Development of a Comprehensive Transformer Material System Analyzer

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Abstract. In view of the phenomenon that the existing dry-type distribution transformers are replaced by aluminum and copper, there is no aluminum wire or aluminum wire-wrapped dry-type transformer standard for distribution in China, and it is impossible to accurately detect whether the dry-type transformer exists in aluminum-based copper. Based on this situation, a high-precision distribution network dry-type transformer comprehensive test system is developed. This system is a combination of transformer property testing, material testing, capacity testing, direct resistance testing, and ratio-ratio testing. It is for dry-type transformers. A high-precision comprehensive test system specially developed. The data conversion method of DC resistance and transformer capacity is mainly used. The method of accurately measuring the transformer ratio and the method of determining the material based on the transformer current density are used to detect whether the dry transformer is replaced with aluminum and copper. Accurately testing the transformer capacity can accurately detect whether the user changed or replaced the transformer nameplate. It can also accurately measure power frequency parameters such as capacity, load loss, no-load loss, impedance voltage, and no-load current of various transformers, thereby improving the ability to detect the quality of power equipment.

1. Introduction
In view of the existing phenomenon that distribution transformers are sub-assembled with aluminum-based copper, and there is no aluminum foil or aluminum wire-wrapped distribution dry-type transformer standard in China, it is impossible to accurately detect the existence of dry-type transformers in aluminum-based copper. The problem [1]-[3], through the implementation of this project, develops a high-precision distribution network dry-type transformer comprehensive testing system to accurately measure the transformer capacity and accurately measure the power frequency parameters such as load loss, no-load loss, impedance voltage, and no-load current. And can accurately detect whether the user changed, change the transformer nameplate, improve the ability to detect the quality of electrical equipment [4], [5].

In the current production of distribution transformers, using aluminum wire instead of copper wire as a conductor material has become an unspoken rule in the industry. The main reason [6] for this is that aluminum wire transformers can reduce costs compared to copper wire transformers and have strong Economical. Transformer is a kind of static electrical equipment made according to the principle of electromagnetic induction. It has the functions of transforming voltage, converting current, and transforming impedance. It is widely used in various fields of engineering [7]. If the transformer uses aluminum wire instead of copper wire, it will cause large power consumption and poor quality of power.
First of all, in principle [8], the two are used as conductive materials. The difference lies in the difference in conductivity. The copper wire has higher conductivity than aluminum wire, and the copper wire has lower power loss, which ultimately leads to the quality of the user's electricity. The difference. From the cost point of view, the difference between copper and aluminum wire is also the price, the same unit of copper wire is about twice the price of aluminum wire. Transformer companies use dry-type transformers to make them bulky and take up a lot of space. In addition, copper wires have higher thermal conductivity than aluminum wires. In terms of safety, long-term use of copper wires has advantages over aluminum wires [9] 

If there are aluminum wires instead of copper wires in the tendering project, there will be serious infidelity. The development of a comprehensive analysis and detection system for the characteristics and materials of dry-type transformers in distribution networks is a combination of characteristics testing, material testing, capacity testing, direct resistance testing and ratio-ratio testing of transformers [10]. It is a high-precision developed specifically for dry-type transformers. The comprehensive test system can easily detect whether the dry-type transformer is filled with aluminum and copper, and can accurately test the transformer capacity, and can accurately detect whether the user changes or replaces the transformer nameplate. It can also accurately measure power frequency parameters of various transformers such as capacity, load loss, no-load loss, impedance voltage, and no-load current [11].

1.1 Project significance
In China, dry-type transformers with only copper or copper wire for dry-type transformers have no standard for dry-type transformers with aluminum foil or aluminum wire, and the aluminum dry-type transformers produced must have copper or copper foil wound around the nameplate. The nameplate of the transformer is actually inconsistent with the nameplate, and the enterprise is falsified [12]. Nowadays, transformers made of dry aluminum in the country can be seen everywhere. Therefore, it is an urgent requirement of the law enforcement agencies to investigate and deal with irregularities and illegally produce dry aluminum transformers. The development of a comprehensive analysis and detection system for the characteristics and materials of dry-type transformers in distribution networks is the first in China and will fill the gaps in the country [13].

1.2 Application prospect
The results of the project research on the identification of dry-type transformers have been adapted to the current requirements for improving the safety and reliability of power systems. They can reduce the maintenance costs of dry-type transformers and reduce the number of maintenance. Therefore, they have a very good application prospect. Based on the research results of the project, it is possible to discover the potential hazards of aluminum-wound dry-type transformers in a timely manner, avoid sudden accidents, and improve the safety and reliability of operations. It is of great significance to apply them in practice.

2. Analysis of dry transformer material synthesis system

2.1. Dry-type transformer test system principle analysis
The related theories of transformers and conductor materials have been studied in depth, and certain researches and researches have been carried out on the production process of transformers and the manufacturing processes of various components. Among them, there are several key points that affect the data:

- Transformer line package design: including high and low voltage turns number design, high and low voltage wire diameter (cross-sectional area) design, different conductive materials, different turns and cross-sectional area requirements;
- Transformer insulation: including internal and external Insulation, wire insulation, etc.

There are many parameters in the transformer design calculation, including core-related dimensions, magnetic flux, package size, wire diameter, winding method, and insulation method. There are also DC resistance, loss, and short-circuit impedance of the wire package. A careful analysis of these parameters reveals that none of the parameters are unique characteristics of copper or aluminum
materials. For example: DC resistance, the direct current resistivity of aluminum material is larger than copper, but can reduce the DC resistance of aluminum winding by increasing the cross-sectional area. In our study of transformer manufacturing related processes, we found a parameter - "current density." This parameter has its own range of values for copper and aluminum in design data and does not overlap. Therefore, after a long period of analysis and discussion, it was decided to try to determine the material of the transformer winding through the current density parameter. Determined by the use of current density parameters to determine the transformer winding conductor material. Next, we need to follow this direction and study the relevant data and processes in detail to obtain a solution: from the transformer's external geometry and measured parameters such as winding currents, calculate and analyze the current density data. The current density, whether it is from the design and calculation link or the test and verification link of the finished transformer, is a calculation parameter and should not be directly tested under the current technical conditions. In order to obtain the current density data, we need to obtain a series of parameters before we can calculate the current density. Known data:

- Transformer winding size, including package height, high and low pressure package thickness;
- The nameplate parameters of the transformer, including capacity, voltage and so on.

Current density, in the design and calculation of dry-type transformers, there are some guiding suggestions. The choice of current density for dry power transformers will directly affect load loss, temperature rise, short circuit mechanical force and material consumption. Normally when dry-type transformers are wound with copper wire, the current density can be selected with a higher initial value of 2-2.6A/mm², while the aluminum wire can be taken with 1.2-1.4A/mm². When the foil-type winding is used, foil is taken into consideration. Due to the skin effect, the current distribution is uneven, so that the current density can be selected to be 2% to 5% lower than the wire winding. Comprehensive calculation data and transformer manufacturer's actual production plan, usually transformer windings using copper material, the current density of about 2A/mm² or more, usually transformer windings using aluminum material, the current density is about 1A/mm² or so, sometimes low In 1A. There is a significant difference in the current densities of the two materials, and the maximum current density of the aluminum material does not coincide with the minimum current density of the copper material. When the transformer is a qualified transformer, the current density of copper and aluminum can be distinguished.

From the above studies, we can find that in this project, if we can accurately obtain a transformer's rated current and conductor cross-sectional area, we can calculate and analyze the transformer's conductor current density, and then analyze the conductor material. After analysis, to achieve material judgment, it is necessary to accurately obtain the cross-sectional area of the transformer and the true rated current. The rated current is a parameter closely related to the true capacity. All parameters need to be obtained through analysis and calculation of external signal test data. This project is to conduct a comprehensive test of a dry-type transformer. The key issues to be solved in the project research process are as follows:

- Accurate judgment of dry-type transformer capacity
In the country, the equipment for testing the capacity of dry-type transformers generally has a lot of defects. Accurately determine the capacity of the transformer and obtain accurate and real rated current. This is the key to solving the problem of dry-type transformer material judgment accuracy.

- Accurately test the current density of high and low voltage packages of dry-type transformers
The ability to accurately test the current density of high and low voltage packages is the key to determining whether the transformer is a copper or aluminum package. The key point ahead is to obtain the true transformer capacity, which is the rated current. The key point is to obtain the true conductor cross-sectional area. The key to the successful development of the project must be a lot of practice to arrive at a correct conclusion.

2.2. Acquisition of conductor cross-sectional area
Current density calculation formula: \( J = I / S \). Among them: \( J \): current density; \( I \): transformer winding phase current; \( S \): conductor cross-sectional area.
According to the above formula, if we need to obtain the current density of the finished transformer, we must obtain a series of accurate parameters: conductor cross-sectional area, phase current. When we face a finished transformer, we can only directly obtain the external dimensions of the transformer's high and low voltage packages. The conductor cross-sectional area can neither be directly obtained nor measured from electrical parameters. Without the cross-sectional area of the conductor, the calculation of the current density cannot be achieved at all. Through the outer dimensions of the package, we can get the cross-sectional area of the entire package. This cross-sectional area is composed of the following parameters: cross-sectional area of the conductor * number of turns, cross-sectional area of the insulating layer, and cross-sectional area of the winding material. If we can determine the area occupied by these structures such as insulating materials, then the cross-sectional area of the conductor can be obtained. In order to accurately obtain the parameters of the conductor cross-sectional area, we have carried out in-depth field analysis of the transformer winding manufacturing process and accumulated a large amount of data. First of all, we can get the height and thickness of the package, and we can get the cross-sectional area of the package. The composition of the cross-sectional area of the wire package is composed of the cross-sectional area of the conductor wire and the cross-sectional area of the insulation layer. The insulating layer includes outer conductor insulation, adhesive layer, and outer insulation of the wire package.

The thickness of the conductor insulation layer is different according to the conductor thickness of different models, and the insulation of different types of wire insulation is different. One thing that can be determined is that any manufacturer of transformers will not arbitrarily thicken the insulation. Insulation layer thickening, will lead to poor heat dissipation, increased material costs, increased stress causes easy cracking and other issues, therefore, the external insulation of the transformer will have a reasonable size in accordance with the insulation requirements. This parameter, which is not specified in the document, is a millimeter. However, the formed transformer is a basically determined data. Therefore, the size of the external insulation, we collected a large number of transformer insulation layer data of various transformer manufacturers, made a database for calculation and processing, and at the same time according to the dry transformer design process and calculation program comprehensive comparison, can be to a certain extent Analyze the insulation thickness of each type of transformer winding.

Second, the question of winding turns. This involves parameters such as transformer ratio and short-circuit impedance of the transformer. For a qualified transformer, if you want to achieve the correct transformer ratio and correct short circuit impedance, the number of turns in the same model should be basically the same. Because most of the current transformer design uses computer-aided design, different parameter combinations such as different number of turns, different heights, and winding thickness can produce different impedances and different material consumption. All manufacturers will select the qualified impedance data set and choose the data set option with the least material consumption. Therefore, qualified transformers have a certain number of parameters. According to this feature, a large amount of related data is also collected to form a database, and comprehensive calculation and analysis are performed to obtain basic data of the number of transformers of each model.

By collecting various data summation transformer winding turns, the final goal is to compare it as a back-end database. For the transformer under test, it must also be measured. The program of measuring the number of turns actually has practical application, which is the conventional transformer ratio test. However, in the current market related instruments and test programs, as well as the requirements of various test procedures for transformers, the required parameters are the ratio or turns ratio, which is a ratio of high voltage to low voltage. This parameter is very effective in routine tests, but it is useless for our project. No one of us can clearly know the number of turns of high and low voltage windings from a variable ratio parameter. The exact number is what we must get. Also, the winding ratios of different connection groups do not equal the turns ratio. So, getting the exact number of transformer turns is also a key point.

Usually we measure the turns ratio by using the voltage method. We also use this method to measure the turns ratio. According to the formula: U1/U2/U3=N1/N2/N3, the voltage U1U2U3 is obtained by
our instrument output or test, which we count as a known quantity. With the additional number of
turns N, we can see that as long as there is a known N value, we can accurately calculate the other N
data.
Therefore, a scheme of a known coil is adopted. That is, a special measurement winding is used. It
consists of a bundle of soft wires, which has a known number of turns and cooperates with the
measurement output of the instrument as part of the active excitation signal. The coil is placed on the
iron core concentric to the transformer and an excitation signal is applied. Then, on the transformer
high and low voltage windings, a voltage signal with the same ratio as the known coil is generated. At
the same time, the output voltage, the voltage of the high and low voltage windings are measured, and
then we know the number of turns of the coil. In this way, we accurately obtain the number of turns of
the high and low voltage windings.
Finally, use the data obtained (cross-sectional area of the package - area of the insulation
portion)/number of turns = cross-sectional area of the conductor. In this way, one of the key problems
is solved, and the conductor cross-sectional area of the transformer winding is accurately obtained. In
order to obtain the accurate winding current, the current density can be calculated.

2.3. Obtaining winding current parameters
The size of the winding current is designed according to the transformer capacity. The conductor
cross-sectional area determines whether the winding can withstand the design current.
In the calculation parameters of the transformer winding, parameters such as the number of turns,
cross-sectional area, and height of the wire package will eventually affect the capacity and impedance
of the transformer. The rated current of the winding operation can be calculated by the formula based
on the transformer capacity and rated voltage. However, the transformer's rated capacity also has the
potential to be ambiguous. It may have an elevation or may be low. Therefore, we cannot use the
nameplate standard capacity or current data to participate in the calculation. In this way, the ability to
accurately measure the capacity of the transformer is also a key issue.
In the nameplate parameters of the transformer, the only parameter that will not be virtually falsified is
the rated voltage. Other parameters, such as capacity, impedance voltage, etc. may not be real data.
Transformer rated current calculation formula, I = S / (U √3), where, I: transformer rated current; S:
transformer rated capacity; U: transformer rated tap bit voltage. When the transformer high voltage
winding is Y type, the current calculated by the formula is the rated current of the winding, that is, the
phase current is the same as the line current. When the high voltage winding is Δ type, the result of the
formula calculation is the line current, and the phase current is also the winding current, and it needs to
be divided by √3. From the above formula, it can be concluded that the rated current of the
transformer winding has a direct and decisive relationship with the transformer capacity (in the case of
known voltage and certain conditions, a transformer is generally not suitable for multiple voltage
levels).
From the above conditions, it can be found that the rated voltage can obtain accurate data. Next,
accurate transformer capacity data must be obtained to obtain the accurate data of the rated current of
the winding to calculate the current density.
The capacity of the transformer is calculated by theoretical calculations, combined with parameters
such as rated voltage and rated current. The transformer capacity parameters cannot be directly tested
unless a full type temperature rise method is used for type testing. Without accurate capacity data,
accurate winding current data cannot be obtained. However, it is not possible to use the full load
temperature rise method to test the transformer capacity. Moreover, using the temperature rise method
can not test the exact capacity of the transformer, only to verify whether the rated capacity marked on
the transformer nameplate is satisfied. Therefore, it is very necessary to find and design a scheme or
equipment that can accurately measure the transformer capacity.
There are some instruments on the market that specifically measure the capacity of transformers. The
principle is to use a calculation relationship between the capacity and the short-circuit impedance of
the transformer. Its formula is (S= ( √3*U^2*U_K)/Z). Among them: U is the transformer rated line
voltage, UK is the impedance voltage, Z is the linear impedance in the test. From the formula, we can
see that in this formula, only the voltage is an accurate known quantity. In addition, the linear impedance value can also be said to be accurate. It is the ratio of the applied voltage to the formed current. There is also one parameter: the percentage of impedance voltage. This parameter is theoretically accurate, but in reality, this parameter has the potential to be falsified. It can be seen from the formula that the percentage of impedance voltage is high, the transformer capacity is large, and the transformer capacity is low. It can be said that the size of the impedance voltage percentage parameter determines the size of the measured transformer capacity. Some of the results obtained by this test are correct, but for transformers with imaginary parameters, his test results are erroneous. Even deviations from the correct data are very large, and the test results are not objective. Therefore, we must find an algorithm and scheme that can objectively determine the transformer capacity.

Through the calculation and analysis of a large number of transformers, the final capacity analysis program is an impedance method combined with a load loss lookup table analysis program. First, through the test, the measured loss is obtained. According to the measured actual data, the short-circuit loss value at the rated condition is corrected as required, and the actual capacity of the transformer under test is obtained by looking up the table.

Transformer short-circuit test (measurement of short-circuit loss) when the test power test results are calibrated to the temperature scale (the rated condition of the short-circuit test is the temperature scale), (correction formula is: P = K × PK, where K represents the temperature coefficient of resistance, the algorithm is K = (235+ temperature scale) / (235+4), where it is the actual temperature at the time of the test. For the correction of the impedance voltage, it is also automatically corrected according to the formula using the measured value.

Where UKT represents the actual measured impedance voltage percentage, PKT represents the measured short-circuit loss at the current temperature, and SN represents the rated capacity of the transformer under test.

At the same time, based on the obtained capacity data and the input transformer rated voltage data, the rated currents on the high and low voltage sides are calculated. Then, based on the measured DC resistance, the rated load loss of the transformer can be calculated. Also check the table to get the actual capacity of the transformer. Comprehensive analysis and judgment in two ways make the analysis and judgment accuracy of the transformer capacity greatly improved.

3. **Dry-type transformer test system hardware and software**

Accurate capacity testing of dry-type transformers: hardware theory and software block diagram design:

3.1 **The hardware structure design of the system**

The following figure shows the system's hardware design schematic. The system can be divided into five major modules: Dry-type transformer interface, standard source output, data acquisition and operation control unit, 7-inch high-brightness color touch LCD screen and upload USB and print interface.

- **Capacity standard source output**

  The module consists of a transformer, rectifier bridge and adjustable resistor. Adjusting the resistance of the adjustable resistor can change the voltage and current value of the primary side of the transformer, complete the voltage and current characteristics of the transformer, thereby realizing the adjustment of the transformer capacity; ensuring the accuracy of the test data of the test items under non-rated conditions

  The power amplifier can provide three-phase precision AC test source.

- **Data Acquisition Module**

  As shown in the figure below, the module uses high-precision AD to sample the voltage and current. The current signal is converted into a voltage signal through the current transformer. The six sampling synchronization signals are composed of a programmable timing force counter and a phase-locked loop. The D converter collects 256 points, and the sampled data is packaged by the CPLD and transmitted to a high-performance CPU. After processing by the CPU, an accurate voltage, current value, and phase between the voltage and the current are obtained, and the formula is used to implement the pairing.

Transformer capacity calculation.
Operation control module
The module consists of an ARM chip, peripheral circuits, and a keyboard. It mainly performs functions such as data conversion, hardware control, display control, system, and key operation.

Display module
The interface can display the corresponding voltage, current, impedance and capacity values according to measurement and calculation, and can manually set the temperature and transformer parameters, increasing the testable range.

3.2 The software structure design of the system
The system software generally includes: a data acquisition module that receives 6 A/D data transmitted from the CPLD, the conversion module converts the 16-bit A/D sampling data into an actual physical quantity under the international system of units; a capacity calculation module according to the transformer parameters and sampling Data, calculated transformer capacity value; temperature parameter conversion module, the current temperature capacity is converted to 75 °C capacity; press the button to resolve the module, according to the prompts to enter the transformer parameters, the current temperature, to achieve the transformer capacity characteristics of the tester to set the analog transformer parameters Display module provides humane LCD display interface. The software design principle flow chart is shown in the figure below.

3.3 The principle of material analysis
Through the above detailed description, the current density of the high and low pressure packages is comprehensively calculated and the dry transformer material is determined. Using a transformer DC resistance tester to test the line-to-line DC resistance $R_{ab}, R_{ac}, R_{bc}$ and $r_{ab}, r_{ac}, r_{bc}$ of the high and low voltage coils to verify whether the capacity of the dry transformer is accurate, so that the true transformer current can be obtained; by using a specific test Coil test transformer ratio, test the number of turns of the dry-type transformer package, and then test the height and thickness of the high-low pressure package through the electronic ruler to calculate the area of the high-low pressure package. After comprehensive calculation and analysis, the cross-sectional area of the conductor can be obtained. Therefore, after comprehensive analysis, we can test the current density of high and low voltage packages.

4. Conclusion
This article analyzes and develops a new type of technical theory—the technical characteristics of current density to analyze the material of the transformer under test. This technology makes the material identification of the transformer easy to operate, low in cost, and can be universally realized. Completely lossless. At the same time, through a direct impedance transformer capacity test program, the test accuracy of the dry-type transformer capacity is greatly improved. Furthermore, a method of measuring the transformer turns ratio using a flexible coil with known parameters was studied.
According to the coil of our known parameters, the exact number of transformer turns can be obtained. Finally, combined with the above, the developed equipment integrates multiple functions, including transformer capacity testing, direct resistance testing, transformer loss testing, transformer ratio, turn ratio, and number of turns testing. The instrument not only realizes these conventional transformer test functions, but also calculates and analyzes the material of dry-type transformer windings through a series of parameter tests and statistical analysis calculations.

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