Statistical Analysis for Condition Evaluation of Power Engineering Equipment

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Abstract: Contrary to the usual condition evaluation of operational equipment in power engineering with the procedures of technical diagnostics, methods can be used which can evaluate the condition of operational equipment on mathematical models and alternative ways. These procedures can be principally used at operational equipment, which is represented in high numbers. The basic of this viewpoint is the mathematical tool of the statistics, which permits to made conclusions on representative samples. Procedures for the estimation of failure probabilities and the condition evaluation of operational equipment are based on statistical data and data bases. In these ones the parameters and characteristics of the operational equipment, as well as maintenance data will be classified. From the acquired parameter and characteristics, behavior patterns and tendencies can showed by formation of cross connections of parameters and the correlation with arisen failures.

INTRODUCTION

One of the most important function of mathematical statistics and basic reliability mathematics is to make conclusions from a small sample to a basic population (Figure 1). Therefore some mathematical functions are relevant for the study of physical objects like failure probability F(t), failure probability density f(t), failure rate $\lambda(t)$, reliability function R(t) and risk. With this functions basics of statistical condition evaluation of network components and power equipment can be done. This functions are also important for the development of models which describe the aging process of network components and power equipment.

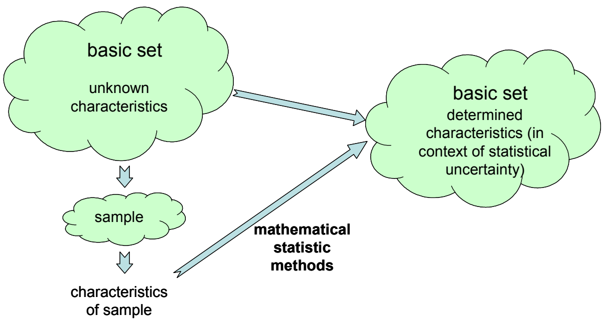

Figure 1: Conlusions from a sample to a basic set

Failure probability F(t) and Reliability R(t)

This characteristic is formed as a real number between 0 and 1 and will be called failure probability F(t) of a random event. The size of the real number depends in this case on time t.
The failure probability is written symbolically P(t<T) or F(t). F(t) indicates the probability for the fact that the regarded operational equipment drops out in the time interval [0...t]. As distribution function and cumulative frequency function F(t) always possesses the characteristics

- $F(0) = 0$ und
- $F(\infty) = 1$.

The reliability R(t) can calculated with equation (1).

$$R(t) = 1 - F(t) \tag{1}$$

Failure probability density f(t)

The derivative of the distribution function F(t) by time results as failure probability density function f(t). If F(t) is differentiable, equation (2) and equation (3) apply. This is given the by the characteristic monotonous rising function of F(t).

$$f(t) = \frac{dF(t)}{dt} \tag{2}$$

$$F(t) = \int_0^t f(t)\, dt \tag{3}$$

Taking into account the conditions of the differentiability of F(t) the failure probability density function can be approximated by equation (4).

$$f(t) = \lim_{\Delta t \to 0} \frac{\Delta F(t)}{\Delta t} = \lim_{\Delta t \to 0} \frac{F(t) - F(t_0)}{t - t_0} \tag{4}$$

Failure rate $\lambda(t)$

The failure rate $\lambda(t)$ which is derived from the sizes of the failure probability F(t) and the failure probability density f(t) describes the quotient of the number of failures in the interval $t+\Delta t$ to the still working units at the time t. A rising failure rate at power equipment is characteristic for aging-determined failures by thermal, electrical, ambiente and mechanical loads as well as of the material aging of the insulation system. Therefore the failure rate and its temporal characteristics can be consulted for the condition evaluation of insulation systems [1] [2] [3]. The determination of the failure rate is usually made by equation (5). The present failure rate determination for units which can not be repaired can be calculated by equation (6). Figure 2 shows determined approximated and exact functions F1(t), F2(t) and failure rates λ1(t), λ2(t) according to equation (5) and (6).

$$\lambda(t) = \frac{f(t)}{1-F(t)} = \frac{f(t)}{R(t)} = \frac{\frac{dF(t)}{dt}}{1-F(t)} \qquad (5)$$

$$\lambda(t) = \lim_{\Delta t \to 0} \frac{1}{\Delta t} \frac{R(t) - R(t+\Delta t)}{R(t)} = \frac{f(t)}{R(t)} \qquad (6)$$

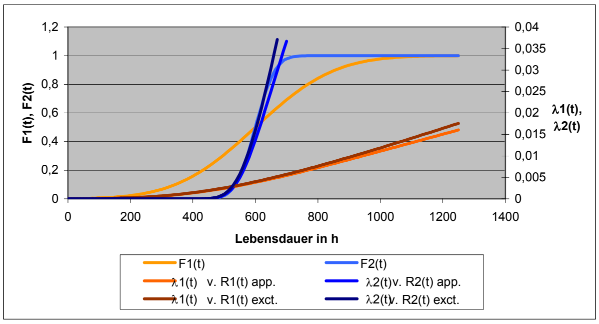

Figure 2: Process of the functions F1(t), F2(t) and failure rates λ1(t), λ2(t); (approx. and exact.)

CONDITION EVALUATION

Figure 3 plots the principle procedures for the evaluation of the condition of electrical equipment. The mentioned statistic methods are based thereby on the basis of investigations with the help of the technical diagnostics and on the events arising in service (i.e. arising failures or defects), which are held in documented form in operational equipment statistics.

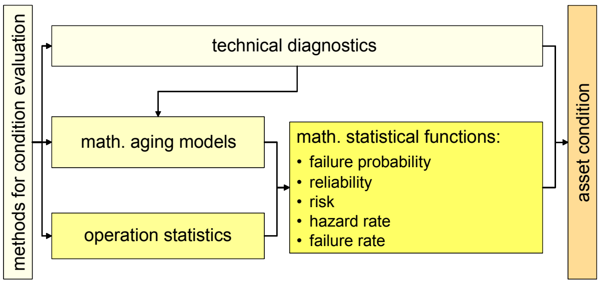

Figure 3: Possibilities of condition evaluation at network components and power equipment

The condition of electrical equipment is dominated by the condition of the insulation system. To evaluate the condition of a electrical network component technical diagnostics have to be used. The technical diagnostics can be divided into a multiplicity of well-known procedures; in principle however into non destructive and destructive procedures [4].

Regarding the application of the technical diagnostics in the asset management these procedures have to work without destruction and without limitation of the lifetime of the power equipment. For accurate determination of the residual electrical strength and the aging degree of the insulation system non destructive diagnostic procedures must be used. By procedures on basis of dielectric measurements the general condition of the insulation system can be determined. Disadvantage of the procedures of the technical diagnostics is the expenditure of time and the disconnection from the network at some technical diagnostic procedures. To exclude these disadvantages and to get an overview of the condition of an asset is helpful to use to statistic procedures [5].

AGING MODELS

Aging models of operational equipment are determined by the influences and loads.
For the determination of the residual electrical strength of the insulation system of the regarded operational equipment extensive attempts are needed, in order to receive a meaningful data record for the formation of an aging model.

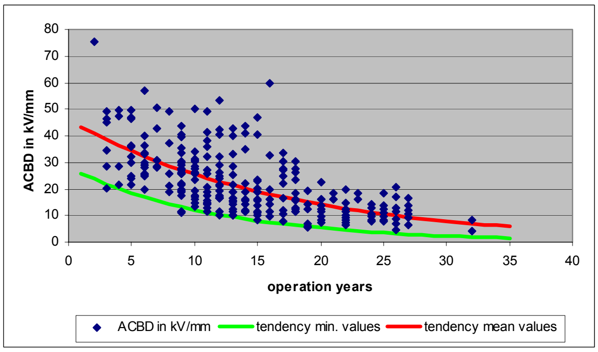

Figure 4: Distribution and tendencies of AC voltage strength of coaxial XLPE insulation systems

Figure 4 shows the temporal process and distribution of the electrical strength of a coaxial insulation system under operating conditions. Each taken up data record of one time unit (year) is described thereby by a distribution function, whose parameters changes with increasing age (Figure 5).

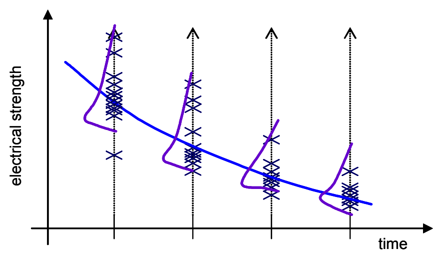

Figure 5: Distribution functions of electrical strength

The change of these parameters can be described by an aging model. This model makes an estimation for the electrical strength distribution function at any time of the operational equipment over the equipment lifetime possible.
Figure 6 show the aging model of the electrical strength of the coaxial XLPE insulation shown in Figure 4, as well as the density distribution function of the load which will stress the insulation system over life time.

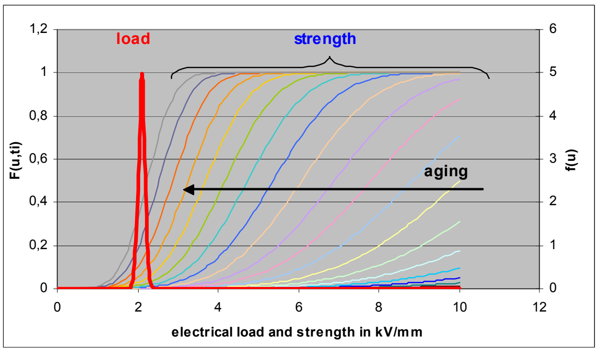

Figure 6: Distribution function of the arising load (red) and the strength of the insulation system

With the use of statistic functions for the distribution function of the load and the electrical strength of the insulation system the failure probability density p(t) of each time unit and the failure rate can be calculated (Figure 7). Figure 8 shows the comparison of the calculated failure rate and a real failure rate of a XLPE coaxial insulation system at a operation time up to 15 years.

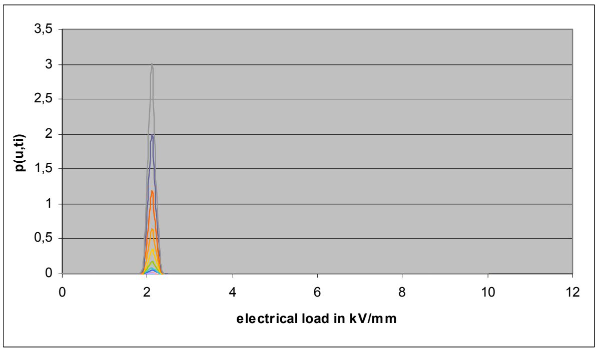

Figure 7: Calculated failure probability density p(t)

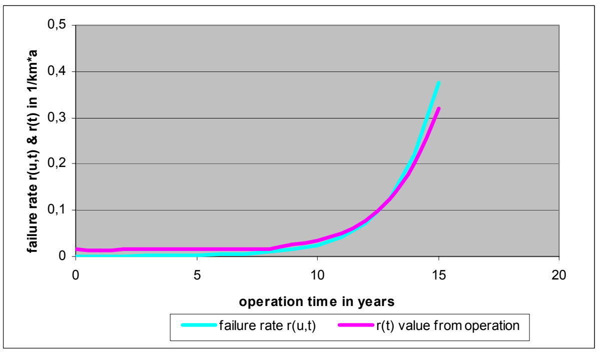

Figure 8: Calculated failure probability density p(t)

OPERATIONAL STATISTICS

A further possibility to determine the aging behavior and the condition of an asset from electrical network and power equipment can be made by the operational statistics and operational data bases. These ones have to be particularly implemented for this purpose and have to possess an appropriate information depth. Statistics, which can show the "life history" of operational equipment are useful for the derivative of maintenance measures.
The most substantial advantage of such statistics and data collections is the collection of arisen failures and their appearance. With that information the failures can be separated into random failures and aging-determined failures. The temporal collection of these failures permits an estimation to the tendency of the future failure rate. With the standardized failure rate of this operational statistics the failure density, the failure probability and risk can be calculated. These parameters can also consulted for the formation of aging models.

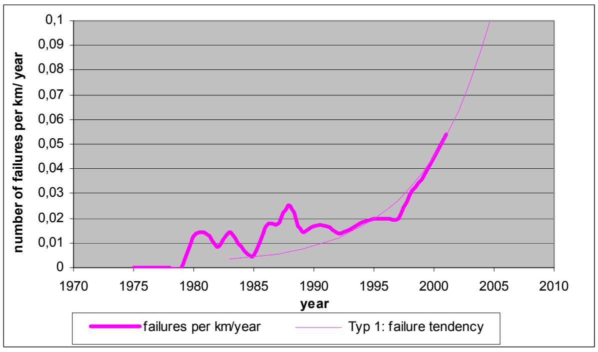

Figure 9: Calculated failure rate of a coaxial XLPE insulation system

CONCLUSIONS

The evaluation of the condition behavior of the operational equipment in power engineering can be done on different ways. Apart from the possibility of the technical diagnostics an evaluation of the condition of an asset can also be done by statistic procedures. Basics for this are the mentioned parameters of failure probability F(t), failure probability density f(t), failure rate λ(t), reliability function R(t) and risk. On the basis of this parameters tendencies of increased failure probabilities can be recognized.
Therefore a concept for the aging procedures is required. The aging procedures can be represented by distribution functions by change their parameters (variance and location parameter) with "aging"-functions. This procedures can not predict the place and the time of arising failures, but this estimation permits the planning of the necessary personal and material expenditure for maintenance in future.

REFERENCES

[1] Praxl G.: Statistische Methoden zur Beurteilung der elektrischen Festigkeit von Hochspannungsisolierungen. Habilitation, TU-Graz, 1985.

[2] Drescher D., Balzer G.: A New Method for Qualitative and Quantitative Evalution of Ageing Behaviour of Electrical Equipment. 14th ISH, Delft, 2003, S 292

[3] O´Connor P. D.T.: Practical Reliability Engineering. Heyden & Son Ltd, 1981, S 88-92

[4] Porzel R., Neudert E., Sturm M.: Diagnostik in der elektrischen Energietechnik. Expert-Verlag, Renningen-Malmsheim, 1996

[5] Körbler B.: Zustandsbewertung von Betriebsmitteln der elektrischen Energietechnik. Dissertation, TU-Graz, 2004

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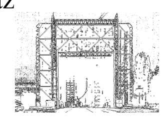

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