Research on Insulation State of 10kV XLPPE Fault Cable Based on Qt Technology

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Abstract. The cross-linked polyethylene cable will undergo thermal aging during service, which will seriously affect the service life of the cable. The current integration method can analyze the charge injection and conduction parameters from the dynamic change rate of the charge over time, and then analyze the insulation state of the polymer. Aiming at the field 10KV fault breakdown cable, this paper uses the current integration method to compare the dynamic change characteristics of the charge of the faulty cable and the new cable, and uses the ratio of $Q(t)$ at $t=600s$ and $t=4s$ to study Charge injection and accumulation situation. Through analysis, it is found that the fault breakdown of the cable, the maximum charge accumulation under high voltage is $9000 \, \text{Q/nC}$, the charge change rate is about $2$, and the dielectric constant is $3.1$, which is much greater than that of the new cable, indicating that the breakdown of the three-phase cable is mainly caused by the cable. It is caused by aging and eventually leads to insulation deterioration and breakdown.

1. Introduction
With the acceleration of urbanization, XLPE cables are widely used in power systems because of their good dielectric properties and physical and chemical properties. However, when the power cable has been in operation for more than 25 years, under the combined action of electricity, heat, mechanical force and environmental factors, it enters the aging failure period [1]. When the cable is in the process of aging and failure, the cross-linked polyethylene molecular chain gradually breaks under the action of multiple stresses, and the microscopic defects continue to expand. Under the action of a DC electric field, space charges are easy to accumulate in microscopic defects, causing local electric field distortion, further accelerating insulation aging, and even causing final insulation breakdown [2-4]], which will cause greater losses to the power grid. Therefore, evaluating the insulation status of power cables is of great significance to the safe operation of power grids.

At present, the evaluation of the insulation state mainly uses performance tests in terms of dielectric, physical and chemical, and space charge. Among them, the research on physical and chemical properties mainly uses differential scanning calorimetry analysis, X-ray diffraction analysis, infrared spectroscopy and other methods to study the chemical groups, oxidation, thermal decomposition, crystallization, and crosstalk of XLPE cable insulation before and after electrical-thermal aging. The difference in the state of the link and the molecular chain, and then the insulation state is evaluated. Chen Zhiyong et al. studied the effects of electrical aging and accelerated water tree
aging on the physical and chemical properties of cross-linked polyethylene insulation through physical and chemical experiments, and established a microscopic model of water tree aging (AWTT). The mechanism has been analyzed in depth [5]. Xu Jun et al. conducted physical and chemical experiments on heat-aged samples at different temperatures and different times, and studied the effects of thermal cracking activation energy, crystal morphology, and molecular structure on the physical and chemical structure of cross-linked polyethylene cable insulation [6]. Regarding the study of dielectric properties, it mainly uses polarization/depolarization current method (PDC), broadband dielectric spectrometer, and theoretical models to analyze the increase in dielectric constant and loss, increase in conductivity, and breakdown field of XLPE before and after aging. Strong and other characteristic parameters, and then obtain the analysis basis of XLPE aging degree. Zhang Qiaofeng et al. studied the influence of the degree of crosslinking on the time domain dielectric properties of crosslinked polyethylene by using the polarization/depolarization current method. The results show that the crosslinking reaction can effectively improve the insulation of crosslinked polyethylene. Performance, and the greater the degree of crosslinking [7]. Ye Gang et al. conducted polarization/depolarization current (PDC) experiments on XLPE accelerated water tree aging samples at different aging stages, and used the IT-LT curve and the extended Debye model to study the time-frequency domain The relationship between electrical characteristics and insulation aging [8]. Regarding the research of space charge, the pulsed electro-acoustic method (PEA) is mainly used to test the space charge. Through the experiment of pressurization and short-circuit process, the space charge distribution, average bulk charge density and Characteristic parameters such as volume charge density attenuation rate. Yin Yi and others of Shanghai Jiaotong University used the isothermal relaxation current method (IRC) to detect the aging conditions of unaged and water-aged, and applied the full-scale full-scale space charge measurement method to study the space charge distribution of the cable body. The research results show that the aging factor and deep trap energy level increase after aging in water, space charge accumulates during polarization, and shallow trap charge disappears during short circuit [9]. Jing Qiang et al. used gas chromatography-mass spectrometry (GC-MS) and space charge method to study the relationship between the type and content of crosslinked by-products remaining in the insulation after different degassing times and the space charge. Studies have shown that the content of cross-linking by-products such as α-methylstyrene, acetophenone, and benzyl alcohol decreases with the extension of the degassing time. With the increase of the degassing time, the average bulk charge density and the attenuation rate of the bulk charge density in the samples with the same short-circuit time decrease [10].

Most of the above detection methods are carried out for sheet-like patterns and cannot be used to test the whole cable as a whole. The space charge test can test the whole cable, but its test electric field strength and temperature range are limited; in addition, its resolution is low, and it is greatly affected by the interference and noise of the test site. [11,12]. In recent years, Takadad and others in Japan have proposed a new method for evaluating the insulation state of cables, which can evaluate the insulation state of cables through the rate of change of charge before and after aging [13-15], but it has not been applied in the field of overall cable inspection in China. Therefore, this paper prepares XLPE cable sheet samples with different aging degrees in the laboratory, and uses the current integration method to study the charge dynamic characteristics of the XLPE samples under different aging degrees under different electric fields. The evaluation of the cable insulation status has a certain meaning.

2. Introduction to the principle of the method

2.1. Overall cable Q(t) test principle

The overall cable test principle of the current integration method is shown in Figure 1. The overall cable test is composed of three parts: a high-voltage DC voltage source, an integral capacitor, an internal analog-to-digital conversion signal detection unit, and a data receiving and processing unit. The high-voltage DC voltage source is connected to the overall cable through the integrating capacitor, and forms a closed loop through the grounding wire. The amount of charge accumulated in the overall
cable can be calculated by integrating the current flowing through the high-voltage circuit, as shown in equation (1). At the same time, the accumulated charge can be evaluated by the voltage induced across the integrating capacitor. An impedance amplifier is used to convert the obtained \( Q(t) \) into a stable voltage \( VQ(t) \). After ADC (analog-to-digital converter), the voltage analog signal is converted into a digital signal, and finally the signal is transferred to the computer software for processing through the zigbee signal transmitter and receiver, as shown in equation (2).

\[
Q(t) = \int_0^t I(t) dt
\]  
\[
VQ = \frac{Q(t)}{C_{int}} = \frac{1}{C_{int}} \int_0^t I(t) dt
\]

Figure 1. Schematic diagram of the overall cable test.

2.2. \( Q(t) \) aging assessment method

The aging state of the cable is related to the accumulation state and level of carriers in the material. Therefore, the aging state of the material can be determined by the amount of charge accumulated in the material. The current integration method uses the initial charge and the change in the charge after the end of the pressure as the insulation state evaluation method, as shown in Figure 2.

\[
\frac{Q(t)}{Q_0} = 1 + \frac{Q_{spac}(t)}{Q_0} + \frac{Q_{leak}(t)}{Q_0}
\]

Figure 2. The rate of change of the amount of charge under different voltages.
When $Q_t/Q_0=1$, $\frac{Q_{\text{space}}(t)}{Q_0} + \frac{Q_{\text{leak}}(t)}{Q_0} = 0$, it indicates that there is only induced charge generated by pressurization at this time, no charge accumulation inside, only instantaneous charging current.

When $Q_t/Q_0>1$, $0<\frac{Q_{\text{space}}(t)}{Q_0} + \frac{Q_{\text{leak}}(t)}{Q_0}<1$, it indicates that charge accumulation (charge conduction) occurs, space charge is dominant, and absorption (polarization) or electrical conduction current exists inside the sample.

When $Q_t/Q_0>1,1<\frac{Q_{\text{space}}(t)}{Q_0} + \frac{Q_{\text{leak}}(t)}{Q_0}$, it indicates that the leakage current charge is dominant at this time.

3. Acquisition and processing of samples
Obtain the cable style from the 10kv three-phase cable faulty cable running on site. The cable has been in service for 5 years and was damaged due to breakdown. At a distance of 20 cm from the breakdown point of the whole cable, the three-phase single-core cable is obtained by cutting off the cross section and stripping off the surface layer and armor layer of the cable. Each single-core cable head and tail of the semi-conductive layer of 10cm each stripped and wiped with alcohol and wrapped in copper foil. At the same time, select a new cable of the same model that has not been put into operation, perform the same steps, and set up a control experiment. The information of the overall cable style is shown in Table 1

Table 1. Basic parameters of the cable.

| Cable number | length | the inside diameter of | Outer diameter | Copper foil length |
|--------------|--------|------------------------|----------------|--------------------|
| New cable    | 76     | 24                     | 34             | 45                 |
| A phase cable| 76     | 24                     | 34             | 45                 |
| B phase cable| 76     | 23                     | 32             | 47                 |
| C phase cable| 80     | 23                     | 35             | 49                 |

4. Experimental results

4.1. $Q_t$ test results
Figure 3. The charge change curve of the new cable and the fault breakdown cable.

Figure 3 shows the results of the charge test results of the new cable and the fault-breakdown cable under different voltages. It can be seen from the figure that the amount of charge increases as the voltage increases. Among them, the charge of the new cable and the C-phase cable remains almost constant with the increase of time. For the A and B-phase cables, when the voltage is less than 8kV, the increase of the charge with time remains constant. When the voltage is greater than 10kV, the amount of charge increases with time. Increasing, of which the B-phase cable has the largest change trend with time.

4.2. Current test result

Figure 4 shows the current test results of the new cable and the fault breakdown cable under different voltages. It can be observed from the figure that the XLPE cable will generate an instantaneous charging current at the moment of pressurization, and then reach a steady state, forming an internal steady state or leakage current. The volatility of the current curve is relatively large at low voltage, and the volatility of the current curve decreases with the increase of voltage. Among them, the current change curves of the new cable and the C-phase cable are both below the order of 10-9, the maximum current of the A-phase cable is about 10-9, and the maximum current of the C-phase cable reaches the order of 10-8.
4.3. Dielectric constant test result

Figure 5 is the relationship curve between the applied voltage of the A-phase cable and the instantaneous interface charge $Q_0$.

Among the new cables, the dielectric constant of the B-phase cable is higher than that of the new cable and the A and C-phase cables.

$$C_s = \frac{2\pi \varepsilon_0 \varepsilon_r l}{\ln \frac{b}{a}}$$

Among them: $C_s$ is the capacitance of the cable, $L$ is the length of the cable, $a$ is the radius of the cable, and $b$ is the diameter of the cable.
5. Discuss

Figure 6 shows the charge change rate of the new cable and the fault breakdown under different voltages. Take K=1.2 as the threshold of space charge injection. From the figure, it can be found that the charge change ratio of the new cable and the phase B cable is close to 1, and there is no obvious change with the increase in voltage, indicating that there is no charge injection at this time. The cable insulation performance is good. With the increase of this voltage, the change rate of the charge amount of the B-phase cable increases significantly, and it is greater than 1.2. At this time, charge accumulation occurs, indicating that the insulation performance of this phase cable is seriously degraded. This is because in actual operation of the cable, it will be affected by factors such as electricity, heat, mechanical stress, moisture, etc., which will cause the cable to age during service, resulting in changes in the molecular structure of the XLPE material, and changes in the energy level density and depth of the trap. The long-term electric charge accumulates under high-voltage direct current. Deterioration of insulation performance most leads to deterioration of XLPE’s dielectric properties, such as changes in parameters such as dielectric constant and current. Among them, the dielectric constant and current of the B-phase cable are greater than that of the new cable, and the A and C-phase cables. The final result causes the B-phase cable insulation breakdown.

6. Conclusion

In this paper, the Q(t) characteristics of the 10kV overall fault breakdown cable are studied, and the following conclusions are finally obtained.

1. When the overall cable ages, the molecular structure and energy level trap density of the XLPE cable change, and then charge accumulation occurs under high DC field strength. According to the results of the Q(t) test, it can be found that the K value of phase A is the largest, and K_B>K_A>K_C>new cable.

2. When the overall cable is in an aging state, the insulation performance of XLPE deteriorates, which is manifested in the increase of dielectric constant, current and other parameters, which will eventually lead to the breakdown of the B-phase cable.

3. The overall cable parameters obtained by Q(t) technology can well reflect the insulation performance of 10kV XLPE cables, and Q(t) technology can be used to provide a basis for evaluating the insulation status of cables with higher voltage levels.

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