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FAILURE PREDICTION IN 50KV MASS-INSULATED POWER CABLE SYSTEMS

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ABSTRACT

Failure data together with the length and the ages of the 50 kV mass-insulated cables still in service are used as input for the statistical analysis. The choice of the appropriate distribution depends on the goodness of fit to the data. The fitted statistical distribution gives the relation of the number of expected failures per kilometre together with the age of the cable. To see what can be expected in the future the population in service together with the obtained failure rate curve is used. This gives statistical information regarding expected failures and critical connections. The analysis can help the asset manager to determine if immediate action has to be taken to meet the business policy e.g. condition assessment, maintenance or replacement.

KEYWORDS

Power cables, statistical failure analysis, Life time data

INTRODUCTION

Liberalization of the electricity market forces asset managers (AM) to choose for the most cost effective strategies on overhaul and replacement of network components. In particular, AM are interested to predict future failures and to determine the remaining life of the assets. Moreover, if failure data are available, statistical failure analysis can be a powerful tool to determine whether replacement is necessary, now or in the future to obtain a certain reliability of the network. For a particular part of the transmission network, in the past years electrical failures are reported in the 50 kV mass-insulated cable systems. This raises a concern about the number of failures to be expected in the future.

Up to now a total length of 56 km is still in service with an age distribution of 40 to 60 years. Reported failures are available over the past 8 years and have taken place in cables of different lengths and ages.

An important aspect in using this failure data together with the data of cables still in service is to take the length of the cables into consideration. The event of a cable failure has to be correlated with the length of the cable. After this the failure data together with the length and the ages of the cables still in service are used as input for the statistical analysis. The choice of the appropriate distribution depends on the goodness of fit to the data.

The influence of time has to be regarded for the discussion of ageing and wear-out processes corresponding to the specific trace of bathtub curve. Different maintenance strategies can be applied depending on the type of component and philosophy of the asset manager [1, 2]:

- Corrective maintenance (CM), which means the exploitation until failure and then repair.
- Time based maintenance (TBM), maintenance based on time based intervals or depending on the use frequency.
- Condition based maintenance (CBM), maintenance actions are performed based on the condition of the component obtained by e.g. measurements, inspection or on-site diagnostics [3, 4, 5].
- Reliability Centred Maintenance (RCM), maintenance based on safety, operational and economic criteria. It is a method by which operators can use failure data, system design redundancies and operating experiences to develop maintenance strategy.
- Risk Based Maintenance (RBM), the probability or likelihood and consequence of a failure results in the risk of a failure. The assessment of the likelihood and the consequence of a failure, resulting in a risk calculation provide a ranking system that can benefit in the choice for risk based maintenance or inspection programs.

For the last two maintenance strategies it is important to now the failure behaviour of a component and what the probability of failure and the failure rate is. For this purpose statistical analysis can be applied to life time data of components. Statistical statements can be generated whether the cables are in their end of life period regarding their age and with respect to the reliability requirements they have to fulfil according to the asset manager strategy. Besides this the statistical analysis can be used to see the development of expected failures in the future. The increase of failures in coming years can be shown together with the confidence bounds. The width of these confidence bounds are related to the amount of failures used for the analysis.

CABLE NETWORK

The mass cable

The cable network consisting of the mass insulated cables still in service has a total length of approximately 56 kilometres. Three phase cable are present, but the main used cable is single phase. In general a mass insulated cables contains a conductor (copper or aluminium) and several layers of paper impregnated with different types of oil, fillers, paper tapes, belt insulation, lead sheath and a PVC jacket, as shown in Figure 1. Mass cables are often used for medium voltage cable network but this type of cable is used for voltages up to 69 kV for three phases belted cables. In this case all cables are used in the 50 kV network. All cables under consideration have a service live longer than 40 years. This type of cable experiences

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different ageing processes during its service life.

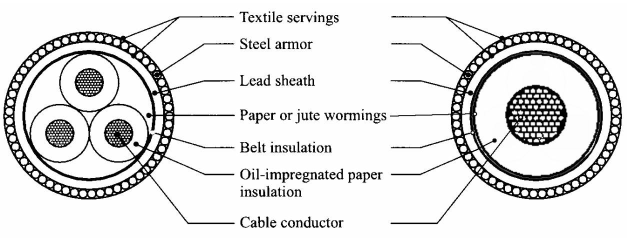

Figure 1 Cross section of typical three-core belted and single core mass cable [6]

The main problems with this type of cable are:

- Temperature changes due to e.g. loading cycles;
- Aging processes of the oil impregnated paper;
- Voids and cavities within or between paper layers;
- Electrical trees in the paper layers;
- Wax and chemical components contains in cellulose bounds;
- Drying out of impregnated paper;
- Moisture penetration in the paper layers.

These factors (together with environmental conditions and temperature changes due to e.g. load cycles) can result in an electric failure of the cable and consequently a loss of power. Such an event is considered as a failure and is used as input for statistical analysis. The mechanical failures, which are mostly caused by digging activities, are not taking into account here.

Life time data of Mass cables

The lifetime data available consist of a total of 18 cable routes with a total cable length of 56 kilometres. The ages are between 40 and 60 years of operation. The lengths of the cables with the years of installation are shown in Figure 2.

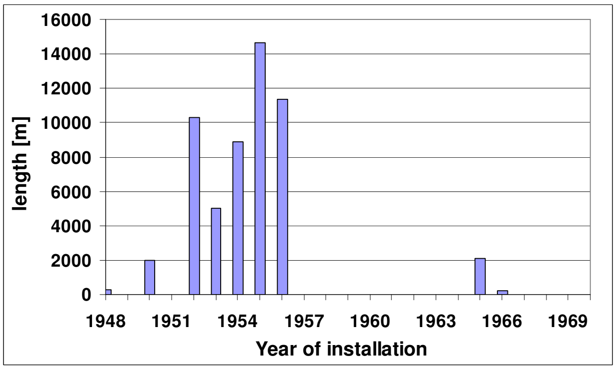

Figure 2 50 kV mass-insulated cable in service, total length of 56 km with 40-60 years of operation

Because of the high age of these cables the asset manager pays higher attention to this type of cable. The analysis can help to make a distinction in the strategies of preventive replacement or the acceptance of a certain amount of failures. Different factors have to be taken into account for choosing the strategy. Societal aspects like the failure acceptability and failure impact and economical aspects like costs for repair, outage costs and spare part costs have to be considered [7].

In these cable connections twenty-five failures are reported for the last eight years. Earlier occurred failures are not known due to merging of companies and changes in the failure registration. The number of failures with the ages of the cables at the moment that the failure occurred is shown in Figure 3. To use these lifetime data for statistical analysis an extra step has to be made, as explained in the next section.

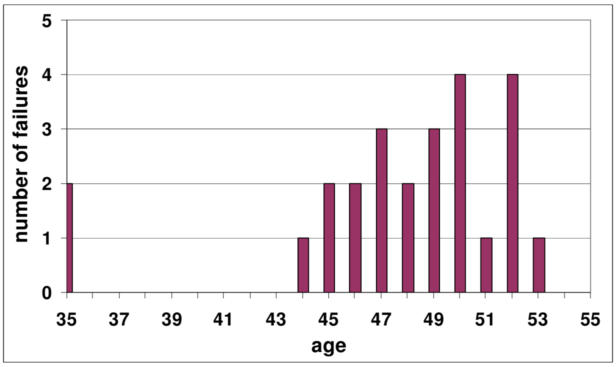

Figure 3 Failures of 50 kV mass-insulated cables, total length of 56 km with 40-60 years of operation

Failure data

The ages of the reported failures has to be related to the length of the cable the failure occurred. To be able to do this the scheme of Figure 4 is used. The ages together with the length of the failed cable is used to get the number of failures per kilometre per age. This is used as input for the statistical analysis, where the lengths of the remaining cables in service are regarded as suspensions.

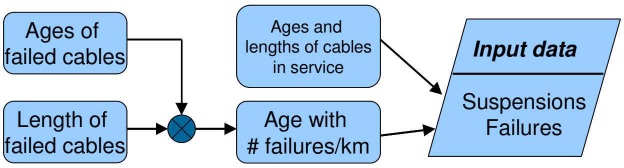

Figure 4 Processing lifetime data to apply statistical analysis

The numbers of occurred failures per kilometre length with the age at failure are graphically shown in Figure 5. This data can not directly be obtained from the data shown in Figure 2 and Figure 3. The next step is to use this failure data together with the length and ages of the cables still in service as input for the statistical analysis and to fit this lifetime data with the appropriate distribution. This is discussed in the next chapter.

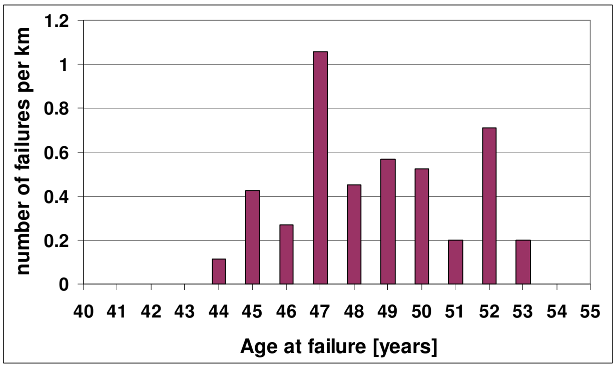

Figure 5 Failures of 50 kV mass-insulated cables per unit of length with ages

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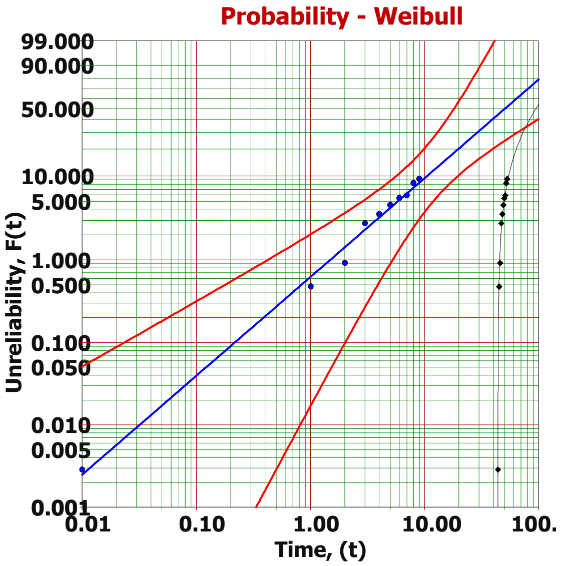
STATISTICAL FAILURE ANALYSIS

The life time data can be fitted by means of analytical statistical distributions. Several distributions can be applied. The most well known are the Normal, Log-normal, exponential and Weibull distributions. For each distribution can be determined how well the distribution fit according to different goodness of fit tests. In this case two tests are used to determine the fit. First the correlation coefficient ρ is calculated. This coefficient is a measure of how well the linear regression model fits the data. The closer the value is to 1, the better the linear fit of the chosen distribution. Secondly the goodness of fit can be determined with the Kolmogorov-Smirnov test. With this test it can be determined whether the fitted probability distribution differs from a hypothesized distribution. These two tests are both used to determine which distribution gives the best fit to the data points.

According to the goodness of fit tests as described above, this data is best fitted with a three parameter Weibull distribution. The choice for a three parameter distribution indicates that there is a failure free period which is indicated with the location parameter γ. The introduction of this third parameter can be explained by the fact that the failures occurring now happen on cables that are 40 or more years old. The fitted distribution through the adjusted data point for the location parameter is shown in Figure 6.

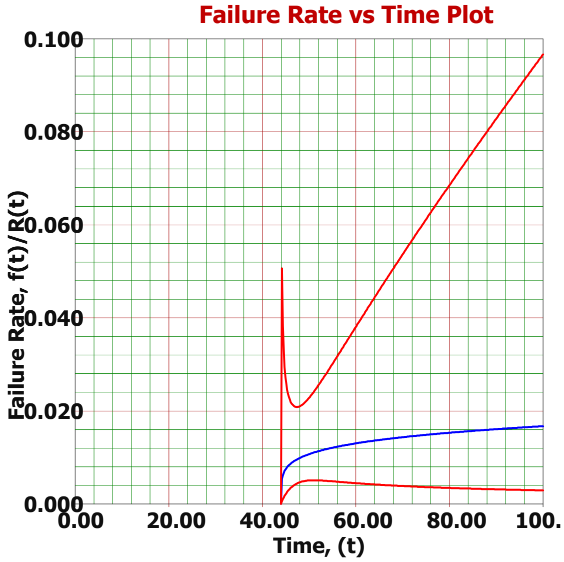


β=1.19959, η=68.96448, γ=43.99000, ρ=0.99648

Figure 6 Fitted three parameter Weibull cumulative distribution function with two sided 90% confidence bounds

In this figure also the unadjusted line through the data points is shown.

The estimated Weibull parameter based on linear regression analysis are for the shape parameter β = 1.2, scale parameter η = 69 years and the location parameter γ = 44 years. The shape parameter is larger then one, which means that ageing can be designated as a reason for failure. However the value of the shape parameter is close to one which indicates that the failure probability increases with increasing age of the cable but very slightly.

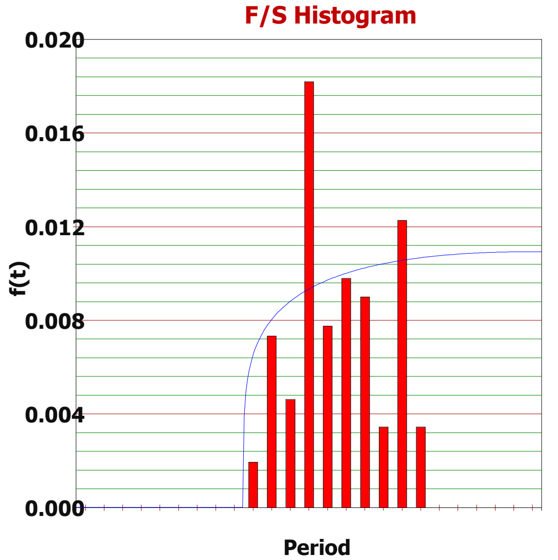


β=1.19959, η=68.96448, γ=43.99000, ρ=0.99648

Figure 7 Failure rate function of the fitted three parameter Weibull function together with the 90% confidence bounds

This effect can be clearly seen in the graph of the failure rate function shown in Figure 7. The failure rate function show the number of failures per kilometre of cable related to the age of the cable. The failure rate starts increasing from the age of 44 years, which is the location parameter of the three parameter Weibull distribution. After this age the failure rate function shows an increase in time, but the slope is not steep.

To get an idea how well the three parameter Weibull distribution fits the life time data, the probability density function can be plotted together with the histogram of the lifetime data, this result in the plot as shown in Figure 8.



β=1.19959, η=68.96448, γ=43.99000, ρ=0.99648

Figure 8 Histogram of the life time data together with the probability density function of the fitted three parameter Weibull distribution

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From the cumulative distribution function it is also possible to get the B-lives. Every industry uses B-lives indicating a certain level of reliability based on the age of a component. In the world of engineering the used B-life starts mostly around B10. This means that 10 % of the total population will fail at a certain age and that 90 % survives. Different industries use different values for an acceptance value for unreliability/reliability depending on the criticality of a failure. For the B-lives also the confidence bounds can be taken into account. For this analysis various B-lives are shown in Table 1. The B5-life is also known as the mean life. If the B-lives are related to the age of the cable population it can be seen that almost the whole population is older then the B1-life. The largest part of the population is around the B10 life. If a reliability of 90% is stated as criterion by the asset manager as the limit for keeping the mass-impregnated cable in service, this means that based on this a large part of the populations is on its end of life.

Table 1 B-lives with the 90% confidence bounds

B-life	Age [years]	90% lower bound [years]	90% upper bound [years]
B1	44	45	49
B10	55	50	64
B50	62	95	186

FAILURE EXPECTATION

The statistical analysis as discussed in the previous chapter can be used to perform a failure prediction in coming years. The failure rate function obtained from the analysis together with the length and ages of the cables still in service are used to calculate to total number of expected failures in the future. This is done for the coming years and the development of the expected failures is shown in Figure 9. In this figure also the 95% upper- and lower confidence bound is shown. For 2007 0.61 failure is expected which can vary from 0.27 up to 1.42 failures with 95% confidence for the whole cable population. The asset manager has to determine if this number of failures is acceptable considering the various aspects as described before.

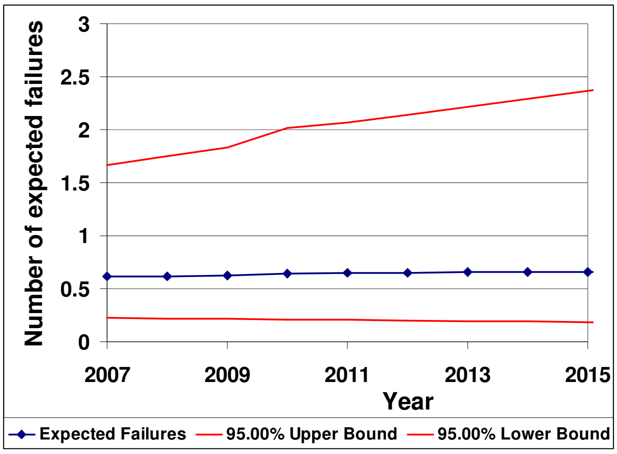

Figure 9 Number of total expected failures in coming years with the 95% confidence bounds

CONCLUSIONS

Statistical analysis can be used as a tool for the asset manager to support the decision process for maintenance- and replacement strategies.
Based on the statistical research as discussed in this paper with regard to lifetime data as available for mass-impregnated cables the following can be concluded:

1) If sufficient failure data are available the statistical analysis can be used to show that the failures occurred in the cables are caused by ageing of the cable (insulation).

2) Depending on the amount of reliability the cable network has to for fill according to the asset manager the cables are in their end of life period if B1 and B10 lives are considered.

3) The failure data may be used to predict statistically the occurrence of failures in coming years. Also with this the asset manager has to determine if the occurrence of these failures can be accepted or that replacement in necessary in coming years.

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