small dispersion.
3.3. Grid voltage acquisition

The voltage acquisition terminal is designed to simultaneously acquire the voltage signal converted by the three-phase PT near the transformer and the voltage of the 220V AC power supply in the substation. The electrical connection diagram of the voltage acquisition terminal is shown in Figure 4. The voltage acquisition terminal is designed with Arm high-speed single-chip microcomputer, 6-channel synchronous 16-bit A/D converter and wireless transmission module.

4. On-site monitoring extension design

4.1. Hardware design

The on-site monitoring extension obtains the current analogy quantity of the capacitive device, and divides it into two channels. After amplifying, compensation and other processing, one way is sent to the field programmable gate array (FPGA) internal frequency measurement logic to complete the signal frequency measurement; the other the routing high-precision A/D converter is converted into a digital quantity, sent to the FPGA, processed by the Naos II data processing unit, and transmitted to the computer workstation in the main control room by the communication module in Zigbee transmission mode. The monitoring terminal has a self-check function. When the self-check function is activated, the signal selection module switches to the power frequency signal generator, and Naos II processes this signal. Motorola M12+GPS is used to achieve precise synchronization between each monitoring station [5].
4.1.1. Leakage current sensor. Taking into account the actual situation of on-site installation and safe operation, an electromagnetic core-through small current sensor was developed. The permalloy with high initial permeability and low loss is used as the core, and deep negative feedback technology is adopted to realize fully automatic compensation of the core. Make the iron core work in an ideal zero magnetic flux state [6]. The sensor can accurately detect power frequency currents from 100μA to 700mA. The phase conversion error is less than or equal to 0.01°, no correction or modification is required. The same as all equipment, the interchangeability is extremely strong. It has excellent temperature characteristics and electromagnetic field interference capability, which fully meets the accuracy of equipment sampling under complex power station site interference.

4.1.2. A/D sampling design. Control A/D to complete synchronous high-speed integer multiple signal sampling and frequency measurement of industrial frequency signals, which requires high-speed equipment to control. In terms of high-speed data acquisition, FPGA has the unmatched advantages of single-chip microcomputer and digital signal processing (DSP), such as high clock frequency, small internal delay, all control logic completed by hardware, fast speed, high efficiency, and flexible composition. Therefore, FPGA device EP1C6Q240C8 of ALTERA company is selected in this design to realize real-time sampling control of A/D conversion chip ADS8505 and measurement of power frequency voltage frequency, and complete data buffering, processing, and transmission functions [7]. Use the development software Quartus II provided by ALTERA company for logic design. Under the Quartus II platform, use the ultra-high-speed integrated circuit hardware description language (VHDL) to design the power frequency measurement module and the logic control timing of A/D sampling.

4.2. Software design
The main function of the on-site monitoring extension software is to synchronize data collection according to the central command, and then package and upload the data through Zigbee wireless communication. The system is equipped with manual self-checking and real-time acquisition functions, and is triggered by interrupt mode. The main program flowchart is shown in Figure 5. In the figure, pips represent a pulse signal with an interval of 1s.

![Figure 5. Main program flow chart](image)

5. System Monitoring
Use the Swiss 2811 electric bridge to detect the AI-6201 dielectric loss factor standard device, and the AI-6201 dielectric loss factor standard device applies signals to the signal acquisition port of the test product, a total of 25 times, the interval time is 60s, and the test product is within the technical specifications the performance is normal. The test data is shown in Table 1. Compared with the initial
measured value of the dielectric loss of the same phase equipment, the variation range is ≤±0.3%, which meets the system design requirements.

### Table 1. Test data

| Dielectric loss device indication value | Test product error value | Dielectric loss device indication value | Test product error value | Dielectric loss device indication value | Test product error value |
|----------------------------------------|--------------------------|----------------------------------------|--------------------------|----------------------------------------|--------------------------|
| 0.005                                  | 0.0014                   | 0.09                                   | 0.000167                 | 0.8                                   | 0.002229                 |
| 0.01                                   | 0.001828                 | 0.1                                    | 0.001938                 | 0.9                                   | 0.002278                 |
| 0.02                                   | 0.000927                 | 0.2                                    | 0.001731                 | 1                                     | 0.001844                 |
| 0.03                                   | 0.000399                 | 0.3                                    | 0.000917                 | 3                                     | 0.00193                  |
| 0.04                                   | 0.000577                 | 0.4                                    | 0.000184                 | 5                                     | 0.002317                 |
| 0.05                                   | 0.002008                 | 0.5                                    | 0.000928                 | 7                                     | 0.000517                 |
| 0.06                                   | 0.000249                 | 0.6                                    | 0.002229                 | 9                                     | 0.000274                 |
| 0.07                                   | 0.001562                 | 0.7                                    | 0.001036                 | 10                                    | 0.001159                 |
| 0.08                                   | 0.000473                 |                                        |                          |                                        |                          |

### 6. Conclusions

The synchronous data collection dielectric loss monitoring system covers the entire monitoring range. Due to the strict synchronization of data collection, the large technical difficulty, the large amount of communication data, and the harsh electromagnetic environment of the substation, it is necessary to build an optical fibbers communication network, which leads to an increase in system cost. This paper attempts to discuss the design of the online monitoring system for dielectric loss of capacitive equipment in substations by analysing the structure. Capacitive mechanism equipment has an important practical application position in high-voltage substations. This research paper is on the online monitoring of dielectric loss of capacitive mechanism equipment. The system has been analysed and designed in detail, and significant results have been achieved, which can be widely replicated and applied.

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