MEASUREMENT METHODS AND INTERPRETATION ALGORITHMS FOR THE DETERMINATION OF THE REMAAINING LIFETIME OF THE ELECTRICAL INSULATION

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Abstract. *The paper presents a set of on-line and off-line measuring methods for the dielectric parameters of the electric generators stator insulation as well as the method of results interpretation aimed to determine the occurrence of a damage and to set up the its speed of evolution. These results lead finally to the determination of the lifetime under certain imposed safety conditions.*

The interpretation of the measurement results is done based on analytical algorithms allowing also the calculation of the index of correlation between the real results and the mathematical interpolation.

It is performed a comparative analysis between different measuring and interpretation methods.

There are considered certain events occurred during the measurement performance including their causes.

The working-out of the analytical methods has been improved during the dielectric measurement performance for about 25 years at a number of 140 turbo and hydro generators from abbot. 60 power plants.

Finally it is proposed a measurement program to be applied and which will allow the correlation of the on-line and off-line dielectric measurements obtaining thus a reliable technology of high accuracy level for the estimation of the available lifetime of the stators winding insulation.

Key words: electric generator, stator insulation, dielectric parameters, residual lifetime.

1. Introduction

The increase of the electric generators power led also to the increase of the requirements related to the generator subassembly reliability. The stator insulation is one of the most important subassemblies; its damaging might lead to long periods of unavailability and to high costs for the recommissioning.

Under these conditions, the periodic dielectric measurements (off-line measurements) proved to be insufficient and it became necessary to be monitored the state of the electric insulation during operation that is to perform dielectric measurements without stopping the equipment (on-line measurements).

For the first stage it has been considered that it is easier to measure on-line the parameters of the partial discharges (PD) and based on them to draw conclusions related to the state of the stator insulation. Later on, it was proved that the information supplied by these on-line measurements are not enough and subsequently the measurements were periodically performed.

Actually, none of the programs for the electric generators predictive maintenance present firm conclusions based only on on-line measurements.

This paper emphasises especially the methods for the interpretation of the results of the off-line and on-line measurements considering the measuring diagrams and the pertaining devices (except the partial discharge analysers) which have not been significantly changed in time. At the same time, it tries to offer an answer based on original analyses to the main question raised by those who operate the electric generators, namely: how long can a stator insulation be used under safety conditions?

2. Direct current (D.C.) measurements

Usually, in D.C. there are measured:
- the insulation resistance (R_{ix})
- the absorption coefficient (K_{abs})
- polarisation index (I_{pol})

The information obtained allow the estimation of the electric insulation state during measurement performance. Due to the evolution of the parameters measured during a short time period it is difficult to work-out some criteria as to provide information on the electric insulation ageing level.

During the last ten years it was performed a calculation method for the stabilised leakage current (I_f) and of the stabilising time (t_s).

The measurements are performed in D.C. at 4-6 voltage levels; on each level there are measured the leakage currents at three different intervals of time (t_1, t_2, t_3) which have to meet the following conditions:

$$t_2 = a t_1 \qquad t_3 = a^2 t_1 \qquad a = 2,3,... \tag{1}$$

The stabilised leakage current is given by the relation:

$$I_f = \frac{I_1 I_3 - I_2^2}{I_1 + I_3 - 2I_2} \tag{2}$$

I_1, I_2, I_3 represent the values of the leakage currents measured in times t_1, t_2, t_3.

The stabilising time is given by the relation:

$$t_s = \left(\frac{KU}{I_a}\right)^{\frac{1}{n}} \tag{3}$$

where I_a is the absorption current which under a good approximation is given by the relation:

$$I_a = 0.1\, I_f \tag{4}$$

The constants K and U can be calculated by means of the Curie relation [1], possibly based on a statistical processing of the results of the measurements performed at different levels:

$$I_a(t) = KUt^{-n} \tag{5}$$

The first levels (R_{iz}, K_{abs}, I_{pol}) offer generally information on the humidity level, the stabilised leakage current (I_f) and the stabilised time (t_s) offers additional information on the electric insulation quality.

The low values of the last two parameters show an electric insulation of good qualities. The surveillance of the evolution in time of these indices allows the estimation of the insulation ageing level.

3. Alternative current (A.C.) measurements

There have been measured in A.C. partial discharge measurements (DP), the tangent of the dielectric losses angle (tgδ) and the electric capacity (C_x) of the analysed insulation volume.

There have been worked-out eight criteria for the estimation of the insulation state but these proved to be insufficient for the implementation due to the difficult interpretation of the primary measurement results and to the impossibility to reproduce the performance conditions of the measurements in the power plants [2].

3.1. Measuring of partial discharges (PD)

The technical condition analysis of an electrical insulation based on PD measuring outputs has been widely developed for the last period aiming at substituting the methods used until now.

PD off-line line measuring are performed by means of well-known conventional diagrams.

The discrepancies resulting between the various practised methods refer to the measured values and especially to their interpreting with the view to obtain simple and accurate answers to the questions raised by the operating staff.

In 1994 we designed a simplified analytical method based on a polyharmonics model, namely the Fourier conversion of a function x(t) that may have several components [3]. This way, we could analyse the PD sequences (trains) analogical with the real PD sequences. The amplitudes spectrum contains two groups of harmonics (G1 and G2) differentiating by the frequency band width and the nature of the amplitudes parameters variation on modifying the pulses number (fig. no 1)

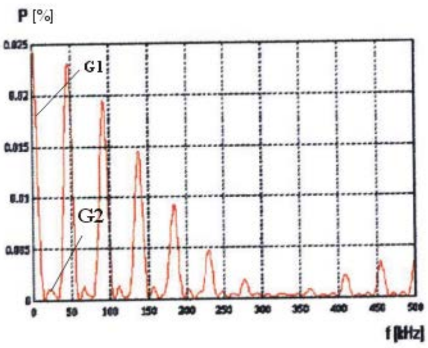

Fig. no. 1. PD power spectrum

The analytical description of the studied models by means of a I-st grade equation.

$$A_{G2}(x) = Kx + b \tag{6}$$

where:

x= PD variable parameter (apparent load, summed up load, energy, etc)

b= free term depending on several factors, among which PD degree of symmetry on both alternates of the proof (testing) voltage.

K= spectrum sensitivity coefficient as against charges in the PD pulse sequences.

The b term may be used as a parameter characterising some essential modifications of PD characteristics into the insulation.

G2 group harmonics is an informing parameter

At on-line measurements we used a coupler consisting of a coupling condenser and an impedance of R-L type connected to the generator null. We chose this diagram to find out the possible faults that may occur in the null area of the stator winding of the power generators.

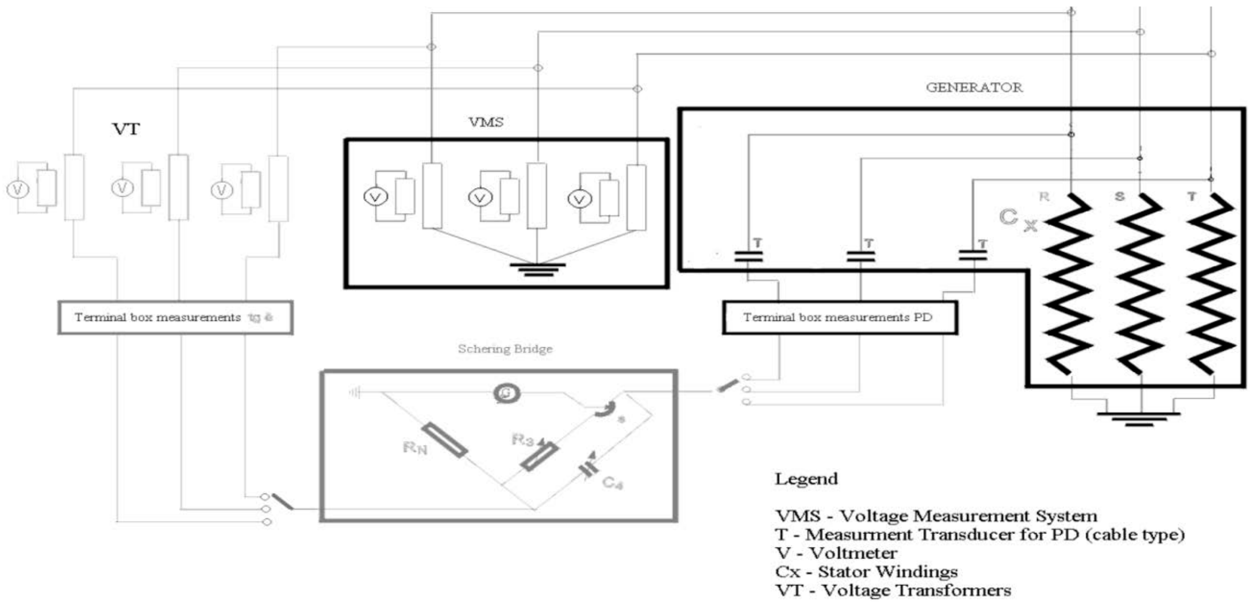

Fig. no. 2. tgδ on-line measuring diagram

on the insulation ageing degree. The sudden increase of a value of a harmonics, on reduced groups of harmonics amplitude in the vicinity of G2 central harmonics, indicates unloading occurrence into the insulation by an energy exceeding the sequence PD average energy and these can be dangerous.

The decrease in time of a reduced number of harmonics maximum parameters parallel with an increase of amplitude values on other harmonics belonging to the G2 group, show the increase of big energy PDs.

The analytical method for interpreting PD measuring outputs can be used both on off-line measuring and on the on-line, too.

Identically, like on the off-line measuring, it is used a Schering bridge with a reversed branches assembly.

For the bridge balancing it is used a voltage reducer, on each phase, parallel connected with the voltage reducers within the protection and measuring diagram, that an electric generator is endowed with. The connection at the measuring bridge of mass terminals of the reduction high voltage windings is made through a terminal box that contains the diagram protection system, too.

The coupling condensers are mounted within the generator box by means of rigid galvanic contact on the outlet bars of the stator windings. The connection to the bridge is made up through a terminal box, similar to the one at the voltage reducers. The assembly do not affect the generator protection and the measuring system and allows the PD on line measuring.

3.2. tgδ measuring

A proper analytical processing of the tgδ and C_x measuring outputs allowed us to draw up an algorithm for the estimation of the residual lifetime to operate under safety conditions imposed to the stator insulation.

The method consists of the calculation of the estimated breakdown voltage by means of measuring performed at a given moment and of the variation in time of this voltage. The algorithm has been fully presented within the previous items [2] and [4].

During the year 1999 we conceived tgδ on-line measuring diagram (fig. no.2).

The on-line measuring of another stator insulation parameter will allow a more accurate estimation of the stator insulation stage.

4. The comparative method for the D.C. and A.C. measuring

For the electric insulation control are used in absolute values parameters (leakage current and D.C. insulation resistance, the capacity or PD parameters in A.C.) as well as in relative values (D.C. absorption coefficient and tgδ or the variation of some parameters depending on the voltage, time, temperature, etc).

The absolute values, obtained as a result of the measuring have a wide variety, fact that leads to serious failures during the measuring performance as well as to the analysis of the results.

Because at the voltage increasing, the test finishes with the insulation breakdown, with the relevant decreasing of the tested circuit resistance, respectively it's normally to presume that the parameters defined as insulation will have the same evolution and thus can be evaluated the breakdown voltage, for the electric insulation by the extrapolation of the non-destructive measuring results.

The following parameters can be defined:

- D.C. insulation resistance:

$$R_i = \frac{U_0}{I_f} \qquad (7)$$

where:

U_o - test voltage
I_f - leakage current

- insulation loss determined by the time variation of the electric field at the ω frequency:

$$R_p = \frac{tg\delta}{\omega C} \qquad (8)$$

where:
C - capacity of the tested insulation volume

During the tests, the values I_f, tgδ, C are measured depending on the voltage and thus are calculated the parameters R_i and R_p.

The results of the measuring performed at TPP1 in Chisinau - Moldavia Republic - on new bars and renewed bars, [5] are shown in the table no. 1

Table no. 1

Bar type	Estimate breakdown voltage [kV]	
	D.C. measuring	A.C. measuring
New bars	30 - 35	28-32
Renewed bars	17-20	16-19

Considering an equivalence coefficient of about 1.7 - 1.75, it can be concluded that the considered parameters are equivalent. Actually, they characterise various electrophysic processes, in the electric insulation, the tests conclusions being additional.

5. Measuring programme project

The specialists that performed and improved the method, included in the present report, have a vast experience as they performed up to now about 350 measuring sets at about 140 electric generators within 60 turbo and hydroelectric power plants.

Most of the measuring have been off-line performed and since 1998 we have also begun the on-line measuring.

During the tests the insulation was destrupted at 6 hydrogenerators and the main causes were the following:

-factory failures (2 generators);

-unproper dielectric measuring during the commissioning and the recommissioning after the intervention upon the stator winding (3 generators);

-over 10 year no dielectric measuring were performed.

At the generators where the insulation failed, during the tests, the repairing period was of 36 hours.

It must be pointed out that at the generators at which constantly (2-3 years) dielectric tests were performed, there were not recorded any events that could lead to machines out of operation.

A test programme and an algorithm of the basic results interpretation , available for all electric generators type, is practically impossible to be p
erformed. The opinions regarding the performance way and the used methods, to get as confidence as possible results, are divided in two categories:

- a small number of measuring and a simple algorithm of interpretation so that to be accessible for the medium training level personnel;

- a large and various set of measuring with a complex algorithm of interpretation able to lead to results with high degree of credibility.

At the performance of an electric insulation status it is important to have in view certain aspects regarding the measured parameters and the measuring possibilities, the electrophysic phenomena that they emphasise as well as their way of correlation.

In order to respond the owner requirements, taking into consideration the real possibilities for the getting of correct results, we selected the following alternative that includes three stages:

1. The performance of the on-line measuring by means of common device endowed with signalling levels that are accessible to a medium level training staff;
2. The periodically performance, in case of over-running of a certain level of present signalling level by the complex on-line measuring, with complex analysers by special trained personnel.
3. To get the higher confidence coefficient conclusions, off-line complex measures have to be taken (in D.C. and A.C.) for supplementing the on-line measuring.

Finally, in order to draw up the list of measuring, the following two aspects should be considered:

- measuring in A.C. do not exclude those in D.C., or reverse, each of them providing additional information.;
-due to the stator winding voltage gradient, the on-line measuring hardly detect faults near the generator neutral

point where the operating voltage in low whereas the off-line measuring detect faults equally all along the stator winding.

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