SERVICE EXPERIENCES IN DENMARK WITH MIXED MEDIUM VOLTAGE (MV) CABLE SYSTEMS CONSISTING OF BOTH XLPE AND PILC CABLES TECHNOLOGIES

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

ABSTRACT

It is no longer permitted in Denmark to use PILC cables in new MV cable systems or as replacement for existing cables. This has led to an increased use of XLPE cables in systems which originally consist of PILC cables only. Among the utilities in Denmark the mixing of cable technologies has given rise to some concerns about how mixed cable systems will influence the failure rates for PILC cables and their accessories. The aim of this paper is to address some of these concerns. For that purpose service experiences with mixed cable systems in Denmark have been analyzed and the findings are presented in this paper. Results from a Danish project with focus on partial discharge measurements in MV cable systems have also been analyzed with the purpose of examining if any relationship between PD activity and mixed MV cable systems can be found. The conclusions drawn from these preliminary examinations are that there is an indication of higher failure rates in mixed cable systems which primarily seem to be due to a high number of premature failures in the transition joints. This is partly supported by the results from the measurement project with focus on PD measurement in MV cable systems.

INTRODUCTION

The first MV XLPE cables were installed in Denmark in the late 1960'ies. The transition from using PILC cables to XLPE cables, however, has only been gradual and some Danish utilities have gone on using PILC cables exclusively until the 1990'ies. Today it is not allowed to use MV PILC cables in new cable systems or as replacement for existing cables. The mixing of PILC and XLPE cable technologies is therefore a necessity.
It is still permitted to make minor repairs with PILC cables, i.e. in case of a failure, and until comparatively recently most utilities have tried to avoid mixing the two technologies, so that repairing of faulty PILC cables or straight joints have been done with short lengths of PILC cable (a few meters). Today, however, it has become common practice to use XLPE cables when repairing faulty MV PILC cables or straight joints. One of the reasons is that the utilities no longer have PILC cables in stock for small repairs (the manufacturing of PILC cables normally used in Denmark has more or less ceased).

The mixing of the two cable technologies have led to some concerns about whether this can lead to higher failure rates in the PILC cable parts in a mixed cable system. Some of the concerns expressed by the utilities are problems related to the prevention of oil flowing to PILC cables from an oil reservoir (normally placed in connection with the cable terminations in substations or ring main units). Lack of oil in the cable and joint insulations could lead to the creation of gas voids due to e.g. oil leaks, thermal expansion of the cables, the local topology along the cable trace, etc.
Some utilities have also experienced premature problems with transition joints between PILC cables and XLPE cables which have given rise to some concerns due to the expected increase in the use of these types of joints in the future.

PILC CABLES IN MIXED SYSTEMS

In the period 2007 and 2008 detailed information about failed PILC cables (accessories excluded) has been collected for the cases where the cause of the failure is related to ageing. The information the utilities were asked to report is whether a failed PILC cable is part of a mixed cable system or a pure PILC cable system. Unfortunately, this information has not been reported for all failed PILC cables in the period. Table 1 shows all reported ageing related MV PILC cable failures in 2007 and 2008 and whether they were part of a pure PILC cable system or a mixed cable system.

Type of cable system	Number of failures	Percentage of total number of failures
Pure PILC	52	19 %
Mixed	30	11 %
Not known	190	70 %
All	272	100 %

Table 1: Failed PILC cables with regards to the type of cable system they were/are part of.

Out of 272 reported ageing related PILC cable failures, information about the type of cable system was only received for 82 failures (30 %). Of the 82 failed cables 52 (19 %) are from pure PILC cable systems and 30 (11 %) are part of mixed cable systems. Under the assumption that the distribution of the 82 failures with regards to type of cable system is representative for all 272 failures, there are vague indications that the failure rate for MV PILC cables in mixed cable systems is higher than the failure rate in pure PILC cable systems. This conclusion, however, should be drawn with some reservations. First of all the exact numbers of pure PILC cable systems and mixed cable systems are not known and it is therefore not possible to estimate a failure rate. It is only assumed that the number of pure PILC cable systems still is significantly higher than the number of mixed cable systems. This is why a significantly higher number of failed cables in pure PILC cable systems should be expected.

Another important fact, which has to be taken into account when the information is analyzed, is that it is not possible to conclude from the received information whether a failed PILC cable is isolated (i.e. oil flow to the failed PILC cable from an oil reservoir is prevented) or semi isolated (oil flowing to the failed PILC cable from an oil reservoir is possible from one side). Both situations are possible in a mixed cable systems and could have an influence on the failure rate for PILC cables.

It is therefore clear that more surveys on failed PILC cables in mixed cable systems need to be done, before we can be certain about what influence a mixed system has on the failure rate for PILC cables - if any at all.

SERVICE EXPERIENCES WITH TRANSITION JOINTS

Beside the failure rates for PILC cables in mixed cable systems, the overall failure rate for cable systems also depends on the failure rate for cable accessories.

Some Danish utilities have experienced a high number of premature failures in transition joints. To investigate how big a problem premature failures in transition joints are, analyses of MV cable joint failures over a period of 10 years (1999 – 2009) have been carried out. The data used are from a Danish failure and interruption database [1], which covers approximately 90 % of all MV systems in Denmark (52458 km).

In Figure 1 is shown the number of failed joints per year in the period. Failed MV joints have been divided into three groups: PILC straight joints, XLPE straight joints and transition joints.

The database, unfortunately, does not contain information about the total number of a specific type of joint. It is therefore not possible to calculate a failure rate. Instead the total circuit lengths included in the database is shown. This information together with the number of failed joints gives an indication of the ratio in failure rates between different MV joints. The assumption is that the number of transition joints is significantly lower than the number of straight joints for PILC and XLPE cables. If the failure rates for XLPE straight joints and transition joints are approximately the same, it would then be expected that the number of failed XLPE straight joints should be significantly higher compared to the number of failed transition joints. According to Figure 1 this is not the case and it is therefore concluded that the failure rate for transition joints must be significantly higher than for XLPE straight joints.

The number of failed PILC straight joints is significantly higher than both the number of failed transition joints and XLPE straight joints. This, a least, suggests that the failure rate for PILC straight joints is higher than for XLPE straight joints. It is more difficult to draw any conclusion about the difference between the failure rates for PILC straight joints and transition joints. It seems reasonable to assume that the number of PILC straight joints still is larger than the number of transition joints. However, failed PILC straight joints are expected to have been in service for much longer time than the bulk of the failed transition joints. This suggests that failures in transition joints are of a premature nature, i.e. they have failed relatively shortly after they have been put into service.

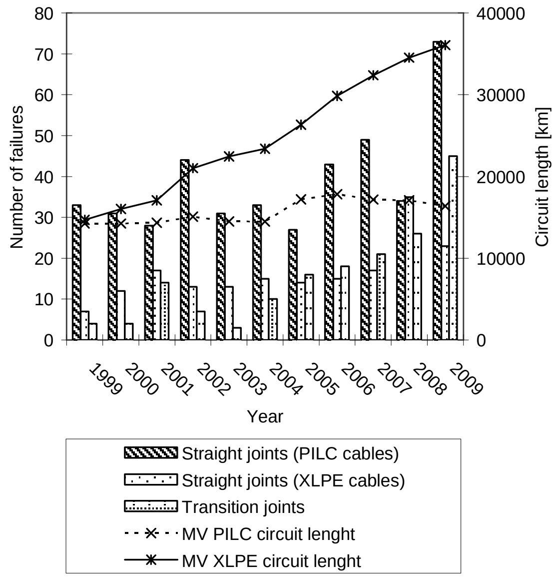

Figure 1: Number of failed MV cable joints between 1999 and 2009.

Service experiences with different transition joints

Transition joints can be divided into two groups based on the used joint technology: Wet design and dry design. In wet design oil or a sealing compound is used as insulation. In dry design the PILC cable is sealed and the joint is more or less designed like an XLPE straight joint. The dry design is exclusively used today. A third group is introduced because it is not always reported in the database whether a failed transition joint is of wet or dry design. Figure 2 shows the distribution of failed transition joints with regards to the type of design used.

52 % of the failed joints have an unknown design. Of the 48 % where the type of design is known, 36 % are of the dry design, and only 12 % are of the wet design. This may indicate two things:

1) The failure rate for transition joints of the dry design is significantly higher than the failure rate for transition joints of the wet design
2) The number of installed transition joints of the dry design is significantly larger than the number of transition joints of the wet design

The explanation is most probably a combination of both items.

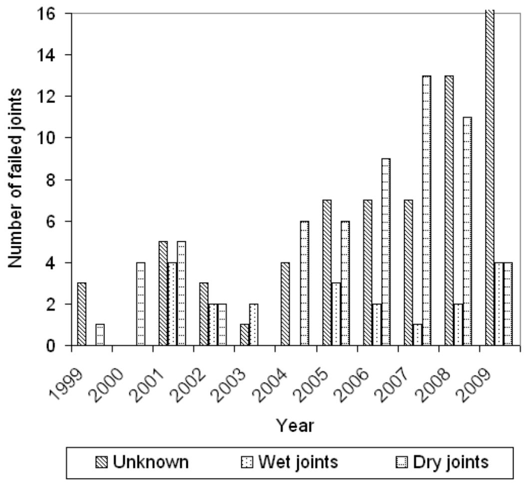

Figure 2: Distribution of failed transition joints regarding used technology.

Cause of failure in transition joints

When utilities report a failed transition joint they are also requested to report the cause of the failure. In Figure 3 is shown the causes of failed transition joints. Unfortunately, this information is not availble for 37 % of the reported failures.

In the case of transition joints of the dry design, 43 % of the failures are due to the assembling process and the cause is unknown for 48 % of the failures (a larger share of these are therefore also expected to be caused by the assembling process). The high number of failures due to the assembling process is in support of the assumption that the bulk of the failed transition joints are premature. In the case where the type of transition joint is unknown the number of failures due to the assembling process is also high, about 20 %, but here ageing counts for the larger share of the failures, about 46 %. Some of these transition joints will also be of the dry design.

The high number of ageing related failures for wet design transition joints also indicates that these in general have been in service longer than transition joints of the dry design.

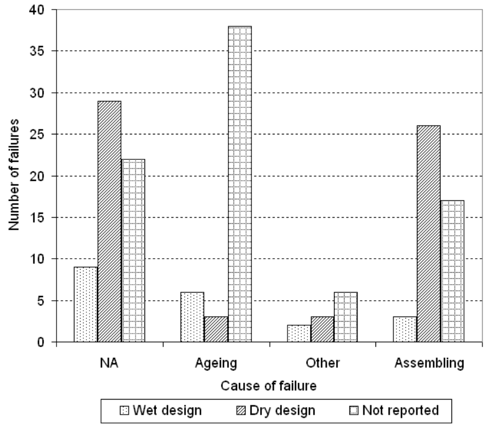

Figure 3: Cause of failure in transition joints.

PARTIAL DISCHARGE MEASUREMENT IN MV CABLE SYSTEM

A joint project between Danish utilities with focus on partial discharges (PD) measurements in MV cable systems has just been concluded [2]. The data achieved in this project have been analyzed with the aim of investigating if there are any relationships between located PD sources and whether the sources are located in pure PILC or mixed cable systems.

In Table 2 it is shown how the PD sources are distributed among three groups of components: PILC straight joints, transition joints and PILC cables. Not surprisingly, most of the located PD sources are in joints (about 2/3) – straight or transition joints. The number of located PD sources in transition joints is more or less the same as the number of PD sources in PILC straight joints. This was perhaps at first a little surprising (and the reason to look at service experiences with mixed cable systems in the first place), but if PD activity is considered to be one of the main failure mechanisms in transition joints of the dry design, this is in good agreement with the failure statistics mentioned.

It has not been possible to find any statistically significant difference between PD sources in PILC cables installed in pure PILC and mixed cable systems, respectively. In most of the cases where the PILC cable with a located PD source was part of a mixed cable system, it was still possible for the oil to flow freely from an oil reservoir from one of the sides to the PILC cable with the located PD source.

Component with PD source	Number of PD sources
PILC straight joints	10
Transition joints	9
PILC cable	11
All	30

Table 2: Located PD sources in MV cable systems in Danish measurement project.

DISCUSSION

It is important for utilities to have a good understanding of how a mixed MV cable system will influence the failure rate in the systems. Such an understanding would give a better basis for decision making when it comes to maintenance and reinvestment. It will be too expensive not to allow mixed cable systems, but it will also be expensive with a cable system with too high failure rates, so the decision will be a weighting of the replacement costs against what an acceptable failure rate for a particular cable system would be. A high failure rate[1] could justify the replacement costs of all or parts of the PILC cables in a mixed cable system.
The service experience (a least the documented service experience) with mixed cable systems is, unfortunately, not good enough today to draw any useful conclusions, except for perhaps dry design transition joints. More work needs therefore to be done.
The information which lacks today in the Danish failure database regarding failed PILC cables is chiefly concerning whether the cables are isolated (oil flow from an oil reservoir to the PILC cable is prevented by XLPE cables), semi isolated (oil flow from an oil reservoir to the PILC cable is possible from one side) or installed in a pure PILC cable system. If this information were available it would be possible to conclude whether it has any statistically significant influence on the failure rates (ageing related failures) for PILC cables.
In the case of transition joints of the dry type design, more work needs to be done, also. The high number of failures in the case of particularly transition joints of the dry type design (which is exclusively used today) due to the assembling process is positive in the sense that it should be possible to reduce the number of these failures. This may be done by being more careful with the assembling process and by making sure that the technician who assembles the transition joint has the proper instruction and education. This, however, is only possible if the utilities examine the failed transition joints, so they can learn from experience what went wrong. Today a database that collects detalied information about the failure mechanism does not exist (only that the cause of failure is due to the assembling process is being stored), which at the moment makes it impossible to list typical failure mechanisms due to the assembling process. More work needs therefore also to be done with regards to failures in transition joints, so that proper action can be taken to avoid or a least reduce the number of these failures in the future.

CONCLUSION

In this paper higher failure rates in mixed MV cable systems have been addressed. Based on the statistical data available today for failures in MV PILC and mixed cable systems in Denmark, it has not been possible to make a conclusion about what influences an isolated PILC cable has on the failure rate for PILC cables – if any at all. More work needs to be done on the subject and in particular, it will be necessary to collect information about whether a failed PILC cable is isolated, semi isolated or part of a pure PILC cable system.
There are, however, strong indications that the failure rate for transition joints of the dry design type is very high, and that the high number of failures is of premature nature and due mainly to the assembling process. However, work still needs to be done regarding transition joints, because the different failure mechanisms due to the assembling process are not documented properly today.

[1] Definition of a high failure rate will depend on the strategy of the utility, the particular cable system and its importance, etc. and it is therefore difficult or meaningless to define a general threshold level.

REFERENCES

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