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ScienceDirect

Procedia Engineering 202 (2017) 168–175

Procedia Engineering

www.elsevier.com/locate/procedia

4th International Colloquium "Transformer Research and Asset Management"

Cellulosic Particles Accumulation and Conductivity Characteristics of Natural Ester Used in Power Transformer

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Abstract

Transformer plays an important role in providing a reliable and efficient electricity supply and is one of the most critical equipment in electric power transmission and distribution systems. The majority of high voltage transformers are filled with liquids that work as an electrical insulation as well as a heat transfer medium. Natural esters are used today for the insulation of high voltage transformers. The paper made comparative experimental analysis of the cellulosic particles accumulation and conductivity characteristics of natural ester and mineral oil under AC and DC electric field. The effect of the electric field on bridging in natural ester and mineral oil has been compared. When the voltage is applied on the oil with cellulosic particles, the particles began to move within the whole electric field. Cellulosic particles bridge was created between electrodes under DC. The conductivity current through the natural ester with particles is smaller. The bridge is thick and strongly bonded under DC electric field. While under AC, the rate of particles accumulation in mineral oil and natural ester are all slower than that under DC electric field. However, there is thin cellulose particles bridge in natural ester after applying AC voltage 120min, this is different from the phenomenon observed in mineral oil. It is better to consider this phenomenon for operation transformer using natural ester.

Peer-review under responsibility of the organizing committee of ICTRAM 2017.

Keywords: transformer; natural ester; cellulose particles; bridging; conductivity

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1877-7058
Peer-review under responsibility of the organizing committee of ICTRAM 2017.
10.1016/j.proeng.2017.09.704

1. Introduction

With the pursuit of high efficiency in electric power transmission and renewable energy, there comes a rapid development in high voltage DC transmission systems. There are fourteen ±800kV/±1100kV Ultra High Voltage Direct Current (UHV DC) projects have been put into operation or in the construction since 2010 to June, 2016. The UHV converter transformer is an essential part of the DC transmission system. It is well known that the oil-paper insulation system is the "heart" of the transformer. Consequently, the electrical performance of the oil-paper insulation system for HVDC transformers is a new research area and has attracted significant interests from both manufactures and utilities [1-10].

HVDC power transformers usually contain numerous tons or over a hundred tons of insulating oil. The insulating oil inside a transformer normally contacts metal, iron core and pressboard insulation. Metal filings or cellulosic residual can be formed in the oil [10-12]. There is cellulose shedding phenomenon for transformer in operation, especially for aged transformers with old oil-paper insulation [10-12]. The level of oil contamination determines the dielectric safety margin of both new and aged oil-paper insulation system [13]. The converter transformer's structure is very complicated. It withstands AC, DC, and the combined DC and AC electrical stress in the operation. During operating condition, the contaminant particles may get excessive charge or even tend to move towards the high gradient electric field regions due to dielectrophoretic (DEP) force [6, 12, 14]. These contaminant particles could form a bridge over a period of time because of the function of DC electrical stress. The bridge may lead to partial discharges or total insulation failure [6, 12]. Therefore, the fully understanding of insulation failure mechanisms will enable us to prevent it with proper measures.

The most commonly used liquid in HVDC transformers is mineral oil because of its low cost and good properties. However, the performance of mineral oil starts to be limited with the environmental consideration [15-19]. Natural ester takes advantages over mineral oil in the aspects of fire safety, environment, and insulation aging, and is found to be suitable for the use in transformer insulation system [15-19]. SIEMENS's 420kV plant oil transformer has been successfully put into operation in Bruchsal, Germany. In recent years, some researchers [6, 12, 20-21] studied the bridging phenomena in mineral oil contaminated with cellulose particles. For bridging and conduction current of mineral oil, previous study mainly concentrated on the sphere-sphere electrode and needle-plane electrode system, the effect of cellulose particle sizes, voltage type (DC, AC and DC biased AC) and electrical field strength. Results showed that cellulose bridging phenomenon occurs when there is DC component and where there is a non-uniform field. However, the bridging forming model and the motion property of cellulose particles in natural ester has not been studied sufficiently. Investigating cellulosic particles accumulation and conductivity characteristics of natural ester is not only useful to further understand the insulation failure and ensure the safe operation of the transformer, but also helpful to guide the transformer insulation structure design, especially for the HVDC transformer which would use natural ester in the future.

In the present study, the accumulation of cellulose particles and conductivity characteristics in natural ester and mineral oil under different DC, AC electrical field strength using spherical electrodes were studied.

2. Experiments

2.1. Sphere-sphere electrode testing system

The test cell used in all experiments was cube glass cup whose volume is 1100ml. A pair of spherical electrodes with a diameter of 13 mm have been used for the experiments. Their distance was 10mm and material was copper. The electrodes could move using a screw drive. The distance between the electrodes could be adjusted. In this experiment, the cup was washed with hot soapy water, and then being repeated washing by hot clean tap water for several times. The washed cup was put into the drying box with hot air flow for drying. Before starting a new test, the dried cup was rinsed with clean mineral oil or natural ester three times. In this way, there is no soap residues on the cup.