Study on Impact Response Characteristics of Capacitive Voltage Transformer

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Abstract. Under the impact voltage, the internal capacitive components of the capacitive voltage transformer are subjected to different voltages. Understanding the impulse response characteristics of the capacitive voltage transformer is of great significance for analyzing the internal insulation fault of the capacitive voltage transformer. In this paper, from the disintegration of a 500kV capacitive voltage transformer, based on the actual measurement of the capacitor and its internal components, the distributed parameter model of the capacitive voltage transformer is established. The response of the capacitive voltage transformer to the surge voltage is analyzed under the condition of lightning intruding wave and long line closing. The analysis shows that the capacitive element of the high-voltage side capacitor divider of the capacitive voltage transformer is subjected to the first and last ends of the capacitive voltage transformer. The voltage is higher than other capacitive components; when a partial capacitive component breaks down in the capacitive voltage divider, the voltage drop of the normal component under the same surge voltage increases, which will accelerate the damage of the capacitive component caused by the surge voltage; analysis conclusion and disintegration The results are in agreement and are of great significance for analyzing the internal insulation damage of capacitive voltage transformers.

1. Introduction

The capacitive voltage transformer (CVT) is divided by a series capacitor, and then depressurized and isolated by electromagnetic transformer. The high voltage in the power system is converted into low voltage supply instrument and relay protection device to realize measurement, measurement and protection [1-4]. Because CVT can prevent system resonance caused by core saturation, it is widely used in 66 kV and above power grid [5-11].

The shunt capacitor of CVT is composed of several capacitor elements in series. In actual operation, the capacitor elements of the shunt capacitor on the high voltage side are easily damaged due to the impact voltage. At present, the research of CVT is mostly based on the lumped parameter model [12- 19], so it is impossible to analyse the voltage distribution inside the shunt capacitor.

Starting from the disassembly of a 500kV fault CVT, the CVT distribution parameter model is established on the basis of the measured parameters of the capacitor and its internal capacitance elements. The voltage distribution and the secondary side voltage waveform of the CVT internal capacitance elements under the action of lightning impulse and closing impulse are calculated, and the internal impulse response characteristics of the CVT are obtained.
2. Brief introduction to the breakdown and disassembly of a 500 kV CVT

After the replacement of a 500kV Line Current Transformer in Sichuan power grid, when charging the line, the opposite side switch trips. After the trip, the operation and maintenance personnel of the side station immediately confirm the on-site primary equipment, and no abnormality is found from the appearance. During the next secondary charging, the switch on the opposite side trips again, and the voltage of phase B of line protection 1 and 2 rises sharply to about 74.5v (normal value is 61V), and remains at about 74.5v, which is determined to be abnormal at the primary side of CVT. After two-line trips, the dispatcher orders to disconnect the CVT of phase B and run the arrester without load. After the line was transferred for maintenance, the high-voltage shift immediately started the dielectric loss test of phase B, and the test results were found to be quite abnormal compared with the delivery date and the last maintenance date.

The model of fault CVT is TYD3 500/√3-0.005H, and its capacitance part is composed of four sections, which has been put into operation for 18 years. The capacitance and dielectric loss test results of the failed CVT are shown in Table 1.

| Number | Initial capacitance (PF) | Experimental voltage (10kV) | Capacitance (pF) | Dielectric loss (%) |
|--------|--------------------------|-----------------------------|------------------|---------------------|
| C_{11} | 20431                    | 33584                       | 20735            | 0.205               |
| C_{12} | 20413                    | 20767                       | 0.246            |
| C_{13} | 20476                    | 20100                       | 0.24             |
| C_{14} | 19938                    | 38070                       | 0.24             |

Among the dielectric loss, C_{11} is the top capacitor connected to the high voltage side. From table 1, it can be seen that the capacitance increases significantly, which means that some of the internal capacitor elements are broken down. C_{11} is composed of 82 capacitor elements in series, each of which has a rated value of 1.675nf. After dissection, the capacitance of each capacitor element is measured, which shows that 20 elements are normal, 36 elements are damaged but not broken down, and 26 elements are completely broken down. According to the site anatomy of C_{11}, some damaged parts of capacitor insulation and the status of each capacitor are shown in Figure 1.

![Figure 1](image_url)

Figure 1 (c) draws the capacitor element in C_{11} from the high voltage side to the low voltage side in turn, and displays its status with gray scale, white indicates that its capacitance value is 1.675nf, black indicates that the capacitance value cannot be measured (completely broken down), and the deeper the gray level is, the more serious the damage is. It can be seen from the distribution of fault capacitor...
elements that the damage probability of capacitor elements at the upper and lower ends is large, and the middle part is relatively small.

3. The establishment of CVT distributed parameter model

The equivalent circuit diagram of CVT internal capacitor is shown in Figure 2.

![Capacitor equivalent circuit](image)

Figure 2. Capacitor equivalent circuit

Where \( C \) is the inherent capacitance of the element, \( R_C \) is the equivalent resistance of the dielectric loss, in addition, the current flowing in the aluminum foil and lead of the capacitor also has certain resistance \( R_n \) and distributed inductance \( L_n \), so the equivalent impedance of the capacitor element is:

\[
Z_e = \frac{R_C}{1 + j\omega R_C} + j\omega L_n + R_n
\]

\[
= \frac{R_C}{(1 + (\omega C R_C)^2)} + R_n \cdot j\omega \left( \frac{C R_C^2}{1 + (\omega C R_C)^2} \cdot L_n \right)
\]

\[
= R_e \cdot j\omega \left( \frac{1}{\omega^2 C_e} \right)
\]

Where \( R_e \) and \( C_e \) are the equivalent resistance and capacitance of the capacitor element respectively, and

\[
\omega = \sqrt{\frac{1}{C R_C^2} - \frac{1}{\omega^2 C_e}}
\]

Generally, the dielectric loss is very small, which can be ignored, that is, \( R_C \rightarrow \infty \), then the above formula can be simplified as

\[
C_e = \frac{C}{\omega^2 C L_n}
\]

It can be seen from the above formula that the larger the \( L_n \) is, the higher the frequency is, the greater the difference between \( C_e \) and \( C \) is.

The parameter test of the normal capacitance element in \( C_{11} \) after disassembly is carried out. First, the DC resistance of the capacitance element is measured with a multimeter. The multimeter actually measures \( R_C + R_n \). The \( R_C \) in the normal capacitance element is very large, so the value measured by the multimeter is infinite. Then, the 50 Hz AC resistance is measured with a capacitance electric induction tester. In the normal element, the \( R_C \) is very large, so the actual measured value is its \( R_n \). The average value of the parameters of the normal capacitor element is measured: \( C \) is 1.673 \( \mu F \), \( L_n \) is 16.5 \( mH \), \( R_C \) is infinite (109 \( \Omega \) is set in the model), \( R_n \) is 65.6 \( \Omega \). When the capacitor breaks down, short the two ends of the capacitor. There is also mutual capacitance between the capacitor elements. The average value of mutual capacitance between the two adjacent elements is 1000pf, the average value of mutual capacitance between the two capacitor elements in the middle interval is 800pf, the average value of mutual capacitance between the two capacitor elements in the middle interval is 600pf, and the average value of mutual capacitance between the two capacitor elements in the middle interval is 600pf. In order to simplify the model, the mutual capacitance between the capacitor elements with greater distance is no longer considered.

The impact response simulation model of 500kV CVT is established as shown in Figure 3, in which the electromagnetic element reference [20] is established.
4. Internal voltage distribution of capacitor under impulse voltage

In this section, two common types of impulse voltage are considered, one is the impulse voltage caused by lightning stroke in the near area of the line, and the other is the impulse voltage of remote closing when the line is empty charged.

4.1 Distribution of impulse voltage caused by lightning stroke in the near area

In order to simplify the analysis, no outgoing line Bay arrester is set, and the voltage distribution of the head end of CVT and its internal capacitor elements is concerned. When 5kA lightning current (2.6/50μs double exponential wave) is wound around the 1km line in the near area, the internal voltage waveform of CVT is shown in Figure 4.

It can be seen from the response of CVT to the lightning intrusion wave in the near area that: (1) the overvoltage of No.1 capacitor at the first end of C_{11} is the largest, and the overvoltage amplitude of
the subsequent capacitor decreases rapidly; (2) the voltage of the capacitor at the end of each capacitor is larger than that of the intermediate capacitor, and the voltage of the capacitor in the whole capacitor shows a trend of large at both ends and small in the middle. The voltage of the middle head end element is higher than that of the tail end element; (3) the lightning impulse voltage of the inner head end element of each capacitor in the upper and lower CVT decreases in turn; (4) the lightning impulse voltage of the two capacitors in the CVT is higher than that of the head end element of the lower capacitor. (5) the over-voltage waveform caused by lightning stroke on the transmission line cannot be reflected in the secondary side of CVT, and the lightning impulse on the primary side cannot be detected through the secondary side of CVT.

4.2 Distribution of impulse voltage caused by air closing circuit
Set the 500kV line length to 200km, with the head end closed and CVT at the tail end. In order to simplify the analysis, the outgoing line Bay arrester is not set, and the internal voltage distribution of CVT is concerned, as shown in Figure 5.
It can be seen from Figure 5 that under the action of closing impulse voltage at the far end of the line, the internal voltage fluctuation process of CVT is more complex, and the voltage distribution trend of single capacitor element is basically similar to that under lightning impulse, the difference is that the voltage amplitude has decreased, the waveform at the line side of closing impulse voltage is reflected at the secondary side of CVT, but the high-frequency component is filtered.

4.3 Distribution of lightning impulse voltage of near area line in case of partial capacitor failure
Suppose that there is breakdown of 20 capacitor elements in 11-30 of C11 capacitor, and 5kA lightning current is still used to wind the line 1km away, the response voltage waveform is as shown in Figure 6.

Compared with the normal situation, when C11 capacitor breaks down, the overvoltage amplitude of related components increases, but the overall distribution trend does not change. It can be predicted that after C11 capacitor breaks down, the normal components will bear higher amplitude overvoltage under the same impulse voltage, resulting in accelerated damage of capacitor components.
5. Conclusion
This section analyses the response of two kinds of impulse voltage which are common in the actual operation of CVT, and draws the following conclusions:

(1) Under the impact voltage, the voltage distribution between the capacitor elements in the capacitor is uneven, and the over-voltage borne by the capacitor elements at both ends of the capacitor at the high voltage side is relatively serious, which explains the phenomenon that the capacitor elements at the high voltage side are easy to be damaged, and most of the damaged capacitor elements are at the upper and lower ends;

(2) For the lightning impulse voltage, the voltage waveform on the secondary side of the CVT is different from the voltage waveform on the primary side. It can be seen that the smaller the time scale of the transient process, the greater the difference between the voltage waveform of the secondary side and the waveform of the primary side;

(3) Once the C_{11} capacitive element breaks down, the magnitude of the surge voltage experienced by the normal component will increase. As the number of damaged components increases, the damage rate of the normal component will increase, causing a vicious cycle.

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