EXPERIMENTAL RESEARCH OF THE ELECTRIC STRESS LEVEL IMPACT ON TRADITIONAL STATE PARAMETERS OF POWER TRANSFORMERS

FELEA I., OLTEAN M., SECUI D.C.
University of Oradea, Universitatii Str.No.1, 410087, Faculty of Energy Engineering,
ifelea@uoradea.ro, ymoltean@yahoo.com, csecui@uoradea.ro

Abstract - The work is structured on 5 parts. In the first part it is made reference to the theme's actuality in terms of the necessity to apply the technical diagnosis to the electric power transformers in order to ensure the corresponding level of electricity supply service. Onwards, it is specified the set of stress and state indicators, by presenting the calculation relations proposed by the authors for the stress indicators' assessment. The third part contains the model proposed for being used in order to assess the exceeding risk of normal values by the two sets of sizes. In the fourth part it is presented a synthesis of the obtained results, and in the last part the conclusions of the analysis are rendered.

Keywords: power transformers, electric insulating oil, stress, state, technical diagnosis.

1. INTRODUCTION

Power transformers (PTs) are elements of utmost importance for the electricity transmission and distribution systems, as they may have the biggest consequences in case of non-availability, are the most complex equipment and their intrinsic investment value is high [1,2]. These are the reasons why the reliability of power transformers is an important concern for users, producers and researchers alike. Reliability centred maintenance [3,4,5] of a PT is a relatively new trend in research with important economic implications.

If we consider the reports recently published in IEEE Transactions on Power Delivery and the Proceedings of CIRED Session only, we can see that an essential instrument of the reliability centred maintenance (RCM) of a PT is the technical diagnosis (TD). The state parameters of the insulation (electro insulating oil and winding insulation) are defining magnitudes for the diagnosis of the technical condition of a power transformer.

The analysis of the contents of gases dissolved in the transformer oil is an already proven method widely used in the technical diagnosis of power transformers. Nevertheless, the research works dedicated to this method are still very topical. A deeper TD method is proposed based on the analysis of the gases dissolved in oil (DGA), using a fuzzy model of the real element (gas contents, concentration ratios).

In order to increase the accuracy of PT - TD methodology a map is proposed in [6] to be attached to such equipment, showing the evolution of the contents of gases dissolved in oil and their ratios. The proposed maps are built by getting together the results obtained through measurements conducted with TD systems, by either real or simulated measurements.

A number of current research works [7, 8] are dedicated to the use of genetic algorithms and evolving neural networks in the TD of a PT, stating that this kind of modelling, helps to identify the complicated relations between the contents of gases and PT typical defects. Experiments and post factum analyses are essential in establishing or confirming the analytical assessment and decision methods in the field of RCM and TD. In [9,10,11] there are presented the results of some experimental tests meant to reveal the influence of impurities, water contents and temperature on the lifetime of the solid insulation in the structure of a PT. Based on these results the authors propose a model for predicting the lifetime of the solid insulation of a PT, considering the weight of the influence factors.

A most accurate evaluation of temperatures in the hottest points of the PT, so that the maximum admitted temperature should not be exceeded, is essential for PT operation and RCM. In this respect, the evaluation of the temperature gradient on the windings is very important A new method is presented in [12] for calculating the temperature gradient on the PT windings. Using the electrical analogy, the author constructs analytical expressions for the heat resistance of the electro insulating oil and the solid insulation in the structure of a PT, depending on the material characteristics and the influence factors (impurities, gas contents, water contents). The management of the remaining lifetime of PT makes the object of [13]. The following influence factors are considered: maintenance strategy, age, operation and loading conditions, conditions of assessing the state of the PT by using a TD system. In continuation of the research works dedicated to PT-RCM [14, 15, 16], our paper intends to analyze how the PT level of transient and steady loading is reflected on the state parameters of the electric power transformers.

This approach represents a newness and has in view the drafting of technical diagnosis subsystems (TDS) of PTs, having the features of expert, dynamic, adaptive and evolved systems toward the present state of the art TDS which are static expert systems in the sense that they can't foresee the evolution of state indicators according to the measure level of stress. As opposed to the approach presented at [15, 16], the present work resorts to assessment and comparative analysis for the two categories of stress size and parameters, and of the level of exceeding risk of normal values.

Within this work, it will be analysed the impact of PTs' stress level, materialised through the values of some of the stress indicators (SI) – static and dynamic – upon the level of the classic state indicators (CSI) of the electrical insulating oil (EO).

2. STRESS AND STATE INDICATORS

To show the level of steady loading, the following magnitudes: were evaluated based on measurements performed on characteristic days (winter, summer) and moments (day/night peaks and off-peaks):

- Mean relative voltage

$$u_m = \frac{1}{mU_{1N}} \sum_{i=1}^{m} U_i \qquad (1)$$

- Mean relative load:

$$\beta_m = \frac{1}{mS_N} \sum_{i=1}^{m} S_i \qquad (2)$$

To show the level of transient overloading, he following magnitudes are calculated:

- Overloading factor at short circuit current;

$$k_{SI1} = \frac{1}{I_N} \sum_{j=1}^{n} N_{k1j} \cdot I_{k1j} \qquad (3)$$

- Overloading factor at overload current:

$$k_{SI2} = \frac{1}{I_N} \sum_{j=1}^{n} N_{k2j} \cdot I_{k2j} \qquad (4)$$

Where:

i, j – unit index, to mark a values order in a run of values of a magnitude;

S_N – nominal power;

U_{1N} – primary nominal voltages of PT;

U_i – momentary value of voltage applied in PT primary;

S_i – momentary apparent load of PT;

m – number of characteristic values of magnitudes over the calculation interval (one year);

I_N – PT nominal current;

(N_{k1j}, I_{k1j}) – number of maximal fast protection releases (N_{k1j}) caused by short circuit current (I_{k1j}) on line „j";

(N_{k2j}, I_{k2j}) – number of maximal time delay protection releases (N_{k2j}), caused by overload current (I_{k2j}) on line "j";

n – number of electric lines representing outgoings from electric stress (short circuit) or overload on the PT under evaluation.

The values of the above magnitudes are calculated for each year with reference to each PT under analyses.

We mention that, the existent EO in the 29 PT isn't the subject of preventive maintenance processes (reclaiming) but only to corrective actions performed when the EO classical state indicators exceed the admitted limits:

- R_{60}- insulation resistance (after 60 s): minimum 300 MΩ
- E – dielectric rigidity: minimum 160 kV/cm
- tgδ – loss angle tangent: maxim 0,15%
- i_a – acidity index: maxim 0,3 mg KOH/g
- c_{H_2O} - water contents: max 30 ppm.

The stress indicators (u_m, β_m, k_{SI1}, k_{SI2}) being relative dimensions, we will work with state indicators too (R_{60}, E, tgδ, i_a, C_{H2O}) with relative values, the measured values being reported to the admitted limit values specified above for the analysed case. The analysing methodology was applied to 29 PTs which function in 18 electric sub-stations (ES) with a value of 110kV/MV from the distribution branch of Oradea electricity (Romania). The PTs present the following features:

- S_N [MVA]: 10 (3 pieces); 16 (17 pieces); 25 (9 pieces);
- U_{1N}/U_{2N} [kV/kV]: 110/6 (9 pieces); 110/20 (20 pieces);
- nominal losses: ΔP_{0N} [kW]: [20÷30] and ΔP_{kN} [kW]: [68÷151];
- number of years from putting its in operation: beyond of 30 (15 pieces), [20÷30] (9 pieces), under 20 (5 pieces);
- type of: TTUS – NS;
- ΔP_{0N} – nominal losses of idle power in core;
- ΔP_{kN} – nominal losses of idle power in iron.

The used electrical insulating oil (EO) is of TR30 type, manufactured by PETROM. The analysing period is of 11 years, during the interval [1999 – 2009].

In fig. 1 and 2 are indicated the values obtained during the analysing period for the two categories of sizes, with reference to one of the analysed transformers.

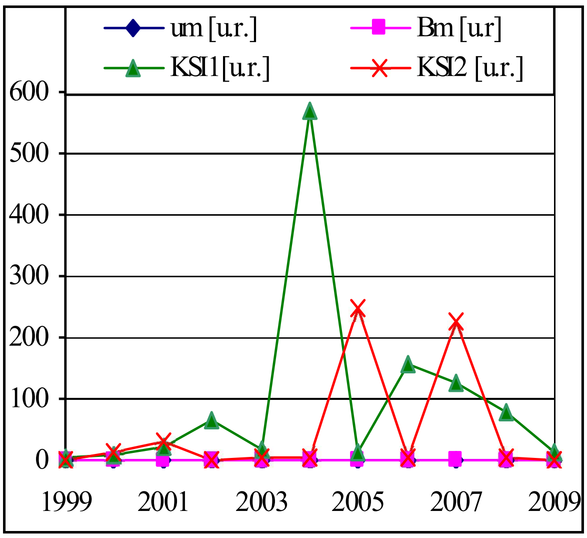

Fig. 1. The process of stress parameters (relative values) for TR 1 from the Centre Oradea Sub-station

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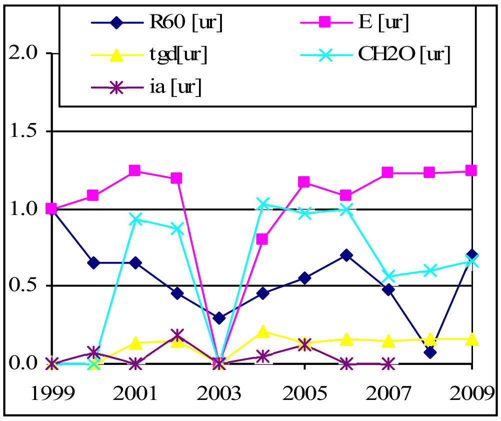

Fig. 2. The process of state parameters (relative values) for TR 1 from the Centre Oradea Sub-station

Such comparative sequential analyses, as well as the overall assessments can be performed for each PT [15, 16].

3. RISK'S ASSESSMENT METHODOLOGY

In accordance with the procedure announced in the first part of the work, in this case we will proceed to the assessment of the level detained by the exceeding risk during the normal (permissible) values' analysis by the two sets of sizes.

We observe:

Xa – permissible (normal) value;

Xm – measured value;

Xa={u_{ma}, β_{ma}, k^{a}_{SI1}, k^{a}_{SI2} } for the stress indicators;

Xa={ R^{a}_{60} , E_a, $tg\delta_a$, i_a^a, $c^{a}_{H_2O}$ } for the classic indicators;

Xm={u_{mm} β_{mm}, k^{m}_{SI1}, k^{m}_{SI2} };

Xm={ $R^{m}_{60}, E_m, tg\delta m, i^{m}_{a}, C^{m}_{H_2O}$ }.

In order to assess the risk level, we will establish the probability (p) for the measured values to exceed the permissible values for each size. Sizes from X_a category have fixed determined values, and indicated by the norms or manufacturer. The measured sizes have the characteristics of aleatory variables which are naturally inserted in the normal parameter distribution: mean value (m) and dispersal (σ) [1,3,4]. For this reason, for assessing the risk level, we will operate with the normal distribution based on the representations from fig. 3 and fig. 4.

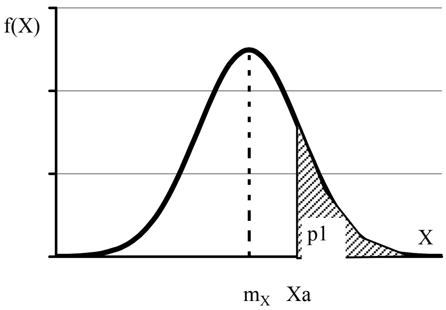

Fig. 3. Assessment of risk for the upper limited indicators

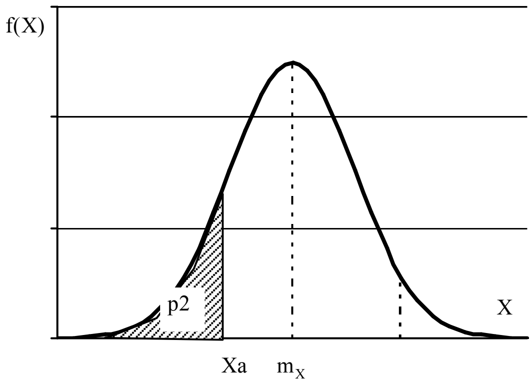

Fig. 4. Assessment of risk for the lower limited indicators

The calculation relations of the risk level (p_1, p_2) are the followings:

$$p1 = \frac{1}{\sqrt{2\cdot\pi}\cdot\sigma_{X_m}} \int_{X_a}^{\infty} exp\left(-\frac{(X_m - m_{X_m})^2}{2\cdot\sigma^2_{X_m}}\right) dX_m \quad (5)$$

$$p2 = \frac{1}{\sqrt{2\cdot\pi}\cdot\sigma_{X_m}} \int_{-\infty}^{X_a} exp\left(-\frac{(X_m - m_{X_m})^2}{2\cdot\sigma^2_{X_m}}\right) dX_m \quad (6)$$

4. OBTAINED RESULT

The assessment methodology of risk level was applied by taking into consideration each stress and state indicators (CSI) for the PTs set with reference to each year from the analysing interval. In fig. 5 and fig. 6 is presented – for exemplification purpose – the distribution's density of relative values for two of the measured sizes (one of stress and one of state).

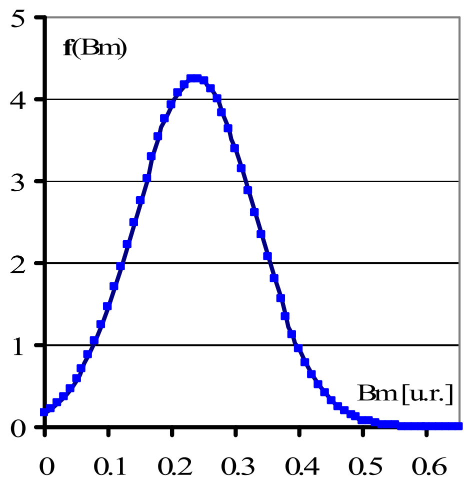

Fig. 4. The function of distribution density for the β_m parameter

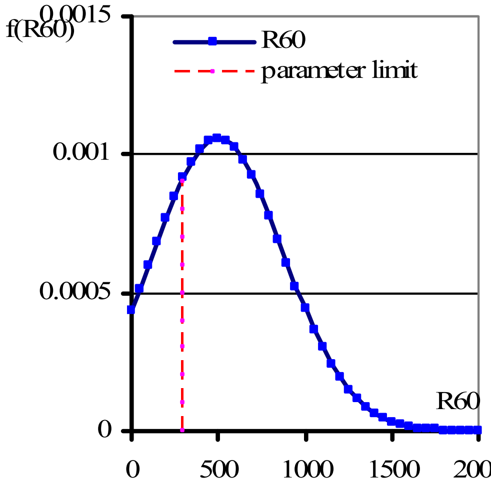

Fig. 5. The function of distribution density for the R60 parameter

The results obtained for the state parameters are indicated in fig. 6, and in fig. 7 – fig.11 is comparatively represented the evolution of the risk level for the stress indicators and for each of the state indicator.

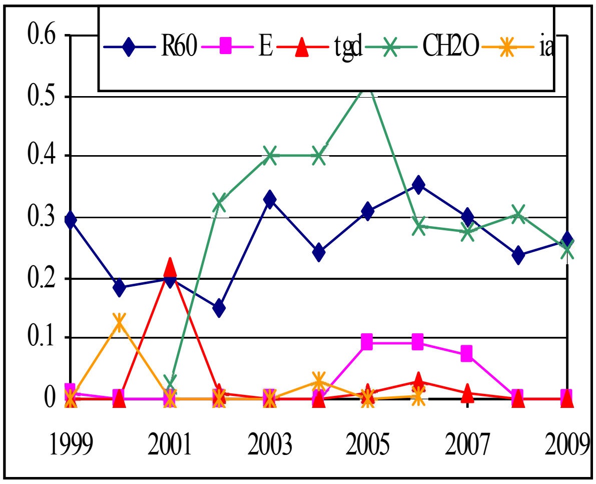

Fig. 6. Evolution of risk level for CSI

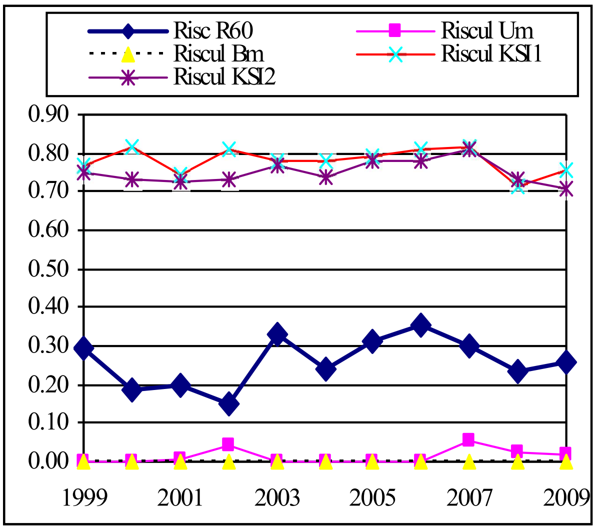

Fig. 7. Evolution of risk for R60 and the stress parameters

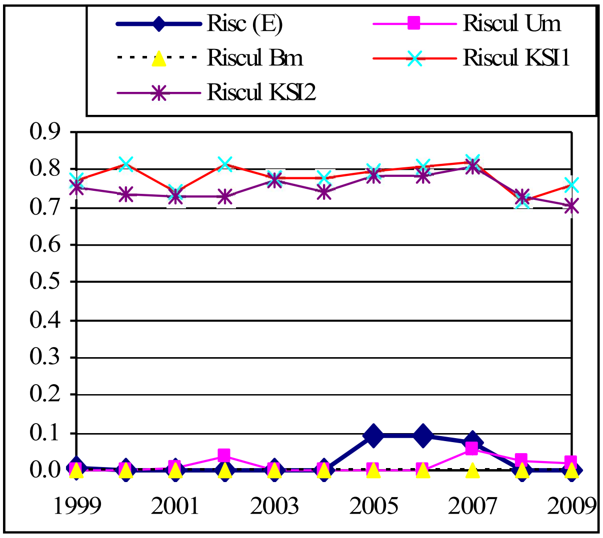

Fig. 8. Evolution of risk for E and the stress parameters

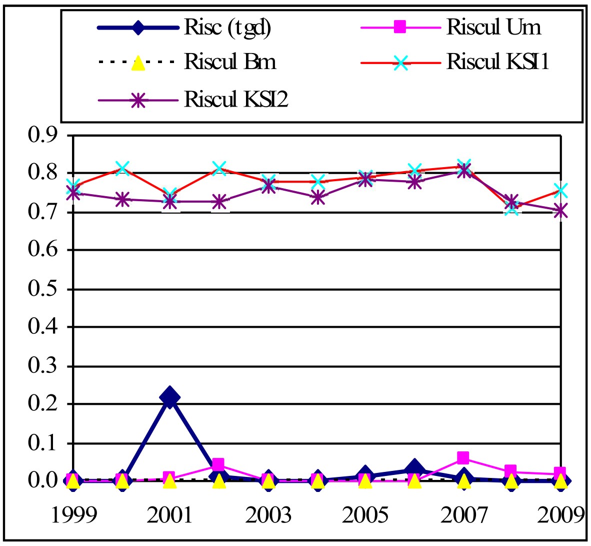

Fig. 9. Evolution of risk for tgδ and the stress parameters

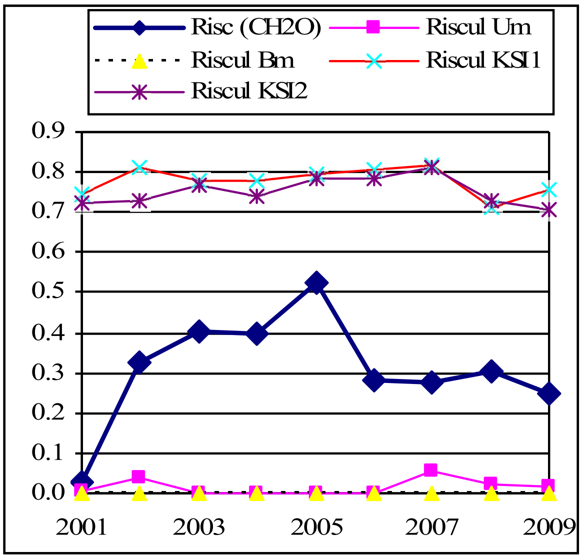

Fig. 10. Evolution of risk for C_{H2O} and the stress parameters

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4. CONCLUSIONS

The technical diagnosis of power transformers (PTs) based on the state of the electro insulating oil is quite a relevant method whose potentiality is still to be further researched and revealed.

The paper follows up with the authors' concerns to assess how the level of loading of a PT_S affects the condition of the electro insulating oil (EO), in order to identify some models for predicting the EO state depending on the level of loading, to be used in the PT reliability centred maintenance strategy.

Considering the relatively short period of analysis (11 years), the low number of transformers (29 PT), the measurement method that may induce errors, the results obtained are considered to be just "a first step"; for final conclusions it is necessary to continue the research work.

The results obtained for the analysed lot of PT_s reflect the followings:

- The risk induced by the continuous load of PT_s (β_m) is null, and the risk induced by the power-supply of PT_s (u_m) is negligible;
- The risk afferent to the transitory overstressing (k_{SI1}, k_{SI2}) is higher than in the case of overstressing of the short-circuit current (k_{SI1})
- The risk afferent to state parameters has differentiated values, as follows:
  - → High values for R_{60} and C_{H2O};
  - → Low values for E, tgδ and i_a by specifying that in the case of indicators (tg δ şi i_a) the relatively high values from 2000 are interpreted as being inconclusive;
- The risk afferent to R_{60} state indicator has the general tendency to grow during the analysing period;
- The risk afferent to C_{H2O} indicator has the general tendency to decrease during the analysing period;
- The risk afferent to the dynamic overstressing indicators (k_{SI1}, k_{SI2}) has the general tendency to grow during the analysing period, with higher values in case of the k_{SI1} indicator;
- From the evolution of the risk level, we identify a good correlation between the dynamic overstress and the R60 indicator;
- The obtained results don't reflect the impact of permanent stress (u_m, β_m) upon the state indicators of PTs;
- The obtained results don't allow the conclusion of the way in which the factors of dynamic overstressing (k_{SI1}, k_{SI2}) affect the evolution of the E indicator.

Corroborating the results published in previous works [15,16] with the results synthesised in the hereby work, it follows that it is advisable for the subsequent analyses to concentrate on the identification of the impact of dynamic overstressing (k_{SI1}, k_{SI2}) upon the quality indicators under the form of electric insulation (R_{60}, E) by researching the correlations at the level of each transformer.

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