Establishing risk-based maintenance strategies for electricity distribution companies

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ABSTRACT: One of the main challenges for electricity distribution companies is to manage the existing assets in the comprehensive and complex distribution system infrastructure. Maintenance and reinvestments are important parts of this. This paper presents a practical approach for establishing risk-based maintenance strategies for electricity distribution systems. The approach has been developed and used in a joint project of six electricity distribution companies in Norway.

1 INTRODUCTION

Electricity distribution is by definition a natural monopoly. Due to this the electricity distribution industry is subject to regulation from authorities.

During the last two decades substantial changes have occurred in the electricity distribution sectors worldwide, changing it from generally being a protected business to being exposed to efficiency requirements and competition through the monopoly regulation of electricity distribution. The process has lead to efficiency improvements throughout the business. From this background the concept of *asset management* has emerged, shifting the companies towards a mindset where the aim is to balance asset costs, performance and risk (Brown & Spare 2004; Nordgård et al. 2007a; Sand et al. 2007).

One of the main challenges for electricity distribution companies now and ahead is to manage the existing assets in the comprehensive and complex distribution system infrastructure. Maintenance and reinvestments are hence important parts of the asset management, as they are measures to control the risks faced by the distribution companies (Nordgård et al. 2008).

This has lead to distribution companies looking with new eyes on their maintenance and reinvestment management regimes, developing risk-based strategies where the emphasis on cost efficiency is balanced against also other important risks - e.g. occupational safety, reputational and environmental impact (Nordgård et al. 2005; Nordgård et al. 2007b). The main focus of these efforts has been to establish a holistic thinking concerning maintenance and reinvestments, incorporating risk management as one of the main principles.

This paper reports on experiences from establishing risk-based maintenance strategies in a group of Norwegian electricity distribution companies. First, some basic aspects about electricity distribution are presented – focusing on what gives this industrial sector somewhat other challenges compared to other sectors. Then the foundations of the maintenance philosophy are described, before we present the main steps in the procedure for establishing maintenance strategies. Improvement analysis is also briefly described. The application of the methodology is illustrated through examples.

2 BACKGROUND

2.1 *Characteristics of distribution systems*

Electricity distribution is by definition a natural monopoly, i.e. it is not cost-efficient to build competing parallel infrastructure to provide this service which is a life-nerve in modern society. The industry is therefore subject to comprehensive regulation from authorities, stating frameworks which the industry can perform its business within.

In industrialized countries electricity distribution systems are to a large degree an already existing infrastructure – most of it being built during the last 50 years. Hence, the distribution companies are now facing the challenges associated with managing a generally ageing infrastructure, which gives maintenance and reinvestments a more prominent position than before.

Electricity distribution systems are characterized by being widely geographically dispersed, having vast numbers of relatively simple components which together constitute a complex system. Most of the infrastructure consists of static components (e.g. overhead lines, cables and transformers), while a minority of the components have moving parts (e.g. load breakers, sectioning switches, transformer tap-changers). Component lifetimes are typically 30 to 60 years.

2.2 *Where are we coming from?*

Through the history of electricity distribution systems, maintenance have always been a part of the business, but in general it has had a low standing, like in many other sectors and industries – see e.g. (Levitt 2003).

Maintenance was generally seen being inferior to other and more expansive business disciplines. The historical background of electricity distribution maintenance has been described by (Furberg 2008) as being:

- Governed by the workers doing the actual work
- Aiming to keep the working staff employed
- Governed more by ideals than professionalism, with emphasis on keeping the assets polished, clean, tidy and newly painted – rather than focusing on what was really needed.

The maintenance was generally based on existing practice and old habits, and not founded on an explicitly stated philosophy. This could be done in a regulatory regime guaranteeing cost recovery for the companies' expenses.

2.3 *Where are we going towards?*

The incentives provided by the regulation of the electricity distribution sector in Norway has challenged this way of handling maintenance activities in the distribution companies: The revenue cap regulation introduced in 1997 has put increased focus on cost-efficiency, aiming to give incentives for the companies to optimally manage their assets, balancing the distribution system expenditure, performance and risk (NVE 2007). In 2001 the CENS arrangement (Cost of Energy Not Supplied) was introduced to provide economical incentives for the distribution companies to keep the system reliability at a socio-economic optimal level (Langset et al. 2001).

Shortly after the introduction of revenue caps, there were tendencies towards cutting costs without having in mind a sustainable balance between cost savings and increased risk. After this transient period, there is now a trend towards developing strategies for maintenance and reinvestments, where cost effectiveness is balanced with other risks. The risk consequence categories typically involve economy, safety, environmental impact, company reputation and quality of supply (Sand et al. 2007).

With this background, six of the distribution companies in Norway (together covering approximately 25 % of all grid customers, and close to 20 % of the distribution system assets in Norway) have joined forces to develop a common framework for their maintenance management (Nordgård et al. 2005; Nordgård et al. 2007b).

In the following chapters we describe how this cooperation have resulted in an overall maintenance philosophy comprising a maintenance management process, and how this philosophy is made operative through maintenance strategies. The aspect of including continuous improvement in the process through analyzing the results of the maintenance strategies is also addressed.

3 THE MAINTENANCE PHILOSOPHY

A maintenance philosophy is defined as the "system of principles for the organization and execution of the maintenance" (ISO/IEC 2002), and is a high-level description of the overall principles for the maintenance management (Nordgård et al. 2005).

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

- The maintenance activities shall be based on risk evaluation, meaning that the activities shall be seen in light of the probability for and the consequence of the incidents they are intended to control.
- The maintenance activities shall be economically evaluated according to the principle stated in the Norwegian economic regulation; minimizing costs of investments, operation, electrical losses and interruptions.
- The maintenance activities and (re)investments shall be closely coordinated, meaning that the maintenance activities must be seen in context to potential renewal of the grid.
- The maintenance shall be performed in compliance with existing rules and regulations.

The principles stated above represent the essence of the companies' maintenance philosophy.

To follow these principles in practice, the maintenance should be included in a holistic maintenance management process where results and experience continuously are being used to improve routines and working processes. The process is illustrated in Figure 1. All the different parts of the model are not described in detail, as we in this paper focus on the two parts indicated by I and II in Figure 1.

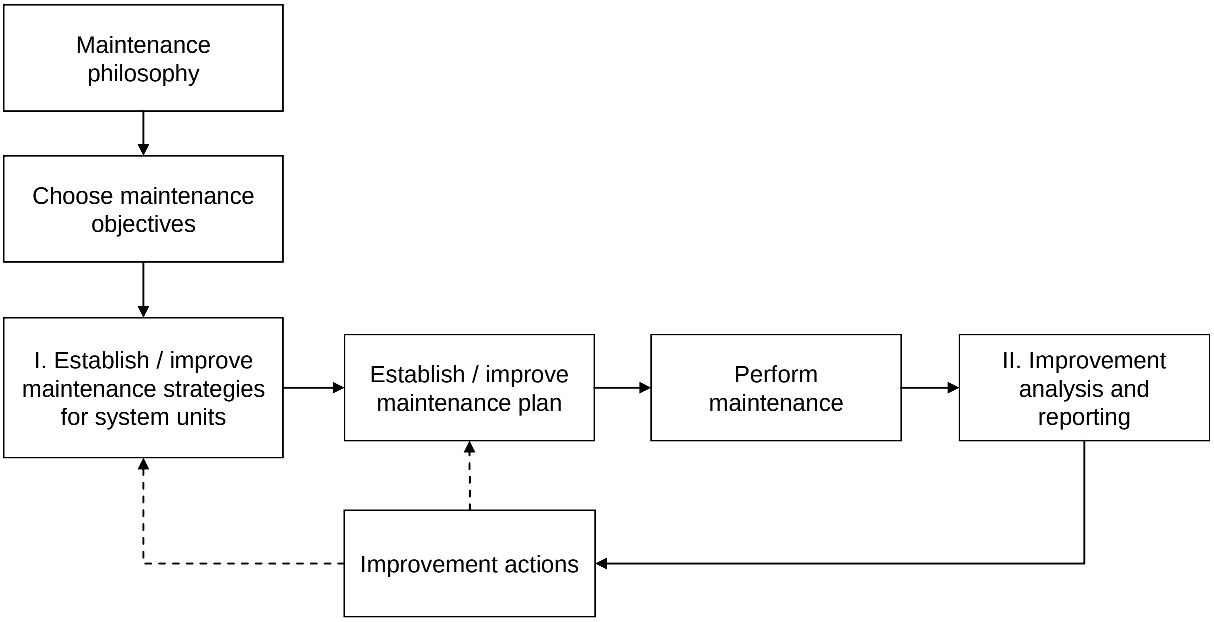

Figure 1 The overall maintenance management process

4 ESTABLISHING MAINTENANCE STRATEGIES

The maintenance philosophy gives the overall principles for how to maintain the system as a whole. To make the philosophy operational, the principles need to be applied to the specific parts or components constituting the system.

This could have been done analyzing the system in a topological manner. However, the vast number of components makes this an impracticable approach.

Instead we choose to use an approach, dividing the system into *system units* consisting of components functionally belonging together.

Each of the system units consists of a number of *component archetypes*, being types of components which are similar in operation and have the same failure modes – regardless of manufacturer, etc.

The aim of the chosen approach is to establish maintenance strategies for each of the identified systems units, which together constitutes the maintenance strategy for the distribution system as a whole.

The steps in the chosen approach of establishing distribution system maintenance strategies are illustrated in Figure 2, and described and exemplified in the following.

The work has been performed in groups of experts from the participating companies – one group for each of the selected system units. Brainstorming sessions and group discussions have been the tool used for perform the work of establishing the strategies.

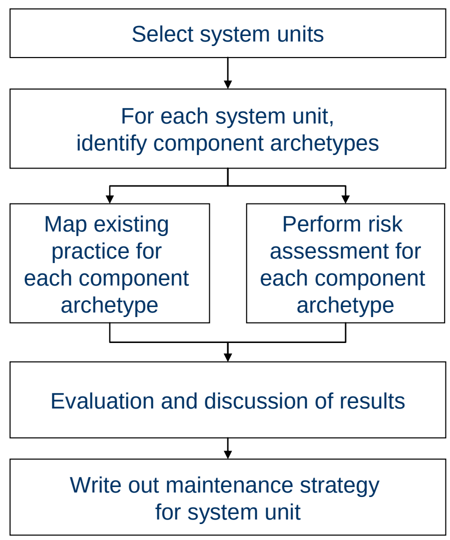

Figure 2 Approach for establishing maintenance strategies

In the following sub-chapters the steps in the approach is described.

4.1 *Selection of system units and component archetypes*

To structure the work of establishing maintenance strategies for the total system has been divided into more manageable parts – consisting of system units and their corresponding component archetypes.
Table 1 lists the system units which so far have been addressed in the project activities, and they cover the majority of the system components, with the exception of cable installations.

Table 1 Division of system into system units

System	System unit
Electricity distribution system	- Low voltage (LV) overhead lines - Medium voltage (MV) overhead lines - High voltage (HV) overhead lines - MV/LV substations - HV/MV primary substations - Protection and control equipment

For each of these system units, component archetypes are identified. Table 2 shows an example on how the system unit 'MV overhead lines' is divided into six component archetypes.

Table 2 Division of system unit 'MV overhead lines' into component archetypes

System unit	Components archetype
MV overhead lines	- Poles (including traverse, insulators, ..) - Phase conductors - Line trace - Pole-mounted switches - Cable terminations - Pole-mounted MV/LV substations

The other system units have also been divided into equivalent component archetypes.

Altogether there have been specified approximately 60 component archetypes covering the six system units listed in Table 1.

Mapping of existing practice and performing risk assessment is hence limited to 60 archetypes instead of the vast numbers of components being in the network. E.g. the risk assessment performed for the component archetype *poles* in Table 2 then applies to the many thousand poles which are found in the network.

4.2 *Mapping of existing maintenance practice*

The majority of the maintenance actions being performed today have their origin in judgments and experience from decades 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. Since the work has background in 6 different companies there were some discrepancies between the existing maintenance practices.

One first step is therefore to examine what activities are being performed today, and to take on a discussion on why different solutions have been chosen earlier. From this process the experts learn from other's experiences and can start the process of converging towards a commonly accepted 'best practice'.

An important aspect of this part of the work is to make sure that the experts in the working groups are using the same terminology. Our experience show that the words used to describe maintenance activities are varying among the companies. Writing out a common terminology, was hence a necessary task to do before starting the mapping of existing practice. The terminology provides a structure for comparing the companies' practices, making them subject to meaningful discussions.

For some of the component archetypes there were widespread consensus, while others showed considerable differences.

An example of mapping of existing practice is shown in Table 3.

Table 3 Example - Mapping of existing practice for condition monitoring activities for wooden poles in MV overhead lines

Condition monitoring activity	Time interval [years] *Company I-VI* I	II	III	IV	V	VI
Inspection	1	1	1	1	1	1
Thorough inspection	10	5/10	5	10	5	10
Measurements	10	10	10	10	10	10
Renewal assessment	-	10	-	10	10	10

The results from the mapping of existing practices also give a basis for estimating what can be achieved through maintaining the grid in a more targeted way.

4.3 *Risk assessment*

To perform the risk assessment, guided brainstorming sessions have been carried out. Experts from all of the participating companies have first identified undesired events related to each of the component archetypes.

Then risk estimation has been performed for the undesired events with regards to the following consequence categories:

- Safety
- Environmental impact
- Reputational impact
- Economic impact.

Risk matrices have been used to illustrate the risk results – providing an intuitive risk picture for each of the component archetypes for each of the consequence categories.

Through the brainstorming sessions potential risk differentiating aspects have also been discovered.

To exemplify this we look closer into the component archetype *poles.*

4.3.1 *Example: Identification of undesired events for the component archetype 'poles'*

Though brainstorming and discussions in the expert groups the following undesired events were identified:

1. Pole breakage
2. Pole askew
3. Fire damage of pole
4. Insulator flashover
5. Conductor falls on traverse / burnt traverse
6. Broken traverse
7. Flashover / discharge of insulator chain
8. Displaced traverse
9. (Partially) defect discharger
10. Person falling down from (and / or with) pole
11. Person climbing in pole and touching live MV parts
12. Poor earthing connections
13. Insulators destroyed by vandalism
14. Impregnation run-off to water and/or soil

4.3.2 *Risk analysis*

The probability and consequence scales shown in Table 4 have been used to perform risk analysis for each of the undesired events. The risk mapping is performed having one specimen of the component archetype in mind.

As sources of estimation of probabilities and consequences there are little statistical material to rely on. Expert judgement has therefore been used as input to the risk analyses.

An example of using risk matrices for risk estimation is shown in Figure 3 for the consequence category *safety*.

Table 4 Probability and consequence scales used for risk estimation

Probability scale
P5 – Highly Probable – More often than once a year
P4 – Very Probable – Once every 1-10 years
P3 – Probable – Once every 10-100 years
P2 – Less probable – Once every 100-1 000 years
P1 – Improbable – Less than once every 1 000 years
Consequence scale
C5 – Catastrophic - One or more deaths – many injuries
C4 – Serious – More than one person with serious injury
C3 – Medium – Medium to serious injuries
C2 – Small – Minor injuries
C1 – Negligible – No injuries

	Consequence				
Probability	C1 Negligible	C2 Small	C3 Medium	C4 Serious	C5 Catastrophic
P_5: Highly probable					
P_4: Very probable					
P_3: Probable					
P_2: Less probable					
P_1: Improbable			8 12	1 6	10 11

Figure 3 Example: Risk matrix for *safety* for the undesired events for wooden poles.

Not all of the initial 14 unwanted events are placed in the risk matrix for safety, because some of them are regarded as not relevant for this consequence category.

Similar risk matrices have been established for the other three consequence categories - environmental, reputational and economic impact.

From Figure 3 is can be seen that events 10 and 11 are identified as being the most critical with regards to *safety* in our risk mapping.

4.4 *Evalutaion and discussion of results*

The risk mappings for all component archetypes has been subject for evaluation and discussions among the experts, concerning whether they give an intuitively right picture for risks related to the different components; risks which we want to control through prescribing maintenance actions.

The risk matrices have shown to be a very useful tool for focused discussions within the expert groups, with their easy-to-understand interface.

In the discussions, possible risk avoiding or mitigating actions have been addressed, with basis in the companies existing practice.

4.5 *Establishing maintenance strategy for a system unit*

Based on the risk assessments and the experience from existing maintenance practice, a qualitative evaluation is performed where the members of the experts groups have discussed the problems, and prescribed which maintenance activities to be performed with what intensity.

Decision support tools – such as the RCM decision logic for choosing types of maintenance activities (Moubray 2000) have been considered, but not formally utilised in our work. This is due to the fact that there are relatively few maintenance options which are available for the component archetypes, and that these are known through the mapping of existing practice.

The formulation of the maintenance strategies for system units consisting of a number of component archetypes is formulated verbally. One example of formulations from the maintenance strategy for MV overhead lines is:

”Thorough inspection of MV overhead lines is to be performed every 10 years for lines younger than 20 years. For lines older than 20 years, the examination is performed every 5 years. It should be performed from the ground.. [ ]. The thorough inspection should be performed by an unbiased, experienced worker specialised in condition monitoring and risk assessment.”

5 IMPROVEMENT ANALYSIS AND REPORTING

A crucial part of any maintenance management system and practice is to “close the loop” of continuous improvement, i.e. to ensure that the organization learns over time and uses this new knowledge to improve. Hence we want to analyze what is being achieved through the maintenance management process, with reference to part II in Figure 1. Implicit in this lies the fact that continuous improvement is not a matter of technical systems alone, but to a large degree also a matter of building a culture of always *wanting and being able* to improve.

Improvement analysis relates very much to analyzing the direct and indirect effects of maintenance actions, i.e. what are the resources spent (time, people, money, materials), and what is the output in terms of failure rates, safety etc. However, we encounter some challenges in this process, e.g. lack of good empiric causal relations between the performed maintenance and the resulting failure rate, and that the vast numbers of components – each of them being ”less important”, makes e.g. condition monitoring activities a trade-off between volume and accuracy.

Hence, it is necessary to bring forward a system for improvement analysis that both encourage the building of a culture of continuous improvement, and at the same time allowing for analysis on sparse data with weak causal relations. We suggest taking on this challenge by addressing it threefold, as stated below:

- Event analysis – including day-to-day fault analysis, HSE events, media events, customer complaints.
- Annual company analysis – evaluating the degree of implementation of maintenance philosophy, the effect of maintenance, etc.
- Annual inter-company comparative analysis - evaluation of goal achievement, identification of improvement actions, etc.

An example of high-level statistics involved in the annual company analysis, giving input to the comparative analysis is given in for component archetype MV overhead lines in Table 5.

Comment:

The distribution companies have so far not come far in analysing and reporting of maintenance achievements, but it is regarded as a crucial part of making the maintenance philosophy operational, and it elaborated more closely in the time to come.

The analysis will result in improvement actions wherever found necessary.

Table 5 Example annual high-level reporting on maintenance cost

Economy	Parameter[1] Abs / %	Indicator[2] Norm.	Target[3] Norm.	Trend[4] 5 yr
Cost PM	6.0 / 27 %	4.5	4.4 (25%)	4.5
Cost CM	6.0 / 27 %			
Interruption cost				
- Non notified	5 (22%)			
- Notified	0.5 (2 %)			
Reinv. Cost	5 (22%)			
SUM	22.5 (100 %)			

1) *Parameter:* The company spent 6 MNOK this year on preventive maintenance. This is 27% of total cost.

2) *The c*ompany's *normalized* costs for preventive maintenance (divided by # km lines) was 4,5 kNOK per km MV overhead line.

3) *The company* has a target value for preventive maintenance costs to max. 4,4 kNOK per km MV-line per year, and to be max. 25% of total cost.

4) *Trend:* The company's *normalized* costs rolling average over the last 5 years was 4,7 kNOK per km MV-line per year

6 CONCLUDING REMARKS

This paper has presented an approach for establishing risk-based maintenance strategies for electricity distribution systems. The approach has been used in a joint project among six electricity distribution companies in Norway.

One of the basic challenges which has been met in this process is establishing a common and standardized terminology within the project group. This is necessary in order to obtain efficient communication between the different companies.

Due to the vast number of components in the system, the approach is based on establishing maintenance strategies for a limited number of component archetypes, hence minimizing the number of risk analyses to be performed, instead of doing it for each and every one of the components in the grid.

Our experience shows that it is hard to find representative statistical data which can support risk assessment in this context. The risk assessments have therefore been based on input from company experts, utilizing their judgments in a structured risk analysis framework.

In order to make the maintenance strategies fully operational, it is important to analyze the reported and observed effects of the maintenance, and to utilize the results in a continuous improvement process. The experience of analysing the maintenance achievements is yet limited, but this is a task which will be further addressed in the time to come.

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