RELIABILITY CENTERED ASSET MANAGEMENT IN DISTRIBUTION NETWORKS - PROCESS AND APPLICATION EXAMPLES -

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ABSTRACT

The usage of asset management methods for the operation of electricity supply networks has become standard in recent years. The goal for the application is the combined control of cost effectiveness and power quality. The related correlations between technical and economical effects of asset management decisions are complex and temporally decoupled, and characterized by sparse data availability.

This paper describes a modular approach for a Reliability Centered Asset Management process. Application examples of this asset management process for distribution systems present the definition and calculation of both component importance and component condition indices, as well as a detailed simulation of both supply reliability and economical parameters into the future.

The detailed and above all quantitative information on both costs and supply reliability are of key importance for network operators in their task to find the optimal balance between cost efficiency and power quality. The application of modern asset management methods can reason at least parts of the basic correlations between costs and quality – even based on today's limited data availability.

INTRODUCTION

Network operators in today's liberalized electricity markets are faced in most countries with the key challenge to balance cost efficiency and quality of supply [1]. While the cost pressure from the general public and the political institutions constantly increases, the requirements from again general public and politics towards power quality are remaining at least constant, if they are not increasing, too. In this context, the usage of explicit asset management methods for the operation of electricity supply networks has become standard in recent years. The particular goal for the application is the combined control of cost effectiveness and power quality.

It is generally agreed that there is a connection between the costs of power systems and the quality the systems are able to deliver. But the related correlations between technical and economical effects of decisions in asset management are very complex and even temporally decoupled. Typically, the economical consequences have immediate effects, while technical consequences – especially on supply reliability – will only show after several years. Also, the practical application of asset management methods still is often difficult because the complex correlations can be modeled only insufficiently or because required input data is not available in suitable quantity and quality.

This paper describes a modular approach for a Reliability Centered Asset Management (RCAM) process, which is based on readily available calculation concepts. Aiming to follow a comprehensive approach, also this process requires certain models and data which are still difficult to acquire in today's operational practice. In this context, results of a recent German research project are shortly presented that help to overcome this gap by enabling meaningful assumptions and approximations. Two application examples for different distribution systems are then presented, each highlighting different aspects of the RCAM process.

PROCESS FOR RELIABILITY CENTERED ASSET MANAGEMENT

Figure 1 gives an overview of the modular structure of the RCAM process [2]. The goal of this process is to analyze and evaluate relevant technical and economical aspects of network operation, and to derive improved asset management strategies for the considered component classes – i.e. strategies for both content and time intervals of preventive maintenance actions, as well as for the technical lifetime specification. In the definition of the component classes (e.g. only one class switchgear, or separated into circuit breakers / isolators / other), the benefit of more detailed results has to be weighted against the availability of suitable input data and against the increasing effort.

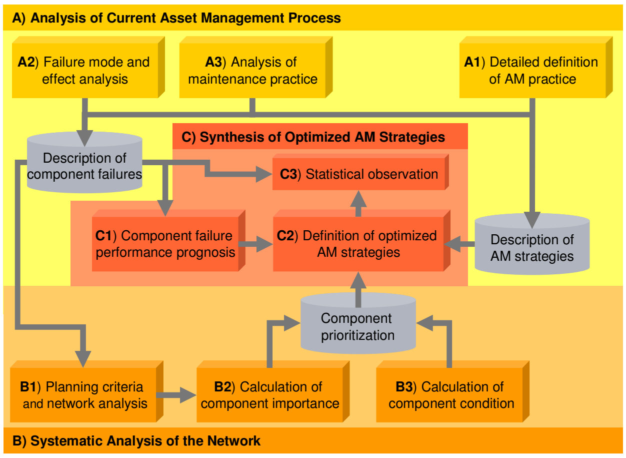

Figure 1 Overview of the RCAM process

The RCAM process is structured into three basic steps, which are again differentiated into separate modules:

- Analysis of current asset management process
  - Detailed definition of asset management practice
    For the separate component classes the respective preventive maintenance actions (e.g. inspections or

revisions) are defined in detail concerning contents and required resources (personnel, costs, …). Also, the replacement strategies, or lifetime definitions respectively, are defined.

  - Failure mode and effect analysis
    On component level, the relevant failure modes and their effects are described. Additionally, the effects of different component failures on the complete system have are characterized.
  - Analysis of maintenance practice
    If appropriate information is available in a systematic format, the occurrences of the different failure modes are analyzed for the separate component classes using the documentation of previous actions.
- Systematic analysis of the network
  - Planning criteria and network analysis
    With regard to long term success of asset management, suitable planning criteria have to be determined and related scenarios for network development have to be defined. Both technical and economical requirements should be considered. The defined planning criteria are the guidelines for component replacements and network extensions.
  - Calculation of component importance
    The importance of components first has to be defined in a suitable way – e.g. using probabilistic supply reliability indices. The calculation should provide rule-based possibilities for adaptations.
  - Calculation of component condition
    A suitable definition of a condition index is of crucial importance. Relevant attributes and related weighting factors are determined. At least for a part of the components, the required condition data should be assessed on site. Again, the scheme should provide rule-based possibilities for adaptations.
- Synthesis of optimized asset management strategies
  - Component failure performance prognosis
    Models for the prognosis of component reliability depending on relevant influencing factors like e.g. age and maintenance history are a crucial requirement for the definition of long term successful strategies.
  - Definition of optimized asset management strategies
    Using the partial results provided by the previous modules – especially concerning the definition of suitable actions, the component prioritization based on importance and condition, and the prognosis of component failure performance – the technical and economical effects of strategy decisions can be assessed. This step thus delivers essential information for the support of decision processes in determining optimized asset management strategies.
  - Statistical observation
    The stochastic influence of outage occurrences on both component and system level requires a dedicated statistical recording of relevant data in order to detect trends and their possible causes as early as possible.
    Moreover, the improvement of the data base is in general very important for asset management.

In an actual application of this modular approach, typically not all these separate steps have to be or can be performed for various reasons. It may often be the case that not all required models and data are available, that relevant tasks have already been executed or that acceptable assumptions exist and can be used as substitutes for the results of certain modules. The modular structure allows that the process is adjusted to the individual requirements.

COMPONENT RELIABILITY DATA

Decisions on asset management strategies will have an effect on the reliability of network components. Increasing the service life or decreasing maintenance efforts will e.g. lead to rising failure rates of affected components.

The modeling of such influences is important for asset management methods – however, required models and data often are not available. In a recent research project, an appropriate damage statistic was compiled and analyzed in order to improve knowledge in this field [3, 4]. Using such statistics, models like e.g. simple exponential functions for the failure rate f depending on the age t according to equation (1) – which are able to match the observed outage history very well – can easily be parameterized.

$$f(t) = a + b\, e^{c\, t} \qquad (1)$$

Figure 2 gives an example of this approach for MV oil cables. The characteristic of the exponential age model first is adjusted to the results of the above mentioned special failure statistic for oil cables. Using parameter a, the exponential function is then moved to match the failure rate of the age-independent VDN statistic [5] in the first 40 year interval. The VDN statistic gives a better representation of general reliability levels due to its large database.

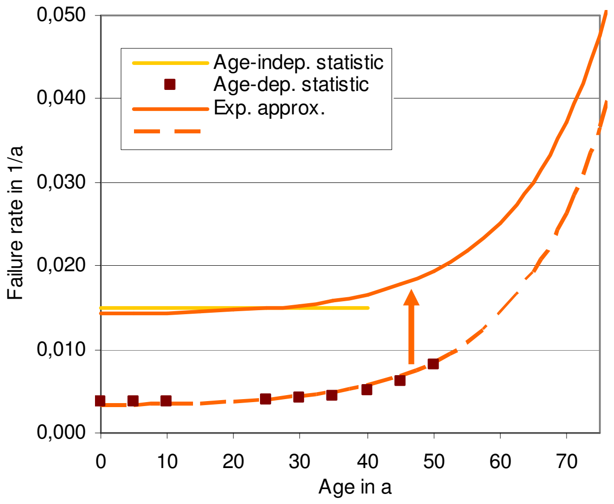

Figure 2 Failure rate approximation for independent single failures of MV oil cables

APPLICATION EXAMPLES

Component Prioritization

One of the major aspects of any asset management method is a prioritization of network components, in order to spend the available resources as efficiently as possible. Often, such prioritizations consider component importance and component condition. Neither component importance nor component condition are technical variables with commonly agreed academic definitions – so suitable definitions for the use in asset management have to be agreed upon.

In the scheme for defining and calculating component condition, typically several different aspects are considered. Such aspects include e.g.:

- **Age** is generally considered to be an important factor for component condition – and it is easily available in most cases from e.g. network information systems,
- **Serviceability**, comprising e.g. the availability of spare parts and skilled staff,
- **Ambient conditions** that the components are exposed to,
- **(Peak) loading**, as related thermal stresses are highly relevant for many ageing processes,
- **General operational experience**, relating to either systematic aspects of certain functional designs or even to individual conspicuities,
- **On-line measurements** of relevant parameters,
- **Condition assessment** by experts during site visits.

For all these condition attributes, a quantitative evaluation scheme and weighting factors have to be agreed so that in the end, one single condition index can be calculated.

Also the definition of the importance index typically considers different aspects, e.g. :

- **Deterministic reliability indices**, like e.g. the number of affected customers per component failure,
- **Probabilistic reliability indices**, e.g. the share of the system's total Expected Energy Not Supplied (EENS) caused by failures involving the separate components,
- **Criticality assessments** of different network areas or network components according to various criteria.

In general, the definitions for both component importance and condition should consider the availability of the required data and reflect the operational experience. Also, it is favorable to include aspects that can be assessed objectively – e.g. results of load flow or probabilistic reliability calculations – rather than only subjective criteria.

In a recent study, a subtransmission system featuring very high supply reliability levels was under consideration – which caused concern to find suitable definitions for the importance index. Using results of probabilistic reliability calculations – here, the share of total EENS caused by failures involving the separate components – proved to be a good measure to identify the few important components in this particular system, see **Figure 3**. An example for component prioritization is shown in the next section.

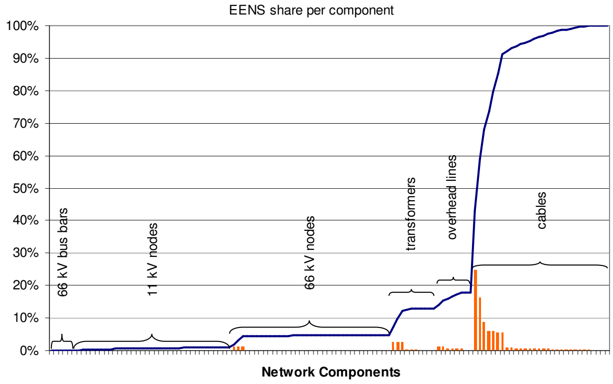

Figure 3 Share of EENS per component for a subtransmission system

Simulation of technical and economical performance

One major challenge in asset management is the different time scale for economical and technical effects of decisions. Changes in preventive maintenance or component replacement strategies will in most cases lead to immediate economical effects – but technical effects, especially on supply reliability, are likely to show only several years in the future. Therefore, it is important to simulate the expected performance in dependence of today's decisions.

Such simulations require, of course, suitable models for the prognosis of component reliability. In this example, robust models based on exponential functions (see above) were used. Also, respective cost models have to be implemented. In this example, the following cost types are considered:

- Investment costs / asset value,
- Preventive maintenance costs,
- Fault clearing costs (depending on failure performance),
- Repair costs (depending on failure performance).

The sum of the three latter cost types is also designated as OPEX in this example. Additional cost aspects, e.g. interruption costs, could easily be included in the analysis.

Three different scenarios are considered for the MV distribution system under consideration:

0 **Base scenario**: It is assumed that network operation continues as usual, i.e. preventive maintenance schedules are not changed and the technical lifetime is 40 years for all components.

1 **No preventive replacement**: Preventive maintenance schedules again are unchanged, but it is assumed that no preventive replacement at all is used, i.e. components remain in service until they fail.

2 **Complex scenario**: All network components are prioritized considering component importance and component condition (see above and **Figure 4**). Depending on the prioritization, components are either replaced immediately (pink area), treated with increased (orange area) or with decreased (yellow area) preventive maintenance efforts and extended service life. In the blue area, operation continues as in the base scenario.

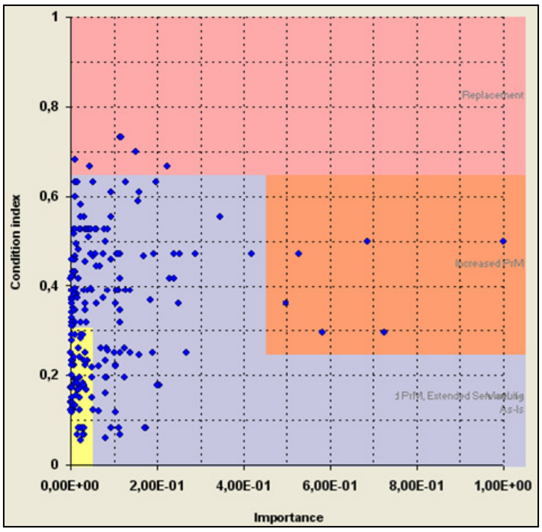

Figure 4 Component prioritization for a MV system

For each scenario, expected cost and reliability indices are calculated over a 20 year period in five-year steps. The results are shown in **Figure 5** for the non-availability and in **Figure 6** for the cost indices.

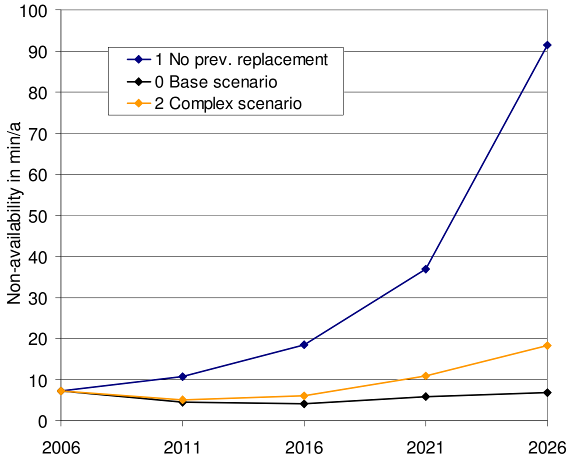

Figure 5 Expected non-availability for a MV system

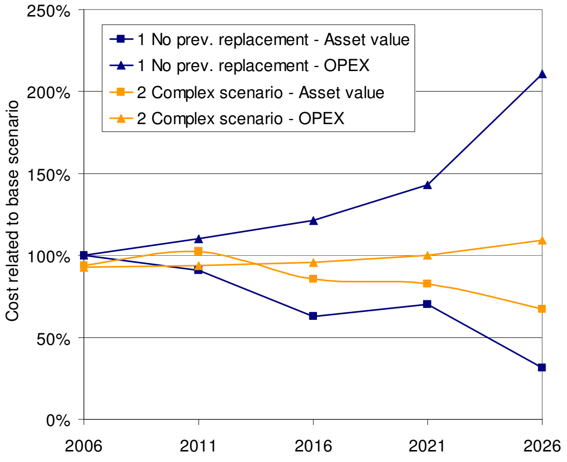

Figure 6 Expected cost indices for a MV system

The expected non-availability varies over time even in the base scenario – according to the changing age structure of the components. Figure 5 shows that the strategy to cancel any preventive replacements leads to a significant deterioration of supply reliability – and to an appropriate increase of the OPEX due to the many failure occurrences. Asset value, of course, decreases significantly in this scenario.
The considered complex scenario also leads to an increase of supply reliability indices – but further calculations show that the level remains constant at about 25 min/a in the long run. However, the OPEX remain at the same levels like in the base scenario, while the asset value decreases due to the extended service life of several components.

CONCLUSION

Today, expectations to save costs in network operation – which in general will impair power quality – are opposed to constant or even increasing power quality requirements of an increasingly “digital society”. Thus the key question for network operators is to find the optimal balance between cost efficiency and power quality. In this context, explicit asset management methods become indispensable. For supporting decisions in the best possible way, detailed and above all quantified information on both costs and supply reliability are required – including prognoses of the future performance in order to safeguard long-term success.
The presented approach for a Reliability Centered Asset Management process defines separate functional modules. This modular structure offers the possibility to adapt the asset management process to the individual situation of different network operators while delivering the most detailed and most significant results.
The meaningful and practice-oriented application of modern asset management methods offers the advantage to objectify and especially to quantify at least parts of the basic correlations between costs and quality – even based on today’s limited data availability.

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