A RISK BASED MODELING APPROACH SUPPORTING LONG TERM MAINTENANCE AND REINVESTMENT STRATEGY DECISION MAKING

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ABSTRACT

The paper presents a new modelling approach which can be used to evaluate risk exposure on the strategic level in a distribution company. The approach represents a top-down concept starting with the total asset base, splitting it into archetypes and simulating risk and maintenance and reinvestment costs for each archetype. A case study is used to illustrate the approach.

INTRODUCTION

Maintenance and reinvestment strategies are important tools to manage the risk in the distribution networks [1]. The objective of such strategies is to optimally allocate resources among various assets, and thus prioritizing assets that are more likely to induce larger risk exposure in the system. This paper outlines a modelling approach which supports maintenance and reinvestment decisions in electricity distribution systems, mainly seen from a company strategic perspective.

THE MODELLING APPROACH

The approach adopted is a top-down approach starting with the total asset base, splitting it into asset archetypes (categories) and simulating risk, costs and return for each archetype. The approach has a lot in common with portfolio management found in the financial sector, being a management approach for analyzing, selecting, monitoring, and measuring the performance of assets that have been placed together. The fundamental idea is to maximize a company's return, within an acceptable level of risk. This requires quantifiable estimates for both the risk and return.

The top-down modelling and simulation approach is shown in Figure 1. The asset base includes all the main distribution system components (e.g. cables, overhead lines (OHLs), transformers and more). The data source of the asset base will typically be the Network Information System (NIS) of the distribution company.

The different steps of the approach are described in the following.

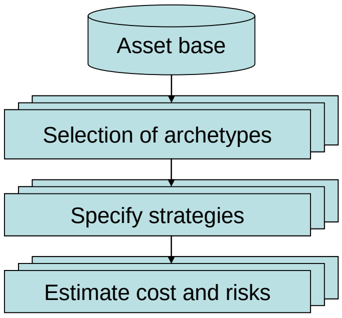

Figure 1 Modelling approach

Selection of archetypes

Each asset has a unique function in the distribution system and can often be considered non-redundant. Undesired events like a failure of one or several assets may lead to significant consequences on economy, reputation, safety or the environment. However, not all assets pose the same risks and therefore, not all assets deserve the same level of attention.

It would be a very comprehensive task to make asset management decisions by analysing separately every single asset in the system. Some kind of grouping of the assets is thus necessary so that similar assets can be subject to the same asset management strategy. A risk assessment process will lead to the identification of asset *archetypes*, varying from the most 'risky' assets to assets that pose negligible risk. In this context, archetypes are defined to be items with similar characteristics that will be subject to the same asset management strategy.

The construction of the different archetypes is based on a top-down approach; starting with identifying main system levels like MV system, LV system, Substations etc. The process leads to a risk differentiated asset tree structure as illustrated in Figure 2, where the categorisation uses five parameters to construct the archetypes:

1. System or voltage level (e.g. MV).
2. Main components (e.g. cables).
3. Component types (e.g. XLPE cables).
4. Component condition (e.g. health index=1).
5. Component Cost Energy Not Supplied (e.g. CENS risk = High).

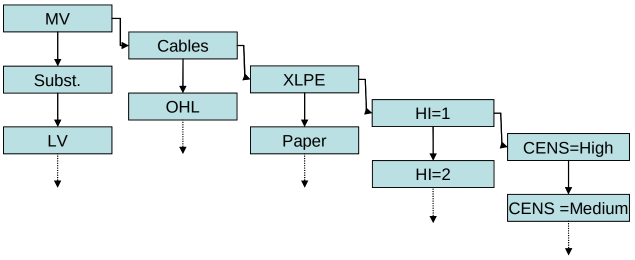

Figure 2 Example of a risk differentiated asset tree structure

The asset tree in Figure 2 is said to be risk differentiated as risk parameters like condition and interruption costs (CENS) are used for the categorisation.

The classification might be done based on asset data from:

- Component archive (name plate data, etc)
- Maintenance system (inspection and condition monitoring data)
- Various simulations (e.g. reliability analyses)
- Operating conditions (location, redundancy)

One main property for the selection of archetypes is that it is user-defined and dynamic – reflecting the varying needs for different analyses. A specific predefined asset tree structure can thus not be recommended.
The tree structure might also be different for different risks – as a distribution substation may not end up in the same archetype from a safety risk perspective as from an interruption cost perspective.

The archetypes should be constructed from the number of parameters that are relevant for the scope of the study. For some assets, the asset tree structure might be quite deep using many categorisation parameters. For others it might be quite shallow constructed only from few parameters.

Specifying Strategies

The next step in the approach given in Figure 1 is to choose maintenance and reinvestment strategies for the different archetypes. All assets in one selected archetype will be subjected to the same strategy when the risks and costs are to be evaluated. The types of strategies that are of main interest are:

- Preventive maintenance (time based, condition based)
- Corrective maintenance
- Reinvestments.

Preventive maintenance (PM) is maintenance activities carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item. Corrective maintenance (CM) is always carried out after a fault when an asset is not longer able to perform the required function. As an example, an overhead line might have many damages i.e. deviations from ideal state, but still being able to perform its required function. Required function should be interpreted in a somewhat broad sense; an overhead lines required function is not only to be able to transport electricity, but also other functional requirements such as being able to withstand a fifty year wind stress without a failure, wooden poles should be safe to climb etc.

Reinvestments are not a part of maintenance, but they are closely related as observations from maintenance activities might lead to reinvestments.

Estimation of risk and cost

The last step in the approach given in Figure 1 is to estimate the risks and costs for the archetype and its chosen strategies. As asset management is a long term process with time horizon of typically 30-100 years (due to the long life time of the assets), strategic decisions taken today should consider a reasonable long planning period, e.g. next 30-50 years.
To estimate risks, various risk indices needs to be specified for different asset categories. A risk indicator is a parameter which provides information about risk, addressing probability aspects or consequence aspects or both.

OVERHEAD LINE CASE STUDY

For the simulation of strategic risk exposure for various maintenance and reinvestment strategies, a software prototype tool has been developed, [2].

In order to estimate how risks evolve over time there is a need for a representation of decreasing asset conditions – assuming a correlation between condition deterioration and the probability of failure for the assets. In the prototype a four state life curve is used; describing the deterioration of an asset from new condition (state 1), via degradation states (states 2 and 3), to a critical condition which is reached at the end of state 4. Failure occurs when leaving condition state 4, entering the failure state, [3]. This life curve modeling is illustrated in Figure 3.

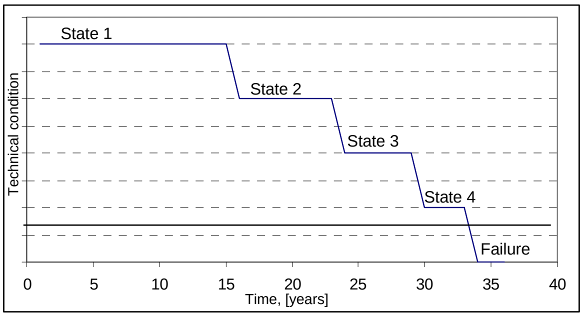

Figure 3 Life curve modeling

The duration of the condition states will typically be determined through expert opinion – supported by condition monitoring results and failure statistics if available and applicable, [3].

The simulations are performed with basis in information obtained from the network information system (NIS) – complemented with information concerning technical condition on the 1-4 state scale as described above.

Description of the case

A simulation have been performed for a selection of 11 kV overhead lines for a distribution company – to investigate how two different maintenance strategies affect the costs and risk - showing how the costs evolve and how the different strategies affect the risk. In the prototype tool it is assumed that reinvestment is performed when end-of-life is reached at the end of condition state 4 in Figure 4. The effect of PM is included as a 3 year leftward shift in the life curve in Figure 3. For the PM strategy, a time based strategy is assumed – with a 10 year interval between maintenance interventions. The parameters used for the estimation are shown in Table 1.

Table 1 – Estimation parameters for the CM and PM strategies

	CM strategy	PM strategy
PM [cost / km]	-	25
Maintenance interval, [years]	-	10
Repair [cost / fault]	50	50
Reinvestment [cost / km]	500	500
Discount rate, [%]	5	5
Time frame, [years]	30	30

The asset base consists of approx. 3200 asset (mostly cables and OHLs) provided from the NIS of a small Norwegian DSO. The asset archetype selected for this example case, are 11 kV OHLs. Figures 4 shows how the estimated costs develop over time for the corrective (CM) and preventive maintenance (PM) strategies.

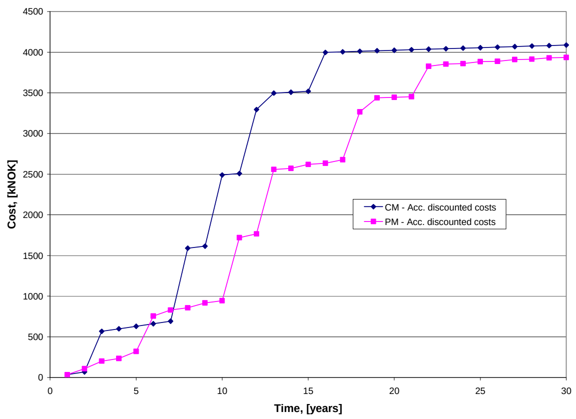

Figure 4 Accumulated discounted costs for PM (red curve) and CM (blue curve) strategies.

Figure 4 shows that for the chosen simulation settings the PM strategy will result in least accumulated discounted costs; mostly due to the fact the reinvestments are delayed due to the effect of PM activities.

The model also simulates the effect of the different strategies on various risks. As an example the estimation of reputation risk is described in the following.

Estimation of reputation risk

To estimate reputation risk, each of the assets have been assigned a reputation risk category; *Low*, *Medium* or *High*. The risk category is used to choose a base risk value for each asset i within the selected archetype. The values are chosen to be unlabeled numbers 1, 5 and 10 for the *Low*, *Medium* and *High* categories respectively. The risk is further scaled according to the health index for each asset for year j. The health index scaling is chosen to be the same as the health index itself, namely numerical values 1-4 for the corresponding conditional states.

The reputation risk for year j for all assets i can now be computed as:

$$Risk_{year\ j} = \sum_{i=1}^{n} HealthIndex\,Scaling_i \cdot Base\,risk\,value_i$$

The asset health indexes will change through the simulation timeframe (as the assets deteriorate), giving a risk index which changes as time evolves.

The results from the reputation risk simulations are shown in Figure 5.

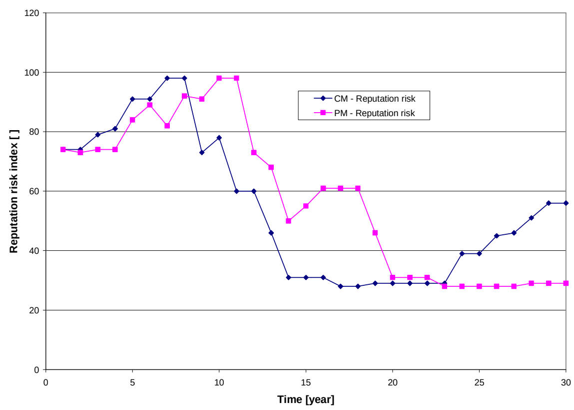

Figure 5 Reputation risk score for PM (red curve) and CM (blue curve) strategies.

Note that a low score i.e. low value of the reputation risk index in Figure 5 is a positive outcome i.e. a low reputation risk.

As reinvestments take place earlier in the period of analysis, the reputation risk score is simulated to be better for the CM strategy compared to the PM strategy for a large part of the simulation timeframe.

MODEL EVALUATION

To investigate the relevance, advantages and barriers for implementation of such a concept, some of the DSO partners in the development project were asked to give their views. The response is summarized below.

Relevance of such a model

DSO's have an ambition to use risk indicators as input to their decision base, and a strategic simulation tool will of useful in order to simulate presumed effects of various maintenance strategies for various assets. To succeed in the strategic management of several hundred thousands assets, it is imperative to group the asset base into a limited number of archetypes and use risk indicators for each archetype in decision making. A long term objective will be to generate maintenance plans using the data from the network information system in combination with estimated risk indicators and triggering rules. In such a context will a strategic simulation tool be valuable to e.g. perform scenario analyses and to explore the sensitivities with regards to parameter changes.

Perceived advantages

A strategic simulation tool can be a valuable addition to today's practices which is mainly based on expert judgments. A structured approach is a prerequisite for good risk management in DSOs. It is expected that such an approach can contribute to long term reduced costs for maintenance and reinvestment planning, implementation, and documentation.

Potential barriers for implementation

A tool as described in this paper will be a strategic tool used by only a limited number of dedicated planners and decision makers within the company. Such a tool will thus be reserved for expert use and it is not necessary to have it widely implemented in the organization. The experts should have the relevant training and knowledge, but implementation and training costs is expected to be limited.

The most important challenge for the use of such a tool as reported by utility partners is data quality. Network information systems and other utility databases contains large amount of data, but data are of uncertain quality and there are also many parameters that the systems might contain, that are not filled in. So, the required data might not be available and as data collection and quality assurance costs time and money, it would be preferable to use simpler simulation models requiring less data in the start-up period. To minimize the initial need for data and still provide useful results is an important goal to pursue as the experience from other modeling attempts show that you can end up with a very sophisticated model, but data are not available for practical use. A refinement of the data according to needs and experience is a task which should be pursued in the continual improvement loop of maintenance and reinvestment management.

CONCLUDING REMARKS

The paper has illustrated a modeling approach to evaluate risk exposure on the strategic level in a distribution company. The use of the approach is briefly illustrated by a case showing the feasibility of performing such analyses.

Distribution companies perceive such a modeling approach to be a useful addition to their asset management toolbox. There will however be challenges related to providing relevant high quality data as input to such a simulation model, as well as obtaining risk indices which provide credible results to be used in asset management decision processes.

The simulation prototype has shown the feasibility of performing modeling and simulations according to the overall procedure. It will however be further elaborated to improve calculation routines, modeling flexibility and user interface.

ACKNOWLEDGMENTS

The work reported in this paper has been performed as part of the research project 'Risk Based Distribution System Asset Management' at SINTEF Energy Research and NTNU, *www.energy.sintef.no/prosjekt/RISKDSAM*.

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