Summary

Forced by pressure from the regulatory authorities, network operators in the liberalized market are increasingly confronted with the need to reduce maintenance costs and expenses for replacement investments while ensuring system availability determined by performance indices in parallel. Measures to enhance efficiency alone do not suffice to fulfill these requirements. Rather, risk-based asset management is well suited to reduce costs while ensuring network quality at the same time. It analyses the reliability and (economic) importance of operating resources and estimates the monetary risk assessed over a longer timeframe. With the proven-in-practice risk-based asset management methodology developed jointly by A.T. Kearney and Salzburg AG, Austria, savings of approximately 15% of the controllable costs in the network can be achieved with nearly constant risk.

Introduction

The EU Directive 19961 introduced the principle of the free market for the generation, trading and distribution of electrical energy. In order to weaken the monopoly in the transmission and distribution networks and to force network operators to become more efficient, a deviation was taken from the full cost approach. The further path in deregulation stretches over a benchmarking market model (Germany) and benchmarking (Norway, England, Austria, etc.) through to penalty payments for energy not delivered on time (Norway, England, Argentina, etc.).

Each of these steps taken by the regulatory authorities increases the economic and technical risk for network operators tremendously. Experiences from countries that have already fully covered this ground reveal that especially the variable costs like operations and maintenance face a squeeze as capital costs can only be reduced over a longer time horizon.

The rapid reduction in costs as requested by the regulatory authorities can have a negative impact on the network’s quality and security. Customers should be provided with network quality for which they are also willing to pay. Neither an overly high nor an overly low network quality is in the interest of the customer.

Risk-based asset management now gives network operators an instrument to design strategies for maintenance and reinvestment with a predetermined risk and to allocate the limited cost budget optimally. In addition risk-based asset management provides deep insight into future network quality and can serve as a valuable starting point for negotiating distribution charges with regulatory authorities. Deployed the right way, risk-based asset management saves approximately 15% of the controllable costs in the network with nearly constant risk. In certain segments of the distribution network, potentials are even considerably higher. A.T. Kearney, in conjunction with Salzburg AG, designed a practice-oriented methodology for risk-based asset management that can essentially be used irrelevant of the type of business organization. In the following we will exemplify the application of the methodology in detail and then list the success factors for implementing risk-based asset management. Subsequently we will highlight very briefly the key aspects of risk-based asset management in transmission networks.

Methodology for risk-based asset management

The initial objective of the risk analysis is to quantify the (economic) risk monetarily and calculate the cost/risk development in the network for various maintenance and investment strategies over several years. The risk here is defined as the product emanating from the probability of occurrence of interference and the degree of damage when such interference occurs. The factor of the degree of damage maps the monetary dimension and will also be defined in the following as the importance of the operating resource.

The probability is dimensionless and is mapped as the reliability $R$ of an operating resource. The reliability

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indicates how probable the interference-free operation of a grid component is from the operational start up or respectively the last maintenance measure at a later point in time. The dimension \( R \) assumes figures between 0 (operating resource failures) and 1 (operating resource functions faultlessly with security) and is derived from the company’s hazard data (see [2] and [3]).

Confidence interval estimates flank the reliability analysis alongside the determination of statistical errors [4]. Systematic errors are also to be estimated in specific individual cases. "Security margins" are derived from the estimates, which must be adhered to in the strategy development. Dependencies of the single components from each other and network redundancies will then be analysed with the methodology of minimal cuts [3] and integrated in the reliability analysis.

The evaluation of the effectiveness of maintenance measures is subsequently to be reviewed in individual cases and focuses on the main causes of the malfunction and maintenance measures. Such analyses are always based on the joint consideration of causes and measures in that the impact of a measure on the respective cause of malfunction and the resulting reduction of the number of malfunctions are defined (see [5]).

As the second dimension of the risk analysis, the importance of the operating resource maps the extent of economic damage in the event the operating resource malfunctions. The single aspects of importance can be divided into three groups.

- Supply security-related importance: costs incurred by breakdowns due to energy not supplied (deficit energy). The extent of damage essentially depends on the network topology.
- Customer-specific importance: breakdowns can lead to recourse claims by customers, e.g. for production operations. In the future it is highly probable that regulatory authorities will impose penalties for energy not supplied (see [6] and [7]).
- Operating resource-specific importance: above average breakdown risks are incurred by single operating resources directly due to a high acquisition value or indirectly due to claims for damage compensation.

The relative allocation of operating resources in line with their importance with a predetermined budget already provides valuable action indicators (see [8]). The methodology presented here leads to a stable, relative allocation with a narrow database yet it also suffices far beyond with a broader database. Through the monetary dimension of importance and subsequently risk, an asset manager can assess the costs and benefits clearly when dimensioning the maintenance and replacement investment budget.

After analysing both dimensions, the actual risk in the network is identified. Given the long-term impact of maintenance and replacement investments, the development of life cycle costs and risks are estimated in a last step under the assumption of an array of maintenance and replacement investment strategies. The impact of the current business strategy must be compared with one or more risk-based strategies. All strategies whose risk development remains in an acceptable area or functions better can be considered for cost reduction. The development of costs/risks of various strategies forms the framework for the annual budgeting process.

Example

In the segment medium-voltage overhead lines, a saving potential of 22% of the maintenance costs p.a. was identified. The saving potential resulted from the reduction of single maintenance measures and replacement investments (Figure 2). By assuming a minimal increase in risks as opposed to the current strategy, e.g. the number of pole replacements p.a. was reduced.

![Figure 2: Savings potential in the medium-voltage overhead line network](image)

In the calculation of reliability, differentiation was made between breakdowns due to 'internal' causes (rotting wood, corrosion, etc.) and 'external' causes (atmospheric effect, external effect). Breakdowns due to internal reasons were registered according to individual components, e.g. support poles, angle support poles and span poles. Breakdowns due to external causes in contrast were directly allocated to a overhead line section. The number of breakdowns was low so that the hazard rate could be fixed constantly and the reliability \( R \) subsequently derived. The reliability function of an overhead line section emanated for

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R(t_1, t_2) = \exp(-\lambda_{t_1}) \cdot (1 - (1 - \exp(-\lambda_{2 SP} t_2))^{t_1}) \cdot \exp(-\lambda_{ES} t_1)^{t_1}.
\]

Here, \( \lambda_1 \) defines the hazard rate due to breakdowns from external causes to a main line section. \( \lambda_{2 SP} = \lambda_{2 SP} \) is the hazard rate due to internal causes to support poles (SP) as well as to span and angle support poles (SASP). \( T \) the number of support poles and \( A \) the number of span and

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2 We use the definition of reliability common in English-speaking countries, as the term thus defined represents the necessary dimension for the risk quantification. See [1] for a different approach.
angle support poles in the overhead line section. The occurrence of a malfunction in conductors, insulators, pole-mounted switches etc. due to internal reasons was negligible in this specific case. With regard to operating times, we differentiate between operating time since the last inspection ($t_1$) and operating time since the last revision (eventually pole replacement etc., $t_2$), motivated by the assumption that damages due to external reasons are discovered during inspections and then repaired (e.g. spliced cable due to lightening), whereas damages due to internal causes (e.g. decay on wooden poles) remain unidentified until a revision or a breakdown.

A modified load flow calculation defines the importance of single overhead line sections as the second dimension of the risk analysis. The maximum performance of the substations was multiplied with an average repair time, the coincidence factor and a mean distribution charge and added to eventual claims for damage compensation along the main line sections up to the respective transformer plant junction. The location of safety facilities was taken into account. In the given network importance figures of 10 € to 140.000 € per actual breakdown therefore resulted for single overhead line sections. At this point it was ensured that operating resources with higher accident risk (for example, road-crossings) received the respectively maximal importance figure and, in turn, are maintained as best as possible by any risk-based strategy. 78% of all overhead line sections revealed importance of less than 1000 € (figure 3). This starkly disproportionate allocation illustrates the potential of targeted risk-based resource control.

Figure 3: Reliability/importance matrix of the medium-voltage overhead line section (excerpt). Each point represents an overhead line section

After mapping the actual condition, the impact of various risk-based strategies and the currently valid strategy were calculated in simulations over the next 15 years or respectively until 2050. The risk-based strategies were selected in a way that the risk only increases minimally. One main result of the simulations concerned the networks’ obsolescence. Just like several other distribution networks, the network in our case example was expanded on a disproportionately large-scale in the 70s. That is why the operators were concerned the networks would become obsolete already without reducing costs and, in turn, trigger a breakdown and/or an avalanche of costs. However, this concern was invalidated. As the risk analysis pinpointed a longer life cycle than expected until now, an appropriate target age allocation will be achieved long-term with a risk-based strategy at lower cost (see strategy II in figure 4).

Figure 4: Age allocation (example: medium-voltage overhead line) and ensuing cost/risk scenarios of two strategies (smoothed)

Analogously to the outlined approach, models for risk-based strategy calculations can be developed in all relevant grid segments and branches and in the future, continually fine-tuned, improved and adapted with target-aligned data gathered.

Success factors for implementing risk-based asset management

In actual practice, it has been proven that adhering to the following factors is critical for successful implementation:

- Conduct a quick scan to determine grid segments with the highest optimisation potential (costs/expenditures, frequency of breakdowns), focus the analysis on prioritised grid segments
- Multi-tier approach in the risk analysis – first age-oriented reliability analysis, then differentiate according to operational condition and finally, integrate condition data
- Estimate the arising errors in the risk analysis and ensure adherence to security margins if strategy is adjusted
- Expand condition monitoring systematically in those areas where the cost/benefit ratio is meaningful
- 80:20 approach: initially only relative allocation of operating resources according to importance and comparison of the current strategy with an alternative risk-based strategy based on the relative risk value
- Early expansion of technical databases in order to approach risk thresholds more precisely thanks to more stable data.

Condition monitoring of operating resources can particularly not be carried out across all areas and simultaneously for all operating resources. Through the

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3 In addition to electricity we applied the methodology also in branches natural gas, district heating and water supply
multi-tiered approach, however, an estimate can be made after each step on which saving potentials can be achieved by more precise analysis. This also clarifies the segments in which and at which price condition monitoring is economically meaningful. An enlarged condition monitoring can be integrated in the analysis at any time without any difficulty.

The gradual implementation furthermore harmonizes ideally with an analogous build up of competencies in the network business division. The quick implementation of the concepts in practice and testing them avoids problems in motivating employees right from the start. A “black-box effect” and ensuing problems of acceptance also do not materialize: employees in the implementation team shape the transfer to practice themselves and are also involved in changes to the strategy. Expert workshops on technical issues lead to double benefits in that they realize a high acceptance of the methodology and lead to technically solid, practicable strategy adjustments drafted by the experts. The innovation impetus triggered by this in the network business division is another decisive, sustained project success.

Network operators should perform a risk analysis once a year and can do so initially without any need to invest in information technology (IT). Improvements in IT and the introduction of a management information system are started after implementing the fundamental processes of risk-based asset management. In this way, the network operators ensure that the IT infrastructure supports actual requirements, fits with the existing IT architecture and reveals a meaningful cost/benefit ratio.

**Particular aspects in transmission networks**

Basically the same methodology introduced can be applied to transmission networks as well. However, transmission networks place higher requirements on hazard data as the behaviour of a smaller number of similar operating resources with higher technical complexity is modelled. Additionally, more complicated network topology requires more complex algorithms in order to determine the importance of overhead line sections. Instead of a modified load flow calculation as in our example, several grid conditions depending on randomly distributed failures lead to the economic importance of single line sections.

**Conclusion**

Cutting costs by enhancing efficiency alone is not a sufficient response to challenges in the liberalized market mid term. Risk-based asset management enables the network operators to respond efficiently to today’s squeeze on costs in the network sector while controlling the risk at the same time and maintaining service at an adequate level – without risking that the networks become obsolete. The application has demonstrated the efficiency of this methodology in actual practice. With current conditions in the market, the risk-based approach is the only methodology mid-term that enables precise maintenance and replacement investment strategies. Innovative companies achieve a sustainable competitive edge in their core business by implementing risk-based asset management at an early stage.

**Bibliography**