REINVESTMENT STRATEGY MAKING FOR DISTRIBUTION NETWORKS

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1. INTRODUCTION

The assets of electricity distribution are of critical importance for continuity of service, safety and economic performance. Stakeholders such as customers, regulators and shareholders are increasingly seeking assurance that the asset management of these companies is sound. While trying to improve their long term profits under technical and regulatory constraints, distribution companies are becoming more and more aware of the 'intangible' aspects of their business. One such aspect is, for example, the impact adverse public opinion can have on their business when assets fail, causing significant consequences, and such incidents are publicized in the media.

Distribution companies are therefore acknowledging that a key to success is the development of holistic strategies for maintenance and reinvestments, where cost effectiveness is balanced with different categories of risk, e.g. related to quality of supply, safety or reputation. Well founded reinvestment strategies are essential in today's distribution system asset management, and the importance is increasing as the infrastructure is aging and the stakeholders' requirements grow.

This paper addresses the process of strategy making for reinvestments in distribution networks and seeks to describe and compare how different strategies affect the system and the corresponding performances and risks. A framework for risk-based decision making is proposed and the approach is further illustrated by a case study. The case describes the development of a reinvestment strategy for improving the earthing systems for lightning exposed MV/LV transformers in a Norwegian distribution grid.

The paper also discusses the use of decision support tools for taking into consideration different decision criteria like economy, quality of supply, reputation, safety. Examples on how Multi-Criteria Decision Analysis can be used in decision making will be presented and discussed.

2. A FRAMEWORK FOR RISK BASED DECISION MAKING

This section proposes a framework for risk based decision making to be used in the process of selecting among strategies for reinvesting in large groups of distribution assets.
The framework is illustrated in the flowchart in Figure 1 and implies several steps, which will be further discussed in the subsequent chapters.

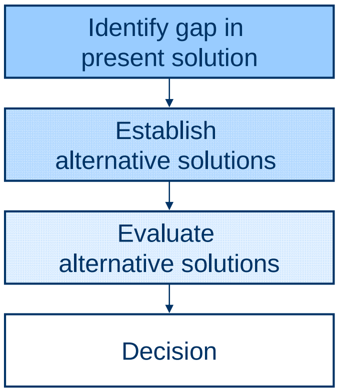

Figure 1 Framework for risk based decision making

2.1 Identifying the 'gap' in present solution

The first step - "Identify gap in present solution" - incorporates an analysis and mapping of risks of the present solution, identifying what is the gap between the present and a desired situation. This analysis will concentrate on aspects which are relevant for a selected number of important consequence categories.

2.1.1 Risk mapping

Risk can be defined as the "*Combination of the frequency, or probability, of occurrence and the consequence of a specified hazardous event*" [1].

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The mapping of the risk related to an asset, or a category of assets will imply to identify:

- The unwanted events with impact on different consequence categories
- The corresponding probabilities and consequences

Risk can be divided into different categories [2-4], for instance economy, quality of supply, safety, reputation and environment. The different categories of risk are more or less linked together (e.g. poor quality of supply can give the company a bad reputation and also imply direct economic loss through CENS).

2.1.2 The risk matrix

A commonly used tool to structure and visualise the risk related to unwanted events is the risk matrix, illustrated in Figure 2. The matrix shows the consequence of an event on one axis and the probability on the other. The combination of probability and consequence is used then to characterize the risk as more or less acceptable.

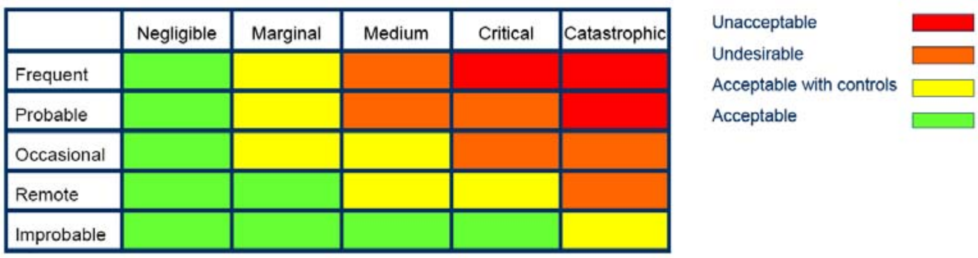

Figure 2 Risk matrix, an example

2.1.3 Data quality and relevance

History of previous failures and faults can be sources of information to say something about the probability and consequences of future failures. Other information, particularly system properties (load flow, redundancy, etc) and information about the components' condition and their exposure to stress are also highly relevant. This may include results from condition monitoring, age of the components, usage, operating environment, time since the last maintenance /inspection, etc. History concerning complaints /negative publicity and relevant events (e.g. personal injury) is also of interest.

However, when the information available is incomplete or irrelevant in a decision situation, expert judgment will be necessary.

2.2. Establishing alternative solutions

Based on the analysis of the present situation, alternative solutions to the problem are established. The alternative solutions should address different possibilities for filling the risk related gap identified for the present solution. The alternative solutions should incorporate both probability and consequence reducing measures in order to control risk. The alternatives will further be evaluated on how they fulfil the requirements of closing the identified gap.

2.3. Evaluating alternative solutions - MCDA

The results from the evaluations of the different alternative solutions will form the input for the final stage: the decision. This can be performed through an informal or qualitative evaluation of the alternatives, or by using a formal decision framework supported by multi criteria decision analysis (MCDA) [5]. The power of MCDA is in facilitating the modelling of decision makers' preferences in a decision situation. These preferences are formed based on the information available and are in fact the ultimate ingredient to the final decision.

One of the MCDA theories most used in practice is the Multi Attribute Value Function Theory (MAVT). In short this theory assumes that in a decision situation, the decision maker has some underlying preferences, for each decision alternative (a) and that these preferences can be modelled through a function:

$$V(a) = \sum_{i=1}^{m} w_i v_i (x_i (a)) \tag{1}$$

where

- $V(a)$ is the overall value (score) for alternative *a*
- $x_i(A)$ is alternative *a*'s performance for attribute i
- $v_i(\cdot)$ is the partial value (score) reflecting the performance for attribute *i*
- w_i is the weight (importance factor) for attribute *i*

The application of MAVT in practice consists of two steps: identifying the scores (v_i) and the identifying weights (w_i) based on dialogs with the decision maker. These elements will then be used to calculate overall values for alternatives and the alternative with highest value will be the recommended one.

3. CASE-STUDY

This case illustrates how a risk-based decision making approach can be used for selecting among different reinvestment strategies for improving MV/LV transformers' earthing system. The example shows the process from the point of collecting data and structuring the problem, up to the selection of a strategy. The case concerns earthing systems for MV/LV transformers, and is adapted from data and information provided by a Norwegian distribution company. Some simplifications and assumptions have been made by the authors.

3.1. Identifying the 'gap' in present solution

Lightning is an important cause of outage and equipment damage in distribution networks. This case study illustrates a risk-based strategy making for improving the earthing systems of MV/LV transformers situated in a region highly exposed to lightning.

The analysis was triggered by massive transformer failures caused by a thunderstorm in 2002. Approximately 140 MV/LV transformers in a small region in Norway were damaged, resulting in customer interruptions, negative publicity and economic loss for the distribution company.

The events revealed that the existing earthing system for the transformers in the area was of poor quality, and a project was launched in order to find a solution for improving the earthing system, to reduce possible future damages caused by lightning in the area. The possible negative impact on quality of supply and public opinion was a major concern for the network company.

3.1.1 General information

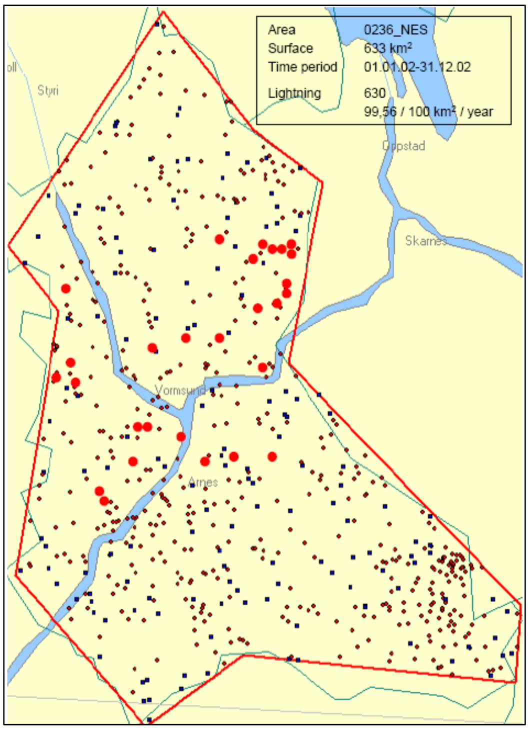

Figure 3 Lightning activity in Nes municipality in 2002[7]

History and statistics concerning previous failures and consequences are important sources of information for risk estimation. Information about the transformers condition (age, information from inspections / condition monitoring etc) and design is also highly relevant as well as information about system properties, including expected CENS per MV/LV substation.

Lightning caused massive failures of MV/LV transformers in Nes municipality in 2002. Figure 3 shows the lightning activity in the area (small dots), together with the transformers that failed in 2002 (bigger red dots).
The municipality is situated in an area where the lightning activity is high compared to the rest of the country. However, the company had not experienced such major events in the past – thus the risk of insufficient earthing had not been previously addressed.

3.1.2 Risk mapping and categorization of assets

The risk associated with different MV/LV transformers may vary, both in terms of probability and consequence of failure. This is because the estimation of these two parameters is highly dependent on the geographical location of each transformer (affecting the probability for a transformer to be hit by lightning) and transformer's position/importance in the topology of the distribution system.

Four groups of MV/LV transformer have been defined based on a risk identification supported by information about lightning activity and system topology. The categorisation is shown in Table 1. Transformers in group 1A have a high probability of failure due to lightning and high impact on economy/reputation, and have thus the highest risk.

Table 1 Index for categorisation of the MV/LV transformers

	HIGH	LOW
Probability of failure due to lightning	1	2
Economy / Reputation	A	B

The economic risk is here considered to be a combination of: the investment cost in new system components (earthing equipment), the cost of repair and the cost of energy not supplied (CENS). Moreover, a major concern for the network company in this case-study was public opinion, since network failures in the area had caused negative publicity in the local press and politicians advocating for action. A good reputation can be also considered as a corporate value in terms of goodwill and branding, and this can be particularly important for non-monopoly business areas such as energy sales, broadband etc.

For this study, a risk matrix was used to further detail the risk the different groups of MV/LV transformers are exposed to. The consequence category chosen here is, again, the combination of CENS and reputation. An interpretation of the risk matrix is that transformers in group 1A have the highest risk, followed by 2A/1B, whilst transformers in group 2B have the lowest risk, and should hence be given less priority.

Figure 4 Risk matrix for characterising the risk due to lightning, for different groups of MV/LV transformers, in terms of CENS/reputation

3.2. Establishing alternative solutions

The following alternatives were identified in order to deal with the risks associated with the remaining MV/LV transformers in the region under study.

1. **Do nothing**
2. **Improve all** - improve the earthing system for all transformers in the area (approx. 400 transformers)
3. **Improve 1A** - improve the earthing system for all transformers in group 1A (approx. 80 transformers)
4. **Improve A, 1B, 2A** - improve the earthing system for all transformers in groups 1A, 1B and 2B (approx 250 transformers)

In order to evaluate the impact of these alternative strategies on risk exposure, the following aspects have been considered: the investment cost in new system components (earthing system), the repair cost, the cost of energy not supplied (CENS) and company reputation. The analysis was done for estimating 'what will happen next time the lightning strikes'. The following table summarizes the alternatives and their performances in terms of the four criteria considered.

Table 2 Decision alternatives and their performances

Criteria	*Alt. 1* **Do nothing**	*Alt. 2* **Improve all**	*Alt. 3* **Improve 1A**	*Alt. 4* **Improve 1A,1B, 2A**
Repair cost (k NOK)	~ 6000	0	~ 4500	~ 2000
Investment cost (k NOK)	0	7800	1660	5200
Reputation (qualitative)	Worse than today	Better than today	Unchanged/ improving	Improving
CENS (qualitative)	Highest	Lowest	Average	Less than average

Several assumptions have been made in order to estimate the different consequence categories, as in the following:

- The repair and investment costs are directly correlated with the number of transformers considered in each alternative.
- It was assumed that the investment cost and the repair cost given failure are the same for all the transformers considered, i.e.: the repair cost – 60 000 NOK/failure, and the investment cost - 20 000 NOK/ transformer. However, the uncertainty associated to these costs is different. While the total investment cost will incur 'now' and it is hence certain, the repair cost is an uncertain quantity being difficult to estimate because the exact number of transformers that will fail is not known. In this example, it was assumed that only around 25% of transformers with the existing earthing system will fail in the next storm. This is based on the observations from the 2002 storm.
- Reputation is also a criterion difficult to measure both in terms of consequence and probability. For this case study, the impact on reputation has been estimated qualitatively, based on general evaluations of company's reputation. It was assumed that future major power interruptions (which may happen in alternative 'do nothing') will lead to lower public opinion locally, which may also have an effect on the company's overall reputation. On the other hand, if no major interruptions will happen in the near future (situation which may occur due to investments in earthing systems, - alternatives 2, 3 and 4) then the local public opinion will remain unchanged on short term with better chances of improvement in the long run.
- Another consequence category difficult to estimate due to the high uncertainty, is the cost of energy not supplied (CENS). This is because it has been considered difficult to predict which are the transformers that will fail. However, according to the initial assumptions, failures of transformers in groups 1A and 2A have been considered to have higher impact on quality of supply to the consumers leading thus to a medium (average) cost of energy not supplied.

3.3 Evaluating alternatives

A MCDA approach was applied to model the decision process of selecting among the alternative solutions. The software OnBalance [6] was used for this purpose. The software implements the Multi-Attribute Value Theory described previously in the paper. This chapter presents examples on how preferences for decision alternatives in different criteria can be modelled and what kind of results one can obtain from such an analysis.

The MCDA analysis implies two main steps. First, alternatives have to be evaluated in terms of each criterion. Figure 5 shows how an example on how alternatives can be ranked on a scale from 0 to 100 in terms of two criteria – *Reputation* (defined qualitatively) and *Investment cost* (defined in monetary terms).

One can observe that while *Reputation* is described and judged in qualitative terms, the preferences for investment cost are represented by a piecewise linear function. In terms of reputation, the alternatives which have potential of improvement in public opinion have been preferred. When it comes to investment cost, the alternatives with lowest investment levels have been clearly preferred. One can observe that the slope of the preference function for this criterion varies on different cost levels, being the lowest for the highest cost levels, with a threshold of around 4000 kNOK.

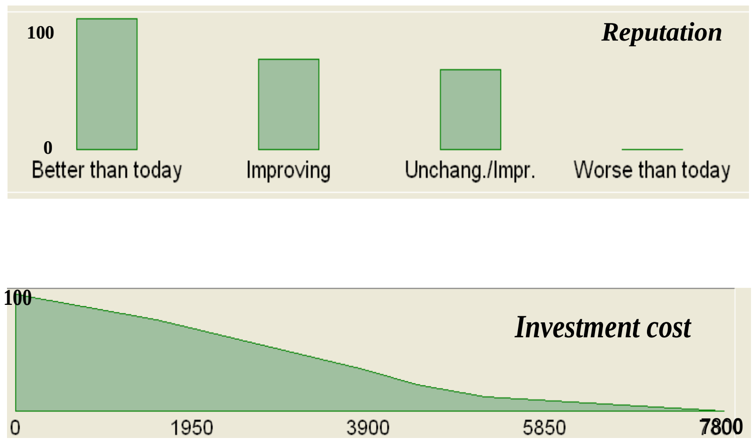

*Figure 5 Preferences for alternatives in **Reputation** and **Investment cost***

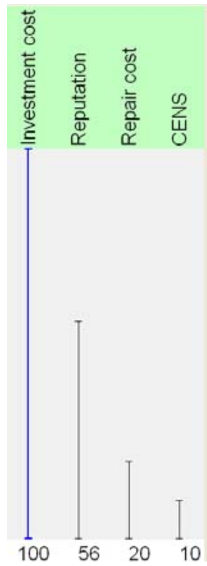

Figure 6 Weighting criteria

In the second step, criteria had to be weighted. OnBalance facilitates the comparison of criteria by trying to ascertain how much one would be willing to trade off in one criterion against another. This is done by selecting a reference criterion as yardstick (usually the most preferred criterion) and then weighting all other criteria accordingly. The weights and ranking of criteria used in this case study is presented in Figure 6.

Figure 7 summarises how alternatives 1-4 were judged with regards to the decision criteria. For example, alternative 1 is clearly the most preferred in terms of investment cost, but the least preferred in terms of reputation, CENS and repair cost.

Figure 7 Ranking alternatives in terms of criteria

The information in Figure 7 was then used to calculate overall values for each of the alternatives considered, as described by equation 1. Figure 8 shows the final ranking of alternatives, and illustrates how the preferences for criteria have contributed to the calculation of these values.

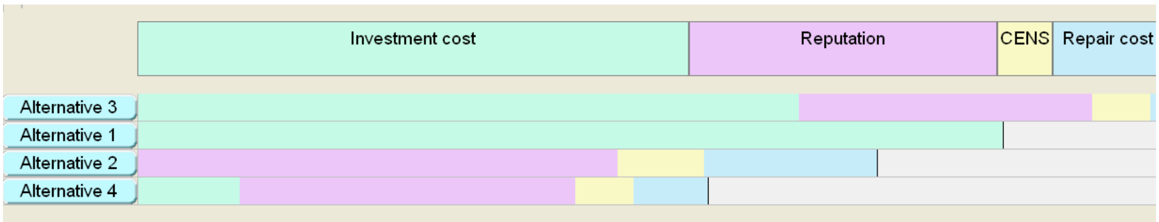

Figure 8 Final ranking of alternatives

Figure 8 shows that according to the initial set of preferences (scores and weights) alternative 3 (*Improve 1A* – the group of MV/LV transformers most exposed to risk) has the highest value, followed by alternative 1 (*Improve all*) and alternatives 2 (*Do nothing*) and 4 (*Improve 1A, 1B, 2A*).

The result of such an analysis would be the recommendation to improve the transformers in group 1A, which are the ones most exposed to risk. Such an action reduces the probability of negative incidents with regards to public opinion and CENS, moving the group downwards in the risk matrix (see Figure 4).

3.4 Additional decision support analyses

One of the advantages when using MCDA software is that one can easily see how the ranking of alternatives changes if the preferences are altered. In the example below three weighting scenarios have been defined in order to simulate how the ranking of alternatives will change.

The three scenarios, illustrated in Figure 9, are:

- the ***initial weights*** as presented above – with *investment cost* as the most preferred criterion
- ***weights'*** - with *repair cost* as the most preferred criterion.
- ***weights ''*** – with *reputation* as the most preferred criterion.

	Investment cost	Reputation	CENS	Repair cost	The Tree
Initial Weights	100	56	10	20	**186**
Weights '	24	50	30	100	**204**
Weights ''	70	100	25	20	**215**

Figure 9 Weighting scenarios

Figure 10 illustrates how the ranking of alternatives changes in different weighting scenarios. One can observe that alternative 2 (Improve all) becomes preferred, when the repair cost and reputation are chosen as the most important criteria.

When choosing to invest in earthing systems for all MV/LV transformers (alternative 2), the risk associated with these components changes from 'yellow' to 'green' in the risk matrix (see Figure 4)

It is also interesting to see that alternatives 3 and 4 change between the 2nd and 3rd place in the last two scenarios, because these two alternatives are sensitive to changes in preferences for repair cost and reputation.

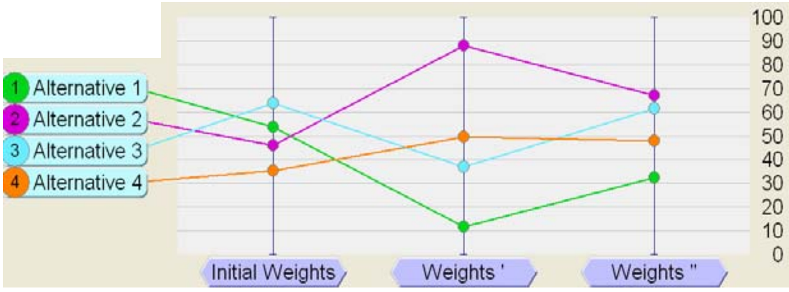

Figure 10 Ranking of alternatives in different weighting scenarios

However, alternative 3 seems to be as preferred as alternative 2 in the last weighting scenario, perhaps because of the improvements it brings in terms of reputation.

As a concluding remark, it is important to keep in mind that the recommendation of a MCDA analysis is highly dependent of the modelled preferences, and hence of the person that makes the judgements and evaluations with the MCDA tool. In a decision making situation it is advisable that this person is the decision maker in charge. Only in such a case, the results of the MCDA analysis will be representative for the decision makers preferences.

4. CONCLUDING REMARKS

This paper addresses the process of reinvestment strategy making, showing an application regarding reinvestment in earthing systems for MV/LV transformers exposed to lightning. A structured risk based decision making process is proposed in order to describe and compare how different strategies affect the system and the corresponding performances and risk. Risk matrices have been used for characterizing groups of transformers and multi-criteria decision analysis (MCDA) has been used to analyse different reinvestment strategies in terms of: investment cost, reputation, CENS and repair cost.

The challenge in this case study, and in general in real life decision situations, is to find relevant and sufficient data and statistics, applicable to the problem at hand. Very often expert judgements and 'gut feeling' should be used in combination with statistical analyses in order to compensates for insufficient data input.

This paper presents examples on how preferences for decision alternatives in different criteria can be modelled using MCDA, and also examples of what kind of results one can expect from such an analysis. The advantage of such an analysis is that it offers a way to structure and document the decisions made. However, it is important that the preferences modelled belong to the decision maker in charge, since the results are highly dependent on the modelled preferences.

The case study was built based on information provided by a Norwegian distribution company and additional assumptions made by the authors. The case shows the analysis process and advocates the use of MCDA as a valuable tool in offering better framework for decisions and better structuring and documentation of results.

Acknowledgements
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REFERENCES

[1] IEC 60300-3-9 Dependability management Part 3 Application guide Section 9 Risk analysis of technological systems.

[2] R. E. Brown and J. H. Spare, "Asset Management, Risk, and Distribution System Planning," presented at IEEE PES Power System Conference and Exposition 2004.

[3] D. E. Nordgård, O. Gjerde, K. Sand, M. D. Catrinu, J. Lassila, J. Partanen, S. Bonnoit, and J. Aupied, "A risk based approach to distribution system asset management and a survey of perceived risk exposure among distribution companies," presented at CIRED - 19th International conference on electricity distribution, Vienna, 2007.

[4] K. Sand, O. Gjerde, and D. E. Nordgård, "Current risk exposure in the distribution sector. Initial study.," SINTEF Energy Research, Trondheim TR A6576, 2007.

[5] V.Belton, T.J.Stewart, "Multiple criteria Decision Analysis – An integrated approach," Kluwer academic Publishers, 2001.

[6] OnBalance – Multi criteria Decision Analysis Software accessible at: *http://www.krysalis.co.uk/ob_home.asp*

[7] SINTEF Energy Research Database on lightning activity.
More info: http://www.sintef.no/content/page1.aspx?id=3204