Calibration Method of Capacitive Equipment Charged Detection Device

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Abstract. On the basis of studying the principle of charged detection of capacitive equipment, a calibration method of charged equipment for capacitive equipment based on high voltage and low voltage is put forward in this paper, and the calibration system of charged equipment detection device is designed and developed. Through the calibration experiment research, the feasibility of the calibration method of the capacitive detector is verified. Through the research of this paper, the problem of calibration test of capacitive equipment charged detection device is solved, and the actual problems in the field are solved, which provides the guarantee for the safe and stable operation of power grid.

Introduction
The substation equipment is classified according to the insulation structure. The large equipment is a capacitive insulation structure, and the equipment is well used in the substation of the power network. Under normal condition, the measurement of capacitive equipment can monitor the concentration or integrity defects of the insulation devices of substation equipment, and it is convenient for the staff to identify and solve the problems in a timely manner[1~4].

At present, a variety of content detection technology equipment manufacturers diversity, testing equipment, quality is uneven, the accuracy of volume detection system to ensure the equipment needed, measurement error, for the capacitive equipment detection system performance of anti-harmonic interference index calibration, the researchers are actively exploring the calibration method. The capacitive equipment charged monitoring principle, calibration principle of capacitive equipment on-line detection device, calibration system of capacitive equipment charged detection device and capacitive equipment charged detection device calibration work on the four aspects of experiment.

Detection Principle of Capacitive Device
The measurement principle of capacitive equipment features is first obtained by capacitive equipment sensor when the voltage and current signals, the waveform acquisition technology will be the data from the time domain or frequency domain into digital waveform discrete signals, using two discrete digital signal through discrete waveform the Fourier transform technique and computer accordingly, so as to calculate the two fundamental signal, then push phase have derived two fundamental difference, finally infer the dielectric loss tangent of capacitive equipment. As shown in Figure 1 below, the current flowing through the capacitive device is used to indicate the operating voltage on the capacitive device.
The periodic signal is expanded by Fourier series. It needs to meet the Dirichlet condition, the first function is continuous at any interval, or there is only a finite discontinuity points of the first kind; function requires absolute integral in a unit can cycle; at the same time in a cycle, only a limited maximum function and the minimum. To meet the above requirements, the voltage and current flowing through the capacitive device can be rapidly decomposed into the sum of the DC and each harmonic part by Fourier series:

\[
\begin{align*}
    u_x &= U_0 + \sum_{k=1}^{\infty} U_{k\alpha} \sin(k \omega t + \alpha_k) \\
    i_x &= I_0 + \sum_{k=1}^{\infty} U_{k\beta} \sin(k \omega t + \beta_k)
\end{align*}
\]

In the formula, \(U_0\) — the direct component of voltage, \(U_{k\alpha}\) — the magnitude of each harmonic of the voltage, \(I_0\) — The direct component of current, \(U_{k\beta}\) — the magnitude of each harmonic of a current, \(\alpha_k\) — the phase angle of each harmonic of the voltage, \(\beta_k\) — the phase angle of each harmonic of the current, \(k=1, 2, 3, 4 \cdots \infty\).

The phase angle of the fundamental wave of the voltage is derived by the formula (3):

\[
\tan \alpha_1 = \frac{\int_0^T u_x \cdot \cos \omega t \cdot dt}{\int_0^T u_x \cdot \sin \omega t \cdot dt}
\]

Phase angle of current fundamental wave beta \(\beta_1\):

\[
\tan \beta_1 = \frac{\int_0^T i_x \cdot \cos \omega t \cdot dt}{\int_0^T i_x \cdot \sin \omega t \cdot dt}
\]

For capacitive devices, the voltage lags behind the current by an angle of 90 degrees. Therefore, the tangent of the dielectric loss angle:

\[
\tan \delta = \tan[90^\circ - (\beta_1 - \alpha_1)]
\]

Therefore, by using the discrete Fourier transform method for amplification circuit, the sensor for the voltage \(u_x\) and current \(i_x\) are decomposed, and then according to the above formula (3), (4) and (5) to calculate the tangent and dielectric loss angle value of capacitive equipment.

**Calibration Method of Capacitive Equipment Charged Detection Device**

(1) High voltage calibration method

The high voltage test circuit consists of testing power supply, high voltage transformer, high voltage capacitor, high voltage dielectric loss analog device and high precision voltage transformer. Among them, high dielectric loss simulation instrument can mimic the corresponding dielectric loss factor values, by adjusting the voltage test can simulate different output current, the capacitor can be changed by changing the electric capacity through certain parameters can simulate the full collocation, current range, dielectric loss and capacitance value. When the test voltage sampling interface is arranged in the high precision voltage transformer, current sampling interface setting simulation
instrument in high voltage dielectric loss, standard measuring equipment and online monitoring device is to test their collection of reference voltage and current signals from the voltage and current sampling interface, both measured and the standard measuring equipment shown in value showing the value standard, the condition monitoring instrument for measuring the dielectric loss and capacitance and current error value.

High pressure calibration method is through the use of simulation of the tested product, capacitor, voltage reference analog equipment, simulation equipment to simulate the dielectric loss of capacitive equipment working state of each voltage signal and current signal, we also use the method of relative and absolute method, and the dielectric loss and the charged detection device, the results were compared. The basic principle of the high voltage method is shown in Figure 2.

![Figure 2](image)

**Figure 2.** The basic principle of the high voltage method.

(2) Low voltage calibration method

The low voltage analog test circuit consists of a standard signal generator and a standard measuring instrument. In the circuit, the standard signal generator can output two frequency signal with phase values and not the same as the current (voltage) value, current and phase measurement standard instrument can accurately measure the two frequency difference of signal, and the calculated dielectric loss factor and capacitance equivalent. At the time of testing, using current and voltage sampling interface, transmits the data to the standard measuring instruments issued standard signal generator and the measured on-line monitoring instrument, both measurement error by state monitoring device for measurement of dielectric loss factor and capacitance and current values.

The working principle of low voltage calibration method is the use of a standard voltage current signal generator, the generator is used to simulate the voltage and current signal of the actual work of capacitive equipment used, standard voltage current signal generating device of the device will have relative dielectric loss to simulate the voltage and current signals for measurement of the simulation test signal. The low voltage calibration method is shown in Figure 3.
Calibration System of Capacitive Equipment Charged Detection Device

The calibration system of capacitive equipment is mainly composed of test control operating platform, test transformer, analog reference test capacitor, and analog capacitor. The test control console by variable frequency power supply, relative dielectric loss and capacitance tester, dielectric loss and resistance current simulation device, relative dielectric loss simulation signal generator and a computer with computer composition; relative dielectric loss and capacitance tester is composed of capacitance and dielectric loss function; dielectric loss simulation device is composed of dielectric loss simulation device, a reference voltage analog device and resistive current component simulation device; the industrial computer is of many function modules are controlled and read monitoring data using the serial port, all the measurement can be controlled by computer. Physical drawing of calibration system for capacitive equipment charged detection device, as shown in figure 4.

Calibration Test of Capacitive Equipment Charged Detection Device

Taking a company AI-6000R capacitive equipment as an example, the test of measurement error and the performance of anti-harmonic interference are carried out. The object of the device is shown in figure 5. :
(1) Measurement error test

1) For capacitive equipment insulation detecting device to carry out error test with a low pressure, 3 parameters of provisions to deal with the current signal, inspection instrument of dielectric loss factor and capacitance of 3 parameters were measured in each test error, measuring range selection of a plurality of measuring pilot measurement. The formula of measurement error (6) is as follows:

\[
\text{Measuring error} = \text{measuring value of charged measuring instruments} - \text{standard tester measurements} \quad (6)
\]

2) Selection principle of measuring points: A total of 6 measuring points, including the minimum detection limit, the maximum detection limit, and 4 other measurement points, are selected within the range of inspection instruments. The test data are shown in Table 1.

| Minimum detection limit | Measuring point 1 | Measuring point 2 | Measuring point 3 | Measuring point 4 | Maximum detection limit |
|-------------------------|------------------|------------------|------------------|------------------|------------------------|
| standard value          | 0.000\%          | 0.10\%           | 1.00\%           | 10.00\%          | 50.00\%               |
| measured value          | 0.002\%          | 0.103\%          | 1.003\%          | 10.01\%          | 50.01\%               |
| measurement error       | +0.002\%         | +0.003\%         | +0.003\%         | +0.01\%          | -0.11\%                |

| conclusion               | Meet the requirements |

(2) Performance test against harmonic interference
The insulation detection instrument of capacitive equipment, applied 3 times in the current detection signal (containing rate 6\%), 5 (containing rate 10\%) and 7 (containing rate 14\%) harmonic interference under the three conditions, the dielectric loss factor and capacitance measurement error still need to meet the requirements of measurement error. The test data are shown in Table 2.

| Measuring point 1 | Measuring point 2 | Measuring point 3 |
|------------------|------------------|------------------|
| standard value   | 0.00\%           | 1.00\%           | 10.00\%          |
| measured value   | 0.001\%          | 1.001\%          | 10.00\%          |
| measurement error| +0.001\%         | +0.001\%         | +0.00\%          |

| conclusion | Meet the requirements |

Table 1. Eerrors test of dielectric loss factor measurement.

Table 2. Performance test of dielectric loss factor measurement against harmonic interference.
Conclusion

On the basis of studying the principle of charged detection of capacitive equipment, a calibration method of charged equipment for capacitive equipment based on high voltage and low voltage is put forward in this paper, and the calibration system of charged equipment detection device is designed and developed. Through the calibration experiment research, the feasibility of the calibration method of the capacitive detector is verified. Through the research of this paper, the problem of calibration test of capacitive equipment charged detection device is solved, and the actual problems in the field are solved, which provides the guarantee for the safe and stable operation of power grid.

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