Check of Temperature-Rise Test of High Voltage Prefabricated Substations with Power up to 1600 kVA

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Abstract - **In the first part of this paper are presented the requirements of 62271-202/2014 – standard for temperature-rise tests of HV/LV prefabricated substations. Also is presented the new installation for temperature-rise test, according to IEC 62271-202/2014 of high voltage/low voltage prefabricated substations with powers up to 1600 kVA and voltages up to 52 kV composed from a three-phase, low voltage AC supply with motor-generator group and a three-phase, high voltage AC supply realized within High Power Laboratory (HPL) of ICMET-Craiova with three single-phase groups autotransformers-transformers. The realized installation is an alternative to temperature-rise tests electrical equipment because it uses a supply different that motor-generator one. In second part there are presented experiments performed on a prefabricated substation.**

I. INTRODUCTION

In accordance with IEC standard, within HPL there are carried out temperature-rise tests as type-tests for HV/LV prefabricated substations. Because HV prefabricated substations have evolved from the point of view of their design, having powers up to 1600 kVA, therefore HPL developed a new installation for these tests. This installation allows testing of prefabricated substations with powers up to 1600 kVA and voltages up to 52 kV, and it is necessary to use two AC three-phased power supplies, one for high voltage part and one for low-voltage part. [1,2,3,4,5]

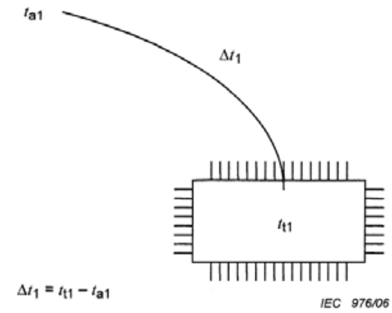
This allows the harmonization of testing techniques from HPL with those from other abroad testing laboratories.

II. REQUIREMENTS OF THE STANDARDS

A. General

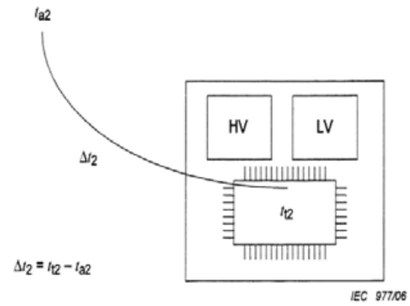
The purpose of temperature-rise tests is to check that the design of prefabricated substation enclosure operates correctly and does not impair the life expectancy of the substation components. Their life expectancy will not be influenced if the acceptable limits of deterioration of insulation through thermal effects are not exceeded. Depending on the results of the temperature-rise test de-rating of the components may be necessary.

In particular, the test shall demonstrate that the temperature rise of the transformer inside the enclosure does not exceed the one measured on the same transformer outside the enclosure by more than the value that defines the class of enclosure, for example, 5 K, 10 K, 15 K, 20 K, 25 K or 30 K. Refer to Figures 1 and 2. [1]



t_{a1} ambient air temperature of the test room
t_{t1} transformer temperatures measured according to IEC 60076-2:2011 and IEC 60076-11:2004
Δt_1 temperature rise of the transformer outside an enclosure

Fig. 1. Measurement of transformer temperature rise in ambient air: Δt_1



t_{a2} ambient air temperature of the test room
t_{t2} transformer temperatures measured according to IEC 60076-2:2011 and IEC 60076-11:2004
Δt_2 temperature rise of the transformer inside an enclosure

Fig. 2. Measurement of transformer temperature rise in an enclosure: Δt_2

B. Test Conditions

The enclosure shall be complete with its components positioned as designed for service. The doors shall be closed and cable access points sealed to represent service conditions. The power and losses of the transformer should be those corresponding to the rated maximum power of the prefabricated substation.

Transformer, high-voltage and low-voltage interconnections, and low-voltage equipment temperature-rise tests will be performed simultaneously.

The test will be executed in a room whose dimension, insulation or air condition will keep the ambient air temperature of the room within the ambient limits specified. [1]

The environment shall be substantially free from air currents, except from those generated by heat from the equipment under test. In practice, this condition is reached when the air velocity does not exceed 0,5 m/s. [1]

C. Test methods

Two situations can be considered, depending of the type of transformers installed in the substation:

- liquid-filled transformers;
- dry-type transformers.

If the substation is equipped with liquid filled transformers two test methods can be used to carry out the temperature-rise tests.

The method requires one single supply of current and method which requires the use the use of independent source of current to supply the high voltage and the low voltage sides of the substation. [1]

The method using the single supply of current requires the following connection of supplying: [1]

- The high voltage switchgear and control gear, the high voltage/ low voltage power transformer and the low voltage switchgear and control gear shall be connected. The outgoing terminals of the low voltage switchgear and control gear shall be short-circuited.

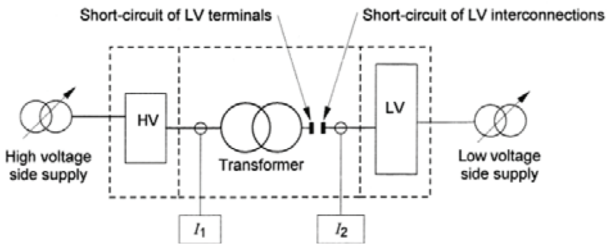
The second method is preferred and it requires different connections of supply for the high voltage and the low voltage sides respectively. [1]

a) High-Voltage side.

The transformer and high voltage switchgear with its tee-off (fuses with correct rating or circuit-breaker) shall be connected and the low-voltage outgoing terminals of the transformer shall be shall be short-circuited. The supply shall be connected to the incoming high-voltage switchgear terminals. Refer to Figure 3.

b) Low-voltage side.

The temperature-rise test on the low-voltage side shall be carried out in accordance with 10.10 of IEC 61439-1 and the following specific requirements. The low-voltage switchgear shall be isolated from the transformer, at a convenient point as close as practicable to the transformer terminals. At this point adjacent to the transformer terminals shall be applied a short-circuit to the connections between the transformer and the low-voltage switchgear. Test current shall be applied to the low voltage switchgear via the outgoing feeders.



I_1 sufficient current to generate the total rated losses of liquid filled transformers or high voltage rated current for dry type transformers
I_2 low voltage rated current of the transformer

Fig. 3. Diagram of the preferred temperature-rise test method

III. Description of the Installation

An installation was made in HPL-ICMET Craiova, according to Fig. 3. This installation consists of two AC three-phase power supplies [2]: [5]

- one supply on low voltage part composed from an motor-generator group (initially existing in HPL)
- one supply on high voltage part composed from three single-phase autotransformers, each of them being coupled through an adapting transformer

The important aspects are related to the power supply composed from three autotransformers of a special construction, three adapting transformers, command and adjust circuit for manual and automatic control of voltage.

The main parameters of the supply composed from autotransformer-transformer group are the following [2]:

- power: up to 200 kVA
- rated adapting voltage: 3x400 V + neutral
- voltage adjustment: 0-400 V with 0.2x$\sqrt{3}$ V step
- frequency: 50 Hz
- output voltage: 3xUs
  where Us = 0-500 V- 1000 V-2000 V
- current adjustment: 240 A - 120 A - 60 A

A. The autotransformers:

The autotransformers are single-phase, with a special construction, with power 70/80 kVA with fine adjustment of output voltage: 0-230/250 V [2].

The magnetic core was made from cool laminated table with crystals oriented on a mantle type core.

The coil assembly was made of copper bars.

The switching of adjustment steps is performed with a collector-brushes system and collecting of voltage from winding is performed with a rolling system which follows the current path.

The operating of autotransformer's cursor is performed with a reducing motor with double rotation sense having the possibilities of blocking and signaling on different positions.

B. The adapting transformers:

The adapting transformers are in single-phase construction, with 70 kVA power and following voltages ratio: U_1/U_2 = 250 V/500 V; 500 V; 500 V; 500 V (so there are four adjust terminals in order to obtain a maximum voltage of 2000 V) [2]. The magnetic core was made of two columns of cool laminated table with oriented crystals, on a mantle type core. The coil assembly was made of copper bars with insulation class F.

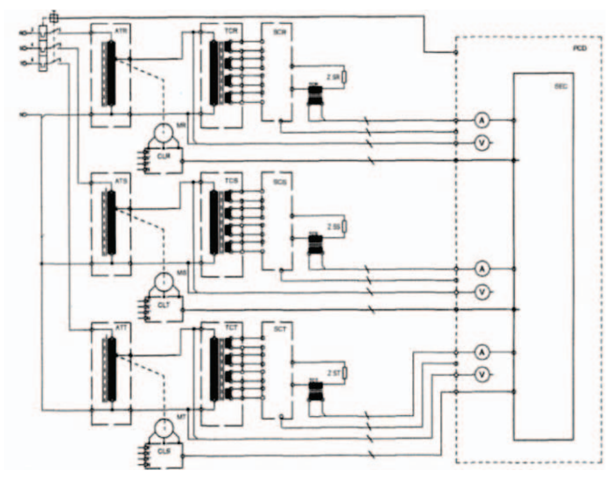
C. The adjustment and command circuits:

The adjustment and command circuits are found into command panel supplied at 24 VDC with positions signalizing possibilities [2]. The command circuit offers the voltages for reducing motor for corresponding operation of autotransformers.

The brute adjustment of voltage and current is performed by choosing the step corresponding to adapting transformers (connection series, parallel and combinations) for the four secondary of transformer and the fine adjustment is performed from autotransformer. The test current is maintained constant through automatic adjustment of transformers.

There is an electronic system for controlling adjustment loop and command algorithm PI - ON/OFF [2]. Block diagram of the high voltage part of installation is presented in Figure 1. Drawer of automated command of the test current The drawer is made up of 3 identical modules, one on each phase, for the automatic regulation of the test current, in order to maintain the amplitude of the current at the stipulated value.
Its functioning is described below:

- By means of a potentiometer the needed value of the test current amplitude is stipulated;
- The test current signal (driven from the TCR, TCS and TCT transformers) is compared with the stipulated signal and, function of the difference between these two currents, there is given a command of increase/ decrease of the test current.



ATR. ATS, ATT - single-phase autotransformers
CLR, CLS, CLT - command block
TCR, TCS, TCT - adapting transformers
ZSR, ZSS, ZST - load impedance
SCR, SCS, SCT - connections adapting system
SEC - electronic control system
TCR, TCS, TCT - current transformers
PCD - command panel

Fig. 4. Block diagram of the high voltage part of installation

IV. EXPERIMENTS

With this installation were created the necessary conditions for performing temperature-rise test and determination of thermal class according to IEC 62271-202/2014 for high voltage/low voltage prefabricated substations with powers up to 1600 kVA and voltages up to 52 kV [1,2,3,4]. Below is presented an example of utilization of this installation for 1600 kVA, 36/0.4 kV prefabricated substation. [4, 5]

A. Test program:

A.1. One test to check the temperature-rise test of the transformer inside of the substation [1].
In the same time the tested power transformer was supplied on high voltage windings at total losses with low voltage windings short-circuited.
During this test the low voltage equipment was supplied through fuses, the short-circuit being made at the end of supply cables [4].

A.2. One test to check the temperature-rise test of the transformer outside of the substation. The tested power transformer was supplied on high voltage windings at total losses with low voltage windings short-circuited [4].

A.3. Determination of thermal class of substation [4].

B. Test circuit:

The test circuit is presented in diagram from Figure 5 [4].

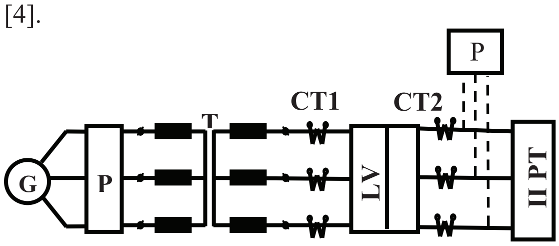


Fig. 5. Test diagram for temperature-rise test

G - Generator type GSAM – 390 kVA, 400 V, 50 Hz (for low voltage part)
PC - Connections panel
T - Adapting transformer made of 3 single-phase transformers of 400 / 25V, 10 kA, 50 Hz
CT1 - Current transformers type CIRSO – 2000 / 5 A
CT2 - Current transformers type CIRSO – 2x50/5 A
LV - Low Voltage equipment
PT - Power Transformer tested
PA - Power analysing device
IIPT - Substation test installation (for high voltage part)

C. Results obtained for temperature-rise tests

Results obtained are presented synthetic in Tables I, II and III below [4].

TABLE I - RESULTS OBTAINED FOR TEMPERATURE-RISE TEST OF TRANSFORMER OUTSIDE THE SUBSTATION

Windings	Determined values						
	R_1' (Ω)	θ_1' (°C)	R_2' (Ω)	θ_a' (°C)	θ_2' (K)	$\Delta\theta$' (K)	$\Delta\theta_u$' (K)
HV	5.33	24.4	6.77	27.7	94.48	66.78	66.26
LV	0.933×10^{-3}		1.18×10^{-3}		93.07	65.37	

TABLE II - RESULTS OBTAINED FOR TEMPERATURE-RISE TEST OF TRANSFORMER INSIDE OF SUBSTATION

Winding	Determined values						
	R_1 (Ω)	θ_1 (°C)	R_2 (Ω)	θ_a (°C)	θ_2 (K)	Δθ (K)	$\Delta\theta_u$ (K)
HV	5.31	24.0	6.92	27.4	102.52	75.12	73.45
LV	$0.932\text{x}10^{-3}$		$1.21\text{x}0^{-3}$		101.25	73.85	

HV - high voltage winding
LV - low voltage winding

Calculation relations:

$$\theta_2 = (R_2 / R_1)*(235 + \theta_1) - 235$$ - for cooper winding

$$\Delta\theta = \theta_2 - \theta_a$$

$$\Delta\theta_u = \theta_u - \theta_a$$

where:

θ_2 , θ_2 ' - windings average temperature (inside the substation and outside the substation)

R_1, R_1' - windings resistance measured in cold condition (inside the substation and outside the substation)

R_2, R_2' - windings resistance measured at shutdown (inside the substation and outside the substation)

θ_1, θ_1' - environment temperature in cold condition (inside the substation and outside the substation)

θ_a , θ_a' - environment temperature at the end of temperature-rise test (inside the substation and outside the substation)

Δθ, Δθ' - windings temperature-rise (inside the substation and outside the substation)

There are also measured values of currents, losses and temperature of transformer inside and outside of substation. There are determined also temperature-rise of low voltage equipment.

D. Determination of thermal class

To assess the thermal class the following relations (IEC 62271-202/2014, clause 6.3) will be applied [1,2,3,4]:

$$\Delta t_1 = t_{t1} - t_{a1}\,; \qquad \Delta t_2 = t_{t2} - t_{a2}\,; \qquad \Delta t = \Delta t_2 - \Delta t_1$$

where:

t_{t1} - temperature of the transformer windings outside the substation,

t_{a1} - environment temperature at the end of transformer temperature-rise test outside the substation

Δt_1 - temperature-rise of the transformer windings outside the substation

t_{t2} - temperature of the transformer windings inside the substation

t_{a2} - environment temperature at the end of transformer temperature-rise test inside the substation

Δt_2 - temperature-rise of the transformer windings inside the substation.

TABLE III - RESULTS OBTAINED FOR THERMAL CLASS DETERMINATION

	Δt_1 [°C]	t_{t1} [°C]	t_{a1} [°C]	Δt_2 [°C]	t_{t2} [°C]	t_{a2} [°C]	Δt [°C]
HV winding	94.48	66.78	27.70	102.52	75.12	27.40	8.34
LV winding	93.07	65.37		101.25	73.85		8.48
Oil	66.26	93.96		73.45	100.85		6.89

Thermal class: 5 K < Δt < 10 K ⇒ Class 10

The aspect of tested product is presented in Figure 6.

Fig. 6. Aspect of tested product

V. CONCLUSIONS

4.1. The achieved installation is a modern one, having one AC supply made of generator-motor group and one AC supply up to 250 kVA made of single-phase autotransformers-adapting transformer, and has the advantage to extend the possibilities of testing the prefabricated substations with powers up to 1600 kVA and reduced noise while operating.

4.2. A new technology was also developed for temperature-rise tests of high voltage/low voltage prefabricated substations according to the requirements of IEC standards. [1]

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[5] Curcanu G., Sbora I., Iancu C., Boltasu C., Pistol P. – Installation for Temperature-Rise Test of High-Voltage Prefabricated Subtations – ICATE 2014, Craiova, Romania.