

Analysis of the influence of low-frequency heating on transformer drying – Part 2: Experiences with a real transformer

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ABSTRACT

This paper presents an experimental study about transformer field drying. Different drying processes were performed on a real transformer. The transformer temperature was monitored during the drying processes by means of internal optical fibre probes. The water reduction achieved by the different drying processes, was quantified by measuring the water content of insulation samples taken from the transformer before and after the drying processes. After every drying process, the transformer was moistened by exposing its active part to air.

The first drying process performed was a conventional drying, which consisted of a first stage of water extraction under vacuum (VD) and a second stage of drying by hot oil circulation (HO). The second drying process was similar to the first but, in this case, LFH was applied to heat the transformer insulation. In the third drying process, the first stage of drying was conducted under soft vacuum.

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1. Introduction

Low-frequency heating (LFH) can improve the efficiency of the processes that are used to dry power transformers in the field. LFH consists of heating the active part of the transformer using the heat generated in the windings when they are fed with current [1–4]. A low frequency voltage (0.5 Hz) is applied to reduce the voltage required to reach the desired current. LFH has been proposed by several authors as a good method to heat the transformer active part during the drying processes. LFH may be applied simultaneously to different drying methods, such as hot oil spray (HOS), drying under vacuum (VD), or hot oil circulation (HO).

In a companion paper [5], a study on the efficiency of LFH was presented. In that paper, different drying processes were simulated using a theoretical model solved by finite element analysis. Experiments were conducted in the laboratory on kraft paper specimens that were subjected to different drying conditions. The effects of using LFH and the influence of the temperature were analysed to quantify the improvement achieved when LFH was applied.

As a continuation of that work, drying experiments were performed on a real transformer. A unit of 5000 kV A, 45,000/15,000 V was subjected to different drying processes. The transformer that was tested was older than 40 years, and it was taken out of service bounding it to experimentation. The transformer was equipped with internal temperature sensors to determine

the temperature distribution inside the transformer during the drying processes and to register the temperature evolution.

Three different drying processes were tested on the experimental transformer. The three processes involved an initial period of drying under vacuum (VD) and a second period of hot oil circulation (HO). In the second and the third drying processes, LFH was applied to the transformer simultaneously with HO and VD. The vacuum applied in the third drying process was soft (0.6 bar), as is sometimes used for transformers that cannot withstand high vacuum in their tanks.

From the end of one drying process to the beginning of the next one, the transformer was exposed to ambient air for eight days to moisten it. Before starting each drying process and after finishing it, insulation samples were extracted from several points of the transformer. The samples were analysed in the laboratory to determine their moisture content.

2. Transformer under test

2.1. Transformer characteristics

The experimental transformer was a real unit manufactured in 1967. The transformer was taken out of service because of its age and because its rated power was too low for the power demand at the time. The characteristics of the transformer are as follows:

- Power: 5000 kVA.
- Primary/secondary voltage: 45,000/15,000 V.
- Primary/secondary current: 64.2/192.5 A.

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- Refrigeration: ONAN (oil natural–air natural).

2.2. Transformer instrumentation

To register the temperature evolution during the drying process, seven optical fibre probes were placed inside the transformer. The fibres were installed in the upper and lower part of the windings, in contact with thin insulation. One fibre was also installed in contact with a pressboard piece located on the top of the transformer, Fig. 1.

3. Experimental study

Three different drying processes were performed on the test transformer. In all cases, the drying process included an initial stage of vacuum drying and a second stage of hot oil circulation. The first drying process reproduced the conventional drying process in which no LFH was applied to the transformer. In the second and the third cases, LFH was applied simultaneously to HO and also during the VD stage. The difference between these two drying processes was the vacuum level applied, as described below.

Before starting each drying process, the active part of the transformer was lifted and exposed to ambient conditions for eight days to increase its moisture content to high levels. At the end of the moistening process, paper samples were taken from the transformer to determine the moisture content at the beginning of the next drying process.

3.1. Conventional drying process

The conventional drying process involved the following stages:

3.1.1. Drying under vacuum

Transformer oil was drained and high vacuum was applied in the transformer tank for 24 h. The vacuum level was maintained within 1 mbar. During that time, the oil was subjected to a degassing and drying treatment outside of the transformer. The transformer active part was not heated during this part of the process, and thus, the temperature remained at ambient values (22–25 °C). The temperatures registered during the first drying period are shown in Fig. 2. The temperature distribution was highly homogeneous throughout the transformer because the different probes registered very similar values.

3.1.2. Hot oil drying

Hot, dry oil was forced to circulate through the active part of the transformer. Then, it was re-circulated through oil treatment

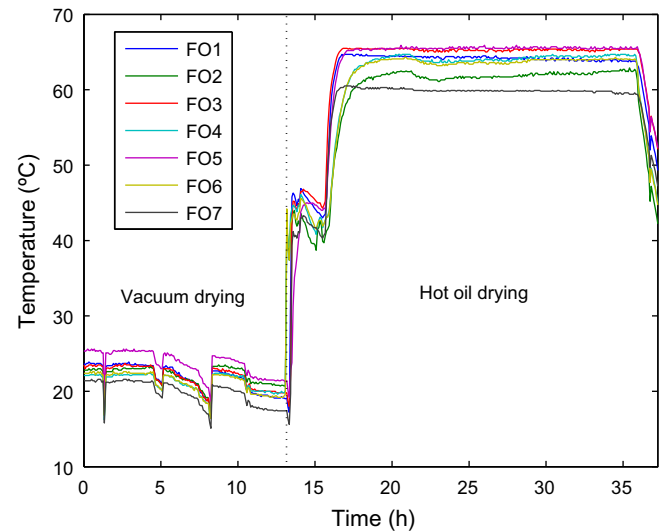


Fig. 2. Temperature evolution during the first drying process. The VD drying period lasted for 24 h. Nevertheless, during the first hours of the VD drying process, the temperature was not registered.

equipment (Fig. 3), where the oil was heated, dried and degasified. Finally, it was re-circulated inside the transformer tank again. The oil temperature at the outlet of the oil treatment equipment was set at 65 °C. The circulation of hot oil was occurred for 24 h at a rate of 3000 l per hour. The temperature inside the transformer during this period was also quite homogeneous and remained within 60–65 °C (Fig. 2).

Before starting the conventional drying process, insulation samples were taken from the transformer. These samples were analysed in the laboratory by Karl Fischer titration. The initial moisture content was approximately 7% in paper and 2% in pressboard. The results of the moisture analysis of the samples are shown in Table 1. Samples were taken again at the end of the process to determine the moisture reduction achieved during the drying process.

The points of sample extraction are shown in Fig. 4. The upper photograph corresponds to a 5-mm-thick pressboard barrier. Paper samples were also taken from the leads connecting the high voltage (HV) winding to the transformer bushing in the three phases (bottom photograph in Fig. 4). The thickness of the insulation of

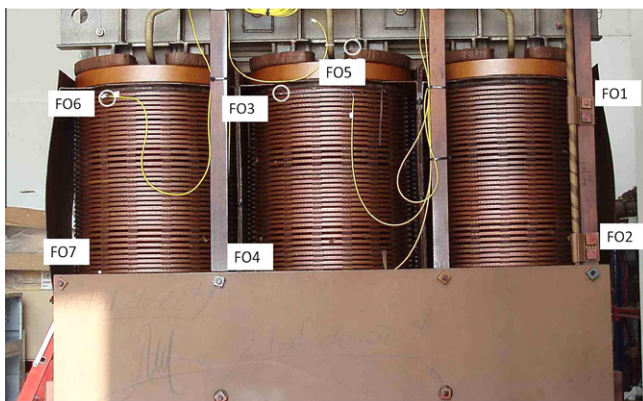


Fig. 1. Temperature measuring points.



Fig. 3. Oil treatment equipment.

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