Analysis on the schemes of 330kV Power Transformer Long Time Induced Voltage field Test based on GB/T1094.3 release version

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Abstract. The principles of 330kV power transformer long time induced voltage field test are introduced in the paper, the varieties of key elements on the test are analysed on GB/T1094.3 release version, some suggestions about test and schemes are suggested finally.

1. Introduction
According to the provisions of GB50150-2016 ‘Electrical Equipment Installation Engineering Electrical Equipment Handover Test Standards’, On-site long-term induction voltage test is the most important handover test project after transformer installation is completed, Can check the insulation status of the transformer effectively, In this way, the quality of the transformer transportation, installation and other aspects are verified, and the safe, reliable and stable operation of the transformer is guaranteed. The method of on-site long-term induced voltage test is specified by national standard GB/T1094.3 ‘Power transformers Part 3: Insulation level, insulation test and external insulation air gap’ The GB/T1094.3-2017 release In this year replaces the previous test standard GB1094.3-2003 [3], As a result, various terms of the induction withstand voltage test have also changed. According to these changes, the 330kV transformer on-site long-term induced voltage test scheme is analyzed and revised, which is necessary for scientific and reasonable testing.

2. The principle of Testing and key elements
When the induced voltage test is carried out, by applying the test device equipped with the test, the test voltage is applied to the low-voltage winding of the test article, and the low-voltage winding generates a magnetic field due to the current flowing, by means of the principle of electromagnetic induction, in the test object The high voltage winding will also produce the corresponding test voltage [4], As shown in Figure 1.

Figure 1. The principle of Testing
The key elements of the test are the test voltage value, the sequence of applying different test voltages, the time to maintain under different test voltages, the requirements of partial discharge measurement, the requirements of background noise level, the test qualification criteria, etc[5]. The test process can be divided into seven stages, each applying a different voltage and continuing for different times, as shown in Figure 2.

\[ U_4 \] is reached after the current test voltage rises from zero, Hold time \( T_1 \), which is the first stage of the test. At this stage, the test voltage is low. It is necessary to observe the partial discharge measurement background of the whole test circuit, and whether there is abnormal partial discharge, so as to judge whether the test can be continued. There is no clear time in this stage, and you can continue to boost after completing background monitoring and other work. The test voltage continues to rise to \( U_1 \) for the time \( T_2 \). This is the second stage of the test. At this stage, the test voltage has reached the level of the normal operating voltage of the transformer. During the test, it is necessary to observe whether there is abnormal partial discharge or partial discharge. Whether the quantity grows. The test voltage continues to rise to \( U_2 \) and maintains time \( T_3 \). This is the third stage of the test. The test voltage has reached the partial discharge measurement voltage, which is higher than the normal operating voltage of the transformer. At this stage, the partial discharge should be observed. Situation, assess whether it is possible to continue to increase the test electricity. The test voltage continues to boost up to \( U_4 \) for the time \( T_4 \), which is the fourth stage of the test. This stage has the highest test voltage. This voltage is also called the boost voltage and is used to simulate the overvoltage that may be experienced in the operation of the transformer. To stimulate potential partial discharge, the test time in this stage is short, and it needs to be converted according to the frequency of the test voltage. After that, the test voltage is reduced to \( U_3 \) and the hold time is \( T_5 \). This is the fifth stage of the test. The test voltage is the partial discharge measurement voltage and the duration is long. The main check is that the transformer is subjected to the analog overvoltage for a long time. Partial discharge situation. The test voltage continues to decrease to \( U_4 \), and the hold time is \( T_6 \). This is the sixth stage of the test. The test voltage at this stage is the same as that of the second stage. The monitored partial discharge condition should be no significant change compared with the second stage. The test voltage continues to decrease to \( U_4 \) for the time \( T_7 \). This is the seventh stage of the test. The test voltage at this stage is the same as that of the first stage. The monitored partial discharge should be unchanged from the first stage. There is no clear time, after the completion of the PD monitoring and other work can continue to reduce the pressure; after that the test voltage drops to zero, the test is over. At different stages of the test, the requirements for partial discharge monitoring, background noise levels, and qualification criteria are also different.
3. Analysis of changes in test protocols

3.1. Test voltage and hold time

GB/T1094.3-2017 and GB/T1094.3-2003, in the seven stages of the test, the test voltage and the holding time have undergone some changes, as shown in Table 1.

| Standard version | 2017 | 2003 |
|------------------|------|------|
| The first stage  | $U_4$ | $(0.4 \times U_r)/\sqrt{3}$ | $0.5U_m/\sqrt{3}$ |
|                  | $T_1$ | Not specified | Not specified |
| The second stage | $U_2$ | $(1.2 \times U_r)/\sqrt{3}$ | $1.1U_m/\sqrt{3}$ |
|                  | $T_2$ | $\geq 1\text{min}$ | 5min |
| The third stage  | $U_2$ | $(1.58 \times U_r)/\sqrt{3}$ | $1.5U_m/\sqrt{3}$ |
|                  | $T_3$ | $\geq 5\text{min}$ | 5min |
| The fourth stage | $U_1$ | $(1.8 \times U_r)/\sqrt{3}$ | $1.7U_m/\sqrt{3}$ |
|                  | $T_4$ | Time converted by frequency | Time converted by frequency |
| The fifth stage  | $U_2$ | $(1.58 \times U_r)/\sqrt{3}$ | $1.5U_m/\sqrt{3}$ |
|                  | $T_5$ | 60min | 60min |
| The sixth stage  | $U_3$ | $(1.2 \times U_r)/\sqrt{3}$ | $1.0U_m/\sqrt{3}$ |
|                  | $T_6$ | $\geq 1\text{min}$ | 5min |
| The seventh stage| $U_4$ | $(0.4 \times U_r)/\sqrt{3}$ | $0.5U_m/\sqrt{3}$ |
|                  | $T_7$ | Not specified | Not specified |

Compared with the 2003 version of the standard, the benchmark of the test voltage changes. The 2003 version is based on the highest voltage $U_m$ of the device. The 2017 version is based on the rated voltage of the winding $U_r$, but the final test voltage value is not obvious. Take the common 330kV transformer with rated voltage of 345kV as an example. The pair of test voltage values is shown in Table 2.

| Standard vision | $U_4$ | $U_3$ | $U_2$ | $U_1$ |
|-----------------|------|------|------|------|
| 2017            | 79.7 | 239.0 | 314.7 | 358.5 |
| 2003            | 104.8| 230.5| 314.3 | 356.3 |

For the 330kV transformer with rated voltage of 345kV, the test voltage of the first and seventh stages has a certain range of reduction. The test voltage of these two stages is relatively low, and these reductions have no effect on the test itself. The test voltages in the second and sixth stages increased slightly; the partial discharge measurement voltage increased slightly, and the enhancement voltage decreased slightly.

The holding time of the test voltages in the first, fourth, fifth and seventh stages did not change; in the second and sixth stages, the holding time of the 2003 version was 5 min, and the 2017 version was not less than 1 min. The main work of the two stages was to monitor the local the background value of the discharge, this change can improve the test efficiency to a certain extent; in the third stage, the hold time of the 2003 version is 5min, and the 2017 version becomes no less than 5min. The main work of this stage is to monitor the partial discharge and determine whether the transformer can continue to test to withstand the enhanced voltage, in the case of abnormal discharge signals, the appropriate extension of the observation time is more conducive to making a
correct judgment.

### 3.2 Partial discharge measurement requirements and test qualification criteria

The 2003 version of the standard requires no more than 100 pC for the partial discharge background noise level. The 2017 version specifies a background noise level of no more than 50 pC and is measured at the beginning and end of the test. This change is not demanding for laboratory tests. However, in the field test, due to the complexity of the on-site interference signal, the difficulty of the test is increased. The same power source and other construction equipment on the same ground network should be deactivated as much as possible to eliminate. Interference [6].

The difference between the two versions of the standard in the test qualification criteria is mainly related to the partial discharge amount, as shown in Table 3.

#### Table 3. The comparison of testing qualification criteria

| Standard vision | 2017                                                                 | 2003                                                                 |
|-----------------|-----------------------------------------------------------------------|-----------------------------------------------------------------------|
| a)              | Test voltage does not drop suddenly                                   | Test voltage does not drop suddenly                                   |
| b)              | Within one hour of the partial discharge test, the discharge record was recorded without a partial discharge of more than 250 pC. | During the long-term test U2 of the partial discharge test, the continuous level of partial discharge is required to be less than or equal to 500 pC. |
| c)              | During the partial discharge test at 1h, the partial discharge level did not increase; there was no sudden increase in the partial discharge level in the last 20 min; | Partial discharge does not exhibit a continuous increase under U2, and it is not necessary to record a higher amplitude pulse during the test. |
| d)              | During the 1h partial discharge test, the increase in partial discharge level does not exceed 50 pC; | The continuous level of apparent charge is less than or equal to 100 pC at \(1.1U_n/\sqrt{3}\) voltage. |
| e)              | The partial discharge level measured when the voltage drops to \((1.2 \times U_n)/\sqrt{3}\) 1h after partial discharge measurement does not exceed 100 pC |                                                                 |
| f)              | If the criteria of item c) or d) are not satisfied, the period measurement time of 1 h may be extended, and if the above conditions are satisfied in the subsequent consecutive 1 hour period, the test may be considered acceptable. |                                                                 |

The partial discharge of the 2003 version of the standard is 500pC, and the 2017 version of the standard is 250pC, which is more stringent; in terms of partial discharge changes, the 2003 version of the standard states that "the partial discharge does not show a continuous increase under the test voltage \(U_2\)"; and the 2017 version of the standard stipulates that "the partial discharge level does not increase during the partial discharge test. There is no sudden increase in the partial discharge level in the last 20 minutes; during the partial discharge test, the increase in the partial discharge level does not exceed 50pC", the 2017 version of the standard The regulation of partial discharge changes is more detailed and easier to judge the operation. In the 2017 version of the standard, the extension of the test time is also added. For transformers with partial discharges that do not meet the requirements, the test time can be extended for further observation.

#### 3.3 The power supply of Testing

The 2003 version of the standard stipulates that a three-phase transformer can be used for three-phase symmetrical pressurization with a three-phase power supply, or a single-phase power supply for phase-
by-phase pressurization test; in the 2017 version, it is stipulated that "three-phase transformers should be pressurized with three-phase symmetrical voltage" More rigorous than the 2003 version. For laboratory tests, generators are usually used as test power sources. It is not difficult to achieve three-phase symmetrical voltage pressurization. In field tests, the test power source is usually a variable frequency parallel resonant system. The three-phase transformers have inherent differences in equivalent parameters. The three-phase variable-frequency parallel resonance system is difficult to achieve the consistency of three-phase synchronous regulation in the test. In the test, the three-phase test voltage will be inconsistent, and sometimes the deviation will be relatively large. Therefore, the field test uses a three-phase symmetrical voltage. Pressurization is difficult to achieve and it is difficult to achieve the test results.

4. Conclusion

(1) The benchmark of the test voltage at different stages of the 2017 version of the standard has changed. The rated voltage of the transformer winding is used as the reference voltage. The test voltage of the transformer with the same voltage level and different rated voltage will be different.

(2) The 2017 version of the standard requires more stringent requirements for the partial discharge, and at the same time refines the judgment criteria for the partial discharge growth in the test; for the transformer with abnormal partial discharge growth, the requirement for prolonging the test time is increased to facilitate further judgment.

(3) The 2017 version of the standard stipulates that “three-phase transformers should be pressurized with three-phase symmetrical voltages”, but this requirement should be treated with caution. When the test equipment cannot meet the three-phase symmetrical voltage in the field, the single phase test can also achieve the test results.

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