SERVICE EXPERIENCE WITH MEDIUM VOLTAGE XLPE CABLES IN GERMANY

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The report deals with service experience obtained with modern 20-kV-XLPE cables installed in the German medium voltage system. In order to establish criteria for their future selection of cables three power supply companies have removed cable samples with a total length of about 3 km from the system after 10 years of service. Both standard cables and cables with longitudinal water blocking systems from six major German manufacturers were involved. These samples were investigated concerning their residual dielectric strength.

1. Introduction

Plastic insulated cables are installed in large scale in Germany since the 1970ies. Owing to the simple construction of these cables and the homogeneity of their insulation, it was assumed to have a robust and maintance-free cable which offered simpler mounting and more economic installation as compared to the mass-paper insulated cable traditionally used in German medium voltage systems. The high expectations concerning the reliablity of the new cable type had to be corrected, when at the beginning of the 1980ies the now well-known service failures due to water-treeing were observed.

The plastic insulated medium voltage cable used in the beginning of its application was according the 1978 German Standard and had an insulation of PE or XLPE, an extruded inner conductive layer, an outer conductive layer usually of graphite and a PVC jacket. At this time the importance of the material cleanness of insulation and semiconductive layers as well as of the homogeneity of the boundaries for the cables operated in humid soil was not sufficiently known. After the experience with service failures which systematically occured at some cable productions, extensive investigations were carried out by power supply companies, manufacturers and research institutes which clarified the phenomenon of water-treeing and the conditions for its occurrence. The conclusions drawn from this research led to a remarkable improvement in the insulation and layer compounds, in the production process and in the quality assurance of the cables. They finally led to the cable today standardized in the European Standard HD 620, Section 5C. The insulation material is exclusively XLPE, the semiconductive layers are triple extruded and the cable has a jacket of HDPE. The cables installed in Germany have to fulfil the long-term ageing test specified in this standard and the corresponding quality assurance tests since approximately 1991.

XLPE cables corresponding to the Standard HD 620, Section 5C, are installed in the German medium voltage system since more than 12 years. Both cable types, standard cables without any special additional measures in the screen area and cables with longitudinal water blocking systems are in use. The development in the supply shares of these two cable types over the years is shown in Fig. 1. It demonstrates that these two types form the majority of the cables installed today, each of them having a portion of about 50 %. The portion of XLPE cables with lateral watertightness is in the order of 4 % and, therefore, sufficiently small to be disregarded in this comparison.

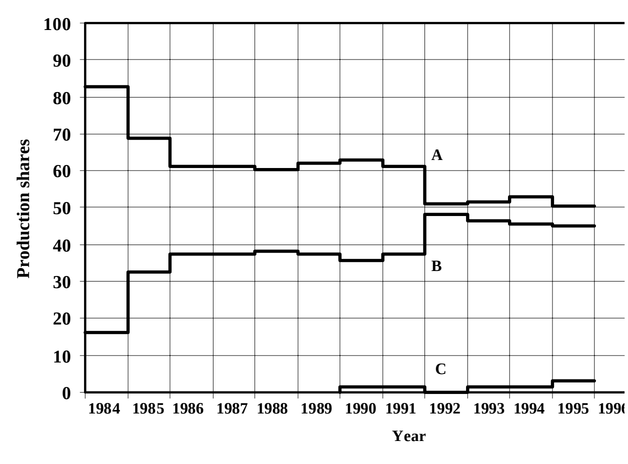

Fig. 1: Production shares of medium voltage XLPE cables in Germany
A: Standard cable
B: Cable with longitudinal water blocking
C: Cable with lateral and longitudinal water blocking

The German failure statistics [1] show that the service experience with this new cable type is extremely good. Nevertheless, there is an ongoing discussion among the experts, whether the existing construction guaranties an adequate service performance of the cables also in future, or whether a lateral water blocking system as usually used for high voltage cables is also necessary for the medium voltage range. In view of this discussion and in order to establish own decision criteria for their cables, the HEAG Versorgungs-AG decided in 1995 to take a representative portion of cables from the six major German manufacturers from service with the aim to establish their insulation properties at FGH in Mannheim after 10 years of service [2].

The cables installed at HEAG Versorgungs-AG have longitudinal water blocking systems and the question arose, whether a similar performance can be achieved by standard XLPE cables without any water blocking measures. Therefore, the two German power suppy companies EnBW EVS AG and RWE Energie AG decided in 1996 to carry out similar investigations on their standard cables [3]. This report summarizes the results obtained and the conclusions drawn from these.

2. Test procedures and cable samples

For the establishment of the residual strength of the cable insulation and the conclusions to be drawn for the service life of the cables, the FGH step test procedure [4] had proven successful for the PE/XLPE cables of the early construction for which service failures have been experieced. As this procedure was going to be standardized also for the long-term ageing test in the European Standards for the evaluation of the residual strength of the tested cables, it was considered as the major procedure to evaluate the residual strength of the service aged cables also. In addition, microscopic investigations of water-treeing in some of the cable samples and the determination of the humidity content were considered.

In order to obtain statistically significant results, 3 cable samples of 15 m length each were cut from the three parallel running phases of different cable connections. The cable connections were selected to equally contain the six major manufacturers in Germany and different humidity conditions of the soil reaching from dry soil to groundwater. All samples had no detected jacket damage. In total the following samples have been taken from service.

- HEAG Versorgungs-AG.
  20-kV-XLPE cable with longitudinal water blocking system.
  72 samples of 15 m length from 24 cable connections.

- EnBW EVS AG and RWE Energie AG.
  20-kV-XLPE standard cable
  123 samples of 15 m length
  from 41 cable connections.

The six manufacturers were about equally represented in the cable samples with exception of manufacterer F for which standard cables of the desired age were not used by one of the two utilities. All cable connections were installed in 1985 which means that the service age was 10 or 11 years at the time of the cable condition investigation.

After removal from service the cable samples were transported to FGH in Mannheim. The cable samples were prepared for the test by taking off the outer layer over a length corresponding to the water terminals used for the tests. At the beginning, water terminals with a length of about 1 m and a maximum breakdown voltage of 216 kV were used. Because of the high breakdown voltages observed, water terminals with a length of about 2,2 m were used lateron.

The residual dielectric strength of the cable samples was determined strictly according to the procedure recommended for service aged cables in [4]. Although after the first results low breakdown values were not expected, the long duration low voltage steps of 3 U_0 for 1 hour and 4 U_0 for 15 min were maintained for all cable samples, in order not to miss important information in case a low breakdown voltage would have been obtained. The further voltage increase by 1 U_0 over 5 min until breakdown is in accordance with the Standards. The tests have been stopped at 25 U_0 (300 kV) and a breakdown voltage of 26 U_0 has been assumed.

The use of the long water terminals required a length of nearly 3 m over which the outer layer of the cable insulation had to be removed. Therefore, a substantial part of the cable sample, i. e. 6 m out of 15 m, was placed inside the terminal. Consequently, a part of the breakdowns at voltage values above 20 U_0 occurred inside the terminals, mostly close to the earth electrode, where the voltage stress is practically equal to that of the cable. Such breakdowns above 20 U_0 have been counted as cable breakdown, therefore.

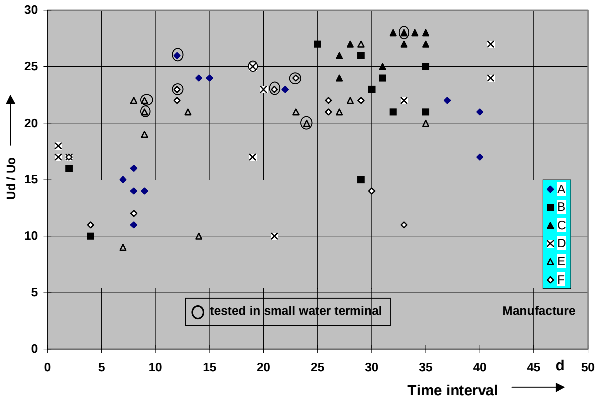

Fig. 2: Breakdown voltages in the power frequency voltage step test dependent on time interval between removal from service and test (U_0 = 12 kV).
Cables with longitudinal water blocking

3. Results

3.1 Residual strength

The first experience with the determination of the residual strength at the power frequency step test have been made in 1995 with the 20-kV-XLPE-cables from HEAG Versorgungs-AG. As the time between the removal of the cables from service and step test at FGH in Mannheim varied remarkably, one of the major concerns was a possible drying out effect of the cables. Furthermore, the step test started with water terminals with a maximum test voltage of 216 kV, because this value was considered sufficient for service aged cables at the beginning. Owing to the high breakdown voltages observed at these terminals all future tests were carried out with the larger 300 kV water terminals which, for same cable samples, prolongated the time interval between removal and test.

Fig. 2 shows the step test breakdown voltages dependent on the time between removal from service and test at the cables with longitudinal water blocking. The time intervals reach from one day to more than one month depending on the transportation and testing arrangement. In particular, the low breakdown voltages around 10 U_0 show no tendency to increase with time. Taking into account that some of the samples did not breakdown at the beginning due to the small water terminal used for the test, also no clear tendency of an average breakdown voltage increasing with time was evaluated. It was concluded, therefore, that the time interval between removal from service and test has a negligible influence on the result and this interval has been disregarded for the tests on the standard cables which followed the year later.

Fig. 3 shows the probability distribution of the breakdown voltages for the standard cables of EnBW EVS AG and RWE Energie AG. **Fig. 4** reports the corresponding dependency for the cables of HEAG Versorgungs-AG. For both diagrams, the distributions are plotted as Weibull dependencies. The most important parameters of these distributions are summarized in **Table 1**, in which the results obtained for the six manufacturers involved are added. The comparison of these results reveils:

Table 1 : Summary of samples and results from the power frequency voltage step test

	Standard cable			**Longitudinal water blocked cable**		
	Number of Samples	**Weibull parameters**		**Number of Samples**		
		Minimum U/U_0	**Nominal U/U_0**		**Minimum U/U_0**	**Nominal U/U_0**
Manufacturer						
A	21	11	24,0	12	11	21,3
B	24	11	18,9	12	10	22,7
C	27	9	24,8	12	16	27,4
D	24	10	20,0	12	10	21,5
E	15	14	22,6	12	9	23,0
F	12	12	18,8	11	11	20,9
Total	**123**	**9**	**21,7**	**71**	**9**	**22,7**

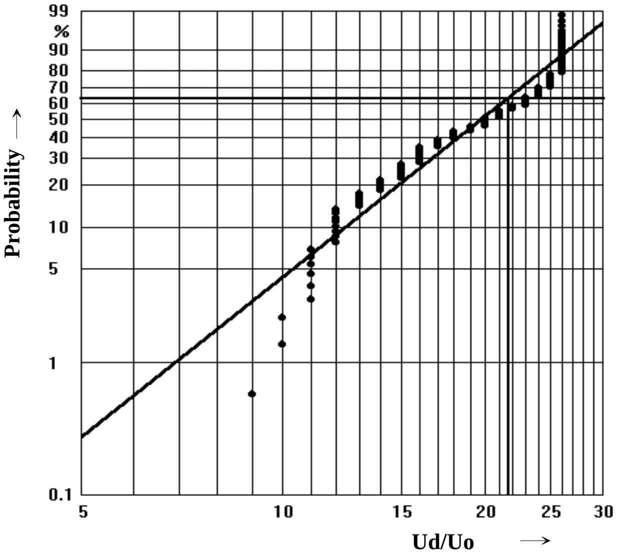

Fig. 3: Weibull probability distribution of breakdown voltages in the power frequency voltage step test (U_0 = 12 kV)
Standard cables

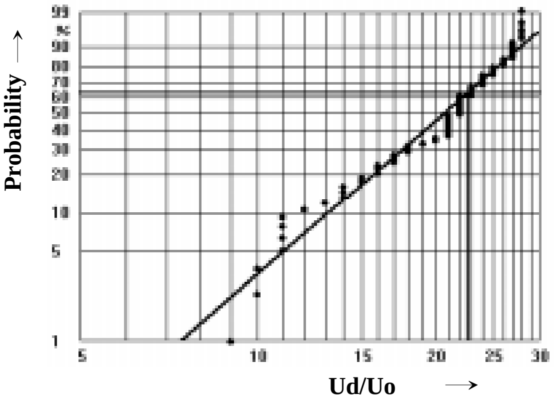

Fig. 4: Weibull probability distribution of breakdown voltages in the power frequency voltage step test (U_0 = 12 kV). Cables with longitudinal water blocking.

Table 2 : Summary of the water content in the materials of the cables with longitudinal water blocking system

Material	Water content in ppm weight Cable PE jacket, water blocking New	 Service aged	 PVC jacket Service aged
XLPE insulation	6	7 – 53	14
Inner semiconductive layer	464	539 – 1730	5952
Outer conductive layer	236	188 – 1775	2054
Soot band below copper screen	46082	22725 – 63261	235498
Jacket	580	388 – 3258	930

- No significant difference can be observed in the results from the standard cable and the cable with longitudinal water blocking system in the screen area. This applies to the nominal value of the Weibull distribution of the breakdown voltages as well as to the minimum breakdown voltage observed in the tests.

- The differences in the results obtained for cables from the six manufacturers involved are in the range of +/– 3 U_0 from the average value as regards the nominal value of the probability distribution. The minimum breakdown voltages vary between 9 U_0 and 12 U_0, if the results for both cable types are taken into account. Although slight differences between the results for the various manufacturers cannot be neglected, they may be affected by statistical variations. Furthermore, the obtained breakdown voltages are high and definite conclusions from these observed differences have not been drawn.

For comparison purposes 6 cable samples from two manufacturers produced in 1984 have been removed from the 20 kV system of HEAG Versorgungs-AG after 11 years of service. The cable had no water blocking system and a PVC jacket instead of the HDPE jacket of the other cables. The results for these cables are significanty lower than those for the cables mentioned above. The nominal value of Weibull probability distribution is 11,9 U_0 and the minimum breakdown voltage is 7 U_0.

3.2 Microscopy of water-treeing

The high breakdown voltages obtained in the power frequency step test led to the supposition that only small water trees will be present in the cable samples. Nevertheless, microscopical observation of possible water-treeing has been carried out, in particular at those cable samples which had breakdown voltages at the lower edge of the reported range. For this purpose a volume of 4 to 6 cm³ has been taken from the insulation of the sample around the point of breakdown. The lower limit of the water tree lengths reported is 0,1 mm.

Five samples from the standard cables and six samples from the cables with water blocking system have been investigated. The results were:

- Standard cables
  - Three of the five samples had no water trees.
  - The maximum water-tree length from the semiconductive layers was 0,7 mm with a density of 0,5 per cm³ insulation.
  - Bow-tie tries had lengths below 0,2 mm and were extremely rare.

- Cables with water blocking system
  - Four of the six samples had no water-trees.
  - The maximum water-tree length from the semiconductive layers was 0,4 mm with a density of 2,4 per cm³ insulation.
  - Bow-tie trees had lengths below 0,5 mm with a density of 5,4 per cm³ insulation, but were observed only in one sample.

As expected, the degradation of the insulation material by water-treeing was very small. Owing to the restricted number of investigated samples and the statistical dispersion of the results, no correllation between water-tree lengths and breakdown voltages has been established. It is evident, however, that the small water-trees discovered correspond well with the high breakdown voltage values.

3.3. Water content of the material

The content of water in the different cable materials has been determined using the Karl Fischer method. In total, 19 samples of service cables from the HEAG Versorgungs-AG and from six new cables have been investigated. In order to obtain some information on possible drying out effects, the water content of the jacket was checked at periods between removal from service and determination of water content reaching from 15 days to 50 days, showing no decrease.

The results obtained for the 25 samples are summarized in **Table 2**. They show that the water content in the material of the service aged cables is increased as compared to that of the new cables. They also demonstrate that the water

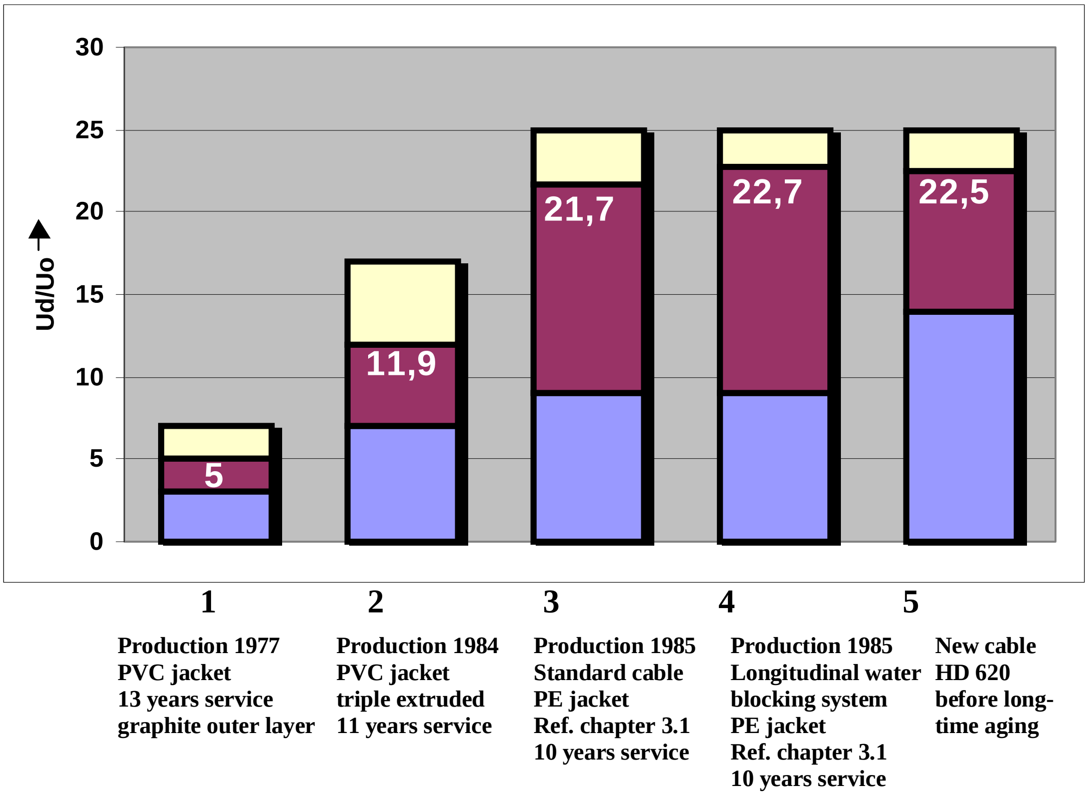

Fig. 5: Column diagram of breakdown voltages of cables ($U_0 = 12$ kV)
Maximum, minimum and nominal value of breakdown voltages in the power frequency voltage step test.

content in the cables with the PVC jacket is substantially higher than that for the cables with the PE jacket. This applies to the semiconductive layers and the soot band below the copper screen, but not to the insulation itself. The establishment of a correllation between the water content in the XLPE insulation with the breakdown voltage determined for the corresponding samples failed for both the cables with PE jacket and waterblocking system and for the cables with the PVC jacket. The water content, therefore, was not considered as a sensitive parameter for the cable quality and was disregarded in the second test series.

4. Conclusions

The conclusions drawn from the results obtained at the service aged cables are mainly based on the breakdown voltage values in the power frequency voltage step test. The improvement obtained in the ageing performance of 20 kV XLPE cables over the years is demonstrated by the column diagram in Fig. 5.

The left diagram is relevant for XLPE cables with PVC jacket used in Germany in the 1970ies. The diagram given belongs to a cable production for which unacceptably bad service experience was achieved. The results given here are based on internal investigations of HEAG Versorgungs-AG, but are supported by numerous measurements at this cable type.

The second left diagram belongs to a triple extruded cable with PVC jacket the results of which are given in chapter 3.1. The cables were produced in 1984 at a time at which the phenomenon of water-treeing and the accellerated insulation ageing associated with it became known to be relevant also for the cable constructions used in Germany. The improvement is already remarkable, but not considered as sufficient.

The three columns at the right belong to the medium voltage XLPE cables with the construction and the quality of the modern cable. The first columns in this group belongs to the standard cables of EnBW EVS AG and RWE Energie AG, the second to the cable with longitudinal water blocking system of HEAG Versorgungs-AG, as both are described in detail in chapter 3.1. Finally, the column at the right end reports the results obtained from the six manufacturers included at the beginning of the long-term ageing test according to the European Standard HD 620, Section 5C. These tests are carried out after a conditioning procedure at new cables before being subjected to the accellerated ageing in water.

The comparison of the service aged cables of the three power supply companies show residual dielectric strength values, which in their majority are in the range of new cables. This, in particular, applies to the nominal values of the Weibull probability distributions and demonstrates that the cables of both construction alternatives have not aged during the 10 years of service. The lower minimum breakdown voltages observed for the service aged cables as compared to the new cables seem to indicate an ageing effect at specific cable conditions. These differences, however, are more probably caused by the dispersion in production quality differences in the year 1985 at which the service cables were produced and the years 1991 to 1993 during which the long-term type testing was started.

The further comparison of the results from the service cables with the results obtained after the 2 years long-term type testing and, in particular, with those from the continuous quality control tests, demonstrates that the ageing observed in this accellerated ageing tests is much more pronounced as that in service [5]. As a consequence, the three power supply companies decided to maintain their decision made in 1985 for the cable type to be installed in their system also in future. This means that the EnBW EVS AG and the RWE Energie AG will continue to use standard XLPE cables in their system and the HEAG Versorgungs-AG will stay with the cable with the longitudinal water blocking.

All participating power supply companies are convinced that the reported excellent service performance of the cables will remain, as long as the cable quality remains at the high level reached today. The low degree of impurities in the insulation material, the selection of adequate materials for the semiconductive layers and the careful production of the cable will guarantee a suitable service performance of the cables also in future. All requirements are suitably checked by the long-term ageing type testing and, in particular, by the continuous quality control testing with the same procedure. The power supply companies, therefore, will continue to require this type and quality control testing for all cables to be applied in their systems.

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