Life Time Investigations at Electric Insulation Systems, Theory and Measurements

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Abstract

For the condition evaluation of an electrical insulation system diagnostic expert systems are used. The positive aspects of these systems are the non-destructive and online operating modus. In some cases the measuring results do not lead to an expressive decision, then destructive tests enables a better estimation of the condition and residual life time. The life time behaviour of an electric insulation system can be mathematically described by the so called life characteristic curve. This model bases on the exponential characteristic of natural processes for aging mechanism, which was already described by the law of Arrhenius. The determination of this curve can be done with successive discharge tests and long-time breakdown tests. To achieve a statistic correct result it is important to ensure that only wear-out failures and no early and random failures are included to the examination. The reason for the necessity of this differentiation finds its reason in the miscellaneous kinds of breakdown respectively aging processes.

Theory of Aging Mechanism

Ageing is defined as the irreversible changes of the properties of an electrical insulation system due to action by one or more factors of influence. Factor of influence is a specific physical stress imposed by operation, environment, or test that influences the performance of an insulation material, insulation system, or electric equipment. Ageing stress causes an irreversible change (usually degradation) to take place with time. Aging leads to an irreversible change of the insulating properties [1].

The condition of an electric insulation system is influenced by different physical loads. Beside electrical and thermal stress also chemical and mechanical loads and their common reaction to the insulation material (multi stress) cause degradation of the insulation behaviour. The basic process at degradation is the thermal aging, where molecular bonding forces break and recombination is not possible any more. For this reason insulating materials have thermal borders for operation, e.g. at IEC 60085 "Electrical insulation - Thermal classification" the maximum long time temperature is defined.

Since the condition of electric machines has to be evaluated models with the focus to aging were developed. For electrical aging the inverse power law describes the degradation process due to electric stress. The lifetime degreases with rising electric field in a double logarithmic function. It has to be taken into account that the inverse power law is limited by the minimum electric field strength – threshold. Below the threshold field no degradation caused by electrical occur. Equation 1 gives the two forms of the mathematical function.

$$E = k_D * t_D^{-1/r} \qquad t_D = c_D\ E^{-r} \qquad \text{Equation 1}$$

E … electric Field, r … lifetime exponent, k_D, c_D … constant

Thermal aging was mathematically described generally by Arrhenius and especially for paper oil insulation systems by Montsinger [2]. The idea of Arrhenius was that all natural processes operate on exponential functions. Montsinger found out that the degradation speed of transformer board doubles at 8 degree rising over the maximum operating temperature. Thermal aging is essentially caused by current losses and partial discharges. The functions for thermal aging are shown in Equation 2.

$$LT\,Arrhenius = A^{\left(\frac{BxT}{C}\right)} \qquad LT\ Mont\sin ger = 2^{\frac{T-90°C}{8°C}} \qquad \text{Equation 2}$$

LT … Lifetime, A, B … constants, T … Temperature

Thermal aging is not relevant for short processes. For this reason electric aging can be observed at tests for short duration or at tests with low (very low) operating temperature. Is the test object exposed to a high electric field, thermal aging can be observed, e.g. partial discharges may accelerate thermal aging. In Figure 1 the processes of thermal and electric aging were shown. Other processes (multi stress) were not considered in this diagram. Beside the early and stochastic failures due to the bathtub curve the failure aging should represent the group of drop outs in the sphere of residual life time.

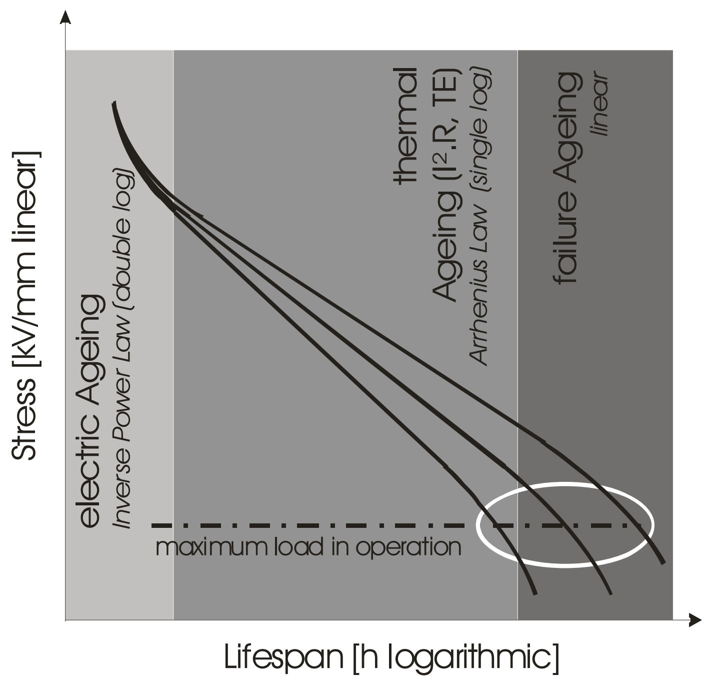

Figure 1: Aging processes, Lifetime in dependence of stress

Measurements

Two examples of lifetime measurements should be given. On the one hand the electrical aging of polymer insulation systems was determined by a cryogenic insulation system and on the other hand a conventional insulation system is represented by generator bars. The lifetime curve was measured in two steps. At first a successive discharge tests was done, the AC step voltage with 5 kV steps up to the breakdown was supplied. Then the statistic distribution was found out with a fitting test as shown in Figure 2.

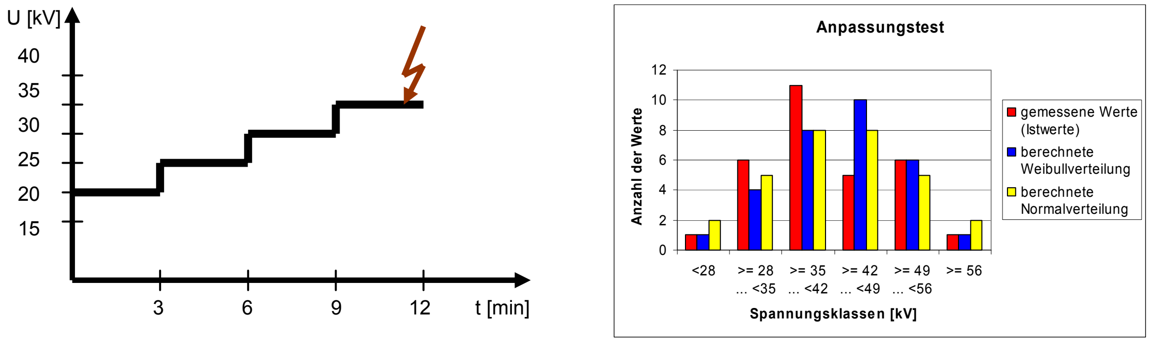

Figure 2: successive discharge test (left) and fitting test (right)

To determine the lifetime curve it was important to know about the distribution of the breakdown voltages. In this case a two parametric Weibull distribution was given, the function is shown in Equation 3.

$$F(u) = 1 - e^{-\left\{\frac{u}{44,3}\right\}^{4,9}} \qquad \text{Equation 3}$$

The exponent of the Weibull distribution gives very important information about the failure type. If it is grater than 1 stochastic and early failures can be excluded, electric aging can be assumed. In the next step the long-time breakdown tests can be started: characteristic loads were applied on the test object. After the breakdown tests the lifespan curve can be constructed and lifetime behaviour can be determined.

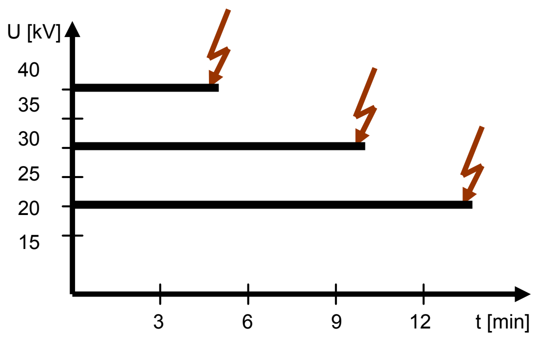

Figure 3: long-time breakdown tests with characteristic loads

The determination of the mathematical function of the measured life time curve was done with numerical methods on PC. For the cryogenic insulation system the inverse power law was taken into account and the Arrhenius law for room temperature systems. The measuring results were compared to life time exponents of insulation systems in the literature.

Results

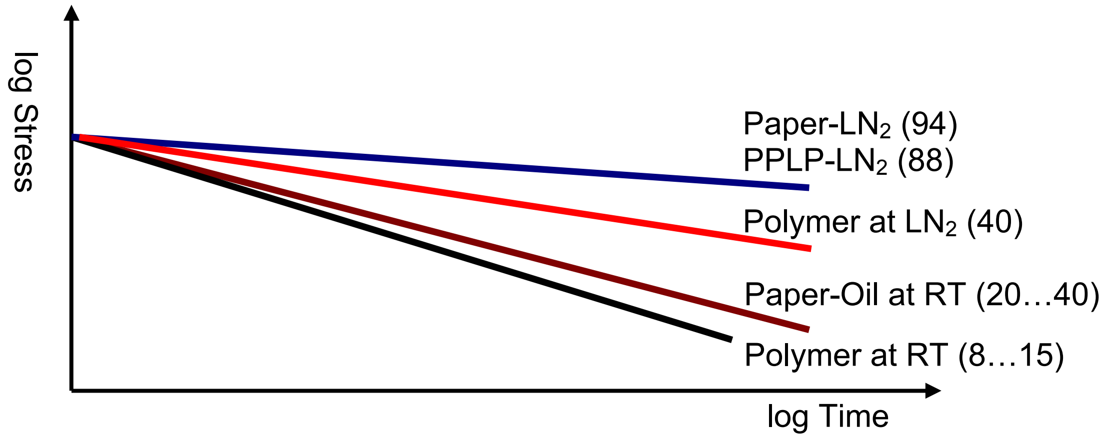

Figure 4: Lifetime curve of different insulation systems, measured and literature of cryogenic and room temperature (RT) insulation systems

Conclusion

The lifetime behaviour can be determined by measurements of breakdown tests and described by mathematical models. It has to be taken into account that the load strength (stress) is over the threshold value of the electric field. As the Figure 4 shows the exponent of room temperature (> 20 °C) is much lower as for cryogenic insulation systems at liquid nitrogen temperature (- 196 °C) because of the effect that thermal aging can be excluded at low temperatures.

References

[1] IEEE Std 1064-1991, "IEEE Guide for Multifactor Stress Functional Testing of Electrical Insulation Systems", 1991
[2] V.M. Montsinger "Loading transformer by temperature" AIEE transactions, Bd. 49, 1930, p. 776-792

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