On the States of Water and its Quantification in Oil Impregnated Power Equipments

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***Abstract*- In this contribution, the different states of water in insulating fluids are presented. It is proposed to separate "solubility limit" and "saturation limit" concepts. It is shown, that confusion of these concepts, results in erroneous interpretation and analysis of the data and, accordingly, in the diagnostic conclusions. The differentiation of water states and consequent analysis methods allows formulating the concept of diagnostics based on water content. The isotherms of water content for some fluids are provided. In view of feature of each of methods of water analysis the equations for calculation of solid insulation humidity and a residual life of solid insulation are given.**

I. Introduction

Composite oil/paper insulation is used in most electrical equipment such as power transformers, capacitors and cables. When the insulating paper is adequately impregnated with oil, it offers the user a material with insulating and mechanical properties of remarkable suppleness. The ready supply of cellulose and mineral oil has, therefore, made these the materials of choice for nearly a century [1]. Water is particularly detrimental to both of oil-paper insulation systems dielectric properties and its resistance to ageing. Breakdown voltage of the insulating oil is reduced with increasing moisture content in the oil. Thus, knowledge about the water content both in the oil and in the solid insulation material is an important basis for the decision about any further action like e. g. on-site drying of the active part.

Because the Achilles heel of these materials comes from their affinity for water, the aim of this paper is regarded as a main task to study the different states of water, to review modern analytical methods used to determine moisture and the usability of water content as a physicochemical tool for insulation condition diagnostic.

II. States of Water in Power Equipment

Refined oils are very complex mixtures and may consist of more than 3,000 hydrocarbons, made up principally of paraffinic, naphthenic and aromatic chains of carbon atoms. Basically these molecules are non-polar; this means that pure oil cannot dissolve water [2]. Although particular attention is paid during the refinery process, there is no guarantee that oil will be free of contaminants. Water can therefore be present under a number of physical and physico-chemical states that can be simplified as:

- dissolved water (molecular distributed and associated),
- dispersed water (colloids and emulsions),
- bounded water (in clusters, adsorbed, in clathrates and chemisorbed).

"Water content" of insulating liquids is referred to the total amount of water in these liquids, regardless its state. The moisture content W is usually related to oil weight (ppm as μg water / g liquid) or to the saturation value (%).

Water in insulating liquid may originate from air moisture in the case of breathing transformer, and as a by-product of oxidation reactions and the thermal decomposition of cellulose-based solid insulating materials. With increasing water content, the gradation of equilibrium states of water in new insulating oil can be presented as follows: dissolved water - dispersed water - free water. Free water is in the form of water droplets having all the physical properties of water, in particular density, allowing it to form sediments.

Even under normal operating conditions, oil-paper composite insulation of power transformer undergoes a slow decay process. Electrical, mechanical and thermal stresses as well as the chemical aggressiveness of dissolved oxygen, combine to accelerate the degradation process. As a consequence, the so-called defaults gases and colloidal suspensions are generated [3]. These suspension and paper decomposition by-products dissolved in the liquid, profoundly changes the insulating oil-water absorption process due to their interactions with water. In contaminated insulating liquids, water is mostly bounded, and water content significantly exceeds the true solubility of water in these liquids. As water content increases, the gradation of equilibrium states of water in contaminated insulating oil can be presented as follows: bound water - dissolved water - dispersed water - free water.

In solid insulation such as paper or pressboard, water can also be present in several states: vapour, adsorbed as a monolayer, adsorbed as poly-molecular layers, condensed in capillaries, and free, as in liquid.

Two additional states of water in liquid and solid insulation must be mentioned to fully describe water in power equipment: vapour in the gas phase (from the gas compartment) and in sediments.

In the scientific literature the terms “solubility limit” and “water saturation limit” are sometimes misused and may lead to erroneous diagnostics/interpretations. There is an obvious need in differentiating these notions:

- Solubility of water (c^*_{H2O}, in mg/kg) is the part of water in insulating liquids that forms an intrinsic solution under saturation conditions (i.e., there is a direct correlation with vapour pressure).