

## RISK ASSESSMENT AS AN INTEGRATED PART OF DISTRIBUTION SYSTEM REINVESTMENT ANALYSIS

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### ABSTRACT

*Maintenance and reinvestment decisions are important parts of distribution system asset management, as means to control risk. Distribution companies are hence increasingly recognising risk assessment as an important tool in this context.*

*This paper proposes a framework where risk assessment is systematically applied when evaluating potential replacement or refurbishment of existing installations or sub-systems. It further describes the use of this framework and how it can support the distribution company work flow. Practical use is illustrated through a case study showing the application of a risk based check-list for reinvestment analysis of MV/LV substations.*

### INTRODUCTION

In the ageing infrastructure of electricity distribution, the emphasis on maintenance and reinvestment is ever increasing and distribution companies are increasingly recognizing risk assessment as an important tool in their asset management [1, 2, 3]. Maintenance and reinvestment decisions are important parts of distribution system asset management, as means to control risk.

This paper focuses on risk assessment as basis for reinvestment decisions, proposing a framework for including risk assessment as a part of the work process of a reinvestment analysis. Further the paper describes the use of this framework and how it can be applied in distribution company decision support. Practical use is illustrated through a case study performed in cooperation with a Norwegian DSO, dealing with reinvestment analysis of MV/LV substations.

### REINVESTMENT ANALYSIS

To describe the work process for reinvestment analysis Figure 1 has been developed, starting with some triggering event, continuing through a chain of evaluations. Examples of triggering events can be:

- Component age
- Results from condition monitoring
- Observed failures
- Load development
- Strain/history (e.g. overload, voltage stress).

It should be emphasised that the triggering event does not trigger the reinvestment itself, but rather the reinvestment analysis.

At first an evaluation of the existing solution is carried out. If the technical conditions as well as the risks are considered acceptable, the system or component is considered not to be a candidate for reinvestment, and no further actions are taken until the next triggering event.

If one or more risks are considered unacceptable, or uncertain, alternative solutions to address the unacceptable risk(s) are established. The proposed solutions should be acceptable with regards to risk, i.e. the identified gaps which are in conflict with requirements or policies, should be closed.

The next step is to evaluate the alternative solutions. If the solutions are technically acceptable (power flow, voltages, etc), LCC-analyses are carried out for each of the solutions, and finally the alternative solutions are compared and a preferred solution is chosen. The decision process will typically be a multi-criteria decision problem. Methods to formally cope with this is not elaborated in this paper, the reader is referred to e.g. [4, 5].

In the following this paper focuses on the two steps “Evaluation of existing solution” and “Evaluation of alternative solutions” as these are the steps where the risk assessment mainly is carried out. It is described how the risk assessment of these steps can be established applying as a general risk based analysis framework.

The described approach is suitable for repetitive reinvestment analyses, i.e. repeated and similar analyses of numerous components – exemplified by MV/LV substations.

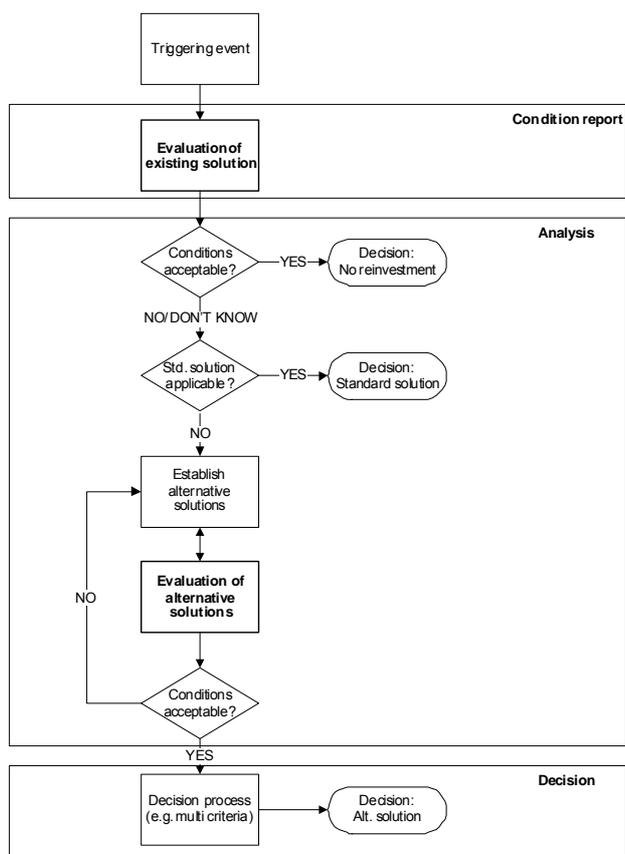


Figure 1 Work process for reinvestment analysis.

**RISK ASSESSMENT AS PART OF THE REINVESTMENT ANALYSIS**

With reference to Figure 1 risk assessment will be included in the steps “Evaluation of existing solution” and “Evaluation of alternative solutions”. To aid an efficient analysis process, the main idea is to create a check-list to be used in the reinvestment analysis, based on critical unwanted events which have been identified for the different component categories. This check-list forms an extract of the risk assessment, to go along with the different technical and economical parts of the reinvestment analyses.

To create such a check-list, one must perform a risk analysis for the different component categories. The process of establishing a check-list is illustrated in Figure 2.

For each component category, unwanted events must be identified. This is done using input from company experts.

The next step is to provide a risk mapping (estimating probability and consequence) for each unwanted event. A suitable tool for supporting this will be risk matrices [6].

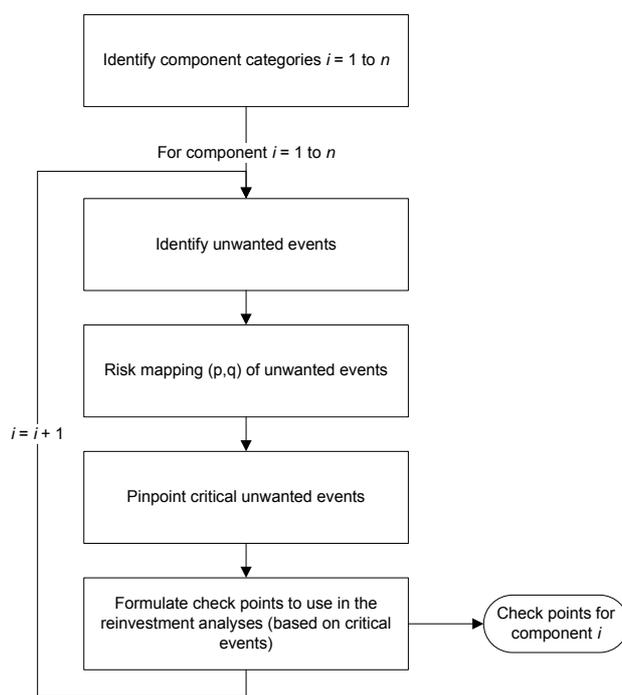


Figure 2 Flow chart for establishing reinvestment analysis check-list.

When a risk mapping has been performed, critical risks with relevance for the renewal decision are pinpointed through a qualitative evaluation. These risks are assumed to be decisive for the component, and the potential renewal must impact them in one way or another, i.e. influence either the expected probability or consequence of the unwanted event.

Based on the identified critical events, a check-list is formulated to be used as a template in the reinvestment analysis.

The risk for distribution companies covers different consequence categories, and the following are considered to be the most important for reinvestment analysis:

- Safety
- Environmental impact
- Company reputation
- Economy.

Unwanted events may have impact on several of the consequence categories.

The application of the proposed framework of Figure 2 is illustrated in the following case study.

## CASE STUDY: RISK BASED FRAMEWORK FOR REINVESTMENT ANALYSIS OF MV/LV SUBSTATIONS

This case study describes the development of a reinvestment analysis check-list for MV/LV substations, following the different steps of the flow chart in Figure 2.

*It should be emphasised that the risk analyses presented in this paper are for illustrative purposes only.*

### Identify component categories

The MV/LV substation is split into the following five sub-systems or components:

- Building
- Cable terminations
- Breakers
- Low-voltage system
- MV/LV transformer.

In the following the risk analysis is shown for the MV/LV transformer. The other component categories are treated in a similar way, but this is not explicitly shown in the paper.

### Identify unwanted events

For the MV/LV transformer the following unwanted events are identified:

1. Oil leakage (with/ without oil collection)
2. Flashover at insulators
3. Oil fire/ explosion (with/ without oil collection)
4. Public complaints about acoustic noise
5. Transformer breakdown (with/ without oil collection)
6. Transformer running hot.

In the process of identifying potential unwanted event, risk differentiation is given special attention.

### Risk mapping of unwanted events

The unwanted events (# 1-6) are plotted in the risk matrices in Table 1 for the four given consequence categories. Due to lack of statistic material, estimation of probability and consequences is based on expert judgement. It refers to an “average component” differentiated with regards to construction etc where relevant.

### Pinpoint critical unwanted events

Based on the risk mapping, the following unwanted events are considered to be the most relevant for renewal decisions:

For safety risk event # 3 has been found to be somewhat critical based on its potential severe consequence. The environmental risk is considered to be most critical for events 1, 3 and 5 given that the transformer does not have a collector for potential oil spill. For reputation risk event # 1 is equally rated as the most critical, while the economic risk is considered to be relatively small – and hence acceptable – for the MV/LV transformer.

**Table 1 Risk mapping for MV/LV transformer.**

		Safety risk				
Consequence ►	Likelihood ▼	Insignificant	Minor	Moderate	Major	Catastrophic
Frequent		Yellow	Red	Red	Red	Red
Probable		Green	Yellow	Yellow	Red	Red
Occasional		Green	Green	Yellow	Red	Red
Remote		Green	Green	Green	Yellow	Red
Improbable		Green	Green	Green	Green	Yellow
					3	

		Environment risk				
Consequence ►	Likelihood ▼	Insignificant	Minor	Moderate	Major	Catastrophic
Frequent		Yellow	Red	Red	Red	Red
Probable		Green	Yellow	Yellow	Red	Red
Occasional		Green	Green	Yellow	Red	Red
Remote		1 (with coll.)	Green	1 (without coll.)	Yellow	Red
Improbable		3, 5 (with coll.)	Green	3, 5 (without coll.)	Green	Yellow

		Reputational risk				
Consequence ►	Likelihood ▼	Insignificant	Minor	Moderate	Major	Catastrophic
Frequent		Yellow	Red	Red	Red	Red
Probable		Green	Yellow	Yellow	Red	Red
Occasional		Green	Green	Yellow	Red	Red
Remote		1 (with coll.)	4	1 (without coll.)	Yellow	Red
Improbable		Green	Green	Green	Green	Yellow

		Economical risk				
Consequence ►	Likelihood ▼	Insignificant	Minor	Moderate	Major	Catastrophic
Frequent		Yellow	Red	Red	Red	Red
Probable		Green	Yellow	Yellow	Red	Red
Occasional		Green	Green	Yellow	Red	Red
Remote		Green	1, 2, 6	Green	Yellow	Red
Improbable		Green	Green	3, 5	Green	Yellow

### Formulate check-points

Based on the critical unwanted events of the MV/LV transformer the following check-list is proposed:

- Insulating medium (dry/oil)
- Transformer condition (worse/average/better)
- Oil collector underneath (yes/no).

To open for other relevant input during the reinvestment analysis, a checkpoint covering “any other circumstances” should be included.

In a similar way a check-list is established for the entire MV/LV substation, covering all component categories. A summary is shown in Table 2.

### Example - Reinvestment analysis

In the following the application of the check-list and incorporation of risk assessment in the reinvestment analysis is illustrated by an example. The check-list from above is applied to a specific MV/LV substation. The results from the “evaluation of existing solution” are listed in the “current state” column in Table 2.

As indicated in the “Current state” column there are found deviations resulting in one red and three yellow cells. (Green cells indicate acceptable risk, yellow cells indicate intermediate risk, while red cells indicate unacceptable risk.)

A.1: A grating is missing from a ventilation hatch, making unauthorised access possible.

- A.5: Marks in the oil collector pit shows that there has been water in it, one or several times.  
 D.1: There is no protection covering the low voltage system.  
 D.2: Single pole low voltage switches.

To close these gaps of the existing solution, two alternatives are proposed:

#### Alternative 1: Minimum solution

This is the minimum solution for closing the gaps. In this alternative the following work is carried out:

- Ventilation grating is replaced, reducing the likelihood of unauthorised access
- The drainage around the building is replaced, reducing the likelihood of flooding
- An enclosure is established for the LV system, reducing the likelihood of contact.

The single pole switches are kept as they are. The cost for this alternative is estimated to 12 000 € The remaining lifetime for this alternative is estimated to be less than 10 years.

#### Alternative 2: New substation

In alternative 2 the entire MV/LV substation is replaced. The cost for this alternative is 100 000 € The remaining lifetime for this alternative is estimated to more than 30 years.

The details of the final multi-criteria decision are not treated as a part of this example.

**Table 2 Example - check-list for MV/LV substation**

Component/ sub system	Current state	Alternative 1	Alternative 2
<b>A. Building</b>			
A.1 Adequate protection against unauthorised access			
A.2 Safe escape route in case of unexpected event			
A.3 Substation easily accessible			
A.4 Tagging on walls			
A.5 Intrusion of water			
A.6 Any other circumstances	-	-	
<b>B. Cable terminations</b>			
B.1 Termination type	Oil filled	Oil filled	Dry
B.2 Partial discharges audible	No		
B.3 Any other circumstances	-		
<b>C. Breakers</b>			
C.1 Breaker type	Air	Air	SF6
C.2 Condition	Average	Average	Better
C.3 Enclosure	Closed	Closed	Closed
C.4 Any other circumstances	-	-	-
<b>D. Low-voltage system</b>			
D.1 Enclosure	Open	Protected	Protected
D.2 Single pole switches	Yes	Yes	No
D.3 Any other circumstances	-	-	-
<b>E. Transformer</b>			
E.1 Insulating medium	Oil	Oil	Oil
E.2 Condition	Average	Average	Better
E.3 Oil collector underneath?	Yes	Yes	Yes
E.4 Any other circumstances	-	-	-
Investment cost [€]		12 000	100 000
Remaining lifetime [years]		< 10	> 30

## CONCLUDING REMARKS

This paper describes a framework of risk assessment applied to potential replacement or refurbishment of existing installations or sub-systems. The approach is suitable for repetitive reinvestment analyses, i.e. repeated and similar analyses of numerous components.

The example illustrates the use of the risk based check-list in order to get a structured and efficient analysis and reporting of the problem and possible solutions.

There are several other aspects regarding the reinvestment analysis that are a part of the framework in Figure 1, which should be dealt with. For instance when choosing input data for specific projects, average values may not be so important, since the candidates for analysis by definition have a condition presumably worse than the average. If not the reinvestment analysis would be pointless. One should therefore look into using expert judgment, choice of sample space and sensitivity techniques when performing analyses.

Also, along with the risk evaluation, different technical as well as economical analyses should be carried out. When the different alternatives are analysed it must be decided which one to choose, taking several criteria into consideration simultaneously. The questions will then be how the results from different analyses should be aggregated, as basis for the final decision.

## REFERENCES

- [1] R. E. Brown, J. H. Spare, "Asset management, Risk and distribution system planning", IEEE PES Power System Conference and Exposition, 2004
- [2] D. E. Nordgård, K. Sand, O. Gjerde, M. D. Catrinu, J. Lassila, J. Partanen, S. Bonnoit, J. Aupied, "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, Wien, 2007
- [3] K. Sand, O. Gjerde, D.E. Nordgård, "Current risk exposure in the distribution sector. Initial study", TR A6576, SINTEF Energy Research, Norway, 2007
- [4] M. D. Catrinu, D.E. Nordgård, K. Sand, J.K. Norhagen, "Multi-criteria decision support in distribution asset management", CIRED 19th International Conference on Electricity Distribution, Wien, 2007
- [5] M. K. Istad, D. E. Nordgård, O. Gjerde, M.D. Catrinu, A. Nybø, B. E. Birkeland, "Risk Informed Decision Support for Reinvestments in Distribution Systems", PMAPS – Probabilistic Methods Applied to Power Systems, Puerto Rico, 2008
- [6] T. Aven, "Risk analysis. Assessing uncertainties beyond expected values and probabilities", Chichester: Wiley, 2008.