How to Measure the Dielectric loss of 500kV Circuit-breaker Capacitor at High Voltage

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Abstract: Measurement of capacitance and dielectric loss of circuit-breaker capacitor is a very important task to ensure safe and stable running of circuit-breaker. However, due to serious electric interference to on-site measurement, dielectric losses of more and more 500kV circuit-breaker capacitor exceeded the limit at 10kV test voltage according to the CSG trial standard. To address the above-mentioned problems, the paper proposes that methods of using different frequency power source and boosting test voltage be utilized to measure the capacitance and dielectric loss. Based on the above measuring methods, several common test schemes are put forward and application ranges are also analyzed followed by capacitance and dielectric loss measurement for some 500kV circuit-breaker capacitor at Liu-dong substation. Test results indicate that the dielectric loss of capacitor reduces as the voltage rises; the change in test voltage frequency can effectively shield the interference from on-site electric field.

Key words: 500kV, circuit-breaker capacitor, capacitance, dielectric loss, high voltage, measurement

Introduction

During the process of capacitance and dielectric loss measurement, due to coupling capacitance between test object and surrounding live parts, the measurement is disturbed by electric field so that real capacitance and dielectric loss cannot be obtained. In addition, according to related test standard, the test should use 10kV test voltage. However, with the improvement of voltage level, the dielectric loss data at 10kV always fails to reflect the conditions of equipment during the operation. To address the above-mentioned problem, the paper proposes that methods of using different frequency power source and boosting test voltage be utilized to measure the capacitance and dielectric loss.

1. Analysis of Improvements in Measuring Method

There are two problems in the on-site circuit-breaker capacitor test: ① Surrounding live components generate the electric field interference for test object so real capacitance and dielectric loss are not measured. ② The dielectric loss is so big at 10kV that the insulation condition cannot be reflected correctly during the running of capacitor.

Thus, this paper is to study the methods of improving circuit-breaker capacitance and dielectric loss test from two aspects:

① Methods to eliminate the interference of electric field. Use the power source which is different from power frequency to apply the voltage to test object and eliminate the interference component from signals.

② To study how the dielectric loss of capacitor varies according to the test voltage and boost the test power voltage to measure.

1.1 Elimination of electric field interference through variable frequency measuring

Between test object and surrounding live part there is stray capacitance, which is related to distance and shape. As the distance decreases and external voltage rises, the influence produced by external power source through capacitance coupling increases significantly.

The diagram of electric field interference is shown in Fig.1. Cn represents standard capacitor. Due to the role of interference source, interference current I_1 generates; the current Ix passing through the test object capacitor Cx is not equal to I_2 but the superposition of I_1 and I_2. As a result, the measuring value deviates from the real value.

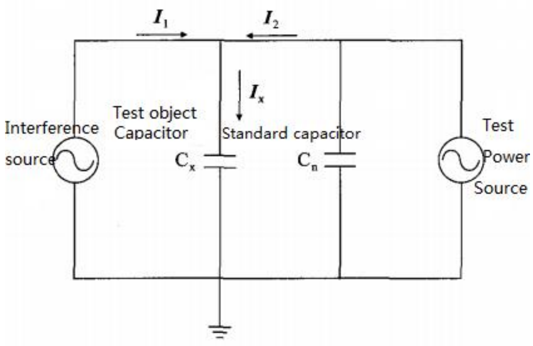

Fig.1 Diagram of electric field interference

When the interference of electric field is severe on site, interference signals coupled from stray capacitance have the same-phase power source and different-phase power source but the frequencies are always consistent with the system power source. Thus, the power source which is different from interference source's frequency is used to conduct the test for test object. Through the hardware and software digital filter, 50Hz interference signal component is eliminated from tested signals, which is shown in Fig.2.

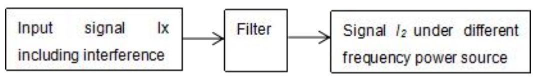

Fig.2 Diagram of variable frequency measuring

The discrete Fourier transform (DFT) technology is utilized to filter. By doing so, a digital filter with ideal characteristics is to be designed. First of all, it analyzes the frequency spectrum of signal and then directly eliminates unnecessary frequency spectrum. Hence, the impure waves are filtered completely, which is shown in Fig.3.

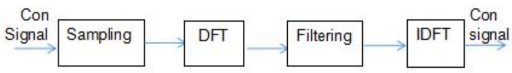

Fig.3 Diagram of DFT filter

As for discrete sequence x(n), its DFT is defined as:

$$X(\Omega) = \sum_{n=-\infty}^{+\infty} x(n)e^{-jn\Omega}$$

Ω： Digital frequency

$$x(n) = \frac{1}{2\pi}\int_{2\pi} X(\Omega)e^{jn\Omega}d\Omega$$

1.2 Relation between dielectric loss of circuit-breaker capacitor and voltage

A common phenomenon tends to appear when the circuit-breaker capacitor runs for a long time: at very low test voltage, the tanδ is very high and even exceeds the limit; however, as the test voltage rises, the tanδ reduces and falls within the range. The capacitor will produce some water and impurities. Water is strong-polarity substance and absorbs impurities easily. Influenced by electric field, ions are generated and dissolved into impregnants, further penetrating into the capacitor paper. The conductivity of impregant paper increases and produces impurity loss. When the voltage rises, the capacity of capacitor goes up while the loss remains the same. As a result, the tanδ tends to decline as the strength of electric field rises. This phenomenon is also called Garton effect, which is shown in Fig.4. The strength of electric field E_0=ωd/2μ (d--distance between solid media, ω -- angle frequency of applied electric field; μ -- live ion mobility)

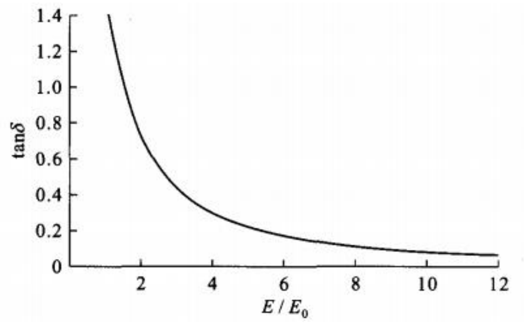

Fig.4 Garton effect

2. Test Scheme Brief

This paper proposes that methods of using different frequency power source and boosting test voltage be utilized to measure the capacitance and dielectric loss. Previously, only in the lab the dielectric loss could be measured at high voltage. As the test equipment downsizes, measurement of HV dielectric loss expands from lab to on-site.

2.1 Mode of voltage boosting -- test transformer

The wiring diagram of test transformer mode is shown in Fig.5. The HV value at various frequencies is provided for test object through variable frequency power source and test transformer (single or series stage).

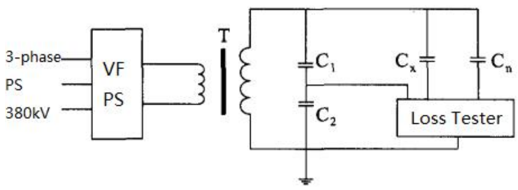

Fig.5 Wiring of capacitance and dielectric loss measurement of circuit-breaker capacitor

T--test transformer

C1&C2--voltage divider

Cx--test object capacitor

Cn--standard capacitor

PS--power source

VF--variable frequency

The advantage of using test transformer to boost the voltage is that you can measure it according to the designated frequency. Without complex matching of equipment and tuning, you can directly measure test objects with medium-small capacitance.

When measuring the test object with large capacitance, if the capacity of test transformer is not big enough, general reactor can be used in the manner of parallel resonance to expand the capacity, which is shown in Fig.6. The required specification and number of reactor are the same as series resonance. Compared with series resonance, this method still has broader frequency range for use. There is no need to perform precise tuning for reactor.

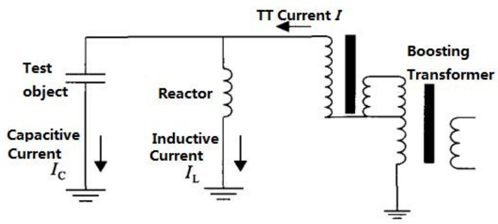

Fig.6 Diagram of capacitance and dielectric loss measurement using test transformer and parallel reactors

The principle of selecting the reactor is as follows: $|I_C-I_L|\leq I$. For instance: at 50Hz, test transformer can output 200mA current; if connected 500mA reactor, the allowable output capacitive current I_C:

Min: 500mA-200mA=300mA

Max: 500mA+200mA=700mA

U: Test voltage

ω: Angle frequency

C: Capacitance

L: Inductance

$$|I_C - I_L| = |\omega CU - \frac{U}{\omega L}| \leq I$$

According to the above formula, it proves that the range of available frequency is proportional to output current of test transformer, namely:

$$\frac{\Delta f}{f_0} = \frac{I}{I_L}$$

f_0: frequency of parallel resonant point

Δf: frequency deviation

Assume f_0 = 50Hz

$$\Delta f = \frac{200mA}{500mA} \times 50Hz = 20Hz$$

Any value between 40Hz and 60Hz can be used.

The available 1Hz anti-interference technology can realize 2 times of anti-interference measurement even though deviating from all integer frequency points. The frequency of test transformer scheme can be designated, which facilitates this application of the anti-interference technology. The advantage of automatic double variable frequency is avoiding anti-interference frequency meanwhile obtaining the data. In comparison with 45Hz/55Hz, the 49Hz/51Hz technology has stronger anti-interference capability and the data is closer to 50Hz.

2.2 Series resonance mode

The parallel resonance's excitation source (test transformer) is in parallel with reactor while series resonance's source (exciting transformer) is in series with reactor, which is shown in Fig.7.

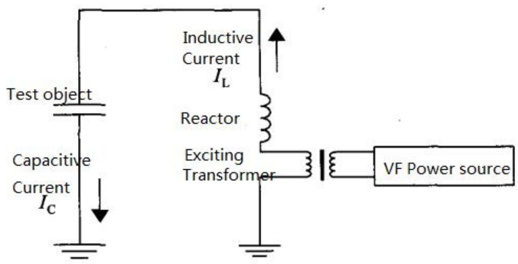

Fig.7 Diagram of capacitance and dielectric loss measurement using reactors in series

1) LC matching

$$f = \frac{1}{2\pi\sqrt{LC}}$$

To obtain reasonable frequency, it is necessary to match reactor inductance (L) with test object's capacitance (C). The inductance is determined by target frequency (f) and test object's capacitance. It is common practice to select one largest test object capacitance and lowest test frequency to determine the inductance. For example, f = 45Hz, C=15000pF:

$$L = \frac{1}{(2\pi f)^2 C} =$$

$$\frac{1}{(2\times 3.14\times 45Hz)^2\times 15000\times 10^{-12}F} = 835H$$

The test voltage is determined by the relation between the current (I) and the inductance (L). U=2πfLI.

Take U=160kV as an example:

$$I = \frac{U}{2\pi fL} = \frac{160000V}{2\times 3.14\times 45Hz\times 835H}$$
$$= 0.68A \approx 0.7A$$

The capacity of reactor is determined by S=IU. Thus:

S=0.7A×160kV=112kVA.

For single reactor with such a large capacity, it is too heavy. Instead, we can use 4 reactors, which is easy to carry and adjust the inductance.

Use four 200H inductance, each is 40kV/0.7A and the capacity per one is 28kVA. There are several kinds of combinations. As for 45~65Hz resonant frequency, there is one formula to calculate:

$$C = \frac{1}{(2\pi f)^2 L}$$

The above formula is used to calculate the C_{max} and C_{min} at 45Hz and 65Hz and results are shown in Tab.1.

Tab.1 Capacitance scale in different test combinations

Reactor combination	Total inductance (H)	Max current/A	Max voltage/kV	45Hz Cmax/pF	65Hz Cmin/pF
4	800	0. 7	40×4=160	15650	7500
2	400	0. 7	40×2=80	31300	15000
2+ 2	200	1. 4	40×2=80	62600	30000
1	200	0. 7	40	62600	30000

2) Quality factor (Q)

The quality factor is another important indicator. It is equal to the ratio of LC circuit's reactive power to active loss, that is, the ratio of test voltage to exciting transformer's output voltage.

The consumed power is supplied by variable frequency power source. The greater the Q is, the lesser power of variable frequency power supply and exciting transformer needs and the lower the needed exciting voltage is. The value of quality factor is determined by production technology. Main methods of improving the value of Q are to reduce the DC resistance of reactor and corona loss.

The too high quality factor also brings another problem. That is, exciting frequency should be closely matched with LC resonance frequency. Basically, the allowable frequency deviation is as follows:

$$\Delta f = \frac{f}{Q}$$

Take 60Hz and Q=50 as an example.

$$\Delta f = \frac{60Hz}{50} = 1.2Hz$$

The range of allowable frequency is 59.4~60.6Hz. Its frequency range is lower than the scheme of test transformer + reactor.

The minimum value of quality factor is 16. According to the definition of Q, the required capacity of exciting transformer is:

$$S_t = \frac{S}{Q_{\min}} = \frac{112kVA}{16} = 7kVA$$

The required output voltage of exciting transformer is:

$$U_0 = \frac{U}{Q_{\min}} = \frac{160kV}{16} = 10kV$$

In this scheme, U_0=10kV, I_0=0.7A, the capacity=7kVA.

3) Anti-interference

If the Q ＞100, the forced oscillation becomes unstable. At this time, only the resonant point can be used to boost the voltage while the anti-interference function is abandoned.

2.3 Comparison of two boosting schemes

From the comparison, it is found that test transformer or parallel reactor is recommended when the capacitance of test object ≤5000pF. When ＞5000pF, the method of series resonance should be used.

3. On-site Test Results and Analysis

The above test scheme was applied in many substations. Test results were consistent with theoretical analysis. Take some 500kV circuit-breaker capacitor at Liu-dong substation as an example to introduce test process and result analysis. The boosting mode of test transformer is used in the test. The test power source rises from 10kV to 80kV; measure one time every 10kV and then declines to 10kV; then measure one time every 10kV. As for each measuring voltage, perform capacitance and dielectric loss measurement at 49Hz and 51Hz. Its average value is taken as measuring value.

Test results are shown in Fig.8-10. It can be seen that the circuit-breaker capacitor's capacitance is the same at each test voltage. However, the dielectric loss tends to fall as the voltage rises. When the test voltage is below 40kV, the dielectric loss varies greatly. If above 40kV, it changes smoothly. The curve of capacitance and dielectric loss during the process of boosting basically coincides with the one of reducing process. In addition, the value of dielectric loss of several capacitors at 10kV is close to 0.4%; the capacitor at the phase-C II busbar side exceeds the value; when test voltage rises to 40kV, the values of these capacitors reduce to 0.1%, which meets the requirement. In such case, the value of dielectric loss at high voltage should be used to determine.

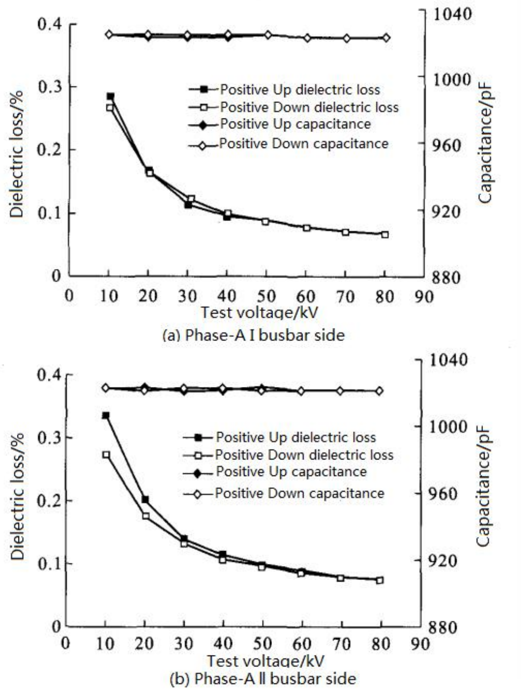

Fig.8 Results of phase-A circuit-breaker capacitor test

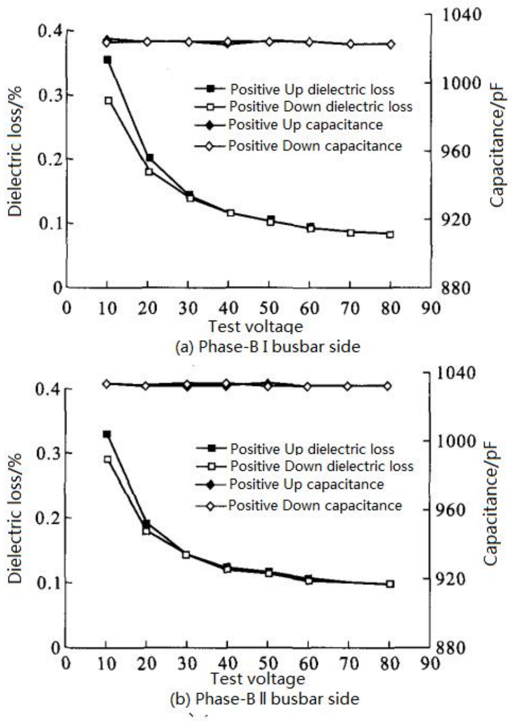

Fig.9 Results of phase-B circuit-breaker capacitor test

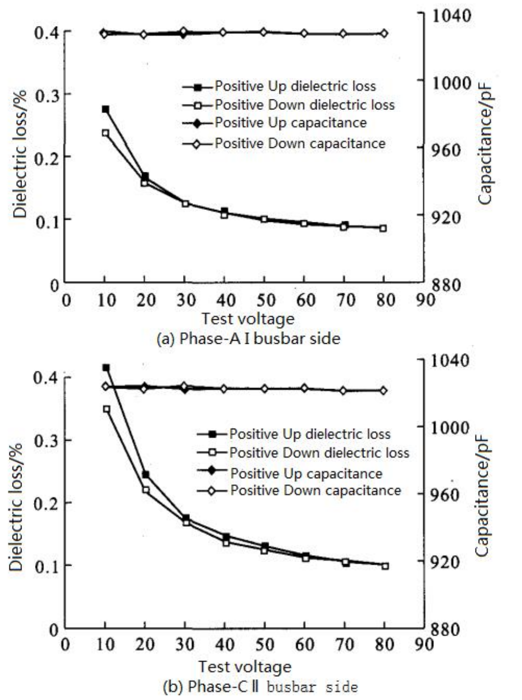

Fig.10 Results of phase-C circuit-breaker capacitor test

In order to compare the test effect by different-frequency power source with the one by power frequency power source, the capacitor at phase-A II busbar side is selected. Its capacitance and dielectric loss are measured at 50Hz power, and the result is shown in Fig.11. It is found that the values distort severely and two curves do not coincide. The interference of live parts are eliminated well by using the different frequency power source. Test results are very good.

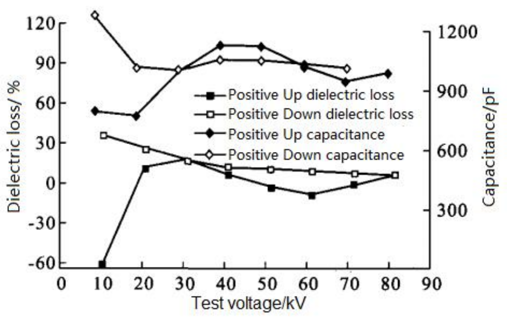

Fig.11 Result of phase-A II busbar side circuit-breaker capacitor test at 50Hz

4. Conclusions

1) Through theoretical analysis, this paper proposes new test methods: use different frequency power source and digital filter to eliminate the interference from on-site live parts to test object and boost the test voltage.

2) Two dielectric loss measuring schemes are introduced: test transformer and series resonance. Their applicable ranges are compared: when the capacitance of test object ≤5000pF, test transformer or parallel reactor is recommended; when the capacitance ＞5000pF, the method of series resonance should be used.

3) Based on the above improvement methods and test schemes for dielectric loss measurement, tests are conducted on site at the substation. Test results indicate that new test methods can not only shield the electric field interference effectively, but also better reflects the insulation condition of capacitor during the running by means of measuring the dielectric loss.