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EVALUATION OF A REPLACEMENT STRATEGY OF A MEDIUM VOLTAGE CABLE JOINT BASED ON STATISTICAL FAILURE ANALYSIS

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ABSTRACT

In the 1970's a specific type of resin cable joint was used in three phase medium voltage cables. These joints have now a considerable contribution in outage time because of breakdown of the resin insulation. From the statistical analyses of the life time data it can be concluded that the joints are in their wear-out life period and that ageing is the main cause for failures. A testing program started a few years ago, influences the number of occurring failures and has a positive effect on the number of occurring failures of joints during service. Preventive replacement of the oldest joints in service can also influence the number of expected failures. A comparison is made between testing and the replacement strategy and it can be seen that at this moment the testing of cable sections is an effective way to decrease the amount of failures.

KEYWORDS

Cable joints, Resin insulation, Statistical analysis, Life time data

INTRODUCTION

Life time data of in service failed components, when available, can be used for statistical analysis. By means of statistical analysis the residual life of assets based on reliability requirements can be determined and future failures can be predicted. Especially for non-repairable components, like resin cable joints, failure analysis can be a powerful tool for replacement strategies, particularly when the components are in the wear-out period of their lifetime.
A specific type of resin cable joints was used in three phase oil-impregnated paper-insulated voltage cables in the seventies. These joints have now a considerable contribution in outage time because of breakdown of the resin insulation. As a result a testing program was started a few years ago, that normally is used to eliminate infant mortality related failures. This shows good results, but the question is whether another replacement strategy can be more effective. The reported failures over the last six years, together with the population still in service are known from different databases and a part of the data is suitable for statistical analysis.
A testing program influences the number of occurring failures and the last years the number of failures during service decreased. The effect of the testing program can be compared with a replacement strategy. Replacement of the oldest joints in service can influence the number of expected failures. In this way it can be seen whether the testing of cable sections is an effective way to decrease the amount of failures.
In this paper the general problems with resin cable joints are discussed, together with the available lifetime data. The influence of the testing program of cable connections on the failure behaviour is also considered. Secondly the statistical analysis of the life time data is shown and the failure expectation which can be obtained from the analysis is presented. A comparison is made between the testing program and a replacement strategy to see the effectiveness of the testing program.

RESIN CABLE JOINTS IN SERVICE

The 10 kV resin cable joints still in service are installed in the period from 1970 up to 1980. These joints are now 27 up to 37 years of age.
The joint is used for 10 kV three phase mass-insulated cables. The three conductors of the cable are soldered or compressed together with a connector. The shield of the cable is connected by means of separate conductors. The mould is filled with fluid resin insulation which solidifies after some time. Then the mould is closed and the joint is finished. The connection and the filling process are shown in Figure 1.

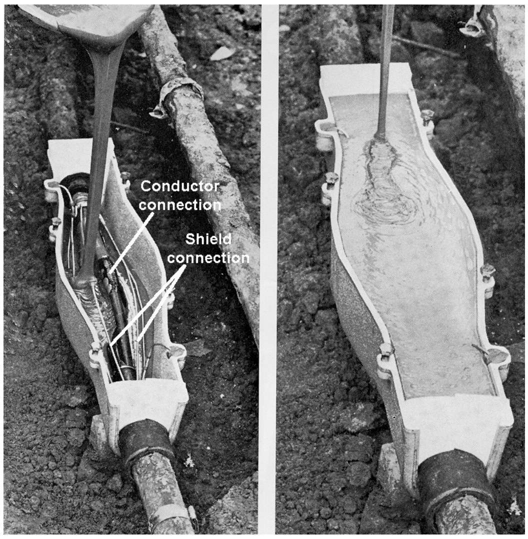

Figure 1 Filling of a three phase cable joint with resin insulation for a mass-insulated cable

Different origins can be designated to stresses of the insulation of the joint. Three categories of stresses can be distinguished [1]:

- Operational stresses, e.g. load cycles, short circuits,

over voltages;
- Environmental stresses, e.g. groundwater, mechanical stresses;
- Human handling, e.g. inaccurate assembly

The different stresses, as described above, can result in insulation defects. Typical defects in a cable joint are [1, 2]:
- Sharp edges on the connectors of the conductors;
- Moisture penetration;
- Cavities in the (resin) insulation;
- Contaminations in the insulation;
- Irregular solidification of the resin;
- Asymmetrical conductor positioning with respect to the phase and/or the shield;
- Conductor problems

All these insulation defects of a resin cable joint can result in a failure during normal operation. This means that the resin insulation breaks down and a phase-to-phase- or phase-to-ground failure occurs. Such a fault is in this paper regarded as a failure of the cable joint.

Life time data

Due to the liberalization in the energy market, also the structure of utilities changed. Smaller companies merged into larger ones. As a result, failure reporting and failure databases were rearranged, changed or created. As a consequence, failure data is available only for the last six years.
During the whole operation of this type of joint a substantial part of the population is replaced in the past. Multiple factors may have affected the number of replacements:
- Replacement of total cable sections;
- Changes in joint design, which can result in higher failure probability;
- Testing of cable sections, with consequentially replacement of the failed joints;
- Change of the cable network structure. Cables can be re-routed or the network is expanded.

As mentioned before a consistent failure database is available since 2002. The numbers of reported failures in this database are shown in Figure 2 .

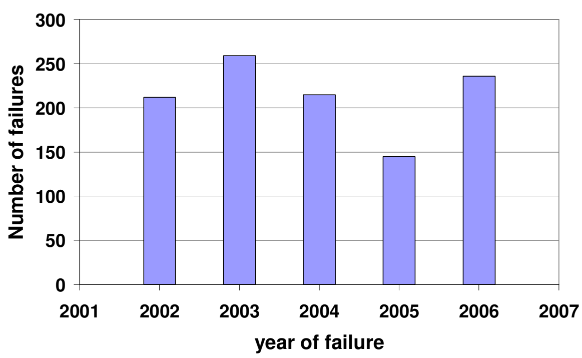

Figure 2 Number of in service failed resin cable joints of the past five years

However, the exact ages of the joints at the moment of failure are not reported. The age of the failed joint is reported in intervals in the failure database. The intervals used are:
- < 1 year
- 1-5 years
- 5-10 years
- 10-20 years
- 20-40 years
- > 40 years

While this type of joint is installed in the seventies, this means all joints are reported in the age interval 20-40 years. Because the exact ages of the failed joints are unknown, this dataset is not suitable for performing statistical analysis.

A total population of almost 9000 joints are still in service. The numbers of joints with their years of installation are shown in Figure 3. These joints are also taken into account for the statistical analysis and are considered as right censored data.

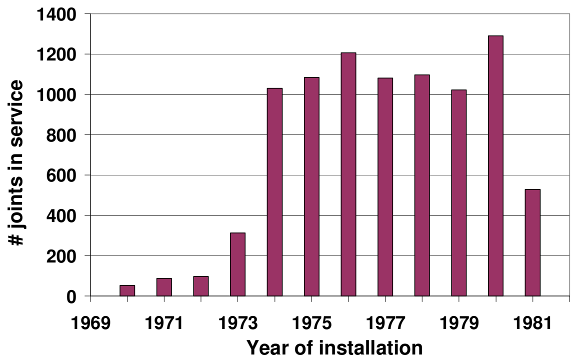

Figure 3 Number of resin joints still in service with their years of installation

For part of the population in a region of the Netherlands more detailed failure data is available. For part of the network the exact ages are reported for the failed joints in the years 2000 to 2002. With these data, statistical failure analysis is performed. The numbers of occurred failures in 2000 to 2002 and the years of installation of the failed joints are shown in Figure 4.

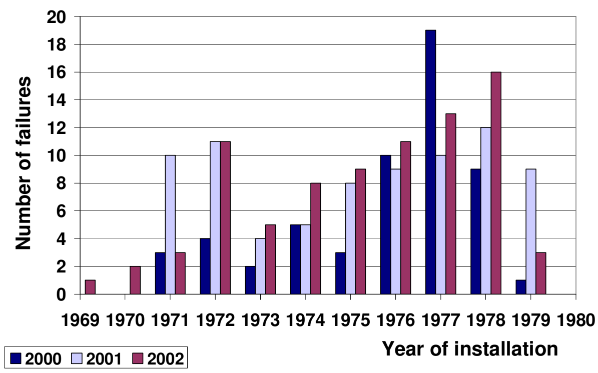

Figure 4 Numbers of failures with the years of installation for the years 2000-2002

Testing of cable joints

A testing program was started a few years ago. During this program, a DC voltage is applied to the cable. This can result in a breakdown of the insulation of the joint. The advantage of this method is that the joints fail under controlled conditions, not resulting in power interruptions. The failed joint is replaced by another type of joint and the test is repeated when more joints are present in the cable connection. Such an approach is the normal procedure for joints with an infant mortality failure character rather than for joint populations with an ageing problem. It is interesting to learn whether the population of joints shows infant mortality (despite of its age) or an ageing failure characteristic. It is observed, that in general a cable connection has no joint failures for the next 4 to 5 years after the test. After the testing program was started a decrease of the total number of occurring failures was visible. Except for the last year when a slight increase of the number of failures was seen. To see the effect of the testing program a comparison can be made with a replacement strategy. If the statistical analysis shows that ageing can be designated as a reason for failure, replacing the oldest joints in service can be suggested, while these have the highest contribution in the number of failures.

STATISTICAL ANALYSIS

The ages of the reported failures, together with the ages of the population of joints in-service are used as input for the statistical analysis. The Normal distribution gives the best fit to the data points based on the goodness-of-fit test (correlation coefficient, Kolmogorov Smirnov goodness-of-fit test [3, 4]). The estimation of the parameters of the fitted Normal distribution results in a mean value μ = 35.1 and standard deviation σ = 4.44 for the Normal distribution. The cumulative distribution function (CDF) and the failure rate function of the fitted Normal distribution are shown in Figure 5.

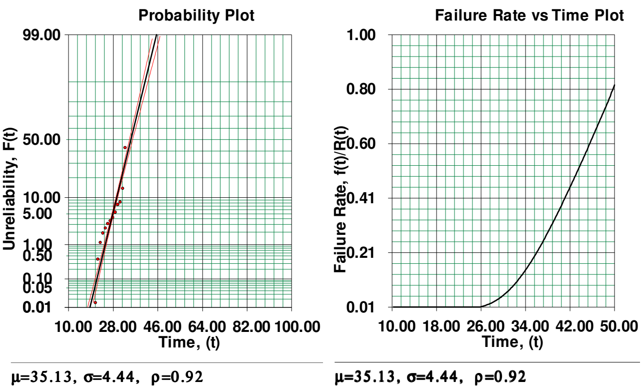

Figure 5 Cumulative distribution function of the fitted Normal distribution and the accompanying failure rate function

From the figure it can be seen that the failure rate function shows a steep character. From this it can be concluded that ageing is the reason for failure of the joint.

Based on the failure rate of the fitted normal distribution and the population of joints still in service the failure rate can be calculated for the coming years. In addition, the calculated number of failures in the period 2000-2002 can be compared with the actually occurred failures. This results in an estimation of failures as shown in Figure 6. From this figure, it can be seen that the calculated number of failures based on the analysis are comparable with the actual number of failures in the period 2000-2002.
The reported failures after 2002 can be taken into account when comparing the actually occurred failures with the expected number of failures. However, the actual number of failures is influenced by a testing program, as mentioned before.
The number of failures that occurred after 2002 follow a decreasing trend, while the number of expected failures follows an increasing trend. This can indicate that the testing program has a positive effect on the failure development. It should be noted that the total number of joints replaced in the period 2002-2006 is larger than the total number of expected failures without testing. However, failures due to testing are controllable and do not result in outages.

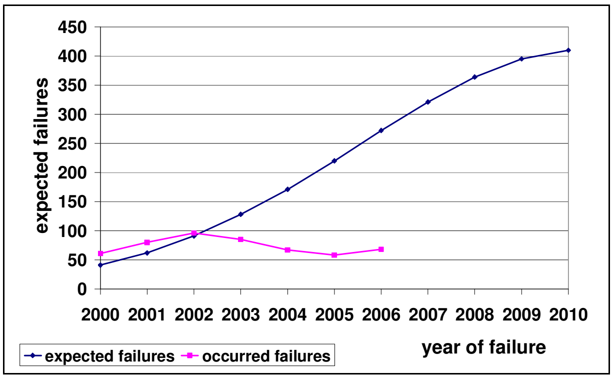

Figure 6 Number of occurred failures in this part of the network and the expected number of failures based on the analysis of the failure data of 2000-2002

INFLUENCE OF REPLACEMENT

The number of failures to be expected in coming years can be influenced by a replacement strategy. For the resin cable joints, the analysis shows that ageing can be pointed out as the main cause of failures. Because of this, an effective replacement strategy would be to replace every year a certain amount of the oldest joints in service. To see the effect of this replacement strategy the expected failure development is analyzed when different numbers of joints are replaced each year, starting in 2002. This year is chosen because of the start of the testing program that year. Preventive replacement of the oldest joints has a positive effect on the number of expected failures. In Figure 7 the development of the number of expected failures is shown when each year, since 2002, a number of 100, 200, 500 or 750 of the oldest joints in service are replaced.
Replacement of the number of 200 joints each year can be compared with the amount of joints replaced each year for testing, but the effect is different. From the figure it can be seen that preventive replacement of the oldest joints has a positive effect on the number of expected failures. But the expected failures are still higher than the occurred failures. Even when 500 of the oldest joints would have been replaced each year, the number of occurring failures would

be higher. The expected failures follow the real occurred failures when each year 750 of the oldest joints would have been replaced. This means that a much higher number of joints must be replaced than now is the case with the testing program and this also would result in the replacement of the total population of joints around 2008.
The effectiveness of testing can be seen when preventive replacement is considered. To achieve the same amount of failures without the testing program, 750 of the oldest joints each year must have been replaced. This is almost more than four times the amount of joints replaced due to testing.

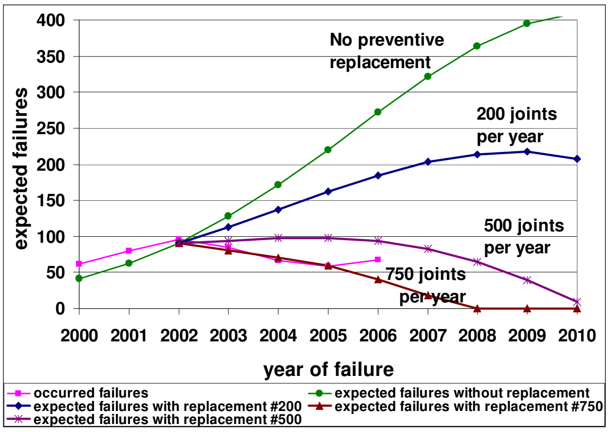

Figure 7 Effect of a preventive replacement strategy on the expected failures development

Increase of failures

The thermal properties of a cable connection are of great importance for a cable connection. Several factors determine the maximum power rating of the cable. Two of them are the thermal properties of the surrounding soil and the ambient temperature, which influences the temperature of the soil [5].
In 2006 the number of failures increased again, despite the testing of cable connections. A striking aspect is that most failures occurred in the summer months. The numbers of failures increase in the months July and August. In these months the temperature is often higher and especially July 2006 was extremely warm. In this month the number of failures was relatively high. This can indicate that a critical ground temperature limit or critical heat transfer to the surrounding air has been passed, which can initiate a failure. When the failures of the last years are compared with the average temperature per month there seems to be an influence of the temperature and the number of failures. The average ambient temperature has an influence on the soil temperature throughout the year, which shows a sinusoidal behaviour. Due to the rise of the soil temperature in the summer months, failures of joints could be initiated, especially while the joints are in their end of life period, as shown by the steep failure rate curve of the fitted Normal distribution. The temperature distribution in the joint is dependant of the soil temperature in the surroundings of the joint. The presence of a hotspot can result in a breakdown due to a rise of the soil temperature. The increase of failures of joints during warm days is not only seen for this type of joint but a same effect is visible for other joint types, e.g. oil filled joints.

CONCLUSIONS

From the statistical failure analysis of a population of resin cable joints, the following conclusions are drawn:

- In order to decide on the proper maintenance strategy with respect to failures it is convenient to know the characteristics of the failure curve. Especially with respect to the important estimation of the residual life of a certain population of assets, the presented statistical analysis shows to be a strong tool in determining the best fit failure curve for a given stochastic distribution of failures. Analyses of the failure data has shown that failures occur due to ageing. The steep rising failure rate function shows that the residual life of the joint population is only a few years.
- The effect of testing is visible, when the number of expected failures is compared with the actual number of occurred failures. These numbers of failures even decreased in the last years, while an increase was expected.
- An active replacement strategy of replacing an amount of the oldest joints each year has a positive effect on the number of expected failures. However the amount of joints that should have been replaced in the last years or have to be replaced in coming years to obtain the same amount of failures is much higher compared to the joints replaced during the testing program. In the end, the asset manager has to determine which strategy is the most cost effective.
- Ambient and ground temperature together with the ageing of the insulation seems to have an effect on the failure behaviour of resin cable joints.

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