MAINTENANCE AND REFURBISHMENT STRATEGIES FOR M.V. SUBSTATIONS

G. Balzer; O. Schmitt; M. Halfmann; A. Hößle
Darmstadt University of Technology; ABB Calor Emag; ABB Calor Emag; Pfalzwerke AG,
(Mannheim) Schaltanlagen AG; Schaltanlagen AG; Ludwigshafen (Germany)

SUMMARY

This paper shows the principles of the developed reliability-centered maintenance strategy (RCM), which takes into account the condition of the equipment and the importance of the equipment in the network.

The condition of the equipment can be evaluated on the basis of different criteria. The importance describes the consequence of the equipment failures on the network and the economic. As a result the RCM-strategy leads to the conclusion which equipment has to be maintained first.

Besides the theoretical principles of this RCM-strategy the authors describe the experience in Germany.

It makes sense to embed the described procedure in a financial management system and to develop a software tool. The general data and measurements of the process (e. g. substation) should fed into the program to assess the condition and the importance of the equipment. Whereas the main data of the equipment (e. g. type, manufacturer, year) are already listed in network information systems. These values have to be directly imported to the software tool. After the overall assessment a ranking of the equipment will be calculated and the responsible engineer has to handle the order via a commercial software tool.

Keywords: Maintenance Strategies - Condition - Importance - Life Cycle
1 INTRODUCTION

Facing the competitive environment the utilities are forced to rethink their maintenance strategies. Economic considerations point out the need for the calculations which are capable to extend the lifetime of equipment and substations and allows an economic and reliable life cycle management. On this way one of the important tasks of the utilities are:

- to select the equipment, which should be maintained
- to make a ranking of the equipment.

The ranking of the equipment gives the opportunity to select those which should be maintained first. If the ranking is derived from a reliability-centered maintenance strategy an optimum solution can be stated. In this paper the term maintenance also covers the replacement of equipment as e.g. necessary for renovation. Whereas paper /1/ describes the principal approach to develop a maintenance strategy for m.v. substations, this report is dealing with the presentation of an assessment, which was performed in the past.

2 MAINTENANCE STRATEGIES

The statistics of German utilities give a rough overview of the age of the equipment, which are installed in the system. For example assuming that the useful lifetime of a circuit-breaker will be about 35 years the new installations of each year can be divided in two parts:

- extension of the system
- replacement of old circuit-breakers.

If a calculation is performed for the main voltage levels in Germany, the average age of the circuit-breakers are as follows:

<table>
<thead>
<tr>
<th>Voltage (kV)</th>
<th>Average Age (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>17.0</td>
</tr>
<tr>
<td>20</td>
<td>20.5</td>
</tr>
<tr>
<td>110</td>
<td>18.2</td>
</tr>
<tr>
<td>220</td>
<td>22.0</td>
</tr>
<tr>
<td>380</td>
<td>15.8</td>
</tr>
</tbody>
</table>

The higher age of the 220 kV c.b. demonstrates the less importance of this level in the transmission system of Germany

Several maintenance strategies are mainly used or in discussion in electrical systems (figure 1) /1/ - /6/:

- corrective
- time-based
- condition-based
- reliability-centered

In a corrective maintenance (CM) strategy, replacement or repair is performed only if a failure occurred. In the case of equipment where investment costs are low and a fault will have only a minor effect, this procedure may result in the lowest overall costs. This strategy will be mainly used in systems with lower voltages. Only severe failure on certain type of equipment will influence the procedure.

A time-based maintenance (TBM) strategy featuring predefined intervals rooted in empirical feedback, where components are replaced after a specified period of use, has been practised as the usual maintenance strategy in electrical power systems for many years. This approach generally produces satisfactory results. It will not, however, be the most cost-effective option in all cases, since the equipment will not usually remain in operation up to the end of the lifetime which is possible.

Since some years, however, there has been a developing shift away from time-based maintenance and towards condition-based maintenance (CBM). Condition-based maintenance is driven by the technical condition of the equipment. Under this approach, all major parameters are considered in order to determine the technical condition with maximized accuracy. For this reason detailed information via diagnostic methods or monitoring systems should be available.

A fourth strategy, which additionally include a reliability-based component, has been under discussion recently, and some applications are already in use /7/. The aim of this approach is to include the influence on the importance of the equipment in the network and the actual condition of the equipment. A maintenance strategy is referred to in this paper as reliability-centered maintenance (RCM) and it has to be noticed that this RCM-method is different considering other RCM-applications which consider equipment only.

Figure 1 demonstrates the main conclusion of the different maintenance strategies mentioned above, depending on the two criteria: importance of the equipment considering the network and the condition. The presented evaluation of maintenance strategies including
the influencing factors gives a hint to the expense for applying a certain strategy.

Figure 1: Evolution process of maintenance strategies

Without a doubt, the RCM strategy offers definite advantages, since besides the condition of an equipment or a system, its importance in the network also crucially influences the maintenance action required. It clearly emerges that network reliability can be upgraded by correct selection of the equipment for maintenance. These equipment will be maintained which have the main influences of the network reliability

3 RELIABILITY-CENTERED MAINTENANCE

A reliability-centered maintenance strategy, which combine the two aspects of condition and importance, requires the following procedure:

- The condition of the equipment has to be determined.
- The importance of the equipment for the network as a whole must be determined, e.g. the influence of equipment failure on the reliability of supply.
- Both information inputs must be combined and evaluated in order to specify the optimum sequence of maintenance work for the individual devices (equipment, substation).

The condition of the total m.v. substation has to be derived combining the condition of the single items of the asset, for example bays, circuit-breakers, instrument transformers, secondary equipment and so on. The condition, e.g. of a circuit-breaker, can be evaluated on the basis of different criteria for example:

- age
- type of circuit-breaker
- number of short-circuit interruptions
- number of switching operations
- experience with this type of circuit-breaker
- measurement results
- know-how of the service department and so on.

In general the condition of a circuit-breaker has to consider the different experiences and failures which were caused by the equipment. Statistical informations are a basis for this analysis comparing the different types of c.b. according to figure 2.

Figure 2: Failures of 100 c.b. per year (primary equipment)

In addition, rating and weighting factors have to be applied to take account of the influence of each criterion on the overall value \( c \) (condition) representing the condition of the equipment.

Both reliability-centered and condition-based maintenance strategies require the same data for assessing the condition of the equipment. Of course, many equipment/network-specific data can be collected for evaluation. In practice, however, they must be restricted to the major influencing variables, for which there is actually utilisable information derived from the process, from relevant statistics, or from manufacturer’s documentation. Results are crucially dependent on assessment of the individual criteria involved in evaluating a particular equipment, and the weightings assigned to them.

Defining an substations’s importance and assessing the consequences of a fault basically constitute a practical but also subjectively influenced value. In this context, there are numerous different parameters to be considered, e.g.:

- non-availability of the substation
- failure rate of the equipment
- substation configuration
- interrupted active power
- kind of customers, social impact
- financial payment in case of loss energy.

Figure 3 shows the basic procedure for linking the two assessment criteria:

- condition of the equipment
- importance of the equipment in the network

Both these criteria are combined in an appropriate manner enabling an overall assessment to be arrived at. The overall sequence of maintenance according to figure 3 will lead to a ranking, which equipment has to be maintained first, second, and so on. This will be
expressed using the index \( o \) combining the two aspects which are mentioned above.

\[ \sum \]

**Figure 3:** Procedure for maintenance planning

The procedure is described in the following. After the values for the \( c \) (condition) and \( i \) (importance) parameters have been calculated, the results (crosses) can be listed in an \( X \), \( Y \) system of coordinates, as shown in figure 4. The \( c \) and \( i \) axes are scaled in such a way that the \( c \) and \( i \) values can at maximum assume the value 100.

A large value for \( i \) signifies that the substation concerned is of high importance in the network. The vertical axis represents the condition of the substations concerned, while the horizontal axis reflects its importance in the network. A cross in the top left-hand corner corresponds to a substation which, although in a poor technical condition, would not cause any major consequences if it fails.

**Figure 4:** Interpretation of the assessment result

\[ c \] condition of the substation \n
\[ i \] importance of the substation

By contrast, a cross in the bottom right-hand corner designates a substation which is in very good condition. A failure of this asset would entail substantial consequences for network operation. The distances \( d_1 \) to \( d_5 \) illustrate the sequence in which the individual substation must be serviced or replaced.

4 COMPARISON WITH PREVIOUS PRACTISE

The evaluation levels \( c_M \) and \( c_R \) are entered in figure 5 in accordance with empirical feedback from the network engineers concerned, i.e. as user-specific data. The parallels to abscissa \( i \) through \( c_M \) and \( c_R \) characteristics limit the areas in which from a technical viewpoint a servicing routine or replacement is required. Area assignment can be defined as follows:

\[
\begin{align*}
100 - c_R & : replacement \\
(c_R - c_M & : servicing, repair \\
< c_M & : no action required
\end{align*}
\]

Inside a particular area, the priority for individual measures is obtained by examining the distances \( d \) from the straight line. With the aid of the classification achieved in figure 5 the necessary maintenance action can be specified. Basically, it is also possible to specify an area of corrective maintenance (CM) in this scheme, i.e. an area in which all the substation needed to be maintained only after a malfunction. These elements are characterized by being below a critical importance threshold, so that a failure has no significant effect on network reliability.

5 EXAMPLE

5.1 Circumstances

Some companies are complaining about the increasing pressure of cost savings in asset management which is accompanied by the necessity to maintain a constantly high level of availability. However, the approaches for achieving these goals differ from each other considerably.

It is obvious, that an one-sided reduction of the maintenance budget, for example in the course of changing from a Time Based Maintenance (TBM) to a Condition Based Maintenance strategy, is often not enough. Especially in this context, it is much more necessary to optimise maintenance processes so that a strategy can achieve its full potential.

A German utility (approximately 6,000 km\(^2\) service area, 1.6 million private and commercial clients, 1,150 staff members) which had realised the importance of optimising maintenance processes wanted in 1999 to audit, evaluate and optimise the existing assets as well as to analyse and optimise the maintenance processes in co-operation with an internationally active consultancy company within the scope of a model project. The electric supply company followed a CBM strategy. The maintenance processes were in line with this strategy and had been optimised. The aim of the project was to reduce the costs of the whole maintenance area by a further 30% and the duration of the project was nine weeks.
5.2 Analysis phase

The total consult concept served as the strategic framework of analysis - a holistic approach for asset management which does not only consider technical aspects (for instance diagnosis, network analysis), but also takes into account commercial factors (for example investment strategies, budget planning) in the analysis figure 5.

**Figure 5:** Consult concept

Auditing the available equipment and comparing them to the existing data bases was the first necessary step for achieving the goals of the project - firstly because until then the maintenance and archiving of data depended largely on the person who conducted it, and secondly because certain data (such as condition and degree of maintenance) was not available for all equipment.

In order to conduct a cost-effective and quick data acquisition of the condition of equipment on a specific day, the e-Pat solution was used. This solution is a software tool for handheld computers which is used to document the evaluation of condition efficiently on the spot. The required data was acquired with the help of the staff members of the client who had been trained thoroughly before that. The data which was acquired in this manner was sent via Internet to central computer on a daily basis. In this way it was possible to evaluate more than 8,000 equipment (substation bays, circuit-breakers, power and instrument transformers, disconnectors and so on) within four weeks, compare the data to the existing data bank of the utility and generate an updated version simultaneously. In addition to that, all critical equipment were identified in this step of the project (critical in the sense that the security of supply depends on them to a large extent in case of a power breakdown).

As an example which detailed informations of the complete asset are stored the following description comprises the main data of the m.v. circuit-breakers, table 1. In total 606 circuit-breakers are assessed with an average value of 22.6 years of operation.

<table>
<thead>
<tr>
<th>type</th>
<th>number</th>
<th>age</th>
</tr>
</thead>
<tbody>
<tr>
<td>air blast</td>
<td>208</td>
<td>34.3</td>
</tr>
<tr>
<td>min. oil</td>
<td>284</td>
<td>20.7</td>
</tr>
<tr>
<td>vacuum</td>
<td>58</td>
<td>7.7</td>
</tr>
<tr>
<td>SF6</td>
<td>55</td>
<td>3.8</td>
</tr>
<tr>
<td>other</td>
<td>1</td>
<td>30.0</td>
</tr>
<tr>
<td>total</td>
<td>606</td>
<td>22.6</td>
</tr>
</tbody>
</table>

Table 1: Main data of the assessed 20 kV circuit-breaker

Figure 6 illustates the distribution of the installation of the c.b.’s. The oldest types are installed in 1952, and if an maximum life time of 40 years is assumed about 90 c.b.’s has to be replaced (about 15 % of the whole installation). A further reduction of the life time to 35 years will increase this value to about 160 c.b.’s.

5.3 Development of strategies

In the next step, the information acquired in the analysis phase was used for developing alternative maintenance strategies. In TBM strategies, the equipment are replaced after a hypothetical period of service life and maintenance is carried out continuously after specific time intervals. A maintenance budget based on this approach corresponds to an index value of 100.

CBM strategies, on the other hand, prescribe replacement or maintenance measures only after an equipment has achieved a certain technical condition. This condition is specified with the help of a so called condition index. The condition index is defined differently for different equipment.

The scenario for a CBM strategy showed of the complete asset a saving potential of 40% compared to that of a TBM strategy. In this connection, it might be interesting to note that the model calculations for the application of a CBM strategy coincided exactly with the amount of the maintenance budget of the client.
However, this was not enough for achieving the goal of the project. Assessing the possibilities of approaches using modern Reliability Centered Maintenance (RCM) was an even more important task. Such approaches distinguish themselves through the fact that they not only take the technical condition of the assets into consideration but also their importance in the overall network.

Assessment of 20 kV substations

The result of the total assessment of the 20 kV substation is listed in figure 7. In addition to that, customer specific critical values for the technical condition of the equipment are defined. In the example shown in figure 7, the critical value for a maintenance measure \( c_M \) of the complete substation is fixed at \( c = 40 \) whereas the critical value for a replacement or retrofitting measure \( c_R \) is fixed at \( c = 60 \).

A further step is to investigate which item (for example circuit-breaker, instrument transformer, civil works and so on) has the most impact on the result assessing the condition of the complete substation. And the benefit may be, that a retrofit solution of one component would increase the condition and further actions are not necessary in accordance with the importance of the substation.

Summarizing the RCM strategy influences the maintenance processes significantly. The optimisation of these maintenance processes offers an additional cost-cutting potential. In addition to that many companies conduct processes that are too complicated and have interfaces that require manual inputs, making them prone to errors.

It may be of interest to consider the condition of the m.v. circuit-breakers in detail. The average value of the condition \( c_{av} \) of the c.b.'s is as follows:

- air blast: \( c_{av} = 67 \)
- minimum oil: \( c_{av} = 50 \)
- vacuum: \( c_{av} = 28 \)
- SF6: \( c_{av} = 37 \)
- other: \( c_{av} = 70 \)

If the values of \( c_M = 40 \) and \( c_R = 60 \) are defined, as discussed above, the air blast c.b.'s should be replaced, whereas the minimum oil circuit-breakers should be serviced. And no actions are necessary for the new types (SF6 and vacuum). According to the assessment the circuit-breakers can be divided into several categories according to table 2.

If the CBM strategy is applied 202 c.b.'s should be replaced in the next time, whereas 271 are in service. An important reduction of the replaced number of c.b.'s is only possible, if the importance of the circuit-breakers for the network is taken into consideration and the maintenance strategy is RCM – based.

<table>
<thead>
<tr>
<th>type</th>
<th>replace</th>
<th>service</th>
<th>no action</th>
</tr>
</thead>
<tbody>
<tr>
<td>air blast</td>
<td>169</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>min. oil</td>
<td>32</td>
<td>217</td>
<td>33</td>
</tr>
<tr>
<td>vacuum</td>
<td>-</td>
<td>2</td>
<td>54</td>
</tr>
<tr>
<td>SF6</td>
<td>-</td>
<td>13</td>
<td>42</td>
</tr>
<tr>
<td>other</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>total</td>
<td>202</td>
<td>271</td>
<td>129</td>
</tr>
</tbody>
</table>

Table 2: Condition of the circuit-breakers

7 CONCLUSION

It makes sense to embed the described procedure in a financial management system and to develop a software tool. The general data and measurements of the process (e.g. substation) should feed into the program to assess the condition and the importance of the equipment. Whereas the main data of the equipment (e.g. type, manufacturer, year) are already listed in network information systems. These values have to be directly imported to the software tool. After the overall assessment a ranking of the equipment will be calculated and the responsible engineer has to handle the order via a commercial software tool.

When looking at this optimized process design concept, the time needed to achieve this goal should not be underestimated. Since, however, the procedure for the basic and crucial core process of network component evaluation has already been defined, and an appropriate PC program for this purpose are already available for high voltage equipments on the market. Further development is targeting only the automatic incorporation of time-dependent evaluation parameters. It is decided to integrate this program into maintenance management system. In the final analysis, computerized maintenance planning in a company necessitates a shared database, to serve as a foundation for both maintenance planning and a higher-order information system for the network /8/.
REFERENCES