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Thermal measurement of an ester-filled power transformer at ultra-low temperatures: steady state

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Abstract

At arctic ambient temperatures, the viscosity of cooling fluids for power transformers reaches extreme levels. This leads to a change of fluid flow and cooling performance, which is even more critical in case of ester fluids and cooling by means of radiators. To ensure reliable operation even under such conditions, a power transformer has been tested under different loads at ambient temperatures ranging from -50°C to -30°C.

In this report, we concentrate on the measurement results for overall cooling performance in steady state. We demonstrate such surprising results as a temperature increase when outside temperature is reduced or when fans are activated for improved cooling. Both effects are due to a change of effectively used cooling surface.

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Keywords: power transformer; low temperature; climatic test; cold start; radiators; ester

1. Introduction

With decreasing temperature, the viscosity of dielectric fluids for power transformers increases enormously. For this reason, natural flow of fluid is reduced at low outside temperatures, and temperatures inside the transformer might reach high levels. This is especially relevant for arctic regions with freezing temperatures down to -40°C or even -50°C, and even more so in case of ester fluids.

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However, even under such conditions, safe and reliable operation of power transformers must be ensured. Therefore, a climatic test program was conducted on a naturally cooled transformer that was filled with a synthetic ester fluid. The single phase auto-transformer (15 MVA / 55 kV) was tested in OWI-lab's large climatic test chamber [7] under different loads at ambient temperatures ranging from -50°C to -30°C.

In contrast to other tests (e.g. [3, 5, 6, 8]), the measurements were not limited to the cold start situation, but also included steady state operation for various different loads, and for temperatures down to -50°C. Compared to the units tested in [3, 8], the test object was larger and cooled by external radiators, which is quite typical for power transformers. The external radiators are particularly remarkable since fluid flow in the small radiator ducts is different from flow at a corrugated tank wall, even more so in case of large viscosity.

Due to the large amount of available data, this report concentrates on giving an overview of the steady state temperature distribution in the transformer for the different heat run tests.

2. The need for low temperature testing

At very low temperatures, transformer cooling liquids become highly viscous. At -30°C, for example, the kinematic viscosity of mineral oils is typically about a factor of 100 larger than at 40°C, and the ratio is even larger for synthetic ester fluids. For Midel® 7131, which has been used in the given measurement series, the viscosity at -30°C is about 4200 mm^2/s (see [4]), i.e. 150 times the value at 40°C or around 500 times the value of mineral oils at 40°C. At -50°C, the fluid is about 10000 times as viscous as mineral oils at 40°C. For this reason, fluid flow is completely different at low temperatures, even more so in case of natural flow, i.e. if flow is only driven by buoyancy forces. These forces are relatively small, and a change of hydraulic resistance by a factor of 10000 clearly has a large effect on flow distribution.

With respect to these low temperatures and extreme viscosities, there are two main points of interest:

- Cold start: When power is supplied to a completely cold transformer, it may take a long time to start flow through the cooling equipment. Especially in case of external radiators, temperatures in the active part can reach undesired levels while flow through the cooling equipment is still insufficiently small.
- Steady state: Also in steady state, temperatures and thus viscosities are different to the usual situation with temperatures of surrounding air around 20°C. Differences in flow distribution and longitudinal oil gradient are expected, and temperatures may even be higher than at normal ambient temperatures.

3. Description of the test object

The tests in the climate chamber have been performed on a single-phase auto transformer with the properties as given in Table 1. Only short circuit heat run tests have been performed, so there have not been any no-load losses in the core during the tests.

The test object has been equipped with 85 temperature sensors (including fiber-optic sensors inside the windings) and 3 moisture sensors. The sensors measure fluid temperatures at bottom and top of the windings, winding hot spot temperatures as well as temperatures in the tank and radiators. In this report, we combine several sensors to yield averaged temperatures, e.g. for top oil in the tank (3 sensors) or bottom oil of the high voltage winding (5 sensors).

Since one main point of interest is cooling performance of external radiators, one half of the wall and cover have been insulated. In this way heat transfer from the tank surface is reduced and the contribution of the radiators is increased (cf. Table 1 which shows the not-insulated surfaces). With this modification, the setup is also representative for larger transformers.