INVESTIGATION TOWARDS THE UPGRADING OF EXISTING 10KV CABLES AND ACCESSORIES TO AN OPERATING VOLTAGE OF 20 KV

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ABSTRACT

In this paper a survey will be given of the investigation to decide in a well considered way on the upgrading of existing 6/10 kV cables and accessories to an operating voltage of 20 kV.
The investigation consists of: a theoretical study, experimental testing and a decision procedure.
The theoretical study has the purpose to evaluate all relevant aspects related to the upgrade, for instance the ageing mechanisms at increased voltage and the corresponding lifetime reduction.
The next step is the experimental testing. The experimental testing consists of laboratory and field testing. The final decision procedure is to decide between three options: the upgrade is considered to be feasible, not feasible or partly feasible (10 kV cable + 20 kV accessories).

INTRODUCTION

Liander, a major utility in the Netherlands wants to investigate the feasibility of upgrading of 10 kV XLPE cable and accessories to 20 kV. The main reasons for Liander to investigate this upgrading are standardization and capacity increase. In [1] and [2] comparable international studies are mentioned. The major reasons for upgrading are more or less similar: increase of capacity [1] and postponement of investments [2].
As at present several voltages are being applied in the distribution network, the decision has been taken to focus for the future on one voltage only, viz. 20 kV.
New components will be 20 kV class, but the existing 10 kV cables and related accessories will be operating at 20 kV, to reduce costs and to limit public inconvenience. Next to the need for standardization, Liander is also interested to know where the limits are when components are being operated above the value for which they have been designed and to learn about the risks of the upgrading.
Will the failure rate increase for both cable and accessory in the same way or will the accessory appear to be more vulnerable than the cable? Liander asked the cooperation of KEMA, the University of Delft and Prysmian to perform this project successfully.

INVESTIGATION PROGRAM

The program to investigate the feasibility of upgrading consists of three steps:
- Theoretical study;
- Experimental testing (Type test and Long term test);
- Decision model.

In the theoretical study all the aspects related to electrical ageing will be considered. Will the electrical ageing increase, when the voltage will be increased to 20 kV? Will it be possible to describe the ageing in a simple formula?
The second step is about testing. At first a type test will be performed on 10 kV cable with both 10 and 20 kV accessories on 20 kV conditions. The 20 kV accessories are included in the type test for the situation that at the very end the 10 kV accessories appear to be a stumbling block.
In that case 20 kV accessories will be used and it is useful to know the compatibility with 10 kV cable. If this test will be unsuccessful, upgrading is not an option.
The successful type test will be followed by the long term test, of which the conditions are derived from the theoretical study. Finally, the decision model will tell us on base of the test results what the options will be.

THEORETICAL STUDY

To understand the effect of doubling the voltage, this study aims to identify the critical ageing mechanisms and the resulting voltage- lifetime (V-t) characteristics, to decide the voltage and duration of long term test.

Ageing mechanisms

Ageing of polyethylene cable insulation is caused by thermal, electrical, environmental and mechanical stresses. These stresses interact with local defects like contaminants, protrusions or cavities to produce local degradation and propagate through insulation gradually, as shown in Figure 1 from [3]. The cable existing in the Liander network is a 6/10kV single core 630mm^2 XLPE insulated cable with longitudinal watertight and radial semi-watertight protection. In its insulation, the thermally activated and electrical accelerated charge motion [4], namely electroluminescence, is the main degradation mechanism. Existence of contaminants and protrusions add to this problem, because they enhance local electric field strength. This problem develops to local insulation degradation at first and electrical treeing later, which will finally lead to breakdown [3]. Partial discharges (PD) occurring in voids can easily develop into electrical treeing and breakdown. But PD degradation has been efficiently prevented in cable produced since 1990s.
Presently, most PD are located in accessories, since voids can still be created in interfaces by mechanical forces resulted from thermal cycles.

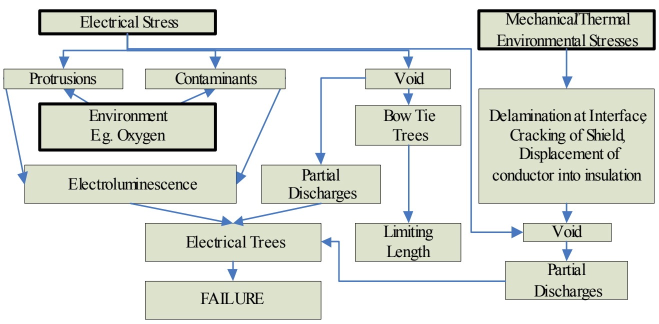

Figure 1: Ageing mechanisms in dry condition [3].

V-t model for XLPE cable

The relation V-t is demonstrated with the solid line in Figure 2.
Region 1 and 2 show the V-t relationship when relatively high voltage is applied and short lifetimes (typically <100 hrs) are observed. Ageing in these regions is caused by thermal & electrical degradation mentioned above. Region 1 is typical for extra high electric stress and large voids (0,1 mm).
In practice, life prediction cannot depend only on the time-to-failure data obtained in less than 10 hours in Region 1. Otherwise, the prediction will be overoptimistic, as the “Prediction 1” shows. Region 3 shows “threshold effect” of XLPE insulation, below which stress value electrical ageing ceases. The value of threshold electric stress for XLPE is theoretically calculated as 5 to 8 kV/mm for 90 °C and even higher for lower conductor temperature in dry condition, but much lower in water [4].
In contrast, the maximum electrical field in the investigated 6/10kV cable is 4 kV/mm when 12/20kV voltage is applied. Thus doubling of the operating voltage is theoretically possible.

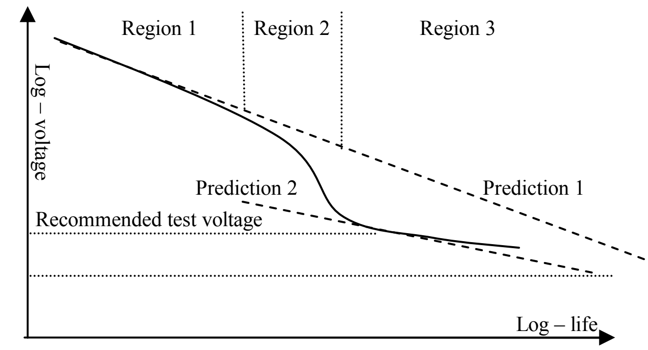

Figure 2: Demonstration of voltage vs. lifetime model and life prediction methods of polyethylene

Test voltage and duration

Based on the V-t model stated above, the inverse power law was selected $L = KV^{-n}$ as the life prediction method, but limit the ageing stress below 8 kV/mm to take the threshold effect into consideration. Consequently, the prediction line is expected to locate to the left of the real V-t curve, as the “Prediction 2” in Figure 2 shows.
This means the predicted lifetime will be a pessimistic prediction. The slope of the prediction line, namely the exponent n in the inverse power law, should be properly decided. Normally larger n value means higher insulation quality.
Many manufacturers report n values to be over 20 for XLPE cables with size-controlled voids [5]. However, doubt about quality control level on our cable drives us to refer to work from Hitachi Cable [6] to learn effect of different types of man made defects in a 6mm cable.
This convinces us that selection of n=9 in long term test include the effect of all known defects.

TYPE TESTING

The type test was performed on a cable YMeKrvaslqwd 6/10 kV 1x630 mm² Alrm with 6/10 kV in a 50 m test loop "cable" and 12/20 kV joints in a test installation "Cable + joints". The test objects were constructed out of pieces of 5 m cable with one joint and two terminations each. The electrical test program is further specified in Table 1.

Table 1: The electrical test program

TEST	HD620 S1:1996 /A3:2007, PART 5 SECTION J	TEST DETAILS	TEST LOOP 'CABLE'	TEST LOOP 'CABLE + JOINT'
Routine test on cable only				
Bending test	Ref 3.2 no 3.1	bending core: 1500 mm	✓	N/A
Voltage Test	Ref 3.1 no 3	30kV/15min	✓	✓
PD test	Ref 3.1 no 4	10kV, < 2pC	✓	✓
Dimensional check cable core	Ref 3.1 no 2.1	-	✓	✓
	Assembly test loops			
Tests @ 10kV level				
Voltage Test	Ref 3.1 no 3	30kV/15min	✓	✓
PD test	Ref 3.1 no 4	10kV, < 2pC	✓	
Heat cycle test	Ref 3.3 no 4	Tan d @ 10kV, cold/hot/cold	N/A	✓
Impulse test	Ref 3.3 no 5	75kV, 10+/-, hot	N/A	✓
Tests @ 20kV level				
Voltage test	Ref 3.1 no 3	50kV/15min	✓	✓
PD test	Ref 3.1 no 4	@ 20kV, < 2pC	✓	✓
Heat cycle test	Ref 3.3 no 4	Tan d @ 20kV, cold/hot/cold	N/A	✓
PD test	Ref 3.1 no 4	@ 20kV, < 2pC	N/A	✓
Impulse test	Ref 3.3 no 5	90kV[1], 10+/10-, hot	N/A	✓
High voltage test	Ref 3.3 no 6	50 kV/15 min	N/A	✓
PD test	Ref 3.1 no 4	@ 20kV, < 2pC	N/A	✓
Long term stability test	Ref 3.3 no 8	30 kV/ 1000 h, 30 heat cycles, 80°C conductor temp max[2].	✓	✓
PD test	Ref 3.1 no 4	@ 20kV, < 2pC	✓	✓
Long term stability test	Ref 3.3 no 8	30 kV/ 1000 h, 30 heat cycles, 95°C conductor temp max.	✓	✓
PD test	Ref 3.1 no 4	@ 20kV, < 2pC	✓	✓

[1] impulse test level was lowered to 90kV instead of 125kV due to terminations flashovers
[2] as thermo-mechanical failures in the test loop 'cable' caused failures, it was decided to run this test at 80°C conductor temperature first.

Before the 20 kV tests were performed first voltage and PD tests at 10 kV were performed. Results of the test objects "Cable + joints": all joints passed the tests at 10 kV level, a number of joints broke down during the high voltage test, after long term stability test at 80°C conductor temperature, and objects broke down during the long term stability test at 95 °C conductor temperature.
Several test objects, with joints from the same, passed the complete test program.
The test loop "Cable"' was performed twice: the first test loop broke down twice as a consequence of the test loop layout. These failures are not related to the increased test voltages and it was decided to redo the electrical test on a second test loop 'Cable 2'. This second test loop was in strict accordance with HD620, with only one 270° bend. This second test loop 'Cable 2' was tested successfully according to the test program as given in Table 1.

LONG TERM TESTING

The purpose of the long term testing is to prove that 10 kV cable and accessories, being operated at 10 kV during a certain time, can be reliably operated at 20 kV. Therefore during several months the cable and accessories will be stressed by over voltage and heating cycles to demonstrate that the remaining life will be about 50 years. The long term test will be performed on two cable types (each 50 mtr length) and two types of accessories. The voltage can be chosen from the table below, assuming a value of n= 9 taken from the theoretical study. The duration of several months is important to allow all kind of ageing processes to be active. After some considerations for the duration of the test a period of 5 months is taken, resulting in 1.7Uo as given in Table 2.

Table 2: Life under different n value

Electrical stress	n=7	n=9	n=12	n=15
3Uo	200 hours	24 hours	50 minutes	2 minutes
2.5Uo	30 days	4.5 days	7.3 hours	28 minutes
2Uo	4-5 months	**1 month**	4.5 days	13.3 hours
1.8Uo	10 months	**3 months**	15 days	2.7 days
1.7Uo	14-15 months	**5 months**	1 month	6.4 days
Uo	50 years	50 years	50 years	50 years

The test procedure is as follows:

- After installation in the field, PD testing will take place at 1.7Uo;
- During the test at 1.7 Uo during 5 months the temperature will be varying daily up to 95 °C;
- When the long term test is completed PD testing will take place again.

No failure may happen during the test, however, if one of the accessories will fail during testing the test may be continued with the remaining components.

DECISION MODEL

After having completed tests a decision can be made about the feasibility of upgrading:

1 The cable does not pass the type test, the upgrading is not feasible;
2 Only the cable passes the type test, the 10 kV accessories will be excluded from upgrading and the long term test will be performed on 10 kV cable+20 kV accessories;
3 Cable and accessories satisfy the type test requirements, the long term test will be performed on cable + 10 kV accessories;
4 Cable does not pass the long term test, the upgrading is not feasible;
5 Only the cable passes the long term test, the upgrading is feasible for 10kV cable+ 20 kV accessories;
6 Cable and accessories pass the long term test; the upgrading is feasible for 10kV cable + accessories.

CONCLUSIONS

In this paper an investigation is described consisting of the following parts:

- Theoretical study;
- Laboratory testing;
- Field testing.

So far the first two parts of the program have been completed. The overall conclusion of the electrical laboratory testing is that 6/10 kV XLPE insulated cable and selected accessories can sustain 12/20 kV test requirements successfully, resulting in the decision to prepare the long term test.

This long term test will take 5 months with the purpose to check the susceptibility of cable and accessories against all kind of ageing processes specified in the program. If the long term test will be completed the decision model will tell us about the feasibility of upgrading. Depending on the test results the following options can be distinguished:

- The cable does not pass the test: upgrading not feasible
- The cable and the 10 kV accessories pass the test: upgrading is feasible
- The cable and only the 20 kV accessories pass the test: upgrading is feasible using 20 kV accessories.

REFERENCES

[1] T.Noske, M.Plass, F.Schreiter and U.Jilek, 'Nachnutzung von 10kV-VPE-Kabelanlagen im 20-kV-Netz, ETZ,heft 6/2006

[2] Y.lLiu, X.cao, Y.Xu, J.Liu, Z.Zhang and Y. Fei, "Insulation state analysis and upgrading feasibility study of existing AC 10kV XLPE distribution cables in Jiangsu Grid of China", CIGRE B1_112_2010

[3] J. Densley, "Ageing and diagnostics in extruded insulations for power cables," in Conduction and Breakdown in Solid Dielectrics, 1995. ICSD'95., Proceedings of the 1995 IEEE 5th International Conference on, 1995, pp. 1-15.

[4] J. L. Parpal, J. P. Crine, and D. Chinh, "Electrical ageing of extruded dielectric cables. A physical model,", Dielectrics and Electrical Insulation, IEEE Transactions on, vol. 4, pp. 197-209, 1997.

[5] Y. Shirasaka, H. Murase, S. Okabe, and H. Okubo, "Cross-sectional Comparison of Insulation Degradation Mechanisms and Lifetime Evaluation of Power Transmission Equipment," Dielectrics and Electrical Insulation, IEEE Transactions on, vol. 16, pp. 560-573, 2009.

[6] G. Katsuta, A. Toya, S. Katakai, M. Kanaoka, and Y. Sekii, "Influence of defects on insulating properties of XLPE cable," in Properties and Applications of Dielectric Materials, 1991., Proceedings of the 3rd International Conference on, 1991, pp. 485-489 vol.1.