EVALUATION OF FAILURE DATA OF HV CIRCUIT-BREAKERS FOR CONDITION BASED MAINTENANCE

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SUMMARY

Permanently new ideas are investigated to optimize maintenance strategies and measures to reduce expenses with constant quality of power supply. Therefore most German network operators attempt to expand the time interval of maintenance. The overall question is how long such intervals for electrical equipment can be expanded without reducing the quality of power supply? In this report a new method is presented which evaluates the future failure frequency coming from disturbance statistics of equipment. It is a direct anticipation from results, how long maintenance intervals can be extended by a tolerated failure frequency.

In a first step high voltage circuit-breakers are assessed and the data base consists of about 8600 items. The history of the circuit-breakers are recorded over the complete life time, so the maintenance measures and the failures could evaluated.

Keywords: Circuit-breaker, failure rate, maintenance

1. INTRODUCTION

Electrical equipment in power transmission and distribution systems are essential for the load flow, to protect other equipment and persons in case of failures. Therefore high requirements for performance and availability are mandatory for these equipment. To secure these properties during total lifetime, extensive maintenance strategies have to be applied.

The terms from area of maintenance follow the definitions in the German standard specification DIN 31051. The most important terms for this report are explained again:

- Inspection: Measures of ascertainment and estimation of actual state of technical equipment
- Service: Measures of preservation of target state of technical equipment
- Replacement: Measures of restoration of target state of technical equipment
- Maintenance: Measures of preservation and restoration of target state as well as measures of ascertainment and estimation of actual state of technical equipment

There is a trend since some years to change the maintenance strategy: Starting with the time based strategy with fixed and short maintenance intervals and for example an assumed time of replacement of 35 years, the utilities try to apply the conditioned based strategy or in the opposite to this to extend the time intervals of the inspection or service depending on the type of circuit-breaker or drive. The
overall problem is to get the experience of the optimum time intervals what is the best suited measure without accepting a higher risk of failures.

Maintenance measures can only be optimized and special strategies can be created, if data about previous events (disturbances and/or maintenance measures) are known. These events should be collected in disturbance statistics by each network operator. These disturbance statistics should contain time of the failure event, type and reason of the failure.

This report presents a method to handle the collected disturbance data so that not only the previous ageing behavior of equipment but also the future ageing behavior can be shown. This new method is exemplary applied to about 8600 HV circuit-breakers ($U_r > 100 \text{ kV}$) with about 6800 failures.

2. FAILURE FREQUENCIES OF EQUIPMENT

The failure frequency of various equipment classes is an important criteria besides the analysis of the failure location. The failure frequency of equipment classes allows comparisons of failures of different equipment and makes reference to several criteria like age, number of operations, time between events etc. Whatever criteria for evaluation is chosen, different statements about previous and future maintenance activities can be achieved. For the estimation of ageing behavior of different equipment, age as criteria is chosen, i.e. all failure frequencies are calculated and illustrated versus age.

In general various ageing patterns can be differentiated according to Figure 1 [1]:

- Teething: describes pure teething problems or burn-in problems which are reduced by progressed operating time
- Wearout: describes wearout problems which are increased by progressed operating time
- Operational: describes problems which appear due to operation
- Ageing: describes common ageing phenomena independent of operation
- Random: describes random problems which do not depend on age or operation
- Bath-tub: is a combination of teething problems and wearout

![Figure 1: Different pattern of failure frequency](image)

The aim of the method for the evaluation of the ageing behavior of electrical equipment is to find a combination of the five elementary and independent behavior patterns, the summation of which must have the minimum deviation (least square method) from the disturbance data. Figure 2 shows the main principle of this method, which is described in detail in [2].
3. DATA BASE OF CIRCUIT-BREAKERS

The complete data base of the evaluated circuit-breakers is listed below regarding type of insulation, arc extinguishing medium and drive (absolute values and percentage):

Type of insulation:  
- air blast: 1357 (15.9 %)  
- minimum oil: 3014 (35.2 %)  
- SF$_6$: 4184 (48.9 %)

Type of drives:  
- pneumatic: 1701 (19.9 %)  
- hydraulic: 3985 (46.6 %)  
- mechanic: 2869 (33.5 %)

In total 8555 circuit-breakers are considered with different insulation material and drives. The age distribution of the circuit-breaker is presented in Figure 3. First installations were in the sixties, most of the pieces of equipment were installed during the seventies, and since the beginning of the last decade the investments were reduced. The average age of the different types of circuit-breakers can be estimated to:

- air-blast: 38.9 years  
- minimum oil: 31.2 years  
- SF$_6$: 14.9 years.

During the last fifty years 6776 events are recorded which are related to the total circuit-breakers population. Table 1 shows the number of disturbances according to the different components: high voltage/insulation - drive – secondary and auxiliary circuits -others. The recorded data involve major as well as minor failures and the values are received from the data bases of the transmission utilities. It has to be stated that the portion of high voltage/insulation failures in case of SF$_6$ circuit-breakers are mainly driven by leakage problems and not due to failures at the live part components of the circuit-
breakers. The listed failures in any case led to a reaction of the service department, so these data are relevant to estimate the optimal service time.

Figure 3: Age distribution

<table>
<thead>
<tr>
<th>c.b. section</th>
<th>type of circuit-breaker</th>
<th>SF6</th>
<th>minimum oil</th>
<th>air-blast</th>
</tr>
</thead>
<tbody>
<tr>
<td>high voltage/insulation</td>
<td>67.7</td>
<td>41.8</td>
<td>29.3</td>
<td></td>
</tr>
<tr>
<td>drive</td>
<td>19.1</td>
<td>42.8</td>
<td>39.8</td>
<td></td>
</tr>
<tr>
<td>secondary &amp; auxiliary circuits</td>
<td>11.5</td>
<td>12.7</td>
<td>23.9</td>
<td></td>
</tr>
<tr>
<td>others</td>
<td>1.7</td>
<td>2.7</td>
<td>7.0</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Failure distribution of different types of circuit-breakers as percentage

4. FAILURE FREQUENCY OF CIRCUIT-BREAKERS

Due to the importance for maintenance strategies and the existing data base circuit-breakers with SF\textsubscript{6} and minimum oil insulation are considered only. Figures 4 (above, minimum oil) and (below, SF\textsubscript{6}) shows the failure frequency versus the age of the circuit-breakers in total. A clear trend of the failure behavior of minimum oil type is obvious, that means after 10 and up to 25 years of installation, the failure rate exceeds the mean value of 1.9 failure/100 c.b. and year. On the contrary to this fact the failures for SF\textsubscript{6} circuit-breakers are randomly distributed over the total installation time and in this case the mean failure rate is 6.0 failure/100 c.b. and year, which exceeds the failure rate of the minimum oil type. For information the failure rate of the air-blast c.b.'s is 2.6 failure/100 c.b. and year but this value is not comparable with the others (see Chapter 5).

Due to the fact, that maintenance activities are applied during the installation time, it makes sense to evaluate the failure frequency depending on the "event-free time" of a circuit-breaker. Events may be failures, tests, services, maintenance measures or commissioning. So there are neither failures nor any maintenance or live-extension measures during event-free time. Such type of illustration is specially suitable to get statements like how long components can operate without maintenance measures, so that the relative failure frequency of component is not influenced by any activities [3].

Furthermore the two most important components of the circuit-breaker are considered separately according to Table 1: high voltage/insulation and drive. In addition the evaluations concentrate only upon SF\textsubscript{6} and minimum oil circuit-breakers due to the low number of air-blast circuit-breakers.
Figure 4: Failure frequency in total of minimum oil (above) and SF\textsubscript{6} circuit-breakers (below)

The figures 5 to 9 show on the left hand side the failure rate of the samples versus event free time. On the right hand side the pattern curves are plotted separately, which fit best to the samples. Finally the different regression curves are summed up and the result is plotted in the figures on the left side again, which shows the overall curve. Due to the reduced number of failures of SF\textsubscript{6} circuit-breakers with mechanic drives these components are not considered. The maximum time range, which is recorded, is for example 17 years (Figure 7), that means during this time no activity is provided at the circuit-breaker.

The Figures 5 to 9 present the following samples:

- h.v. components of 4184 SF\textsubscript{6} circuit-breakers with 3163 failures (Figure 5);
- h.v. components of 3014 minimum oil circuit-breakers with 2206 failures (Figure 6);
- 3473 hydraulic drives of SF\textsubscript{6} circuit-breakers with 1734 failures (Figure 7)
- 1072 hydraulic drives of minimum oil circuit-breakers with 674 failures (Figure 8)
- 2270 mechanic drives of minimum oil circuit-breakers with 95 failures (Figure 9)

The principle procedure is explained using Figure 7: In this case there are three overall curves to derive the least deviation from the mean value of the samples:

- combination of teething, random and wearout behavior.

The final result of the evaluation is, that teething problems seem to be the main reason for the failure rate of components. That means the probability of a failure event is high in the same year as maintenance activities have taken place. This distinct behavior can obviously be seen in case of hydraulic drives in the opposite to mechanic drives. The same failure frequency pattern can be deduced from the behavior of the high voltage components of circuit-breakers. The hydraulic drives of SF\textsubscript{6} circuit-breakers show a wearout problem after 13 years due to the long recorded time period of 17 years, but no ageing phenomena can be detected. In contrast to this a clear ageing and minor teething prob-
lems are observed in case of the mechanic drives of minimum oil circuit-breakers, but the observed event free time is reduced compared to hydraulic drives. The second class of failure behavior is the random pattern, that means the failure occur constantly over the considered time period.

Figure 5: High voltage components of SF₆ type circuit-breakers

Figure 6: High voltage components of minimum oil circuit-breakers

Figure 7: Hydraulic drives of SF₆ circuit-breakers
5. ASSESSMENT OF THE RESULTS

Comparing minimum oil and SF6 breakers the different technical boundary conditions should be considered:

- Minimum oil circuit breakers reached their maximum performance per interrupting unit in the mid seventies with approximately 145kV/31.5kA. Major manufacturer stopped then development activities and minimum oil technology was replaced by SF6 technology.
- SF6 units reach now 300kV/63kA or even more. From the mid seventies on SF6 technology is the dominating technology.
- In addition to that requirements from the grid and consequently from the standard side have increased: short circuit current, capacitive current switching, electrical and mechanical endurance, type testing and so on. These additional requests may lead to higher stresses for components of SF6 circuit breakers compared to those of minimum oil devices.

Mechanic and hydraulic drives can be characterized by following aspects, which can be described as follows:

Figure 8: Hydraulic drives of minimum oil circuit-breakers

Figure 9: Mechanic drives of minimum oil circuit-breakers
- Hydraulic drives are complex; require high quality and perfect material. These aspects are some times difficult to check during production and commissioning. On the other hand only a few parts are moving ones and because of natural greasing by hydraulic oil wear is low.

- Mechanic drives are easier to check during production and commissioning. Nevertheless the high number of parts (many of them moving), grease that may disappear, increasing friction, and mechanical deformation, may increase wear over age.

- As a consequence hydraulic drives have more teething problems and show less ageing behavior

- In addition it has to be mentioned that in many applications hydraulic drives are used to operate heavy SF₆ breakers e.g. puffer breakers for 50-100 kA, whereas mechanic spring drives are mainly used to operate breakers which need less drive energy like SF₆ self blast breakers.

As a result of the evaluation it can be stated that in many cases the maintenance interval can be extended depending on the type of circuit-breaker, especially on the type of drives in use. Due to the teething problems, which are relevant for high voltage components as well as for hydraulic drives, the maintenance measures should be performed more carefully. Furthermore it is recommended to monitor the condition of components. As a consequence the possibilities of manual interventions on the circuit-breakers thus increasing the risk of teething problems can considerably be reduced. Regarding the hydraulic drives it is obvious that the maintenance intervals can be extended up to 12 or 15 years. Whereas the interval of a mechanic drive should be about 10 years. But due to the low number of recorded failures this value is a rough estimation.

In principle the network operator has to make sure that the failure rate does not exceed the level he is willing to accept. The main goal is to observe the failure behavior continuously and built up a proper data collection it is also necessary to define levels of importance at any point where a circuit breaker is installed [4]. From the correlation between failure behavior and mentioned levels the network operator can define the risks depending on the time interval of maintenance and can decide which risk level at the different system points is acceptable. Together with the relation between maintenance costs versus new equipment costs it will be possible to find a reasonable time for replacement.

6. CONCLUSION

By using the discussed evaluation method it is possible to recommend maintenance intervals for condition based maintenance. This method was applied to calculate the intervals for high voltage circuit-breakers of SF₆ and minimum oil type with hydraulic and mechanic drives. Teething problems are the most often observed failure pattern whereas ageing phenomena of the high voltage component could not be detected up to 15 years. In a next step this procedure will be applied für power transformers.

7. REFERENCES