Research on transformer drying technology based on low-frequency heating principle

Qiang Liu¹, Liang Lv²*, HaoMing Zuo³, Sen Wang¹, Chen Mao¹, and Yuanjie Zhang³

¹ Electric Power Research Institute of State Grid Shaanxi Electric Power Company, Xi’an, Shannxi, 710100, Country
² State Key Laboratory of Electrical Insulation and Power Equipment, Xi’an Jiaotong University, Xi’an, Shannxi, 710049, China
³ Shaanxi Power Transmission and Transfer Engineering Company, Xi’an Jiaotong University, Xi’an, Shannxi, 710014, China

*Corresponding author’s e-mail: lvliang@xjtu.edu.cn

Abstract. In the process of current transformer field insulation treatment, temperature becomes the key factor to limit the treatment effect, leading to the low heating efficiency and poor effect when installing new transformers in winter. Restricted by the power of hot oil circulating heating method in the current field operation, it is difficult to improve the actual heating effect simply by increasing the power of oil filter. Based on the principle of low-frequency short circuit heating of transformer winding, a low-frequency heating device of high-power transformer winding is developed, which can be used for the insulation heating and drying treatment of large power transformers. With the method of inputting 0.2~1Hz ac power supply on the high voltage side of the transformer and short-circuit on the low voltage side, the inductive reactance of the transformer winding is reduced, the working voltage in the short-circuit heating process is reduced, and the required power capacity is reduced, so that the device is simple, small in size and light in weight. It is proved by many field heating tests that the drying method can achieve the desired effect and greatly shorten the working cycle.

1. Introduction

The moisture contained in the insulating material is one of the important factors affecting the insulation performance of the transformer. The moisture accelerates the aging of the insulating material, reduces the dielectric performance of the insulation and the initial voltage of partial discharge, and then affects the insulation strength and operating life of the whole transformer. Therefore, the insulation drying treatment is quite key in the field installation of the large transformer, maintenance of hanging cover and aging cleaning of insulation.

Short-circuit heating method, also known as copper loss drying method, is to short-circuit the winding on one side of the transformer (usually low-voltage winding), and apply AC voltage on the other side of the winding (usually high-voltage winding), making the winding flow current, and using the heat generated by the transformer load loss to heat transformer insulation. Short-circuit heating method does not affect the normal development of transformer hot oil cycle. It uses the heat generated by load loss to heat transformer insulation, which can effectively cooperate with the hot oil cycle from the outside of the insulation to heat inside, making insulation heating more uniform. Short-circuit
heating method for transformer heating does not need additional insulation materials and magnet coil, and since the heat directly produce from winding insulation process, the drying effect is superior to the ordinary method of hot oil circulation. Besides, the oil filter does not need to provide too high oil temperature to prevent degradation caused by high temperature of transformer oil in the heating process[1-2].

In this paper, aiming at the main problems encountered in the field insulation treatment of the transformer, a method of improving the field insulation treatment by using low frequency heating is proposed, the relation between terminal voltage and power supply capacity for short-circuit heating under different frequencies is studied, and a low frequency current short-circuit heating device is developed.

2. Development of low frequency current short-circuit heating device
When the field winding is heated with electricity, high voltage, high current and large capacity demand are required, besides, the power supply voltage added on the primary side is required to be adjustable to meet the demand of temperature change, so the existing three-phase AC power supply cannot be used directly. Therefore, NPC (diode embedded) three-level inverter circuit is selected as the main circuit of the heating power in this paper[3-6], and the single-phase topology is shown in Figure 1.

![Figure 1. Single-phase topology diagram of NPC three-level inverter.](image)

Connect the heating power supply to the primary side of the transformer to be dried, short-circuit the secondary side, adjust the output voltage amplitude and frequency of the heating power supply according to the requirement of temperature, and use the heating winding and core to heat the transformer oil.

As NPC three-level circuit can be regarded as a combination of three single-phase three-level circuits with output voltage with phase difference of 120 degree, the single-phase three-level circuit is used to analyse its model. One phase of the dehumidification system topology is shown in Figure 2.

![Figure 2. One phase of the dehumidification system topology.](image)
C₁ and C₂ in the figure represent the DC side voltage-dividing capacitor, the voltage Uₜ on the DC side is provided by an external rectifier circuit, O is the midpoint of DC capacity, T₁ T₂ T₃ T₄ are the power electronic switching devices, and the three-level circuit load side is connected to LC filter link, and then connected to the transformer primary side, and the secondary side is short-circuited. And the short-circuit current is used to heat the transformer. Figure 3 is a 780kVA heating device developed for field transformer drying, with a maximum output voltage of 750V and output current of 600A. Compared with the traditional heating device, it is small in size and light in weight, easy to transport, and meets the requirements of field operation.

![Figure 3. Picture of low frequency auxiliary heating unit.](image)

3. Research on low frequency current short-circuit heating method

The range of the specified frequency of the output current is set as 0.2 ~1 Hz. The upper frequency limit is set to prevent the output current from reaching the command current value due to the excessive influence of the inductive reactance of the load transformer. The lower frequency limit is set to prevent the magnetic saturation of the load transformer[7-8].

When short-circuit method is used to heat the transformer, the heat generated by copper loss of the transformer is mainly relied on, while the heat generated by iron loss is ignored.

The resistance value in the figure is:

\[ R = \frac{P \cdot U_{N}^{2}}{S_{N}^{2}} \]  

(1)

The inductance value is:

\[ L = \frac{U_{N}^{2}}{S_{N} \cdot \omega} \]  

(2)

When the rated current is applied to the transformer at different frequencies, the high voltage terminal voltage is calculated as follows:

\[ U = (R + 2\pi fL) \cdot I_{N} \]  

(3)

The relationship of the required system power capacity is:

\[ S = (R + 2\pi fL) \cdot I_{N}^{2} \]  

(4)

The calculation results of terminal voltage and power supply capacity required for short-circuit heating under different frequencies of this transformer are shown in Figure 4.
In the heating process, the voltage at the pressure end of the transformer and the power supply capacity are obviously related to the frequency. Reducing the working frequency during the heating treatment can effectively reduce the voltage applied at the high-voltage end of the transformer and reduce the requirements on the power supply capacity. At the same time, it is found through calculation that the influence of winding inductance is reduced under the condition of low frequency, and the required reactive power is greatly reduced. On the premise of ensuring the constant heating capacity, reducing the frequency can effectively improve the power factor and power utilization ratio of the power source. The relationship between the power factor and frequency of the short-circuit method is shown in Figure 5.

According to Figure 5, the demand of power supply equipment when short-circuit method is used to heat the transformer at different frequencies, when the frequency is reduced, the power demand significantly reduces. For example, under the condition of 1Hz, compared with the condition of power frequency, the voltage and power capacity at the pressure end of the transformer and power capacity are reduced by 96.7% and the power factor is increased by 30 times when the heating capacity is guaranteed to remain unchanged.

4. Conclusion
1) This paper designs a new type of low-frequency heating device aiming at the problems of uneven heating and insulation damage caused by heating and drying of transformers at present.
2) By analyzing the influence of current frequency on voltage and capacity, it is pointed out that the frequency of low-frequency transformer heating in the field should be between 0.2~1 Hz.
3) With the method of reducing the power frequency to reduce the inductive reactance of transformer winding, the working voltage of short-circuit heating is reduced and the required power capacity is reduced, making the device simple, small in size and light in weight, easy to use and safe, and convenient for field application.

References

[1] LIU Rui, LI Jinzhong, ZHANG Shuqi. Study on the on-site heating method for large-scale power transformers [J]. Proceedings of the CSEE, 2012, 32(1): 193-197.

[2] GUAN Lan, LI Bo, LIU Rui, et al. Development and Application of Low Frequency Short-circuit Current On-site Heating Device for the UHV Converter Transformer [J]. Proceedings of the CSEE, 2012, 34(12): 6585-6591.

[3] AKAGI H, HATADA T. Voltage balancing control for a three-level diode-clamped converter in a medium-voltage transformer-less hybrid active filter [J]. IEEE Transactions on Power Electronics, 2009, 24(3): 571-579.

[4] AKAGI H, KONDO R. A transformer-less hybrid active filter using a three-level Pulse Width Modulation (PWM) converter for a medium-voltage motor drive [J]. IEEE Transactions on Power Electronics, 2010, 25(6): 1365-1374.

[5] WANG C C, LI Y D. Analysis and calculation of zero-sequence voltage considering neutral-point potential balancing in three-level NPC converters [J]. IEEE Transactions on Industrial Electronics, 2010, 57(7): 2262-2271.

[6] POU J, ZARAGOZA J, CEBALLOS S, et al. A carrier-based PWM strategy with zero-sequence voltage injection for a three-level neutral-point-clamped converter [J]. IEEE Transactions on Power Electronics, 2012, 27(2): 642-651.

[7] Garcia D F, Garcia B, Burgos J C. Analysis of the influence of low-frequency heating on transformer drying – Part 1: Theoretical analysis[J]. Electrical Power and Energy Systems, 2012(38): 84-89.

[8] Garcia D F, Garcia B, Burgos J C. Analysis of the influence of low-frequency heating on transformer drying – Part 2: Experiences with a real transformer[J]. Electrical Power and Energy Systems, 2012(38): 90-96.