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

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INTRODUCTION

In the ageing infrastructure of electricity distribution, the emphasis on maintenance and reinvestment decisions is ever increasing – focusing on doing the right thing at the right time.

Maintenance and reinvestment decisions are important parts of distribution system asset management, as means to control risk. Distribution companies are increasingly recognizing risk assessment as an important tool in distribution system asset management [1, 2, 3].

This paper describes a concept of risk assessment applied to projects regarding potential replacement or refurbishment of existing installations or sub-systems. Such projects are referred to as *reinvestment projects*.

A project is an individual job, limited in time and costs, as opposite to a continuous process, e.g. reoccurring maintenance activities. The handling of reinvestment projects relates to specific non-routine reinvestment decisions, that cannot be directly covered by the rules of the distribution company maintenance and reinvestment strategies, and hence need to be dealt with individually.

The paper focuses on risk assessment as basis for reinvestment project 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 this can support the distribution company work flow. 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. A triggering event is an event leading to an evaluation of a system or component. Examples of such events are age, results from condition monitoring, failures, load development or 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.

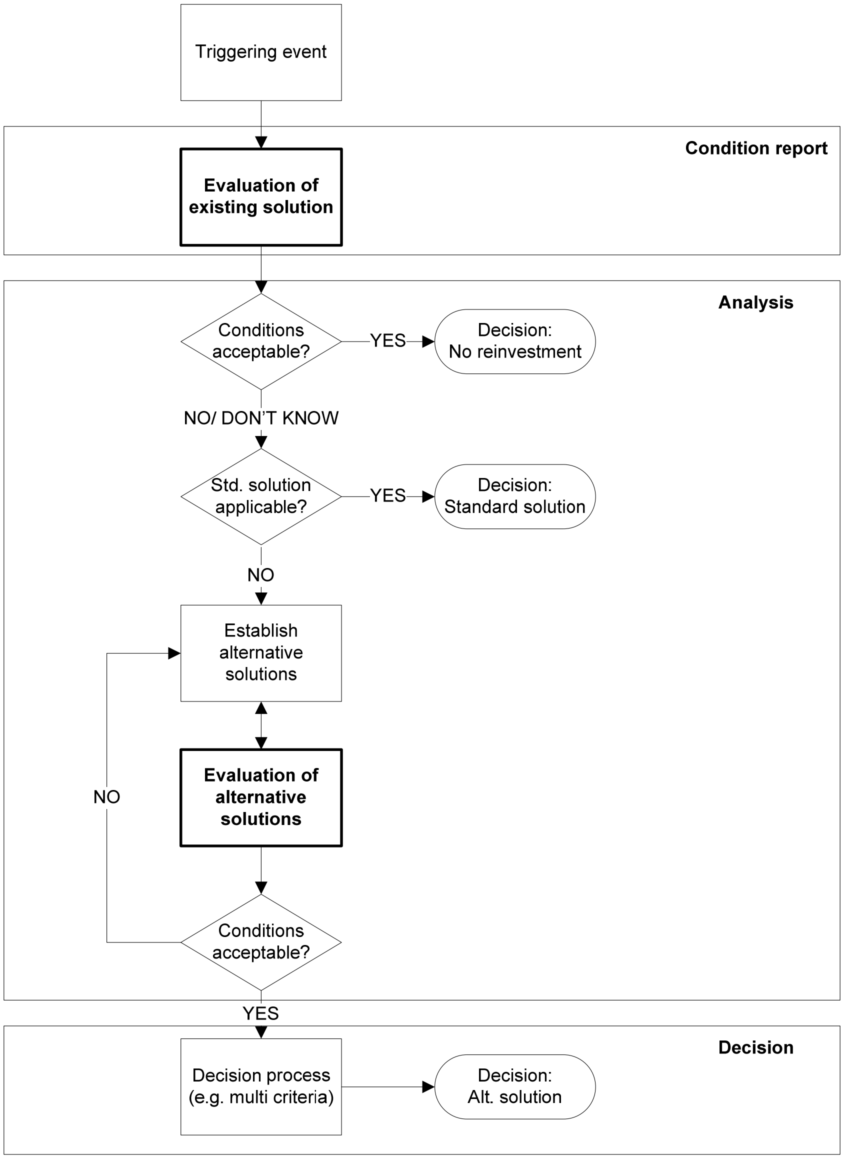

Figure 1 Work process for reinvestment analysis.

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

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

The next step is to carry out an evaluation of 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 evaluated and a preferred solution is chosen. For examples of such decision making, see e.g. [4, 6].

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. As a case study a framework is established for renewal of MV/LV distribution substations.

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

RISK ASSESSMENT

This paper deals with including risk assessment as a part of the work process of reinvestment analysis. With reference to Figure 1 the 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 for use in the reinvestment analysis, based on critical unwanted events which have been identified for the relevant component(s). This check list forms a basis for the risk assessment, to go along with the different technical and economical parts of the reinvestment project analyses.

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

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

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

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

Based on the identified critical events, a list is formulated containing check-points 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 projects:

- Economy
- Safety
- Reputation
- Environment.

The application of the proposed framework of Figure 2 is illustrated in a case study describing the development of a reinvestment analysis check list for MV/LV substations.

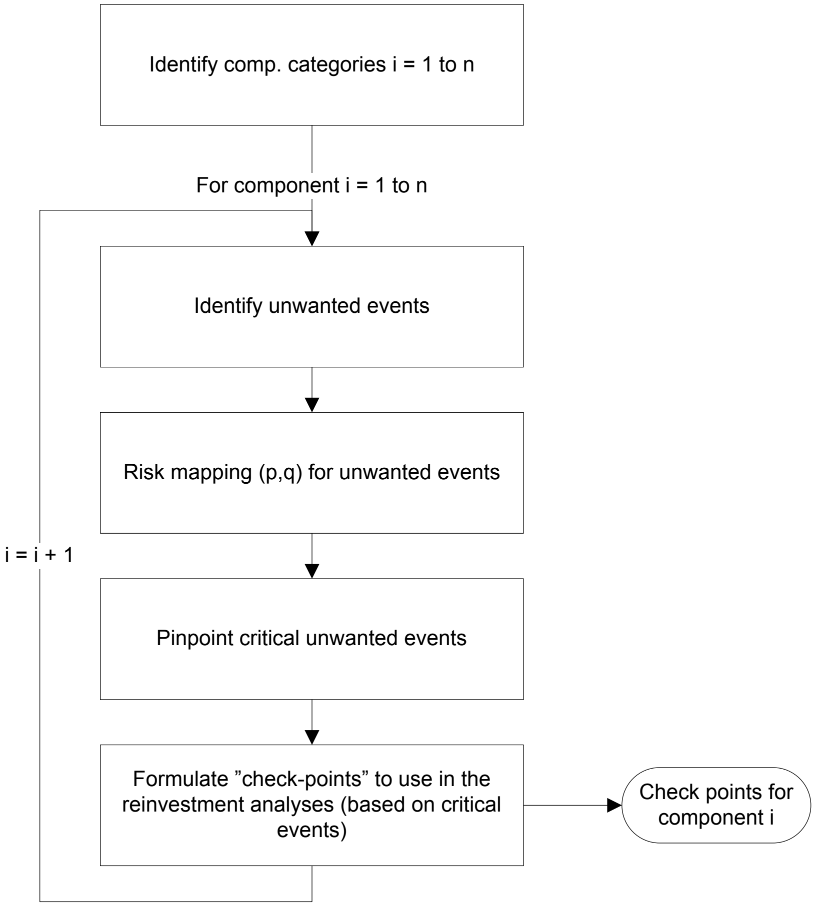

Figure 2 Flow chart for establishing reinvestment analysis check list.

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

In the following the steps of the framework from Figure 2 are applied to incorporate risk assessment in the reinvestment analysis of MV/ LV substations. As a starting point unwanted events are identified related to the different consequence categories and evaluated regarding risk (probability and consequence). The risk analyses are based on inputs found in [5].

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

Identify component categories

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

- Building
- Cable terminations
- Epoxy-insulated breakers
- Low-voltage system
- Air insulated breakers
- SF_6 insulated breakers
- 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
2. Flashover at insulators
3. Oil fire/ explosion
4. Public complaints about acoustic noise
5. Transformer breakdown
6. Transformer running hot.

Risk mapping for unwanted events

These unwanted events (# 1-6) are plotted in the following risk matrices for the four given consequence categories. Estimation of probability and consequences is based on expert judgement, and refers to an "average component" differentiated with regards to construction etc where relevant.

Table 1 Risk mapping for MV/ LV transformer.

Safety risk					
Consequence ▶ **Likelihood ▼**	Insignificant	Minor	Moderate	Major	Catastrophic
Frequent	🟨	🟥	🟥	🟥	🟥
Probable	🟩	🟨	🟥	🟥	🟥
Occasional	🟩	🟩	🟨	🟥	🟥
Remote	🟩	🟩	🟩	🟨	🟥
Improbable	🟩	🟩	🟩	🟩 1, 3	🟨

Environment risk					
Consequence ▶ **Likelihood ▼**	Insignificant	Minor	Moderate	Major	Catastrophic
Frequent	🟨	🟥	🟥	🟥	🟥
Probable	🟩	🟨	🟥	🟥	🟥
Occasional	🟩	🟩	🟨	🟥	🟥
Remote	🟩 1 (with coll.)	🟩	🟩 1 (without coll.)	🟨	🟥
Improbable	🟩 3, 5 (with coll.)	🟩	🟩 3, 5 (without coll.)	🟩	🟨

Reputational risk					
Consequence ▶ **Likelihood ▼**	Insignificant	Minor	Moderate	Major	Catastrophic
Frequent	🟨	🟥	🟥	🟥	🟥
Probable	🟩	🟨	🟥	🟥	🟥
Occasional	🟩	🟩	🟨	🟥	🟥
Remote	🟩 1 (with coll.)	🟩 4	🟩 1 (without coll.)	🟨	🟥
Improbable	🟩	🟩	🟩	🟩	🟨

Economical risk					
Consequence ▶ **Likelihood ▼**	Insignificant	Minor	Moderate	Major	Catastrophic
Frequent	🟨	🟥	🟥	🟥	🟥
Probable	🟩	🟨	🟥	🟥	🟥
Occasional	🟩	🟩	🟨	🟥	🟥
Remote	🟩	🟩 1, 2, 6	🟩	🟨	🟥
Improbable	🟩	🟩	🟩 3, 5	🟩	🟨

Pinpoint critical unwanted events

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

For **safety risk** events # 1 and 3 have been found to be somewhat critical based on their 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.

Formulate "check-points"

Based on the critical unwanted events of the MV/ LV transformer the following inspection list is established:

- Insulating medium (dry/oil)
- Transformer condition (worse/average/better)
- Oil collector underneath.

To open for other relevant input when performing the reinvestment analysis, a checkpoint covering "any other circumstances" should be included.

In a similar way the following inspection list is established for the MV/ LV substation, covering all component categories:

Building:
- *Adequate protection against unauthorised access*
- *Safe escape route in case of unexpected event*
- *Substation easily accessible*
- *Tagging on walls*
- *Intrusion of water*
- *Any other circumstances*

Cable terminations:
- *Termination type (oil filled/ dry)*
- *Audible partial discharges*
- *Any other circumstances*

Breakers:
- *Breaker type (Epoxy/SF6/air)*
- *Condition (worse/average/better)*
- *Enclosure (complete/semi/open)*
- *Any other circumstances*

Low voltage system:
- *Enclosure (open/protected)*
- *Single pole switches*
- *Any other circumstances*

Transformer:
- *Insulating medium (dry/oil)*
- *Condition (worse/average/better)*
- *Oil collector underneath?*
- *Any other circumstances.*

Example - Reinvestment analysis

In the following the application of the inspection list and incorporation of risk assessment in the reinvestment analysis (see Figure 1) is illustrated by an example. The inspection list from above is applied to a specific MV/ LV substation. The results from the “evaluation of existing solution” is listed in the “current state” column in Table 2 below.

Table 2 Example from inspection of MV/ LV substation

Component/ sub system	**Current state**	**Alternative 1**	**Alternative 2**
A. Building			
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. Cable terminations			
B.1 Termination type	Oil filled	Oil filled	Dry
B.2 Partial discharges audible	No	🟩	🟩
B.3 Any other circumstances	-		
C. Breakers			
C.1 Breaker type	Air	Air	SF6
C.2 Condition	Average	Average	Better
C.3 Enclosure	Closed	Closed	Closed
C.4 Any other circumstances	-	-	-
D. Low-voltage system			
D.1 Enclosure	Open	Protected	Protected
D.2 Single pole switches	Yes	Yes	No
D.3 Any other circumstances	-	-	-
E. Transformer			
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 [kNOK]		100	800
Remaining lifetime [years]		< 10	> 30

As indicated in the “Current state” column there are found deviations resulting in one red and three yellow cells:

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, two alternative solutions 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 100 kNOK. The remaining lifetime for this alternative is estimated to less than 10 years.

Alternative 2: New substation
In alternative 2 the entire LV substation is replaced. The cost for this alternative is 800 kNOK. The remaining lifetime for this alternative is estimated to more than 30 years.

CONCLUDING REMARKS

This paper describes a concept of risk assessment applied to projects regarding 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, representing a compact and understandable evaluation and documentation of the problem and possible solutions.

There are several other aspects regarding the reinvestment project 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. One should therefore look into using expert judgment, sample space and sensitivity techniques when performing analyses.

Also, along with the risk assessment, different technical as well as economical analyses usually are 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, and how the decision should be made.

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