Return to Session

SERVICE EXPERIENCES FOR MV CABLE NETWORK – OPTIMISTIC OR PESSIMISTIC STATE OF THE ART?

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ABSTRACT

The answer to the question put in the title of the paper depends on the quality of cable lines elements, the quality of installation works and the proper maintenance during service. The most important are service experiences. The analysis of service data is focused on MV cable lines.

KEYWORDS

MV cable lines, cable insulation quality, XLPE insulation, service experiences.

INTRODUCTION

The observed dynamic development of urban areas and the necessity of electrical energy supply to the objects located in the cities is the reason of the inseparable grid system development. Investors building new and modernizing the existing electrical lines face the dilemma: what kind of lines should be used: overhead or cable? More and more often the answer seems to be very clear because of the protest of people against installing high voltage overhead lines in the vicinity of their houses and gardens. Recently, the social aspect has gained the primary importance among factors influencing investment decisions. Therefore, in the next years one should expect much more rapid development of the cable systems of all levels of voltage.
Table 1 is based on information provided by [1] and presents the length of medium voltage networks in a number of European countries, as well as the percentage of underground cables in these networks. It can be seen that most of the countries have achieved to underground more than two thirds of their medium voltage networks, while the rest countries have achieved quite important percentages of cable lines.

Table 1. Situation of European MV networks [1]

Country	Km of network	Length of network [m/habitant]	Percentage underground [%]
Austria	57 000	7,0	15
Belgium	65 000	6,4	85
Denmark	55 000	10,5	59
France	574 000	9,5	32
Germany	475 000	5,8	60
Italy	331 000	5,7	35
Netherlands	101 900	8,9	100
Norway	92 000	20,5	31
Portugal	58 000	6,1	16
Spain	96 448	2,4	30
Sweden	98 700	12,3	53
UK	372 000	6,3	81

General data about network sizes in Poland, at the end of 2005, in respect to the network voltage are following [2]:

- 400 kV 4 831 km
- 220 kV 8 123 km
- 110 kV 32 310 km
- MV 233 855 km
- LV 486 994 km
- terminals LV 143 666 km

Overhead lines are used in the first two voltage levels only. The highest level of voltage in Poland for cable lines is 110 kV. It should be pointed out that Polish grid system exploits in some power plants four sections of 700-800 m length of cables at voltage of 220 kV with paper-oil insulation. Network of 110 kV lines are made as cable lines in a small percentage. The share of cables in the 110 kV network is small but since last few years it can be observed its dynamic increasing. The MV network also contains mainly overhead lines. Underground cables constitute only about 27% of the total MV network length.
Presently published data concerning the length of 110 kV cable lines refer unfortunately only to the lines exploited by public utility power industry. Up to now the data about the cable lines installed by industrial electrical network have not been collected as well as in case of grid systems operated by the rail and by industry. The Fig. 1 shows only the 110 kV cable lines length development operated by the distribution companies and National Grid Company. Underground lines are very often only short sections of cable lines operating in industrial plants. But cable lines are used more often in medium voltage systems [3].

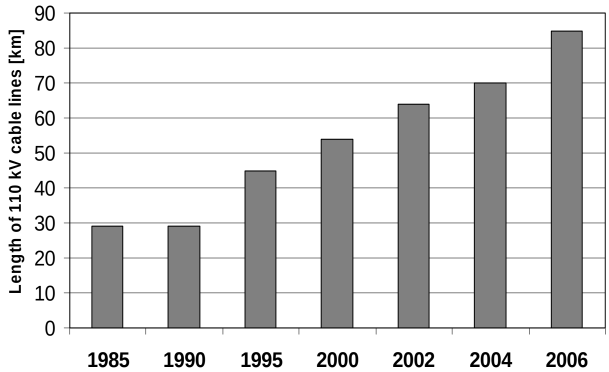


Figure 1: Length of 110 kV cable lines in PL network

Every year the percentage share of cables in electrical power network is increasing. This tendency is observed in medium voltage and high voltage systems. But the answer

Return to Session

to the question put in the title of the paper depends on the quality of cable lines elements, the quality of installation works and the proper maintenance during service. The most important part of cable line is the cable itself – in the cable the most important part is insulation. Therefore in the first part the results of insulation tests will be shown. The answer to the question from the title would be given only in the form of data analysis from the service of cable lines. The second part of the paper is devoted to service experiences. The analysis of service data is focused on MV cable lines because 110 kV cable network is still not long enough.
Presently, the decision to install underground cable, instead of building overhead lines is made more often not only on technical or economical grounds. The more environmentally public press is influencing decision-making processes leading to increased demand for underground cables.
The percentage of cable lines in the total length of MV network maintained by power distribution companies is between 10% and more than 90%, depending on the number and size of cities or towns in the area of operation. In Poland, the primary voltage in MV distribution system is 15 kV. The 20 kV voltage is used rarely. Small networks of 6 kV, 10 kV and 30 kV also exist in many cities and towns. Still the most popular are MV cables with impregnated paper insulation. Some of this cable lines have been in use without failure for more than seventy years. Although cable designs are slightly different, the service experiences are very positive. However materials used for cable construction are different - draining and non-draining impregnant, various types of paper, etc. Cable manufacturing technology is relatively complicated. Equipment used for installation is often of considerably physical size, and a skilled personnel is required. Public perception, of these cables is that they may create an ecological hazard with the possibility of impregnate leakage to underground waters when the cable's outer layer is ruptured . On figure 2 is presented one of the most often present of the defect for old design of mass-impregnated cables - cracks of the lead coat.

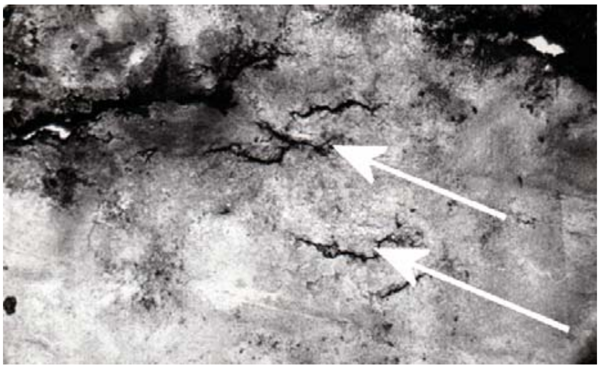


Figure 2: Cracks of the lead coat for the old design of paper insulated MV cable

Throughout the world MV cables with extruded insulation, mainly crosslinked polyethylene, are replacing cables with paper insulation. Also in Poland XLPE cables are becoming more popular, due to the easy of laying, maintenance and very good properties. The circuit length of XLPE cable is growing and it is used as standard cable for medium voltage and for 110 kV lines. It is world-wide unquestionable fact that crosslinked polyethylene is now the most widely use cable insulation.

IMPROVEMENTS OF XLPE QUALITY

Improvement of extruded cable insulation was announced by preliminary test, which results were presented in 1999 [4]. In that time tests were carried out on the two kinds of insulation from MV power cable. Continuation of that comparative tests show very optimistic results. Three kinds of crosslinked polyethylene samples were tested: the first (called XLPE-A) used by cable manufactures for the first MV cables with XLPE insulation, second one (called XLPE-B) used in 1998 and third one (called XLPE-C) which was in use in 2005.
Technological progress and quality improvement of XLPE cable insulation were carried out through the following tests: volume resistivity, dielectric loss factor, resistance to electrical treeing, resistance to water treeing and investigations based on IR spectrophotometry. Test was carried out on the XLPE plate samples.

Volume resistivity: The resistivity of dielectric materials is very important electrical parameter characterizing quality of insulation system. Measurements were performed using Keithley 6517 Electrometer. The resistivities shown on table 2 are the average values from 20 measurements for each kind of samples.

Table 2. Volume resistivity of polyethylene samples

Sample	Volume resistivity [$\Omega \cdot$cm] and standard deviation
XLPE-A	$(4{,}60 \pm 0{,}84) \times 10^{16}$
XLPE-B	$(2{,}20 \pm 0{,}37) \times 10^{17}$
XLPE-C	$(7{,}04 \pm 0{,}25)$ x 10^{17}

Results shows, that the new generation of polyethylene has much higher volume resistivity than polymers used in the first years of using XLPE cable insulation. It means, the present kind of crosslinked polyethylene has a much higher level of purity and much less ionic contaminations [5].

Dielectric loss factor: The value of power loss factor of XLPE cable insulation is generally low. In some researchers opinion water treeing influences on changes of tan δ. On another hand, there is no relationship between the dielectric loss factor and degradation of insulation by water treeing. Among the others, tan δ measurements may be useful for estimation of the overall water tree degradation. Presented on the table 3 results are mean values of 20 measurements.

Table 3. Mean value of dielectric loss factor

Polyethylene	Mean value of tan δ	Standard deviation
XLPE-A	0,00215	$0{,}192 \times 10^{-4}$
XLPE-B	0,00020	$0{,}045 \times 10^{-4}$
XLPE-C	0,00024	$0{,}037 \times 10^{-4}$

Direct comparison shows improvement of one order of magnitude for new samples comparing to older ones. It speaks very well of purity improvements and quality of technological process used in polyethylene manufacturing.

Resistance to electrical treeing: Time-to-breakdown values were determined by means of the needle test. Steel needles of the curvature radius equal to 10 μm were applied.

They were inserted to such a depth, so that the polyethylene insulation was 2 mm thick. Time-to-breakdown was measured using 50 Hz voltage equal 15 kV. The resistance to electrical treeing of tested samples was done by determining time-to-breakdown for a given series of samples on 20 measurements. The results are shown on the table 4.

Table 4. Time-to-breakdown results for XLPE samples

Weibull-distribution parameters	Insulating material		
	XLPE-A	XLPE-B	XLPE-C
63%-quantile η [min]	445	695	814
shape parameter β	3,42	11,40	14,7

Resistance to water treeing: The test set-up used in Poznan University is some modification of one suggested by CIGRE. After water treeing ageing each sample was examined using an optical microscope with 100× magnification. The counting of water trees in tested polyethylene was repeated 3 times for each sample. The number of water trees was measured in 20 slices which were cut (from the outer surface of insulation) in the samples by using a microtom (Table 5).

Table 5. Average number of vented water trees for XLPE samples aged in NaCl solution; electric stress 6 kV/mm

Time of ageing	Number of vented water trees		
[h]	XLPE-A	XLPE-B	XLPE-C
160	0	0	0
200	0	0	0
405	161	17	0
450	178	18	0
515	193	34	0

Investigations based on IR spectrophotometry: Investigations based on IR spectrophotometry have been carried out from many years for an XLPE cable and PE insulation aged in different conditions at The Poznan University of Technology. Several dozens of the IR spectrograms for the virgin cable insulation samples and for the samples aged in real field or laboratory conditions were analysed. The investigations of insulation conducted for a cable material (plate specimens and sections of real cable insulation), field-aged or aged in laboratory conditions under electric stress, high temperature, water, ultraviolet radiation, demonstrated that an endurance against the ageing process is far greater for crosslinked polyethylene XLPE-C than for a polyethylene XLPE-A. The analysis of all obtained IR spectrograms and comparison of spectrograms for both new and aged kinds of polyethylene samples have shown high resistance of insulation on all used types of ageing.

SERVICE EXPERIENCES

Data from service experiences will be shown on results from different utilities. How a first example of experience with MV network is shown services data from five utilities [6]. A near 12 000 km of MV cable lines length was taken account of in the statistics investigation. Figure 3 shows the percentage share of overhead and cable lines content in distribution network for analysed utilities, figure 4 share of failure rate. Shares of cable types installed in the analysed MV cable network are shown on table 6. Figure 5 presents share of MV cable network failure – for cables, accessories and due to mechanical damages for one exemplary year. Among failures of cables in the first place are damages of PE insulated cables – this kind of cables is only a small part of the analysed underground network (Fig.6).

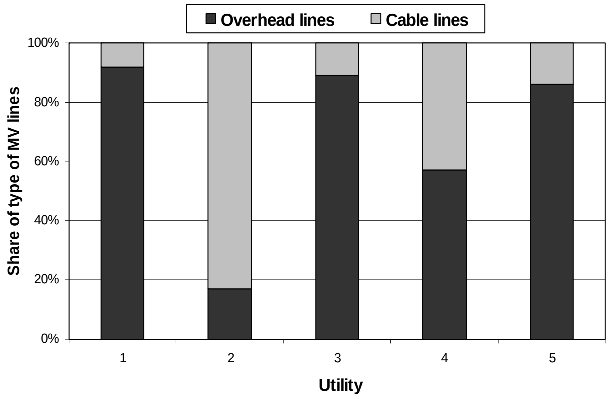


Figure 3: Types of MV lines for 5 exemplary utilities

Table 6. Share of type of cables in MV lines

Utility	Share of the types of cable [%]		
	PAP	PE	XLPE
1	57	29	14
2	90	3	7
3	76	15	9
4	59	12	29
5	69	19	12
Total	77	10	13

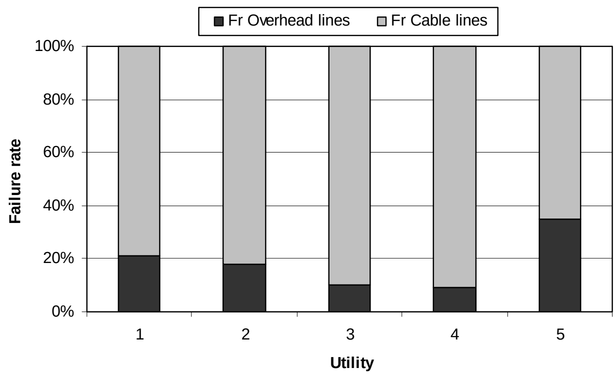


Figure 4: Percentage share of cable and overhead lines failure rates

Analysed network contained (at the end of 2000) 77% of cable lines with paper-impregnated insulation, 12% with XLPE insulation and only 11% with PE insulation.
Utility companies and cable manufactures have become interested in results of cable service analysis. Among failures of cables, on the first place are damages of PE insulated cables – in spite, this kind of cables is only small part of the analysed underground network 10% – table 6 and figure 6.

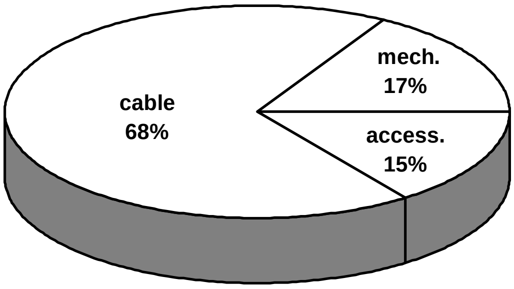


Figure 5: Failures in analysed network: failure of cables, accessories and mechanical damages

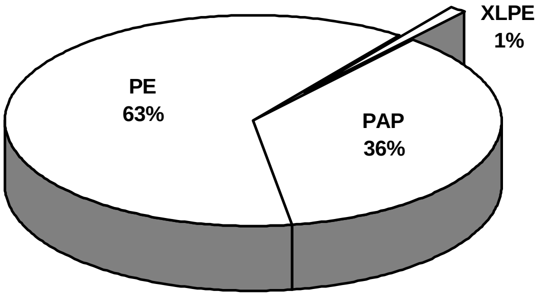
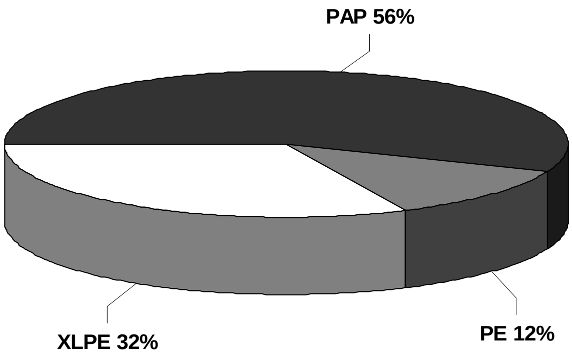


Figure 6: Cables failures in respect to types of cable insulation for 5 Utilities

It was found that, the service data from another distribution companies only slight different. On figures 7 – 11 results for exemplary Utility A, Utility B and Utility C are shown. In this case – the latest results are for year 2004 or 2005.



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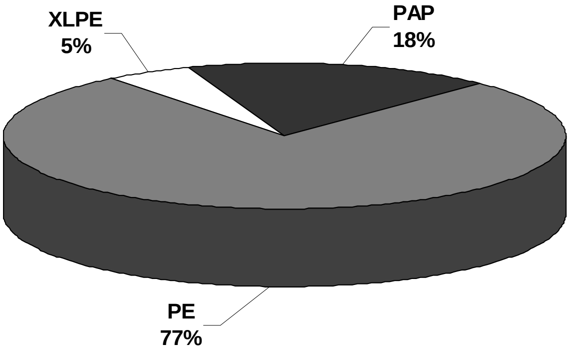
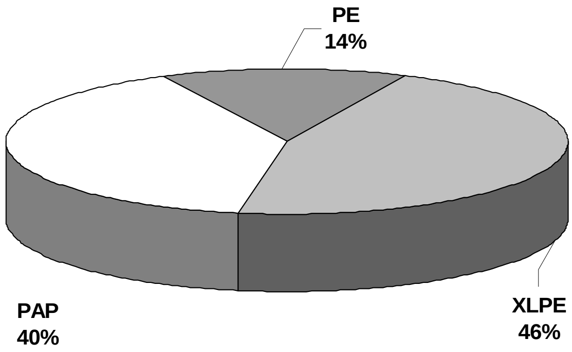


b)

Figure 7: Shares of cable: a) type installed in Utility A; b) cables failures in respect to types of insulation



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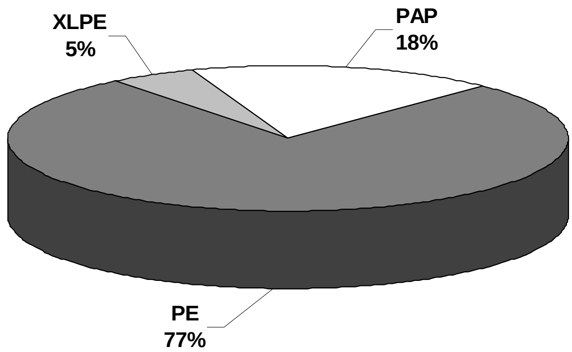

b)

Figure 8: Shares of cable: a) type installed in Utility B; b) cables failures in respect to types of insulation

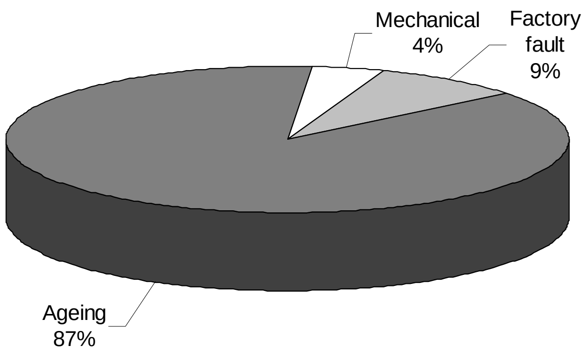

Figure 9: Reasons of failures of PE cable in Utility B

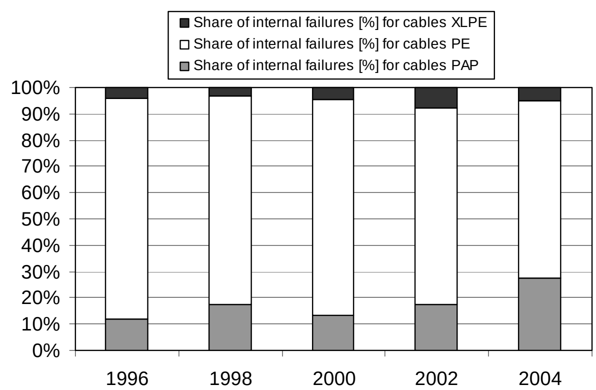

Figure 10: Share of internal failures of MV cable in Utility B

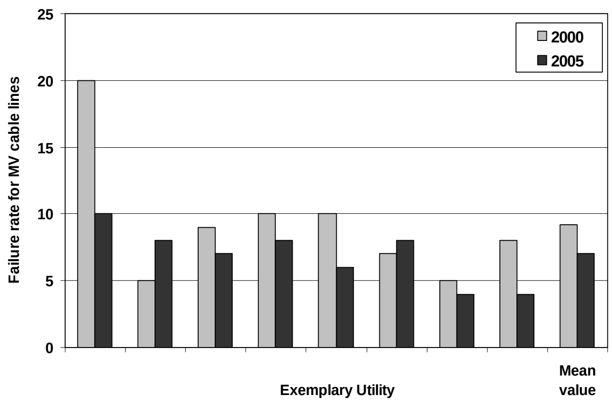

Figure 11: Cable lines failures rate for Utility C

Failure of the cables – itself are the main reasons of service problems with cable lines. The second element is cable accessories. It is difficult to compare experiences from differ utilities because on the marked is so many commercial available types of accessories. Figure 12 shows exemplary data from one of distribution company. Type 4 it is old design of outdoor termination for cables with impregnated paper insulation. The number of that type of termination installed in network is rapidly decreasing therefore in short time it will be not source for service problems.

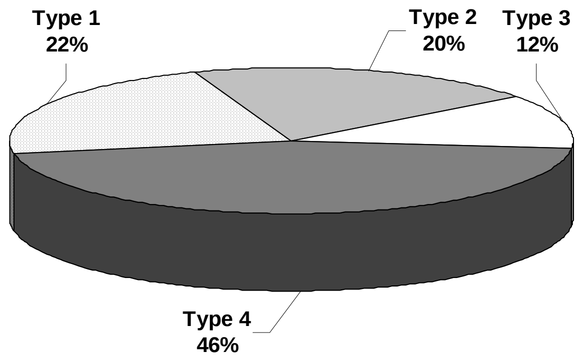

Figure 12: Share of failures of different type of cable terminations for Utility C in exemplary year

In each case – service experiences from each, different distribution companies – lead to conclusion that relatively high (in some network during particular year) failure rate still come form presence of the first generation of PE insulated cable.

It has to be repeated, that obtained the relatively high failure rate of MV cables is definitely still the result of very low reliability of the first generation of cables with PE insulation. Mainly affected are those „progressive” distribution companies who in the past eagerly introduced new technologies. Today they still operate the longest networks made of PE insulated cables. Due to very low reliability of PE insulated cables some of distribution companies have service problems with MV cable network. Especially low reliability is demonstrated by cables with graphite paint on the outer surface of cable insulation and with screens on PE insulation in the form of semiconductor tape. These types of cables were manufactured when PE insulation was first introduced on the Polish market. The change of design of MV power cables with extruded insulation was in that year when we had to started to use XLPE instead PE insulation. On the figure 13 it is shown the place of failure of 15 kV power cable with PE insulation; design with tape screen on insulation.

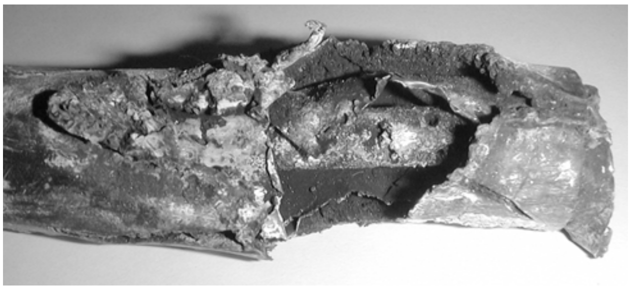

Figure 13: The effect of failure the first generation of 15 kV PE cables

The service data confirmed a very good quality of XLPE cables. In addition, it should be noticed that the first XLPE cable lines were installed in the beginning of the 70's.

The service data confirmed that quality of XLPE cables is very well. In addition, we have to notice, that the first XLPE cable lines were installed in the beginning of seventies.

But for each cases of analysed data – the level of failure rate for cable lines year after year is smaller and smaller – figure 14. The result of that analysis of service data was done for near full distribution network in our country. We can surely say that from this picture is another optimistic answer to the question put in the title of the paper.

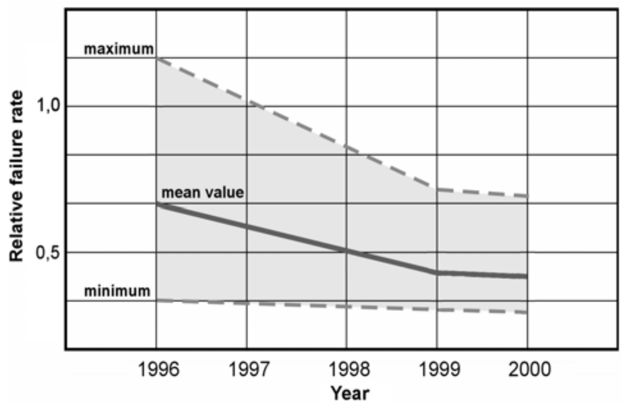

Figure 14: Improvement of condition of MV cable network - decrease of failure rate

Return to Session

CONCLUSIONS

Crosslinked polyethylene has gained world-wide acceptance and is replacing thermoplastic polyethylene and impregnated paper as MV cable insulation. This tendency is also observed in Poland. Comparable to the best world standards [7], power cable manufacturing methods used in Poland and improvements in cable installation works and procedures have had a very positive effect on reliability of cables in electrical networks. Every year their failure rates are decreasing. Therefore we can surely say that from statistics data analysis is only optimistic answer to the question put in the title of the paper.

In the past some distribution companies clearly prefer installing MV cables with paper insulation impregnated with non- draining compound. But the most companies however, in line with the world tendency, are widely introducing cables with XLPE insulation as a replacement of damaged cables and in new installations. In present time for all distribution network – power cables with XLPE insulation are only one solution.

Another very optimistic conclusion is from very high quality of XLPE insulation. Improvement of quality of XLPE cable insulation is shown from the results of measurements some properties of XLPE insulation, which have been used by cable manufacturer near thirty years ago and present. Statistical data from the service experience of Polish distribution companies confirm conclusion about high quality of XLPE insulation widely use from last years by cable manufactures.

Still observed relatively very low reliability of PE insulated cables is forcing electricity companies to replace them as quick as possible depending on economical aspects. Very often one cable failure is initiating a number of consequent failures. Therefore, cable reparation is not the solution and replacement of the entire cable is required. In the nearest years this problem will gradually decay.

General conclusions from data analysis and results from research tests for MV cable networks are very optimistic. Especially if we will remember of so significant installations of HV and EHV XLPE cable systems [8, 9].

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