INTELLIGENT STRATEGIES FOR THE RENEWAL OF CABLE NETWORKS TAKING QUALITY AND ECONOMIC ASPECTS INTO CONSIDERATION

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ABSTRACT

A high proportion (approx. 30 %) of the entire network costs is generated by the medium-voltage cable networks, which also have a large influence on the unavailability of electric supply (approx. 65%). It is essential to bring both the network costs and the unavailability in line against the background of the economic and technical marginal conditions by means of developing maintenance strategies in asset management.

INTRODUCTION

Between the Fifties and Seventies high investments were made in the electricity supply networks so that much of the equipment has now reached the foreseen lifespan. A large portion of the current replacement value of the networks lies in the earth-laid cables which makes it very difficult and also expensive to obtain an evaluation of their condition.
Due to the high excavation costs in comparison with the equipment costs, an early replacement of a length of cable is not economically justifiable. Intelligent renewal strategies can help to implement high reliability of supply in an old cable network using a minimum budget. The condition of the cables, the development of current load and supply, the supply reliability and possible network optimisation must all be taken into consideration because they could influence the network structure and capacity [1].
The Paper showns how intelligent strategies can realise an optimized renewal of cable networks in consideration of condition and age of cables, different network concepts, fixed budgets for maintenance or high reliability.

AGEING AND BREAKDOWN OF CABLES

The process of ageing as a result of electrical, thermal, chemical or mechanical stress can be observed for all cables. At this time no model of ageing exists which includes all factors of influence. In practice it can be observed that all cables XLPE or paper insulated, show a highly deviating supply reliability.

The vast majority of cables in the net have now reached the foreseen lifespan of 50 years without changes in the frequency of failure occurrence.

Essential for the development of a renewal strategy is a forecast of the failure rate for the whole lifetime of a cable. In electric power companies information about cable type, start of operation and current load is generally stored in database or GIS Systems.

The reasons for a cable breakdown can be separated into fault location and cause:

Fault location: cable, joints or terminations. The German VDN statistic on outages and availability shows that 78 % of typical faults occur in cables and 22 % in joints.
Fault cause: It is important to decide between electrical breakdown occurring with external action or without recognizable cause. Failure without recognizable cause means a breakdown because of decreasing electrical strength. Failure with external action results to 95 % from earthworks. More than 95 % of all failures in XLPE and PILC cables result from one of these types.

MODELS FOR CABLE AGEING

To simulate the ageing and breakdown of cables, three scenarios were developed. In all scenarios the period between cable laying and maximum lifetime forecast is an approximation by a linear function. The maximum lifetime forecast for the cables is: PILC 70a, XLPE 50a and cables with water trees 30a. This linear function can be determined by the breakdown frequency at the date of laying HA,0, the current breakdown frequency $H_{A,akt}$ and the average age of the cables in a group t_{akt}:

$$\boldsymbol{m} = \frac{\boldsymbol{H}_{\mathrm{A,akt}} - \boldsymbol{H}_{\mathrm{A,0}}}{\boldsymbol{t}_{\mathrm{akt}}} \qquad \text{Eq. 1}$$

Assuming that the breakdown frequency changes after exceeding the maximum lifetime forecast and that the breakdown caused by earthworks is unchanged, the following scenarios were developed:

Scenario 1 – linear

$$\boldsymbol{H}_{\mathrm{A,1}}(\boldsymbol{t}) = \boldsymbol{m} \cdot \boldsymbol{t} + \boldsymbol{H}_{\mathrm{A,0}}\ . \qquad \text{Eq. 2}$$

Scenario 2 – exponential

After forecast lifetime t_{pL} the failure frequency increase exponential. The factor α describes the increase of breakdowns 40 years after forecast lifetime (t=t_{pL+40}):

$$H_{A,pL+40} = \left(H_{A,pL} - H_{A,F}\right)\cdot\alpha + H_{A,F} \qquad \text{Eq. 3}$$

The exponential increase $H_{A,2}(t)$ for $t > t_{pL}$ can be described as:

$$H_{A,2}(t) = H_{A,pL}\cdot e^{\lambda\cdot(t-t_{pL})} \qquad \text{Eq. 4}$$

with $H_{A,pL} = H_{A,1}(t = t_{pL})$ in Eq. 2

The growth constant λ from the e-function can be calculated by the inverse funktion:

$$\lambda = \frac{\ln\left(H_{A,pL+40} / H_{A,pL}\right)}{40a}. \qquad \text{Eq. 5}$$

Figure 1 shows the run of the curves for the linear scenario and the exponential scenario.

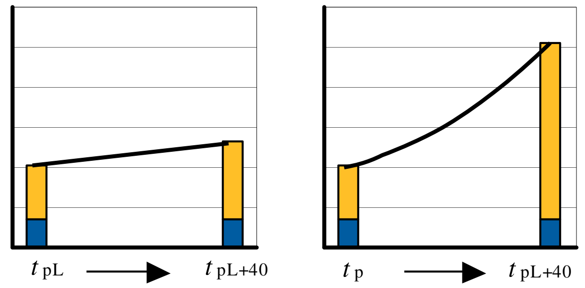


Figure 1: Linear scenario (left) and exponential scenario (right) of cable ageing after exceeding the maximum lifetime forecast. Blue: constant breakdowns caused by earthworks, Yellow: condition based breakdowns

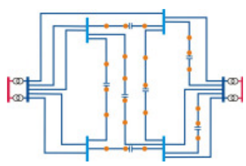
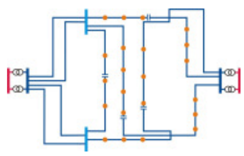
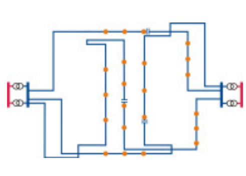
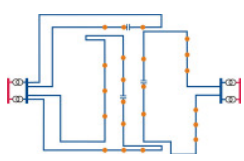
ACTUAL STATE AND NETWORK VERSIONS

The research for the optimal renewal strategy was accomplished at different network models. Starting from the current state of the net, four networks were generated using optimization strategies. Table 1 shows the network plan of the current state and the four network versions taking into consideration the quantity of equipment, life cycle costs, reliability und specific network properties.

The best performance in consideration of life cycle costs (cost of renewal and maintenance for 40 years), amount of equipment, reliability and reduced cable length is shown by network version two. In consideration of the current state only, the SAIDI parameter increases about 23% because of the increase of stations (NSt) in the cable lines.

Because of the misfeature of no load transfer between the transformer stations, network version 3 is no longer taken into consideration.

Table 1: Specific network properties of the current state and the network versions

	Network plan	specific network properties
Actual state		Distribution station net - high life cycle costs + max. reliability of supply - high quantity of equipments - max. grid length
Version 1		Red. distribution station net + high reliability of supply + low grid length + low restructuring costs
Version 2		Radial network between transformer stations + min. life cycle costs + low quantity of equipments + simple network plan + low grid length
Version 3		Open ringed network - no load transfer between transformer stations + low life cycle costs + low grid length

FAILURE DEVELOPMENT IN CASE OF CORRECTIVE MAINTENANCE

In cable networks the predominant maintenance strategy is corrective maintenance. Condition based maintenance is only applied in case of noticeable increase in cable failure rate. To consider the specific network parameters under corrective maintenance, the failure models with increasing failure frequency were applied in the different network versions. Every cable section assigned a failure rate depending on cable type and age. Figure 2 shows an example for a cable linkage consisting of five sections with the failure rate for the years 2006-2046. The different failure frequency is shown depending on cable type and age.

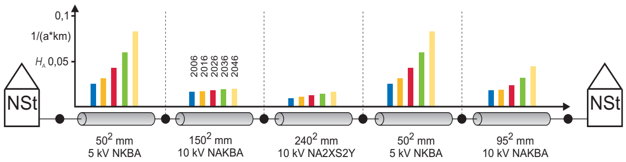


Figure 2: Example of a cable linkage with different sections and specific failure frequency for 2006-2046 (Scenario 2 – exp low)

The SAIDI parameter in the current state of the net is shown in Figure 3. In particular the exponential growth of the failure frequency will change the current good reliability. In the case of corrective maintenance of the cable network and without renewal, this means a continuous enhancement of manpower and budgets for fault clearance.

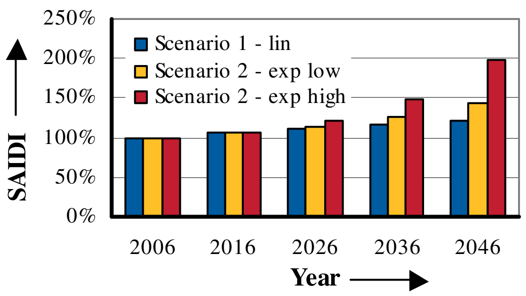


Figure 3: SAIDI parameter in the current state of the net over a period of 40 years

RENEWAL STRATEGIES IN CABLE NETWORKS

An important part of an efficient renewal strategy is a priority list of all cable sections taking into consideration qualitative criterions such as cable type, cableage, properties of the soil surrounding and consequences of supply interruption.

The combination of renewal strategy and priority list decides on the point in time and the number of cables for renewal. Aim of the renewal strategy can be a constant reliability in combination with a fixed budget or to achieve an average age of the cable net. The main aim in the following is a constant or target reliability to achieve a fixed budget for fault clearance and a fixed frequency of faults. Under consideration of a renewal coefficient k between 1% or 1,5% simultaneously an acceptable average age and a homogeneous age distribution can be achieved (see Figure 4).

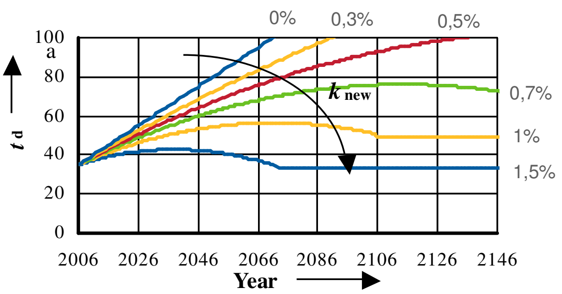


Figure 4: Consideration of average age of the cables t_d for different renewal coefficients k_{new}

With a renewal coefficient between 1-1,5% the renewal of a cable network can only be realised over periods of 50-80 years. Because of these long periods the renewal strategy is not a fixed list. It is necessary to adapt the priority list due to changes in grid design (network expansion or deconstruction, loadflow change) or outside influences (legal requirements/ penalties due to failure frequency).

After creation of the priority list the cable sections can be renewed in descending order. Regular calculations of reliability, budget and/or average age of the cables help to control the objectives of renewal.

The following two long-term objectives will be considered:

1. Constant reliability in combination with a fixed budget for fault clearance (based on 2006).
2. Maximum increase of 50% for failure frequency and reliability (based on 2006).

The influence of the renewal strategy on SAIDI, SAIFI and average cable age t_d under consideration of Objective No. 1 for the current state of the net is shown in Figure 5.

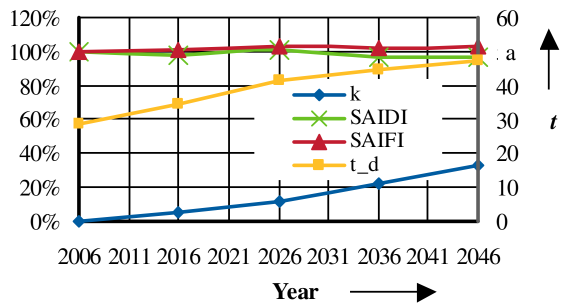


Figure 5: Dependence of renewal rate k, SAIDI, SAIFI and average cable age t_d of the current state of the net with scenario 2 -exponential low- and Objective No. 1

To achieve Objective No. 1 on a long-term basis the renewal rate for Network Version 2 must be higher than for the current state of the net with the effect that the average cable age does not increase so much.

Further, it can be seen that for the next 10-15 years a low renewal rate is sufficient to achieve a constant reliability in combination with a fixed budget for fault clearance. By rotational control of the renewal parameters, for example in steps of 10 years, the renewal rate can be adjusted.

While changing the renewal rate permanently, a homogeneous age distribution can not be achieved. But in the next 40 years the contingent of cables over 50 years old can decrease from 90% (without a renewal strategy) to 60% (with renewal strategy) as shown in Figure 6.

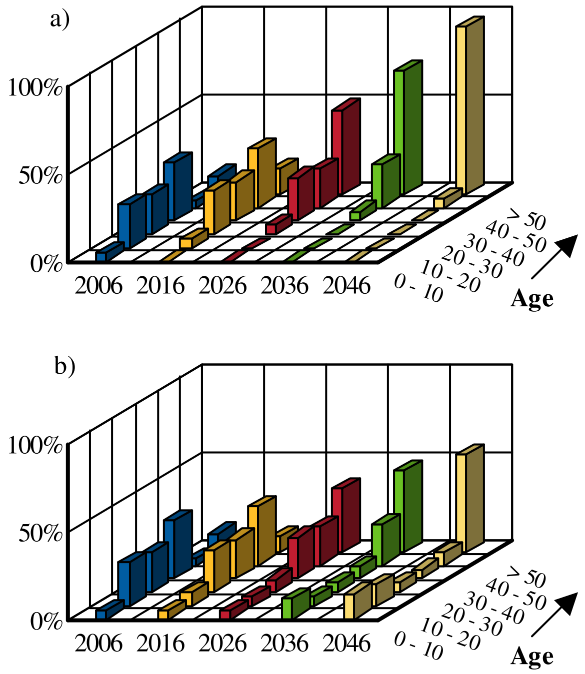


Figure 6: Average cable age in the current state of the net from 2006 to 2046 for scenario 2 – exponential – low (a) without renewal (b) renewal with Objective No. 1

Figure 7 shows an overview of the specific network parameters and renewal strategies for a period of 40 years taking different network versions into consideration. The parameters are based on the current state of the net and corrective maintenance. For the reliability the values of the year 2046 were compared with the values for 2006.

The costs for fault clearance and network operation achieve a minimum. Because of the necessary budget for the cable renewal, the total network costs are higher in comparison with the current state of the net without renewal, whereas penalty costs because of a declining reliability have not been considered.

Based on a long-term consideration the comparison of the different network versions and renewal strategies show the best alternative as a combination of Network Version 2 and renewal Objective No. 1. The failure frequency can be significantly decreased (-80% in comparison to the current state of the net) although the medium durability of supply interruption increases because of the higher number of stations in the cable lines. If needed, short-circuit display with remote indication can help to reduce the time of supply interruptions. Furthermore, a bulk of the cable network (50%) can be renewed and a good medium average cable age can be achieved by 2046.

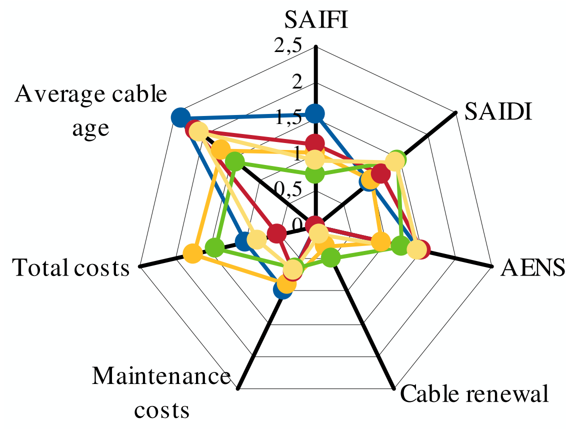


Figure 7: Specific network properties in dependence of renewal objectives for a period of 40 years based on the current state of the net and corrective maintenance

- Current state of the net, corrective maintenance
- Current state of the net, renewal with Objective No. 1
- Network version 2, corrective maintenance
- Network version 2, renewal with Objective No. 2
- Network version 2, renewal with Objective No. 2

CONCLUSION

Intelligent renewal strategies can help to achieve a constant network quality, or even to improve it, thus influencing the expenditures and costs for dealing with breakdowns. Here the renewal of parts of the cable network must have priority, taking condition, risks and importance into consideration. By combining renewal strategies with a priority list the specific network parameters can be influenced. Taking equipment data, operating experience, the capitalised value of the network and the reliability into account, intelligent renewal strategies can help guarantee the future supply at low network cost. In order to set up priority lists for cable renewal, it is imperative that in future breakdowns and damages are described in detail.

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