CALCULATION OF RISK LEVELS FOR SUBSTATION FAILURES IN A FULL SCALE IMPLEMENTATION

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ABSTRACT

The paper presents an overall methodology for calculation of risk levels based on observations resulting from field inspections of MV/LV substations.

The methodology represents a higher degree of automatic handling of observations of risky conditions, suitable for managing a large number of observations in a low-laborious and efficient manner.

The methodology has been tested in real life applications in the maintenance information system for Norwegian distribution grid companies, showing its feasibility for processing a large number of observations, and presenting this in an informative and interactive manner for company decision makers.

INTRODUCTION

Electricity distribution companies throughout the world have become ever more focused on asset management as the guiding principle for their activities. Within asset management, the concept of risk is a key issue, together with handling of cost and performance. There is an increased awareness of the need to include risk analyses into the companies' decision making processes.

Much of the work on risk in electricity distribution systems has been focused on aspects of reliability of supply, since it is an important feature of the product of electricity, and it is high on the agenda for regulatory authorities in many countries.

However, electricity distribution companies are also concerned with other types of risks relevant for their decision making. This typically involves intangible risks, such as safety, environmental impacts and company reputation since these types of risk represent are important in distribution company decision-making [1].

This paper describes a method for standardized and automatized risk evaluation of observed risky conditions in MV/LV substations, using field observations from inspections as input to a predefined risk assessment methodology.

BACKGROUND

Risk based methodologies as basis for asset management.

Risk is related to possible future events and their consequences [2]. Risk analysis is relevant in most decision situations, since by assessing risk, we seek to look into the future and use this insight to make good decisions.

The risk for a given process or activity can be described through answering a triplet of questions [3]:
- What can go wrong?
- How likely is that to happen?
- If it does happen, what are the consequences?

The answer to the first question describes one or more undesired events; the answer to the second is a probability statement, while the answer to the third question is a description of potential consequences – which typically will be multidimensional (e.g. economic, reputational and safety consequences).

The focus in this paper is on an effective estimation of risk related to MV/LV substations based on observations from inspections, with the aim to support large scale automated calculations, which can provide an efficient information basis for decision makers.

Utilizing condition observations from field inspection in risk estimates

Observations of the condition of different assets in MV distribution networks are performed on a regular basis through different kinds of field inspections.

Several thousands of observations are made every year, and a systematic, holistic decision process is required in order to fully utilize these condition observations to support the strategic goals of the company. To include them in a risk management process is considered the most suitable approach to do this.

Observations from field inspectors can be used to estimate risk itself, the probability of undesired events or the asset condition - which in turn can be used to estimate probabilities.

The overall goal is to use observations to categorize risk conditions observed in MV/LV substations and to use the risk categorization as input to decision making and prioritizing assets.

Automated computer-aided categorization is necessary in a full-scale implementation as the number of MV/LV substations easily reach several thousand even for not very large DSO's, making individual judgments highly time-consuming and this practically impossible.

METHODOLOGY

The risk estimation methodology is based on assigning risk related to a set of predefined check-points for MV/LV substations.

Predefined check-points

There has been developed a set of approximately 100 pre-defined standard check-points for MV/LV substation inspections. These standard check-points are based on the most common and the most risky unwanted events which can occur in various types of MV/LV substation assets.

These check-points are grouped into various risk categories, depending on the type of consequence caused by unwanted events related to each check-point.

Examples of consequence categories are:

- Reliability of supply
- Safety
- Environment
- Economy
- Reputation

Typically; when evaluating check-points concerning reliability of supply, the field inspector should estimate the probability for given unwanted events, while the consequence is calculated by the information system through network analysis.

For some check-points the network information system can provide support for the probability judgment by combining externally given strain parameters (e.g. weather exposure, proximity to coast, ..), with asset condition estimates from the field inspector, so that the maintenance information system can calculate probability of unwanted events as a function of condition and strain.

The risk level related to a specific observation can be determined in different ways, depending on risk category and the nature of the identified problem. Figure 1 shows the different principles for field inspector judgement and processing method.

Judgement principle	Explanation
Risk	Risk estimated directly by field inspector
Probability	Probability estimated by field inspector, consquence and risk calculated by application.
Condition	Condition estimated by field inspector, strain and consequence calculated by application. Application calculates risk.
OK / not OK	OK/not OK estimated by field inspector. Application calculates risk based on one of the principles risk, probability or condition. Input parameter level is predefined in the application.

Figure 1 - Judgement principles and risk evaluation

Table 1 shows a few selected examples of check-points for MV/LV substations and judgement principles applied to them

Table 1 - Examples of check-points with consequence categories and judgements principles

Check-point name	Consequence category	Judgement principle
PD in cable termination	Power reliability	Probability
Earth fault	Safety	OK / not OK
Oil leakage transformer	Environment	Risk
Surface corrosion transformer	Economy	Condition
Tagging	Reputation	OK / not OK

Initial studies show that approximately 5 % of the check-points relate to *environment* and 5 % to *reputation*. *Reliability of supply*, *safety* and *economy* count for approximately 30 % each.

This shows that other categories than power reliability are equally important in determining risk level based on field observations.

Observation risk levels

The basic principle in this methodology is to determine a risk level on all observations that are recorded on components in the grid. Observations are done in different situations, such as:

- scheduled inspections,
- when performing work in the grid,
- reports to company call centre, or
- automated readings from sensors.

Figure 2 shows the relation between risk levels and the priority for correction of the observation.

Risk level	Correction priority
Very high	Immediate
High	As soon as possible, normally within days/few weeks.
Medium	Within one year or before winter.
Low	By occasion
Very low	No correction

Figure 2 – Estimated risk level and priority of correction

Figure 3 illustrates the risk matrix where risk level is set as a combination of probability and consequence of an unwanted event.

Risk		Consequence		
		Low	Medium	High
Probability	High	Medium	High	Very high
	Medium	Low	Medium	High
	Low	Very low	Low	Medium

Figure 3 – Risk matrix

As an input to the probability estimate for some of the check-points, Figure 4 shows how the probability dimension of the risk matrix further can be described as a function of condition and strain.

Probability		Strain		
		Low	Medium	High
Condition	Critical	Medium	High	High
	Significantly degraded	Medium	Medium	High
	Somewhat degraded	Low	Medium	Medium
	Like new	Low	Low	Medium

Figure 4 – Probability matrix, combining observed condition with externally given strain.

Example: Estimating reliability of supply consequence of a failure

The consequence of a failure with a subsequent outage consists of several dimensions. The *Cost of Energy not Supplied* (CENS) represents the economic dimension, while *safety* and *environment* are examples of intangible dimensions.

In the Norwegian income cap regulation CENS is included as a cost for the distribution company. That gives the utility incentives to build and operate the grid in a socioeconomic optimal way. In the calculation of CENS it is possible to utilize six different customer groups, and thereby different cost rates of an outage. The cost rate is further combined with time and duration of the outage. The time and duration of an outage defines the energy not supplied, which is used by the regulator as part of their process to measure the utilities efficiency [4].

The grid topology is essential for the calculation and investigation of a critical MV/LV substation. MV/LV substations with high power consumption are more critical because of the possible high cost of energy not supplied during an outage. Every substation represents a CENS based on the connected customers, and in a radially operated grid the disconnection of one substation may cause interruption of several substations on the same feeder.

In a situation where switches can isolate the fault and restore the power supply from another feeder the CENS related to the faulty substation is reduced, because it is possible to feed the substations from another feeder.

The economic value of CENS indicates how critical an outage of a substation is, for a standard outage with 1 hour duration. By applying a grading system with grades from 1 to 3, we can divide the substations by economic impact of an outage. Grade 1 indicates *Low consequence* and grade 3 indicates *High consequence*.

CASE STUDY

The case is based on real data for MV/LV substations in a small distribution company in the western parts of Norway. In a population of approximately 1500 substations CENS and a parameter for societal impact of an outage were used to determine consequence levels.

CENS was calculated by simulating disconnection of all switchgears in the grid, and in each case calculating CENS levels for 1 hour interruption and then relating this to affected substations. The simulation was done by relating all disconnections to a heavy load hour in order to map the relative consequence for the substations. The next step is to use the CENS values to determine a discrete consequence level for each of the substations.

The grid used in this study is a mainly radially operated grid and therefore it is relatively simple to calculate the consequence of an interruption caused by substation failures. In a few cases alternative supply is an option and this was used to correct (reduce) the calculated CENS.

Table 2 shows the consequence levels chosen.

Table 2 Consequence levels for CENS.

Consequence level	CENS [kkr]
1. LOW	< 5
2. MEDIUM	5 - 25
3. HIGH	> 25

Using these consequence levels, the MV/LV substations grouped themselves in the consequence levels as shown in Figure 5.

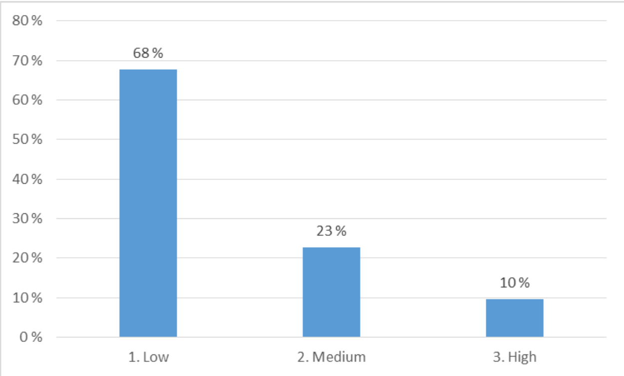

Figure 5 - Grouping of MV/LV substations in CENS consequence levels.

The next step was to include other (non-monetary) consequences than CENS. This was done through a parameter representing customers with high societal impact. The following customer categories were included:

- Aviation
- Education
- Health and care services
- Governmental
- Business and industry
- Infrastructure and communication

For all MV/LV substations, these aspects were investigated.

The method used will use the highest consequence level for each substation, such that societal impact consequence, decided by company strategy, will override CENS in cases where CENS consequence level is lower. I.e. the highest obtained consequence level for all consequence categories will decide the overall consequence level for a given substation.

This provided the following distribution of substation consequence levels:

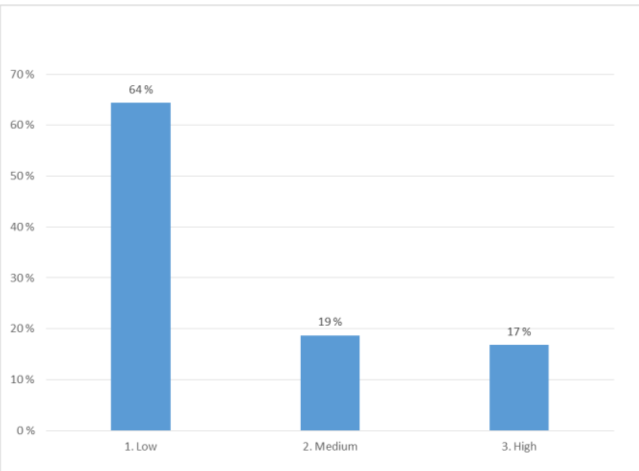

Figure 6 - Distribution of consequence levels based on consequence estimates for both CENS and Societal impact.

It is obviously a challenge to determine the correct intervals for definition of consequence levels and the choice of intervals therefore becomes a strategic decision where simulation of different strategies can be used to see how consequence levels for observations are distributed

The strategic decision will depend on the company's ability and ambitions to deal with the number of high risk observations which come as a result from the chosen consequence levels.

Figure 7 illustrates how observations are shown in the maintenance software. In this example, only high-risk observations are displayed.

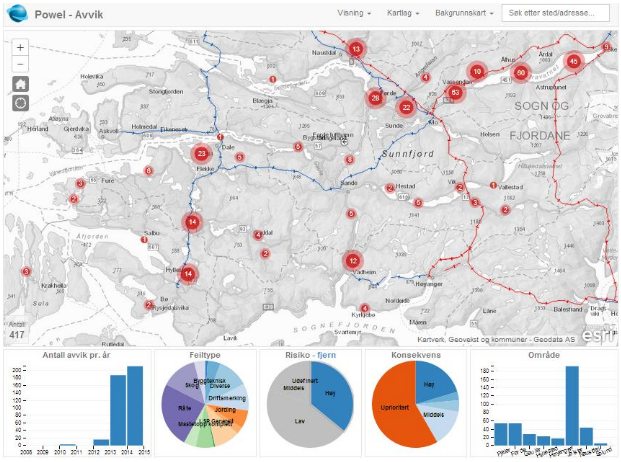

Figure 7 - High risk observations (Norwegian text in example)

CONCLUDING REMARKS

The paper presents an overall methodology for risk classification of observations resulting from field inspections of MV/LV substations.

The methodology represents a higher degree of automatic handling of observations of risky conditions, suitable for managing a large number of observations in a low-laborious and efficient manner.

The methodology has been tested in real life applications in the maintenance information system for Norwegian distribution grid companies, showing its feasibility for processing a large number of observations, and presenting this in an informative and interactive manner for company decision makers.

Due to the different nature of condition data recorded, it is necessary to determine the risk level using three different methods, called judgement principle in this paper. Consequence level on substations, reflecting both economic and non-economic consequences will only play a role for one of the judgement principles identified. Initial studies indicate that approximately 40 % of the check-points will relate to judgement principles applying consequence level on substations. Further studies will reveal the percentage of risk levels that will be determined in this way, which in next turn will reveal the importance of calculating strategically agreeable consequence levels for ML/LV substations.

The methodology and the maintenance system software will be further developed in order to gain more experience with the approach and its results.

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