A Novel Method for Distribution Transformer Short-circuit Test

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Abstract. Short-circuit test of distribution transformer is an important test to check out the short-circuit resistance of distribution transformer. This paper presents a novel short-circuit test method of distribution transformer based on energy storage short-circuit test device, which can complete the short-circuit field test of distribution transformer. The basic principle of the device is introduced, and the feasibility of the method is verified by simulation and experiment.

1. Introduction
In the process of transformer operation, it may be impacted by short-circuit current. For example, when the transformer is in normal operation, there is a sudden short circuit fault in the secondary side, and a large over-current will appear in the winding[1]. Under the action of short-circuit current, it will produce huge electric power to all parts of the transformer and make the winding temperature of the transformer rise rapidly. Although this process lasts for a short time, it is a severe test on the short-circuit dynamic stability and heat resistance of the transformer[2,3].

Short-circuit test is the mechanical strength withstand test of transformer under the action of short-current. It is an assessment of the comprehensive technical ability and technological level of transformer manufacturing. In the case of sudden short-circuit of distribution transformer, huge short-circuit force will be produced in the winding. If the transformer design is not perfect and the short-circuit resistance is not enough, such huge short-circuit force will damage the winding insulation and structural parts, affect the insulation performance of the transformer, or loose the winding, twist and deformation, break the wire, or even collapse the whole winding, or due to insulation loss The winding is burnt out due to the turn to turn short circuit[4,5].

If a transformer is short-circuit damaged during the operation of the system, it will lead to a large area of power failure. At the same time, it is very difficult to repair the damaged transformer winding on site. The repair of the transformer is not only limited by the lifting conditions of the site, but also has strict requirements on the climate, environment and season[6]. It is difficult to meet the requirements of the maintenance process on site, and it is generally well repaired on site. It is almost impossible, so many transformers have to return to the factory for repair or renovation after short circuit fault, and the maintenance period will be more than half a year, which will cause huge economic losses.

Therefore, it is necessary to assess the short-circuit current withstand level before or during the actual operation of the transformer. Large capacity transformer will produce large short-circuit current under short-circuit condition. At present, only a few national test stations can complete large-scale transformer short-circuit test[7]. However, the establishment of the test station requires a large amount of initial investment, and in the process of test, it is necessary to send the factory or repaired transformer to the
test station for short-circuit capacity test, so the test cost is large. For small capacity distribution transformer is commonly used, and the short-circuit current is small, so a novel method is needed to realize the on-site verification of transformer short-circuit test.

2. **Energy storage short-circuit test device**  
The energy storage short-circuit test device is composed of four units: incoming line unit, phase-shifting transformer, frequency converter and output filter, which is shown in Figure 1.

![Fig.1 Principle block diagram of energy storage short-circuit test device](image1.png)

The specific working mode of the device is as follows: the incoming line unit completes the switching of 10kV power supply; the phase-shifting transformer converts 10kV power supply into 36 groups of three-phase power supply after phase shifting to supply the power unit of high-voltage variable-frequency power supply; the variable-frequency power supply is composed of 36 three-phase rectifier single-phase bridge inverter power units, 36 power units are divided into 2 groups, and the output of each group of 18 power units is in series. The highest 11kv frequency conversion power supply can be obtained at the head and tail end of the power unit; after the two groups of power units are connected into V-type connection, the output can get 10kV three-phase power supply.

The principle of power unit is shown in Figure 2.

![Fig.2 Principle block diagram of power unit](image2.png)

Two groups of power units operate in parallel and can output two times of current. Each phase output through LC filter can make the output waveform smoother and obtain smaller harmonics. If more current output is needed to adapt to different load requirements, the synchronous interface can be reserved in the control system to meet the needs of parallel operation.

In the unit, a, b and c are a group of windings from the phase-shifting transformer, and ac1 and ac2 are the inverter outputs of the power unit. When SPWM pulse signal is applied to the control poles g1, g2, g3 and g4 of IGBT, the output voltage of single-phase pulse width modulation can be obtained at the output terminals ac1 and ac2, and the total output voltage of multiplying the number of cells by the cell voltage can be obtained when multiple cells are cascaded.

The wiring principle of inverter three-phase power output is shown in Figure 3.
Fig. 3 Wiring diagram of three-phase power

The input of each power unit in the figure uses an independent voltage source to represent a group of windings on the secondary side of the phase-shifting transformer; the output of each power unit in each group is connected in series, and the 10kV high-voltage output can be obtained between the head end of the first unit and the tail end of the last unit, and the three-phase 10kV output power can be obtained after the two groups are connected into V-type wiring.

In single-phase application, the high-voltage output contactor automatically shortens the two output terminals A and C, and the single-phase power supply is led out from the terminal between A and B. The wiring principle of single-phase power output is shown in Figure 4.
3. Short circuit current calculation

This paper takes distribution transformer S11-200/10 as the research object, which capacity is 200kVA. The high voltage short circuit impedance under each tap is shown in Table 1.

| Tap | Short circuit impedance $zt\%$ | Short circuit impedance $Z_t(\Omega)$ | Short-circuit reactance $X(\Omega)$ | Resistance component $R(\Omega)$ |
|-----|-------------------------------|-------------------------------------|-----------------------------------|-------------------------------|
| 1   | 4.10                          | 22.60                               | 21.84                             | 5.80                          |
| 3   | 4.03                          | 20.15                               | 19.39                             | 5.49                          |
| 5   | 3.95                          | 17.82                               | 17.05                             | 5.18                          |

Fig. 4  Wiring diagram of Single-phase power
In equation (1):

\[ Z_t = \frac{U_t^2 \times z_s}{100S}, \]
\[ Z_s = \frac{U^2}{S}, \]
\[ I_{sc} = \frac{U}{\sqrt{3}(Z_s + Z_t)}, \]
\[ I_{sc} = I_{sc}/\sqrt{3}, \]
\[ i_p = K\sqrt{2}I_{sc}. \]

\[ (1) \]

In equation (1):

\( Z_t \) is short-circuit impedance of sample.

\( Z_s \) is short-circuit impedance of system. The system impedance is less than 5% of the short circuit impedance, which is ignored.

\( S \) is apparent capacity, which is 500MVA according to the standard.

\( I_{sc} \) is RMS value of line symmetrical short circuit current.

\( I_{sc} \) is RMS value of phase symmetrical short circuit current.

\( i_p \) is first peak of phase asymmetric short circuit current.

According to the calculation, the short-circuit test current under each tap can be obtained as shown in Table 2.

| Tap | Phase | \( i_p \) (A) | \( I_{sc} \) (A) | \( I_{sc} \) (A) | Peak coefficient |
|-----|-------|---------------|-----------------|-----------------|-----------------|
| 1   | A     | 293           | 155             | 268             | 1.889           |
| 3   | B     | 309           | 166             | 287             | 1.867           |
| 5   | C     | 328           | 178             | 308             | 1.843           |

**4. Test verification**

According to the calculated short-circuit current, the energy storage short-circuit test device is used to carry out the field test. The two groups of power units are connected into V-shape and output three-phase power. The distribution transformer and field test is shown in Figure 5.

![Fig.5 (a)S11-200/10 distribution transformer, (b)Field test](image)

According to the standard, 100% short-circuit current was applied to the three phases in turn for three times, and a total of nine tests were carried out on the three phases. In this test, the waveform was abnormal during the phase B 1-tap test, and the test was stopped for a total of 4 times. The test current waveform is shown in Figure 6-9.
Fig. 6 Three phase current waveform of 1-tap, 1st test

Fig. 7 Three phase current waveform of 1-tap, 2nd test
The reactance values of the transformer before and after the test are measured, and the results are shown in table 3.
Table 3 Reactance measurement results of 1-tap test

| Times     | Reactance measurement | Phase reactance deviation (%) |
|-----------|------------------------|------------------------------|
|           | Phase reactance value (Ω) | A | B | C | A | B | C |
| Before test | 21.38 | 20.79 | 20.78 | / | / | / |
| 1st test   | 22.47 | 20.81 | 21.70 | 5.07 | 0.06 | 4.46 |
| 2nd test   | 22.65 | 20.83 | 21.54 | 5.91 | 0.19 | 3.69 |
| 3rd test   | 22.83 | 20.86 | 21.39 | 6.75 | 0.34 | 2.95 |

After the first test of phase B 3-tap, the reactance cannot be measured.

According to Figure 6-9 and Table 3, during the first test of phase B 3-tap, the current waveform is distorted, and the reactance cannot be measured which is beyond the allowable range of the standard. So it can be judged that the test distribution transformer is unqualified.

In order to verify the correctness of the judgment results, the core hanging inspection of the transformer is carried out, as shown in Figure 10-11.

Fig.10 Before test

Fig.11 After test

Compared with Figure 10 and 11, it can be seen that under the impact of short-circuit force caused by short-circuit current, the c-phase winding is seriously deformed after short-circuit test, and the short-circuit test of the distribution transformer is unqualified. The feasibility of energy storage short-circuit test system to carry out short-circuit test of distribution transformer is verified.
5. Conclusion

This paper introduces the basic principle of energy storage type short circuit test device. Taking S11-200/10 distribution transformer as the research object, the short-circuit current is calculated according to the transformer parameters, and the short-circuit test is carried out based on the energy storage short-circuit test device.

The test results show that the energy storage short-circuit test device can complete the field short-circuit test of distribution transformer and get accurate results, which verifies the feasibility of the device for short-circuit test of distribution transformer. It provides a novel test method for short-circuit test of distribution transformer, solves the problem of field test, and has certain application value.

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