REALIZATION OF LONG-TERM INVESTMENT STRATEGIES FOR MEDIUM VOLTAGE CABLES

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ABSTRACT

As a result of the liberalization of the electrical energy market, asset managers have to solve conflicting tasks: Reduction of the life cycle costs while ensuring high system availability. In general the decision-making process of asset management can be divided into four steps which start with the evaluation of the long term strategy and stop with a concrete maintenance activity of a certain equipment. This paper describes the first step of the overall asset management process to derive the optimal strategy for the equipment.

There are different management tools to improve operation efficiency. One possibility is to measure the impact of the technical and financial boundary conditions to determine the entire costs for a group of equipment in consideration of the unavailability at system nodes. Consequently, the different effects concerning investment and maintenance strategy, for example the useful lifetime, the extension of the service cycle, the evaluation of life cycle costs of pieces of equipment and the yearly budget, can be investigated.

The principal task of this analysis is to develop a long-term concept for the maintenance and investment strategy, comprising the capital expenditures (CAPEX) as well as the operational expenditures (OPEX).

To complete this task suitable equipment models are required. These models should be able to simulate the equipment behavior for a simulation horizon of for example 30 to 70 years, according to the service life time of the different components.

Beside the determination of the financial requirements caused by the current maintenance and renewal strategy, the essential advantage of a dynamic asset simulation is to evaluate the influence of different strategies on the final result. Such influences could be the modification of a maintenance strategy or the postpone of a renewal measure. This information will be of notable interest during the discussion with appropriate national authorities concerning the investment strategy and the resultant financial expenditures.

The paper describes the fundamental proceeding in the case of dynamic asset simulations and their importance during the decision making process based on replacement strategies for medium voltage cables. For this, an ageing model is required which provides the asset manager with information about the age distribution of medium voltage cables after a certain simulation time as well as about the cost assessment comprising CAPEX and OPEX.

INTRODUCTION

In general the decision-making process of asset management can be divided into four steps:

- evaluation of a long-term strategy,
- utilization of the reliability centered maintenance,
- selection of the suitable maintenance activities and
- the optimal service for components [1].

This paper describes the first step of the overall asset management process to derive the optimal maintenance and investment strategy for the equipment for several decades (e.g. extension of the service cycle).

To achieve this goal, an ageing model is required which incorporates the technical and financial boundaries and delivers the yearly capital and operational expenditures (CAPEX and OPEX) of the assets under consideration of the unavailability at the system nodes. CAPEX are caused by new installations and OPEX consist of:

- repair costs (caused by minor and major failures),
- maintenance costs (inspection and overhaul) and
- costs due to expected energy not supplied.

Hence a long-term plan for the maintenance and investment strategy of the system can be developed. The model should be convenient to simulate the system behaviour in a suitable time horizon of e.g. 30 to 70 years, according to the service life time of the different components. In order to receive this information the following work steps are necessary:

- condition assessment and failure behaviour for a group of equipment,
- development of an ageing model for different equipment groups,
- determination of cause-and-effect-chains in consideration of the personal and financial boundary equipment,
- implementation of dynamic simulations and
- analysis of results for the decision making process.
LONG – TERM STRATEGY DEVELOPMENT

**Ageing model**

To develop an ageing model, a preceding decision making process is necessary to determine the simulation horizon, the life cycle of the assets, the behaviour and value of the failure rates during the life cycle and consequential the number of condition states in the model. The behaviour of the failure rate during the life cycle is used to define the number of necessary condition classes of the Markov model according to [2].

Apart from this the following assumptions were made for the ageing model:

- The condition of the assets changes every year depending on the age, this leads to the fact that a transition from one condition class to another is ensured.
- Each asset cannot stay longer in a condition state than the residence time of that condition state. Therefore it is guaranteed that the asset is replaced after a maximum life cycle.
- The equipment must have the possibility to age artificially, this means that the asset behaves older than its real age and permits that, if for example a service can no longer be provided for a special type of equipment a replacement is recommended earlier than expected.
- A constant failure rate is assumed within a condition state.

The assignment of assets into the condition states of the ageing model have to be accomplished with the aid of a condition assessment. The components go through the different states during their life time, whereby the maintenance measurement can slow down or accelerate this process, which depends on the success of the maintenance measure and on their cycle. From the aforementioned reasons it follows that a substantial task is to assign all assets to the different condition states and to specify the transition rates between them.

To achieve appropriate results the ageing model must be adapted to the special type of asset as good as possible, due to the fact that each type has a different behaviour regarding the condition and the failure rate. Therefore it is necessary to derive deviating ageing models, one for each type of the equipment and to simulate the various ageing processes by different models.

**Functional chains**

The ageing or the behaviour of assets, respectively is one part of the asset management process. Fig. 1 shows the integration of ageing in the asset management process with the aid of functional chains, which represents the causes and effects of several factors.

The use of ageing models for the amelioration of the asset management process provides the asset manager with the following results:

- the age distribution of devices in a grid,
- the number of installed assets,
- the number of assets which leave the ageing model each year,
- the behaviour of the different asset types and
- the yearly expenditures for
  - replacement,
  - new installations,
  - repair of minor and major failures,
  - inspection and overhaul as well as
  - expected energy not supplied [3].

With this information the total expenditures for a group of assets and the consequences for the entire system during the complete simulation period of for example 40 years can be evaluated.

All these costs can be combined for the calculation of the aforementioned CAPEX and OPEX. These two values lead to the expected financial expenditures for a fleet of equipment of an entire system and therefore different investment and maintenance strategies can be derived.
The next chapter shows an example and describes the behaviour of different cable types during their useful life time.

AGEING MODEL FOR 10-KV CABLES

Input data

For this example the following two different cable types will be investigated:

- thermoplastic-insulated cable and
- paper insulated mass-impregnated cable.

Apart from this a further classification for transmission and distribution systems is required to simulate a lifelike reproduction of the assets. Therefore four different ageing models are necessary which work in parallel and the results can be summed up to receive the information about the whole group of assets.

Fig. 2 and Fig. 3 show the age distribution of the paper insulated and thermoplastic-insulated cables. It can be seen that a large number of the paper insulated cables already exceed, in this case, the accepted maximum life time of 70 years. This leads to the fact that all these assets have to be replaced in the first year of the simulation. The thermoplastic-insulated cables have a considerably lower amount than the paper insulated ones, but it is assumed that every piece of cable which has to be replaced will be replaced by a thermoplastic-insulated cable. Therefore the number of these cables will strongly increase during the simulation time.

![Fig. 2: Age distribution of the paper insulated mass-impregnated cables.](image)

![Fig. 3: Age distribution of the thermoplastic-insulated cables.](image)

The developed ageing model which simulates a maximum life cycle of 70 years consists, in this case, of five different condition states. Each condition state has a certain failure rate. The estimated failure rates of the model during the life cycle have to follow nearly a typical bathtub curve. This curve is a hazard function and describes the expected failure rate of electrical equipment with time: initially high, dropping to near zero for most of the system’s lifetime, then rising again as it retires. The individual classes of the ageing model can be taken from Tab. 1.

<table>
<thead>
<tr>
<th>class</th>
<th>age range</th>
<th>hazard function in p.u.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1-5</td>
<td>1,0</td>
</tr>
<tr>
<td>2</td>
<td>6-25</td>
<td>1,0</td>
</tr>
<tr>
<td>3</td>
<td>26-40</td>
<td>1,0</td>
</tr>
<tr>
<td>4</td>
<td>41-55</td>
<td>2,0</td>
</tr>
<tr>
<td>5</td>
<td>56-70</td>
<td>4,0</td>
</tr>
</tbody>
</table>

To translate the values of the hazard function to values per km and year different values for the cables were defined: 1 p.u. is attributed to a value of 0,0065 per km and year for paper insulated mass-impregnated cables and to a value of 0,0002 per km and year for thermoplastic-insulated cables. According to the operation experience another assumption is that after a duration of 40 years 10 % of the cables are already replaced and due to the ageing behaviour only 5 % are still in operation at the end of the useful life time.

Results

In this chapter the results of CAPEX and OPEX will be discussed. Fig. 4 shows the total investment budget as well as the investment budget separated for transmission and distribution systems for new cables under consideration of a constant financial amount for each component during the time period. The investment peak in the first year (2008) results from the age evaluation according to Fig. 2. Due to the high number of cables which are older than 70 years a replacement in the first year is required. Furthermore a second investment peak occurs between 2035 and 2045 which is a result of the investment peak in the sixties and seventies in Germany and can also be seen in Fig. 2.

![Fig. 4: Investment budget per year (CAPEX).](image)

The total investment values range from 12 M€ in the first years to 600 k€ and has a value of 4 M€ in the last year. To avoid investment peaks like shown in Fig. 4 a maximum investment limit can be implemented. Is the investment limit
lower than the available capital the investment must be
postponed to the following years. This mirrors the optimal
use of personal as well as of financial resources.

Fig. 5 shows the composition of the operational
expenditures and the total amount (OPEX). It is assumed
that 80% of the cables which have reached the maximum
residence time will be replaced. Since the annual repair
costs as well as the annual expenditures for inspection and
overhaul (maintenance costs) and the power losses (energy
not supplied) are calculated on the basis of the cable length
a continuous decrease of the costs can be seen. Apart from
this a further reduction occurs in the first years due to the
fact that the paper insulated mass-impregnated cables are
replaced by thermoplastic-insulated cables which have
lower maintenance costs.

A further important fact is that the cost of losses have
the biggest amount of the total yearly operational costs. The
cost increase in the first years is caused by the old cables
which are not taken into account at the initial point and are
replaced in the following year. Therefore the value of the
operational costs range from 810 k€ to 570 k€ in the last
year, due to the reduced replacement which is like
aforementioned 80% of the total equipment which leave the
ageing model.

Fig. 5: Financial expenditures for operational costs per year (OPEX).

As a last step the number of major failures per year which
are shown in Fig. 6 will be considered.

It can be seen that the failure values caused by paper
insulated mass-impregnated cables have a distinctly higher
amount than the thermoplastic-insulated ones because of the
higher length of laid cables and the more than threefold
higher failure rates of the paper insulated cables. The
maximum number of failures of the paper insulated cables
occurs between 2023 and 2031, because most of these
cables are old and therefore error-prone which can be seen
from Fig. 2. After that the curve shape of the paper insulated
cables decreases and the one of the thermoplastic-insulated
cables increases considerably, because all new installations
are of the thermoplastic-insulated cable type. But the total
amount of failures of thermoplastic-insulated cables remain
lower due to the fact that the failure rates are lower and only
80% of the cables which leave the model will be replaced.

CONCLUSIONS

The development of an ageing model and the
implementation of an asset simulation enables the asset
manager to get information about the expenditures for
different years under the today`s boundary conditions (e.g.
failure rate, overhaul and inspection cycle, duration and
material costs for an overhaul or inspection). By changing
the boundary conditions for example extension of the
maintenance cycle, the influence of the financial
requirements and the system reliability can be derived and
optimized considering increasing failure rates.

Apart from this the ageing model delivers information about
the real and artificial age and the length of the cables in
general and for each cable and network type. This is
required for the calculation of the profitability and the cost
assessment as well as for the determination of the proper
amortisation which is an obligation by law.

Furthermore the developed ageing model can be
implemented for different maintenance and renewal
strategies which allow a comparison of different strategies
as well as different grids, whether the ageing model is
extended to simulate a whole grid. This will be of special
interest in case of the discussion with the appropriate
national authorities regarding the investment strategy and
the financial expenditures which can be derived form the
afore described ageing model.

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