Experimental Research on Partial Discharge of High Voltage Direct Current

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Abstract. Under the action of long-term high-voltage DC voltage, the insulation of electrical equipment is inevitably aging, and it is necessary to monitor its insulation status. Since insulation defects of different nature damage electrical equipment to different degrees, the identification of defects is very important. To this end, a DC partial discharge detection system based on AC partial discharge detection equipment was built, focusing on key issues such as the choice of test power supply, the choice of test frequency, and the choice of pressurization methods. The successful completion of the on-site partial discharge test of UHV converter transformers has provided valuable practical experience for the future on-site partial discharge tests of UHV converter transformers, and provided important tests for the establishment of on-site partial discharge test standards for UHV converter transformers. in accordance.

Key words. HVDC, converter transformer, partial discharge, anti-interference, ultrasonic positioning, broadband.

1. Introduction

HVDC transmission has the advantages of wide coverage, long transmission distance, low line loss, and large transmission capacity. It provides a lot of theoretical foundations for the optimal allocation of energy resources in my country. At present, some power companies in my country have begun to try to use high-voltage direct current transmission lines for power supply, which not only ensures the continuity and safety of power supply, but also provides a lot of convenience for power companies to supply power to remote load centres and maximize energy resources Utilization will truly achieve the goal of reducing investment costs and improving the economic benefits of power companies. Under the action of long-term high voltage, electrical equipment will inevitably suffer from problems such as degradation of insulation performance and partial discharge.

Partial discharge is an electrical discharge in an insulating medium. This discharge is only limited to a part of the measured medium and only partially bridges the insulation between conductors. This discharge may occur in the vicinity of the conductor. Partial discharge in some weak parts of transformer insulation under the action of strong electric field is a common problem in high voltage insulation. Although partial discharge generally does not cause penetrating breakdown of insulation, it can cause local damage to dielectrics (especially organic dielectrics). If partial discharge exists for a long time, it will cause insulation deterioration or even breakdown under certain conditions [1]. The
partial discharge test of the transformer can not only understand the insulation status of the equipment, but also find out many problems related to manufacturing and installation in time, and determine the cause and severity of the insulation failure. Generally speaking, the higher the voltage level of the transformer, the smaller the insulation margin. Therefore, the partial discharge test on the transformer is the most important assessment in the manufacture and operation of the transformer.

The main purpose of this research is to combine the actual UHV DC project, and to cover the research and selection of test equipment parameters, test equipment manufacturing, field anti-interference measures research, field corona control, large equipment transportation, field assembly of test equipment, etc. On various topics, relevant key technical issues were studied, and the application of partial discharge test technology for UHV converter transformers was completed to ensure the completion of the UHV DC demonstration project on schedule.

2. DC partial discharge detection system

The detection circuit of high-voltage DC partial discharge is shown in Figure 1. It is composed of a high-voltage DC voltage generator (the highest voltage is ±35kV), a coupling capacitor $C_k$ of 1nF and a high-frequency current transformer HFCT. Coupling capacitors and testing equipment are placed in a shielded room to minimize interference and noise in the test. The partial discharge detection equipment is PD Check made by Tech Imp, Italy, with a bandwidth of 50MHz and a sampling frequency of 100MHz. In this paper, corona discharge, creeping discharge and internal discharge under the action of positive and negative DC voltage are tested.

![Figure 1. Schematic diagram of high-voltage DC partial discharge detection circuit](image)

2.1. Selection of pressurization method

There are two kinds of pressure methods commonly used in field test, namely unilateral pressure method and symmetrical pressure method. Unilateral pressurization is a voltage application method in which one end of the valve side winding of the UHV converter transformer is grounded, and the other end bears the entire test voltage. The test requires an intermediate transformer. The factory test of the UHV converter transformer adopts unilateral voltage [2]. Its advantages are simple loop, convenient reactor compensation adjustment and voltage and current measurement, and small potential difference at each end of the tested product. The disadvantage is that the intermediate transformer has a large capacity and a high voltage level, which leads to an increase in volume and weight, which puts forward higher requirements for the design of the intermediate transformer. The test wiring diagram is shown in Figure 2.
The symmetrical pressurization method is to apply the test voltage symmetrically to both ends of the winding on the valve side of the UHV converter transformer, and the two test transformers are connected symmetrically and grounded in the middle. The advantages of the symmetrical pressurization method are that a single intermediate transformer and high-voltage reactor bear the test voltage low, the test loop interference is small, and the test equipment has a small capacity and volume, which is convenient for transportation [3]. The disadvantage is that the potential difference at each end of the tested product is large, and the compensation adjustment of the reactor and the measurement of voltage and current are inconvenient. In order to reduce the interference of the test circuit and facilitate the transportation of test equipment, the partial discharge test of UHV converter transformer is selected as the symmetrical pressurization method.

2.2. Selection of test frequency
When major transformer manufacturers conduct partial discharge tests on transformers, most of them use double-frequency generator sets with a power supply frequency of 200 Hz. However, in order to reduce the unit's own partial discharge level, the engine chooses to use the brushless excitation method. At present, the domestically produced 250Hz frequency multiplier unit manufacturing technology is relatively mature, and when the 250Hz unit is in the transformer partial discharge test, the active power loss of the tested transformer is higher than 200Hz The unit is small, and the required capacity of the motor can also be reduced, which is conducive to starting, especially for the existing 250Hz unit, we have mature test and use experience [4]. Therefore, after technical and economic comparison, the 250Hz intermediate frequency generator set was chosen.

3. Analysis of discharge method
3.1. Corona discharge
Corona discharge is a needle-board model with adjustable distance, in which the needle is extremely high-voltage and the plate is grounded. Figure 3 shows a typical spectrum of negative corona discharge (~10kV). The relationship between the discharge amplitude measured by the partial discharge detection equipment and the corresponding time, the discharge times corresponding to the discharge amplitude and the discharge times corresponding to the discharge time interval are given. Each point represents 1 discharge, a total of 2000 discharges.
Figure 3. Typical spectrum of negative corona discharge

It can be seen from Figure 3 that the amplitude of the negative corona discharge is very concentrated. Through analysis, the relationship between the amplitude of the two adjacent discharges of the negative corona discharge, and the relationship between the amplitude of the discharge and the interval of the previous discharge are obtained [5]. The former is close to a horizontal line, indicating that the amplitude of the negative corona discharge has nothing to do with the previous discharge interval, and the discharge interval also presents a concentrated nature.

3.2. creeping discharge

The creeping discharge model is also a needle-board model, the difference is that the needle electrode is in contact with the solid insulating sheet (XLPE) placed on the plate electrode. The needle is extremely high-voltage and the plate is grounded. The discharge starting voltage for negative polarity creeping discharge is ~15kV. When the applied voltage increases to ~30kV, a strong discharge sound can be heard from outside the shielded room. At the same time, with the sudden drop of the applied voltage, it is judged that a flashover has occurred. But because the discharge was too fast and too strong, no discharge data was recorded. In the negative surface discharge without flashover, two types of discharge are found: one is concentrated discharge A with small amplitude, and the other is scattered discharge B with large amplitude [6]. Discharge A has the properties of corona discharge, and discharge B is the creepage along the interface between XLPE and air (creeping discharge). Considering that creeping discharge is always accompanied by corona discharge, this paper puts the two discharges together for statistical analysis. Figure 4 shows a typical profile of negative polarity creeping discharge (~24kV). Compared with the negative polarity corona discharge, the discharge repetition rate of the negative polarity creeping discharge is lower (the time corresponding to 2000 discharge points is 43s), but it is higher than that of the positive polarity corona discharge. And the discharge amplitude of the negative corona is dispersive.
Figure 4. Typical pattern of negative polarity creeping discharge

3.3. Internal discharge
The internal discharge model is a cavity surrounded by solid insulation (epoxy resin). The internal discharge was measured under both positive and negative DC voltages. Due to the symmetry of the discharge model, the positive internal discharge has the same characteristics as the negative polarity. This article gives the test results under the negative polarity and the discharge starting voltage It is 24kV. Figure 5 shows a typical spectrum of internal discharge (-35kV).

Figure 5. Typical spectrum of internal discharge

Figure 5 shows that the internal discharge is also dispersive. Compared with Figure 4, the discharge repetition rate of internal discharge is greater than that of creeping discharge. Regardless of the discharge amplitude, the probability density of the discharge amplitude or the probability density of the discharge time interval, the internal discharge (symmetric electrode model) and the creeping discharge have very similar patterns [7].
4. Estimation of active power loss and active current of the tested transformer

The calculation formula for the active power loss and active current of the tested transformer under different test voltages is as follows.

\[
P_s = \left( \frac{U_s}{U_N} \right) \left( \frac{f_N}{f} \right)^6 \times \left( \frac{f}{f_N} \right)^{1.6} \times P_0
\]

\[
I_{Ra} = \frac{P_s}{U_s}
\]

In the formula, \(U_s\) is the test voltage, kV; \(f_s\) is the power frequency during the test, 250Hz; \(P_0\) is the no-load loss of the converter at 50Hz, kW; \(I_{Ra}\) is the active current, A; \(U_N\) is the rated voltage, kV; \(f_N\) is the rated frequency, Hz. The estimated values of active power loss and active current of the tested transformer under different voltages are shown in Table 1.

| parameter name | Test voltage | Calculated |
|----------------|--------------|------------|
| \(P_s / kW\)  | 1.5U_s / √3 | 319.44     |
|               | 1.3U_s / √3 | 242.74     |
|               | 1.1U_s / √3 | 178.48     |
| \(I_{Ra} / A\) | 1.5U_s / √3 | 1.21       |
|               | 1.3U_s / √3 | 1.06       |
|               | 1.1U_s / √3 | 0.92       |

5. Conclusion

The paper analyses the partial discharge test phenomenon and the handover test standard of the transformer when it leaves the factory, and proposes and compares the on-site partial discharge test schemes of two UHV AC transformers with symmetrical voltage and unilateral voltage. The following conclusions can be drawn through the verification of the on-site handover test: a) The UHV transformer has a high-test voltage and is prone to interference such as external floating discharge and casing corona discharge. b) UHV transformer handover test standards are strict, requiring high requirements for field equipment and shielding measures. c) It is verified by the on-site handover test that the UHV transformer can meet the requirements of the handover test standard and the unilateral pressure test scheme is feasible.

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