DEVELOPING AND IMPLEMENTING A RISK BASED MAINTENANCE STRATEGY FOR DISTRIBUTION COMPANIES

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INTRODUCTION

During the last years there has become increasing awareness among the Norwegian network companies related to developing holistic maintenance strategies taking into account both economy and other more qualitative criteria such as safety, environmental impact and company reputation. Risk analysis has shown to be an efficient method when performing this task. The paper deals with the main elements regarding implementation of a maintenance strategy.

BACKGROUND

Since the deregulation of the Norwegian electricity sector and the introduction of the income cap regulation, there has been a period of much focus on cost cutting among the Norwegian grid companies. The regulatory regime gives strong economic incentives towards extending lifetime of old components and postponing new investments, [4].

The electricity distribution sector has for several years been cutting reinvestments and maintenance costs - and both quality of supply and safety have shown a satisfactory quality during this period. This has been possible due to the amount of investment in the sector in the past, and the fact that the companies have been more conscious concerning choosing which tasks to prioritise. But in the longer run this practice cannot be followed without it causing unacceptable conditions.

As a result of this there has become an increasing awareness among the companies on developing holistic strategies for the maintenance of the grid in an adequate way. In this setting it is important that the focus on cost effectiveness must be balanced with the aspects of operating the grid in a safe manner; thus seeking solutions where economy, reliability, health, safety and environment (HSE) issues are all being sufficiently taken care of. Handling this multi criteria challenge is the basic and complex challenge the network companies are facing under the existing regulatory regime, and risk management has been found to be the key approach to face this challenge, [1,3].

The picking of “low hanging fruits” achieved by unilaterally cutting costs is drawing towards an end, and the electricity distribution sector is now at a turning point. Fundamental changes in the way of thinking concerning the maintenance activities are necessary, and the utilities have to develop and implement more efficient tools and strategies as well as improving the competence.

In several projects at SINTEF Energy Research these challenges are being addressed using risk management based approaches, [1-4]. This work is done in close cooperation with a number of participating utilities. This paper presents results from two projects addressing the topic of establishing maintenance strategies and implementing them - one research project with a more overall point of view, and one implementation project where the aim is to develop and implement holistic risk based maintenance strategies for some of the largest electricity distribution companies in Norway.

ELEMENTS OF IMPLEMENTING A MAINTENANCE STRATEGY

Three major activities of the process of implementing a risk based maintenance strategy are described in the following:

- Developing an overall philosophy for the maintenance activities
- Developing decision support and maintenance work descriptions based on risk analysis
- Defining indicators and targets for maintenance monitoring and management using balanced scorecard techniques

These activities will be further described in the following chapters.

The overall goal is to make better decisions regarding maintenance activities and thus making the strategies more efficient and in accordance to the company goals. Focus is also on implementing the strategies within the organisation and increasing the companies’ competence regarding risk based maintenance strategies.

![Figure 1 – Schematic description of elements of maintenance strategies](image-url)
MAINTENANCE PHILOSOPHY

In order to have clear primary goals and visions when working with establishing and implementing maintenance strategies, the following principles have been identified as guidelines for the network companies’ work:

- **The maintenance activities shall be based on risk evaluation.** ‘Risk evaluation’ meaning that the activities shall be seen in light of the probability for and the consequence of the incidents they are meant to prevent.
- **The maintenance shall be performed in compliance with the existing rules and regulations.** Explicit requirements shall be a basis for the maintenance activities, but the companies should also make their own judgements and the results should be documented whether if coincides or diverges from the existing requirements. For much of the network business there exist no explicit demands for how the maintenance should be performed.
- **The maintenance shall be seen in context with a holistic operation and investment strategy.** For the network companies this means that the maintenance activities also must be seen in connection with the renewal of the grid.

To follow these principles the maintenance should be included in a holistic maintenance management model where results and experience are being used to improve routines and working processes. This is illustrated in Figure 2.

The principles stated above represents the essence of a risk based company maintenance practice.

DECISION SUPPORT AND MAINTENANCE DESCRIPTIONS

The principles stated in the previous chapter are of little or no value if they can not be used for practical purposes in maintenance planning.

Emphasis must therefore be put on developing decision support methods which can be applied in practice when analysing real maintenance needs, often with a limited amount of data available.

Two main approaches are being used in the work of developing the maintenance strategies and descriptions:

- **Evaluating existing practice** in the different companies and finding the best, and
- **Risk analysis** based on probabilities and possible consequences of different events for different types of equipment.

The two approaches represent different stages in the establishing of a risk based maintenance strategy. **Evaluating existing practice** can be performed as an initial step towards identifying the efficiency improvement potential. The **risk analysis** will typically use the results from the initial survey of practices as a basis for setting time intervals of preventive maintenance actions and differentiating between various classes of risk exposure. This is illustrated in Figure 3. The approaches are further described in the next sub-chapters.

Evaluating existing activities and finding best practice

The majority of the maintenance actions being performed today have their origin in judgements and experience from years of operating the grid. It may not at the time of origin have been called ‘risk analysis’, but the results will in many cases be in accordance with the principles of such.

One first step of evaluating and improving the maintenance practices of a group of different utilities, is to examine what activities are being performed today, and to take on a discussion on why the different solutions have been chosen earlier. From such a process one can learn from other’s experience and converge towards a strategy representing the best practice.

For each utility the following aspects must be examined for each network component:

- Existing maintenance actions
- Maintenance intervals
- Cost per maintenance action
The analysis of the different practices also gives a basis for estimates of the potential which can be achieved through maintaining the grid in a more efficient way.

Risk analysis

As a basis for the risk analyses the concept of risk matrices have been used. It gives an efficient way of illustrating the combination of probability and consequence for different relevant unwanted events which can occur, [1,2].

From our project activities the following risk aspects have been identified as important to consider:
- Personnel safety
- Environmental impact
- Reputation
- Economic risk

Risk matrices have been established for all of these four aspects – where the consequences and probabilities have been classified into five categories each.

Example – risk analysis for air insulated MV switches

In the following an example is given on how the risk analysis for air insulated MV switches in grid substations has been performed.

The dominant unwanted event for the criteria Personnel safety has been identified as Event 1: Personnel injury caused by malfunction of manually operated switch with a burning electric arc as a result.

The following scales of probability and consequence applies to this risk element for this event.

Probability scale¹:
- 5 – Highly Probable – Once every 1-10 switchings
- 4 – Very Probable – Once every 10-100 switchings
- 3 – Probable – Once every 100-1 000 switchings
- 2 – Less probable – Once every 1 000-10 000 switchings
- 1 – Improbable – Less than every 1 of 10 000 switchings

Consequence scale;
- 5 – Catastrophic – One or more deaths – 10 or more injuries
- 4 – Very serious – More than one person with serious injury
- 3 – Medium – Medium to serious injuries
- 2 – Small – Minor injuries
- 1 – Insignificant – No injuries

The following factors have been identified as relevant for differentiating the various switches regarding the risk exposure for personnel safety:
- Age (new ≤ 24 years, N), old (> 24 years, O)
- Operating environment (exposed (E), clean (C))
- Enclosure (open (O), half enclosed (H), fully enclosed (E))
- Switch operation (close¹ (C), remote² (R))

In Table 1 the risk assessment for event 1 is plotted as Event(Age; Environment; Enclosure; Operation), e.g. 1(N;E;E;C) meaning event 1 - a new switch in an exposed environment, fully enclosed with close operation of the switch.

The risk matrix in Table 1 is divided into three zones – one “Acceptable” zone (lower left), one “On-the-limit” zone (middle) and on “Unacceptable” zone (upper right). These are marked with different shadings in the table.

<table>
<thead>
<tr>
<th>Risk level</th>
<th>Consequence of event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

For the other three risk criteria (Environmental impact, reputation and economic risk) there has been found no other risk combinations which make it comparable with the risk identified for personnel safety.

Based on the risk classification performed it can be seen that a differentiation of the maintenance activities (and level) for different components is appropriate.

There exists no formal analytical link between the risk classification as shown in Table 1, and the chosen activities and intervals of the resulting maintenance scheme. The activities and intervals are therefore established on basis of the combination of existing practise, the results from the risk analyses and expert opinions as illustrated in Fig. 3.

The relevant maintenance activities for the MV air insulated switches are:
- Functional test
- Full overhaul of switch
- Replacement evaluation

The Functional testing is an activity which is preformed triggered on a time interval (or by special events), while the overhaul of switches and the renewal evaluation is performed based on condition monitoring.

In Table 2 are the results on how the maintenance scheme for functional testing of air insulated switches presented. The intervals stated in the table are chosen based on experience...
and best estimates on the differentiation between risk categories obtained from the risk matrix. In addition the functional testing should be performed in case of the event “Outage” – that is when the switch is deenergized for one reason or another,

The probability of sub-event 1 depends on the type of switch, technical condition (including environmental influence) and the size of the current in the switch at the time of operation. The probability of sub-event 2 depends on the type of switch, while the probability of sub-event 3 depends on the enclosure of the switch protecting the operator from the electric arc (barriers). The probability of the total event is the product of these sub-event probabilities.

The impact of the technical condition for the probability $P_{12}$ is in the example taken into account by including the factors age and operating environment. We have made the assumption that old switches (age $> 24$ years) in an exposed environment, have a poorer condition (and higher failure probability) compared to new switches located in a clean operating environment.

Traditionally the estimation of probabilities has been based on failure statistics and experiences. In our example it is possible that there can be found relevant statistics due to the fact that there exists a large number of switches (within the company or others), and the existence of a national statistic for MV switches.

The limitation of the failure statistics is that it does not separate on type of fault, type of switch (manufacturer), age, operating environment, etc. Still the statistics can give certain indications of the relevant numbers – at least in combination with knowledge of the component and local conditions (expert opinions). It can for example be of interest to see whether (and – in case – how often) similar faults and events have happened before.

Knowledge about the components’ technical condition is ideally the best basis to estimate the expected remaining lifetime and the corresponding failure probability for a given component, but gathering such information can often be laborious and the estimation of technical condition complicated. To make use of information concerning technical condition when estimating remaining lifetime and failure probabilities for maintenance and renewal planning, it is necessary to limit the approach to few and simple condition parameters. It is important to find an appropriate balance between theory and practical implementation.

### Communicating the risk analysis results

The results from the risk analyses (and the documentation of considerations having been made) represent an efficient basis for communicating the impacts of a risk based maintenance strategy for relevant decision makers, for example:

- Regulatory authorities
- Company owners and board of directors
- Employees implementing the strategies in practice

The risk analysis gives the participants a common platform for discussing the practical impacts of applying such an approach to network maintenance planning. [2]. It is probable that one gets discussions concerning the validity of the choices having been made in the analysis, and the risk analysis framework can easily be applied to see how other choices will impact the analysis results.

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**Estimation of probability**

The example in the previous section shows how a risk analysis can be used to evaluate the need for preventive maintenance and renewal of elder MV air insulated switches. The analysis covers an unwanted event originating in switches having a degraded technical condition. [1].

The event analysed is “personnel injury with a given consequence as a result of an electric arc caused by a malfunction of switch when being manually operated.” How can the probability of this event be estimated? We suggest starting describing and analysing the chain of causes for the event, with the aim to establish a fault tree with basis in the actual root cause.

The root cause in this case is a degraded technical condition of the switch. The chain of causes consists of the following elements:

1. Malfunction of the switch when operating
2. The malfunction resulting in an electric arc
3. The electric arc resulting in personnel injury of a certain extent.

The probability of sub-event 1 is the product of the probability of the switch being operated ($P_{11}$) and the probability of malfunctioning at when operated ($P_{12}$). $P_{11}$ depends on how often the switch is operated, and $P_{12}$ depends on switch type, technical condition (including environmental influence) and the size of the current in the switch at the time of operation.

The probability of sub-event 2 depends on the type of switch, while the probability of sub-event 3 depends on the enclosure.

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**TABLE 2 - Maintenance scheme for Functional test (“F.test”) of air insulated MV switches**

<table>
<thead>
<tr>
<th>Act.</th>
<th>Init. Event</th>
<th>Interval [years]</th>
<th>Event</th>
<th>Age</th>
<th>Enc</th>
<th>Env</th>
<th>Op</th>
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</thead>
<tbody>
<tr>
<td>F. test</td>
<td>C / E</td>
<td>12</td>
<td>Outage</td>
<td>N</td>
<td>E</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>F. test</td>
<td>C / E</td>
<td>8</td>
<td>Outage</td>
<td>N</td>
<td>E</td>
<td>E</td>
<td>C</td>
</tr>
<tr>
<td>F. test</td>
<td>C / E</td>
<td>9</td>
<td>Outage</td>
<td>N</td>
<td>H</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>F. test</td>
<td>C / E</td>
<td>6</td>
<td>Outage</td>
<td>N</td>
<td>H</td>
<td>E</td>
<td>C</td>
</tr>
<tr>
<td>F. test</td>
<td>C / E</td>
<td>6</td>
<td>Outage</td>
<td>N</td>
<td>O</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>F. test</td>
<td>C / E</td>
<td>4</td>
<td>Outage</td>
<td>N</td>
<td>O</td>
<td>E</td>
<td>C</td>
</tr>
<tr>
<td>F. test</td>
<td>C / E</td>
<td>8</td>
<td>Outage</td>
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<td>C</td>
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<tr>
<td>F. test</td>
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<td>4</td>
<td>Outage</td>
<td>O</td>
<td>H</td>
<td>E</td>
<td>C</td>
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<tr>
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<td>C / E</td>
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<td>Outage</td>
<td>O</td>
<td>O</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>F. test</td>
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<td>Outage</td>
<td>O</td>
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<td>E</td>
<td>C</td>
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<tr>
<td>F. test</td>
<td>C / E</td>
<td>12</td>
<td>Outage</td>
<td>N</td>
<td>*</td>
<td>C</td>
<td>R</td>
</tr>
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<td>*</td>
<td>E</td>
<td>R</td>
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</tbody>
</table>

1: $C =$ Calendar, $E =$ Event
2: $Age, Enclosure, Environment, Operation$
MONITORING THE RESULTS FROM THE MAINTENANCE ACTIVITIES

The results from maintenance activities can in general be difficult to measure in an objective manner. This is due to the fact that maintenance primarily has the purpose of preventing unwanted events, and the effects of this work can be hard to keep track of. But it is still important to keep an eye on the maintenance results in order to see whether the chosen approach give the desired results.

Balanced scorecard (BSC) techniques can be used in order to perform the measuring of results from the maintenance activities. The use of BSC can assist to:
• Visualise and communicate the strategy
• Keep focus on some selected key performance indicators
• Show the obtained results and the trends in the company’s maintenance related results

Measuring parameters must be chosen in order to obtain the best view of the maintenance results practically possible. The following parameters are examples on what can be included in the maintenance management follow-up system:
• The number of unwanted events as a result of degraded technical condition and / or the performance of maintenance activities
• Absence from work due to accidents and injuries
• The number of not performed work orders. The backlog can be sorted in preventive and corrective maintenance.
• “Top 10” failure modes for the network components
• Number of interruptions (short (<3 min) and long (≥ 3 min))
• Quality of supply and compensation for energy not supplied, as established through the Norwegian CENS-arrangement [5]
• Maintenance costs
• Number of negative articles in newspapers and media
• Number of negative customer feedbacks

Through monitoring a number of company key performance indicators, the maintenance management and other stakeholders get a perception of the network behaviour and how (among other things) the planned maintenance activities affect the network quality. Following trends over time deviations can be identified and addressed – for example through an intensified maintenance scheme or a renewal of critical components.

CONCLUSIONS

The paper has shown some of the major elements which must be included when applying risk management as the key approach to development and implementation of maintenance strategies in network companies. Risk analyses have shown to be an efficient tool for handling this task.

Our experiences have further shown some challenges for the network companies – for example through need for:
• New and better competence among the staff planning and executing the maintenance strategies.
• More and better surveillance and monitoring of the network behaviour over time
• A more integrated – and thus complex - maintenance management model.

The results from and the documentation of the risk analysis is also a very important and effective basis for communicating the risk level and exposure to relevant parties – e.g. regulatory authorities or owners, [2]. It has proven to be valuable in establishing a common arena for discussing the aspects of risk management as a principle for operating and maintaining the network.

Challenges to be further addressed in our research activities are the representation and estimation of probabilities for unwanted events in the risk analysis, and further work concerning the practical implementation and use of risk based approaches.

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REFERENCES


