SHORT LITERATURE SURVEY ON THE RELIABILITY OF EHV XLPE CABLES

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1 INTRODUCTION

In this short survey, literature from three major recent conferences on EHV power cables are studied in order to find the present opinion of utilities and other important companies (R&D groups, test houses, manufacturers) on the reliability of EHV XLPE cables. EHV stands for Extra High Voltage which roughly covers the voltage classes starting with 220 kV. These conferences are:

- the Cigré conference in Paris, August 2004: Chapter 2,
- the Jicable conference in Versailles, June 2003: Chapter 3
- the Cigré conference in Paris, August 2002:Chapter 4.

Cigré is a world-wide operating organization, covering all electric power aspects, mainly directed to HV and EHV. Every two years there is a conference with participants from all over the world, showing the latest developments on these items. Power cables has its own committee and paper session. The committee HV cables (B1) arranges studies by working groups on important subjects on power cables, some of their work is reflected in papers. Furthermore, the papers come from other sources. Information can be found on their website www.cigre.org.
Jicable is a conference organised by the French SEE (www.see.asso.fr) on power cables only, but now covering low, medium, high and extra high voltage cables. It is one of the largest conferences in the world on power cables only, held each 4 years, attended by many important utilities, manufacturers, etc. Their Jicable website comes alive when a new conference is approaching, expected in 2007.
Both conferences, from Cigré and Jicable, are not scientific, as sometimes IEEE related conferences are. Their approach is more practical and comparable to the ICC (Insulated conductor conference approach (www.ewh.ieee.org/soc/pes/icc), well known in the USA. Since EHV XLPE cables have their basis in Europe and Asia, it is also a fact that main developments and recent opinions are probably covered by Cigré and Jicable, being a reason to restrict the short survey to these conferences.

The main conclusion from the literature survey are drawn in Chapter 5 and references are specified in Chapter 6.

2 LITEREATURE FROM CIGRE 2004

In reference [2] information is given about the reason why various countries in the Asian region are switching to XLPE, leaving fluid filled cables. In this reference, it is not only stated that there are very few problems with the performance of new XLPE cables, but that there is concern about the remaining life off older cable types. This is related to the water tree degradation, extensively discussed in among others [3]. Nowadays this ageing problem is fully under control, due to reliable testing and additional water protection measures in XLPE cables. In the 10 Asian countries involved, XLPE cables are used in Indonesia up to 150 kV (chosen for reliability reasons!) to Japan up to 500 kV.

Reference [2]

To further CIGRE representation in the Asian Oceania region a workshop was conducted early in 2003 under the sponsorship of the Malaysia National Committee of CIGRE. There was representation from cable experts from 10 countries in the region. The purpose of this paper is to provide a report on the issues raised at that workshop with the objective of sharing the experiences of this region with the broader international community and at the same time, encouraging greater participation in CIGRE by experts in this region.

2. DESIGN PRACTICES – CABLE - ACCESSORIES – SYSTEMS
2.1 XLPE cable design. *Most countries agreed that due to maintenance problems with fluid filled cables they were adopting XLPE. They agreed that overall there are very few problems relative to the performance of new XLPE cables but some very significant concerns by a number of countries in regards to the remaining life and performance of early XLPE cables, particularly those which did not have fully sealed metallic sheaths. On the other hand, Japan suggested the trend might be to make EHV cable without a metallic sheath or to accept the Moisture Barrier designs. Japan also proposed the introduction of DC – XLPE cable up to and including 500kV.*

Reference [4] is from cable manufacturer Brugg, from Switzerland. This manufacturer claims that he delivered 20 km of XLPE cable in the voltage range of 300 to 400 kV, with 93 accessories, installed in the last ten years and having excellent service behaviour. This information was not verified by independent parties, but on the other hand, there have been no messages from customers so far disputing the manufacturer's statement.

Ref [4]

More than 1950 km of cables and 6900 accessories up to 400 kV have been installed in the last 10 years, and they have displayed excellent operating behaviour (Tables 1 and 2).

Rated Value

	60 - 109 kV	110 - 170 kV	171 - 300 kV	301 - 500 kV	Total
kms	310	1.398	216	20	1.944

Table 1 Experience in HV- and EHV-XLPE-cables

Rated Value

	60 - 109 kV	110 - 170 kV	171 - 300 kV	301 - 500 kV	Total
Units	93	5511	1206	93	6903

Table 2 Experience in prefabricated and pre-tested accessories

Reference [5] is from some important Japanese Tokyo Electric Power, Cansai Electric Power and Chubu Electric Power, with support of Japanese cable manufacturers. In their introduction they state that "*This* (XLPE) *cable is capable of handling currents of up to* (a voltage level of) *500 kV, and has been successively used in practical applications.* In fact, Japan is leading in the world concerning the application of EHV XLPE cables.

Ref [5]

1. Introduction
In Japan, the realization of high density power transmission in major city areas requires the effective utilization of limited underground space, available, for example, in tunnels and ducts. Thus, for many years, particular efforts have been directed towards reducing the construction period, cutting the cost, and improving the reliability of extra-high voltage lines. This has necessitated a reduction in the number of joints, and thus long cable manufactured in continuous length had to be transported from the factory to the installation site, an undertaking that required the development of technology to installation the cable directly from the unloading point. At the same time, it has become essential to maximize the transportation length of the cable and to reduce its weight. In response to these needs, cross-linked polyethylene insulated cable with a reduced insulation thickness and the joints suited to it has been developed in Japan. This cable is capable of handling currents of up to 500 kV, and has been successively used in practical applications.

Pirelli also claims that EHV XLPE cables have excellent reliability, see reference [6]. As with Brugg cable, in the case of this manufacturer too some suspicion concerning the claimed XLPE cable behaviour is correct. But also in this case, concerning the cables discussed by Pirelli, no conflicting messages are known.

Ref [6]

A precondition for the acceptance of the new cable technology was the proof of its long-term reliability [ref 1 in this article]*. Extensive test programs have been carried out and the excellent test results convinced all parties that long-term performances of such advanced cable systems could be considered appropriate. First long distance EHV XLPE cable systems have been installed since the late 90's, typical examples of which are:*

- *420kV XLPE cable systems with natural cooling for 800 and 900 MVA/cct (interconnection feeders for the city of Copenhagen, Denmark (22 km + 10 km), in service since 1997* [ref. 2 in this article]
- *400kV XLPE cable systems with ventilated air cooling in tunnel for 1120 MVA/cct (diagonal interconnection throughout the city of Berlin (~24 km), in service since 1998* [ref. 3 in this article]
- *500kV XLPE cable systems with tunnel and duct installation for 1200 MVA/cct (interconnection feeders for the city of Tokio, Japan (~ 40 km), in service since 2000* [ref. 4 in this article]
- *400kV XLPE cable system with ventilated tunnel installation for 1720 MVA/cct ("siphon" intersection of an existing OHL at Barajas Madrid Airport (~13 km), under construction)*

Despite its relatively young age, extruded EHV cable systems technology is convincingly demonstrating its appropriateness and increasingly extending its application for all kinds of interconnections, leveraging on some key features, e.g. reduced environmental impact, ease of installation and no need for maintenance.

3 LITERATURE FROM JICABLE 2003

The first paper with interesting information is from ABB [7]. ABB takes the present experience with their cables and accessories operating at stress levels of 12 to 14 kV/mm as an expectation for other operating systems that could work on the actual EHV voltage class range at a similar electric field stress of 12 to 14 kV/mm due to other dimensioning of the cable. Although this extrapolation has some drawbacks, it is a reasonable approach. ABB assumes that based on this approach, for EHV cable this would lead to 0.024 failures per 100 km per year (or 0.038 failures per 100 miles per year).and for the EHV accessories about 0,01 failures per 100 accessories per year. In reference [1], an XLPE double circuit of 15.5 miles with 48 accessories per circuit phase (= 288 accessories in total) has been chosen for comparison with a HPFF cable. For such an XLPE cable double circuit, the ABB figures in this reference would lead to a total number of faults in 40 years of 1.4 failures for the cable and 1.2 failures for the accessories, making in total about 3 failures for this 15.5 miles double circuit per 40 years. This is an excellent reliability indeed (if ABB's assumptions are correct).

Ref [7]

operational AC design stress between 12 and 14kV/mm at the conductor screen.

To employ stress levels similar to 220kV and 400kV for cable systems being subjected to high mechanical stresses requires a solid reliability record. The failure rate for components in ABB's cable systems is given in Table 1 below (expressed as number of failures/100km and year for cables and number of failures/100 accessory items and year for accessories).

Table 1: Failure rate for XLPE cable system components.

Population	Failure rate
Cables (1973-2003)	0,024
Tape molded joints (1982-2003)	0,013
Prefabricated terminations (1985-2003)	0,008
Prefabricated joints (1990-2003)	0

As can be seen, the failure rate of the insulation systems is very low (implying a very high reliability).

The second relevant paper on EHV cables showing major projects realized in Europe is [8]. This paper describes the standards applicable to EHV cables, but also gives a good overview of documents created by Cigré working groups, which are supporting people that are dealing with these cables. Moreover, and that is important here, the authors say that the experience with EHV cables in Europe is very good. All the existing circuits are summarized. The paper has authors from European cable manufacturers only, but as far as KEMA is aware, all statements made by the authors are correct.

The 400 kV XLPE cable projects mentioned in this paper and completed at least one year ago:

- Germany, Berlin (1998-2000), 70 km single core cable in a tunnel, 1600 mm^2 Cu, 78 prefabricated and premoulded joints
- Denmark, Copenhagen (1997-1999), 104 km single core cable direct buried, 1600 mm^2 Cu, 114 prefabricated and premoulded joints

The 400 kV XLPE cable projects underway or just completed are

- Spain, Madrid (2004) 78 km single core cable in a tunnel, 2500 mm^2 Cu, 96 prefabricated and premoulded joints

- Denmark, Jutland (2004) 84 km single core cable direct buried, 1200 mm^2 Al, 96 premoulded joints
- UK, London (2005) 60 km single core cable direct buried, 2500 mm^2 Cu, 60 pre-fabricated joints.

Ref. [8]

For example, the first 225 kV extruded cable was installed in Europe (France) in 1969 and is still in operation, with excellent service reports. Similarly, 400 kV extruded cables have been used in French nuclear plants since 1985. Later, the first large 400 kV extruded transmission underground systems were installed in Europe: Denmark, Germany then Spain. When designing, testing, manufacturing and installing EHV cable systems, European cable manufacturers followed IEC 62067 standard as weil as all existing recommendations issued by CIGRE SC B1.

4 LITERATURE FROM CIGRE 2002

No relevant papers on reliability issues were found.

5 CONCLUSIONS

In general, this short survey gives the impression that utilities and manufacturers are satisfied with the reliability of EHV cables so far. Reliable data over a long period of application is not available, such cables are too short in service, with most projects realized in the last 10 years.

6 REFERENCES

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