Diagnostics of the dielectric properties of cellulose-aramid insulation used in oil-filled power transformers using polarization methods

Abstract

Currently, the insulation systems of power transformers (including high-power transformers) are based on thermally upgraded KRAFT-grade cellulose papers impregnated with mineral oils. These are non-biodegradable liquids derived from the refining of crude oil. With technological advancements, the energy market is seeking new materials with improved physicochemical properties whose use will not pose a threat to the natural environment, as is currently the case, particularly during the operation of cellulose-oil insulation in large power transformers. Nevertheless, it is important to be aware that the implementation of new electrical insulating materials into widespread operation requires a series of tests and analyses and, above all, the knowledge of reliable diagnostic tools to assess the condition of the insulating system used. The efficiency of this process is fundamental to the safe operation of power equipment. This dissertation undertook the task of testing a new type of insulation with a cellulose-aramid hybrid structure combining the best features of commonly used KRAFT-type cellulose insulation and NOMEX® synthetic aramid fiber insulation. To impregnate the cellulose-aramid NOMEX®910 insulation, biodegradable electrical insulating esters were used, i.e. MIDEL® 7131 synthetic ester and Nytro® BIO 300X natural ester. The purpose of the laboratory tests conducted was to verify one of the well-known and widely used diagnostic methods, i.e. the PDC method for diagnosing the condition of the said insulation system. The paper presents the results of laboratory tests illustrating the influence of measurement temperature, degree of thermal aging and degree of moisture in the insulation on the waveforms of I_P polarization and I_D depolarization currents obtained on NOMEX®910 insulation samples. Due to the fact that synthetic esters are increasingly used during the modernization of old transformer units, the paper also analyzes the influence of the degree of mixing of synthetic ester with mineral oil on the waveforms of PDC currents. In the further part of the work, the time waveforms of I_P polarization and I_D depolarization currents obtained during diagnostic measurements were used to carry out analyses of polarization processes occurring in the tested insulation systems. The results of the analyses are the regression functions of the E_A activation energy (determined based on the Jonscher equation and the temperature Arrhenius plot) and the dominant time constants τ_1 and τ_2 (determined based on the Deby'e equation), combined with the polarization processes of aramid and cellulose fibers, respectively, i.e. the components of the cellulose-aramid insulation NOMEX®910. The final aspect of the implementation of the research and analysis included in this work was to check the repeatability and reproducibility of the research results. These aspects, which are a check on the reliability of the research results described in the paper, were confirmed based on statistical analysis in the form of parametric and non-parametric significance tests.

The result of the research and analysis described in this paper, is the confirmation of the research hypotheses, set before the implementation of laboratory tests based on theoretical assumptions. Thus, it was confirmed that the PDC method successfully can be used to diagnose the condition of an insulating system built on the basis of a cellulose-aramid paper NOMEX®910 impregnated with synthetic (MIDEL® 7131) and natural (Nytro® BIO 300X) esters.