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The Experimental Study of Breakdown Characteristics for Oil-paper Insulation under Low Temperature

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Abstract: The large power transformer will operate under low temperature in Inner Mongolia, Xinjiang and Northeast provinces in China. In order to study the breakdown characteristics of transformer oil-paper insulation at low temperature, a high-voltage and low-temperature test system for transformer oil-paper insulation breakdown characteristics was established. The effects of content Water to oil and oil-paper composite insulation breakdown characteristics in -50 ° C to 20 ° C range were obtained. The experimental results show that the breakdown voltage of the transformer oil decreases and then increases with the decrease of the temperature. For the oil-paper composite insulation, when the water content is low, the breakdown voltage increases with the decrease of the temperature. When the water content is high, the breakdown voltages decrease significantly in the early stage. When the temperature is below -10 ˚C, the breakdown voltage increase sharply but decrease significantly after reach the peak value. The lower temperature correspond to the minimum breakdown voltage, and the lower the breakdown voltage.

Introduction

Large power transformer is a key equipment in power grid. The oil-paper insulation in transformer can be influenced by the environment temperature under operating. In Inner Mongolia, Xinjiang and Northeast provinces of China the temperature difference between day and night is big and low ambient temperature appears sometimes. Under low temperature oil-paper insulation have different breakdown characteristics compared with normal temperature [1~3].

The features of transformer oil have been studied under different ambient temperature. Viscosity variation law, pour point characteristics, physical and chemical properties and dielectric properties are all researched [4~9]. But studies about the breakdown characteristics is relatively rare, especially the oil-paper composite insulation. Aiming at the breakdown characteristics of transformer oil-paper insulation under low temperature, this paper studied the different oil-content transformer oil and the oil-paper composite insulation's breakdown characteristics under low temperature. The influence law of temperature variation on breakdown characteristics was obtained. The research results provide experimental foundation for the operation and fault diagnosis of transformer in low-temperature areas.

Experimental System and Methods

The established experimental system is shown in Fig.1.

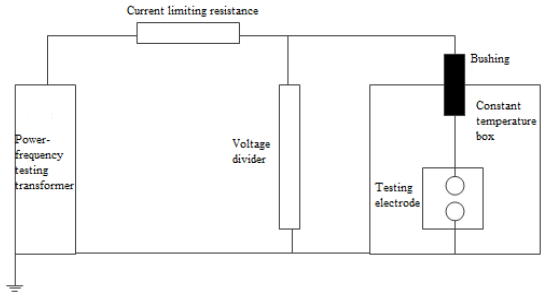
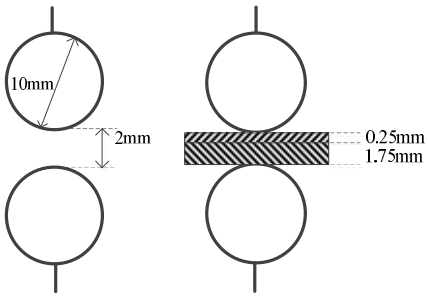


Fig 1. experimental system

As Fig.1 shows, the source is fundamental frequency power supply and its rated voltage is 200kV with the capacity of 200kVA. With a high voltage bushing it is connected to the experimental cavity in the constant temperature box through a 100MΩ current limiting resistance. The sample electrode is placed in a ceramic container, contained by the constant temperature box. The inner of ceramic container is filled with transformer oil. Voltage divider is used for testing the voltage.

When conducting tests on transformer oil, the sphere-sphere electrode system was used. The diameter is 10mm and the distance of the gap is 2mm. When doing oil-paper composite insulation experiments, the insulation is consisted of composite layer with the whole thickness 2mm, and the upper is a 0.25mm thick transformer insulation paper with nether a 1.72mm thick cardboard. Then the composite insulation sample is placed between the electrode gap and pressed well. Figure. 2 presents the structures of the two different samples and electrode.

Before the tests, we just put the experimental object and model in a 80˚C oven to dry them for a week. Then they were impregnate sufficiently and pumped vacuum. Finally they were stored in drying box until the experiments.



(a) oil sample (b) oil-paper composite insulation sample

Fig.2 Structure of test samples

Experimental Results and Analysis

In order to understand the rules micro water content's influence on breakdown characteristics of transformer oil under low temperature, four oil samples with diverse water content were used. In the range of 20˚C to -50˚C，the breakdown test was conducted each 5˚C. When breakdown happened, the sample was changed and totally five samples were used in each experiment. The testing result is the average breakdown voltage of the five test objects. The experimental results of four diverse micro

water content are shown in Fig.3.

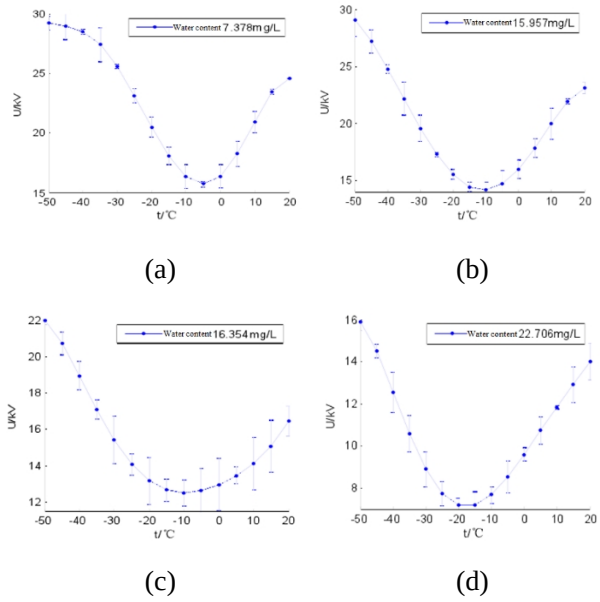


Fig.3 The distribution of oil breakdown voltage with temperature

As we can see, during the dropping process of temperature, the breakdown voltage of the transformer oil with different contents of water drops first and then increases, which implicates a minimum value under a certain temperature. The temperature of that minimum voltage is lower when the water content is larger, besides the minimum value is smaller too. At the beginning of the temperature dropping, the micro water gradually precipitates from the molten state and forms micro suspended polar water polo. Under the circumstance of inhomogeneous electric field, these water polo extend to be polar ellipsoid in the field direction. Plenty polar ellipsoids are connected in series as the “conductive bridge”. The “conductive bridge” weakens the insulation of the testing sample, leading to a lower breakdown voltage.

Besides, there are impurities unavoidably and their dielectric constant are always larger than oil. So the impurities can also consist an “impurity bridge” in the electric field. Both the “impurity bridge” and “water bridge” make the breakdown voltage of the damp oil drop significantly. In the later period of temperature dropping, the precipitated water starts to drop for the sake of gravity. And as the viscosity of oil increases with the decreasing temperature, the mean free path of micro water declines. When the voltage is applied, the mean free path is not enough for water to earn energy. So the water polo can’t ionize to form an electron avalanche and result in ionization breakdown. The existence of micro water is no longer the main reason about the “conductive bridge” breakdown. So lower the temperature is, higher the breakdown voltage is.

In order to find the laws micro water content’s influence on breakdown characteristics of oil-paper composite insulation under low temperature, four composite samples with different water content were made. In the temperature range of 20˚C to -50˚C， the experiment was conducted every 5˚C. After breakdown the testing object was changed and totally three samples were tested in each experiment. The testing result is the average breakdown voltage of the three testing objects. Fig.4 gives the experimental results of four diverse micro water content.

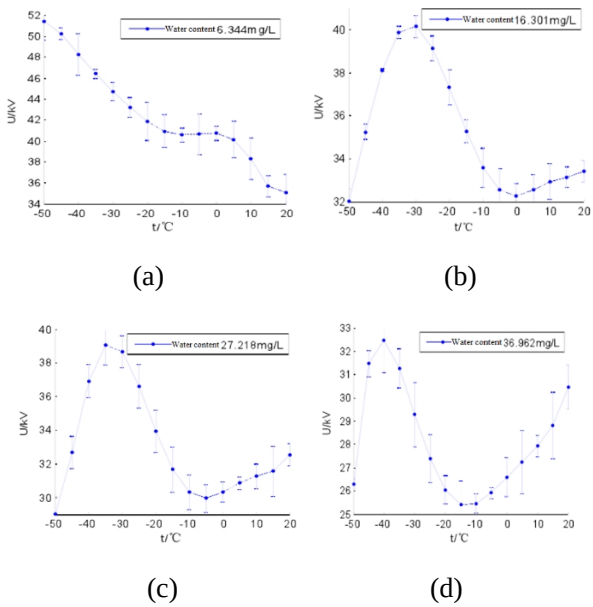


Fig.4 The distribution of oil-paper insulation breakdown voltage with temperature

From Fig.4 we can find all voltage curves except the 6.344mg sample tend to decline heavily at the early stage of temperature dropping. Then the breakdown voltage inclines significantly when below -10˚C. After reaching a peak is decreases again. A minimum value appears at a certain temperature. Higher the water content is, lower the corresponding temperature of the minimum breakdown voltage is, and the voltage is smaller at the same time. Considering the breakdown curve of oil-paper composite insulation structure, the regularity can be explained by the same reason in pure oil at the early stage, which is the “water bridge” and “impurity bridge” theory.

In composite insulation there exists the hysteresis phenomenon during the precipitation process of water. The micro water in oil precipitates at a low temperature, then follows the precipitation process of water in paper under a lower temperature. At the later stage the precipitation of water in the inner of paper can directly cause a second reduction of breakdown voltage under lower temperature. The water component in oil exists always as a molten state, which is difficult for water to gather. So in this condition the micro water polo can’t weaken the insulation strength. Once the transformer is exposed in low temperature and operating for a long time, the inner oil’s viscosity increases and solubility decreases. Then the micro water changes from a molten stage to a suspension state. The precipitated water then moves in the direction of the electric field in transformer.

After a period of time a gathering area of moisture small particles is formed. Even the temperature recovers, the water component can not absolutely dissolve in oil-paper insulation system. And water is free in oil, gathering more and more. During the freezing and recovering process the dissolution and precipitation of micro water are not completely reversible. And temperature changes will precipitate a large number of micro water, which directly leads to the drop of the insulation strength of oil-paper insulation structure in transformer.

Conclusion

By conducting the power frequency breakdown experiments of sphere-sphere electrode with pure oil or oil-paper composite insulation system under low temperature environment, conclusions can be drawn as followings:

1. The power frequency breakdown voltage of transformer oil has a tendency of increasing after falling in the whole range of temperature variation. In the low temperature the voltage inclines with decreasing temperature. The micro water in oil significantly cuts down the breakdown voltage, and more the water is, lower the voltage will be.

2. When the water content is low, breakdown voltage decreases with dropping temperature. When the water content is high, the voltage drops heavily at the beginning of temperature falling but increases significantly when the temperature is below -10˚C. Then after reaching a peak value the voltage drops again. The corresponding temperature of minimum voltage is lower with a higher water content, and the voltage is lower, too.

References

[1] Y.X. Zhou, J.W. Huang, Y.C. Sha, et al: Electrical properties of oil-paper affected by water conductivity during paper making process [J]. High Voltage Engineering, 2015, 41(2):382-388.

[2] S.Z. Ren, L.S. Zhong, et al: Influence of copper sulfide on the electrical field distribution and breakdown characteristics of oil-paper composite insulation [J]. High Voltage Engineering, 2010, 36(10): 2444-2449.

[3] W. Lampe: Power transformers and shunt reactors for arctic region [J]. IEEE Transactions on Power Delivery, 1986, 1(1): 217-225.

[4] R.M. Hakim: The properties of an insulating oil and its fractions at low temperature [J]. IEEE Transactions on Dielectrics, 1975, 10(4):124-134.

[5] M. Gao, G. F. Li, J. Z. Li, et al: Study on insulation characteristics of transformer oil at low temperatures[C]‖ Power Engineering and Automation Conference. Kyoto, Japan: IEEE, 2011: 27-30.

[6] K. Wang, L.X. Yang: The study on influence factors of transformer oil electrical performance[J]. Electrical Power Constitution. 2008, 29(8): 59-61.

[7] C. Zhao: Experimental research on transformer oil-paper insulation under low temperature[D]. Harbin, China: Harbin University of Science and Technology, 2011: 34-44.

[8] X.W. Zhu: Study on influence of the breakdown characteristic of oil-paper insulation in convertor transformer under different temperatures[D]. Harbin, China: Harbin University of Science and Technology, 2011: 30-41.

[9] I. Fofana, H. Hemmatjou, F. Meghnefi, et al: Low temperature and moisture effects on oil-paper insulation dielectric response in frequency domain[C]‖ Electrical Insulation Conference. Montreal, Canada:IEEE, 2009: 368-372.