RESULTS FROM DANISH FAILURE STATISTICS FOR MEDIUM VOLTAGE XLPE CABLES

Jens Zoëga Hansen
Danish Energy Association – Denmark
jzh@danskenergi.dk

ABSTRACT

In this paper is given an overall assessment of the condition of the medium voltage XLPE cable population in Denmark. The assessment is based on results from Danish failure statistics. It is concluded that there are no significant signs of an increasing failure rate for dry-cured XLPE cables after a service time of a least 30 years. It is also shown that a large part of the failures take place while the system is operated at elevated phase-to-earth voltage on sound phases due to an earth fault somewhere in the system. An analysis also shows that the systems often are operated with an earth fault in 30 minutes or more before the XLPE cable failure occurs, which is interesting when comparing to recommended test duration for power frequency testing of MV cables.

INTRODUCTION

In Denmark like in other countries the first installed XLPE cables in the 1970ies had very high failure rates after only a few years in services. This was primarily due to the growth of water trees in the XLPE insulation. The cross-linking process of polyethylene used for the first XLPE cables was based on steam, which meant that the insulation in new cables contained significant amounts of water already from the start and therefore good conditions for the growth of water trees. In the late 1970ies the main cable supplier at that time to the Danish marked changed the cross-linking process from steam- to dry-curing using hot nitrogen instead to initialize the cross-linking process. This reduced the water content in the cables significantly and led afterward to a remarkable fall in the failure rate.

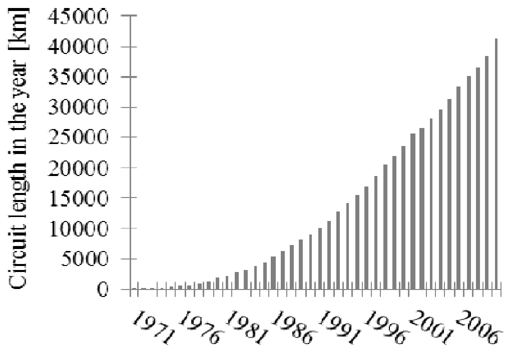

Figure 1: Circuit length for XLPE cables.

Today approximately 41000 km XLPE cables are installed in Denmark, cf. figure 1: most of them dry-cured. A large part (about 25000 km) has been installed during the last 15 years as part of the replacement of overhead lines with cables. This represents a large investment for the Danish utilities over a relatively short time period, which could lead to a big investment backlog in the future. Therefore, it is important to follow the condition of the cables as a function of service time so that the utilities can decide on the most optimal maintenance plan to reduce such an investment backlog in the future.
In this paper results from a failure statistic are presented to address this topic. Other inputs will be necessary in the decision making process, but results from a failure statistic such as the failure rate as function of service time could say something about the expected lifetime for the cables.

XLPE CABLES USED IN DENMARK

MV XLPE cables used in Denmark are today normally designed in accordance with [1]. Table 1 is a timeline with a description of the most significant changes to cable design and the manufacturing process during the last 40 years from one of the main cable suppliers to the Danish marked. Changes in design and manufacturing processes should be taken into account in the failure statistic.

Year	Description
Late 1960ies	First MV XLPE cables are installed
1975	Three core cable (with round aluminum cores)
1978	Dry-curing (nitrogen used in the vulcanization process)
	Tandem extrusion: Extruded adherent insulation screen on large single core cables
1981	Sector-shaped solid aluminum core (three core cables)

Table 1: Timeline for XLPE cables in Denmark [2].

The majority of DSOs use 3-phase cables with individually screened cores. After 1981 both sector shaped and round cores have been widely used.
In general there is no tradition for using a radial water barrier (metal foil under the PE sheath) in Denmark. Water treeing is therefore a potentially aging mechanism in dry-

cured XLPE cables too, because water relatively easily can penetrate the PE sheath from the surroundings. Water tree-retardant XLPE insulation is not used in Denmark either. Whether the lack of a radial water barrier or other means to prevent or inhibit the growth of water trees will pay-off in the end or cost too much in reduced lifetime will be interesting to observe in the failure statistic. For the moment being no change in current practices is expected.

FAILURE STATISTIC

Since the late 1960ies information about failures in the MV and HV systems in Denmark have been collected in a joint failure statistic between the Danish DSOs. Due to the many aging related failures on XLPE cables installed in the 1970ies it was decided in the beginning of the 1980ies to supplement this failure statistic with more detailed information for aging related failures on XLPE cables. Detailed descriptions of installation year, cable design, laying condition and how the system was operated at the time of the failure were added to the failure report.
Today detailed information has been collected for approximately 665 failed XLPE cables, where the failure has been ageing related. This does not account for all ageing related failures on XLPE cables. A comparison with the general failure statistic shows that 665 ageing related failures accounts for approximately 50% of the ageing related failures on XLPE cables since 1980, cf. figure 3. Particularly in the 1980ies not all DSOs who sent detailed information about XLPE cable failures participated in the general failure statistic. In the 1990ies and zeroes on the other hand there have been some difficulties in getting all DSOs to send detailed information about ageing related XLPE cable failures.

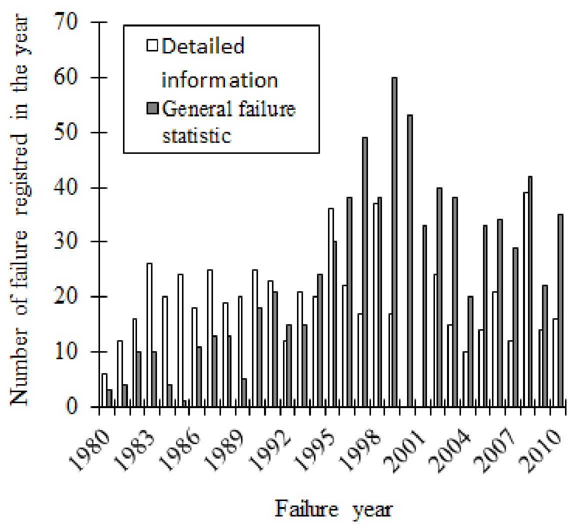

Figure 3: Registered ageing related failures on MV XLPE cables

SOME GENERAL OBSERVATIONS

In the periode between 2005 and 2010 the number of registered failures in the general failure statistic were 174, 198, 221, 231, 156 and 135, respectively. Third party damage accounts wihtout comparison for the largest share of these failures: 63%, 63%, 74%, 72%, 78% and 64% of the failures in the period. Ageing related failures accounted in the same periode for approximately 19%, 17%, 13%, 18%, 14% and 26%. The reasons for close to 20% of the failures cannot be accounted for. It is assumed that ageing related failures accounts for a large share of these too, because if the initializing cause and the failure mechanism is unknown it seems plausible that the failure is related to ageing. However, in this context ageing should be used in a broader sense and would for example also account for an old damage to the PE sheath due to eg. third party damage or a stone, which has led to accelerated ageing of the cable and in the end to a fault. Both examples are encountered regularly in the failure statistic for MV cables.
In figure 4 is shown the failure rate for XLPE cables in the periode 2005-2010. The significant drop in the failure rate between 2008 and 2009 can be explained from the failure rates due to third party damage, cf. figure 4. A similar shape of the failure rate due to third part damage has been found for MV PILC cables allthough the significant drop already took place between 2007 and 2008.

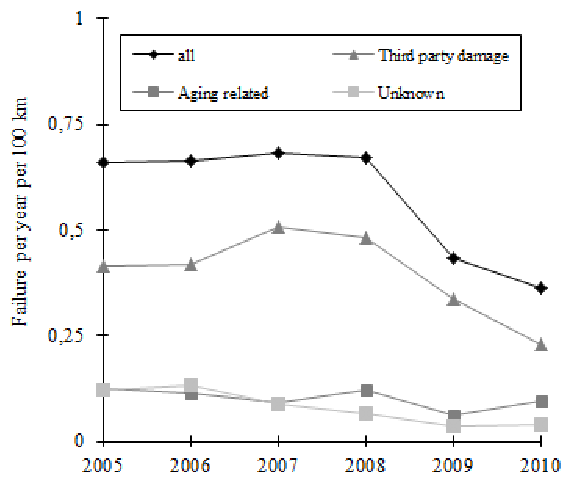

Figure 4: Failure rate for XLPE cables betweeen 2005 and 2010.

The very low failure rate for XLPE cables indicates that at the moment no significant problems with MV XLPE cables seem to exist. In comparison the overall failure rate for MV PILC cables in Denmark is close to 3 failures per year per 100 km. Nevertheless, because of the large share of cables with relatively short service times (less than 15-20 years), cf. figure 1, incipient problems with XLPE cables installed in the late 1970ies and the 1980ies could be hidden in the overall failure rate, which doesn't take service times of the failed cables and the age distribution of the XLPE cable population into account.

FAILURE RATE AS A FUNCTION OF SERVICE TIME

On figure 5 are shown all registered failed cables with known installation year (665 failed cables). It can be observed that most failed XLPE cables have been installed before 1980, which means that these cables are mostly steam-cured and not dry-cured according to table 1. Because of different service experiences with steam- and dry-cured cables it has been decided in the following treatment to differentiate between cables installed before 1980 and cables installed after 1980. In that case most steam-cured cables should be treated in the first mentioned group and most dry-cured in the latter.

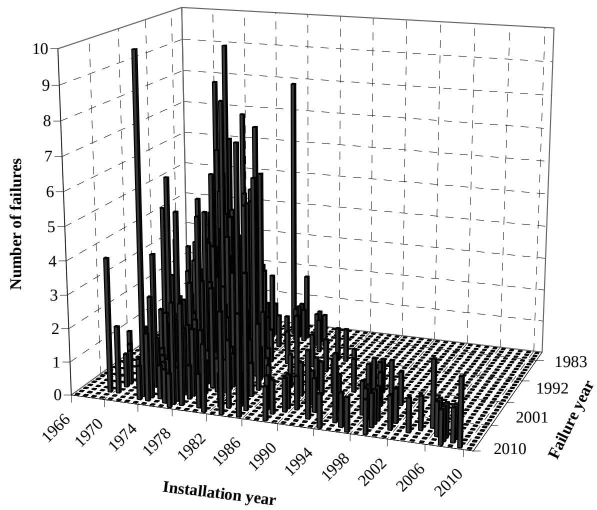

Figure 5: Registered failed cables with known installations year.

The failure rate is calculated using the following equation:

$$\lambda_h = \frac{\sum_i \sum_h N_{i,h}}{\sum_i \sum_h L_{i,h}} \cdot 100 \qquad \text{[Failure per year per 100 km]}$$

λ_h	Failure rate for cables with service time *h*
$N_{i,h}$	Number of failures in year *i* on cables with service time *h*
$L_{i,h}$	Length of cables with service time *h* in year *i*

Cables installed before 1980

On figure 6 is shown the failure rate as a function of service time for MV XLPE cables installed before 1980. The assumption has been made that non of the cables have been taken out of service. This means in particular that the failure rate after 15 – 20 years is underestimated because most of the cables installed in the 1970ies are no longer in service. However, it has been well known for decades that these cables have poor performance, so this is not important. What is important when comparing steam-cured with dry-cured XLPE cables is the first mentioned poor performance after only a few yaers of service.

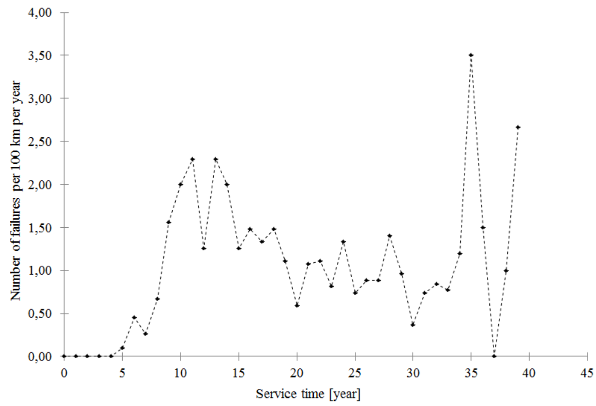

Figure 6: Failure rate as a function of service time for XLPE cables installed before 1980.

Cables installed after 1980

On figure 7 is shown the failure rate as a function of service time for cables installed after 1980. It can be observed that the failure rates in general are very low, which also is expected because the overall failure rate, cf. figure 4, is very low. There could be an indication of a rising failure rate for cables with service time approaching 30 years. However, because the observed rise in the failure rate is so low and because the rise is from one very low level to another low level it is difficult to conclude that a rise so far actually has been observed. A least such a conclusion should be drawn with caution. The higher failure rate after close to 30 years could also be due to the fact that some steam-cured cables could have been installed around 1980 and therefore be included in the failure rate. However, it will be interesting in the coming years to follow the development in the failure rate, when a larger share of the XLPE cable population reach service times of 30 years or more.

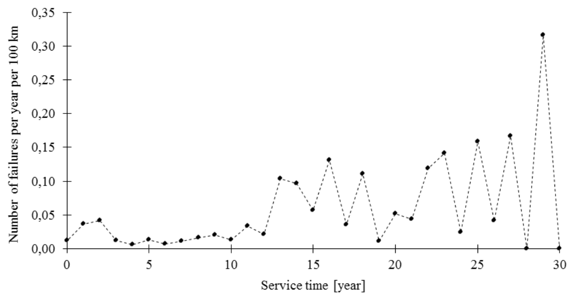

Figure 7: Failure rate as a function of service time for XLPE cables installed after 1980.

The failure rate on figure 7 is underestimated due to the fact that the installation years of the cables only are known for approximately 50% of ageing related failures since 1980. However, the real failure rate is not expected to be significantly higher or have a significantly different shape: nothing in the general failure rate suggests that.

OPERATING MODE OF THE SYSTEM

On figure 8 is shown how the system was operated at the time of the failure. The figure is based on information from 709 failed cables. ‘Other’ covers failures initialized by switching operation, lighning events, testing, etc.

In Denmark MV system is either resonance earthed or operated with an isolated neutral, which means that the systems can be operated with an earth fault present, but with an elevated phase-to-earth voltage on sound phases. Close to half of all ageing related failures on XLPE cables happen while the system is operated with an earth fault, cf. figure 8. In the failure statistic there are also several examples where one earth fault has created a cascade of faults on XLPE cables due to the elevated phase-to-earth voltage on sound phases.

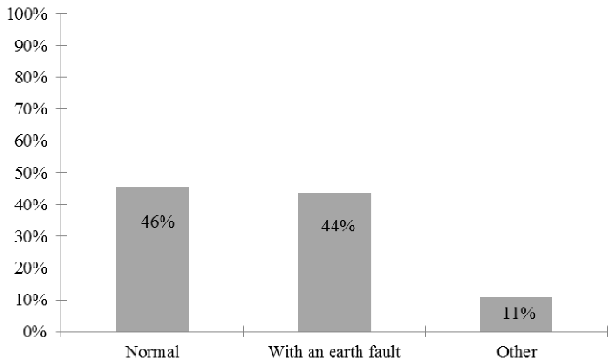

Figure 8: How the system was operated at the time of the failure.

In figure 9 it is shown how long time a system has been operated with an earth fault before a failure on a XLPE cable happened. The figure is based on 279 failures where this time interval is known. Close to 40% of them happen within 5 minutes after the first earth fault and 60% happen within 30 minutes. However, close to 30% of the failures happen within 60-120 minutes or more after the first earth fault. This could be interesting information in case of maintenance test where cables are stressed with an overvoltage during a preset time to provoke a fault at a weak point. Several recommendations for power frequency testing of cable systems exist, e.g. CENELEC [3] and IEC [4]. Both focus on after installation test. They generally agree on the test voltage, which is set to $2U_0$ in [3] and the phase-to-phase voltage [4], but differ on the recommended test durations, which are 15 minutes in [4] and 60 minutes in [3]. Compared to the experiences from the Danish failure statistic, cf. figure 9, these recommended test durations would potentially have been able to find approximately 50% [4] and 70% [3] of the 279 failures in figure 9.

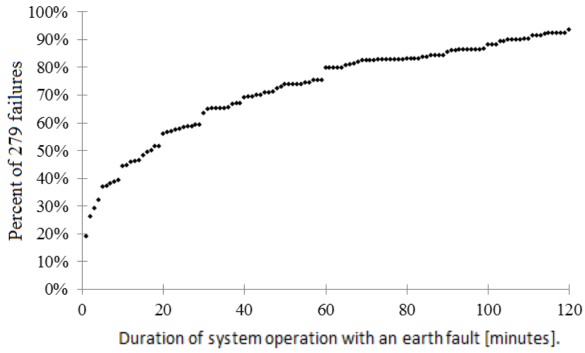

Figure 9: Duration of system operation with an earth fault before a second earth fault occurs on a XLPE cable.

CONCLUSION

Service experiences with dry-cured MV XLPE cables are at the moment good in Denmark. The overall failure rate is very low and has dropped in recent years. Third party damage is without comparison the most common cause of failure on MV XLPE cables.

In case of ageing related failures there could be an indication of a rising failure rate as function of service time for dry-cured XLPE cables approaching service times of 30 years, but the observed increase is small and from a very low level to another low level, so such a conclusion should be drawn with caution. More collected data in the coming years could confirm or disconfirm this.

The failure statistics indicate that a large share of the ageing related XLPE cable failures (close to half) occur while the system is operated with an earth fault and therefore at an elevated phase-to-earth voltage on sound phases. Where the time duration is known (279 failures) a large share (30-40%) of these failures have happened after the system has been operated with an earth fault in 30 – 60 minutes or more.

REFERENCES

[1] HD620 S2 part 1 and 10D, 2010, CENELEC

[2] PEX kablernes blå bog, NKT Cables

[3] HD620 S2 part 10C, 2010, CENELEC

[4] IEC 60502-2/Ed2/A1/CDV, 2012, IEC