DETERMINATION OF THE BREAKDOWN VOLTAGE OF PE/PVC MATERIALS FOR APPLICATION FOR THE HIGH-VOLTAGE CABLE SHEATH

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Abstract: Currently, the outer cable sheaths are dimensioned for mechanical protection. Usually, the breakdown strength in case of high voltages is unknown. For better information basis and for the configuration of effective voltage protection, it is necessary to know the breakdown strength for nominal and transients stresses. For several sheath materials, breakdown voltage U_d and the inception field strength E_i test are carried for nominal (50 Hz) and for switching and lightning impulse voltage. For determination of breakdown voltage U_d of outer cable sheaths a direct test and an indirect test procedure can be use. The direct test is performed at the cable probe. For indirect test, cable sheath probes would be tested. The test configuration and the procedure for dielectric withstand tests are introduced. In this paper, the results of the dielectric withstand tests are presented.

1 INTRODUCTION

Currently, long cable segments are used more and more. For example, the connection of off-shore wind parks and implementation of new transmission and distributions systems are nowadays no more feasible without using cables. The normal current and voltage of main isolation are determined by international standards. Transients in cable systems, e.g. switching, fault and lightning, lead usually to high-voltage over mechanical protection (and as result over the outer sheath) because of inductive and capacitive coupling between conductor and shield. Especially, cross-bonding of long cable sections can cause at cross-bonding point high voltages, which exceeds the voltage withstand of cable sheath (see Figure 1 CP 1).

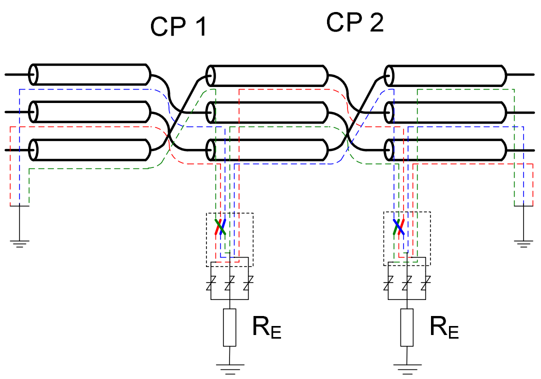

Figure 1: Sectioning of 380 kV-cable system

Because of having a too high earth resistance R_E, it is possible that sheath-voltage limiters are not effective in this situation. Representative shield - to earth voltages are shown in Figure 2.

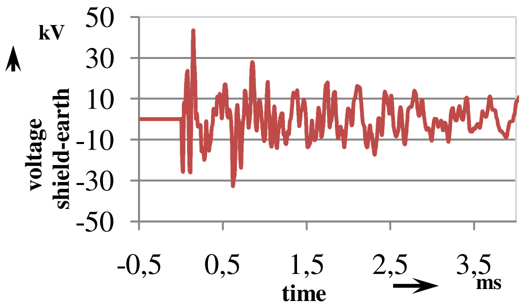

Figure 2: Calculated shield-earth voltage at cross-bonding point (CP1) after switching a 380 kV-cable

Since cable sheaths are only designed as a mechanical protection, insulation coordination is not possible. The breakdown withstand of cable sheath is usually not available. The breakdown of a 110 kV-cable is shown in Figure 3.

Figure 3: Cable sheath damage after breakdown at a 110 kV-cable

2 DETERMINATION OF THE BREAKDOWN VOLTAGE FOR CABLE SHEATHS

The breakdown voltage U_d and inception field strength E_i (referred sometimes also as breakdown field strength E_d) of cable sheaths can be identified directly or indirectly using a cable sheath probe.

The indirect way to determine the breakdown voltage $U_{d(p)}$ and the inception field strength E_i of cable sheath is possible at a slightly inhomogeneous field. Figure 4 shows the selected test configuration ($r_{el} = 25\ mm$) to obtain the breakdown voltage $U_{d(P)}$.

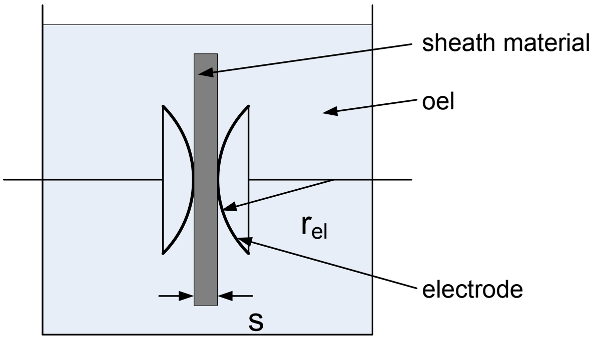

Figure 4: Test configuration for the indirect determination of breakdown voltage $U_{d(p)}$

Using the measured breakdown voltage $U_{d(p)}$ and the thickness of the probe isolation material (the distance between electrodes) s, the inception field strength E_i of the isolation material probe can be calculated.

By having this calculated inception field strength E_i and knowing the geometry of cable (see Figure 5), the cable sheath breakdown voltage $U_{d(M)}$ can be determined with relation (1):

$$E_i \times r_i \times ln\frac{r_a}{r_i} = U_{d(M)} \qquad (1)$$

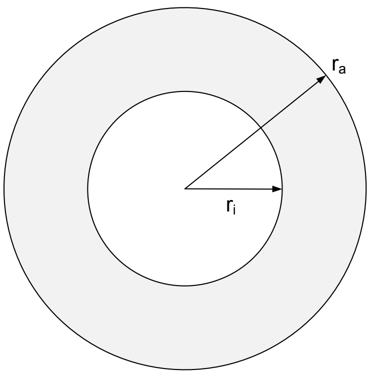

Figure 5: Cylindrical configuration for describing the inception field strength E_i

The determination of cable sheath breakdown voltage $U_{d(M)}$ is also possible by performing the breakdown test at a real cable probe. For this purpose, the cable is firstly swathed by a metal foil as the high-voltage electrode. The shield is connected to the earth potential. The conductor is also earthed by connecting to shield. The test configuration is shown in Figure 6.

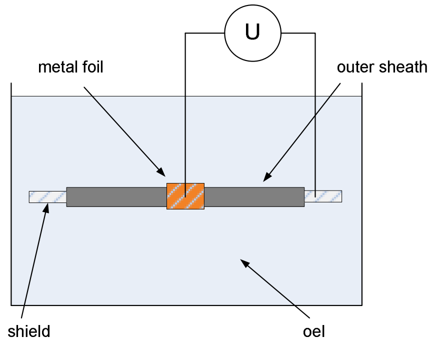

Figure 6: Test configuration for direct determination of the breakdown voltage $U_{d(M)}$

In order to evade a flashover during the test, the insulation material probe is completely placed in the insulation oil.

3 CONTENT OF INVESTIGATION

The inception field strength E_i is determined for cable sheath materials with different compounds. The cable sheath probes are taken from new medium- und low-voltage cable. In the case of applying the same material compounds, the results can also be used for high-voltage cable by measuring the geometry and the thickness of insulation s. In Figure 7, the cable sheath probes prepared for the indirect test are depicted.

Figure 7: Cable sheath probes prepared for the indirect determination of breakdown voltage U_d

The technical data of investigated probes are given in Table 1. The insulation thickness tolerance can be ± 0.2 mm, and it is considered no more subsequently.

Table 1: The technical data of investigated probes

probe	cable type	U_r kV	sheath type	s mm	r_i mm	r_a mm
A	NA2XS(FL)2Y	12/20	PE	2.8	16.4	19.2
B	2XS(F)2Y	12/20	PE	2.8	13.8	16.6
C	NAYY	1	PVC	2.,5	16.3	18.8

Exposing cables in UV radiation (sunlight) can lead to an accelerated aging. This process can be declined through a proper stabilizer. For example, carbon black can be an effective stabilizer. It is applied especially at PVC and PE in small quantities (2 % to 3 %). In PVC sheath of the low voltage cable C, softener and chalk are used in larger quantities beside Polyvinyl chloride (PVC).

The compounds of the investigated cable sheath present properly the typical available cables on the market. In order to compare, the breakdown voltage U_d is determined for PE and PVC insulation material probes without ingredients as well.

The inception field strength E_i depends considerably on the voltage shape. In order to achieve the same behaviour as those in the power system transients, the following over voltages U_{rp} [1] are applied: 50 Hz-AC, slow front overvoltage (250/2500 µs) and fast front overvoltage (1.2/50 µs). Subsequently, the former is referred as switching impulse, whereas, the latter is referred as lightning impulse.

In order to derive the inception field strength E_i for other cable sheath thicknesses, the breakdown test is carried out for PE and PVC probes with various insulation thicknesses s (1, 2, and 3 mm). The PE and PVC materials are used as the base material for manufacturing cable sheaths.

By knowing the dependence of insulation thickness s on the inception field strength E_i, the breakdown voltage can be determined for various cable mantel thicknesses. Figure 8 shows the approximate dependence of insulation thickness s (i.e. electrode distance) on the inception field strength E_i.

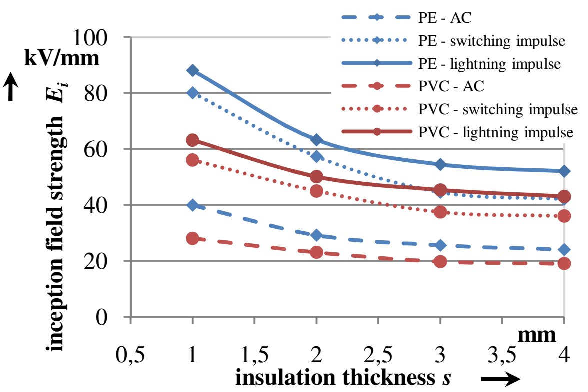

Figure 8: Measured the inception field strength E_i of PE and PVC for different voltage shapes versus the insulation thickness s

For the thicknesses greater than 3 mm, the inception field strength E_i changes slightly and converges to a constant value. In case of the insulation thicknesses smaller than 3 mm, the breakdown voltage U_d is rather higher. This effect is known as thin layer effect and explains the relative high the inception field strength E_i by small insulation material thicknesses s. The reason of the non-linear dependence is an aggravated charge carrier multiplication for very short electrode distances.

4 RESULTS OF BREAKDOWN TEST

4.1 Indirect test

The determination of the breakdown voltage $U_{d(P)}$ is performed several times (5 times per voltage shape) for each cable sheath type. Performing the test in a larger scale was not possible because of the difficulties by providing the insulation probe, and it was also not necessary due to have a slight deviation in the results. The result shown in Table 2 are the 50 %-quantiles of the normal distributed breakdown voltage $U_{d(P)}$.

Table 2: Breakdown voltage $U_{d(P)}$ of cable sheath probes

probe		*cable A*	*cable B*	*cable C*
50 Hz-AC	kV	41	39	38
switching impulse (SI)	kV	103	117	79
lightning impulse (LI)	kV	114	129	91

Using the measured breakdown voltages and the insulation thickness s, the inception field strength E_i of cable can be calculated. In Table 3, the inception field strength E_i of PE and PVC base materials for different insulation thicknesses are presented.

Table 3: The inception field strength E_i of cable sheath probes

	cable A	*cable A*	*PE*	*cable C*	*PVC*
	s = 2.8 mm	*s = 2.8 mm*	*s = 2.8 mm*	*s = 2.5 mm*	*s = 2.5 mm*
AC	16	15	26	16	21
SI	40	46	46	34	40
LI	44	51	56	39	47

The results for cable sheath probes are also shown illustratively in Figure 9.

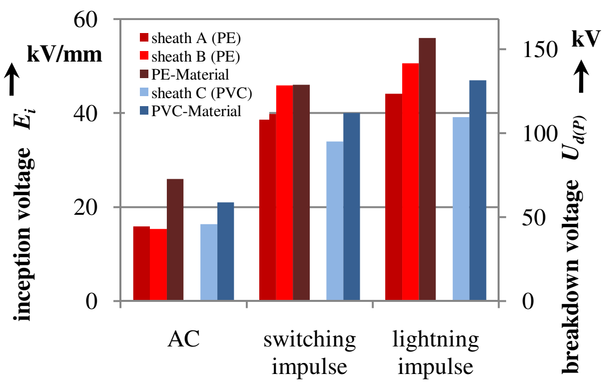

Figure 9: Comparison of the inception field strength E_i (the indirect test)

One can observe from Figure 9 that the inception field strength E_i of cable sheath materials are partially lower than those from the PE and PVC base materials. For 50 Hz-AC test, this difference is about 50 %.

The higher difference between the inception field strength E_i of cable sheath A, B, and base materials in AC test in comparison with impulse tests can be explained by time dependence of the breakdown process. The higher conductance of cable sheath because of containing carbon black results in decrease of the breakdown voltage in the case of 50 Hz-AC test which have a relative longer stress time. But the higher conductance plays no important role in breakdown process at impulse tests.

4.2 Direct test

According to (1), the cable sheath breakdown voltage $U_{d(M)}$ can be determined by indirect test. The direct determination of breakdown voltage is possible. But in comparison to the indirect way, it is more sophisticated. As a sample, the results both methods on the cable A are given in Table 4.

Table 4: Calculation of the cable sheath breakdown voltage $U_{d(M)}$ in comparison to indirect test

	direct Test	*indirect Test*	*relative deviation*
switching impulse	94 kV	96 kV	2 %
lightning impulse	103 kV	105 kV	2 %

The relative deviation of results for direct and indirect way is about 2%.

5 CONCLUSION

The external mechanical protections of high-voltage cables are stressed during the transients with very steep voltages in the power system. In the case of the high specific earth resistance and as result the high spreading resistance, cable sheath breakdowns are possible at the cross-bonding points.

In order to take effective measurements for limiting the voltage during fast time variable processes, the breakdown voltage $U_{d(M)}$ of cable sheaths should be at least approximately known. Using a breakdown test on the PE and PVC cable sheath probes, the inception field strength E_i and breakdown voltage $U_{d(M)}$ of cable sheaths can be derived.

The inception field strength E_i of cable sheaths are especially be 50 Hz-AC test lower than values of the PE and PVC base materials. The cause of this difference can be declared by usage of the carbon black ingredient which is about 2 to 3 %.

The inception field strength E_i of cable sheath materials with a thickness up to 3 mm depends significantly on the thickness s of the insulation probes. In the case of high-voltage cable $U_r \geq 110\,kV$ with cable sheaths dicker than 3 mm, the inception field strength limit can estimated using relation of cylindrical field (1) to determine the breakdown voltage (see Table 5).

Table 5: Inception field strength E_i at cable sheaths thicker than 3 mm

probe		*PE cable sheath*		*PVC cable sheath*
		A	*B*	C
50 Hz-AC	*kV/mm*	*≈15*	*≈15*	38
SI	*kV/mm*	*≈40*	*≈31*	79
LI	*kV/mm*	*≈50*	*≈36*	91

The inception field strength E_i of the PE and PVC cable sheath probes can be different in dependence of their ingredients. This fact can be observed by determination of the inception field strength E_i of cable sheath A and B under impulse voltage. Therefore, major deviation of the inception field strengths for real cable is possible.

The breakdown voltage $U_{d(M)}$ can be determined using a direct or an indirect test. The difference between results of these methods is about 2 % for the investigations done in this work.

It should be noted that the investigations are carried out on new cable sheath probes. Mechanical problems due to cable installation can lead to decrease of the inception field strength. This reduction of breakdown voltage $U_{d(M)}$ should be considered if necessary. In the future works, the influence of cable installation can be investigated.

6 REFERENCES

[1] IEC 60071-1 : 2006
Insulation co-ordination – Part 1: Definition, principles and rules