EXPERIENCES USING QUANTITATIVE RISK ASSESSMENT IN DISTRIBUTION SYSTEM ASSET MANAGEMENT

Dag Eirik NORDGÅRD
Norwegian University of Science and Technology – Norway
Dag.E.Nordgard@elkraft.ntnu.no

Geir SOLUM
Trondheim Energy – Norway
Geir.Solum@trondheimenergi.no

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 comprehensive 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 in their asset management approaches.

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. However, electricity distribution companies are also concerned with other important risks being 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, 4].

In contrast to the numerous methodologies developed for reliability calculations and decision support [5], one will find few application of structured analyses to support decisions concerning intangible risks, even though experience from Norwegian utilities indicates 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 analyses covering also other risks than reliability in the decision making context.

This paper will first give a short description of categories of methods which are available for risk analysis, also stating today's practice among Norwegian distribution companies. To illustrate the use of more formal quantitative risk assessment (QRA) a case is provided to illustrate the use of a bow-tie model on a distribution company decision problem – addressing environmental risk. The paper concludes with remarks concerning the applicability of QRA for decision support in electricity distribution companies, and what is seen as main benefits and challenges of using such methods.

RISK ASSESSMENT

Almost every activity will include some kind of risk, and even though striving to reduce it, it will be impossible to achieve a complete elimination of risk – and hence we will always face the problem concerning the acceptability of a given risk; if the perceived benefits outweigh the risk.

Categories of methods for risk analysis

In general there are three different main categories of risk assessment methods, as stated in Table 1, [6].

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

Table 1 Categories of methods for risk analysis [6]

Main category	Type of analysis	Description
Simplified risk analysis	Qualitative	Informal procedures that analyses risk using brain-storming sessions and group discussions.
Standard risk analysis	Qualitative or quantitativ e	More formalised procedures in which recognised risk analysis methods are used. Risk matrices are often used to present the results.
Model-based risk analysis	Primarily quantitativ e	Formal methods using e.g. event tree analysis (ETA) and fault tree analysis (FTA) are used to calculate risk.

Quantitative risk assessment methods are included in the third category, *Model-based risk analyses*.

Status among Norwegian distribution companies

The Norwegian regulations state that risk assessment shall be performed and documented when planning and operating electricity distribution systems. 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, 7].

Quantitative risk analysis using bow-tie models

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

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_Σ are the aggregation of all end events into a common risk measure.

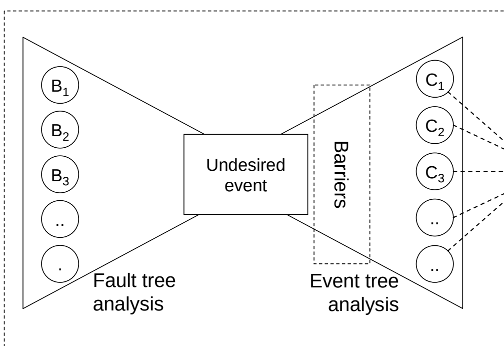

Figure 1 Conceptual bow-tie model

Different QRA-methods are available, see e.g [6]. In the case study in this paper a bow-tie model is chosen for modelling a risk problem. The bow-tie model is used due to its ability to provide a intuitive modelling and yet requiring relative few numerical inputs.

To illustrate the application of QRA as input in electricity distribution decision making, a case has been established. The case is an example of a risk related discussion which may appear for a distribution company.

We emphasise that the case is made for illustrative purposes, and that it does not represent the decision basis for a real decision.

CASE STUDY

Problem description

MV/LV transformers are located throughout the distribution system, typically containing 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 often difficult to find statistical material which can provide valid support in choosing numerical values to use in the modelling. One will therefore have to rely on input from expert judgment [8, 9]. *All numerical data used in the 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, *and*
- Oil spill due to lightning strikes 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*".

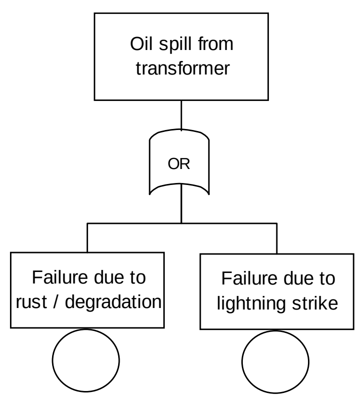

Figure 2 Fault tree for the risk study

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

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

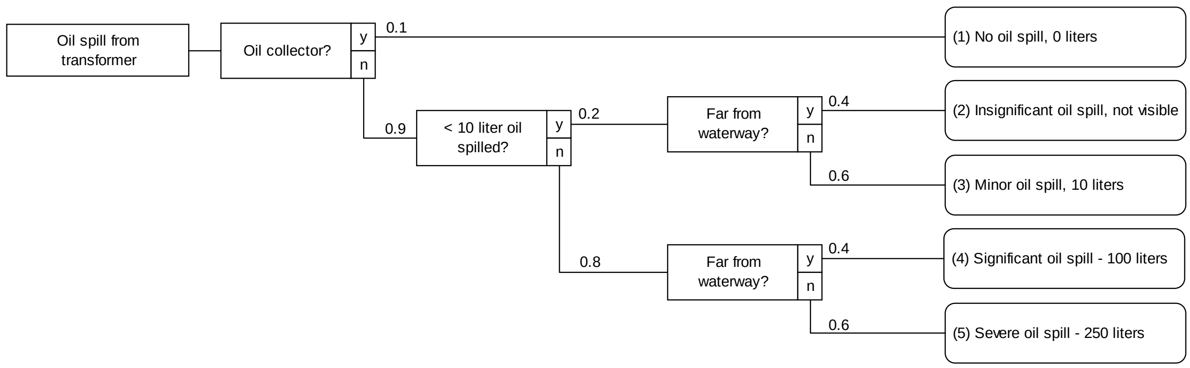

Figure 3: Event tree model for possible outcomes following *Oil spill from transformer*

The unavailability due to the basic events is modelled as given in equations 1 [10] and 2:

Basic event 1
$$q_{Degradation} = \frac{\lambda_{Degradation} \cdot \tau_{inspection}}{2} \quad (1)$$

Basic event 2
$$q_{Lightning} = \lambda_{Lightning} \quad (2)$$

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:

- $q_{oil\ collector}$ = 0.9, i.e only 10 % of the transformers in the area have oil collectors underneath
- $q_{< 10\ liters}$ = 0.8, i.e. in only 20 % of the cases are the oil spill less than 10 litres
- $q_{away\ from\ waterway}$ = 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 and the barriers, the results presented in Table 2 are obtained.

Table 2 Results from the event tree analysis

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

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.

Evaluation of the results:

Health: The impact of the health of people drinking the water is assume 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:

- 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 earlier stage.
- Performing a more thorough risk evaluation with respect to the chance of direct lightning strikes, and possibly improving earthing in order to get at better protection of 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.

CONCLUDING REMARKS

This paper have elaborated on the application of quantitative risk assessment used for decision support, in order to provide structured management of risk also for risks other than reliability.

It is the authors' opinion that it can be 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 explicit risk modelling as provided by a bow-tie model may also be of help to find 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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