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Application of Bayesian networks for risk analysis of MV air insulated switch operation

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ABSTRACT

Electricity distribution companies regard risk-based approaches as a good philosophy to address their asset management challenges, and there is an increasing trend on developing methods to support decisions where different aspects of risks are taken into consideration. This paper describes a methodology for application of Bayesian networks for risk analysis in electricity distribution system maintenance management. The methodology is used on a case analysing safety risk related to operation of MV air insulated switches. The paper summarises some challenges and benefits of using Bayesian networks as a part of distribution system maintenance management.

1. Introduction

During the last 10–15 years, electricity distribution companies throughout the world have been ever more focused on *asset management* as the guiding principle for their activities (see e.g. [1–3]). The concept of asset management in general has developed during this same period of time, using input from a number of industrial sectors—such as water supply, transportation and energy supply. All of these sectors share a reliance on an infrastructure of physical assets that provides the foundation for their businesses [4,5].

Asset management in electricity distribution companies is about the complex balancing of cost, performance and risk—taking into account different aspects such as economic performance, quality of supply, safety and environmental impact [2,6]. Together with handling of cost and performance, the management of risk is therefore a key issue for electricity distribution companies, and there is now an increasing awareness towards taking risk analysis into account in the decision making context [7]. For some of the risks there are methods and tools already used within the electricity distribution sector—such as economical risk analyses and quality of supply risk analyses (reliability analyses). For others – and more intangible risks, for example safety issues – there is less culture and practice for performing structured risk analyses to support decisions.

Maintenance activities are important parts of the asset management scheme, to control the distribution companies' risk [4]. Historically, maintenance activities have been decided based largely on existing practice, producers' recommendations and to some extent direct regulation from authorities, with little application of formal analyses to support or reject the existing paradigms [8]. However, there is now an increasing trend among electricity distribution companies on developing maintenance strategies where different aspects of risk are sought included in a holistic way [9,10].

Electricity distribution companies recognise that there are significant potential for improvement in their analytical approaches within maintenance assessment, and there is a need to test methods to support risk analysis in this context. Such methods can contribute to more optimised spendings on maintenance activities.

Bayesian networks is a risk modelling and analysis approach that has been applied for various types of analyses for different purposes in different industrial sectors (see e.g. [11–13]). Due to its versatility and ability to represent complex relations, it is also of interest to use this approach in electricity distribution company decision support.

This paper presents a methodology for using Bayesian networks for risk analysis in electricity distribution company maintenance management. The methodology emphasises on analysing intangible risks, like safety. Such risks are especially important in medium voltage (MV) distribution systems, where the impact of failures on reliability is not as widespread as on higher voltage levels. Hence intangible risks constitute more prominent decision criteria in MV systems [8]. The methodology is illustrated through a case analysing safety risk related to the operation of MV air insulated switches.

Section 2 presents background concerning MV electricity distribution systems, risk analysis and Bayesian networks. Section 3 introduces the proposed methodology, while in

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Section 4 the methodology is used on the case. Section 5 discusses some of the main results, while Section 6 summarises the paper with some concluding remarks.

2. Background

2.1. MV electricity distribution systems

MV electricity distribution systems are the electricity distribution infrastructure on voltage levels from 1 to 36 kV, connecting the higher voltage transmission and sub-transmission systems to the regular customers of the low-voltage distribution level.

MV electricity distribution systems are characterized by being widely geographically dispersed, having vast numbers of components. Component lifetimes are typically 30–60 years, but there are large variations around the average values.

Most of the MV electricity distribution networks in industrialised countries are an already existing infrastructure, most of them having been built during the last 50 years. The electricity distribution companies are therefore facing the challenges of managing a generally ageing infrastructure [7,14]. Hence, maintenance and reinvestment strategies have a more prominent position than before on the companies' agendas, and the distribution companies recognise a general need for methods and tools to support maintenance and reinvestment decisions [15].

2.2. Risk analysis in MV electricity distribution system maintenance management

Electricity distribution companies are generally facing multidimensional decision problems when addressing maintenance and reinvestments, covering aspects such as economic impact, safety, environmental impact and company reputation [16]. To support decision making, risk analyses is therefore an important contributor. Various categories of risk analysis methods are available—from simplified risk analyses methods to model-based ones [17]. *Quantitative risk assessment* (QRA) methods are model-based risk analysis approaches, which are used to explicitly model causal relations and achieve quantitative measures of risk [18].

The application of QRA methods can be advantageous for maintenance analyses, through structuring different input data into an analytical framework for analysis of specific problems of concern, for example safety related issues. Bayesian networks is a promising QRA method which have been tested in electricity distribution system asset management [19,20]. The general modelling capabilities of the method makes it applicable to a variety of risk related challenges [21].

2.3. Bayesian networks used for risk analysis

Bayesian networks is a general modelling framework which has been used in risk analysis in many different settings (see for example [11–13]). Bayesian networks is a general modelling approach, offering a compact presentation of the interactions in a stochastic system by visualising system variables and their dependencies. Due to their versatility, it is of interest to test the usefulness of Bayesian networks in electricity distribution system risk management.

A Bayesian network consists of two main parts: a qualitative part and a quantitative part. The qualitative part is a directed acyclic graph where the nodes mirror the system variables, and the edges of the graph represent the conditional dependence between variables. The quantitative part is a set of conditional probability functions, stating the relations between the nodes of the graph.

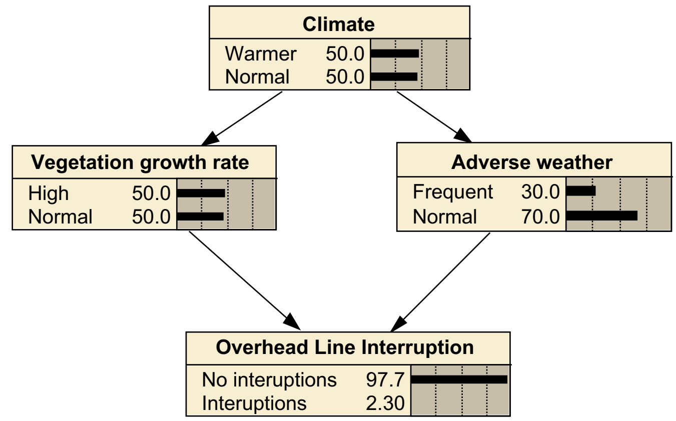

Fig. 1. Simple example of Bayesian network modelling the probability for overhead line interruptions.

2.3.1. Simple example

Fig. 1 shows a simple example of a Bayesian network established to model how vegetation growth and adverse weather may influence the occurrence of overhead line interruptions in electricity distribution networks—and how changes in the climate can affect this.

The network consists of four two-state random variables given by the nodes in the graph:

- *Climate*
- *Vegetation growth rate*
- *Adverse weather*
- *Overhead line interruption*

The arrows in the diagram represent dependencies between nodes and can be interpreted as causal relationships. For example, the probability of *Overhead line interruption* is dependent on the two parent nodes: *Vegetation growth rate* and *Adverse weather*.

Fig. 1 also indicates a causal relationship between the node *Climate* and both *Adverse weather* and *Vegetation growth rate*. The arrows in the graph represent the assumption that a variable is conditionally independent of its non-descendants given its parents in the graph. Hence, *Overhead line interruption* is conditionally independent of *Climate* given the parent nodes *Vegetation growth rate* and *Adverse weather*.

The underlying assumptions of conditional independence encoded in the graph allow calculating the joint probability function as

$$f(x_1 \ldots x_n) = \prod_{i=1}^{n} f(x_1 | pa(x_i)) \quad (1)$$

Hence, the conditional probability can be calculated, e.g. the probability of overhead line interruption given the parents:

$$f(Overhead\ line\ int. | Adv.weather, Veg.gr.rate) \quad (2)$$

For the example, in Fig. 1, the initial input is that there is a 50% chance of the climate getting warmer (in a given region being subject for the analyses), and hence 50% chance that it will stay normal.

Table 1 shows the chosen values for the conditional probability tables for the nodes *Vegetation growth rate* and *Adverse weather*.

These probability estimates represent degrees of belief concerning how the growth rate and the weather will be for a given period of analysis. Such conditional probability tables can be derived from statistics, expert judgment, simulations, etc.