

## MAINTENANCE STRATEGIES FOR DISTRIBUTION NETWORKS

M. Marketz<sup>1\*</sup>, J. Polster<sup>1</sup>, M. Muhr<sup>2</sup>

<sup>1</sup> KELAG - Kärntner Elektrizitäts-Aktiengesellschaft, Klagenfurt, Austria

<sup>2</sup> University of Technology, Institute of High Voltage Engineering and System Management, Graz, Austria

\*E-mail: michael.marketz@kelag.at

**Abstract:** Against the background of the current legal and economic demands on maintenance, this paper reports on maintenance strategies for distribution network components that will enable reliable power supply at lower cost of maintenance for components. The work is based on the analysis of the current situation of supply quality and maintenance of several distribution network operators. If one is familiar with the behaviour of failures of network components and with the supply quality of the networks, the comparison of the various approaches to maintenance facilitates the determination of short-term saving potential. In a further step, maintenance strategies with a strong focus on condition evaluation, as well as on system and risk, are examined and evaluated. New concepts for assessing the condition and importance of network components are introduced. It is shown that reliable statements about condition are a prerequisite for implementing system- and risk-oriented maintenance strategies. Reliable statements about the condition and importance of network components are used for adequately determining the risk of network component outage. In the long term, maintenance costs could be influenced by more simplified network and plant structures. The potential cost reduction is evaluated by means of real networks.

### 1. Introduction

The developments in energy politics over the last few years have put electricity distribution network operators under heavy and increasing cost pressure. Due to specifications of the regulation authorities, network operators are today faced with the difficult task of keeping networks up despite reduced revenue while at the same time guaranteeing appropriate and generally accepted reliability of networks. High demands are made on the maintenance of networks, as maintenance reduced for mere cost reasons leads to higher technical and economic risks and consequently to negative effects on the quality of networks. Against this background, this paper discusses maintenance strategies for distribution networks that can have an influence on component-related maintenance costs while preserving network quality and safety.

### 2. Methodology

The examinations start from a detailed and structured analysis of current maintenance practices in electric distribution networks. For the analysis, several network operators are compared with each other based on the knowledge about their networks' supply quality.

Originating from the results of this analysis, alternative maintenance strategies with a strong focus on the condition as well as system- and risk-orientation are examined. First, suitable criteria for determining the condition and the importance of the equipment of the network are defined. Reliable statements about the condition and importance of components are then used to determine the risk of the equipment failures. With regard to the long-term influence on maintenance costs, simplified network and plant structures in medium-voltage networks are examined by way of example (Fig. 1).

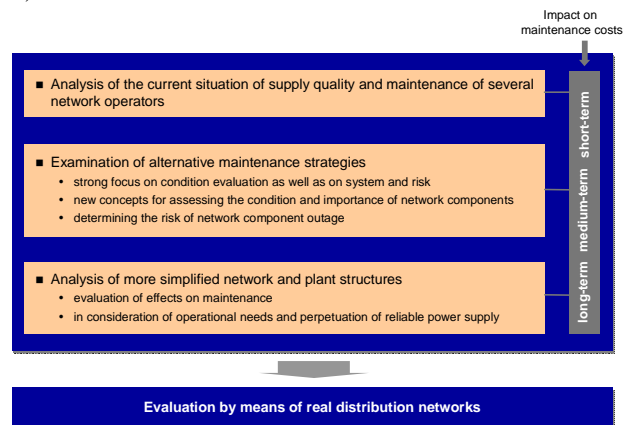


Fig. 1: Procedure

### 3. Maintenance in practice

In the course of analysing the way distribution networks are maintained, measures of classical maintenance, i.e. measures that serve purely to keep up function, are observed in a systematic way. A distinction is made between inspection, servicing and repair measures. The objects of the analysis were the medium- and low voltage levels, including high/medium voltage transformation.

As an adequate depiction of the connection between maintenance and availability of network components is currently impossible, the supply quality of distribution networks must be analysed first, followed by an analysis of practical maintenance on which the above quality is based. Supply quality and practical maintenance are analysed by cross-comparison of several network operators under consideration of the different structural characteristics of the individual supply areas. The cross-comparison of maintenance measures shows short-term saving potential for every network operator, if the failure behaviour of components and the supply quality

of the networks are known. These savings can be achieved through optimisation of inspection and servicing, mainly by expanding the inspection frequency of overhead lines and medium/low voltage (MV/LV) substations, and by adjusting the strategies for servicing of medium voltage (MV) switchgear sections and high/medium voltage (HV/MV) transformers.

#### 4. Alternative strategies

An analysis of practical maintenance shows that it is, above all, component-oriented strategies that are used to keep up the operability of operating systems, plants and networks of power distribution networks. In this paragraph, alternative strategies for maintenance are examined with a view to influencing component-related maintenance costs. The term “alternative strategies” covers both improved component-oriented and system-oriented strategies. Table 1 shows the criteria that apply to maintenance measures of different strategies. Reliable assessment of the technical condition of components is not only the prerequisite for implementation condition-based maintenance strategies; it is also the basis for the application of system- and risk-oriented maintenance.

measures strategy	inspection	servicing	repair	renewal
corrective	-	-	in case of outage	in case of outage
time-based	according to intervall	according to intervall	in case of outage	according to intervall
condition-based	cyclic or continuous (monitoring)	according to condition	in case of outage	according to condition
reliability-centered	„strategies overall process“ considering the importance of the network components to system reliability			
risk-based	cyclic or continuous (monitoring)	according to condition, importance and outage risk	in case of outage	according to condition, importance and outage risk

↑  
quantification of outage costs

component-based maintenance strategies  
 system-oriented maintenance strategies

Table 1: Maintenance measures of different strategies

In the framework of practically oriented considerations of system- and risk-oriented maintenance, assessment criteria for evaluating the condition and importance of components are defined first. They form the basis for subsequent evaluations. Examinations are carried out by way of example of existing networks.

#### Assessment of component condition

The condition of components is mainly assessed by visual inspections in the framework of cyclic inspections. These inspections are normally carried out by the experienced maintenance staff. Visual inspection is followed by cause-driven, targeted examinations, immediate servicing or repair measures. The use of technical diagnostic procedures is increasingly considered also for distribution networks [1]. For economic reasons, the use of such procedures depends mainly on the value or importance of the component to be monitored. It can be said that in addition to or support of visual inspection, more and more procedures

of visual diagnostics (Thermovision) are being used (among others also by KELAG) because of the increasing age of the components and the increase in their utilisation. In some cases and for individual components (e.g. circuit breakers, transformer tap changers), existing information, about network control systems or protective and control devices, is used to draw conclusions about maintenance frequencies.

Example of assessment: Transformers are among the most important components of power supply; for one, due to the comparably high acquisition costs and second because of their importance for reliable power supply. As much as 16% of the current high/medium voltage transformers in the network area under examination will soon exceed the originally expected technical service life of forty years. Another 15% will reach this service life in the next one to five years. Against this background, the assessment of the technical condition must be optimised to determine critical units by means of defined condition criteria. The condition of high/medium voltage transformers is examined according to the following criteria:

- Age
- Insulation Oil Analysis (DGA; for generator step up transformers also Furan analysis)
- Level of load
- External condition
- Condition of the tap changer (incl. control device)
- Special occurrences (short circuits, overvoltages, transports)

The assessment of transformers by means of these criteria is based on operation experience, analyses of historical data and on failure and damage statistics. Quantity and quality of data differ widely from case to case; for some criteria there is insufficient information available from the past. In such cases the experience of the operators as well as that of other network operators is useful, at least when it comes to gaining information about the operating history of the transformer.

To assess the overall condition of transformers, the results of the individual criteria are summarised. Fig. 2 shows the evaluation of the overall condition of five selected network transformers. The overall condition Z is determined on the basis of the weighted individual conditions, with weighting done according to the experience of the network operator. The Dissolved Gas Analysis (DGA) is very meaningful and therefore the most important criterion. Based on the benchmarks for concentrations of the most important key gases, graded action scenarios are determined depending on how much the benchmarks are exceeded. Past experience with comparable components, taking age, type and level of load into account, offers additional aspects of condition assessment.

The overall assessment contributes considerably to estimating future maintenance expenditure and the need for replacement investments as it identifies critical components. Hence, it is the starting point for strategic and economic considerations (replacement investment) and risk analysis.

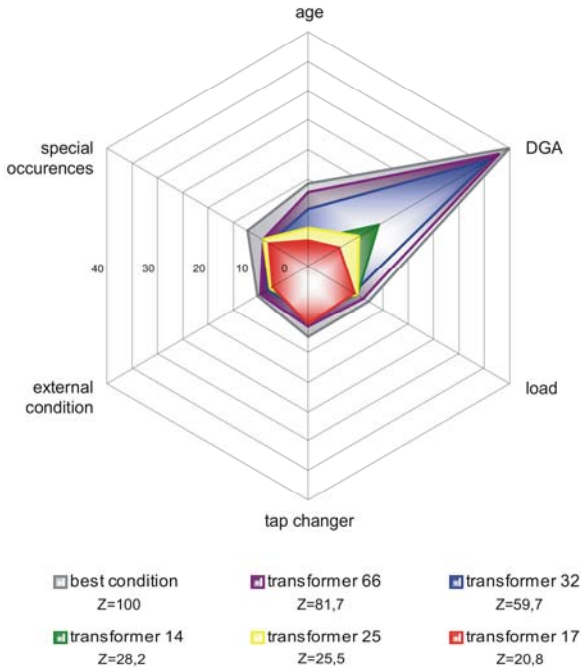


Fig. 2: Assessment of condition of high/medium voltage transformers

**Assessment of component importance**

In the past, data gained from experience were used to assess the importance of components. Today, due to the increasing risk-orientation, higher demands are put on the assessment. The various aspects of importance are assigned to reliability-related, risk-related and general, i.e. non technical, criteria.

Example of assessment: In the following example of assessment, the importance of components is examined by means of two rural medium voltage networks of KELAG. On the basis of the findings of the maintenance analysis, the contribution of lines (noticeable maintenance expenditure possible) and switchgear sections (various strategies in cross-comparison) to the unreliability of the network is determined. Frequency ( $H_D$ ) and probability ( $p_{rD}$ ) of supply interruptions are suitable benchmarks for that. The deficit energy is calculated with regard to the assessment of the economic risk linked to the breakdown of a component. As the reliability analysis cannot take all criteria of importance into account, major, non-technical and risk-related aspects are assessed separately. Results show that the influence of switchgear sections on the unreliability of the network is low (Fig. 3).

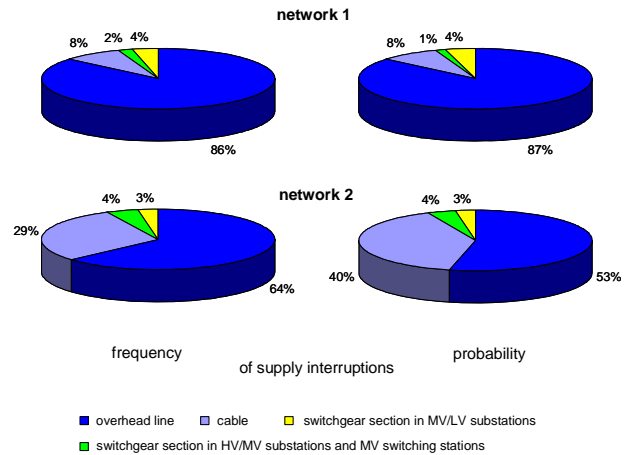


Fig. 3: Unreliability of supply broken down according to component contributions

This results from the low proportion of supply deficits caused by switchgear sections in HV/MV substations and switchgear sections in switching stations (circuit breaker sections) and fields in MV/LV substations (switch-disconnectors). Switchgear sections with circuit breakers are more important than sections without circuit breakers. Within the different types of switchgear sections, no clear criteria for importance can be defined. The maintenance of medium voltage switchgear sections can thus, on principle, be done according to reliability-centered conditions; it seems to be inappropriate to rank the maintenance measures within the switchgear section groups of HV/MV substation, MV switching station and MV/LV substation according to priority.

Compared to the switchgear sections, the importance criteria of individual medium voltage lines can be clearly defined. The results show few, individual overhead line sections to be particularly important. They account to a high degree for the unreliability of networks and can be assigned priority as far as maintenance measures are concerned.

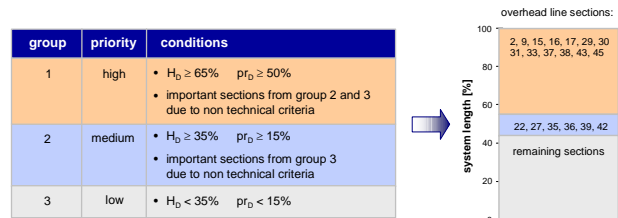


Fig. 4: Assignment of overhead line sections to maintenance groups

Contrary to today's inspection methods, where all overhead line sections are treated more or less the same, measures can be shifted to the benefit of more important

sections. Thus, overhead line sections can be divided into groups with different maintenance priorities (Fig. 4).

The results suggest that a reliability-centered approach in line maintenance is purposeful. In addition to the reliability-centered secondary conditions, specifications concerning operational safety, personal safety and environmental protection have to be taken into account. This, in turn, requires the appropriate assessment of the condition of critical components. In addition, the risk of supply interruption due to line outage must be properly evaluated.

### Risk assessment

The risk of component failure can be assessed with reliable statements about the condition and the importance of a component. Depending on the type of component, different methods of risk assessment may have to be taken. The examples of assessment described in this paper show that the risk of overhead lines can be assessed on the basis of reliability analyses. Critical line sections can be identified on the basis of their contribution to the reliability of the overall system. The condition is depicted indirectly via the availability of lines, but in future it should be determined for each line section and thus be closer to reality. In the case of high/medium voltage transformers, the technical risk is determined as a function of the condition and the importance of the transformer and estimated on the basis of the five selected transformers as shown in Fig. 2 (Fig. 5). The technical risk caused by external influences is not taken into account.

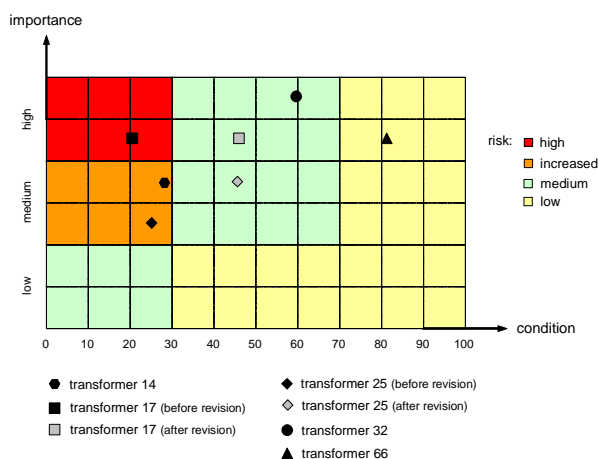


Fig. 5: Appraisal of failure risk of high/medium voltage transformers

Due to the fact that the majority of transformers in the supply area of the network operator under examination are in rather good condition, the technical and economic risk of transformer failure is low, apart from the identified critical cases. These critical units were determined by means of condition analysis and have an increased and/or high technical failure risk that is also

determined by the importance of transformers in the network. As the distribution networks in the network area under examination are generally configured in such a way that redundancies are available via reserve transformers and the subordinate network level, the technical condition of the transformers is the risk-determining factor.

Based on the assessment of the condition and the subsequent risk assessment, concrete maintenance measures were introduced for transformers 17 and 25 (Fig. 6). The development of fault gases dissolved in oil by means of DGA showed in both cases load-dependent local hot-spots with temperatures between 300 and 700°C. During the revisions, severely burnt contacts on the voltage selector on the secondary side 10/20 kV were found to be the places of failure.

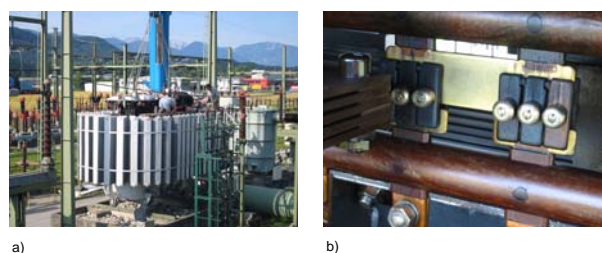


Fig. 6: Overhaul measures, transformer 25  
a) removal of the transformer core b) charred contacts on the voltage selector switch

The economic risk linked to component breakdown can be lowered by either reducing the probability of an actual failure or by limiting the consequences of such failure. The probability of failures caused by internal causes (that can be influenced) can be reduced through maintenance and renewal measures. The consequences of failures can, for example, be limited by redundantly designed networks. Exemplary studies show that the maintenance costs and – if any – activities required for component exchange are decisive for the monetary outage risk. The amount of outage costs is thus determined by the re-acquisition value of the broken down component, also because penalty or damages are currently not part of the Austrian regulation model [1, 3].

### 5. Influence of network and plant structure

Maintenance costs can, in the short term, be influenced by the right choice of the maintenance strategy. In the long run, activities for expansion, reduction and renewal (e.g. due to age) of the networks can reduce the maintenance expense if they are linked to structural adjustment and/or optimisation measures, i.e. lead to simpler network and plant structures. Simplified network structures will, in any case, have to be assessed under the aspect of maintaining sufficient supply quality and by taking operative effects into account.

Exemplary studies of rural medium voltage networks show how choice and change of station concepts can influence network costs and supply quality. The simplified structures do not only affect investment costs but also have a considerable influence on maintenance costs because of the reduction of assets. This influence is considerably higher than the short-term influence on maintenance costs achieved by adjusting the maintenance strategies [1]. Further studies now aim to assess how fast theoretical cost reduction potentials can really be achieved in practical application without any undesired effects, such as temporary or future severe reduction of quality [4].

## 6. Conclusions

Against the background of the current legal and economic demands on maintenance, options of influencing component-related maintenance costs are discussed. The studies are based on the analysis of real distribution networks. The following important findings and results can be summarised:

- If the failure behaviour of the components and the supply quality of networks are known, a cross-comparison of the maintenance practices of several network operators facilitates the determination of short-time saving potential. It is seen that the expansion of inspection and servicing cycles in particular has a positive effect on short-term cost reduction.
- Based on selected assessment criteria, a secured assessment of components with regard to condition is possible. The overall assessment of component condition contributes considerably to estimating future maintenance expenditure and the need for replacement investments as it identifies critical components.
- Reliable statements about condition and importance are the prerequisites for implementing system- and risk-oriented maintenance strategies. System-oriented strategies can reduce maintenance costs without having a substantial effect on the reliability of the network. This is achieved by ranking the maintenance measures by priority depending on the component's influence on the network reliability and the condition of the component.
- The risk of outage costs to be incurred by the network operator under examination is, at present, mainly determined by the necessary maintenance costs in this field. The amount of outage costs is thus determined by the re-acquisition value of the broken down component.
- Simplified network and plant structures do not only affect investment costs but also have a considerable

influence on maintenance costs. This influence is considerably higher than the short-term influence on maintenance costs achieved by adjusting the maintenance strategies.

The savings potential that can be achieved if the measures of maintenance adjustment discussed herein are implemented is, in general, not quantifiable as it depends on company-specific factors (among others on inputs to increase efficiency, current maintenance strategy, technical design of components and design of plant, network structure, topographic conditions, legal framework). Based on the findings of the component-related analysis of maintenance, the next step will be to examine how maintenance costs can be influenced by organisational measures and measures relating to the network.

## 7. References

- [1] Marketz, M.: Maintenance strategies for distribution networks in the liberalized electricity market. Dissertation. Graz University of Technology, December 2003
- [2] Muhr, M.; Körbler, B.; Sumereder, C.: Thermovision als Diagnosemethode für Freileitungen. ETG Fachtagung Diagnostik elektrischer Betriebsmittel, Köln, März 2004, pp. 247-249
- [3] Polster, J.: Risk and asset management in utilities. Dissertation. Graz University of Technology, November 2003
- [4] Egger, H.; Draxler, R.; Marketz, M.; Fritz, W.; Lüdorf, K.: Influence of strategies for network cost reduction on the development of quality of supply. ISH 2005, Beijing