METHODS FOR MAINTENANCE AND REINVESTMENT STRATEGY MAKING IN DISTRIBUTION SYSTEMS

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ABSTRACT

This paper discusses the process of maintenance and reinvestment strategy making in distribution companies. It presents several examples illustrating decisions that have to be made, analyses that can be done and methods that can be used at each step in the strategy making process.

1. INTRODUCTION

Distribution systems comprise large amounts of assets which are geographically dispersed. These assets can be grouped in different categories based on: type, installation year, condition, importance in the system, exposure to extreme weather conditions, etc. In order to get the most out of the assets, utilities need to design maintenance and reinvestment (M&R) strategies that will allow an optimal allocation of resources among asset groups.

An overall M&R strategy will generally include specific strategies for all groups of assets. Each group-specific strategy should give guidance concerning which maintenance principle to use, namely: run-to-failure, preventive maintenance, condition-based maintenance or modification / design improvements [1]. It should also provide the means for finding the correct balance between maintenance and reinvestments by including rules both for routine actions (which maintenance activities to be carried out and how often) but also rules that may trigger certain procedures to be undertaken as for instance (‘when maintenance costs are expected to be larger than x €, the case should be dealt with as an individual project, and a reinvestment analysis should be performed’).

The design of M&R strategies is not an easy task, mainly because of all the risks distribution networks are exposed to. A recent survey [2] reveals common risk related challenges distribution companies in Norway, Finland and France must face, and discusses the need for formal decision support procedures for managing risks in all asset management decisions – including M&R decisions.

An important challenge when applying any risk analysis method is to find relevant numerical values to use in computations. Experience shows that one often will find little help in statistics alone due to lack of representative data.

Approaches that combine input from statistics with expert judgment, if appropriately used, can provide valuable decision support.

The scope of this paper is to discuss and give examples of decisions that have to be made and methods that can be used in practice, at each step in the design of an M&R strategy. The paper summarizes several research results in the RISK DSAM project, currently in progress at SINTEF Energy Research, Norway.

2. THE DEVELOPMENT OF MAINTENANCE AND REINVESTMENT STRATEGIES

2.1 General procedure

An M&R strategy is a set of medium-to-long term plan concerning how to maintain different groups of assets in line with the overall asset management objectives. The process of designing a general M&R strategy for a distribution company should comprise the following main steps:

1. Decide how to categorize the assets.
2. Analyze and choose relevant maintenance strategies for all asset categories.

2.2 Categorization of assets

The main decision here is how to group the assets in a distribution system, in order to be able to design common M&R strategies suitable for all components in each specific asset group. It is important to identify the most relevant criteria (or characteristics the assets should have) for grouping the assets. Typical criteria for categorization of distribution assets are:

1. asset type - e.g. 12kV MV air-insulated load switches in MV/LV sub-stations.
2. age/condition.
3. location - the geographical location and environmental conditions in which the asset is installed.
4. cost – maintenance and replacement costs.

More sophisticated categorization criteria can be: the component’s importance (criticality) in the system, the risks the component is exposed to or the risks it induces in the system by its unavailability, the information (quantity and quality) that is available about the component the virtual age, or combinations of all the above criteria. However, these criteria are less adopted in practice because they are difficult to measure. For example, the importance (value) of an equipment in the system depends on the variation of system's risk caused by its absence from the system [3]. This is a very complex function of system configuration, failure probabilities of all system components, load levels etc, and can be measured in terms of cost of energy not supplied, (CENS), consumers satisfaction, safety levels, etc.

Example: Risk-Based categorization of MV/LV transformers

This example is described in [6] and proposes a procedure for risk-based categorization of MV/LV transformers. A thunderstorm in 2002 in a small region in Norway caused massive transformer failures (approx. 140 MV/LV transformers failed) revealing that the existing earthing system for the transformers in that particular distribution system area was of poor quality. The event caused customer interruptions, negative publicity and economic loss for the distribution company. Because such events have not been common in the past, the risk of insufficient earthing had not been previously addressed.

In the categorization of transformers, it has been assumed that components at different geographical locations can not longer be treated in the same way because they are exposed to different risk levels. This is because the probability for a transformer to be hit by lightning depends on its geographical location. Moreover, transformer's position/ importance in the topology of the distribution system affects the consequence of failure- which, in this example, was calculated in terms of economy (cost of energy not supplied) and reputation.

A risk matrix was used to characterize the risk the different transformers were exposed to. Based on this, four transformer groups were defined as shown in Figure 1. The completion of the risk matrix and the selection of transformers in each group have been done using a qualitative risk evaluation based on information about lightning activity, system topology and expert opinion.

	Negligible	Marginal	Medium	Critical	Catastrophic
Frequent					
Probable					
Occasional		1B	1A		
Remote		2B	2A		
Improbable					

Figure 1 Risk-based categorization of MV/LV transformers

This categorization has been further used in the estimation of the risk reduction M&R strategies can induce on the four asset groups, as described in [6].

2.3 Analysis of relevant strategies for specific asset groups

The M&R strategy for a group of assets should specify which maintenance activities (or combinations of maintenance activities) should be performed and what should trigger changes in the maintenance plan. Some basic maintenance activities are: inspection, service (for example, routine adjustment), repair, refurbishment (overhaul), and replacement. In case of special (triggering) events, a decision to be made is whether to maintain or to replace and when to replace a specific component.

A M&R strategy should be based on one of the two basic overall maintenance principles: *corrective maintenance* ('run to failure') or *preventive maintenance* (scheduled, condition - based or reliability centered maintenance) [5]. This decision will depend on an overall evaluation of the assets in a group and analysis of the expected impacts different strategies can have on:

- The resources employed - the expenses incurred in maintaining, repairing or replacing the equipment [4].
- The expected revenue lost by the utility due to equipment failure - energy not supplied and penalties.
- Personnel safety.
- Reliability of supply.
- Public opinion (customers' satisfaction).

The way to measure and compare these impacts is often difficult because:

- Relevant statistical data about components are rarely available - to compensate for this, expert opinions are often used.
- Quantitative as well qualitative data have to be taken into consideration.
- Many different risk aspects have to be taken into consideration.

These challenges have been addressed through several research activities in the Risk-DSAM project. A general procedure for maintenance and reinvestment risk assessment has been proposed, and this comprises: problem identification, information gathering, risk analysis and decision making [7]. Further, the aim was to offer AM (asset managers) decision support tools that can be applicable at each of these steps, allowing them to take into consideration several risk aspects and several decision criteria into real life decisions.

Bayesian Networks [8], bow-tie models [9], multi-criteria analysis (MCDA) [7], have been proposed as relevant tools that can provide realistic modelling of component failure and estimation and comparison of expected consequences of various maintenance alternatives. In the following section examples of analyses that can be made when designing M&R strategies are discussed. The assets studied were 12kV air insulated breakers situated in indoor MV/LV substations.

Example: M&R strategies for MV/LV switchgear equipment

Two types of analyses will be illustrated in the following examples:

- The overall selection of M&R alternatives for the switchgear equipment and the substation
- A risk-based evaluation of maintenance activities and the measurement of expected consequences – in particular safety risk.

Overall analysis of M&R alternatives

This example, described in [7] illustrates the comparison and selection of relevant M&R alternatives for the switchgear equipment situated in indoor MV/LV substations.

The equipment of the substation (three air insulated load breakers, a transformer (315kVA, oil-filled) and additional equipment) has been under regular inspection and minimal repair the last several years. The last observations revealed water infiltration into the building accommodating the circuit breakers and partial discharges on the cable terminations connected to the circuit-breakers. One of the circuit breakers failed in the past and has been replaced, another had no failure although corrosion and partial discharges were observed while the third has failed and has not been repaired.

Because of the position and importance of this substation in the local distribution system, the following issues had to be considered when deciding a maintenance strategy: costs, safety of personnel, distribution network's reliability and public opinion. The asset manager took an active part in identifying six possible alternatives: replacement of the entire substation including relocation, rehabilitation of the whole substation or only the damaged circuit breakers, or take no action.

The consequences of the six alternatives have been estimated quantitatively and qualitatively and in terms of cost, safety, reliability and public opinion and are summarized in the table below.

Table 1 M&R alternatives and expected consequences

ALTERNATIVES	CRITERIA				
	Economy (cost, NOK*)	Reliability CENS (NOK*/year)	Safety		Public opinion
			Risk of injuries	Risk of intoxication	
1. New substation	560 000	small	small	small	1
2. Partial rehabilitation	99 000	40 000	medium	medium	-2
3. Total rehabilitation	430 000	small	medium	small	1
4. Relocation	700 000	small	small	small	0
5. Change circuit-breakers	270 000	medium	medium	medium	-2
6. No action	0	60 000	Very high	Very high	-3

*NOK = Norwegian krone, CENS = Cost of energy not supplied

The final selection of alternatives has been done based on a ranking of all alternatives in terms of asset manager's judgments. In this example, the judgments (or values) have been modeled using a Multi-Criteria Decision Support Software (PRIME). The advantage with this software is that total values for the analyzed maintenance alternatives are estimated based on asset manager's *preference information* (scores and criteria weighting) *that can be expressed imprecisely/incompletely*. The value intervals in Figure 2 illustrate the imprecision/ uncertainty in judgments. The results for the 'Maintenance' case-study show that the alternative of building a new substation has been preferred. This is explained in [7] by the fact that the asset manager cared most about safety, then system reliability, economy and public opinion.

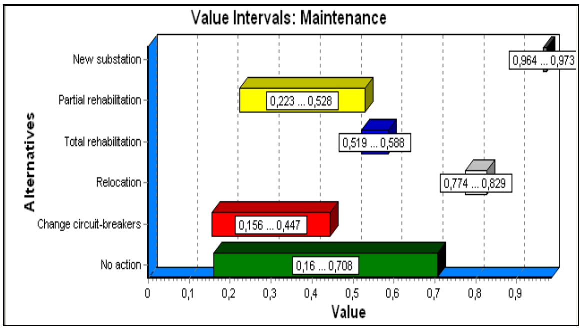

Figure 2 Ranking of M&R alternatives based on AM's preferences

The advantages of such an analysis are:

1. The possibility to structure the decision problem and take into consideration multiple criteria and uncertainty.
2. The possibility to visualize and record AM's judgments and how these contribute to the justification of the final decision.
3. This analysis can be done for any asset group and can be used in the development of M&R strategies.

Risk-based evaluation of maintenance activities

To complement the above overall analysis we propose in the following a more in-depth analysis for M&R of 12kV air insulated breakers situated in indoor MV/LV substations. Details about these examples can be found in [8] and [9].

The focus is on the safety aspect, generally seen as an important premise in the design of M&R strategies. The safety risk was assumed to be directly related to the slow movement of the switch during operation, which leads to uncontrolled electric arcs in the switchgear. Several factors have been indicated by experts to contribute to this unwanted event: component's age, operating environment, maintenance interval (history), and encapsulation of the switch.

Figure 3, from [8], illustrates an example on how to model the safety risk using a Bayesian network (BN) approach. The failure mode of slow operation of the switch was assumed to depend on two critical states: *switch poles stuck* and *slow operating mechanism*. The safety has been measured in terms of potential loss of life (PLL) that was assumed to depend on:

- The probability of slow operation of the switch, which

may result in a burning electric arc.
- The encapsulation of the switch.
- Whether or not the operator is wearing protective clothing.

The quantitative safety risk model based on BN is an example on how to structure and quantify the knowledge and assumptions of company experts into an analytical model. Detailed information about the process of building up the BN model and parameter estimation are given in [8].

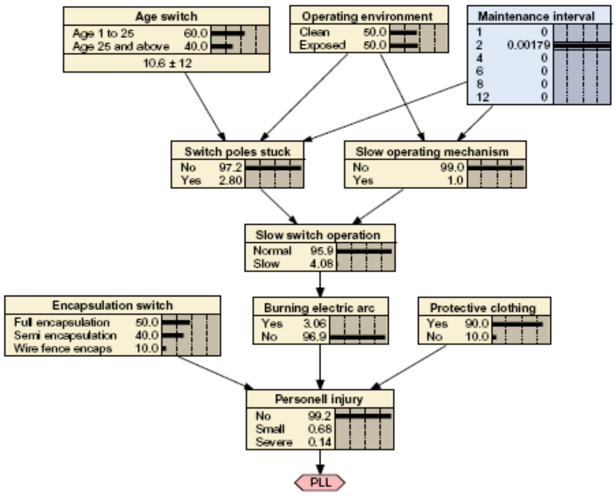

Figure 3 BN safety model of air insulated switches, [8]

The results of this type of analysis contribute to an increased understanding of safety risk and better informed M&R decisions.

Another issue that can be studied in more depth [9] is how to take into consideration the risk associated with different *maintenance activities* (and intervals) as for instance: visual inspection and functional control. Quantitative risk analysis (QRA) can be used to provide comparable risk estimates for different switchgear configurations and to include this information in the M&R strategy making.

Acknowledgments

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CONCLUSION

The paper discusses examples of analyses that can be done when designing M&R strategies, with focus on asset categorization and analysis of relevant strategies. Several challenges make the development of M&R strategies difficult:
- Relevant statistical data about components are rarely available - to compensate for this, expert opinions are often used.
- Quantitative as well qualitative data have to be taken into consideration.
- Many different risk aspects have to be taken into consideration.

In order to meet these challenges, Bayesian Networks, bow-tie models and multi-criteria analysis have been used because they can provide realistic modelling of component failure and estimation and comparison of expected consequences of various M&R alternatives. Such tools contribute to an increase understanding of the risks involved and better informed M&R decisions.

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