EXPERIENCES USING QUANTITATIVE RISK ASSESSMENT IN DISTRIBUTION SYSTEM ASSET MANAGEMENT

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ABSTRACT
The paper reports on the use of quantitative risk assessment for decision support in distribution system asset management. The total risk picture for distribution companies includes various risks, and there is a need to have methods to analyse also other risks than reliability. Quantitative risk assessment methods can utilise company expert knowledge in an explicit manner and provide a better basis for risk-informed decision making.

INTRODUCTION
Moving from an era of large scale system expansion, the electricity distribution companies now face the challenge of managing the existing assets of the distribution system infrastructure. The concept of asset management is hence adopted as the ruling paradigm among distribution companies [1, 2].

Within asset management distribution companies are developing strategies for maintenance and reinvestments, where the emphasis on cost effectiveness is balanced with other important dimensions of risk [3]. The understanding and management of risk are therefore key issues for distribution companies.

Traditionally much work within risk management in distribution systems has focused on the aspects of reliability. This focus is understandable, since it is surely an important feature of the electricity distribution infrastructure, being a focal area for regulatory authorities in many countries [4]. However, electricity distribution companies are also concerned with other important risks which are relevant for their business. This may typically involve risks related to economic performance, but also more intangible risks such as occupational safety, environmental impact, company reputation and more – see e.g. [1, 3, 5].

In contrast to the numerous methodologies developed for reliability calculations and decision support [6], one will find few application of structured analyses to support decisions concerning intangible risks. Experience from Norwegian utilities indicates however that a large percentage of decisions taken in MV electricity distribution are motivated by other risks than the reliability.

There is therefore a need to incorporate quantitative analyses covering other risks than reliability in the decision making context.

RISK ASSESSMENT
Almost every activity will include risk, and it will be impossible to achieve a complete elimination it. We need to decide whether to accept a given risk or not, and methods for risk analysis are hence important decision making tools.

Categories of methods for risk analysis
In general there are three main categories of risk assessment methods, as stated in Table 1, [7].

The three categories represent an increasing degree of formalism and modelling sophistication. The choice of method depends on the purpose of the study, the need for resolution, input data available, etc.

Table 1 Categories of methods for risk analysis [7]

<table>
<thead>
<tr>
<th>Main category</th>
<th>Type of analysis</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simplified risk analysis</td>
<td>Qualitative</td>
<td>Informal procedures that analyses risk using brainstorming sessions and group discussions.</td>
</tr>
<tr>
<td>Standard risk analysis</td>
<td>Qualitative or quantitative</td>
<td>More formalised procedures in which recognised risk analysis methods are used. Risk matrices are often used to present the results.</td>
</tr>
<tr>
<td>Model-based risk analysis</td>
<td>Primarily quantitative</td>
<td>Formal methods using e.g. event tree analysis (ETA) and fault tree analysis (FTA) are used to calculate risk.</td>
</tr>
</tbody>
</table>

Quantitative risk assessment methods are included in the third category, Model-based risk analyses.
**Status among Norwegian distribution companies**

The Norwegian regulations require that risk assessment shall be performed and documented when planning and operating electricity distribution systems. However, the regulations do not state how this should be done.

The general status for Norwegian utilities is that risk analysis is becoming more and more acknowledged as an important tool. The state-of-the-art among the distribution companies for the analysis of intangible risks is a combination of the two first risk analysis categories; where simplified risk analyses is combined with presentation in risk matrices [3, 8].

**Quantitative risk analysis using bow-tie models**

QRA will provide an explicit representation of cause / effect relations, and give numerical estimates for the risk.

Different QRA-methods are available, see e.g [7]. In the following case study a bow-tie model is chosen for modelling the risk. The choice is made due to the method’s ability to provide an intuitive modelling and yet requiring relative few numerical inputs.

Figure 1 shows the concept of a bow-tie model - combining the results from fault tree and event tree analysis in order to establish the cause/effect relations related to a specific undesired event. $B_i$ represents basic initiating events in the fault tree analysis leading to a specified undesired event, and $C_j$ represents possible end events resulting from the event tree analysis. $C_\Sigma$ are the aggregation of all end events into a common risk measure.

**Problem description**

MV/LV transformers are located throughout the distribution system, and they typically contain 150-300 litres of oil depending on their MVA rating. The case evaluates environmental risk related to oil spill from distribution transformers located within the drainage basin of drinking water reservoirs.

**Risk modelling**

A characteristic of such decision problems is that it is often difficult to find statistical material which can provide valid support in choosing numerical values to use in the modelling. We will therefore have to rely on input from expert judgment [9, 10]. *All numerical data used in this case study is hence based on the judgment of company experts and the analyst.*

**Fault tree analysis**

Through discussions with company experts two main failure modes have been identified:

- Oil spill due to degradation of the transformer casing
- Oil spill due to strokes of lightning destroying the transformer.

The two failure modes can be modelled in a fault tree as shown in Figure 2, contributing to the top event; “Oil spill from transformer”.

The following data have been chosen to be used for the purpose of this analysis:

- $\lambda_{\text{Degradation}} = 2.0 \times 10^{-3}$ (Estimated failure rate due to degradation; Approx. 1 - 5 out of 1500 transformers have a leakage due to degradation each year)
- $\lambda_{\text{Lightning}} = 1.5 \times 10^{-3}$ (Estimated failure rate due to lightning; Approx 2 – 3 out of 1500 transformers experience breakage due to lightning each year)
- $\tau_{\text{inspection}} = 1$ year. Maintenance interval for inspection of transformers.

![Figure 1 Conceptual bow-tie model](image1)

![Figure 2 Fault tree for the risk study](image2)
The unavailability due to the basic events is modelled as given in equations 1 [11] and 2:

\[ q_{\text{Degradation}} = \frac{\lambda_{\text{Degradation}} \cdot \tau_{\text{inspection}}}{2} \]  
\[ q_{\text{Lightning}} = \lambda_{\text{Lightning}} \]  

Based on the above given data, and assuming independence between the different basic events, the unavailability for the top event ‘Oil spill from transformer’ is estimated to be 0.0025. Given a case where a company have 25 transformers within the drinking water drainage basin, this gives 0.0625 occurrences of the top event per year. I.e. one can expect an event occurring on average every 16 years.

**Event tree modelling**

In order to establish an event tree model – see Figure 3 - the following potential barriers are considered:
- Whether there is an oil collector present
- Whether there only a limited amount of oil which leaks (< 10 litres)
- Whether the transformer is located far from a waterway (stream or river) leading directly to the drinking water reservoir.

The numerical estimates chosen for these barriers are:
- \( q_{\text{oil collector}} = 0.9 \), i.e only 10% of the transformers in the area have oil collectors underneath
- \( q_{< 10 \text{ liter oil spilled}} = 0.8 \), i.e. in only 20% of the cases the oil spill are less than 10 litres
- \( q_{\text{away from waterway}} = 0.6 \), i.e. 60% of the transformers are located just near a stream or river leading directly into the drinking water reservoir.

Based on the results from the fault tree analysis, the event tree in Figure 3 and the probability estimates for the barriers, the results presented in Table 2 are obtained.

**Evaluation of the results:**

**Health:** The impact of the health of people drinking the water is assumed to be neglectable due to the fact the drinking water reservoir contains enormous amounts of water – but there will always be uncertainty related to such assumptions. If the oil spill occurs at an unfavourable spot, the impact can at least be noticeable.

**Reputation:** The distribution company considers the reputational impact to be the greatest risk in this case. Even small oil spills will be highly visible on the water surface – and it will have a negative impact on the distribution company’s reputation among the general public and other relevant stakeholders.

**Possible ways of mitigating the risk:** The QRA will not give an answer to whether the risk is acceptable or not – this decision must and should be taken by the decision maker. However, the QRA helps to structure knowledge and various assumptions into a transparent risk analysis framework.

Based on the results – acknowledging the uncertainty related to the results – there are several possible actions which can be identified even at this stage:

**Figure 3: Event tree model for possible outcomes following Oil spill from transformer**

**Table 2  Results from the event tree analysis**

<table>
<thead>
<tr>
<th>End event</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated Oil spill [litres]</td>
<td>0</td>
<td>1</td>
<td>10</td>
<td>100</td>
<td>250</td>
</tr>
<tr>
<td>Frequency of occurrence</td>
<td>0.006</td>
<td>0.005</td>
<td>0.007</td>
<td>0.018</td>
<td>0.027</td>
</tr>
<tr>
<td>Expected time between occurrences [years]</td>
<td>167</td>
<td>200</td>
<td>143</td>
<td>56</td>
<td>37</td>
</tr>
<tr>
<td>Expected annual oil spill</td>
<td>0.00</td>
<td>0.00</td>
<td>0.07</td>
<td>1.80</td>
<td>6.75</td>
</tr>
</tbody>
</table>

The total expected annual oil spill to the drinking water reservoir is 8.6 litres. The most critical event with an oil spill of 250 litres will expectedly occur approximately every 37 years.
- Taking a proactive position concerning the replacement of old transformers in the area in question - replacing with transformers with environmental friendly types of insulation oil.
- Prescribe higher attention to inspection of transformers located within the drainage basin of drinking water reservoirs in order to identify severe degradation at an early stage.
- Performing a more thorough risk evaluation with respect to the chance of direct lightning strikes, and possibly improving transformer earthing in order to get at better protection of the transformers.
- Improving emergency preparedness concerning oil spills, having equipment ready and training in cleaning up oil spills.

The QRA model can be used to simulate the effects of the various mitigating efforts, e.g. relocation of transformers, construction of oil collectors, etc.

CONCLUDING REMARKS

This paper has presented an application of quantitative risk assessment used for decision support, in order to provide structured risk analysis also for risks other than reliability.

It is the authors’ opinion that it is beneficial to use quantitative risk assessment methods to analyse some selected risk problems. The main motivation for this is to increase understanding of the risk problem, to structure and document the risk assessment process, and hence provide an improved basis for risk-informed decision making.

An formal risk modelling as provided by a bow-tie model may also be of help to identify solutions to risk problems, addressing both the probability of occurrence and the potential consequences. It is also efficient with regards to obtaining quantitative measures on the differences between various solutions.

Among the challenges of using QRA is the difficulty in finding numerical input parameters to use in the modelling. Experience shows that statistical material will rarely be available, and one must therefore rely on expert judgment in the analysis process. Approaches using QRA will also be more laborious and time-consuming.

Finally it should be emphasised that QRA should not be the sole basis for decisions regarding risk, but rather be used as one of the inputs to the decision process, contributing to making decisions risk-informed.

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REFERENCES