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**Maintenance scheduling according to reliability targets and actual equipment performance**

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A method of optimising the lengths of period between maintenance has been developed taking into account targeted reliability and annual equipment performance. Process of privatisation urges the new distribution companies to rationalise maintenance in order to achieve targeted performance in terms of system interruption frequency and system interruption duration at a minimum cost. One of the most efficient ways to keep the cost down is rational maintenance i.e. optimising lengths of period between planned maintenance.

Maintenance, in general, is divided into preventive and corrective maintenance. Due to low budget or shortage of staff and skills, most utilities extended the periods between maintenance from the manufacturer’s recommendation. As a result of this the system performance has usually deteriorated and the risk of equipment failure has increased. More careful scheduling, based on priority of elements to be maintained could, however, improve the system performance.

An example of maintenance scheduling for a group of circuit breakers described in the paper. The lengths of maintenance periods for the circuit breakers (CB) groups are based on the targeted and actual breakers performance. The CBs throughout the system are divided into several groups according to the required reliability. Targeted failure rates for the CB groups would be taken from a separate reliability study throughout the system. The starting length of the period between maintenance checks is the manufacturer’s recommendation. The first revision of the period between the maintenance is after the first maintenance check. If the performance of CBs in that interval was high and the targeted reliability has not been changed, the period of maintenance could be extended. However, there is a maximum period of extended maintenance when minimum maintenance or check must be performed.

An important element in the calculation, constant performance monitoring, ensures that the overall performance of CBs, on an annual basis, does not require earlier maintenance scheduling. The model re-adjusts scheduling of maintenance for each group. As most of electrical systems change configuration during the equipment lifetime, the model has an option to set new Mean Time Between Failure (MTBF) target and define the priority list of CBs to be maintained.

The method, therefore, provides guidelines to maintenance scheduling accounting for two major factors: targeted MTBF for each CB and actual equipment performance. This method can be extended for other equipment such as cables, transformers, protection etc. as well as transmission systems.
MAINTENANCE SCHEDULING ACCORDING TO RELIABILITY TARGETS & ACTUAL EQUIPMENT PERFORMANCE

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ABSTRACT

Maintenance scheduling of circuit breakers according to their reliability targets and actual performance has been considered. A model was developed to calculate maintenance intervals between two preventive maintenance checks. Relationship between the reliability targets, actual performance, maintenance intervals and preventive maintenance costs is discussed and established.

INTRODUCTION

Maintenance is a combination of all technical and administrative actions, intended to retain or restore equipment in a state in which it performs a required function.

In general, maintenance consists of preventive and corrective maintenance [5]. The first one is planned in advance and mainly covers regular checks and replacement of parts according to manufacturer’s recommendations. It comprises maintenance intervals that are evenly spread over the lifetime of the equipment.

The corrective maintenance is applied if a failure of equipment was detected and specific work is required to be done. In some extreme cases of fatal failure, replacement of the failed equipment may be the only option [1]. Maintenance could be improved by optimising the length of maintenance interval between two maintenance checks. The maintenance intervals would be scheduled accounting for actual equipment performance and Mean Time Between Failures (MTBF) targets.

However, extending the maintenance intervals without a detailed analysis is likely to result in the network performance deterioration with increased risk of equipment failure.

MAINTENANCE SCHEDULING MODEL FOR CIRCUIT BREAKERS

Distribution companies have widely adopted the method of scheduling the preventive maintenance according to the manufacturer’s recommendations. Low budget and shortage of staff and skills in the recent years imposed considering other approaches to maintenance.

The process of privatisation also urges the distribution companies to rationalise maintenance in order to achieve targeted performance in terms of system average interruption frequency and system average interruption duration at minimum cost.

The key factors to optimise the maintenance are considered to be ‘required (targeted) reliability’ and ‘actual performance’.

A mathematical model has been developed for a group of circuit breakers to analyse the impact of reliability targets and equipment performance on maintenance. The model considers a group of fifty circuit breakers of the same type and the same manufacturer.

The circuit breakers are located across the network at various locations. A typical part of the network is represented in Figure 1.

![Figure 1: Typical part of the network](image-url)
a different MTBF requirement that can be calculated for each element. Required reliability of a network element depends on the consequences of its failure. It is also dependent on CB location in the network, existence of parallel elements, nature of the load to be supplied, etc. [3].

MTBF targets in Table 1 have been estimated for the circuit breakers on Figure 1. The high MTBF of 18 years is associated with the CB6 where no redundancy in terms of additional breakers is provided. CBs in parallel lines such as CB 1 and 2 could have lower MTBF, while some CBs can have low MTBF requirement simply because they feed less important load and consequences of failure are not significant.

Table 1: MTBF target for model circuit breakers

<table>
<thead>
<tr>
<th>Circuit breaker (designation)</th>
<th>MTBF Target (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CB1, CB2, CB4, CB5</td>
<td>12</td>
</tr>
<tr>
<td>CB3, CB7, CB10</td>
<td>15</td>
</tr>
<tr>
<td>CB6</td>
<td>18</td>
</tr>
<tr>
<td>CB8</td>
<td>5</td>
</tr>
<tr>
<td>CB9</td>
<td>8</td>
</tr>
</tbody>
</table>

MAINTENANCE & MTBF TARGET

The model is set to calculate recommended maintenance intervals from 1990 throughout the equipment expected lifetime. The performance of the equipment in the last ten years has been taken into account on an annual basis providing the actual expected MTBF. For the comparison purpose, the performance in this example has been assumed the constant through the lifetime of the equipment. Maintenance interval is calculated on annual basis for each CB. The calculation is based on the actual performance of the equipment (using the updated failure rate) and MTBF target i.e. expected performance for each CB.

The maintenance interval is then recalculated accounting for the manufacturer’s recommendations on maintenance and reliability. The corrected maintenance intervals are shown in Figure 2.

The calculated maintenance interval for the CB8, which has a MTBF target of 5 years, is increasing through the life cycle reaching the maximum of 7.7 years near the life end. On the contrary, the maintenance interval for CB6, which has the MTBF target of 18 years approaches the maximum of 2.1 years close to the beginning of the life cycle. For circuit breakers with lower MTBF target the maintenance interval is increasing approaching the maximum near the end of the life cycle. The maintenance interval for circuit breakers with higher MTBF target reaches the maximum at the beginning of the life cycle and remains constant through the rest of the life.

Once the maintenance intervals have been calculated and corrected for the manufacturers requirement, the actual expected MTBF can be checked for each CB. For the assumed constant actual performance throughout the lifetime of the equipment, the calculated MTBF for the circuit breakers with different MTBF target is shown on Figure 3.

The calculated MTBF values are generally below the starting MTBF value that is based on a generic data and the statistics representing the expected reliability of the equipment.

The maintenance interval for the considered breakers varies from 2 years to 7.7 years depending on an individual MTBF targets as in Figure 3. Defining the MTBF target for various circuit breakers in the network has therefore an impact on the maintenance intervals and consequently on maintenance costs. Figure 4 shows the relation between the targeted reliability and the length of periods between the maintenance.

Figure 2: Calculated maintenance interval for circuit breakers with various MTBF target

Figure 3: Calculated MTBF for circuit breakers with various MTBF targets

Figure 4: shows the relation between the targeted reliability and the length of periods between the maintenance.
Increasing the interval between two maintenance checks will reduce the number of checks for the life cycle of the circuit breaker. This will consequently reduce the maintenance costs.

The lower the MTBF target, the longer the maintenance interval is. The lower the number of maintenance checks, the lower the maintenance costs are.

In the following example for MTBF target of 10 years, the maintenance time is increased to approximately 4 years. This would halve the number of maintenance checks compared with the initially recommended maintenance time of 2 years, and consequently reduce the maintenance costs.

![Figure 4: Calculated maintenance interval for circuit breakers with different performance](image)

Relation between the MTBF target, maintenance interval and number of preventive maintenance checks for circuit breaker life cycle is shown in Table 2.

Table 2:

<table>
<thead>
<tr>
<th>MTBF target</th>
<th>Maintenance time</th>
<th>Number of maintenance in the lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>7.7</td>
<td>5.19</td>
</tr>
<tr>
<td>8</td>
<td>4.8</td>
<td>8.33</td>
</tr>
<tr>
<td>12</td>
<td>3.1</td>
<td>12.9</td>
</tr>
<tr>
<td>15</td>
<td>2.5</td>
<td>16</td>
</tr>
<tr>
<td>18</td>
<td>2.1</td>
<td>19.04</td>
</tr>
</tbody>
</table>

The MTBF target and preventive maintenance costs required for the life cycle of circuit breakers is illustrated in Figure 5.

![Figure 5: Maintenance cost vs. MTBF target](image)

For the lower MTBF targets, as illustrated in Figure 5, the preventive maintenance costs get lower as a result of reduced number of preventive maintenance checks.

The MTBF targets should be set up according to the network reliability analysis. The values set lower than in the reliability analysis would result in decreased element reliability as well as faster equipment deterioration leading to additional costs.

**MAINTENANCE & PERFORMANCE**

Circuit breaker performance influences the length of interval between two maintenance checks. The model was evaluated with the same MTBF target but different failure rates for the circuit breaker group. The actual failure rate for each year was calculated considering the generic failure rate and the previous years performance. The performance of the equipment should comprise both active and passive failures identified during the maintenance checks. Three cases have been considered in the analysis. The first one with excellent performance i.e. performance failure rate of 0%, the second one with the average performance failure rate of 5% and the third one with bad performance i.e. failure rate of 10%.

The calculated maintenance interval for the above cases is shown in Figure 6.

Figure 6 indicates that the calculated maintenance interval varies slightly for the cases considered, although the breaker performance varies significantly.
The calculated maintenance interval for the three considered cases varies from 2.45 to 2.75 years. The calculated MTBF for the considered circuit breaker performances also does not change significantly, but only varies slightly as shown in Figure 7.

Preventive maintenance costs, therefore, can only be slightly corrected for a significant improvement in the circuit breaker performance. In order to improve the performance of the equipment, continuous monitoring could be applied [2]. The on-line condition monitoring can monitor the breaker performance, alarm all abnormal states and help in future maintenance scheduling.

It appears from the analysis that significant costs would be required to achieve high performance of the breakers [4]. On the other hand, the saving in the preventive maintenance costs to achieve that performance may not be justified.

Figure 6: Calculated maintenance interval for different CB performances

Figure 7: Calculated MTBF for different CB performances

CONCLUSION

The model described in the paper calculates the maintenance interval for each individual circuit breaker. The calculation takes into account the MTBF target for the particular breaker and the actual performance of the associated CB group. The analysis shows that the length of interval between two maintenance checks largely depends on the MTBF target. Maintenance cost of preventive maintenance is consequently dependent on the MTBF target. The calculated maintenance cost is lower for lower MTBF target. The actual performance of the equipment can change the length of maintenance interval. However, considering the assumptions in this report, there would be no significant impact on maintenance scheduling. More reduction in maintenance costs can be expected through setting the correct MTBF targets for the circuit breakers, compared to the traditional approach of all circuit breakers having the same MTBF target throughout the network.

REFERENCES