

## Info Letter No. 16

# Hot-spot temperature and service life of transformers

Power transformers are key components of an electrical supply grid.

The failure of a transformer not only has major economic consequences for the energy supplier, it can also lead to serious losses for consumers. For this reason, it makes sense to monitor the transformer as closely as possible, to take its "temperature curve" (the thermal image) so as to collect information about the current load and the expected remaining life. This task can - based on IEC standards - be solved by electronic measurement and computing facilities.

The thermal situation in the transformer can be represented graphically (see Figure 1), where this is a simplified view of a complex situation.

### The following simplifications are necessary:

- it is assumed that the oil temperature in the tank increases linearly from the bottom to the top.
- Another assumption is that the average temperature of the winding is also linearly parallel to the oil temperature with a constant temperature differential  $g$ , increasing from the bottom to the top.
- it is assumed that the hot spot temperature (P) is higher than the temperature of the winding (hot) at the upper end of the winding. The increase in temperature between the hot spot in the winding and the oil temperature in the tank is designated as a constant  $Hgr$  (hot spot at top oil gradient). Studies have been able to prove that the factor  $H$ , depending on the transformer size, short-circuit impedance and winding design, can vary between 1.0 and 2.1.

The abbreviations used in the diagram are explained below. Measured values are identified by a solid square (■), calculated values are identified by a solid point (●).

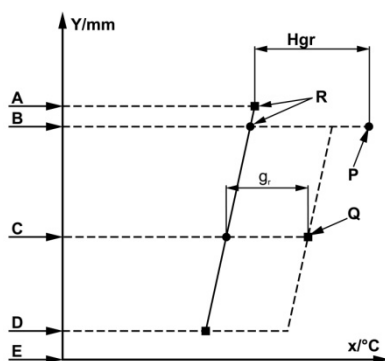


Figure 1

- A: Upper layer of oil
- B: Top end of the winding
- C: Centre of the winding
- D: Bottom end of the winding
- E: Represents the bottom of the tank

- P: Hot point or hot-spot temperature
- Q: Average winding temperature
- R: Points that are assumed to be at the same temperature
- X: X-axis of the graph shows the temperature
- Y: Y-axis indicates the relative position of the individual points

To determine the hot-spot temperature, in addition to the oil temperature  $\Theta_0$  a phase current  $I$  and some transformer-specific characteristics are required.

In most cases, this interpretation will lead to sufficiently good results, because it may be assumed that the transformer is loaded approximately uniformly.

In this case:  $I1 \sim I2 \sim I3$

The hot-spot temperature is calculated according to the following model:

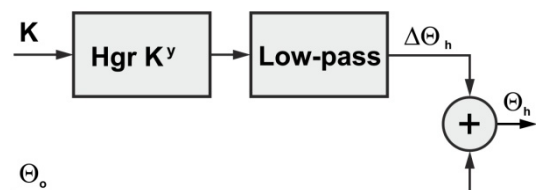


Figure 2

- K: Load factor =  $I / IN$
- $\Theta_0$ : Oil temperature (measured)
- Hgr: Hot-spot to top oil gradient
- $\Delta\Theta_h$ : Hot-spot temperature increase
- $\Theta_h$ : Hot-spot temperature
- y: Winding exponent
- Low-pass: Illustration of the thermal capacity of the transformer

In addition to the operating current, the oil temperature is the most important measure for the estimation and calculation of the hot-spot temperature  $\Theta_h$ . The respective measured oil temperature, together with the current and the characteristics of the transformer are used in the equation, so as to obtain a thermal image of the transformer. On this basis, in addition to the hot-spot temperature, the lifetime consumption of the insulation can also be calculated.

### Lifetime consumption

The "Lifetime consumption" information is derived from the equations specified in CEI/IEC 354/ VDE 0536.

The lifetime consumption should not be confused with the operating hours described earlier. The "Operating hours" only count the time where the transformer is under voltage, while the thermal ageing is taken into account in the lifetime consumption.

The relative thermal degradation of the insulation as a factor of the temperature and time is determined by the Arrhenius equation:

$$Lifetime = e^{(\alpha+\beta)/T} \tag{1}$$

$\alpha$  and  $\beta$  constants, which are determined by tests on the isolation  
 T thermodynamic temperature in K

In the temperature range from 80... 140 °C the Arrhenius equation can be replaced with the slightly simpler Montsinger relationship.

$$Lifetime = e^{-p\Theta} \tag{2}$$

P constant  
 $\Theta$  Temperature in °C

According to scientific publications the lifetime consumption in transformers in the range of 80 to 140 °C doubles when the temperature increases to about 6 K.

The relative lifetime consumption at a temperature  $\Theta_h$ , relative to the normal lifetime consumption at a temperature  $\Theta_{hN}$ , can be determined from the following equation.

$$V = \frac{Lifetime\ consumption\ at\ \Theta_h}{Lifetime\ consumption\ at\ \Theta_{hN}} \tag{3}$$

$$V = 2^{(\Theta_h - \Theta_{hN})/6} = e^{0,693(\Theta_h - \Theta_{hN})/6}$$

The value  $\Theta_{hN}$  for a transformer is specified according to CEI/IEC 354 / VDE 0532 Part 1/11.71 as 98 °C. This temperature corresponds to the operation of a transformer at rated load at 20 °C coolant temperature, when the hot-spot temperature is 78 K, i.e. 13 K above the average over temperature of 65 K. These temperature conditions correspond to the normal ageing of the insulation.

From equation (3) with  $\Theta_{hN} = 98$  °C the following equation can be derived in decadic logarithms.

$$V = rel. Lifetime\ consumption = 10^{(\Theta_h - 98)/19,93} \tag{4}$$

This relationship is shown in the following table:

$\Theta_h$ in °C	relative lifetime consumption V
80	0.125
86	0.25
92	0.5
98	1.0
104	2.0
110	4.0
116	8.0
122	16.0
128	32.0
134	64.0
140	128.0

**Example:**

10 hours at 104 °C and 14 hours at 86 °C consume (10 x 2) + (14 x 0.25) = 23.5 hours lifetime during 24 hour operation.

Note that below 80 °C, the lifetime consumption is negligible.

If the load and ambient temperature are constant, the relative lifetime consumption is calculated using the relationship  $V \cdot t$ .

where "t" is the time under load and V is the relative lifetime consumption from equation (3).

In general – the operating conditions are not constant – the lifetime consumption of the transformer is calculated using the following equation:

$$L = \frac{1}{t} \int_{t_1}^{t_2} V dt \quad oder \quad L = \frac{1}{N} \sum_{n=1}^N V \tag{5}$$

n: Number of a time interval  
 N: Total number of the same time intervals

**Practical recommendation**

An optimal load is achieved when the two parallel operating transformers are loaded at 75%. Then, if a transformer drops out, the other transformer can be loaded at 150% for 20 min.

*The series will be continued.  
 We will gladly supply missing Info Letters at any time!*