ONSITE DIAGNOSTICS AND CONDITION EVALUATION OF ROTATING MACHINES

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In this paper the focus is laid on the diagnostic methods for rotating machines with respect to condition evaluation. In an overview the diagnostic measurements were presented and discussed. The most important factors for evaluation criterions were insulation resistance, dissipation factor, partial discharge and voltage withstand test. Some of these test results deliver absolute parameters and some have to be evaluated relatively. For the condition evaluation the absolute parameters deliver the information about the compliance of threshold values (passed/failed) to guarantee save operation within the next service interval. The relative parameters are helpful to find weak points in the electric insulation system, e.g. with PD pattern recognition the source of failures can be detected. In dependence of the maintenance strategy the results of the measurements and condition evaluation give helpful information for the decision of the further operation or if there have to be done any measures as overhaul, servicing or repair.

Key words: Dissipation factor, Partial discharge, Resistance

1. INTRODUCTION

For the economic use of high voltage equipment, it is necessary to evaluate the condition of the used components. Machines are important and also critical components in power plant and power generating system. Therefore, an appropriate maintenance program should be applied with the aim to anticipate maintenance before the components are failing and to make the power system more reliable. If the condition is known, the most economic maintenance strategy can be realised. Inspections can be planned on a long-term basis and the component lifespan can be fully used. This is the reason why different monitoring-, analysing- or diagnostic systems become a fixed part in power generation, transmission and distribution systems. Diagnostic tests are usually performed either ON- or OFF-line. OFF-line tests and inspections of a machine are mainly carry out as routine tests at planned interruption according to a time-based maintenance strategy. During operation ON-line tests are carried out either on continuous or periodic basis. The advantage of these ON-line methods is that they can be efficiently used for trend analysis and especially for optimizing the timing for routine interruption for OFF-line diagnostic tests. Thus a change from time-based maintenance to condition-based maintenance is possible.

2. BASICS

Different ageing effects respectively ageing mechanism caused by electrical, thermal, mechanical, chemical or ambient loads change the properties of the electric insulation system and it comes to an degradation of the material. In the final stage of the ageing the electric insulation breaks down and the equipment falls out. For this reason different methods and measurements for the evaluation of the condition are used.

2.1 DIELECTRIC DIAGNOSTICS

The observation and evaluation of the effect between the electromagnetic field and the material is called dielectric diagnostics. The different polarization mechanisms and the reaction of the dielectric will be acquired. Material and device-specific parameters such as capacity, dissipation factor and insulation resistance give information about changes in the insulation medium. Thereby aims are the detection of structural changes, humidity, pollution and electrical discharges.

Insulation resistance - The measurement of the insulation resistance gives information about the presence of insulation barriers. In the context of trend analysis, for example the aging and humidification of insulations with cellulose components can be pursued. The insulation resistance results from a resistance network as reproduction of the material and surface attributes. With the guard-ring arrangement, a separate evaluation of the volume resistance and the surface resistance of an insulating sample can be made.

Capacity- and dissipation factor - The dissipation factor and/or capacity measurement are classical methods for the actual condition evaluation of insulating systems. It gives important parameters for the aging condition evaluation of an insulation system. For a comparison, the measurement must be done at the same conditions than in the past.

The classical circuit for the evaluation of capacity and dissipation factor is a "C / tan δ" Schering Bridge. It is characterised by the fact that the object reality is stressed closed to high voltage, which can be measured. New computer-based measuring systems work according to the principle of a vectorial impedance measurement in the frequency range by analysing the fundamental harmonic of the currents [1]. Thereby the dissipation factor is determined from the phase shift of the current signals of a measuring branch and the comparison branch.

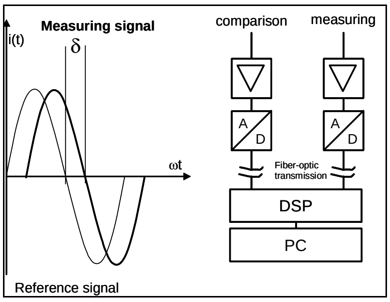

Fig. 1: PC based measurement of the dissipation factor [1]

Polarisation/Depolarisation Current Analysis (PDC) - The procedure uses DC voltage to test the specimen. From the DC voltage step a polarization / depolarization current results in the insulating medium, which decays exponentially. The temporal process, the size and the shape of the PD current give information about condition and characteristic values (oil conductivity, polarization time constants).

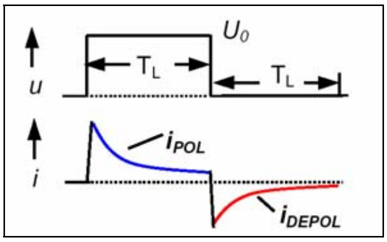

Fig. 2: Measurement and the principle distribution of the current [2]

It is a pulse-like current during the instant of voltage application, which decreases during the polarization duration to a certain value given by the DC conductivity of the insulation system. After the polarization duration voltage supply is interrupted and the test object is grounded. Thus, the discharging current jumps to a negative value, which goes gradually towards zero.

2.2 PARTIAL DISCHARGE DIAGNOSTICS

The presence and the strength of partial discharges in electrical resources are criterions for the insulation quality. Partial discharge (PD) measurements will be used as non-destructive checks for the insulation of high-voltage resources during quality tests in the factory and in service.

Partial discharges are local enhancements of the electric field in the area of inhomogeneities. On stator windings PD occurs whenever there are small air gaps or voids in or on the surface of the insulation. For the measuring, physical effects, such like optical, electrical and acoustical appearances, will be used. Different measuring methods depending on the electrical equipment are used for the PD behaviour analysis.

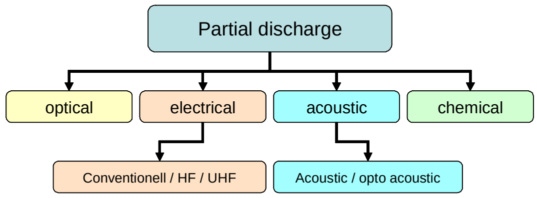

Fig. 3: Category groups for partial discharge detection

The most applied method uses capacitive sensors permanently mounted within the stator or on the stator terminal.

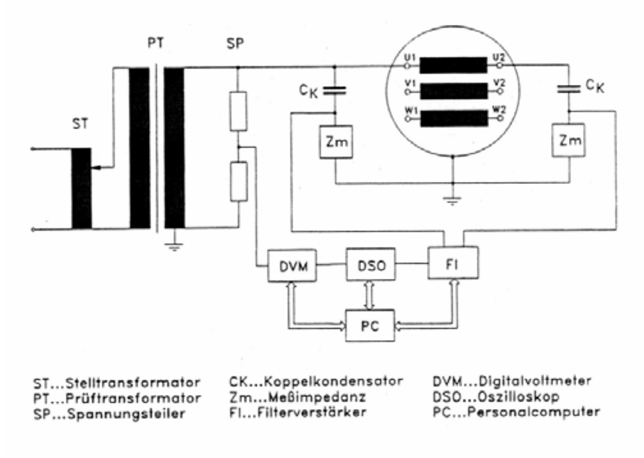

Fig. 4: PD Test Circuit [3]

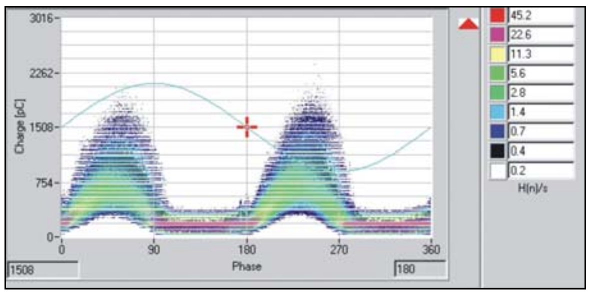

Fig. 5: PD Fingerprint of a Hydro Generator at rated voltage

As example of PD measurements a fingerprint of a hydro generator is shown in Fig. 5. The graph illustrates the level and the phase position of discharges. The number of the discharges is represented by the colour of the dots.

3. CONDITION EVALUATION

The condition evaluation of rotating machines is the basis for the decision over further operation, maintenance, repair of renewal. For the optimization of the maintenance expenditure for cost-intensive electrical machines the strategy of condition based maintenance (CBM) is of considerable importance. Different procedures of the technical diagnostics are used for accurate condition evaluation of the active components of the machines. Hereby, the insulation system of the stator winding represents a particularly critical generator component as demonstrated by international surveys and breakdown statistics. [4]

Apart from the diagnostic measurements the technical characteristic data (e.g. year of manufacture, insulation system, soldering technique) and the constantly logged data (e.g. starts, operation hours, reconditioning measures) supply valuable information for a condition evaluation and risk assessment of the machinery.

This paper highlights possibilities for continuing condition evaluation of the machinery and represents a guide for the decision in continuing operation, applying maintenance measures or in renewal respectively about investment within the focus on rotating high voltage machines.

A <u>three-step concept</u> can be applied for the condition evaluation of the machinery [4]. The goal of this three-step approach is to identify machines with worse condition and high risk of default.

3.1 LOAD OF STATOR WINDING

A first insight into possible risk ranges was generated from the comparison of operation hours and starting processes of the stator windings. Therefore the “equivalent operation hours” was calculated.

An example for the visualization of the condition evaluation for the rotating machines of an utility is given in the figure below. The load of the stator winding was determined by collecting the operational dates with respect to the operating hours, number of starts and age of the machines.

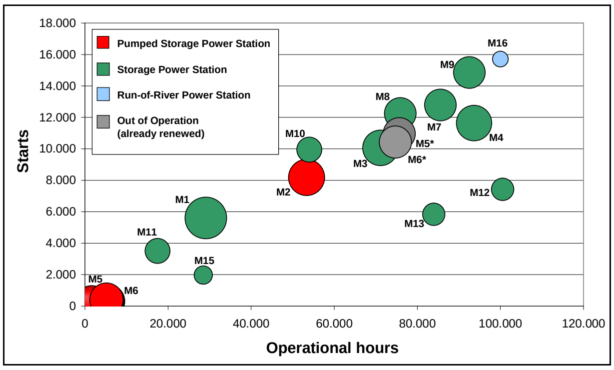

Fig. 6: Operation hours and starting processes of the stator winding [4]

3.2 TECHNICAL DIAGNOSTICS

Different measuring and testing methods were applied to the machines in the past. Observing the tendency of the measured values (trending) the aging of the insulation can be pursued. Due to transverse comparisons of the measurement results of the comparable machines certain sequences regarding their technical condition can be made. The "worst" machine in each case can be determined. The interpretations in the test reports play an important role in the evaluation of the technical condition.

In Figure 7 the results of dissipation factor measurements on different generators are given. The pump storage machines were higher loaded within operation, for this reason the tanδ behaviour shows a characteristic sharp bend in the curve (PD-inception).

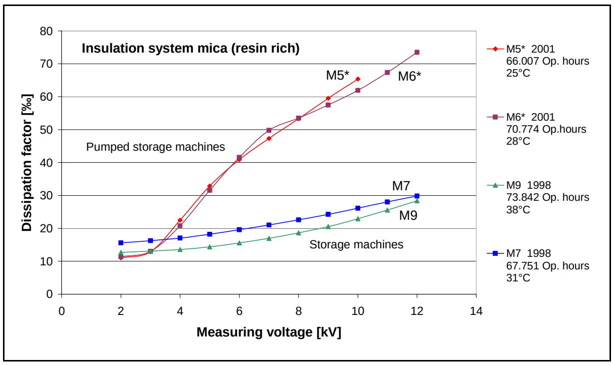

Fig. 7: Comparison of the dissipation factor of different machines with the same insulation system [4]

3.3 QUALITATIVE CHARACTERISTICS

Also dates of so called qualitative criterions can be collected and quantified. Following aspects were considered:

- *Modes of operation* (pumped storage, storage, run-of-river)

- *Age* of the generator and stator winding
- *Insulation system* - an evaluation is made on the basis of different material properties, dielectric properties and the design of the systems with or without inner potential grading
- *Soldering technique*
- *Degree of pollution*
- *Movement traces* of the winding and *loose slot keys*

3.4 QUANTIFICATION OF CONDITION - BENCHMARKING

After all dates were collected and measurements were done the quantification of the results can be done under the considerations of table 1.

Condition	
1	**New condition** partly increased characteristic values due to incomplete hardening of the insulation; risk-free operation is expected
2	**Good condition** no and/or marginal signs of electrical aging; risk-free operation is expected
3	**Satisfactory condition** Aging is clearly ascertainable; e.g. deviations between line and neutral point generator bars (partial discharge measurement) or high rises at the dissipation factor values; medium risk of default is expected
4	**Little satisfactory condition** strong signs of electrical aging; e.g.: high partition discharge activity; increased risk of default is expected
5	**Bad condition** high risk of default is expected

Table 1: Guidelines for quantification of condition

After quantifying each machine the condition characteristics were given and a benchmarking diagram can be developed. Normally the benchmarks were displayed within a bar graph diagram as shown in Figure 8. To estimate the risk of default three category groups were determined. Machines in the red area have a high risk of default. The yellow area is defined as medium risk area and the green one comprises machines with low risk of default.

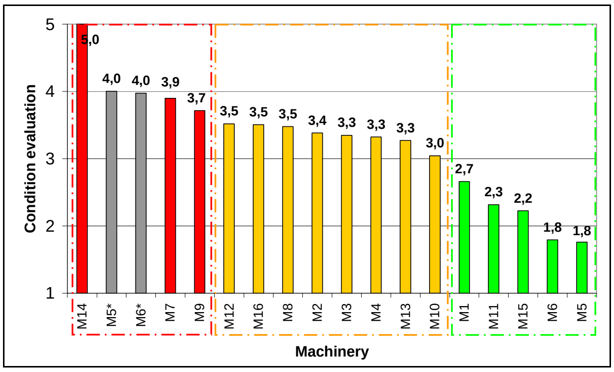

Fig. 8: Benchmarks of rotating machines [4]

4. CONCLUSION

In this paper diagnostic measurements and the results of diagnostic investigations at rotating electric machines were discussed. With the operational dates, results of diagnostic measurements and qualitative criterions a quantification of the condition is possible by the means of the mentioned guidelines. The methodology of condition evaluation was shown within a three step concept to gain a benchmarking of the observed machines. With the results of condition evaluation and the benchmarks a risk analysis is possible. The result of the risk analysis helps about the decision over further operation/maintenance strategy. Within a good machine condition a further safe operation is possible, at satisfactory condition the necessary maintenance measures have to be done and in the worst case parts have to be repaired or the full machine has to be replaced. Applying diagnostic tools and condition evaluation a safe operation and uninterrupted power supply should be guaranteed.

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