Mechanical Design and Electrical Experiment of Large Current Connector for Transformer Terminal and Drain Wire in Distribution Network

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Abstract: The terminal and the drain wire of distribution transformers are generally connected by bolts, which appears not only reliable, convenient and simple in connection and assembling, but also easy to disassemble. However, the bolt connection is prone to fail, and it is easy to loosen under force. In this paper, a bolt-free quick connection design is proposed, which introduces a large current connector plug-in structure between the voltage side terminals of the transformer and the drainage line instead of the existing bolt connection. Through the experiments performed, the performance test indicators of the large-current connector after being connected to the transformer seems to meet the requirements, and is suitable for extreme environment with humidity, dust, ultraviolet rays and other harsh, which effectively improves the flexibility and convenience of the distribution transformers operation.

1. Introduction
The safe operation and service life of the distribution transformer depend on the connection design of the transformer terminal and the drain wire. Under extreme environmental conditions, the commonly used bolt connection design of the distribution transformers have affected the normal use of the transformer, and it is necessary to optimize the connection design of transformer terminals and drain wires. Literature [1] proposes the use of fixed bolts in the installation of pipeline brackets in order to facilitate construction, which has poor dynamic load resistance and limited bearing capacity. Literature [2] proposes to increase the contact surface through surface treatment, which may effectively reduced the looseness of the bolt connection through the friction force of the large-strength bolt. Literature [3] proposes that the large-strength bolt seems better seismic performance, but the connection will still be loosen off by the extreme external environment. Literature [4] proposes that the rust and paint layer on the flange contact surface are thoroughly cleaned, which is polished to solve the heating failure of the bolts along the transformer bell box. Literature [5] proposes a method to deal with the overheating of the bolts, so that replaces the original one with epoxy insulating gaskets. Moreover, one of the bolts is connected to the ground wire, thereby the floating potential is eliminated and the bolts are no longer overheated. Literature [6] analyzes the reason for the discharge of the bolts installed on the bracket beside the body of the distribution transformer, which changes the bolt insulation to the integral polyester insulation sleeve so that the mechanical strength of the bolt insulation is further improved. In summary, the research and application of boltless connection for distribution transformers seems rare. This paper proposes a new mechanical plug-in structure of the connector which is used in the side
terminals and drain wires of a distribution transformer. In addition, the relevant indicators of the large current connector after being connected to the transformer are tested with good performance.

2. Mechanical design scheme of the large current connector

2.1. Parameter settings

Combining with the requirements of the low-voltage side of the distribution transformer, the mechanical design scheme of the large-current connector is proposed. The technical parameters are shown in the following table:

| Item                           | Parameter       | Item                           | Parameter |
|--------------------------------|-----------------|--------------------------------|-----------|
| Rated current                  | 600A            | Temperature rise at 1.5 times rated load | Temperature rise of transformer tank housing and connectors for continuous operation for 2 h \((K)\leq85\) |
| Rated voltage                  | 400V            | Plug use-life \(\geq1000\) times |
| Insulation resistance          | \(\geq5000\)MΩ | Flammability rating \(\text{UL 94V-0}\) |
| Contact resistance             | \(\leq0.02\)mΩ | Protection level \(\text{IP67}\) |
| Withstand voltage level        | \(\geq5000\)V  | Operating temperature \(-40-+80\)℃ |
| Temperature rise under rated load | Transformer top oil temperature rise limit \((K)\): the part in the air\(\leq55\), the part in the oil\(\leq15\) | Salt spray grade \(48\)H neutral salt spray |

In order to meet the requirements of the above technical parameters, a large-current connector is designed to connect the terminals: 18.0 turn spring terminals is selected with rated current 630A. 300mm² cable is connected so as to control the compression size and ensure the wire harness maintaining force beyond 4700N.

2.2. Insulation structure

According to the insulation performance requirements in the GB/T16935.1-2008/IEC60664-1:2007 standard, the electrical insulation distance and creepage distance are found. The insulating material used in this design is imported PA66, which is doped with anti-corrosion, anti-ultraviolet and other fillers during the molding process, in order to ensure its withstand voltage and insulation resistance. The insulation structure is shown in Figure 1. Because the transformer will experience rain and other erosion during long-term outdoor operation, the insulation performance and the insulation resistance value to the ground should be improved, so that the safety margin is set to 1.2.

![Figure 1. Insulation structure](image)

The optimized design of the plug and socket structure of the quick plug-in large-current connector is shown in the figure below.
3. Electrical performance test of large current connector

3.1. Transformer no-load test

In order to evaluate the working effect of the large-current connector installed on the distribution transformer, the no-load loss and no-load current of the transformer are necessary to be measured, which used to verify whether the design calculation and manufacturing process of the transformer core meet the standards, such as overheating and partial insulation.

According to GB/T 1094.11-2007, the transformer’s no-load test conditions: ambient temperature (5℃~40℃), humidity (0~93%RH). The accuracy of the transformer should not be less than 0.2, and the accuracy of the instrument should not be less than 0.5. The rated voltage with the rated frequency is applied to the low-voltage winding and the large-voltage winding is open, so that the no-load loss and no-load current are measured.
3.2. Transformer load test
The load test of the distribution transformer is carried out, and the load loss and short-circuit impedance are measured after the large-current connector is installed in the transformer, so that calculates the operating efficiency of the transformer.

Figure 4. (a) Test diagram, Figure 4. (b) Physical environment

Transformer load test conditions: ambient temperature (5°C~40°C), humidity (0~93%RH). The accuracy of the transformer should not be less than 0.2, and the accuracy of the instrument should not be less than 0.5. According to GB/T 1094.11-2007, a voltage similar to a sine wave is applied to the large-voltage winding at rated frequency, and the low-voltage winding is short-circuited. While the applied voltage winding current reaches the rated current, the rated current can be less than 50% and the measured load loss value is multiplied by the square of the ratio of the rated current to the test current.

3.3. Transformer temperature-rise test
Distribution transformer temperature-rise test includes, 1) checking the temperature-rise of windings, iron cores after the large-current connector is installed in the transformer, 2) obtaining the relevant parameters of the transformer in the working state and the overload state. Test Conditions include: 1) GB/T 6451-2015 oil-immersed power transformer technology and GB/T 1094.2-2013 Temperature-Rise of Power Transformers, the short-circuit method. 2) In the first stage, the total loss should be 4898W, and the actual total loss should be 4898W. A current of 23.1A is applied to the primary side, and the transformation ratio is 25, which is equivalent to an applied current of 577.5A on the low-voltage side.3) Under the second stage of overload, a current of 34.2A is applied to the primary side, which is equivalent to a current of 855A applied to the low-voltage side.

Figure 5. Physical image of temperature-rise experiment of distribution transformer
4. Test results and analysis

4.1. No-load test results

The no-load experimental data of the distribution transformer is shown in Table 2:

| Line voltage (V) | Line current (A) |
|------------------|------------------|
| AB | BC | CA | Average |
| 401.77 | 399.96 | 400.11 | 400.61 |
| Average |
| AB | BC | CA | Average |
| 401.20 | 399.63 | 399.55 | 400.13 |

| Average voltage (V) | Active power (kW) |
|---------------------|------------------|
| AB | BC | CA | Average |
| 401.20 | 399.63 | 399.55 | 400.13 |
| 0.05 | / | 0.34 |

After the large-current connector is installed in the distribution transformer: 1) the no-load loss of the distribution transformer is 0.3932kW, which is less than 0.57kW, and 2) the no-load current of the distribution transformer is 0.1488%, which is less than 0.8%, and 3) the experimental results meet the requirements of relevant standards and technical specifications.

4.2. Load test results

The distribution transformer load test data is shown in Table 3:

| Line voltage (V) | Line current (A) |
|------------------|------------------|
| AB | BC | CA | Average |
| 238.70 | 237.30 | 237.16 | 237.72 |
| 13.46 | 13.56 | 13.50 | 13.51 |

| Active power (kW) | Data after temperature correction |
|-------------------|----------------------------------|
| AB | BC | CA | Load loss | Impedance voltage (%) | Short circuit impedance | Load loss (kW) |
| -0.94 | / | 2.17 | 1.23 | 4.12 | 10.30 | 4.50 |

After the large-current connector is installed in the distribution transformer, 1) the short-circuit impedance of the distribution transformer meets the requirements, and 2) the load loss of the distribution transformer is 4.51kW, which is less than 4.52kW, and 3) the experimental results meet the requirements of relevant standards and technical specifications.

4.3. Temperature-rise test results

The experimental data of temperature-rise distribution transformer is shown in Table 4. The average temperature-rise of the large-voltage winding is 60.7K, the average temperature-rise of the low-voltage winding is 60.5K, and the temperature-rise of the top oil is 40.1K, which meets the temperature rise requirements. Finally, the corrugated sheet of the fuel tank is not deformed.

| Item | Ambient temperature | Top oil temperature | Inlet temperature of Radiator | Outlet temperature of radiator |
|------|---------------------|---------------------|-------------------------------|-------------------------------|
As shown in Figure 6, in the temperature-rise test of the distribution transformer, the winding environment temperature is 20.3°C. 1) Under large-voltage load, the winding resistance starts at 2.8Ω, and the winding resistance will gradually decrease, and the winding temperature-rise is 59.7K. 2) Under low-voltage load, the winding resistance starts at 0.004089Ω, and the winding resistance will gradually decrease, and the winding temperature-rise is 59.5K.

5. Conclusions
Aiming at the bolt connection between the large and low voltage side terminals of the distribution transformer and the drain wire, this research proposes an alternative design for the mechanical plug structure of the large current connector. After the electrical experiment on the transformer with the new large-current connector connected, it shows that 1) the mechanical performance of the practicability and convenience is improved, and 2) the test indicators of the electrical performance meet the requirements of national standards and technical specifications, and 3) it is suitable for outdoor working environments with rain, humidity, dust, ultraviolet rays and other harsh.

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