MAINTENANCE AND REPLACEMENT DECISION SUPPORT SYSTEM

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SUMMARY

This paper presents results from the project "Maintenance and Replacement Models for MV Distribution Network", where a number of decision support models for maintenance and replacement have been developed. The models are used for analysis, assessment and choice of technical-economical optimal decisions regarding maintenance and replacement. Several of the models have been implemented in a PC prototype program (VefoNet), and tested by Danish, Norwegian, and Swedish utilities.
The conclusions from the test utilities were very positive, and it was recommended that the models and prototype program should be commercialized and integrated with other systems in the utilities.

INTRODUCTION

The utilities are today turning their focus toward economy and profitability. This is the case in most countries even though the specific conditions are different. One of the important areas, where the role of economic optimisation will grow, is maintenance and replacement of components in the network. Maintenance and replacement is not only a question of technical matters, but indeed also of economic.

Furthermore new regulations regarding economic compensation to the consumers for energy not supplied to end users is coming up as in e.g. Norway, and utilities are met with bench-marking requirements. This will make a technical-economical optimal maintenance and replacement even more important.

In the '50 and '60 the electric power network was heavily enlarged due to the increase in energy consumption. The result is a large fraction of old components in the network for which maintenance is required or replacement is relevant in the near future.

Unfortunately, it is difficult to identify the best decisions regarding maintenance and replacement. It is difficult to answer questions like: When is the technical-economical best time for the replacement of a component? Should an old component be replaced, or is it better to continue maintenance? How often should a given component be maintained?

The utilities have no or very few tools to support such decisions. This paper describes several models which can assist the utilities in optimising the maintenance and replacement. The developed models are implemented in a prototype of a PC based decision support system (VefoNet), which also will be described.

GENERAL MODEL

There has been developed a number of decision support models supporting the maintenance and replacement staff in making technical and economical optimal decisions. The models are based on the same general model, as illustrated in Figure 1. The figure shows the main elements which will be a part of a decision support model. The models shall in principle describe all relevant considerations/conditions regarding a maintenance and replacement decision for a component.
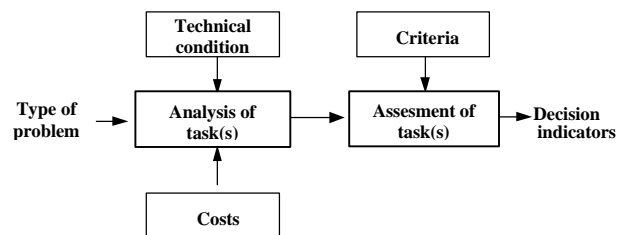

Figure 1. General model describing the elements of the developed decision support models.

The basis for the models is the type of problem (task) which the user wants to assess, e.g. identification of optimal time for replacement of a transformer or identification of the most critical components in the network.

The general model describes the relevant analysis and assessments. Furthermore the general model describes the information which is necessary - technical condition, costs and criteria. Some types of problems include assessment of several alternative tasks e.g. replacement or maintenance.

Need for strategy
The decision support models must be easy to use and integrated with other tools that the utility is using for maintenance and replacement planning purposes. It is important to establish a strategy for the use of the models, which is in accordance with the overall maintenance and replacement planning strategy in the utility.

The models must be used systematically and extensively in order to be really useful. Sporadic, or casual, use will reduce the benefit, and after some time lead to minimal use and interest among the planners. This will again stop the further development and updating based on new knowledge and experience with regard to ageing of components, replacement criteria, costs, etc.

A distribution network consists of a large number of items. It is not convenient or cost-effective to carry out annual analysis and assessment of the items on individual basis. The utilities must therefore develop selective and more cost-effective strategies, concentrating the analyses on the potentially most critical components, if decision support models and tools shall have any chance to be an important and integrated part of the planning of maintenance and replacement.

IMPLEMENTED MODELS

Several decision support models for maintenance and replacement have been developed, and the following six models has been implemented and tested:

1. "*Present value model*" where the technical and economical optimal time for a replacement task is assessed based on a capitalisation principle.
2. "*Age profile model*" where consequences of different replacement strategies are analysed.
3. "*Budget model*" where economical consequences of certain decisions are analysed.
4. "*Criticality model*" where tasks and components are ranked according to decreasing criticality.
5. "*Replacement vs. repair model*" where the profitability of a replacement instead of a repair is analysed.
6. "*Transformer replacement model*" where replacement of a transformer is analysed on the basis of capitalised losses and costs of a new transformer.

Each model supports different types of problems and returns different type of decision indicators to the user. An overview is given in Table 1.

In the following these models will be further described.

Present value model
The present value model is designed for analysis of consequences of doing a certain task at different times. The model is most useful for replacement tasks or bigger maintenance tasks, e.g. rehabilitation of a component.

The model calculates the present value (the sum of the cost during a period of e.g. 20 years at compound interest) for different years of doing the actual task (action time). The user gets an overview of the cost elements, and the total costs for different action times, including a proposed optimal action time.

Table 1. Overview of decision support models

Model	Type of problem	Decision indicators (output)
Present value model	When to do certain maintenance and replacements tasks?	Overview of economic consequences for different action times and optimal action time for each task.
Age profile model	What is the consequence of different replacement strategies?	Age profile, component type profile, and budget. Action times for each task.
Budget model	What are the economical consequences of a certain plan?	Budget for actual plan.
Criticality model	Which components is most critical and should be treated first?	List of components with decreasing criticality.
Replacement vs. repair model	What is most optimal if a component fails, replacement or repair?	Maximum allowed cost for repair.
Transformer replacement model	Are there any economical benefits of replacing a transformer?	Overview of economical consequences for replacement of the transformer.

The calculation of present value, PV, is based on the following formula:

$$PV = C_0 + C_1(1+r)^{-1} + C_2(1+r)^{-2} + \ldots C_{N-1}(1+r)^{-(N-1)}$$

C_i is the total costs in year no. i (i=0 correspond to the present year), r is the rate of interest per year, and N is the calculation period in years.

The model does the present value calculation for all possible action times (years) within the calculation period. For a replacement task of a component the model will use information about the old component for computation of annual costs before the action time, and information about the new component for computation of annual costs after the action time. The investment cost will be included in the costs at the actual action time.

The total annual costs are the sum of the following cost elements for the actual year:

- Investment
- Operation and preventive maintenance
- Corrective maintenance (repair)
- Interruption cost due to the component
- Losses (for transformers)
- Non-ideal technical conditions
- Non-ideal construction of the component

These costs are both real cost elements (e.g. investments, preventive and corrective maintenance, losses) as well as elements which normally are not directly connected with costs, e.g. interruption cost, technical condition, and construction. Capitalised costs for interruption of consumers are determined on basis of probability and consequences of interruptions during the actual year and a capitalisation factor. The capitalised costs of technical condition and construction of the component are both fictive costs representing the importance of registered, non-ideal technical conditions (e.g. rust and defects), and the importance of non-ideal construction (e.g. constructions with environmental or personal hazards). In practice this information is based on inspections of the component. Non-ideal conditions for the component is registered, and for each registration an amount is added representing the importance of the condition.

By the described method the user will get a decision indicator in form of a graph as illustrated in Figure 2. Each column in the graph represents the present value e.g. the total costs during the calculation period. The different columns represent different action times. The illustrated example is an analysis of a 10 kV switchgear, and it shows that the total cost is at a minimum if the replacement is done within 5-7 years. If the switchgear is replaced later than this, the cost during the calculation period (here 25 years) will increase.
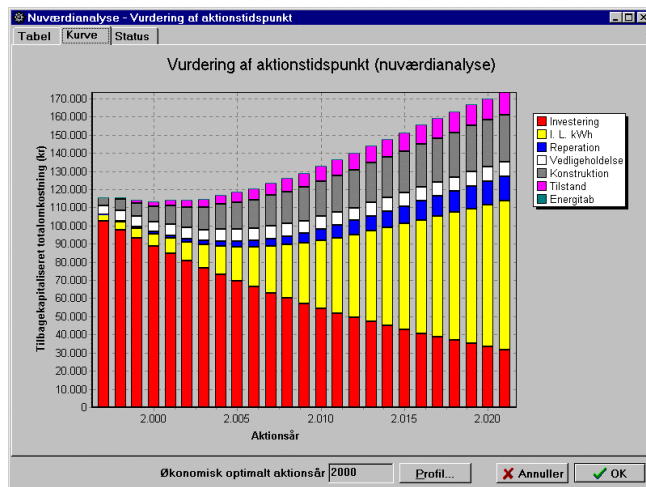

Figure 2. Output from the present value calculation.

The results from the model are of course dependent on the underlying data, and the accuracy of the result is not better than the accuracy of the underlying data. The user should have this in mind when using the model.

Furthermore the model gives the possibility of examining the influence of varying different parameters.

Age profile model
In order to avoid periods of high-peak replacement in the future, it is of vital importance to control the age profile of the items in the network.

The consequences of different replacement strategies based on different replacement criteria can be analysed. Examples of replacement criteria are expected lifetime, maximum age, undesirable technical solutions, technical condition, fixed number of items per year, etc.

Results from the model include which items that should be replaced and in which year, average and maximum age, and total costs during the period of analysis.
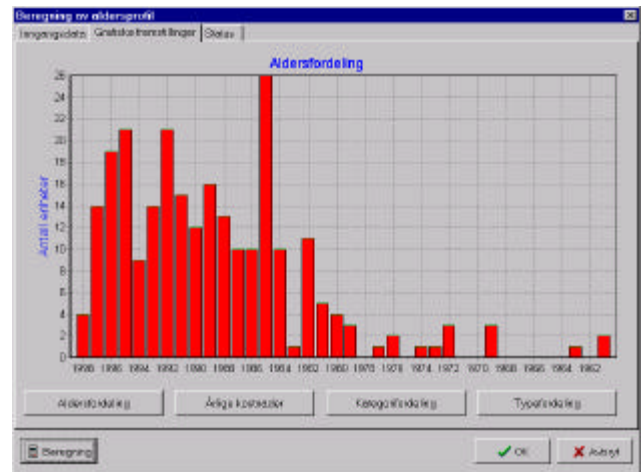

Figure 3. Example of output from the age profile. An age profile – the number of components as function of the year in which the components was put into service – is shown.

Budget model
The budget model calculates the expected total annual costs for all items and all years in the period of analysis, i.e. the model calculates the expected total annual costs for the given project. The calculations are based on the recommended year for replacement from one of the other models, or manual adjustment of this year.

If all items are replaced at the "optimal" time, the total costs can vary significantly from one year to the other. By manually changing the actual year for replacement for some items, the annual costs can be evened out over the period of analysis.

The budget model should therefore be run after all the other models have been run, and after the first plan is established. Economical consequences of the decisions can thereby be analysed.

Criticality model
The criticality model ranks the components according to their criticality. The model can thereby be used to identify the components which should be replaced, or need larger maintenance tasks in the coming years.

The model is based on the term criticality. It is assumed that critical components are the maintenance- and replacement-requiring components.

A component is defined to be critical if it has high importance and bad condition.

To determine the condition of a component a formerly developed method is applied (see e.g. [1] and [2]). The method which is commercially used today is based on a score system. Points are added to a component's score due to:

- Age
- Technical condition
- Construction

The points thereby reflect the condition of the component. Points for construction and technical condition are added as a result of inspection reports.

The importance of a component is here defined as the consequences of a failure of the component with respect to interruption of the consumers. A component is important, if the expected interruption time is long and the expected energy not supplied due to a failure is large.

In this model criticality, CR, is computed as the product of condition, CO, and importance, IM:

$$CR = CO \cdot IM$$

If the condition, CO, and the importance, IM, is calculated as relative terms (0-100 %), the criticality, CR, also will be a relative term (0-100 %). Figure 4 shows an importance-condition diagram with the components plotted. Besides this plot, the model returns a list of the components sorted in order of decreasing criticality.
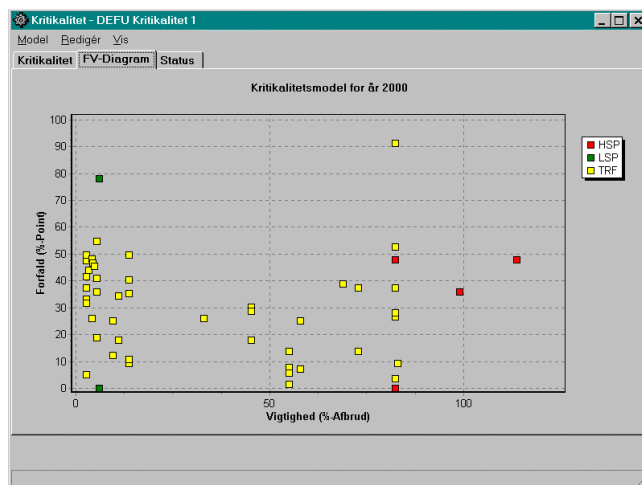

Figure 4. Graphic output from the criticality model. Each dot represents a component in the importance-condition viewgraph.

Replacement vs. repair model
When an item, which is scheduled for replacement during the next few years, has an unexpected failure, it can be economical to do the replacement in advance rather than to repair today and replace as planned. Based on investment cost and expected increase in operating, maintenance and interruption costs, the model calculates how expensive a repair can be, before it is economical to advance an already planned replacement.

Transformer replacement model
Transformers manufactured before 1960-65 have significantly higher losses than newer transformers. The model calculates whether it is economical to replace the old transformer to reduce the total annual costs based on the utilisation time, load-factor, loss parameters, cost of losses and transformer and replacement costs.

COMPUTER PROGRAM (VEFONET)

To be able to test the developed models, the models have been implemented in a PC computer program (VefoNet). The VefoNet program has been developed as a prototype program; some functionality is missing, but the program can perform its basic task: run the models.

The method in the program is built on projects. A project describes the objects to be examined and consists of one or more components and a task connected to each component. The user can define one or more projects. In a project there is a possibility for storing decision indicators returned from the models in form of an action time, as well as the time the user decides to carry out the task. The main-window of the program with two open projects is seen in Figure 5.
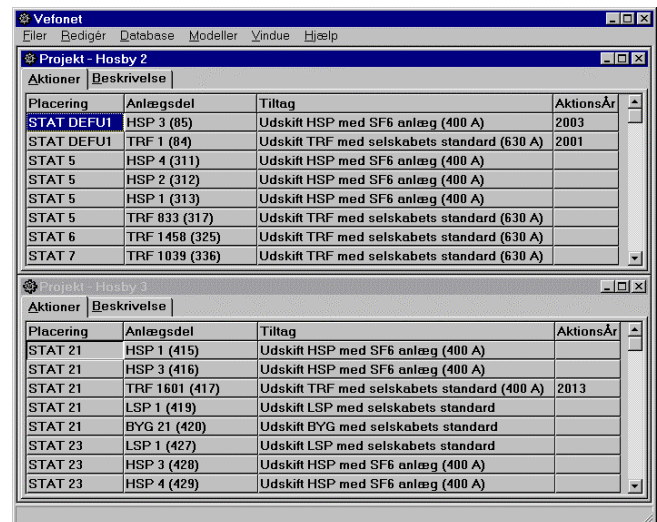

Figure 5. Main-window of the PC prototype program (VefoNet) with two active projects on the screen.

The idea is that the user can build a project, run one of the models returning decision indicators. On this background the user makes a (temporary) decision about the component and the task. Using this decision he can use another model to get another assessment and so on. Finally the user ends up with a number of decisions which represent his plan. Furthermore the user can build two alternative projects, run the models and compare the results.

The principal design of the VefoNet program is seen in Figure 6. A database deals with the data needed for the models. This includes component information, condition information, economical data etc. It is possible to import data from other systems (databases), and all user access goes through a common user interface.
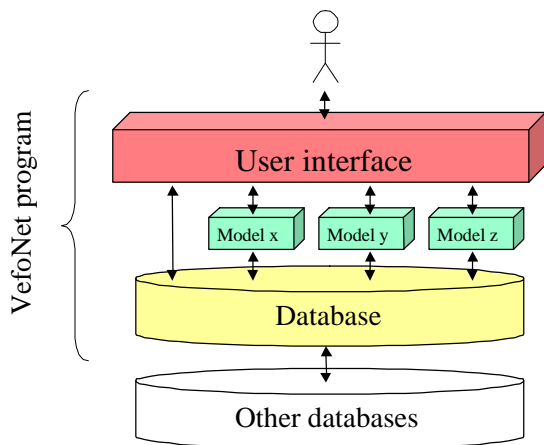
Figure 6. Schematic view of the elements of the VefoNet program.

In the prototype program distribution transformers, MV switchgear, LV switchgear equipment, buildings, MV cables and MV overhead lines are supported.

TEST AND EVALUATION OF VEFONET

The VefoNet prototype program including the six developed models has been used and tested at several pilot utilities in Norway, Denmark and Sweden. The test was carried out in December 1997 and August 1998.

The test included primary evaluation of the models and test of the method in the program (use of projects), assessment of the required data and evaluation of the implemented user interface. The system has been used for more than 7000 components without problems. In Norway a co-ordinated test has been carried out for a 22 kV overhead network and a 11 kV cable network. The results from this test are presented in [3].

The general conclusions from the testing at the pilot utilities are positive. The basic principle in the program (projects, components and tasks) is user-friendly, and the models generate understandable and acceptable decision indicators.

It has been assessed that the present value model gives the user a good overview of the cost distribution dependent on the action time. The user should only use the model result for a precise determination of action time if he does a simultaneous assessment. The model gives a unique possibility to consider technical and economical parameters at the same time, but this requires a capitalisation, which can be difficult to understand.

The age profile model is suitable for approximate estimation of the total volume for replacement within a period of analysis based on simple criteria. This model is also suitable to make an initial ranking of components with regard to replacement. An age profile analysis can be carried out with only year of installation or manufacture as input data, but it is better also to include some state information about the components. This is done by sorting all actual components into one out of five predefined

categories. The determination into categories is an initial technical and safety of personnel assessment based on simple criteria, which can be repeated (updated) e.g. every fifth year.

Category I comprises components that obviously should be replaced as soon as possible, while Category II and Category III comprise components that are expected to be replaced within the next five and ten years respectively. Components of Category IV and V are not subject for replacement within the next ten years.

The criticality model is an extension of a previously developed point score model. This makes it easy for the users to understand and accept the model. The model can rank the components, and thereby it can be an important tool to focus the available resources at the utility.

Using a computer system like VefoNet has additional benefits besides the support to the maintenance and replacement planning. Storing maintenance and replacement relevant information in a central computer system ensures that the information about the components is available for all personnel in the company. The dependence on a few persons with high knowledge about the components is reduced, and knowledge is easier transferred to new staff members.

CONCLUSIONS

A number of decision support models regarding maintenance and replacement have been developed. The models have been implemented in a PC based decision support prototype. The prototype and the models have been tested by a number of Danish, Norwegian and Swedish utilities.

It is concluded, that the developed models support the decision process in the utilities, and that the output from the models is understandable and acceptable. The developed PC program gives the utilities a variety of tools for the decision process. It is recommended by the test utilities that the system is commercialised, and that the models should be integrated with the utilities' maintenance and planning function.

The project has been a joint venture project between Danish, Norwegian and Swedish utilities, and the experience from this constellation has been very positive.

ACKNOWLEDGEMENT

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