AUTOMATION OF THE TEMPERATURE ELEVATION TEST IN TRANSFORMERS WITH INSULATING OIL

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Abstract. The automation of the temperature elevation test is outlined here in both concerning the oil temperature elevation and the determination of the winding temperature elevation. While automating this test it is necessary to use four thermometers, one three-phase wattmeter, a motorized voltage variator and a Kelvin bridge to measure the resistance. All the equipment must communicate with a microcomputer, which will have the test program implemented. The system to be outlined here was initially implemented in laboratory and, due to the good results achieved, is already in use in some transformer manufacturing plants.

Keywords: Transformers, Automated tests, Temperature elevation

1. Introduction

In the past, the temperature elevation test was done only in the first prototypes from the manufacturers and because there were only a few electrical power utilities, upon the purchase. This way, despite being a long and cumbersome test, as it was seldom done, it did not payoff the investment to be automated. A better option was to address it to an accredited laboratory upon request and with the follow up from a manufacturer representative and a purchaser inspector.

Another relevant factor is that the older transformers, mainly the distribution ones, that had to comply to standards in force with respect to their losses, had their design completed with older techniques and tooling, resulting in a bigger and heavier core than the ones obtained with state-of-the-art techniques.

This way, for a certain power the older transformers are bigger than the current ones; as the allowed losses values almost do not change, the current transformers do not dissipate the heat generated internally so easily. Thus the design of the tank and the radiators became more critical. So, the manufacturer must perform more temperature elevation tests, what justifies the implementation of this test automation at the laboratory.

2. The Classic Test

The temperature elevation test is made up of two distinct parts; the temperature elevation top of oil and the temperature elevation of the windings [1].

Through the routine tests previously performed, the value of the total losses is calculated; this value must be maintained constant throughout the test of temperature elevation top of oil.

By beginning the test, the temperature on top of the oil and at least three ambient temperatures must be measured, with thermometers placed around the transformer so that, at regular time intervals, the operator notes down the temperature values, checks if the total losses value is correct and calculates the temperature gradient of the oil concerning the ambient temperatures measure.

The test is considered stable when the temperature elevation top of oil has not varied more than 1 °C for the last three hours.

The value of the temperature elevation top of oil must be less or equal to the values tabulated according to the standard NBR3356 [2].

The second part of the test consists in circulating the rated current in the windings for one hour, switching off, disconnecting the cables, connecting the Kelvin bridge in a winding and making a set of readings of resistance and their respective times within a time frame of four minutes at most.

With the pairs resistance x time it is possible to make a plot and by making a logarithm extrapolation for t=0, to obtain the winding resistance value upon the switching off.

This way, upon the switching off, the average temperature of a winding, through the method of the resistance variation, is determined by the equation:
$$T_{\text{hot}} = \frac{R_{\text{hot}}(t = 0)}{R_{\text{cold}}} (K + T_{\text{cold}}) - K$$

Where:
$$K = 234.5$$ for copper and $$225$$ for aluminum.

This test introduces two main setbacks: the first is the constant need for an operator always paying attention to the value of the total losses applied to the test subject and correcting it if necessary, besides reading the temperatures and noting them down. The second setback and maybe the most critical one is usually related to the disconnection, where experience and skill is required for handling and reading of the measurement equipment.

3. Test Automation

So as to have this test automated it is necessary to use a personal computer and equipment to measure active power, temperature and ohmic resistance with features of communication with the personal computer.

3.1. Temperature Elevation of Top of Oil

The control program initially commands the closure of the motorized varivolt relay, making the voltage to elevate until the active power read from the wattmeter is the same as the power of the total losses previously calculated and inputted in the program. If the active power is higher than the desired one, a closure command will be issued to another relay which will make the voltage to decrease. This process assures that the value of the total losses remains constant throughout the entire test. At the same time, temperatures are also measured and the temperature elevation of top of oil is calculated.

This way, the control program cycles through the process outlined, storing all the measured and calculated data until the thermal balance occurs, that is, until the temperature elevation of top of oil is smaller than 1°C in the last three hours.

3.2. Temperature Elevation of the Windings

After the thermal balance takes place, the temperature elevation of the windings must be determined. The method used is the resistance variation, which is the temperature determination by comparing the electrical resistance of the winding in temperature to be determined with its resistance at a known temperature [1].

The known resistance and temperature is obtained during routine tests and is technically called cold resistance, that is, measured at ambient temperature before any test is begun.

For this second part of the test, the rated current of the windings must be circulated for at least one hour. This way, now the control program adjusts the voltage variator voltage until the current is equal to the desired one. This process is repeated for one hour, after which it is necessary to disconnect the transformer source supply and to connect the Kelvin bridge in a winding.

The control program, in this point of the test, while communicating with the Kelvin bridge, makes a set of readings of ohmic resistance of the winding selected, storing them with their respective times, always within the time frame of four minutes.

For the other windings, the test is repeated always applying the rated current for one hour.

For determination of the ohmic resistance value, upon the switching off, an exponential regression is done by the least square method [1].

4. Experimental Results

4.1. Equipment Used

The following equipment were used for the test automation:

a) Three-phase digital wattmeter with the following characteristics:
- Three voltage channel from 0 to 350 V each;
- Three current branches from 0 to 5 A each;
- Four input for thermometers from 0 to 100 °C;
- Two independent relays with contacts usually open;
- Communication with microcomputer through serial RS-232.
b) Three-phase digital “Kelvin Bridge” with the following characteristics:
- Six input channels, “four wires each”, three for the high voltage bushings and three for the low voltage bushings;
- Measurement range from 0.001 mΩ to 1000Ω;
- Serial RS-232, for communication with the microcomputer.

This equipment reads the individual resistance of each channel, according to the control program request. Its internal source, upon turning on and off varies the voltage ramp-like to minimize the inductive effects in the windings. It also has protection at the inputs against voltage surges.

c) Measurement table, containing basically three potential transformers and three current transformers, with several taps.

4.2. The “Software”

The control software, called eleva.exe, was developed by using the Turbo Pascal programming language and it has approximately twenty thousand programming lines.

The main functions and features implemented are the following ones.

4.2.1. Input for Test

This option allows to input a transformer in the software database to perform the test. It can be done either automatically or manually. In the last case, the operator is requested to type all the data necessary to the test as kind of connection, power, AT voltage, BT voltage, total losses, cold resistance values with the respective temperature and also time in seconds that the Kelvin bridge took to stabilize the cold resistance readings.

In the automatic mode the program searches all the information necessary to the input of the test in the TRANS4.EXE program database, which is used for the routine tests management.

4.2.2. Test of Elevation of the Oil Temperature

As the name implies, this option is used to perform the first part of the test. However, it still allows the operator to do the test in three distinct ways, namely:
- Standard test, with total losses from the onset;
- Test with initial overload of 30% for five hours;
- Test with reduced total losses of 20%.

In the second case, the test is abridged to some hours, due to initial overload.

The third case is allowed by standard and it is used when the power source applied to the transformer is not enough for it to reach the value of the total losses calculated.

In this case, the following correction is applied by the program [1]:

$$\Delta \theta_o = \Delta \theta_i \left( \frac{\sigma_o}{\sigma_{or}} \right)^{0.8}$$  \hspace{1cm} (2)

Where:
- $\Delta \theta_o$ = Elevation of the oil temperature over the coolant temperature, with total losses in °C;
- $\Delta \theta_i$ = Elevation of the oil temperature over the coolant temperature, with reduced losses in °C;
- $\sigma_o$ = Total losses in [W]
- $\sigma_{or}$ = Reduced losses in [W]

4.2.3. Test of Elevation of the Winding Temperature

This option of the program allows to apply the rated current of the windings for one hour, at the end of which we can proceed to the hot resistance measurement.
4.2.4. Measurement of the Hot Windings Resistance

In this option the program, using the Kelvin Bridge, makes ten readings, with their respective times in the windings selected. One or two windings can be read in the same disconnection respecting the limit of four minutes.

For the other windings it is necessary to repeat the test outlined in section IV.2.3.

To ease and to take the least time possible in the disconnection of the transformer it is interesting to prepare a fast commutation system between the transformer and the Kelvin bridge. Figure 1 illustrates a fast commutation option.

![Test arrangement](image)

**Figure 1. Test arrangement.**

During the temperature elevation test, switch SH1 is closed, maintaining the secondary in short-circuit and the switch SH2 is turned to the position A, feeding the transformer. The commutation is done in the following sequence:

a) The voltage variator is disconnected and a chronometer is manually triggered;

b) Switch SH2 is commutated from A to B;

c) Switch SH1 is opened;

d) The program is allowed to begin reading in the windings selected and the chronometer is stood still. The program later will request the time recorded in seconds. If only the reading of a winding was selected, the ten readings will be made along the four minutes time frame allowed. If the option selected was reading in two windings, ten points are initially read in the LV’s winding, in the interval of one minute and next ten more readings in the HV’s winding in the remaining interval of three minutes.

It is important to comment that the measurements of cold resistance were made with the same Kelvin bridge, by using a specific program for that.

This program besides making the readings of the ohmic resistances of the windings, also recorded the stabilization time of the inductive effect.

In the test of measurement of the hot resistance, this time is used to guide the beginning of readings.

4.2.5. Calculations and Reports

This option allows the test results to be seen on the screen of the computer and to be printed. These test results are:

- Plot of the temperature elevation along the time without initial overload (figure 2) and with overload (figure 3).

Plot containing the pairs of points, resistance and time, and the extrapolation curve for \( t = 0 \) (figures 4 and 5).
Figure 2. Temperature elevation without initial overload.

Figure 3. Temperature elevation with initial overload.
Figure 4. RH1H2, RH2H3 and RH1H3 versus time.

Figure 5. RX1X2, RX2X3 and RX1X3 versus time.

The values calculated for the winding temperatures with respect to the oil and for the winding with respect to the ambient temperature are shown in table 1.
Table 1. Winding temperatures with respect to the oil and the winding with respect to the ambient temperature.

5. Conclusion

The automation process for the temperature elevation test has shown to be very useful and practical because it contributes to ease and standardize two critical points of this test, which are: long stabilization follow-up for the temperature top of oil and for disconnection and hot resistances measurement.

With this system some manufacturers start the test right after office hours and it is completed the next morning, ready to make the hot resistance measurement.

With the use of the initial overload option, the test can be started in the morning and finished in the same day.

Besides the program eleva.exe, the authors have developed all the measurement equipment: three-phase digital wattmeter, three-phase Kelvin bridge, and controlling circuit for the voltage variator and temperature reading. Thus a maximum interaction of the set has been achieved.

The program, however, can be adapted to control other similar equipment from the manufacturer, provided they have communication serial interface.

6. References

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