INSULATION CONDITION OF DRY-CURED XLPE CABLES MEASURED OVER A PERIOD OF 13 YEARS

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ABSTRACT
Since 2001, a series of diagnostic measurements has been carried out on dry cured XLPE cables without water barrier. Initially 56 cable sections were included in the program and from 2010 another 30 cable sections were added. The cable sections were installed in 10 to 20 kV systems in the period between 1982 and 2010. The objective of the measurements was to get an assessment of the insulation condition and the rate of change in insulation condition for these cable sections.

The method used for the measurements is dielectric spectroscopy where dielectric losses in the insulation are measured at VLF voltages in the range between 0.5 \( U_0 \) and 1.5 \( U_0 \) in the frequency range around 0.1 Hz.

The measurements have shown that only a few of the cables monitored since 2001 are still in good condition. Most of them have aged slightly or significantly in the measuring period. Three of the cable sections were found to have a bad insulation condition with high risk of failure in case of an overvoltage, and one of the cables actually later failed during a single-phase earth fault on another cable.

INTRODUCTION
In Denmark like in other countries the first installed Medium Voltage (MV) steam-cured XLPE cables in the 1970s had a very high failure rate after only a few years in service. In the late 1970s the main cable supplier at that time to the Danish market changed the cross-linking process from steam-curing to dry-curing. This reduced the water content in the cables significantly and led afterwards to a remarkable reduction in the failure rate for MV XLPE cables. In fact no significant rise in the failure rate for dry-cured MV XLPE cables has been observed in the failure statistics after approximately 35 years of service time with these cables as reported in [1].

However, unless the insulation is protected against moisture by water barriers water trees will also grow in dry-cured XLPE cables and eventually cause failures. In Denmark there is no tradition for using MV XLPE cables with water barriers. The extent to which the lifetime of the cables is influenced by the missing water barrier is therefore a relevant and important question for the Danish utilities.

DIAGNOSTIC METHOD
The measurements were carried out using the method called dielectric spectroscopy [3]. VLF voltages in the range between 0.5 \( U_0 \) and 1.5 \( U_0 \) and with frequencies typically between 0.03 Hz and 0.3 Hz were applied, and the dielectric losses in the insulation were measured.

Based on the variation of the dielectric losses with voltage and frequency, the cables were classified into four condition categories, corresponding to increasing levels of ageing:

- Good cables with low losses
- Aged cables with voltage dependent losses
- Significantly aged cables with transition to leakage current at the highest applied voltage level
- Bad cables with leakage current occurring at normal operating voltage.

CABLES INCLUDED IN THE PROGRAM
Initially 56 cable sections mainly installed during the 1980s were included in the program in 2001 and from 2010 another 30 cable sections installed in the 1990s were added.

The installation years of the cable sections in the program are shown in Figure 1. A cable section installed in 2010 is not shown, but is still included in the analysis.

Cables from different manufacturers are included in the program, but one cable manufacturer dominates due to historical reasons.

In 1998 and 1999 diagnostic measurements revealed signs of ageing also in dry cured cables and this led to the initiation of a 6-year measurement program which started in 2001 and is described in [2]. In 2010 this measurement program was continued with addition of a new batch of dry-cured XLPE cables. The objectives of both of the measurement programs were to get an assessment of the insulation condition and the rate of change in insulation condition for these cable sections.

This paper presents the results and conclusions based on these diagnostic measurement performed over the last 13 years.
The cable sections in the program are operated at system voltages of 10 kV, 15 kV or 20 kV. No distinguishing between the different system voltage levels is done in the analysis, but the majority of the cable sections are operated at 10 kV.

Loading of the cable sections has not been taken into account, but it is expected that most of the cable sections in the measurement program are lightly loaded, as they are typically installed in rural areas.

INSULATION CONDITION

In 199 measurements carried out during the 13-year period it was possible to assess the insulation conditions of the measured cable sections. At the conclusion of the measurement program in 2014 it was still possible to assess the condition of a least 49 cable sections out of the total of 86.

Two cable sections were no longer in service, but had been assessed at earlier measurements. In 35 cable sections it was no longer possible to assess the condition of the cables, most likely due to additional losses from the cable accessories as reported in [4]. However, a large part of these 35 cable sections had been diagnosed at previous measurements and the results of these measurement are included in the analysis. Approximately 25 % of the 35 cable sections have never been assessed properly, e.g. due to high additional losses from cable accessories.

Until 2007, the integrity of the cable sheath was checked as a part of the diagnostic measurement. However, as reported in [4] it was not possible to find a conclusive relationship between the integrity of the sheath and the insulation condition of the cable. As of 2010, a check of the integrity of the sheath was therefore no longer performed as a part of the cable measurement and only the dielectric losses were measured.

Insulation condition as a function of installation year

In Figure 2, the insulation condition is shown as a function of the installation year. The figure is based on measurements performed in the period 2010 – 2014. Only the assessment based on the latest measurement on a given cable section has been included. In total, the insulation conditions of 46 cable sections have been assessed in the mentioned period.

Approximately 50 % of the cables installed in the 1990s have been found to be aged today. About 25 % of the cable sections are still in good condition. Less than 20 % of the cable sections are significantly aged. One cable installed in 1998 was assessed to be in bad condition, but as mentioned later in this paper the assessment of this cable section is questionable.

Insulation condition as a function of age

It is attempted to illustrate the dependency on age of the insulation condition in Figure 3, where the cumulative age distributions within the four condition categories are depicted. The figure is based on 199 measurements performed in the period between 2001 and 2014. This means that each cable section is represented more than once in the figure and in many cases also in more than one condition category, because all cable sections have been re-measured a least once.
In total 84 measurements have resulted in the assessment “good”, 58 in the assessment “aged”, 52 in the assessment “significantly aged” and 4 in the assessment “bad”.

Figure 3 shows an influence of age on the insulation condition, which also is to be expected. The population of cables in good condition are in general younger than the population of aged cables which again are younger than the population of significantly aged cables. And the significantly aged cables are generally younger than the population of cables in bad condition.

However, the figure also shows that there are significant overlaps in age between the different condition categories. This indicates, as expected, that other parameters than age have a significant influence on the insulation condition. Examples of such parameters could be damages during installation, old third party damages, different service conditions, stones pressed into the sheath, etc.

Finally, it should be emphasized that Figure 3 is not based on measurements on 199 unique cable sections, but on 199 measurement on 82 different cable sections, so the different condition categories are not fully independent of each other.

Changes in insulation condition

During the 13 years of measurement many of the cable sections have changed to another condition category and some have changed more than once. These cable sections are shown in Figure 4 a) to d). The figure shows the age at the measurement before and after a cable section changed condition. It is therefore only possible to determine an interval of one or more years in which the change in insulation condition has taken place.

20 cable sections have changed condition from “good” to “aged”, cf. Figure 4 a). Some variations between the cable sections are observed. For 14 cable sections the change from “good” to “aged” has taken place in the age interval between 15 and 25 years, but with some indication of that the change has taken place closer to an age of 15 to 20 years than 25 years.

Figure 4: Cable sections which have changed insulation condition during the 13 years of measurement.
8 cable sections have changed condition from “good” to “significantly aged”, cf. Figure 4 b). This means that the conditions of the cable sections have not been assessed while the cables were in an aged condition. Less variations between the cable sections are observed and the changes seem to take place in the age interval between 15 and 20 years. This is basically the same interval as for the cable sections which have changed from “good” to “aged”, but in Figure 4 b) the cable sections have changed condition twice during the time interval between measurements.

3 cable sections have changed condition from “good” to “bad”, cf. Figure 4 c), which means that these cable sections have not been assessed while they were in an aged or significantly aged condition. Except for the cable section with ID 68, the changes in condition have taken place between an age of 20 and 30 years.

5 cable sections have changed condition from “aged” to “significantly aged”, cf. Figure 4 d). Some variation between the cable sections can be observed, but the change in condition has in most cases taken place within a relatively small age interval.

Based on Figure 4, it is difficult to say anything conclusive about when a cable changes from one insulation condition category to another. Too much variation between the different cable sections is observed, which also indicates that other parameters than age influences the aging of the cables. However, it seems reasonable to conclude that in general, cables in the program do not show signs of aging until an age of approximately 15 to 20 years.

**Cable in bad condition which subsequently failed**

In [4], a cable installed in 1983, which was assessed to be in bad condition, was described. In 2001 the cable was found to be in good condition with low dielectric losses but in 2007 transition to leakage current was measured at 1.5 \(U_0\) (9 kV), and the leakage current response was maintained after lowering the voltage to \(U_0\) (6 kV) as shown in Figure 5. Based on the measurement it was therefore assessed that the cable was in a bad condition and that the probability of failure was high in case the cable was operated at an elevated voltage due to e.g. a single-phase earth fault somewhere in the system.

This cable has subsequently failed in 2009 while the system was operated with a single-phase earth fault on another cable in the system resulting in an elevated voltage on the two sound phases.

In 2010 a new measurement was carried out on the cable section. Unfortunately, the results of the measurement were less conclusive due to additional losses in the cable accessories used to repair the failure, but the measurement still indicated that the cable was in a bad condition.

It has not been possible to carry out further measurements on the cable section since 2010, but until now, no additional failures have been observed in the cable section.

![Figure 5: Measured dielectric losses in 2007 on one of the phases in a cable assessed to be in bad condition.](image)

**Cable in bad condition which subsequently has been hipot tested**

One cable section installed in 1998 was in 2014 assessed to be in bad condition. Transition to leakage current was observed at 1.5 \(U_0\) (9 kV) and the leakage current response was maintained after lowering the voltage to \(U_0\) (6 kV) as shown in Figure 6 b). In 2010 the same cable section had been assessed to be in good condition, because no leakage current response or voltage dependency of the losses was observed, cf. Figure 6 a). This represents a significant change in condition assessment over a relatively short time period.

After the measurement in 2014 a hipot VLF test was performed. The cable section was tested at 0.1 Hz and 3 \(U_0\) in one hour. The test was passed (no failures) and according to the utility’s assessment criteria it was concluded that the cable section was in acceptable condition.

A subsequent dielectric spectroscopy measurement has not yet been performed on the cable section to check whether the dielectric losses still indicate that the cable section should be in a bad condition.

A possible explanation for the high dielectric losses measured in 2014 compared to the losses measured in 2010 could be contributions to the losses from dirt and/or moisture on the cable terminations. However, if this was the reason it would normally also be observed in the losses measured at 3 kV and in particular in the first measurement at 6 kV. As seen in Figure 6, this is not the case, as the losses measured at 3 kV and at the first measurement at 6 kV in 2010 and 2014 are comparable. No change of accessories in the cable section has taken place, so until now no explanation for the change in the dielectric losses has been found.
CONCLUSION

The service experience with dry-cured MV XLPE cables is very good. No significant rise in the failure rate has been observed after approximately 35 years of service time. However, the results of diagnostic measurements presented in this paper have shown that only a few of the 86 dry-cured XLPE cables monitored since 2001 are still in good condition. Most of them have aged slightly or significantly in the measuring period.

The results have shown that the cables in the measurement program have begun to exhibit signs of aging after about 15 to 20 years of service time. For cables younger than that, the insulation condition has in general been good.

A clear age dependency of the insulation condition has been observed. However, a significant age overlap between the different insulation condition categories has been observed too, which indicates that other parameters than age have a significant influence on the aging rate.

Three of the cable sections were found to have a bad insulation condition with high risk of failure in case of an overvoltage, and one of the cables actually later failed during a single-phase earth fault on another cable section. Another one of these cables was subsequently hipot tested and passed the test. So far, no explanation has been found of the difference between the assessments based on the dielectric losses and the hipot test, respectively.

The measurement program has now been stopped, just like it was in 2007, but it may be reinitiated some years from now.

REFERENCES


