Risk assessment methods applied to electricity distribution system asset management

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ABSTRACT: This paper highlights some aspects of the many facets of electricity distribution system risk assessment – describing the different risk consequence categories which are relevant in the whole risk picture with regards to their characteristics, their type of impact and applicable risk analysis methods. The paper illustrates that distribution system asset management constitutes of a variety of more or less conflicting objectives – and that there is no single risk assessment method which cover all the different aspects of distribution system risk.

1 INTRODUCTION

Electricity distribution systems are a vital infrastructure in modern society. The management of such systems consists of balancing cost, performance and risk – taking into account different aspects such as economic performance, quality of supply, safety and environmental impacts (Brown & Spare 2004; Sand et al. 2007). These aspects often constitute conflicting objectives in the decision making processes.

Electricity distribution is by definition a so-called natural monopoly – i.e. it is not socio-economic efficient to build competing parallel infrastructures to provide this service. In order to prevent abuse of monopoly power, the industry is subject to extensive regulation from authorities.

During the last two decades substantial changes have taken place in the electricity distribution sectors worldwide, changing it from generally being a protected business to being exposed to efficiency requirements and benchmarking through the monopoly regulation of electricity distribution. The process has lead to efficiency improvements throughout the business. Motivated by these efficiency requirements, the electricity distribution companies have intensified their efforts of creating more efficient ways of managing their business, trying to be on the competitive edge as measured by the regulatory authorities benchmarking practices (NVE 2007).

On main trend is that the electricity distribution companies have been increasingly focusing on the concept of *asset management* as guiding principle for performing their business – see e.g. (Kostic 2003; Brown & Spare 2004; Tor & Shahidehpour 2006). The area of asset management has emerged from different industries which all have in common the importance of an infrastructure of physical assets for performing their business Asset management covers widely – encompassing a multitude of aspects in distribution system planning and operation (BSI 2004a). Risk management is important among these aspects, being a part of asset management decision support methodology.

There is an increasing awareness among electricity distribution companies on developing holistic strategies for asset management, seeking solutions where all relevant risks consequence categories are being sufficiently taken care of – see e.g. (Nordgård et al. 2007; Istad et al. 2008).

This paper highlights major trends in the application of risk analysis in electricity distribution system asset management.

The paper first gives a description of the concept of asset management, pointing out how this is applied in the electricity distribution sector. It further states how risk assessment is included in electricity distribution system asset management, and how risk assessment methods are used to address various risks. Different risk consequence categories which are relevant for electricity distribution are listed, and each of them is described both in terms of their characteristics, their type of impact and what methods are applicable for analyzing them. Finally some concluding remarks are made concerning using risk-based approaches in distribution system asset management.

2 ELECTRICITY DISTRIBUTION SYSTEM ASSET MANAGEMENT

The electricity distribution sector has been increasingly focusing on the concept of asset management as guiding principle for performing business.

For example, the UK regulator, Ofgem, has explicitly encouraged the distribution companies to get certified according to the publicly available specification PAS 55 "Asset Management" (BSI 2004a; BSI 2004b), in order to establish a adequate level of competence in asset management within the distribution companies, to assure long term asset risk management and establish greater clarity of the policies and processes that underpin the investment decisions of network companies (Williams et al. 2007).

The concept of asset management covers (at least) two aspects; the management of the physical infrastructure, and the management of the organizational aspects. In this paper we focus on the first of these two aspects, namely the infrastructure management.

A very general definition of asset management is given in specification PAS 55-1 (BSI 2004a): *"Asset management is simply the optimum way of managing assets to achieve a desired and sustainable outcome"*.

The importance of risk management (as a means of avoiding undesired events) is highlighted in the more formal definition of asset management: *"systematic and coordinated activities and practices through which an organization optimally manages its assets, and their associated performance, risk and expenditure over their lifecycle [..]"* (BSI 2004a).

This definition emphasizes the lifecycle aspects of cost, performance and risk exposure – where performance is a measure of what is achieved, while risk exposure represents foresight – looking into potential future outcomes, with the aim to avoid undesired events.

From this definition we can see that risk management is well integrated in the asset management scheme. The principle of continuous process improvement is also a guiding star of asset management, integrating the different aspects of a sound asset management in a *plan-act-review-improve* circle. Risk assessment as a part of the asset management process of continual improvement, is illustrated in Figure 1 (BSI 2004b).

3 RISK AND RISK ASSESSMENT IN ELECTRICITY DISTRIBUTION SYSTEM ASSET MANAGEMENT

The understanding and management of risk are key issues for distribution companies in their asset management approaches.

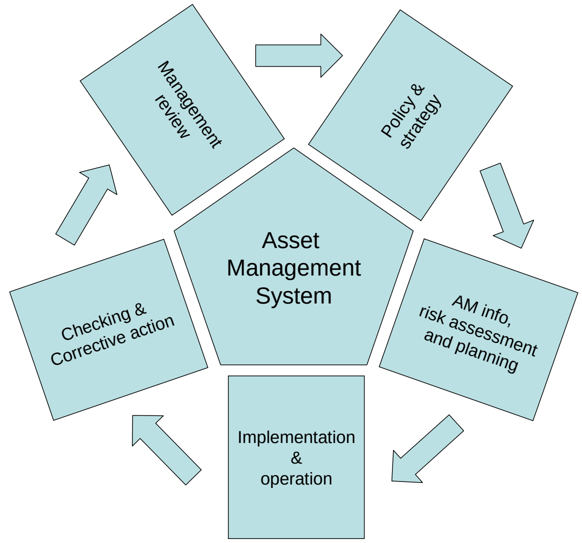

Figure 1. Asset management system elements – Continual improvement – based on (BSI 2004b).

Much work within risk management in distribution systems have focused on the aspects of reliability, see e.g. (Fangxing & Brown 2004; Bertling et al. 2005). This focus is understandable, since it is surely an important feature of the product delivered by the electricity distribution infrastructure, being a focal area for regulatory authorities in many countries (Eurelectric 2005).

However, electricity distribution companies are also concerned with other important decision criteria representing relevant risks for their business. This typically involves more *intangible* risks such as safety, environmental impact and company reputation.

In contrast to the numerous methodologies developed for reliability calculations and decision support (Billinton et al. 2001), one will find less application of structured analyses to support decisions concerning other risks, even though they represent an important motivation for decisions taken in electricity distribution systems. Some examples can yet be found – see e.g. (Hamoud et al. 2007; Nordgård 2008).

3.1 *Distribution system risk*

The electricity distribution companies acknowledge that there are many facets to the risk picture that they face. In (Sand et al. 2007) a study is presented identifying different aspects of the electricity distribution company risks. The consequence categories are shown in Table 1.

All of these risks are not applicable to every decision situation in the distribution companies, but the consequence categories constitute a whole of risk assessments that should be kept in mind when addressing distribution company risk.

Table 1 Different consequence categories in distribution system asset management – based on (Sand et al. 2007).

Risk consequence categories
- Economic risk - Safety risk - Environmental risk - Quality of supply risk - Reputational risk - Vulnerability risk - Regulatory risk

In the following chapters we look further into each of these risk consequence categories. The presentation is based on the authors' knowledge and experience regarding the application of risk assessment methods in electricity distribution – first and foremost among Norwegian distribution companies. Some of the risks are well defined with respect to risk analysis methods, while others have less history of being subject to structured risk assessment.

3.2 *Taxonomy for categorisation*

To describe the various risks we have chosen a taxonomy consisting of descriptions of their:
- Risk characteristics,
- The type of impact the risks will have, and
- The type(s) of risk assessment methods which are applicable.

3.2.1 *Risk characteristics*

The characteristics of each risk consequence category are provided as a high level description, not going into detail.

Some important aspects of each risk are highlighted as to why this is an area of concern for the distribution companies.

3.2.2 *The degree of impact of risk*

The different risk consequence categories have their differences with regards to the extent of their impact. In our review of the risk consequence categories, three types of impact are used:
- Local impact – denoting impact coming from dedicated components causing "concentrated" accidents or incidents.
- System impact – denoting impact occurs when failure in component(s) or sub-systems provides widespread impact affecting extensive parts of the distribution system.
- Corporate impact – denoting risks which impact on foundation for performing the business. This may be as a consequence of a preceding local or system impact, or due to a independent incident

3.2.3 *Categories of methods for risk analysis*

In (Aven 2008) three main categories of risk assessment methods are presented, as stated in Table 2. These categories are used to provide a generic grouping of the different categories of methods for risk analysis.

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 2 Categories of methods for risk analysis – grouping based on (Aven 2008)

Category	Type of analysis	Description	Example of methods
Simplified risk analysis	Qualitative	Informal procedures that analyses risk using e.g. brainstorming sessions and group discussions.	- Coarse risk analyses - Brainstorming sessions
Standard risk analysis	Qualitative or quantitative	More formalized procedures in which recognized risk analysis methods are used. Risk matrices are often used to present the results.	- Risk analysis assisted by HAZOP - Risk matrices - Job safety analysis
Model-based risk analysis	Primarily quantitative	Formal methods using e.g. event tree analysis (ETA) and fault tree analysis (FTA) are used to calculate risk.	- Fault tree analysis - Event tree analysis - Reliability analyses - Bayesian networks - Electrical system simulation - Benchmarking methods

Table 2 indicates that the more sophisticated the method gets, it will inevitably get more specialised. For model-based risk analyses there are a variety of analysis methods which can be used to analyse specific risk scenarios in detail.

The need for data - and its resolution - is also increasing significantly from the simplified risk analysis methods to the model-based ones.

4 DESCRIPTION OF VARIOUS ASPECTS OF RISK VALID FOR DISTRIBUTION SYSTEMS

In the following chapters the risk consequence categories listed in Table 1 are described closer, using the taxonomy presented in chapter 3.2.

4.1 *Economic risk*

4.1.1 *Characteristics of economic risk*

Economic risk is related to the potential loss of money – i.e. through higher cost than anticipated or through loss of income. Potential economic loss influences all aspects of electricity distribution system asset management.

Before the introduction of income cap regulation it was sufficient to analyse investments with respect to costs (because of cost coverage). In an income cap (or price cap) regulatory regime distribution companies also evaluate projects with respect to income effects, since the difference between the allowed income (stated by the regulatory authorities) and the total costs (opex + capex) constitute the company profit.

Hence, the main economic planning objective for the distribution companies is to minimize all relevant costs while meeting relevant restrictions.

The Norwegian regulator, NVE, has in their regulations given incentives for the companies to minimise the expected net present value of the following cost elements (NVE 2007):

- Investment cost (including reinvestment and renewal costs)
- Operating and maintenance costs - including utility repair and damage costs
- Cost of electrical losses
- Customer outage costs i.e. costs of energy not supplied (CENS)
- Congestion costs.

Uncertainty – and hence risk – is related to all of these cost elements, some more than others.

4.1.2 *Impact of economic risk*

Economic risks will typically have impact on corporate level.

4.1.3 *Methods applicable for analysing economic risk*

To analyse economic risk net present value (NPV) analyses are widely used – preferably accompanied with sensitivity analyses to investigate the effect of variation of input parameters. In some case risk matrices can be used to present and visualise the economic risk being part of a decision basis.

Input to the economic analyses can be provided through by other model based analyses, e.g. reliability analysis, load development forecasts, etc.

4.2 *Quality of supply risk*

4.2.1 *Characteristics of quality of supply risk*

The distribution companies are being increasingly subjected to regulatory regimes that explicitly take into account the quality of supply to the consumers (Eurelectric 2005).

One example is the Norwegian regulation scheme of Quality adjusted revenue caps, where the network companies' revenue caps are adjusted in accordance with the customers' interruption costs (Langset et al. 2001).

In addition to regulation of the interruption, there are also standards regulating the technical phenomena of quality of supply (CENELEC 2007).

4.2.2 *Impact of Quality of supply risk*

Quality of supply may impact both on local and system level – depending on the type of problem, its' size etc.

4.2.3 *Methods applicable for analysing Quality of supply risk*

Costs related to power supply interruption is a part of the economical risk – and hence NPV calculations are a methods also here. Model based methods for estimation of expected reliability and interruption conditions may provide input data for the NPV calculations.

To estimate potential impact on the technical quality of supply phenomena, various electrical system simulations may be utilised, e.g. load flow analyses, short circuit analyses, etc. The power system physical laws are well defined and the system therefore relatively easy to model and simulate.

It should be noted that depending on the regulatory regime, quality of supply phenomena might be dealt with in a purely economical way and hence contribute as an economical risk scenario. The cost of energy not supplied is one example – penalties when exceeding contract values another. So, care should be taken to avoid double counting of risk impact.

4.3 *Vulnerability risk*

4.3.1 *Characteristics of vulnerability risk*

Vulnerability is a characteristic of a system's inadequate ability to withstand an unwanted event, limit the consequences, and recover and stabilize after the occurrence of the event (Doorman et al. 2006).

The electricity supply is essential for the quality of everyday life, for the safety of people and for the economy. Vulnerability of the electric power networks therefore affects the society as a whole.

In our context vulnerability risk is used to describe high impact, low probability events that might have such a widespread effect on important societal functions.

Norms regarding the security of electricity supply considers the supply to end-users irrespective of the causes for a power system of not being able to ensure a sufficient security of supply.

4.3.2 *Impact of vulnerability risk*

By its nature vulnerability risk have widespread impact on system level and also on corporate level.

4.3.3 *Methods applicable for analysing vulnerability risk*

To analyse vulnerability risk various system simulations are applicable; e.g. contingency analyses, dynamic analyses etc. Other – more generic – model-based risk analysis methods are also applicable (e.g. fault tree and/or event tree. Simplified and standard risk analyses methods (brainstorming, plotting in risk matrices) can also be used for more coarse analyses of vulnerability. Risk matrices can be used as a tool to visualise the results.

4.4 *Safety risk*

4.4.1 *Characteristics of safety risk*

Safety considerations are often decisive for actions in the distribution system. The risk covers both occupational and third party safety.

For third party safety the concern is mainly coming from the potential accidental touching of live electrical system parts, e.g. the conductor wires of overhead lines.

Occupational safety is in addition covering various aspects related to the construction, operation and decommissioning of components in the distribution system.

4.4.2 *Impact of safety risk*

Safety risk will in most cases have a local impact, affecting people being relatively close to the scene of the incident or accident. Severe incidents or accidents affecting safety may also have a corporate impact.

4.4.3 *Methods applicable for analysing safety risk*

For analysing safety risk simplified and / or standard risk analyses methods are mostly applied – e.g. through performing brainstorming sessions to identify undesired events, and illustrating the results in risk matrices. Job safety analysis is yet another relevant approach used in the operational phase of asset management.

4.5 *Environmental risk*

4.5.1 *Characteristics of environmental risk*

Environmental hazards emerging from distribution companies are mainly related to pollution (e.g. emissions of oil from oil-filled components, SF_6-gas leakages, etc). Visual pollution – e.g. from overhead lines crossing through nature - is also a factor, together with electric and magnetic fields emerging from distribution system components.

Another potential environmental risk aspect is that pollution-abatement equipment such as pumps and filters often depend on electricity. Power outages might hence have environmental effects.

4.5.2 *Impact of environmental risk*

Environmental risk related to distribution system components can both have a local impact, affecting the sites being close to the scene of the incident / accident, and a global impact, since some pollutants have a global impact e.g. emissions the green house gas SF_6 used in various types of switchgear.

4.5.3 *Methods applicable for analysing environmental risk*

To analyse environmental risk simplified or standard risk analyses are most often applied. Risk matrices are often used to present and visualise the risk analysis results.

4.6 *Reputational risk*

4.6.1 *Characteristics of reputational risk*

Goodwill among various stakeholders are important aspects of running a business and this is also valid for distribution companies. They are aware of their reputation in order to improve or maintain it, and also to brand other business areas that the companies might be directly involved in –e.g. broadband services, alarm services, installation services etc.

Reputational risk will often be closely linked to other risk – such as quality of supply, safety, environmental risk, vulnerability and so on. The companies' performance on the other risk areas may hence affect the reputational risk.

4.6.2 *Impact of reputational risk*

Reputational risk related to distribution system components can both have a local impact, affecting only people being close to the scene of the incident. Depending on the type of incident or accident the reputational risk may also have corporate impact.

4.6.3 *Methods applicable for analysing reputational risk*

To the extent that reputational risk are formally analysed, this is done through simplified or standard risk analyses, using risk matrices to present and visualise the results.

4.7 *Regulatory risk*

4.7.1 *Characteristics of regulatory risk*

Due to the fact that electricity distribution companies are natural monopolies, they are being subject to extensive regulation from the authorities. Changes in the regulatory framework – e.g. due to political decisions, new regulatory models, etc. – can have large impact on companies.

If the regulatory regime is not well designed, a socio-economic beneficial project (i.e. a project with positive net present value of the cost minimisation objective function) might give a negative net present value income-wise and hence not be realised. Regulatory risk might play an important role when assessing strategies, and might for example lead to a reinvestment and maintenance adverse philosophy.

Regulation concerning certain component design may also enforce replacements, etc.

4.7.2 *Impact of regulatory risk*

Regulatory risk will by its nature have impact on corporate level.

4.7.3 *Methods applicable for analysing regulatory risk*

To analyse regulatory risk, all types of risk analyses is applicable; from simplified standard risk analyses, to highly detailed analyses using simulations to investigate the effects of various future scenarios on the company situation in changing regulatory frameworks - e.g. through data envelopment analysis (DEA), etc.

4.8 *Summary*

The survey of various distribution company risks in the previous chapters illustrate a variety of different aspects which are included in the total risk picture, and the variety of applicable approaches to analyse these risks.

Table 3 summarises the results of the different consequence categories, indicating the predominant attributes of the various risk consequence categories. What can be seen from the table is that there is no single method or approach which can be said to cover all aspects in one common risk analysis framework. It will rather encourage the use of many different approaches to analyse distribution system risk, depending on the type of problem.

5 THE MULTI CRITERIA NATURE OF RISK MANAGEMENT IN ASSET MANAGEMENT

The different risks listed in the chapters 3 and 4, all constitute parts of the rather complicated jig-saw puzzle of distribution system asset management, and should all to be kept in mind in a holistic asset management framework.

For a majority of asset management decisions there will not be relevant to include all risk aspects into the decision, but for a great deal we need to take into account more than one risk (e.g. safety and economic performance) and these risk may often be counteractive, meaning that the optimum solution for one risk will not be favourable for other(s), and vice versa. In a decision making context we will therefore have to deal with compromises between various aspects representing expected performance and risks.

5.1 *Decision problem example*

As an illustration we can consider the reinvestment of a MV overhead line, including rebuilding of pole-mounted MV/LV transformers to arrangements on the ground.

Figure 2 Example: Reinvestment of MV overhead line

The potential reinvestment will have risk related to cost occurring during the building process, and the future impact on the allowed company income is subject to regulatory risk. A new overhead line with ground mounted transformers will represent a reduction in occupational safety risk (due to less need for climbing), but leave the third party safety risk relatively unchanged. Environmental risk due to potential transformer oil emissions can be reduced, if rebuilding transformed on the ground with oil collectors, while the visual pollution remain unchanged. The reinvestments impact on vulnerability risk is neglectable.

This simple case illustrates the multi-criteria nature of such decision problems.

Table 3 Summary of risk consequence categories, their predominant impact and risk analysis methods.

	Risk impact			Risk analysis methods			
Risk consequence categories	Local	System	Corporate	Simplified	Standard	Model-based	Methods used
Economic / financial risk			+		+	+	NPV-analyses
Safety risk	+		+	+	+		Brainstorming, Risk matrices
Environmental risk	+	(+)	+	+	+		Coarse risk analysis
Quality of supply risk	+	+		+	+	+	NPV-analyses, Power system Analysis
Reputational risk	+		+	+	+		Coarse risk analysis Risk matrices
Vulnerability risk		+	+	+	+	+	Coarse risk analysis Risk matrices, Power system analysis
Regulatory risk			+		+	+	Coarse risk analysis Risk matrices, Simulation (e.g. data envelopment analysis)

5.2 *The challenge of optimizing*

To perform a formal optimization we have to be able to express some objective function with its restrictions, and to find *the solution* which minimizes (or maximises) this function.

To do this it is necessary to formulate each of the risks in the same terms (usually money or utility value) – see e.g. (Vatn 1998).

Monetisation raises some ethical questions – e.g. on putting value on safety and loss of life, and whether it is representative for the companies and society's attitude towards risk to use the expected values when dealing with safety risks or environmental risks, or if we should be more risk averse for such consequence categories.

For decision support purposes it can also be questioned if the purpose of a decision support tool is to compute the answer of the decision or whether its' role is to provide input for the decision maker to use in his or her own considerations.

In the process of utilising risk assessment in a more structured manner in electricity distribution, it is our opinion that one should try to establish better analysis approaches for each of the risk aspects before jumping to the aggregation of risks into on common measure with the aim to perform a full optimization – emphasising to provide decision support rather than decision optimization.

There are however multi-criteria decision methods which can contribute to bridging the gap towards aggregating partial results into a common decision framework – see e.g. (Catrinu & Nordgård 2009). This is not further elaborated in this paper.

6 CONCLUDING REMARKS

This paper highlights some aspects of the many facets of distribution system risk assessment – characterising the different consequence categories which are relevant in the whole risk picture.

The application of holistic risk analyses in distribution system asset management is relatively new – and the companies have to get more experience using risk assessment approaches in their distribution system asset management.

The purpose of risk assessment should be to analyse uncertainty about future outcomes in a structured and traceable manner and to provide better foundations for making asset management decisions.

To obtain a structured approach to analyze the various aspects of distribution company risk, there is a need for strengthening the distribution companies with regards to:

- Competence
- Methods and tools
- Input data.

All of these aspects need to be elaborated further in the years to come

It is the authors' opinion that it is not realistic to obtain one unified risk assessment method which can cover all the different risks, but rather to develop analyses for the different risks, each of them constituting a part of the total decision basis.

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REFERENCES

Aven, T. (2008). Risk analysis. Assessing uncertainties beyond expected values and probabilities. Chichester, Wiley.

Bertling, L., Allan, R. & Eriksson, R. (2005). "A reliability-centered asset maintenance method for assessing the impact of maintenance in power distribution systems." IEEE Transactions on Power Systems 20(1): 75-82.

Billinton, R., Fotuhi-Firuzabad, M. & Bertling, L. (2001). "Bibliography on the Application of Probability Methods in Power System Reliability Evaluation 1996-1999." IEEE Transactions on Power Systems 16(4).

Brown, R. E. & Spare, J. H. (2004). Asset Management, Risk, and Distribution System Planning. IEEE PES Power System Conference and Exposition 2004.

BSI (2004a). PAS 55-1: Asset Management. Part 1: Specification for the optimized management of physical infrastructure assets, The Institute of Asset Management, British Standards Institution.

BSI (2004b). PAS 55-2: Asset Management. Part 2: Guidelines for the application of PAS 55-1, The Institute of Asset Management, British Standards Institution.

Catrinu, M. D. & Nordgård, D. E. (2009). Incorporating risk analysis and multi-criteria decision making in electricity distribution system asset management ESREL 2009. Prague, CRC.

CENELEC (2007). EN 50160 Voltage characteristics of electricity supplied by public distribution systems.

Doorman, G. L., Uhlen, K., Kjolle, G. H. & Huse, E. S. (2006). "Vulnerability analysis of the Nordic power system." IEEE Transactions on Power Systems 21(1): 402-10.

Eurelectric (2005). The Operating Environment for Distribution Companies. W. G. D. Issues. Brussels, Eurelectric: 119.

Fangxing, L. & Brown, R. E. (2004). "A cost-effective approach of prioritizing distribution maintenance based on system reliability." IEEE Transactions on Power Delivery 19(1): 439-41.

Hamoud, G., Toneguzzo, J., Yung, C. & Wong, A. (2007). "Methodology for assessing safety risk from failure of transmission station equipment." IEEE Transactions on Power Delivery 22(3): 1972-8.

Istad, M. K., Nordgård, D. E., Gjerde, O., Catrinu, M. D., Nybø, A. & Birkeland, B. E. (2008). Risk Informed Decision Support for Reinvestments in Distribution Systems. PMAPS - Probabilistic Methods applied to Power Systems, Rincón, Puerto Rico.

Kostic, T. (2003). "Asset management in electrical utilities: how many facets it actually has." Power Engineering Society General Meeting, 2003, IEEE 1: 275-281 Vol. 1.

Langset, T., Trengereid, F., Samdal, K. & Heggset, J. (2001). Quality dependent revenue caps - a model for quality of supply regulation. CIRED 2001, London, UK, IEE.

Nordgård, D. E. (2008). Quantitative risk assessment in distribution system maintenance management using bow-tie modeling. 16th Power Systems Computation Conference (PSCC), Glasgow

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

NVE (2007). Regulations covering financial and technical reporting, income caps for network operations and transmission tariffs. Reg. No. 302 of 11 March 1999 - changed as of 7 Dec 2007.

Sand, K., Gjerde, O. & Nordgård, D. E. (2007). Current risk exposure in the distribution sector. Initial study. Trondheim, SINTEF Energy Research.

Tor, O. & Shahidehpour, M. (2006). Power distribution asset management. Power Engineering Society General Meeting, 2006. IEEE.

Vatn, J. (1998). "A discussion of the acceptable risk problem." Reliability Engineering & System Safety 61(1-2): 11-19.

Williams, L., Jami, I. & Argent, S. (2007). Good practice asset risk management: A regulator's tale. 19th International Conference and Exhibition on Electricity Distribution, Vienna, Austria.