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Comparative study of the degradation rate of new and regenerated mineral oils following electrical stress

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Abstract: The objective of this contribution was to study the behaviour of new and regenerated insulating oil used in power transformers under the influence of an electric stress. To estimate the degradation rate of the dielectric fluids, one thousand (1000) successive breakdowns were generated according to the IEC 60156 standard. The parameters such as dissipation factor (Tan δ), resistivity, total acid number (TAN) and oil water content were measured and examined following IEC/ISO standards. Good correlations have been obtained between TAN/resistivity and Tan δ which might provide a 'picture' of the fluid condition. The dissolved oxidation products for the two dielectric fluids (after the application of electric breakdowns) was evaluated by Fourier-transform infrared spectroscopy. The results obtained indicate that the degradation of the parameters is significant and confirms the influence of an alternative electric field (AC) on the new and regenerated oils. It was also suspected that inhibitors and antioxidants were removed from the oil after regeneration. Their concentration should therefore be monitored and replenished when necessary.

1 Introduction

Power transformers are one of the vital and expensive elements in the industry of electrical energy. Their essential functions in the transmission and distribution allow them attracting the attention of engineers and researchers. Especially, their insulation mainly composed of mixed cellulosic materials and oil, are of concerns. Their condition and lifespan can be mathematically or experimentally evaluated by the physicochemical, electrical or mechanical characteristics of their insulation system [1, 2]. A large number of power transformers are filled with mineral oils because of their advantages that constitute unique combinations of dielectric, cooling and oxidation stability properties [3].

Power transformer oil undergoes continuous deterioration and degradation because of electrical, thermal, mechanical and environmental stresses occurring during operation [4]. Therefore, any deterioration in the oil can lead to premature failure of the equipment. When the mineral oil is subjected to high thermal and electrical stresses, gases are generated from the decomposition of the molecules [3].

The electric stress accelerates ageing, possibly by increasing the precipitation of acid produced from the oil degradation onto paper surfaces. Chemically speaking, the acid build-up will worsen the insulating paper tensile strength.

Aggressive decay products being absorbed by the solid insulation attack the cellulose fibres too. Sludge produced may stick onto the large surface of power transformer, and affects heat transfer between the core/coil and the tank/radiators surfaces.

The cracking process of cellulose (depolymerisation by a succession of chemical reactions) causes chain scissions along with the release of gases and moisture into the surrounding oil and some large molecules such as furfurals. In the complex oil-impregnated dielectrics used in high-voltage insulation, oil is usually the weaker component of the system, both in dielectric strength and in reaction to environmental stress. Knowledge of the stability of insulating oils under electrical stress is of utmost importance to both electrical-equipment designers and operating engineers.

The process of decomposition of insulating oils under electric stress begins with the breakdown of unstable mineral oil molecules covalent bonds. Oxygen, moisture or other chemical reactive radicals can spontaneously be generated; the process being catalysed by heat [5, 6]. Free radicals are very reactive and can adversely affect the physicochemical and dielectric properties of the insulating oil. The sources of energy at the origin of a covalent bond splitting are three folds:

- The strong electro-magnetic stress at the origin of the free electron injection process in the insulating fluid [7, 8].
- The thermal stress generated by the active parts.
- Finally, the aggressiveness of dissolved oxygen.

Free electrons (e-) accelerated by electric field are primary source for the breakdown of vulnerable covalent bonds (~4 eV≈386 kJ mol^{-1}). Electrons escape from the conduction band of the metal conductor and are emitted from its surface, especially during very short but frequent voltage surges [9, 10].

2 Motivation for the work

The goal of this study is to study the behaviour of new and regenerated mineral oils under the impact of an electric stress. For this purpose, the degradation rate of some physicochemical and the electric properties of the insulating oils was assessed. All the obtained results are compared and analysed.

3 Sample description

3.1 New oil

Power oil, a naphthenic, uninhibited, mineral oil produced by APAR INDUSTRIES LTD was considered. This high grade is referenced as new oil. Power oil serves as comparison baseline for the regenerated oil in the following benchmark tests.

3.2 Regenerated oil

This study proposes a regenerated oil sample, recovered by a process of regeneration based on the principle of a physical and chemical treatment. The proposed protocol of regeneration was already verified [11] by coupling the centrifugation, the