Assessment of the Actual Condition of the Electrical Components in Medium-Voltage Networks

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***Abstract*—Due to the large amount of electrical equipment and the costs of an individual diagnosis in medium-voltage networks, a general consideration of some representative electrical components is necessary to assess the actual condition of the electrical equipment.**

For a life model of electrical components, the individual aging phenomena of representative electrical components, as well as the general aging mechanisms of insulating materials, are taken into account in this paper. The aging of insulating materials can be estimated by an electrical breakdown occurring in electrical components so that the relationship between lifetime and failure probability of electrical components may be studied using the life model, the probabilistic failure model, and the enlargement law which are reasonably able to investigate the cause & consequence of failure in medium-voltage networks. Thereby, a new approach is developed for the assessment of the actual condition of electrical components in terms of failure time, failure probability, hazard rate, and other related variables of electrical components in medium-voltage networks. These reliability issues will support the decision-making in future deregulation of the electric energy market.

Furthermore the model is verified through some electrical components like conductors, cables, transformers, and circuit-breakers with their specific failure statistics. It is demonstrated that the method is able to assess the actual condition of electrical components in medium-voltage networks with reasonable, accurate data.

***Index Terms*—Actual condition, assessment, electrical component, failure probability, hazard rate, medium-voltage network, probabilistic failure density.**

NOTATION

b	correct coefficient taking into account the reaction of materials due to combined stress application
B	activation energy of thermal degradation reaction
E	electrical stress
E_0	scale-parameter for the lower limit of electrical stress, below which the aging can be neglected
$E_{63\%}$	electric withstand strength at the failure probability of 63%
$f(t)$	probabilistic failure density
$F(t)$	distribution function
$h(t)$	hazard rate
L	lifetime
L_0	scale-parameter for the lower limit of lifetime, below which the aging can be neglected
L_1	element of lifetime
L_m	total lifetime of m lifetime elements
n	voltage-endurance coefficient
P	failure probability
P_1	element of failure probability
P_i	failure probability of the failure event i
P_m	total failure probability of m non-dependent failures
t	time
Δt_j	the jth time period
T	conventional thermal stress
V	volume
V_1	element of volume
V_m	total volume of m volume elements
β	shape-parameter of Weibull-function
ϑ	absolute temperature
ϑ_0	reference temperature

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I. INTRODUCTION

THE primary technical function of an electric power system is to provide electric power and energy to its customers at the lowest possible cost, and at acceptable levels of reliability. The specification of what constitutes acceptable levels is a difficult problem which requires a trade-off between quality and costs [1]. This requirement must be always kept in view during the phases of system planning, design, operation, and maintenance. Fig. 1 shows that the complementary cost generally increases with higher reliability. On the other hand, the costs of the electrical equipment associated with failures decrease as the reliability increases. The total cost, the sum of these two individual costs, exhibits a minimum, and so an "optimum" or target level of reliability is achieved. Thus the integrated cost benefit analyses involving customers and their decisions, in an asset management's view, could be a more rewarding and applicable approach.

The traditional approach [2], [3] to deal with this requirement is based on the analysis of "worst-case conditions", and on the use of "safety factors". The approach represents past experience by single facts or numbers, without assigning any degree of likelihood to future expectation. Therefore, the approach does not provide enduring analytical models by which the consequences of each failure can be effectively used on a predictive basis in the future.

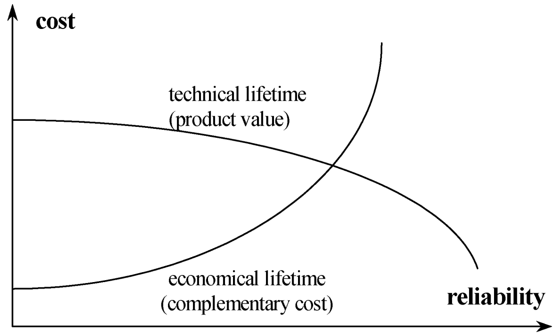

Fig. 1. Relation between cost and reliability.

A more realistic way of incorporating past experience is to identify all events which have contributed to that experience associated with a comparative degree of likelihood to future expectation. Once the past experience is represented by statistical parameters, the application of special analysis and design techniques is carried out on the basis of the probabilistic approach. The assumption can be made that failures, which have randomly occurred in the past, will also randomly occur in the future. Therefore, past performance can be understood, and future performance can be predicted in a more consistent way [4], [5].

By using the minimum quadratic deviation criterion (e.g. Chi-square test), the fitted curves or trends have to be chosen from a set of functions which do not provide any information about the parameters of the electrical equipment, and the technical operating conditions of networks. The future failure distributions seldom completely fit the data from past experience, and care must be taken to ensure that significant errors are not introduced through different equipment types, service conditions, and network structures. Thus the validity of the approach must be restricted to a large extent. The most important aspect to remember is that the time-sequential simulation is only a mathematical approach, and cannot give a complete understanding of the physical implications in failures. Therefore, a new evaluation approach should not only reflect and respond to the way electrical equipment fails, but also deduce the consequences of failure which can result from the relevant physical phenomena.

From the failure statistic of German utilities [6], and the previous research work [7], it can be concluded that there are two basic kinds of failure in medium-voltage networks: external failure, and internal failure (Table I). Excavator work, storms, or accidents can cause an external failure. This kind of failure is almost independent of the aging of electrical components; thus probabilities of its appearance are assumed to be constant throughout the whole lifetime of electrical components, while hazard rates can be derived from [6]. The internal failure is strongly correlated to the aging of electrical components, where hazard rates are not constant during the whole lifetime. Therefore, the aging phenomena of electrical components are taken into account for the assessment of the actual condition of electrical components.

Investigations have shown that aging of materials in electrical components is often found to contribute to the internal failure due to the degradation stresses, such as electrical, thermal, mechanical, and environment stresses [8]–[12]. Thus it becomes necessary to analyse the material characteristics (i.e. aging tests) to assess the technical usability of electrical components. The aging of insulating materials can be assessed by an electrical breakdown occurring in electrical components. From a statistical point of view, the probability of electrical breakdown is described by the probabilistic failure model as a consequence of the breakdown test. Along with the life model, the probabilistic failure model on the lifetime, and the other related reliability issues, is given. Combined with the enlargement law for a whole network, such a system of models helps to predict the failure events of electrical components and networks under various operating conditions.

TABLE I
FAILURE STATISTIC [7]

Electrical Component	Failure Percentage	External Failure	Internal Failure
Overhead Line	23 %	70 %	30 %
Cable System	46 %	98 %	2 %
Secondary-substation	24 %	64 %	36 %
Switchgear-station	7 %	64 %	36 %

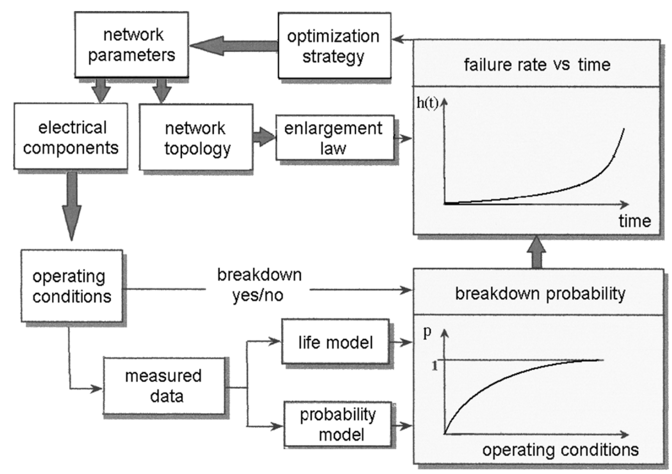

Fig. 2. Technical asset management.

Therefore it is the asset manager's task presented in Fig. 2, to quantify the parameters of medium-voltage networks (equipment inventory, network topology, etc.), as well as the technical operating conditions (voltage level, working load, operating time, etc.), and to manage their correspondence with each other (reliability, maintenance, etc.). With the conditions of assessment (network parameters, and operating conditions), the multiple models (life model, probabilistic failure model, and enlargement law) with the time-sequential Monte Carlo simulation [4], [5], [13] allow a calculation of the consequences in terms of failure probability, hazard rate, system reliability, etc. These issues estimate the behaviors of electrical equipment, and medium-voltage networks as a whole. Based on the assessment of reliability and technical lifetime, the deterministic costs, and the maximal economical lifetime can be achieved by an optimization of the actions & procedures of maintenance.

II. Aging Mechanisms of the Electrical Components

From the following aging mechanisms of individual electrical equipment in the different service conditions, the general degradation properties of insulating materials can be derived. On the basis of these investigations, some empirical correlations are established which, with a minimum of adjustable parameters, can predict the degradation degree of the electrical equipment under the influences of the various stresses described in Section III.

To model a medium-voltage network, the whole network can be divided into four main electrical components: cable system, secondary-substation, overhead line, and switchgear-station (gas-insulated switchgears and metal-clad switchgears including insulator, protection, and local control), where some associated electrical equipment are combined into a complete electrical component. Models for the assessment of the actual condition of each individual electrical component are required to determine the lifetime, and the failure probability of the considered electrical components in medium-voltage networks.

A. Cable System

In medium-voltage cables of cable systems, many failures are caused by damage due to digging activities. Quite a few electrical breakdowns are also caused by water trees as a major degradation occasion. In the presence of water, the corrosion of reinforcing tapes, and the change in the crystalline structure of cables, are the dominant aging factors. Combined with harsh environmental conditions, an excessive loading (electrical stress) may cause an increase in the dissipation factor of insulating materials [11], [14].

In general, the character of tree growth, and the aging of solid materials follow the inverse-power relationship [11], [15].

The aging process of most insulating materials speeds up when the temperature of materials is increased. Due to overheating, failures may occur as a result of the increased losses inside insulating materials [14], [16]. The behavior of a chemical-bond-breaking reaction can be expressed by using the Arrhenius Model [15], [17].

B. Secondary-Substation

The failure probability of transformers in the secondary-substation is primarily related to the aging of on-load tap-changers. During the usual operation of on-load tap-changers, their operating reliabilities are affected by the particles produced in the insulating oil corresponding to the temperature, as well as to the operating frequency [18], whose relations can be approximated by the Arrhenius Model, and the Inverse Power Model, respectively.

In oil-impregnated transformers, much attention has been paid to the condition diagnosis of the cellulose insulating materials (paper and pressboard). The insulating paper around the conductors decays if it has been previously aged due to the heat dissipation of windings, the loss induced by eddy-current or the presence of water [8], [9]. Thus, the effects of temperature and water on the actual condition of the insulating paper of transformers should be taken into consideration when the life model is made.

Like other solid and liquid insulating materials, the life characteristics of transformers can be well described by the Inverse Power Model, and the Arrhenius Model [15].

C. Switchgear-Station

For the development of the life model, aging mechanisms of insulating gas, and of solid insulators used in gas-insulated switchgears, are reviewed. A conducting particle attached to the surface of insulators may generate partial discharges if it is located in a position with a high electrical stress. If the electrical stress continues for a long time, the decomposition products caused by the partial discharges degrade the surface of insulators, and lead to the generation of tracks. Some deterioration of insulating gases coincides with these disturbances if they occur. When conducting particles are present in gas-insulated switchgears, the dielectric strength of insulating gases and solid insulators tends to decrease with time if a voltage is applied [10], [15]. This is named the voltage-time characteristic of insulating gases, which satisfies the empirical Inverse Power Model [10].

The aging of protection & control systems with electromechanical solid-state components results from the deteriorating properties as they occur at the end of their lives. For micro-electronic components, the thermal stress is expected to be a key factor in the aging of protection & control systems [19], which addresses the life characteristic of solid materials [15], [17].

D. Overhead Line

Corrosion is the most adverse consequence of aging for conductors of overhead lines. The amount of corrosion depends mainly on the environmental conditions due to wind, storm or ice [12]. The influences of mechanical stress and temperature on conductors can be also described by the Inverse Power Model, and the Arrhenius Model [17], [20].

The main reasons for the failure of overhead lines are stochastic accidents, thus in most cases, chances of their appearance are assumed to be constant.

III. Life Model

From the general degradation properties of electrical components, it is known that the typical aging processes of electrical components are considered to be partial discharge, formation of water trees, and electro & thermochemical processes, which result in the development of the life model of electrical components described essentially by the Inverse Power Model, and the Arrhenius Model.

The life model for electrical components, in the presence of an electrical stress, can be shown to follow the inverse-power-law, e.g.

$$L = L_0(E/E_0)^{-n} \tag{1}$$

If a mechanical stress is considered, the mechanical life model is equivalent to the electrical one, which can be expressed by the Inverse Power Model [20].

When the thermal stress is present due to an overheating of materials, an empirical model based on the Arrhenius Model can be described by

$$L = L_0 e^{-BT}, \quad T = 1/\vartheta_0 - 1/\vartheta \tag{2}$$

If a generic combination of electrical & thermal stresses is applied to an electrical component, the proposed multi-stress life model can be derived from a suitable combination of a couple of single-stress models, e.g. the Inverse Power Model, and the Arrhenius Model

$$L = L_0 (E/E_0)^{-n} \cdot e^{-BT}, \quad T = 1/\vartheta_0 - 1/\vartheta. \tag{3}$$

This can simply be done by assuming that aging rate under these combined stresses is the product of aging rates under each single stress [21].

As both electrical and thermal stresses influence each other, the combined electrothermal life model will result in an overestimation of the synergism between stresses, which leads to an underestimation of life especially at high stresses. Therefore, it seems reasonable to introduce a suitable corrective function $(E/E_0)^{bT}$ to consider the influence between the stresses, and to achieve a better fit of experimental data. In this case, the following expression has been assumed for L:

$$L = L_0 (E/E_0)^{-(n-bT)} e^{-BT} \tag{4}$$

It is a more reliable approach to determine the parameter n of (4) by aging tests for individual electrical components.

IV. Probabilistic Failure Model

When an electrical breakdown occurs in insulating materials under an electrical stress, the failure has to be specified by the so-called electric withstand strength, which is assigned to the event "non-breakdown" at the highest electric field strength, but derived from the event "electrical breakdown." Therefore, an accepted statistical model of determining the likelihood of failure at given stresses can be well described by a two-parameter Weibull-function

$$P = 1 - \exp\left[-\left(\frac{E}{E_{63\%}} \right)^{\beta} \right] \tag{5}$$

The electrical breakdown may occur if an over-voltage is applied, or if an electrical component is aged by temperature or time. Therefore, a criterion for the electrical breakdown is consistent with the electrical or thermal stress, thus the electric withstand strength $E_{63\%}$ can be explained by the appropriate life model (4). For the estimation of $E_{63\%}$ in (5), the lifetime L for the failure probability of 63% in (4) is substituted to determine the failure probability of an electrical component under the influences of electrical and thermal stresses:

$$P = 1 - \exp\left[-\left(\frac{E}{E_0} \right)^{\beta} \cdot \left(\frac{L}{L_0} \right)^{\frac{\beta}{n-bT}} \cdot e^{\frac{\beta BT}{n-bT}} \right] \tag{6}$$

As a multi-stress model, the Weibull-function (6) provides a probabilistic failure model giving the failure percentiles for each pair of stresses.

V. Enlargement Law

An electric power system consists of several tens of thousands of assets, and a large number of electrical components. The basic problem is that, in laboratories or test plants, only an individual electrical component (e.g. a cable with certain length and diameter) with a short test duration (e.g. the accelerated aging tests) can be investigated. For practical applications, it is desirable to describe the properties of all electrical components, and to predict the extended lifetime of the whole system in service.

From a statistical point of view, all these questions can be dealt with by using the enlargement law [22], which represents the practical application of multiplication for non-dependent probabilities. The independence of the failures, which take place in parallel with respect to space (volume-effect) & time (time-effect), is thereby assumed.

The total failure probability P_m can be derived from the failure probabilities P_i for $i = 1, 2, \ldots, m$, according to each failure event.

$$P_m = 1 - \prod_{i=1}^{m} (1 - P_i) \tag{7}$$

If an element component, with an element volume V_1 & an element lifetime L_1, has a reference failure probability P_1, the total component, with the continuous volume V_m & the continuous lifetime L_m, has the total failure probability P_m. (7) can consequently be derived from the integral

$$P_m = 1 - \exp\left[\frac{1}{V_1 L_1} \int^{L_m} \int^{V_m} \ln(1 - P_i) dV dL \right], \quad m = \frac{V_m L_m}{V_1 L_1} \tag{8}$$

In the case of a gas-insulated switchgear with m installed insulators, the total failure probability of the device would be greatly increased by a sum of the failure probabilities of each individual insulator according to (8). For instance, a gas-insulated switchgear with a total of 10 insulators, corresponding to a lifetime of 10 years & a failure probability of 1%, would have a cumulative failure probability of 40% during the expected lifetime of 50 years. When insulators are stressed in a uniform field, only those insulators stressed by the maximum electric field strength have to be considered in this way.

VI. Application of the Models

For instance, the voltage endurance coefficient n of (1) results directly from the long-term aging test or the accelerated aging test, if two lifetimes L_1, and L_2 of an electrical component at the ambient temperature are plotted versus the electric field strengths E_1, and E_2, respectively:

$$n = \frac{\log L_1 - \log L_2}{\log E_2 - \log E_1} \tag{9}$$

The purpose of the life model is to assimilate the lifetime measures obtained at high stress level during the accelerated test to calculate the lifetime at service level conditions.

TABLE II
THE PARAMETERS OF (6)

n	b	B	β	L_0	E_0
7.0	6000 K	17000 K	25-70	$4.5 \cdot 10^4$ year	5 kV/mm

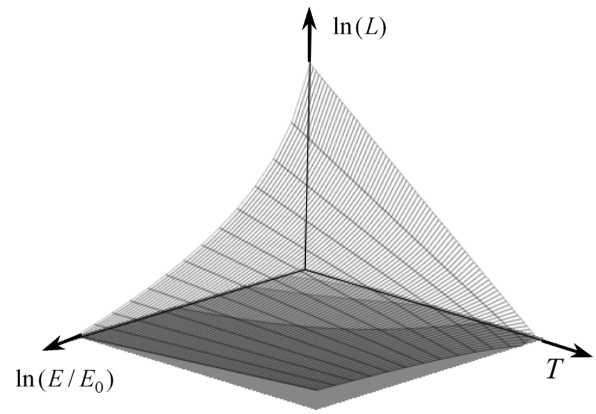

Fig. 3. Life model for electrical stress, and temperature.

In a similar manner, if two probabilities P_1, and P_2 from the breakdown test at ambient temperature are plotted versus the electric field strengths E_1, and E_2, respectively, the shape-parameter β of (5) can be calculated from

$$\beta = \frac{\log\left[\ln(1-P_1)/\ln(1-P_2)\right]}{\log E_1 - \log E_2} \tag{10}$$

On the basis of the known parameters n & β, the thermal coefficients b & B of (4) can be obtained by an aging test at two different temperatures. This can be realized by the application of an electrical stress, which leads to the electrical breakdown when the electrical component is aged by temperature. These parameters are summarized in Table II. In most cases, no change of these parameters is to be expected under service conditions as long as the material properties do not significantly change.

The models characterized by four parameters, i.e. n, b, B, and β, provide the lifetime of an electrical component shown in Fig. 3. In the case of the combined electrothermal stresses, the three-dimensional lifetime can provide the electrical life lines at $T=0$, or the thermal life lines at $E-E_0=0$, which follow the Inverse Power Model, or the Arrhenius Model, respectively.

For the estimation of the aging behaviors of electrical components, the failure probability is described versus the lifetime L in (8). By a repeated coincidental trial, the failure probability of an electrical component appropriately follows the distribution function $F(t)$, which is specified as a cumulative effect of failure probabilities. As long as the variable t is larger than the lifetime L, failures will immediately occur. Therefore, the failure effects can usually be described by the continuous variable t rather than by the discontinuous lifetime L.

$$F(t) = P_m(L \le t) = \sum_{\Delta t_j \le t} P_m(L = \Delta t_j) \tag{11}$$

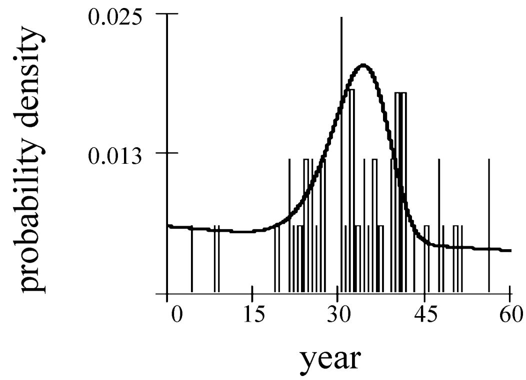

Fig. 4. Conductor: calculated (full line), and statistical probability densities of failure.

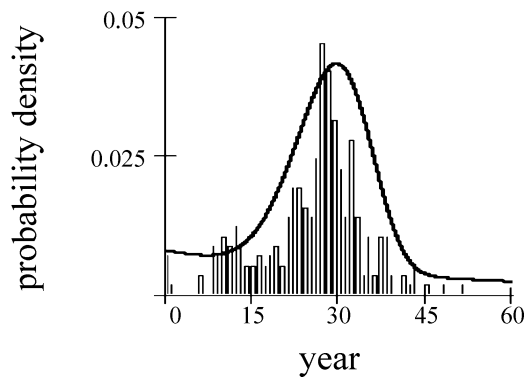

Fig. 5. Cable: calculated (full line), and statistical probability densities of failure.

Sometimes the failure probability is confronted with the continuous variable within a certain interval, i.e. the probabilistic failure density $f(t)$. The probabilistic failure density, and the hazard rate $h(t)$ are determined by the distribution function $F(t)$ of failure:

$$f(t) = \frac{dF(t)}{dt} \tag{12}$$

$$h(t) = \frac{1}{1-F(t)} \cdot \frac{dF(t)}{dt} \tag{13}$$

For electrical components, the hazard rate and the probabilistic failure density are the most important criteria besides the failure time. The hazard rate and the probabilistic failure density allow electrical components in different asset classes to be compared with each other, and to make reference to several criteria like age, number of operation, time between events, etc. Whatever criteria for assessment are chosen, proper maintenance activities can be performed.

The calculation method of the probabilistic failure density is demonstrated by some electrical components, e.g. conductors, cables, transformers, and circuit-breakers for 60 years (100 years for conductors). Figs. 4–7 present the results of the theoretical modeling as described above, and of the operational experience documented in a failure statistic [23].

For the comparison of the probabilistic failure densities, the calculated results for electrical components are shown in Fig. 8. Based on these data, the hazard rates of electrical components in Fig. 9 can be obtained by using (13). For a calculation, the

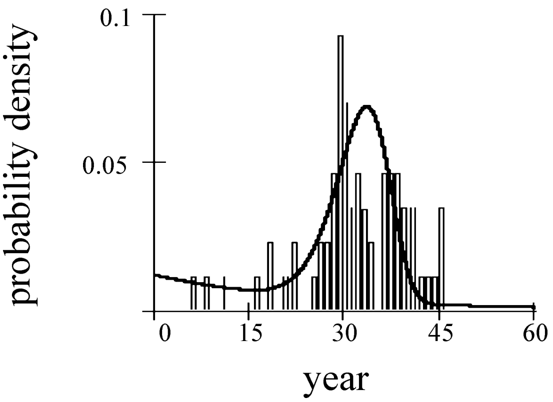

Fig. 6. Transformer: calculated (full line), and statistical probabilities of failure.

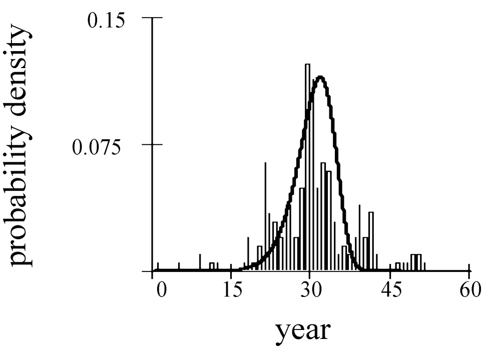

Fig. 7. Circuit-breaker: calculated (full line), and statistical probabilities of failure.

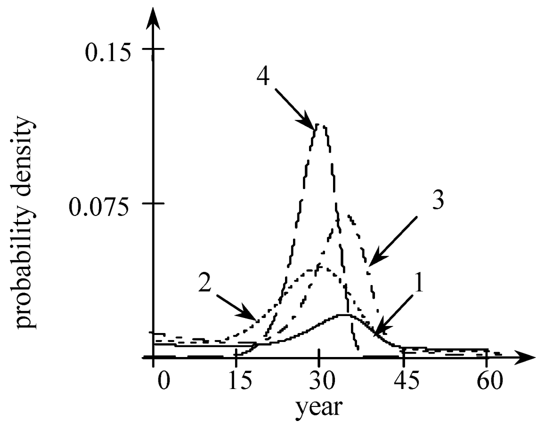

Fig. 8. Calculated probability densities of failure. 1—conductor; 2—cable; 3—transformer; 4—circuit-breaker.

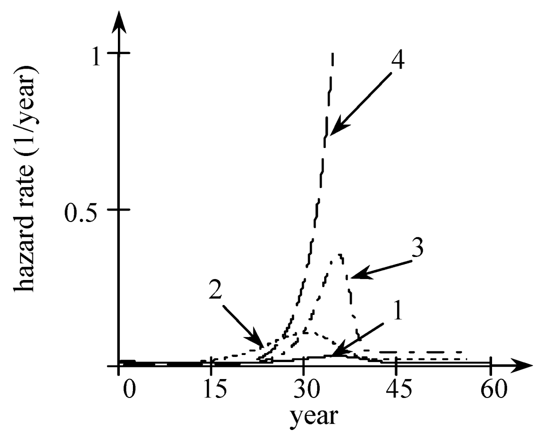

Fig. 9. Calculated hazard rates. 1—conductor; 2—cable; 3—transformer; 4—circuit-breaker.

characteristic parameters of (6) are determined on a model conductor, and on a model cable. With the enlargement law of (8), the total probability densities of failure, and the hazard rates for conductors and cables of 1 km, can be calculated.

For many practical problems, the Weibull-distribution is taken as a suitable model to describe the accidental failure of electrical components. The Weibull-distribution represents the uncertainty of failure exactly, at least if the failure probability results from a large number of independent failure events. For instance, the maximum probabilities of failure for conductors, cables, transformers, and circuit-breakers are about 8%, 9%, 14%, and 0.1% for the first 15 years; and approximately 21%, 50%, 42%, and 60% for 30 years, respectively. At early stages of operation, transformers have higher failure probabilities, and are problematic in networks. Of course, these problems are quickly remedied by manufacturers with technology changes.

From Figs. 4–7, the expected average lifetimes of electrical components can be estimated to be about 25, 22, 30, and 29 years for conductors, cables, transformers, and circuit-breakers, respectively. This is in line with the findings based on considerations about the critical physical phenomena, and investigations of the statistical long-term performance.

As shown in Fig. 9, the hazard rates of circuit-breakers are constantly low during the first several years of operation. Because circuit-breakers suffer from the switching actions during operation, their hazard rates rise over years according to the increasing right wing of the well-known "bathtub curve" after about 20 years of operation. Contrary to this fact, the hazard rates for conductors and cables are randomly distributed over the total operational time. The average hazard rates in this case are 0.01, and 0.028 failures/year which obviously does not exceed the hazard rates of other electrical components.

In comparison to the other probability densities and hazard rates, the probability density of circuit-breakers is narrow, and high because the total area under the curve is equal to 1 (i.e. a probability of 100%). The aging phenomena of circuit-breakers due to frequent operation cause a steep increase of the hazard rate at the end of life, thus indicating an impending failure, and showing the strong influence of aging on failures.

In the case of transformers, the influence of corrective maintenance can be seen. Due to regular maintenance, an extreme increase of the hazard rate can be avoided. Consequently, the peak value of the probabilistic failure density for transformers is lower than for circuit-breakers.

The failure behavior of conductors, and of cables differs from the increasing hazard rate. It has to be noted that the failures of conductors, and of cables are caused mainly by stochastic events, e.g. storm, and excavator work, whose hazard rates are constant. In the case of a grounding fault, the failure reason for cables is dominantly the decrease of the electric strength of insulating materials. The temporary peaks of the hazard rates are

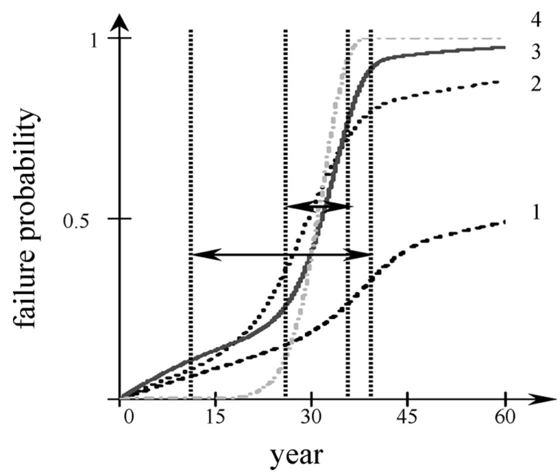

Fig. 10. Calculated failure probabilities. 1—conductor; 2—cable; 3—transformer; 4—circuit-breaker.

caused by the aging of materials as well as the device replacement. At about 30 to 35 years, those aged conductors and cables are exchanged. In comparison to cables, the peak value of the probability density is lower for conductors, and declines over time.

Now the influences of stresses on the probabilistic failure densities, and on the hazard rates of electrical components can be investigated. With declining stress and low temperature, the probabilistic failure densities are broader, and the slopes of the hazard rate decrease just as for conductors and transformers. In contrast to this, cables operate at a poor ambient, and circuit-breakers have worse stresses. At comparable probability densities of failure & hazard rates, conductors, and transformers reach the end of their lives after a longer operating period compared to cables, and circuit-breakers, respectively. The reason for this longer life is that conductors and transformers have a lower load, resulting in reduced stresses.

An integral over the probabilistic failure density is the cumulative probability distribution of failure in Fig. 10. The curves indicate the failure probabilities from 0 to 60 or 100 years. Therefore, all surfaces below the various curves correspond to a probability of 100%. From the cumulative probability distribution, some necessary information describes that failure risks are quantified in dependence on the operating time. For example, if the confidences of the failure probability are limited between 10% and 90%, then the ranges of aging times for transformers, and circuit-breakers are given from 10 to 38 years, and from 25 to 35 years, respectively.

It can be clearly seen that, for a certain period, the system reliability performance is not affected. However, as soon as electrical components are overstressed, and the aging effects become visible, there is a general increase in the hazard rate with time. This proves that all further failures are stimulated, and the decrease of reliability is thus very sharp. These results presented in Figs. 8, 9 and Fig. 10 show that cables have more failure risks than the conductors, and the circuit-breakers have more failure risks than transformers; thus maintenance strategies should be taken to prevent premature damages.

VII. Conclusion

As part of the technical asset management, an advantageous method has been developed for the purpose of assessing the actual condition of electrical components, and the reliability of distribution networks.

Typical aging processes of electrical components are considered to be due to electrical, thermal, and mechanical processes. Therefore, the aging processes are transferred into a life model, which is represented by the Inverse Power Model, and the Arrhenius Model. In reliability calculations of medium-voltage networks, the multi-model resulting from the life model, the probabilistic failure model, and the enlargement law is applied to provide effective predictions of the failure probability, and the hazard rate of electrical components of medium-voltage networks.

The calculation method of the failure probability is demonstrated by some electrical components in distribution networks. These results confirm the validity both of the proposed models, and of the calculation method.

The increasing hazard rate of circuit-breakers due to the aging phenomena can be calculated. This proves that all further failures are stimulated, and the decrease of reliability is very sharp.

Due to low temperature or declining stress, conductors or transformers have the broader & lower probability densities of failure than cables or circuit-breakers, respectively.

From the failure behaviors of conductors and cables, it can be concluded that failures are mainly caused by stochastic events whose hazard rates are constant.

In this way, it is possible to estimate the reliability of electrical components, and to assess the electric power systems with reasonable, accurate data.

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