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A Study of Two Different Approaches Regarding the Large Power Transformer Units Operating Regimes

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Abstract – The paper compares the operating regimes of the large power transformer units, as they are defined in CEI 60354 and CEI 60076-7, indicating the differences between them. The modification of the operating conditions with the load connected to the secondary winding of the transformer unit is underlined. Further, the paper presents the software applications for evaluating the operation of the transformer in different regimes, their maximum loading limits, as well as the maximum loading time, according to the thermal models presented in the two standards.
Keywords: large power transformer units, operating regimes

I. INTRODUCTION

Transformers are important and expensive elements of the power system. The unusual temperature increase inside the unit may cause the rapid thermal deterioration of the insulation and subsequently the thermal failure of the unit. In order to use the transformer units in the substation at their full capacity and avoid failures due to temperature increase at the same time it is very important to study their entire thermal behavior carefully.

At present, special attention is given to the admissible loading regimes of the large power transformer units at the international level. Until recently, it was considered necessary to limit the transformer unit loading, if the system condition allowed it, so that never to surpass their rated power on purpose. This conception is no longer considered efficient as, in case its load is limited at the rated power, the power transformer should be maintained under-loaded most of the time (because the ambient temperature is usually above 20^{o}C). The short-term loading, especially at lower ambient temperatures, does not diminish the transformer life time very much [1].

In order to know the short-term and long-term loading limits of a transformer unit, the hot-spot temperature should be estimated as precisely as possible. Moreover, the accurate calculation of this temperature helps to realistically estimate reliability and the remaining life time of the transformer unit insulation system [2].

Consequently, considering the overloading effects on the transformer unit life time, as well as on its efficient operation from the economic point of view, guides for the power transformer loading have been developed.

The loading guides have been developed on the basis of the following main principles and hypotheses:
-transformer's life time depends on the paper insulation mechanical and dielectric property modification due to thermal ageing;
-the temperature is not uniform in the case of most of the power transformers. Consequently, the part that operates at the highest temperature is the one that will suffer the fastest thermal ageing rate. Thus, the temperature that gives the global ageing rate is the so-called "hot-spot temperature – HST";
-the effects of thermal ageing are given by Arrhenius equation;
-the thermal ageing is linearly cumulative;
-the loss of half of the initial tensile strength of the insulation represents the quantitative criterion for evaluating the insulation remaining life time. Usually, this also means the termination of the transformer life time, that occurs then, when the mechanical resistance of the conductor insulation can no longer resist the mechanical forces caused by a short-circuit in the system, as the insulation deterioration causes the transformer breakdown.

Some users, who have loaded the power transformers according to the current standards, have noticed that the life time loss calculated in agreement with these standards is less than the life time loss determined by means of a comprehensive analysis of the insulation, carried out after taking out the transformer from the tank. The number of transformers that broke down due to overloading is not so great. These observations

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determined the users to think that the loading guides from these standards are too restrictive [3].

The explanation of these observations is based on the following:
-few transformers operate at an ambient temperature equal to that taken as reference for the rated power, namely:
-the maximum annual average ambient temperature: 20°C;
-the maximum daily average ambient temperature: 30°C;
-the maximum temperature for an hour: 40°C;
-most of the power transformers, except for those in the power stations, can stand cyclic peak loading that seldom determine the temperature to attain the limits specified in these standards.

The reasons that make it more difficult to establish the admissible loading regimes of the large transformer units (whose power surpasses 100 MVA) than of the smaller and medium–size ones are the following:
-the heating caused by the leakage flow is difficult to control in the case of the large power transformers;
-the research activity in the field of the combined effects of thermal ageing and short-circuit stress have led to the conclusion that the loss of life time is greater in the case of the large power transformers;
-as the large power transformers rated voltage is higher, the dielectric stresses they have to withstand are greater, so that they require a more insulation.

II. GUIDELINES

In [4] and [5] the following loading regimes are defined:
-the normal cyclic loading – is performed at a higher ambient temperature, or at a load current that is greater than the rated one during part of the cycle but, from the point of view of the relative thermal ageing rate (according to the mathematical model), this is equivalent to the rated loading at the normal ambient temperature. This is carried out taking advantage of the lower ambient temperatures or low load currents during the rest of the loading cycle. When the regimes are planned, this principle may be extended to ensure long periods of time when the cycles with relatively higher thermal ageing rate than the nominal rate are compensated by cycles with a lower thermal ageing rate;
-long-time emergency loading – loading resulting from the taking out of operation for a long time of certain elements of the system that will not be reconnected before the transformer attains a new steady-state temperature regime;
-short–time emergency loading – it is an unusually heavy transient loading (for less than 30 min.) due to the occurrence of one or several unexpected events that greatly disturb the normal loading of the system.

Among the factors that influence the operating regimes of the large transformer units, the following should be mentioned:
-the rated power with regard to the altitude of the site and the ambient temperature;
-the actual operating power, considering the actual wear;
-the admissible operating powers and currents;
-the admissible overloading duration;
-the extreme taps of the on load tap changer.

In all the transformer unit standards, the rated currents are defined under the following conditions:
-the altitude of the mounting place should not surpass 1000 m above the sea level;
-the average annual temperature should not be higher than +20ºC;
-the air average daily temperature should not be higher than +30ºC;
-the maximum temperature of the cooling agent should not be higher than +40ºC (in the case of the air-cooled transformers) and +25°C (in the case of the water-cooled transformers).

By means of the relations given in [4] and [5], the software applications HST_LC and HST_LC_TR, enabling the determination of the operating conditions of the large power transformers that allow a supplementary life time consumption, have been developed.

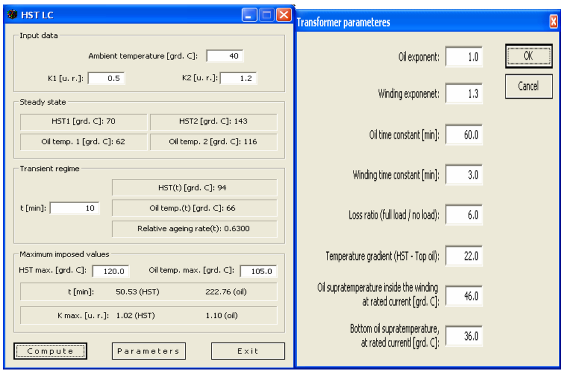

Figure 1. Main window of the software application that establishes the regime of the transformer units according to IEC 60354 (left); transformer unit parameter setting window (right)

The user interfaces for HST_LC and HST_LC_TR are given in Fig.1 and Fig. 2.

The main input data are:
-the ambient temperature, in °C;
-the loading time, in minutes;
-the initial loading factor, K_1 and the final loading factor, K_2, in relative units.

The main output data are:
-for the steady-state regime: the hot–spot temperature and the top oil temperature for K_1, and K_2, respectively;
-for the transient regime:

-for HST_LC: the hot-spot temperature, top oil temperature and the relative ageing rate considering the loading coefficient K_2 for the time period t, in minutes, specified by the user;

-for HST_LC_TR: the initial and final top oil temperature, as well as the hot-spot temperature and the ageing rate, in relative units.

According to the maximum values set by the user for the hot-spot temperature and / or the top oil temperature, the time, in minutes and the maximum value of the loading factor, K_2, in relative units are calculated, enabling the transformer unit safe operation.

The output quantities are calculated by means of the transformer unit parameters defined in [4] and [5]. The parameters are set by the user in the windows presented in Fig. 1 and Fig. 2 (right side).

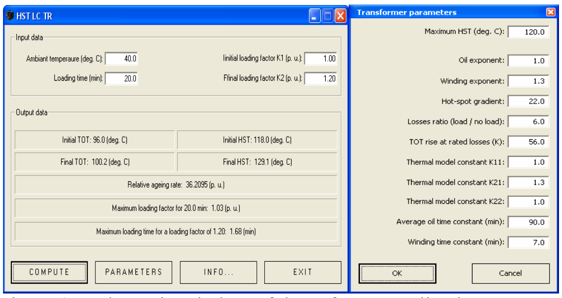

Figure 2. The main window of the software application establishing the large power transformer regime according to IEC 60076-7 (left); the transformer unit parameter setting window (right)

The calculated values compared by means of both software applications are presented below.

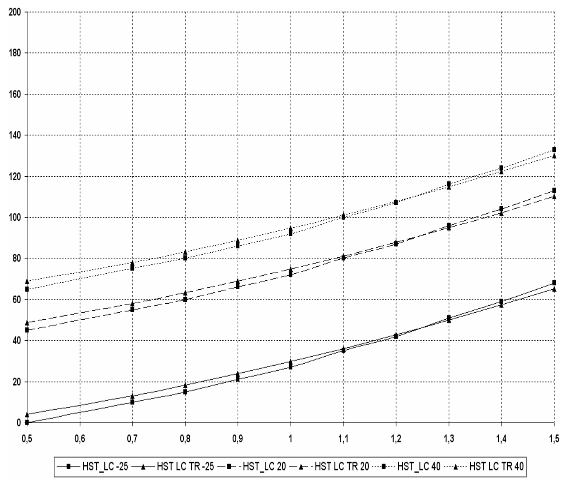

Figure 3. The compared results for different ambient temperatures for $K_1 = 0.5$ and loading time = 30 min

These last three figures (Fig. 3, Fig. 4 and Fig. 5) point out the differences between the two thermal models for different temperatures and loading times.

Based on these observations we can conclude that the thermal model in [5] provides the highest hot-spot temperature when the transformer unit is underloaded, and a lower value when the transformer unit is overloaded, suggesting that the transformer unit can operate longer when it is overloaded, according to this loading guide.

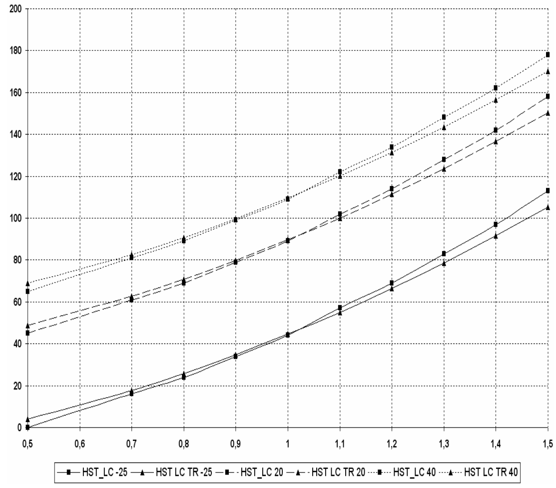

Figure 4. The compared results for different ambient temperatures for $K_1 = 0.5$ and loading time = 120 min

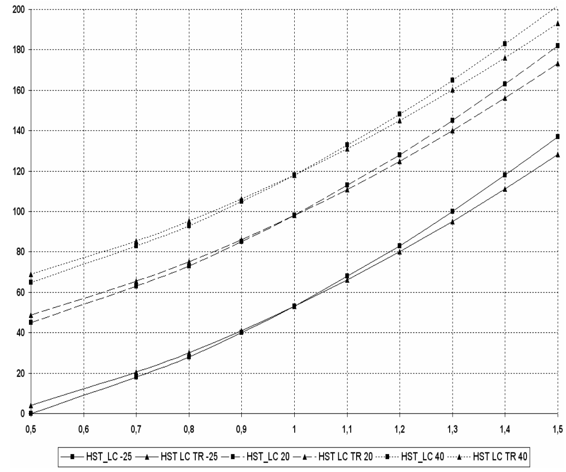

Figure 5. The compared results for different ambient temperatures for $K_1 = 0.5$ and loading time = 1440 min

Table 1. Comparison of admissible time interval values (in minutes) for a transformer unit overloading

K1	K2	IEC 60076-7	Manufacturer
0.5	1.1	Infinite	180
	1.2	168.4	90
	1.3	81.57	60
	1.4	47.59	30
	1.5	29.2	15
1	1.1	Infinite	60
	1.2	79.51	30
	1.3	19.79	15
	1.4	9.69	8
	1.5	6.37	4

At lower loading time values, the differences between the two models are not significant, but then, when the loading time increases the differences increase in their turn.

Under transient regime, the admissible period of time (in minutes) for operating under overload conditions, determined according to [5] is longer than the one guaranteed by the transformer unit manufacturers (see Table 1).

III. FIGURES AND TABLES

This paper compares the operating regimes of large power transformers (whose power is greater than 100 MVA), defined in IEC 60354 and IEC 60076-7.

Software applications enabling the study of the large power transformer unit behavior under different operating regimes, as well as their operating limits have been developed.

On the basis of the data obtained by means of the software applications, the following conclusions can be drawn:

Under steady-state regime conditions, the obtained values are comparable;

Under transient regime conditions the values resulting from the calculation model are much more permissive than the ones guaranteed by the transformer unit manufacturers.

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