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MODEL FOR LIFETIME ESTIMATION AT HYDRO GENERATOR STATOR WINDING INSULATION

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***Abstract* – This paper present a model for lifetime estimation at hydro generator stator winding insulation when at hydro generator can be appear the damage regimes. The estimation to make by take of the programming and non-programming revisions, through the introduction and correlation of the new defined notions**

Keywords: *model, estimation, lifetime, hydro generator, insulation*

1. INTRODUCTION

The normal exploitation duration of hydro generator is T. This duration T is a very long around 30 years. In this time is included and fact which the winding hydro generator must be correctly operate and not to be defected. To permanently want estimation of winding insulation lifetime, knowing on the hydro generator operate can be appear the inadequate operating regimes or can be appear defects which carry at premature ageing of insulation, having consequence the short lifetime of this at the time T1
The defects which at hydro generators owning to, in principal, deterioration of insulation, was elaborated a matrix model for estimation of insulation lifetime.
The main parameter on the base to estimate the winding lifetime is tangent of dielectrically losses tgδ [1]. This value is increase on the exploitation duration of hydro generator and to considerate that from certain value or high value of this, the probability of insulation break-down being high, the insulation is not accepted maintaining in operate

2. MODEL FOR LIFETIME ESTIMATION AT HYDRO GENERATOR STATOR WINDING INSULATION

On the normal operation of hydro generator is programming the revisions of which number is considerate is p, but exist and non-programming revisions or reparations owning to defects of other hydro generator subassemblies or errors in system or at turbine. Number non-programming revisions or reparations [2] are equal with r .

The stator winding of hydro generator is constituted from many coils. The number of coils is n. If the only coil is defected the all winding is compromise. Therefore, insulation state of each coil must be following.
The insulation state will be following in permanently with help by acquisition data system, the results being used for direct calculus, but and the data base for simulations for determination the another insulation parameters [3].
To define the ”matrix of normalized estimated initial lifetime”, the matrix:

$$\left[\varepsilon_k^0\right],\ k=\overline{1,n}, \tag{1}$$

namely:

$$\left[\varepsilon_k^0\right]=\begin{bmatrix}\varepsilon_1^0\\ \varepsilon_2^0\\ \dots\\ \dots\\ \varepsilon_n^0\end{bmatrix} \tag{2}$$

where:

ε_k^0 - coeficient of normalized estimated initial lifetime of k coil insulation

n – coil numbers of hydro generator stator

Incipient this matrix is unitary column matrix:

$$\left[\varepsilon_k^0\right]=\begin{bmatrix}\varepsilon_1^0\\ \varepsilon_2^0\\ \dots\\ \dots\\ \varepsilon_n^0\end{bmatrix}=\begin{bmatrix}1\\ 1\\ \dots\\ \dots\\ 1\end{bmatrix} \tag{3}$$

which is associated of winding initial state at putting in operation for first date.
Every parameter ε_k^0 of matrix will be associated the initial value corresponding of coil insulation $tg_k^0\delta$ [4], which is determined on the measurements and on the simulations.

At the every revision, with values obtained through acquisition but and directly measurements of insulation then when the hydro generator is out of function.
Will be defined the "matrix of normalized estimated fluent lifetime", $\left[\varepsilon_k^i\right]$ the matrix associated for current lifetime in hydro generator operation:

$$\left[\varepsilon_k^i\right]=\begin{bmatrix}\varepsilon_1^i\\ \varepsilon_2^i\\ \dots\\ \dots\\ \varepsilon_n^i\end{bmatrix} \quad (4)$$

with:

$$0<i<Z \quad (5)$$

Z – maximum number of estimations which making during lifetime of hydro generator and which reflected state of stator coil.
The precision of values ε_k^i of matrix depending by parameter values through the parameters are calculated. In time of hydro generator operating know a part of interesting measures; therefore the estimating precision is not high. The improvement of estimation will be making in revision moments, the programming revision being in p number:

$$\Delta p=\frac{T}{p} \quad (6)$$

with:
Δp - interval of time between two programming revisions
again the number of non-programming revisions is r.
Will be to define the "matrix of normalized estimated current lifetime for programming revision j", the matrix $\left[\varepsilon_k^j\right]$. This matrix shows the estimated lifetime in moment in which to execute the respective revision. This estimation will be determined by correction matrix $\left[c_k^j\right]$, which is diagonal matrix

$$\left[c_k^j\right]=\begin{bmatrix}c_1^j & 0 & \dots & \dots & 0\\ 0 & c_2^j & \dots & \dots & \dots\\ 0 & \dots & c_3^j & \dots & \dots\\ \dots & \dots & \dots & \dots & 0\\ 0 & \dots & \dots & 0 & c_n^j\end{bmatrix} \quad (7)$$

for each $j=\overline{1,p}$, programmed revisions,
with:

$$0\le\left[c_k^j\right]\le 1 \quad (8)$$

where:
j – ordinary number of programmed revision
Thus:

$$\left[\varepsilon_k^j\right]=\left[c_k^j\right]*\left[\varepsilon_k^{j,t}\right] \quad (9)$$

namely:

$$\begin{bmatrix}\varepsilon_1^j\\ \varepsilon_2^j\\ \dots\\ \dots\\ \varepsilon_n^j\end{bmatrix}=\begin{bmatrix}c_1^j & 0 & \dots & \dots & 0\\ 0 & c_2^j & \dots & \dots & \dots\\ 0 & \dots & c_3^j & \dots & \dots\\ \dots & \dots & \dots & \dots & 0\\ 0 & \dots & \dots & 0 & c_n^j\end{bmatrix}\cdot\begin{bmatrix}\varepsilon_1^{j,t}\\ \varepsilon_2^{j,t}\\ \dots\\ \dots\\ \varepsilon_n^{j,t}\end{bmatrix} \quad (10)$$

where: (7.6)
$\left[\varepsilon_k^{j,t}\right]$ - „matrix of normalized estimated theoretic lifetime for programming revision j", determinate on the base of standards .
If the hydro generator function is in according with theoretical previsions, the diagonal $\left[c_k^j\right]$ are unitary coefficients, being the unitary diagonal matrix. This situation is rarely in practice and only on the short time intervals:

$$\begin{bmatrix}c_1^j & 0 & \dots & \dots & 0\\ 0 & c_2^j & \dots & \dots & \dots\\ 0 & \dots & c_3^j & \dots & \dots\\ \dots & \dots & \dots & \dots & 0\\ 0 & \dots & \dots & 0 & c_n^j\end{bmatrix}=\begin{bmatrix}1 & 0 & \dots & \dots & 0\\ 0 & 1 & \dots & \dots & \dots\\ \dots & \dots & \dots & \dots & \dots\\ \dots & \dots & \dots & 1 & 0\\ 0 & \dots & \dots & 0 & 1\end{bmatrix}$$
(11)

The connection between the normalized estimated lifetime matrices associated at two consecutive programming revisions is:

$$\left[\varepsilon_k^j\right]_p=\left[\varepsilon_k^{j-1}\right]_p-\left[\varepsilon_k^{\Delta p}\right] \quad (12)$$

namely:

$$\begin{bmatrix}\varepsilon_1^j\\ \varepsilon_2^j\\ \dots\\ \dots\\ \varepsilon_n^j\end{bmatrix}=\begin{bmatrix}\varepsilon_1^{j-1}\\ \varepsilon_2^{j-1}\\ \dots\\ \dots\\ \varepsilon_n^{j-1}\end{bmatrix}-\begin{bmatrix}\varepsilon_1^{\Delta p}\\ \varepsilon_2^{\Delta p}\\ \dots\\ \dots\\ \varepsilon_n^{\Delta p}\end{bmatrix} \quad (13)$$

The each value $\varepsilon_k^{\Delta p}$ of $\left[\varepsilon_k^{\Delta p}\right]$ matrix will be determinate with relation:

$$\varepsilon_k^{\Delta p} = \varepsilon_k^{j-1} - \overline{t_{\Delta p}} \qquad (14)$$

the normalized value $\overline{t_{\Delta p}}$ being:

$$\overline{t_{\Delta p}} = \frac{t_{\Delta p}}{T} \qquad (15)$$

For j = 1 to obtained the "matrix of normalized estimated initial lifetime" $\left[\varepsilon_k^0\right]$.

If exist and the non-programming revisions, the remaining lifetime must be re-estimative because the errors from system influence and insulation quality. In these conditions "matrix of normalized estimated current lifetime for non-programming revision i" $\left[\varepsilon_k^i\right]$, is:

$$\left[\varepsilon_k^i\right] = \left[c_k^r\right] \cdot \left(\left[\varepsilon_k^j\right] - \left[\varepsilon_k^{\Delta \cdot t_{j,r}}\right]\right) \qquad (16)$$

with:

$$\left[\varepsilon_k^{\Delta \cdot t_{j,r}}\right] = \begin{bmatrix} \varepsilon_1^{\Delta \cdot t_{j,r}} \\ \varepsilon_2^{\Delta \cdot t_{j,r}} \\ \dots \\ \dots \\ \varepsilon_n^{\Delta \cdot t_{j,r}} \end{bmatrix} \qquad (17)$$

$\left[\varepsilon_k^{\Delta \cdot t_{j,r}}\right]$ - matrix of estimated lifetime between programming revision j and non-programming revision r, if the non-programming revision r was produced at normalized interval $\overline{\Delta t_{j.r}}$ after programming revision j.
and

$$\left[\varepsilon_k^i\right] = \left[c_k^r\right] \cdot \left(\left[\varepsilon_k^j\right] - \left[\varepsilon_k^{\Delta \cdot t_{r-1,r}}\right]\right) \qquad (18)$$

with

$$\left[\varepsilon_k^{\Delta \cdot t_{r-1,r}}\right] = \begin{bmatrix} \varepsilon_1^{\Delta \cdot t_{r-1,r}} \\ \varepsilon_2^{\Delta \cdot t_{r-1,r}} \\ \dots \\ \dots \\ \varepsilon_n^{\Delta \cdot t_{r-1,r}} \end{bmatrix} \qquad (19)$$

$\left[\varepsilon_k^{\Delta \cdot t_{r-1,r}}\right]$ - matrix of estimated lifetime between moments of non-programming revisions r-1 and r, if the non-programming revision r was produced at interval $\overline{\Delta t_{r-1,r}}$ after non-programming revision r-1.

The normalized times $\overline{\Delta t_{j.r}}$, respective $\overline{\Delta t_{r-1,r}}$ have the expressions:

$$\overline{\Delta t_{j.r}} = \frac{\Delta \cdot t_{j,r}}{T} \qquad (20)$$

respective:

$$\overline{\Delta t_{r-1,r}} = \frac{\Delta \cdot t_{r-1,r}}{T} \qquad (21)$$

The resulted matrix $\left[\varepsilon_k^i\right]$ from (16) and (18) relations will be ulterior renamed for non-programming revisions with r index, the applied corrections for "matrix of normalized estimated lifetime", $\left[\varepsilon_k^r\right]$ was realized with help the correction matrices type $\left[c_k^r\right]$, matrix of diagonal type:

$$\left[c_k^r\right] = \begin{bmatrix} c_1^r & 0 & \dots & \dots & 0 \\ 0 & c_2^r & \dots & \dots & \dots \\ 0 & \dots & c_3^r & \dots & \dots \\ \dots & \dots & \dots & \dots & 0 \\ 0 & \dots & \dots & 0 & c_n^r \end{bmatrix} \qquad (22)$$

The $\left[c_k^r\right]$ matrix is "correction matrix for each of $r = \overline{1,q}$ non-programming revisions". The matrix terms are obtained on the base of measurements and of simulations at hydro generator with standard help [1], [5]. The estimated remaining time for winding will be determined in each moment by $\left[\varepsilon_k^i\right]$ matrix, with condition:

$$\left[\varepsilon_k^i\right] > 0 \qquad (23)$$

namely:

$$\begin{bmatrix} \varepsilon_1^i \\ \varepsilon_2^i \\ \dots \\ \dots \\ \varepsilon_n^i \end{bmatrix} > \begin{bmatrix} 0 \\ 0 \\ \dots \\ \dots \\ 0 \end{bmatrix} \qquad (24)$$

if, ever, on the hydro generator operating will be find that:

$$\left[\varepsilon_k^i\right] < \left[\varepsilon_k^{\Delta p}\right] \qquad (25)$$

namely:

$$\begin{bmatrix} \varepsilon_1^i \\ \varepsilon_2^i \\ \ldots \\ \ldots \\ \varepsilon_n^i \end{bmatrix} < \begin{bmatrix} \varepsilon_1^{\Delta p} \\ \varepsilon_2^{\Delta p} \\ \ldots \\ \ldots \\ \varepsilon_n^{\Delta p} \end{bmatrix} \tag{26}$$

where, can be considerate, in natural mode, that:

$$\begin{bmatrix} \varepsilon_1^{\Delta p} \\ \varepsilon_2^{\Delta p} \\ \ldots \\ \ldots \\ \varepsilon_n^{\Delta p} \end{bmatrix} = \frac{1}{p} \begin{bmatrix} \varepsilon_1^0 \\ \varepsilon_2^0 \\ \ldots \\ \ldots \\ \varepsilon_n^0 \end{bmatrix} \tag{27}$$

Must be attention the stopping of hydro generator in short time because to estimate that from another revision the (24) condition not is performed.

The determination of life time is making on the base of (23) relation, obtained by relations (9), (11), (12), (14), (15), (16), (18), (20), (21).

Must be specified that "matrix of normalized estimated theoretical lifetime at programming revision of j ordinal" $\left[\varepsilon_k^{j,t}\right]$, the value indicated in standards is used only at the first revision, ulterior used a matrix $\left[\varepsilon_k^{j,t}\right]^*$, will be denominated "matrix of normalized estimated corrected theoretical lifetime at programming revision j". The matrix values are iteratively determined on the standards in correlation with the presented elements in this paper and on the calculus base and simulations for each case.

Theoretical, in this moment, the maximum precision for determination of matrix values coefficients $\left[\varepsilon_k^i\right]$ will be obtained , if to replace the diagonal matrices $\left[c_k^j\right]$ and $\left[c_k^r\right]$ will be used the square-matrix $\left[c_{xy}^j\right]$:

$$\left[c_{xy}^j\right] = \begin{bmatrix} c_{11}^j & c_{12}^j & \ldots & \ldots & c_{1n}^j \\ c_{21}^j & c_{22}^j & \ldots & \ldots & \ldots \\ c_{31}^j & \ldots & c_{33}^j & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots & c_{n-1,n}^j \\ c_{n1}^j & \ldots & \ldots & c_{n,n-1}^j & c_{nn}^j \end{bmatrix}$$

(28)

respectively $\left[c_{xy}^r\right]$:

$$\left[c_{xy}^r\right] = \begin{bmatrix} c_{11}^r & c_{12}^r & \ldots & \ldots & c_{1n}^r \\ c_{21}^r & c_{22}^r & \ldots & \ldots & \ldots \\ c_{31}^r & \ldots & c_{33}^r & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots & c_{n-1,n}^r \\ c_{n1}^r & \ldots & \ldots & c_{n,n-1}^r & c_{nn}^r \end{bmatrix} \tag{29}$$

the coefficients c_{xy}^j, c_{xy}^r, $x = \overline{1,n}$, $y = \overline{1,n}$, $j = \overline{1,p}$, $r = \overline{1,q}$ shows interaction between x and y coils.

3. CONCLUSIONS

The determination of winding insulation lifetime is very importance, because by this can be estimate in every moment the remaining lifetime of insulation, avoiding in this manner the appearance of insulation defects in function of hydro generator. For this was conceiving an estimation method in continuous mode of hydro generator insulation lifetime.

Was conceiving an matrix calculus model for determination of hydro generator insulation lifetime, in which was introducing the concept of "matrix of estimated lifetime" with various sub ranges: "initial", "current", "programming revision", "non-programming revision", associate at conditions which appear in exploitation and on the these base can be determined the "normalized estimation lifetime".

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