

Technical Memorandum 2004-03-15 / H Nordman

AVERAGE OIL TEMPERATURE RISE IN DISTRIBUTION TRANSFORMERS WITHOUT AN EXTERNAL OIL CIRCULATION

1. GENERAL

In order to define the average winding to average oil temperature rise, denoted g below, a proper method to define the average oil temperature is necessary. In the past this has been reasonably easy to do for transformers with an outer oil circulation. The average oil temperature has been calculated as the average of the top oil temperature and the bottom oil temperature. In this case the top oil temperature has been taken as the average of the pocket oil temperature and the outlet oil temperature – values which are pretty close to each other (normally a difference of 1...2 K). The inlet oil temperature has been considered as the bottom oil temperature. In old designs the inlet pipes have been taken to the bottom of the tank, which has yielded a well mixed, homogenous bottom oil into the windings.

In power transformers made today, the radiator inlet pipes are normally located somewhat below the midheight of the tank. Measurements have shown, that there is a gradient of 10...20 K between the “official” bottom oil, i.e. the measured inlet oil and the stagnant oil at the bottom of the tank. Nevertheless, the average of the top oil and this circulating “official” inlet oil has yielded average oil temperatures which in turn have yielded reasonable g -values.

The most tricky case is distribution transformers without an external oil circulation, and without sensors fitted into circulating bottom oil. According to Std C57.12.90-1999, § 11.2 Moment c) the bottom oil is defined as follows: “Where the bottom liquid temperature cannot be measured directly, the temperature difference may be taken to be the difference between the surface temperature of the liquid inlet and outlet.” This has been made for a 2 500 kVA distribution transformer equipped with a number of thermal sensors, and to which several heat run tests were made.

2. THE TRANSFORMER, THE SENSORS AND THE TESTS

The transformer was a 3-phase 2 500 kVA, 20500+-2x2.50% / 710 V, YNd-connected standard transformer with a short-circuit impedance of 6 %. The LV-winding was an Al-foil winding with 1 internal cooling duct, and the HV-winding was an Al-flat conductor winding with 2 internal cooling ducts. The radial length of the cooling ribs of the corrugated tank was 250 mm, with a centre distance of 40 mm between the ribs.

In test nr 1 (=constant load current 1.00 pu during 8.5 h) totally 24 sensors were located inside the transformer, two sensors were located in the two oil pockets, one sensor was fitted outside the tank at the top of the cooling ribs and one at the bottom of the cooling ribs. Of the internal sensors, 8 were fitted to the top of the windings of the phase C and 15 were located in circulating oil.

In test nr 2 (=constant load current 1.00 pu during 5 h) the number of sensors fitted to the top of the windings of phase C was increased in order to measure the real hot spot. In this case 9 sensors were embedded in the top of the LV-winding, and 6 sensors were embedded in the top of the HV-winding.

The tests were made in the tap position 3 (= the principal tap), and the tests described in this TM were made at a load current of 1.00 pu.

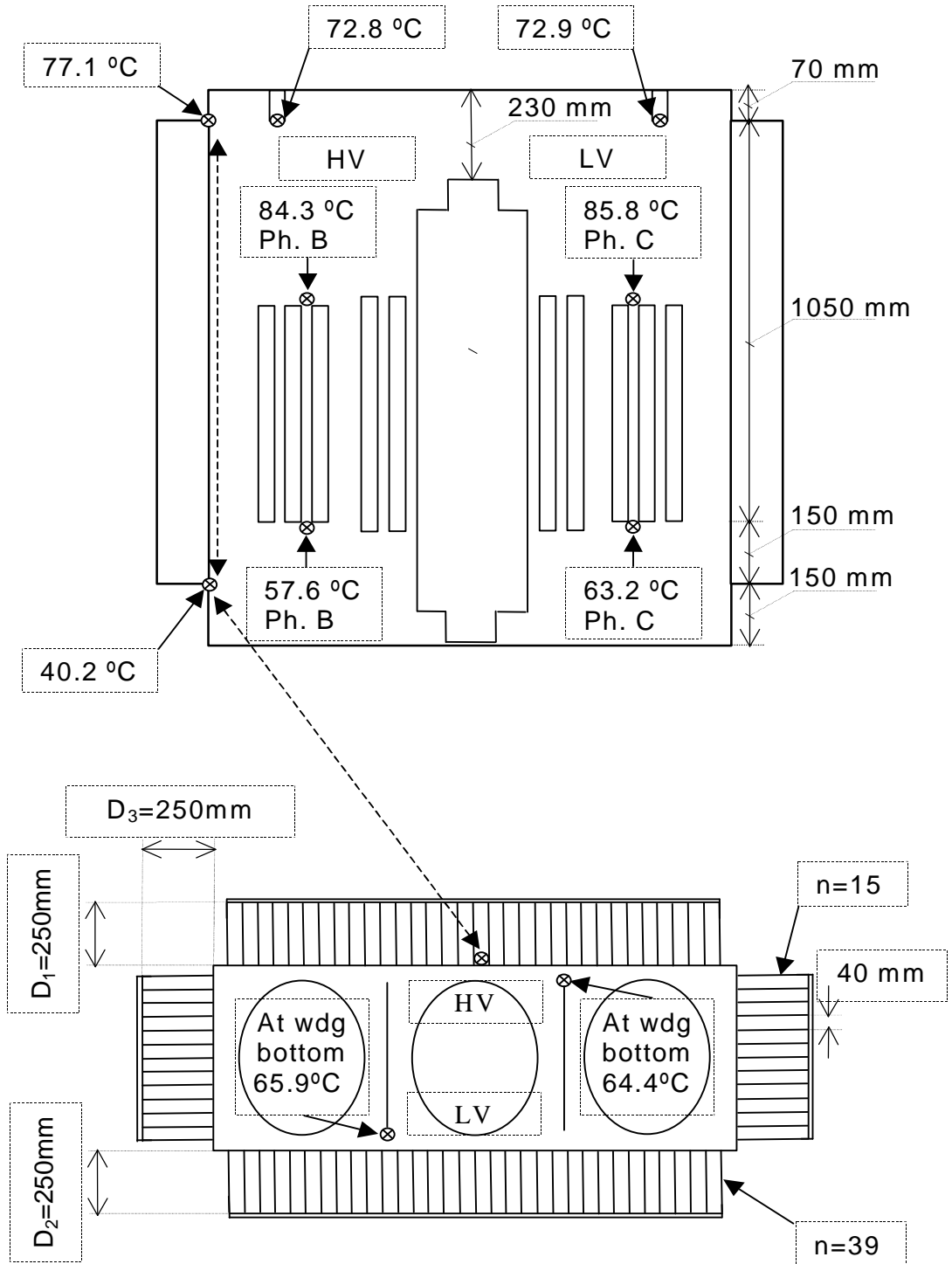


Figure 1. Temperatures at the end of 1.00 pu current supply during 8.5 h in an ambient temperature of 24.8 °C. The Warm Resistance Curves yielded the following winding average temperatures: $LV_{Average} = 89.5\text{ °C}$; $HV_{Average} = 85.3\text{ °C}$.

The hot spot temperature rises above top oil temperature measured in the two oil pockets (one at each end of the transformer tank) were as follows after 5 h constant supply 1.00 pu: $LV_{\text{Hot-spot}} = 24.5 \text{ K}$; $HV_{\text{Hot-spot}} = 21.8 \text{ K}$.

3. CALCULATED AVERAGE WINDING TO AVERAGE OIL GRADIENTS

The g-values of the windings were calculated with the old classical method based on a “neutral surface” within each layer, from which the temperature drops to the layer surfaces are equal on both sides. This method has proved to be very accurate in case of layer windings in ONAN-cooled transformers of the size 10...20 MVA (the deviations between calculated and measured g-values have been of the order of 1...3 K). The calculated values for the 2 500 kVA unit were as follows:

- $g_{LV} = 18.6 \text{ K}$.

- $g_{HV} = 15.5 \text{ K}$.

4. MEASURED AVERAGE WINDING TO AVERAGE OIL GRADIENTS

4.1. Gradients based on bottom oil temperature measured inside the transformer

According to Fig. 1 the bottom oil temperatures measured inside the transformer, at the bottom level of the winding block were: 57.6 °C; 63.2 °C; 65.9 °C; 64.4 °C. It seems then reasonable to assume that the inlet oil into the windings is approximately equal to the average of these four values, i.e. to 62.8 °C. With a bulk top oil temperature of 72.8 °C, we will then get a bulk average oil temperature of 67.8 °C, i.e.

- $g_{LV} = 89.5 - 67.8 = 21.7 \text{ K}$ with a hot-spot H-value of $24.5 / 21.7 = 1.13$.

- $g_{HV} = 85.3 - 67.8 = 17.5 \text{ K}$ with a hot-spot H-value of $21.8 / 17.5 = 1.25$.

4.2. Gradients based on IEC 60076-2

The rule in IEC is as follows: “For ONAN transformers up to 2 500 kVA, with plain or corrugated tanks or individual cooling tubes mounted directly on the tank, the average oil temperature rise above ambient air temperature may be taken as 80 % of the top oil temperature rise.” Then the average bulk oil temperature will be equal to $0.8 \times (72.8 - 24.8) + 24.8 = 63.2 \text{ °C}$, i.e.

- $g_{LV} = 89.5 - 63.2 = 26.3 \text{ K}$ with a hot-spot H-value of $24.5 / 26.3 = 0.93$.

- $g_{HV} = 85.3 - 63.2 = 22.1 \text{ K}$ with a hot-spot H-value of $21.8 / 22.1 = 0.99$.

4.3. Gradients based on IEEE C57.12-90 – 1999

In this case the average bulk oil temperature will be equal to $72.8 - 0.5 \times (77.1 - 40.2) = 54.4 \text{ °C}$, i.e.

- $g_{LV} = 89.5 - 54.4 = 35.1 \text{ K}$ with a hot-spot H-value of $24.5 / 35.1 = 0.70$.

- $g_{HV} = 85.3 - 54.4 = 30.9 \text{ K}$ with a hot-spot H-value of $21.8 / 30.9 = 0.71$.

NOTE: In this case it has been assumed that the expression "...temperature of the moving liquid at the top and the bottom of the cooling means." means the temperature at the top and the bottom of the cooling ribs. In this case the bottom of the cooling ribs was located approximately 150 mm below the bottom of the winding block. Unfortunately, a surface temperature record at that height level was not made in the tests.

5. SUGGESTED IEEE TASK FORCE

Both IEC and (even worse) IEEE yield unreasonably high average winding to average oil gradients for the measured 2 500 kVA unit. It is suggested that a new Task Force: "Determination of average liquid temperature in distribution transformers." is created within the WG - Temperature Rise Test – Section 11.0 C57.12.90.