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Applied Risk Analysis for High Voltage Equipment

Christof SUMEREDER, Michael MUHR
Institute of High Voltage Engineering and System Management
Graz University of Technology,
Graz, Inffeldgasse 18, 8010 Graz, AUSTRIA
E-mail: sumereder@tugraz.at

Abstract: For a save and reliable operation of high voltage equipment the maintenance strategy and condition evaluation is a sufficient part for the utility. Within the maintenance program diagnostic measurements should be evaluated carefully. Only the results of both, diagnostic measurements and analysis of the machine operating dates can give a view to the actual condition of the power equipment. For this reason the measurements and data analysis has to be treated independent and carefully. Based on failure statistics and the results of diagnostics and condition evaluation the reliability of the machines can be determined. For the risk assessment the different kinds of risks and their probability so as the magnitude of damage have to be analyzed.

The aim of the diagnostic measurement is to find out any weak points in the machines. Current state of the art at machine diagnostic measurements is to determine the insulation resistance, the dielectric dissipation factor and the partial discharge behaviour.

Risk is defined as product of probability and damage of failures. The technical risk analysis of each machine can be done on the basis of the condition evaluation. Until now it is not usual to determine and evaluate the economical and juridical risk in the same detailed way. The aim of the risk analysis is to find any machines with poor condition and high probability for a failure and to prevent the case of a breakdown. Applying risk management the whole machine park can be operated in a save and reliable way.

Keywords: failure analysis, maintenance; risk analysis;

1. Maintenance of rotating machines

1.1 Maintenance Strategy

The maintenance of rotating machines is the basis for a save and reliable operation [1, 2]. In former times the time based strategy was applied but due to the tendencies in the liberalization of the electricity market a change at the machine operators can be observed. Nowadays a combination of condition and risk based strategy is chosen. For this reason the condition and the risk has to be determined. The implementation of the results can be done absolute by comparing the results with limit values or relatively by creating benchmarks.

In this paper the focus should be laid on the benchmarking method. In Fig. 1 the sequences of the maintenance measures were shown. Normally the inspection intervals t_i of generators were between 3 and 5 years, depending on the age and condition [3]. The servicing periods were given by the producers. Additional servicing jobs have to be done if the condition (green line) is in the range of the maintenance limit (blue line). Applying this maintenance strategy the limit for damages (red line) should be never reached.

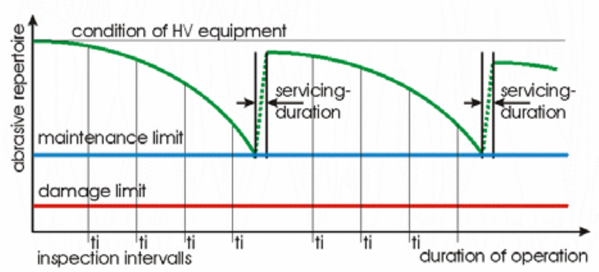

Fig. 1 - maintenance strategy of rotating machines

For the condition evaluation the technical condition has to be determined by the means of technical diagnostic measurements but also the operational dates and qualitative criterions of the insulation system have to be evaluated.

1.2 Maintenance Measures

The term maintenance is defined in different standards [4-6] and for every utility maintenance is a duty by law. There were international Standards as well as national where the measures of maintenance were classified. As example the ÖNORM M8100 distinguishes between the terms inspection, servicing and reconditioning, shown in table 1.

Maintenance			
planned, preventive, condition oriented		failure incident	
Inspection	**Servicing**	**Reconditioning**	
Detection and evaluation of actual condition	Measures to keep desired condition	Measures to restore desired condition	
Condition control, diagnostic of damage to remove faults, trending	Delay or prevent time relevant faults	Time dependant reconditioning	Damage dependant reconditioning
Selective tests and measurements	lubricating, cleaning, adjusting, exchanging, conservation	Overhaul from functional condition	Repair after breakdown or failure
Revision			
Combined measures consisting from components: inspection, servicing and reconditioning			

Table 1 - measures of maintenance [5]

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The interval of the inspections and servicing depends on the age and condition of the machines. The main task of the inspection is to detect any deviations from normal condition by visual inspection (Fig. 2) or diagnostic testing.

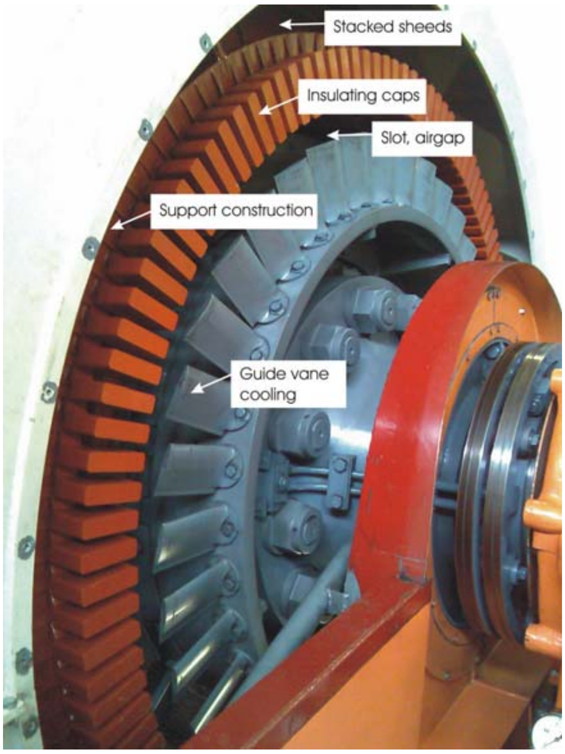

Fig. 2 – visual inspection

In Fig. 2 typical places of interest for a visual inspection at a generator were shown. The electrical insulation system mostly can only be investigated, if the covering of the stator is dismantled [7].

2. Condition Evaluation

2.1. Operational Dates

Under the term operational dates following aspects have to be considered: age of the machine, load during lifetime, number of operating hours and starts, type of machine, interval of servicing etc. Collecting these dates a first important view for the general condition can be estimated. Creating a benchmark the type of machine has to be brought to account. Pump storage machines were much more loaded as run of river machines, so the operating hours have to be weighted by the number of starts [8].

2.2. Technical Diagnostics

The standard program for the condition evaluation is the insulation resistance [9], the dielectric dissipation factor [10, 11], the partial discharge behavior [12, 13] and a withstand voltage test [14]. But also additional diagnostic tests can be applied [15]. For the insulation resistance and tan δ there were absolute limits given in standards, depending on the type of insulation system and nominal values of the machines.

Collecting the historical results a trend analysis can be done and the change of the observed parameters can give important information about the deterioration in the electrical insulation system.

In Fig. 2 an example of the historical development of the partial discharges is given. The PDs were rising with lifetime respectively load of the machine. After 30 years of operation of this pump storage power motor-generator there were significant PDs from 0,2 times rated voltage. This means that PDs were present during the normal operation of the machine and the deterioration of the electric insulation system goes permanently further. Resuming the results this machine has to be evaluated with a poor mark due to this significant PD behavior.

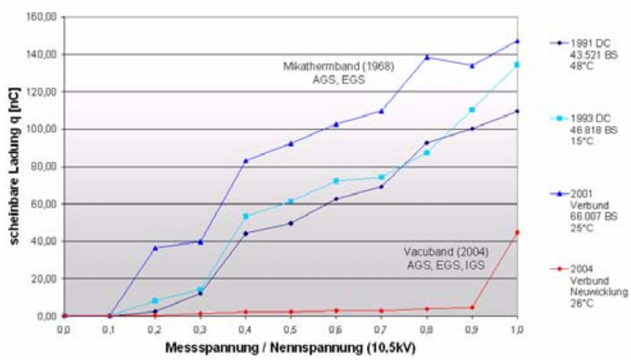

Fig. 3 – chronological development of PD behavior

Beside the apparent load of PDs (Q_{IEC}) also the fingerprint gives information about the location and failure type of the PD. A risk assessment according the IEC standard can be done.

Normally the diagnostic measurements were carried out as onsite measurements with a transportable regulating transformer. For new machines a test voltage of $2xU_0$+1kV according to the standard [14] is used. But normally a reduced test voltage ($1{,}5xU_0$) for operationally aged machines is applied.

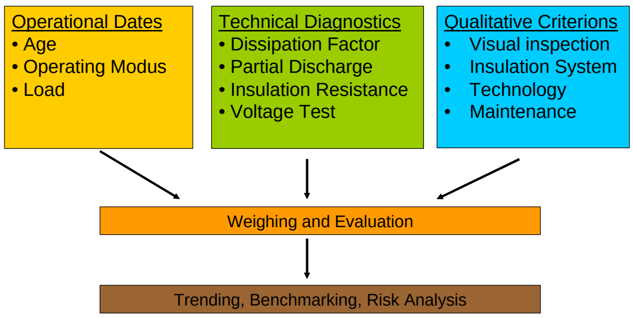

Fig. 4 – condition evaluation

2.1. Qualitative Criterions

Under the term qualitative criterions following aspects have to be considered: results of visual inspection, type of insulation system, type of soldering technology, experience of service personal, failures and incidents in the past or at similar machines etc.

2.1. Condition Assessment

After collecting the dates a relative assessment can be carried out. Each parameter has to be evaluated adequate to gain expressive benchmarks. The result can be represented numerical or graphically in a diagram as bar graphs.

3. Risk Management

Risk Assessment is an often used management tool. Classically it is a process in four steps. The first step is the "identification of the risk", and then the different kinds of risk have to be evaluated and analyzed. Under handling of the risk different measures to minimize or delete them have to be done and finally the controlling of the risk gives an optimum result. Risk can be divided into following aspects [16]:

- technical risk
- economical risk
- judicial risk (laws, contracts)
- management, financial and trading risks
- ecological and environmental risk
- other risks

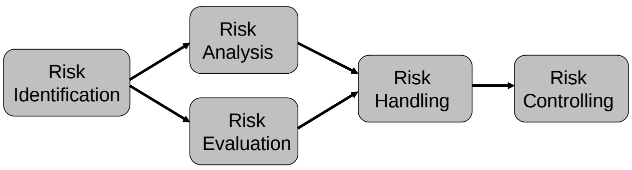

Fig. 5 – risk management

Depending on the politics and philosophy of the operator, further decisions relating to the analysis, evaluation and handling of the risk could also occur.

3.1. Risk Identification

To analyze the risk of operation and of a failure and to evaluate the damage and costs several management tools can be used. One of the most popular is the risk matrix. The risk matrix displays the probability of a fall out in dependence of the consequential damage. The determination of the failure probability can be done by the statistical relation between technical condition of the power equipment or with a database of the statistical lifetime. The evaluation of damage has to be done for each power equipment separately under the consideration of the economical consequences for the company [17].

In Fig. 6 an example for a risk matrix is given. A whole collective of machines of an electric utility was evaluated. The matrix shows the different condition and importance levels scaled in different colors. On the x-axis the consequences respectively the importance of a damage and on the y-axis the probability of failure occurrence respectively the condition is quantified for eight apparatus. The position of the equipment can be interpreted as:

- **High risk:** red area, the risk due to failure probability and damage is not acceptable
- **Normal risk:** yellow to orange fields show equipment under normal operational behavior, not immediate measures were necessary
- **Low risk:** green fields, equipment is new or no consequences in case of fall out

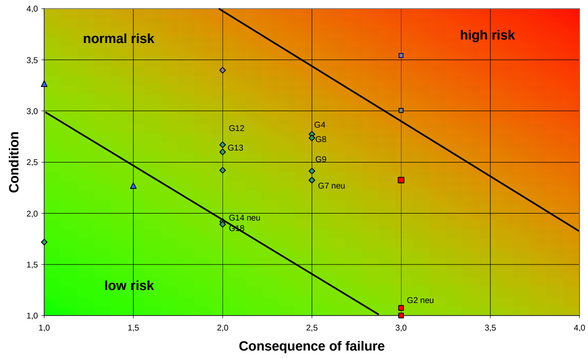

Fig. 6 - risk matrix and risk assessment

3.2. Risk Analysis

One possibility for the risk analysis is to compare the results of the condition assessment with lifetime statistics. The precondition is that the statistical dates meet the properties of the electrical insulation system. The application of statistical charts has to be done with great care otherwise the result is not representative!

Knowing the failure probability f(t), the reliability R(t) and the failure rate λ(t) can be derived. In Fig. 7 the statistical functions where shown for three different electrical insulation systems.

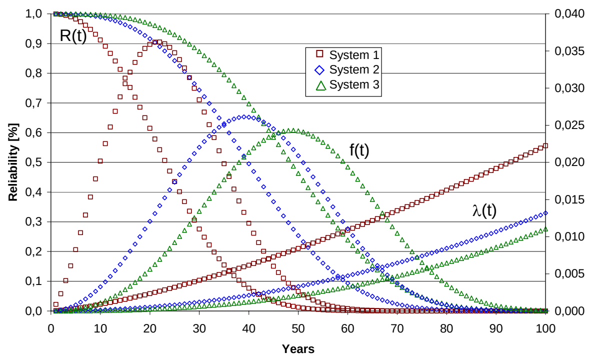

Fig. 7 - Reliability, failure density and failure rate of three different electrical insulation systems [18]

3.3. Risk Handling

The task of risk handling is to prevent, reduce, transfer or finally to accept the risk, see Fig. 8. If a high and therefore not acceptable risk is present measures to reduce the risk have to be applied immediately. The reduction of risk can be achieved by maintenance, replacement of parts of the machine or in the most expensive way a full exchange.

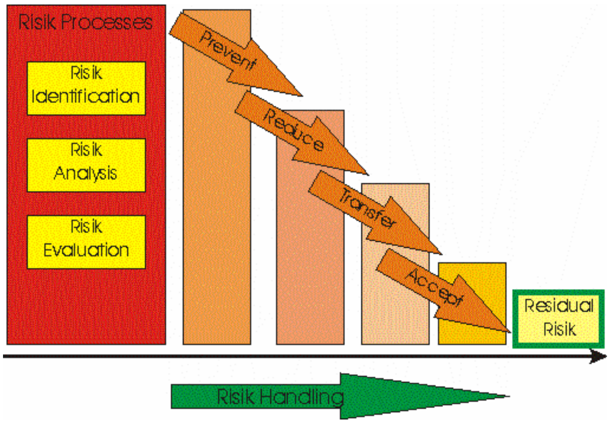

Fig. 8 - Risk handling

Handling power transformers recommended measures to improve the condition can be found in appropriate standards. For rotating machines there is no comparable standard and the measures have to be chosen carefully. Firstly a classification of typical PD patterns and a risk evaluation is done in [14].

There are no general rules for ideal measures of risk handling of generators. In the practice of utilities always economical aspects have to be fulfilled. The costs of the risk measures have to be opposed to the profit. In many cases it will be useful to accept a residual risk. In some cases also a transferring of the risk can be done, e.g. maintenance services can be transferred by outsourcing to a service provider.

3.4 Risk Controlling

Finally the controlling of the risk has the same priority as the other measures in risk management. After the risk measures were implemented and finished the risk should be evaluated again to see if the desired success resulted.

Within risk controlling the success of each measure can be observed. Equipment of high risk should be shifted to areas of better condition or lower failure impact.

4. Summary

In this paper the theory and practice of maintenance for rotating machines and the strategy for the operation were discussed. To evaluate the condition technical diagnostic measurements have to be evaluated carefully but also operational dates and other qualitative criterions should be observed.

The knowledge base of risk management was investigated and the main steps in risk evaluation were shown. The risk matrix is one of the most popular tools in risk management and enables a general view to the actual situation of the machine park. Handling and controlling the risk is a demand to successful risk management.

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