A PREDICTION OF DISTRIBUTION TRANSFORMERS AGING BASED ON TANK INFRARED TEMPERATURE MEASUREMENTS

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ABSTRACT

This paper aims to establish criteria that correlate the distribution transformer tank temperature with the top-oil temperature, a parameter used to compute the life expectance. Therefore, an easy reading on the tank thermal behaviour through an infrared camera could be converted in a top-oil temperature. The results by the proposed methodology shown errors lower than 4 °C. Consequently, this technique appears to offer an opportunity to improve the evaluation criteria for overload distribution transformer and the management of equipment overload capability.

INTRODUCTION

Temperature oil profiles in distribution transformers represent the most important limiting factors for their loading. However, the monitoring of oil and indirectly winding thermal behaviour of these devices has not been a common practice. Some reasons for this are related to the difficult of having a specific temperature sensor at each transformer, the distance between equipments and electrical substation, the cost of an online thermal monitoring system and others.

To fill this gap, the infrared camera is an interesting tool to check the equipment temperature once that some essential information could be obtained by this instrument. For this reason, infrared thermography has taken an essential role in preventive maintenance programs in diagnosing the reliability of electrical equipments [1].

When thermography is applied to verify the temperature of transformers, the images from the camera give a thermal mapping of the tank of the equipment [2], [3]. However, it is necessary to know the oil temperature that could not be obtained directly by the thermal images.

Thus, some questions could arise about this subject, like:

- Could some relationship between the tank and the top-oil temperature in a distribution transformer be established?
- What is the better mathematic function to model this correlation?
- Does the tank versus top-oil temperature depend on the transformer rated power and its numbers of phases?

This paper aim to present the results by testing ten distribution transformers to answer these questions. The top-oil temperature measurements were carried out by a PT100 sensor. At the same time, the top and middle of tank temperature were also measured by an infrared camera. With both results, it was possible to establish a correspondence between the tank temperature on the top and middle with the top-oil temperature.

Finally, another two distribution transformers were test to verify the attachment of the proposed methodology. The results show good agreement with the measured top-oil temperature.

TEST TRANSFORMERS

Ten distribution transformers were submitted to the temperature rise tests. This group of equipments had transformers new, used and repaired, single-phase and three-phase, different rated power and insulation level and distinct radiator configuration. The main electrical characteristic of these equipments are show in the Table 1.

Table 1 – Main characteristics of the transformers submitted to the tests.

Group	Number of Phases	Rated Power [kVA]	Number of Transformers
1	1	10	5
2	3	15/30	5
Total			**10**

It could be noted that the main group was separated in two subgroups according to the number of phases and rated power. A criterion adopted was that each subgroup would have, at least, five transformers. Hence, the second subgroup has 15 kVA and 30 kVA transformers, with the objective to reach the minimum number of equipments per group.

TEST PROCEDURE

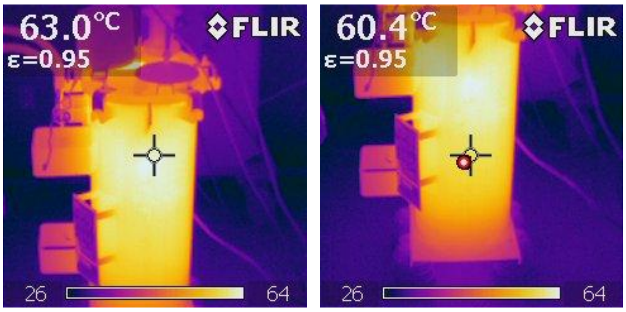
All the experiments were carried out in the High Voltage Laboratory thermal test facility of Federal University of Itajubá. This area of test has an automatic system to perform standard tests in distribution transformers.

The main idea of the experiment was to heat the transformer, measure the top and middle tank temperature by an infrared camera and evaluate the top-oil temperature by a conventional sensor.

First of all, it was carried out the calibration of the infrared camera by comparing the temperature measurements at the infrared camera and at thermocouples installed at the top and the middle of the tank transformer. Then, it was set the emissivity of the tank transformer in order that both equipments indicate approximately the same temperature value. This step was performed in an ambient temperature. After setting the emissivity of the tank, the tests were carried out according to the Brazilian Standard ABNT NBR 5440 [4]. First of all, it was measured the no-load loss, the winding resistance at ambient temperature and after the load losses of the transformer. Basically, there are initial conditions to start the temperature rise test. The transformer was in a short-circuit configuration and then it was applied a current that generated the total losses of the equipment. The transformer was maintained at this current until steady stated temperature was reached. Subsequently, it was applied the rated current in the equipment.

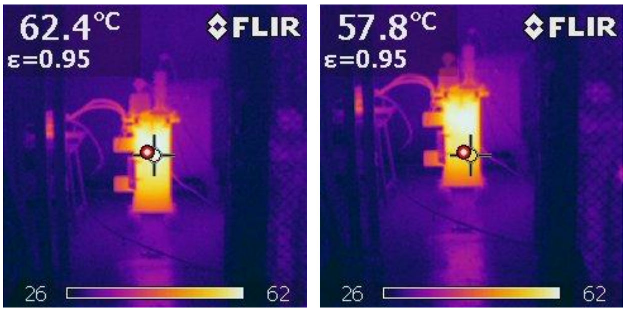
After reaching a new thermal steady state, the top-oil temperature was measured by a PT100 sensor and the top and middle temperature of the tank was measured by the infrared camera. In the total, it was taken four measurements per equipment, two close and others far to the transformer. These measurements near to the transformers were adopted to simulate inspection conditions of equipments installed at ground level. On the other hand, the measurements distant try to reproduce the conditions when the transformers are installed on poles.

The Figure 1 (a) and (b) exhibit examples of pictures took close to the transformer, when measurements were carried out on the top and middle of tank equipment, respectively. Likewise, the Figure 2 (a) and (b) show pictures took far of the equipment, when measurements were carried out on the top and middle of tank transformer, correspondingly.



(a) (b)

Figure 1 – Pictures took closed to the distribution transformer. (a) On the top of tank; (b) On the middle of tank.



(a) (b)

Figure 2 – Pictures took far to the transformer. (a) Top of tank; (b) Middle of tank.

Normally, each test started at the end of a day and allowed to run overnight so that steady state was reached during the morning of the following day. Several readings were taken to verify if the temperature rises were constant. Then, the tank and top-oil temperature measurements were carried out.

RESULTS

With all the measurements, it was carried out a statistical analysis of the results. First, it was observed that the readings close and far of the transformers are approximately the same. For this reason, both results were grouped. Nevertheless, the values on the top and middle of tank were distinct from each other, because the middle of tank temperature was lower than the top of tank temperature, as expected. For these reasons, it was decided to work with two series of data only: top and middle of tank temperature. Initially, it was considered to deal with several mathematics equations to correlate the top-oil temperature in function of tank temperature. In these cases it was measured the thermal behaviour of the transformer only under rated current. Therefore, there are no data about the performance of tank and oil temperature below rated conditions. In Figure 3 there is no information of the thermal behaviour from 0 °C to 30 °C. Therefore, the type and the shape obtained by the statistical fitting could not reach a good fitting.

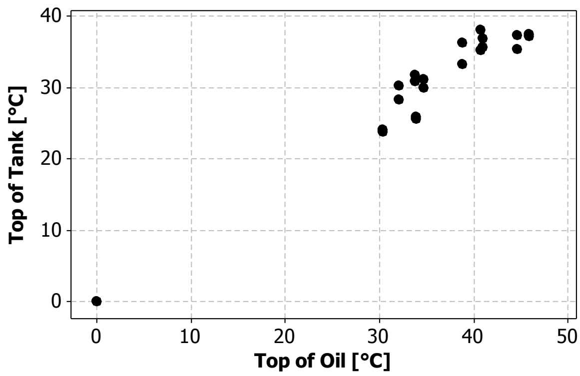


Figure 3 – Scattering plot between the rise of top-oil and top of tank temperature over the environment temperature.

For this reason, it was proposed to calculate the ratio between top-oil and tank temperature for each measurement. Thus, it was obtained a series of data that were grouped and analysed in a statistical way.

Analyzing the distribution of the relation between top-oil and tank temperature, it is expected to establish some useful factor that could be took into account to compute the top-oil temperature based on tank thermal behaviour.

The Figure 4 shows a histogram of the values of the ratio between top-oil and top of tank temperature for group 1 set of transformers *RT*.

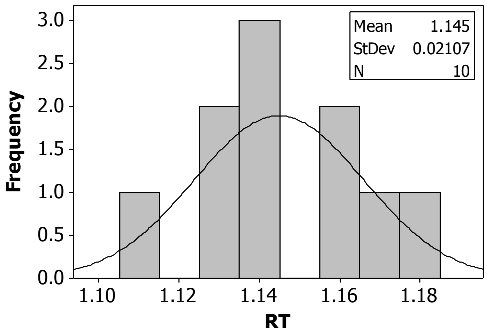


Figure 4 – Histogram of the ratio between top-oil and top of tank temperature for the group 1.

In Figure 4 the average value of *RT* is 1.14 with a standard deviation of 0.02. In the same way, it was plotted the histogram of the values of the ratio between top-oil and middle of tank temperature, called *RM*, as shown in Figure 5.

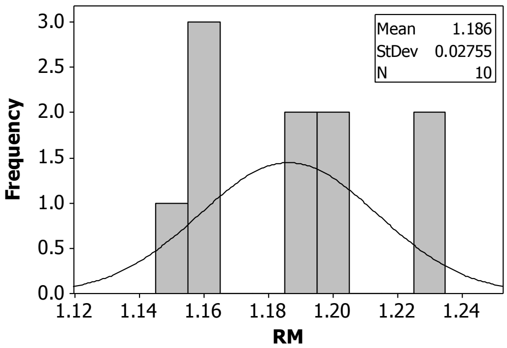


Figure 5 – Histogram of the ratio between top-oil and middle of tank temperature for the group 1.

For the transformers in group 1, the most probable value of RM is 1.19 with a standard deviation of 0.03. The same analysis was carried out for the *RT* and *RM* factors for group 2 and for all transformers. Figures 6, 7, 8 and 9 show the histograms of *RT* and *RM* factors for group 2 and *RT* and *RM* factors for all transformers, respectively.

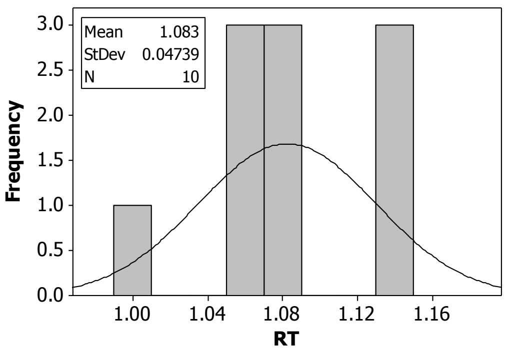


Figure 6 – Histogram of the ratio between top-oil and top of tank temperature for the group 2.

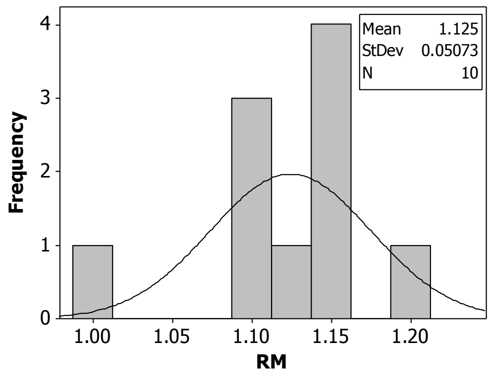


Figure 7 – Histogram of the ratio between top-oil and middle of tank temperature for the group 2.

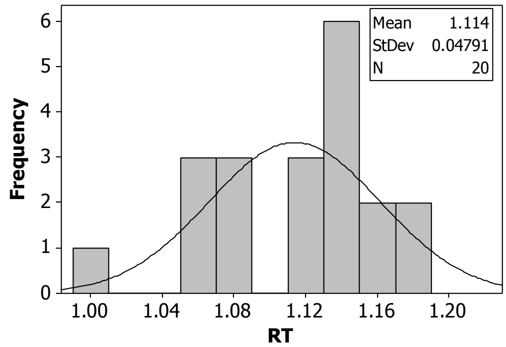


Figure 8 – Histogram of the ratio between top-oil and top of tank temperature for all the transformers.

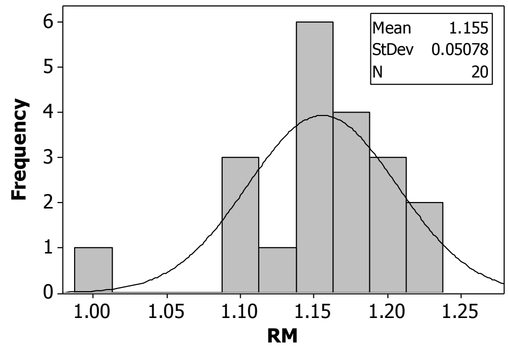


Figure 9 – Histogram of the ratio between top-oil and top of tank temperature for all transformers.

A summary of the test results to the group 1 and 2 is shown in Table 2 that presents the minimum, maximum, the most probable value for *RT* and *RM* and the standard deviation.

Table 2 – RT and RM factors characteristics for the group 1 and 2.

	Group 1		**Group 2**	
	RT	**RM**	**RT**	**RM**
Minimum	1.11	1.15	0.99	1.00
Maximum	1.18	1.23	1.15	1.19
Average	**1.14**	**1.19**	**1.08**	**1.12**
StDev	0.02	0.03	0.05	0.05

Table 3 show the results for all transformers. Similarly, the minimum, maximum, mean value of *RT* and *RM* and the standard deviation of the samples are shown.

Table 3 – RT and RM factors characteristics for all transformers.

	Total	
	RT	**RM**
Minimum	0.99	1.00
Maximum	1.18	1.23
Average	**1.11**	**1.16**
StDev	0.05	0.05

With the results obtained, it is expected that using the most probable value of *RT* or *RM* times the infrared thermal indication, the transformer top-oil could be estimated. To verify the proposed methodology, some tests were carried out in two independent samples. The results are shown hereafter.

RESULT VERIFICATION

Two distinct distribution transformers, both 30 kVA and called TR_1 and TR_2, were tested to verify the method proposed in this paper. Both equipments were submitted to the standard heat-run test, as described previously. When the thermal steady-state was reached, the temperatures of the top and middle of the tank were measured by an infrared camera. Also, the top-oil temperature was registered to verify the agreement between the calculated and measured values.

The Table 4 shows the temperature values on the transformer tank and on the top-oil. As observed that the thermal values of the tank are lower than the top-oil temperature in all the cases, as expected.

Table 4 – Measurements carried out on the tank transformers and on the top-oil.

	Top of Tank		**Middle of Tank**		**Top-oil**
	Close	**Far**	**Close**	**Far**	
TR_1 [°C]	47	47	46	46	55.2
TR_2 [°C]	55	55	53	53	59.8

Finally, with the average values of *RT* or *RM* factors times the temperature of the tank, it was possible to compute the top-oil temperature for the two transformers. The results and the calculated errors are shown in Table 5.

The values present in Table 5 show a good agreement between the calculated top-oil temperature using factors proposed in this paper and the measured top-oil temperature. The maximum discrepancy was 8%.

Table 5 – Calculation of the top-oil temperature by the RT and RM factors and errors.

		Group 2		**All**	
		RT	**RM**	**RT**	**RM**
TR_1 [°C]	**Calc.**	51	52	52	53
	Test	55			
	Dif.	-4	-3	-3	-2
TR_2 [°C]	**Calc.**	59	59	61	61
	Test	60			
	Dif.	-1	-1	+1	+1

CONCLUSIONS

- There is no obvious difference between the results reached by the *RT* and *RM* factors from the group 2 and from all transformers;
- In the same way, there is no evident distinction between the results obtained by measuring the temperature on the top and on the middle of tank;
- The difference between the calculated and measured top-oil temperature was acceptable and the results show good agreement;
- More exhaustive tests have to be performed to get more representative samples and improve the methodology, as transformers quantity as in the equipment characteristics diversity.

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