DEFINING AND EVALUATING THE PARAMETRICAL RELIABILITY OF POWER TRANSFORMERS IN OIL

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ABSTRACT

The paper is structured in three parts. The first part explains the parametrical reliability of the power transformers (PT) in oil in context with its global reliability. Is presenting the proposed model to parametrical reliability evaluate of PT. There explains the parametrical risk failure of PT and its global parametrical reliability.
In the second part are presented the studies results, effected to a number of 29 PT, the nominal power being between [10 ÷ 25] MVA, located in electric stations of 110 kV/MV, administrated by ELECTRICA Company Branch of Oradea - Romania. There are determinate the paths successions stages by technical diagnosis of PT and there is exemplified the state parameters evolution in time. There gives the values of parametrical reliability function in relation with the three parametrical categories defined for the PT state. There is presented a assessment between the failure risk by derive of parameter and the unexpectedly failure risk by the analyzed PT. The conclusions as well as the recommendations to the analyzed PT exploitation activities are presented in the last part of the paper.

INTRODUCTION

The electric PT are equipment from the structure of electric energy distribution and transmission systems with main importance, because implies the most consequences in case of unavailability, there are the most complex, and the intrinsic investment is the most higher. The PT reliability presents an important object of preoccupation for the users, producers and research medium. RCM method [3] of PT is a relatively new study direction, with important economic implications.
Viewing only the recent published papers in IEEE Transactions on Power Delivery and in Proceedings of CIRED Sessions, it may be established that within of reliability centered maintenance (RCM) of PT a very important instrument is the technical diagnosis (TD) [1,2,4÷7]. The state parameters of insulation (the electro insulating oil and the insulations of windings) are defining magnitudes for technical state diagnosis of PT.
The IEEE standard [8] stabilizes the testing and interprets modes of contain of gases in oil, and the mainly recommended two methods are: the method of Rogers and method of Doernerburg.

In [6] is proposed to profound the TD method by the gases analysis dissolved in oil (DGA), to appeal to a fuzzy model of real element (gases contains, ratio of concentrations). To increase the TD method exactness of PT is proposed [7] to elaborate some maps attached to equipment, in which is inscribed the evolution of contains of dissolved gases in oil and its ratio.

A series of actual researches [4÷6] are dedicated to applying of genetic algorithms and of evolutionary neuronal networks to TD of PT, sustaining the fact, that, by this type of modeling may be identifying the complicate relationships between the gases contains and typical failures of PT.

The experiments and the post factum analysis are essential to establish or to confirm of evaluating analytical models and decisions in RCM and TD domain [2,6].

The most exactly evaluation of the temperature in the most warm points of the PT, with the scope to avoid the admitted temperature, is essential in exploiting and RCM of PT [1].

Continuing the above preoccupations [2,3], in the paper we propose to profound the RCM strategy referring on PT, by defining and evaluating of its parametrical reliability, considering the gases contain in oil, but other significant parameters for state and life time of PT. The qualitative evaluation refers on 29 PT administrated by Distribution Power and Supply Branch of Oradea (DPSO), one of 41 branches of Romanian ELECTRICA Company.

DEFINITION OF PARAMETRICAL RELIABILITY

In the structure of a PT are components where the failure event comes unexpectedly and respectively, gradually (fig.1.)

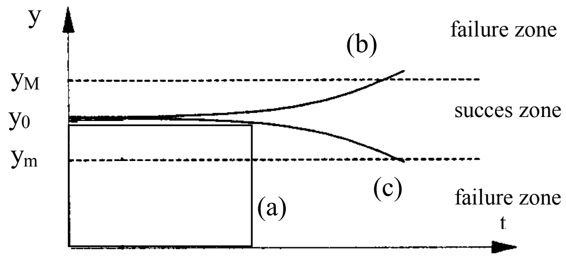

Fig.1 – The failure mode of components in PT
a - unexpected failure; b,c – gradual failures
y – determinant parameter; y_M – maximum admitted value; y_m – minimum admitted value; y_0 – the initial value

The stabilized reliability basing on gradual failures statistical events for the PT, is named as the PT's parametrical reliability. The reliability of PT is composed from the 2 components, in concordance with the established models [3]: parametrical reliability (that reflects the gradual failure of the established parameters) and reliability evaluated by the events of unexpected failure.

The stage of the PT are characterized by the determining parameters value, this values may be grouped in three categories:

- Parameters viewing the general stage of the insulation (y_{1i}): resistance of insulation at 15" ($R_{15} \equiv y_{11}$) and at 60" ($R_{60} \equiv y_{12}$); coefficient of absorption ($k_A \equiv y_{13}$); tangent of the losses angle ($tg\,\delta \equiv y_{14}$);
- Traditional parameters of the oil of transformer (y2i): dielectric rigidity ($E \equiv y_{21}$); tangent of the losses angle ($tg\delta_U \equiv y_{22}$); content of water ($C_{H20} \equiv y_{23}$); density ($\rho_U \equiv y_{24}$); acidity index ($i_a \equiv y_{25}$); kinematical viscosity ($v_U \equiv y_{26}$);
- Contain of gases in oil and its weights (y_{3i}): ($H_2 \equiv y_{31}$); ($CH_4 \equiv y_{32}$); ($C_2H_6 \equiv y_{33}$); ($C_2H_4 \equiv y_{34}$); ($C_2H_2 \equiv y_{35}$); ($CO \equiv y_{36}$); ($CO_2 \equiv y_{37}$); Acetylene/Ethylene (y_{38}); Methane/Hydrogen (y_{39}); Ethylene/Ethan ($y_{3.10}$); Ethan/Methane ($y_{3.11}$); Dioxide of carbon / Monoxide of carbon ($y_{3.12}$); total contain of gases in oil ($y_{3.13}$).

In most cases, the determinant parameters of PT may be approximated in the degrading process by a normal distribution that results from 2 aleatory processes [2,3,4]:

- long terms modifications, due to external factors;
- nonreversible modifications provoked by aging.

The indices, useful in decision processes of RCM strategy applying are: function of parametrical reliability, probability of failure and the remained lifetime. To evaluate these indices, is used the aleatory variable "time of good operating" ≡ "time of maintain the determinant parameter in admitted limits".

The reference values (at 20^0C) are as follows:

- the maximum values for: y_{14}, y_{22}, y_{23}
- minimal values for: y_{11}, y_{12}, y_{13}, y_{21}
- intermediate values for the other parameters.

Generally, the limit values are considered constant, in this case too, to evaluate the reliability indices, it will made the significant parameters distribution comparative analyze in relation with the admitted limits. For the PT's determinant parameters, the represented causes are possible, see fig.2.

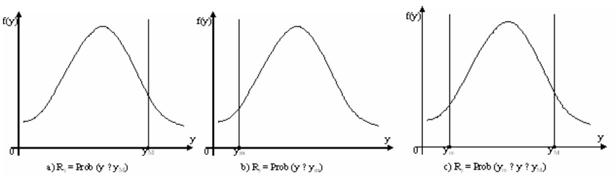

Fig.2 – The PT's parametrical reliability function (R_y) evaluate referring on determinant parameter (y), f(y) – is the density of y aleatory variable distribution y

Knowing the f(y) indices, it may evaluate the other indices too, that may present interest, which characterize the reliability of PT [3].

One of the evaluating model generalizations is that where the admitted limits are considered as aleatory variables too, with a domain of variation in function with the stress factor variations [5].

The parametrical reliability function of PT is expressed as:

$$R_p = R_1 R_2 R_3 \tag{1}$$

where:

$$R_1 = P_{rob}(y_{11} \geq y_{1ml}; y_{12} \geq y_{1m2}; y_{13} \geq y_{1m3}; y_{14} \leq y_{1M4}) = \\ = \prod_{i=1}^{3} \int_{y_{1mi}}^{\infty} f(y_{1i})dy_{1i} \int_{0}^{\infty} f(y_{14})dy_{14} \tag{2}$$

$$R_2 = P_{rob}(y_{21} \geq y_{2ml}; y_{22} \leq y_{2M2}; y_{23} \leq y_{2M3}) \cdot \\ \underset{i=4,6}{\underline{P_{rob}}}(y_{2mi} \leq y_{2i} \leq y_{2Mi}) = \int_{y_{2mi}}^{\infty} f(y_{21})dy_{21} \cdot \int_{0}^{y_{2M2}} f(y_{22})dy_{22} \cdot \\ \int_{0}^{y_{2M3}} f(y_{23})dy_{23} \cdot \prod_{i=4}^{6} \int_{y_{2mi}}^{y_{2Mi}} f(y_{2i})dy_{2i} \tag{3}$$

$$R_3 = \underset{i=1,13}{\underline{P_{rob}}}(y_{3mi} \leq y_{3i} \leq y_{3Mi}) = \prod_{i=1}^{13} \int_{y_{3mi}}^{y_{3Mi}} f(y_{3i})dy_{3i} \tag{4}$$

The mathematical expression of [$f(y_{1i})$; $f(y_{2i})$; $f(y_{3i})$] density distribution, are stabilized on base of statistical data's [3]. Utilizing the same statistical data, it may be stabilizing the analytical expressions of (y_{1i}, y_{2i}, y_{3i}) too, in relation with the time variable of (t):y_{1i} (t); y_{2i} (t); y_{3i} (t).
Solving the equations

$$\begin{cases} y_{1i}(t) = y_{1mi}; i = \overline{1,3};\ y_{14}(t) = y_{1M4};\ y_{21}(t) = y_{2m1}; \\ y_{2i}(t) = y_{2Mi}; i = \overline{2,6};\ y_{2i}(t) = y_{1mi}; i = \overline{4,6}; \\ y_{3i}(t) = (y_{3mi}; y_{3Mi}); i = \overline{1,13} \end{cases} \quad (5)$$

there are obtaining the TBF – good operating time - variables values referring on each parameter (TBF_{1i}, TBF_{2i}, TBF_{3i}).
If the evolution of a (y) parameter it may be considered linear, then the evaluation are simply, and it may write:

$$\left\{ y = y_0 + v_y t;\ y_0 = \frac{y_I t_{II} - y_{II} t_I}{t_{II} - t_I};\ v_y = \frac{y_{II} - y_I}{t_{II} - t_I} \right. \quad (6)$$

v_y – evolution velocity of the parameters
In this case, by measuring the (y_I, y_{II}) values of parameters at two moments (t_I, t_{II}) are determining the constants of the line (y_0, v_y), than the TBF's variable values referring on respectively parameter.
The useful of TBF values evaluation (TBF_{1i}, TBF_{2i}, TBF_{3i}), is evident, the prophylactic verification program and the predictive maintenance of PT – the RCM strategy components – making in concordance with the variables of TBF values for category of parameters or for those ensemble [8].

THE RESULTS OF A STUDY CASE

The evaluation of the parametrical reliability was made for 29 PT, located in electric stations of 110 kV/MV of DPSO, elaborated by ELECTROPUTERE Craiova (Romania) with the following characteristics:

- nominal power (S_N) [MVA]: 10 (2 pieces); 16 (17 pieces); 25 (10 pieces);
- nominal voltages (U_{1N}/U_{2N}) [kV/kV]: 110/6 (8 pieces); 110/20 (20 pieces); 110/20/6 (1 piece);
- years from operation: above 30 (15 pieces); (20 ÷ 30) (9 pieces), under 20 (5 pieces);
- type: TTUS - NS

The three categories of parameters are verified annually, in normal mode, measuring off-line. The ensemble of the measured values (date base) represents the registering of the made measurements in period of [1999 ÷ 2005]. Must be mentioned, that the DGA method is applied only to 16 PT from the 29, using analyzer of type AMS – 500 and TFGA – P200 [3,8].
The statistical data processing was for a lot of PT made, referring on the parameters for that the number of measurements are enough high and credible. In this sense, we must mention that, that weren't statistical processing made for $y_{1.4}$, $y_{3.8} \div y_{3.11}$ şi $y_{3.13}$ parameters.

For the representation from fig. 5, were utilized the relative percentage values of parameters, having as reporting base the reference values from table 1.

Table 1. Reference values of TP parameters

Parameters	Value of reference	Parameters	Value of reference
y_{11}	500 MΩ	y_{26}	22 %
y_{12}	600 MΩ	y_{31}	100 ppm
y_{13}	1,2	y_{32}	120 ppm
y_{21}	160kV/cm	y_{33}	65 ppm
y_{22}	0,15%	y_{34}	50 ppm
y_{23}	30ppm	y_{35}	35 ppm
y_{24}	0,89 g/cm^3	y_{36}	350 ppm
y_{25}	0,3mg KOH/g	y_{37}	2500 ppm
		$y_{3.12}$	[3; 10]

The statistical data processing results are in table 2 presented, where are specified for each parameter the (N) volume of the values and the values of (n) that exceeds the admitted limits considered constant.

Table 2 – The results of statistic proceedings

Characteristics / Symbol parameters	Parameters of Normal distribution		n/N	Constants of line		TBF [years]
	m	σ		a	b	
y_{12}	13.12	8.80	0/55	-0.45	14.64	ND
y_{21}	8.05	8.07	0/34	-3.38	19.64	ND
y_{22}	8.14	7.11	0/43	-2.04	15.49	ND
y_{23}	21.60	16.61	7/64	0.48	20.32	>10
y_{25}	34.07	33.19	25/64	2.62	27.32	2.93
y_{31}	195.64	133.40	11/68	-0.24	202.63	ND
y_{32}	2152.35	1349.84	26/68	40.49	2235.23	6.54
y_{33}	15.12	11.23	59/68	-0.19	15.83	>10
y_{34}	790.51	773.86	12/156	93.86	390.57	ND
y_{35}	269.91	30.31	1/158	-0.65	272.04	>10
y_{36}	0.0610	0.05	3/111	-0.005	0.08	ND
y_{37}	28.08	8.37	29/88	1.02	24.42	5.47
$y_{3.12}$	0.064	0.10	2/129	-0.005	0.09	ND

ND - undetermined

In fig. 3 is representing the distribution density for the three parameters with the highest impact on the parametrical reliability of PT, and on fig. 4, the y(t) characteristic for 6 determined parameters. All evaluations are for the parameters relative values, in relation with the reference values.

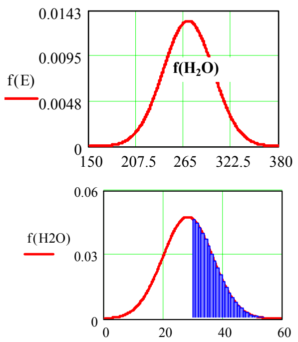

Fig. 3–Distribution density of some state parameters of PT

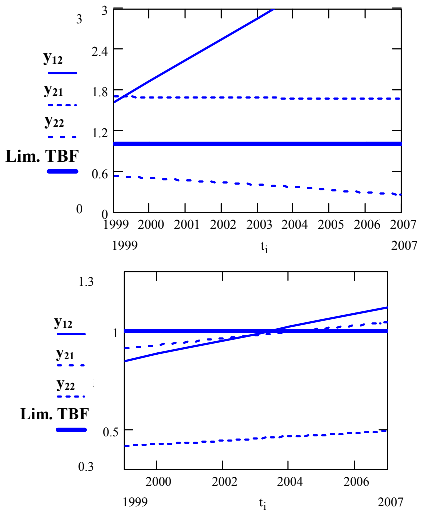

Fig. 4 – Evolution in time of some determinant parameters for state of PT

Basing on statistical data, there was computed the reliability function values in relation with each category of parameters, obtaining the following results:
$R_1 = 0{,}8789$; $R_2 = 0{,}9484$; $R_3 = 0{,}8044$; $R_p = 0{,}6705$. The PT reliability level established basing on suddenly failures is more better ($R_b = 0{,}998$) [1,2].

CONCLUSIONS

The technical diagnosis of PT on the base of the electro insulating oil state is a method with a distinct importance, that valence doesn't be yet researched and evidenced completely. The state parameters of PT may be analyzed as aleatory variables that have importance in statistical processing. By determination of characteristics and interpreting the selection of the aleatory variables based on the models of parametrical reliability, are obtained the reliability indices values utilized for RCM strategy of PT. The parametrical reliability of PT may be differenced evaluate in relation with the three categories of parameters:

- parameters viewing the general state of the insulation (R_1);
- traditional parameters of the transformer oil (R_2);
- Contain of gases in oil and those weight (R_3).

The mathematical expression of the determinant parameters density distribution for PT state, is essentially in utilize of modern methods of technical diagnosis basing on fuzzy logic and artificial neuronal net. Referring on the obtained results, we conclude the followings:

- The normal distribution models the statistical dates with a sufficiently precision, representing the measured state parameters;
- The analyzed PT's parametrical reliability level is much under the determinant reliability level basing on suddenly statistical failures;
- Parameters with the biggest impact on PT's parametrical level, are from the category of "gases contain in oil", principally of: carbon dioxide, acetylene, carbon monoxide and water contain;
- From the category, that reflects the general state of the PT, parameter R60 has the greatest impact on parametrical reliability of PT;
- Evolution in time of state parameters of PT leads to optimist predictions for prophylactic verifications periodicity and of works frequency of RCM type.

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