Cable Research Testing

Ludovic **BOYER;** Nexans, (France),
ludovic.boyer@nexans.com

ABSTRACT

In extruded HVDC cables, the electric field distribution in the insulating material is depending on its geometry, the temperature distribution and voltage variations. When operated, extruded HVDC cables are submitted to load variations and ripples generated by the AC to DC conversion stations. These stresses induce an ageing of the cables and may thus reduce their reliability. A careful selection of the different materials composing the cable and an understanding of their ageing processes have thus to be performed with research testing.

In the present paper, a brief review of some of the testing methods, from plates to cables, will be drawn, and a presentation of the undergoing development for cable testing will be done.

KEYWORDS

HVDC; XLPE; Material testing; Space charge.

INTRODUCTION

An extruded cable must follow different steps from its production to its operation, with for instance:

- Extrusion
- Degassing
- Transportation
- Installation
- Operation

In order to be commercially competitive, all these steps must undergo optimizations. For instance, to be extruded, the rheological parameters of the cross linked low density polymer (XLPE) must be compatible with the extrusion lines.

When extruded, the amount of generated by-products must be contained as they may negatively affect the cable reliability. Thus, the cable must be submitted to a post-production treatment stage which duration depends on the amount of by-product generated during extrusion and the allowed density of by-products for normal operation of the cable.

Concerning ground transportation, the maximum allowed tonnage will limit the total cable length to be transported from the production site to the installation site. In fact, the higher the cable weight per meter, the shorter the length to be transported and thus the higher the amount of cable joints to be installed, and so will be the duration of the cable installation.

Once installed, the cable must operate during several decades without interruption. Among others, it must withstand temperature variations (either due to climate changes or load variations), voltage reversals, lightning impulses and switching surges from the voltage conversion stations.

In all the aforementioned steps, optimizations are performed through material comparisons and an understanding of their behaviors under different conditions. However, as when operating, a cable failure is often a consequence of the rupture of its dielectric, the discussion held in this paper will be focused on dielectric tests and characterizations.

In the frame of the technical brochure TB-496 launched by the Cigré working group B1.32, development tests may include breakdown tests, electrical resistivity measurements and space charge characterizations when the studied dielectrics are submitted to electro-thermal stresses.

In the following sections, a brief review of some of the testing methods, from plates to cables, will be drawn, and a presentation of the undergoing development for cable testing will be done.

BRIEF REVIEW OF ELECTRICAL TESTING OF DIELCTRIC MATERIALS

Electrical breakdown strength

Electrical breakdown strength of a dielectric material represents the maximal electric field it can withstand without permanent failure. This key parameter can be used for screening and material ranking in development phases. Usually, the higher the breakdown strength, the better the material is. Furthermore, the breakdown strength of a dielectric is a design criterion, as it usually defines the lowest insulation wall thickness of a cable system. Also in this case, a high breakdown strength is preferable to achieve an economically competitive cable system.

Breakdown tests can be performed under different conditions with, for instance, application of gradually increasing magnitudes of DC voltages steps or lightning voltage impulses, under isothermal or thermal gradient conditions. DC breakdown tests may be used to evaluate the intrinsic performance of the dielectrics while lightning voltage impulses may be used to check the integrity of the tested dielectrics.

Electrical resistivity measurements

Electrical resistivity of XLPE materials greatly depends on the applied electric field and temperature. This dependency is commonly described by using the following expression for the electrical resistivity $\rho(E,T)$ *[Ωm]* of the material:

$$\rho(E,T) = \rho_0 \, Exp[-\alpha T] Exp[-\beta E], \qquad (1)$$

with ρ_0 *[Ωm]* the resistivity of the material at zero field and zero temperature, α *[°C^{-1}]* and β *[mm/kV]* temperature and electric field coefficients, respectively.

These dependencies can be such that a thermal gradient in a cable insulation may induce an inversion of the electric field, as illustrated in Figure 1 below for the case

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of a full size cable submitted to a test voltage of 600 kV.

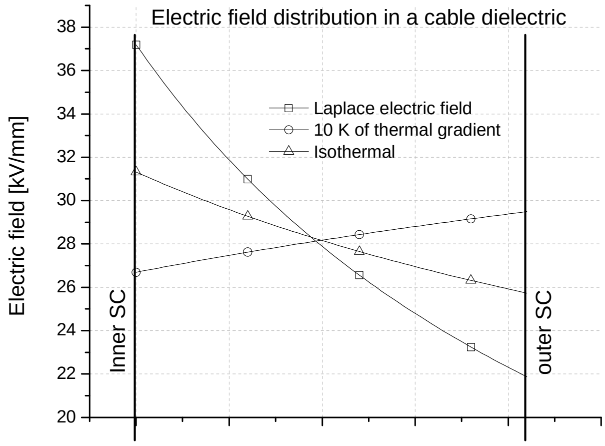

Figure 1: Illustration of electric field inversion in a full size cable with a thermal gradient across its insulation (arbitrary resistivity parameters).

It can be seen from this figure that the highest electrical stress is transferred from the inner wall of the cable dielectric to the outer wall when the dielectric material goes from isothermal to thermal gradient conditions.

Resistivity measurements are usually performed by submitting the studied sample to various temperatures and electric fields which are representative of its operational conditions. However, as the transient behaviour of a specially developed HVDC dielectric is slow, an optimal procedure for the measurement conditions must be found. For instance, in order to limit the influence of the material transient response on the measurement duration, it is advisable to perform resistivity measurements starting from the highest temperature and electric field, then by progressively decreasing the temperature. This is illustrated in Figure 2 below [1].

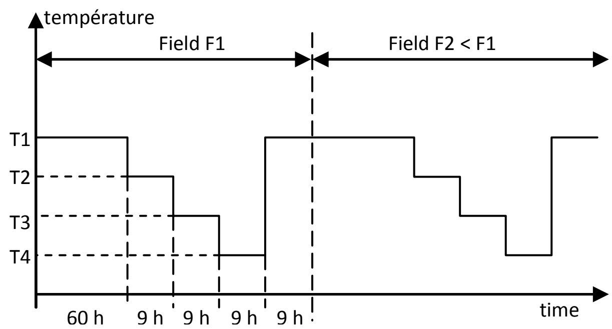

Figure 2: Illustration of resistivity measurement procedure [1].

Space charge measurements

Under operational conditions, HVDC cable systems are submitted to load variations and possibly voltage reversals. Under such conditions, space charges may build up and induce further distortions of the electric field in the material insulation. These distortions can be such that the breakdown strength of the cable system may be greatly reduced over time. This evolution of the breakdown strength of the cable system has an impact on its design. It is thus important to acquire a better comprehension of the space charges build-up and evolution mechanisms in the cable dielectrics. This can be done thanks to space charge measurement methods such as the Thermal Step Method (TSM) or the Pulse Electro-Acoustic method (PEA). For both methods, a transient local disequilibrium of the space charges contained in the dielectric is induced either by a thermal (TSM) or an electrical (PEA) stimuli.

Concerning the TSM, the measured response of the system submitted to the thermal stimuli is a current which, after being processed [2], gives the electric field distribution in the material dielectric. Concerning the PEA method, the measured response is voltage which, after being processed [3], gives the space charge distribution in the studied sample. In both cases, a simple mathematical operation either gives the space charge (TSM) or the electric field (PEA) distributions.

Space charge monitoring is usually performed in accelerated ageing campaigns during which the samples under test are submitted to electric fields and possibly temperatures higher than in normal conditions. The main difficulty is to select the adequate constrains has the space charge build-up mechanisms greatly depend their magnitudes. Non optimum selection of the ageing conditions may thus lead to erroneous interpretations of the space charge build-up mechanisms.

OVERVIEW OF THE DIFFERENT TESTED SAMPLES

Research and development tests involve samples of various scales from plates to full size cables. These have important impacts on the test procedures, sample preparation and test equipments, as illustrated in Table 1 below.

Table 1: Illustration of the scale differences involved in the preparation of different tested samples.

	Plate	Model cable	Full size cable
Extrusion/ reticulation duration	< 1 h/plate	> 3 days (depending on required length)	> 3 days (depending on required length)
Post-production treatment	1 day	< 1 week	> 1 week
Dielectric thickness	≈1.5 mm	≈ 6 mm	> 15 mm
Duration of test preparation	< 5 h	> 1 day	> 1 week
Occupied area during tests	< 3 m²	< 20 m²	> 40 m²

From this table, the different logistical and economical efforts required to perform tests on the different samples become obvious. The following sections describe the technical advantages and drawbacks of each type of samples.

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Plate samples

As seen from Table 1, plate samples are the easiest ones to produce. Large quantity of samples can be produced, treated then tested quite rapidly, which allows one to obtain statistical results. Plate samples thus represent ideal candidates for the early stages of material research and development.

In the material selection stage, interaction of different cable materials can be studied on plate samples. This is the case for the interaction of semi-conductive materials and dielectric materials [4] [5]. In the study held by H. JANAH et al. [5], the influence of the type of semi-conductive material on residual space charges in a dielectric was observed by mean of TSM, as shown in Figure 3 below.

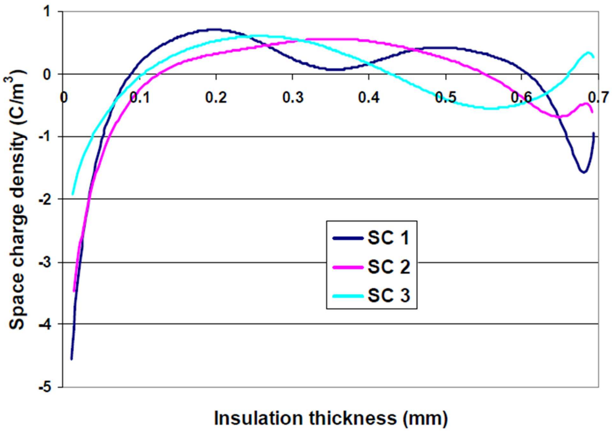

Figure 3: Space charge distribution in a plate sample dielectric with different semi-conductive materials as electrodes, after [5].

In this study, the plate sample was subjected to an electric field of 40 kV/mm and a temperature of 70 ℃ during 4 h prior to space charge characterization under short-circuit and room temperature. The influence of the semi-conductive material on space charge density accumulation can clearly be seen from this result, with the worst combination being the one with the semi-conductive material SC1, as it heads to the highest amount of accumulated space charges especially at the vicinity of the interfaces.

Albeit easy to study, the geometry of plate samples is obviously different from the cables as well as its manufacturing procedure (i.e. press moulded for plates versus extruded for cables). The results from studies performed on plate samples may thus not be completely representative of the electrical behaviour of an extruded cable.

Model cables

Taking into account a scale effect, the dielectric behaviour of model cables is representative of the one of full size cables as they share similar extrusion processes.

Furthermore, due to the lower demanding efforts to produce and test model cables when compared to full size, different dielectric materials can be compared either with breakdown strength characterizations or space charge measurements.

Concerning space charge measurement, the sample showing the lowest electric field distortions when submitted to electro-thermal stresses is often preferred as it usually contains the lowest magnitude of space charge density distributions. This is illustrated in Figure 4 below, where two model cables with different dielectric materials where submitted to a maximum (in magnitude) Laplace electric field of -23 kV/mm and a core temperature of 80 ℃ [6].

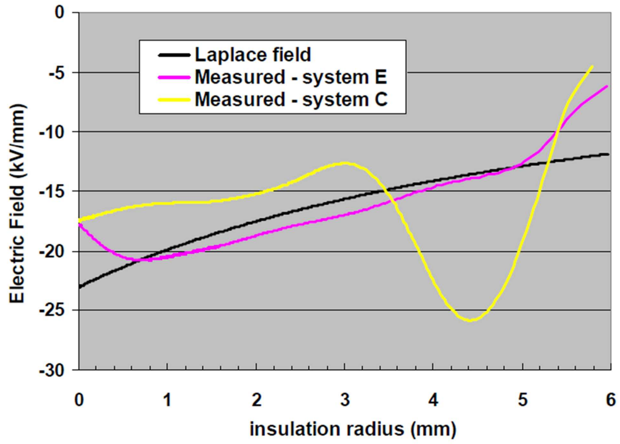

Figure 4: Comparison of electric field distribution in two model cables when submitted to electro-thermal stress, after [6].

From this study, using the model cable system E in HVDC applications is preferable, as it shows a lower field distortion when compared to the Laplace electric field.

Furthermore, model cables can be used to simulate some of the complex full scale cable configurations such as interface between a cable dielectric and its accessory in space charge characterizations [7], [8]. This is illustrated below in Figure 5.

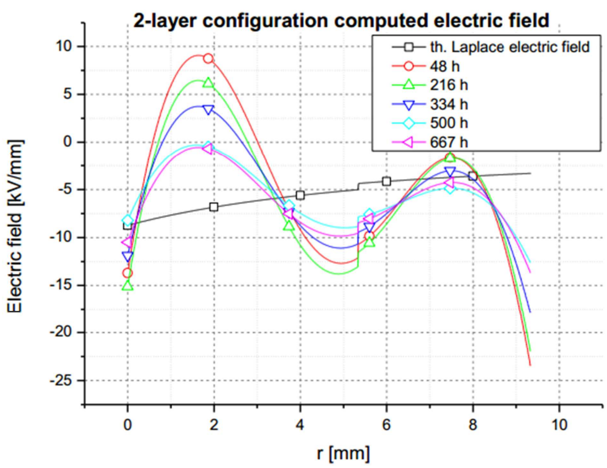

Figure 5: Evolution of the electric field distribution in a two-layer model cable configuration, after [8].

In this study, a model cable in a two-layer configuration was submitted to a maximum (in magnitude) Laplace electric field of -9 kV/mm and a thermal gradient of 20 ℃. It can be seen that the electric field distortion in the two layers tends to decrease during the ageing campaign, indicating that the total amount of space charge density also tends to decrease.

Full size cables

As the cable systems provided to the customers will be connected to voltage conversion stations, the full size cables will be subjected to switching surges, which may affect the space charge build-up in their dielectric in long term operation.

In the frame of the monitoring of the performance evolution of HVDC XLPE cables, as well load management, when connected to voltage source converters (VSC), a partnership between Alstom Grid and Nexans has been launched. The evolution of the electrical parameters of a full scale cable when submitted to load cycles superimposed to switching surges will be monitored by the mean of PEA, dielectric spectroscopy and TSM [9].

Toward this objective, Nexans, together with University of Montpellier, is currently adapting the TSM to a full scale cable for long term characterizations. These adaptations aim at limiting the temperature drop in the thermal diffuser to 1 ℃ during the measurement phase and to optimize the calories transfer from the thermal diffuser to the cable by modifying its design.

The limitation of the temperature drop in the thermal diffuser is performed by adding a buffer tank, as shown in the block diagram in Figure 6 below.

Furthermore, as the TSM relies on the diffusion of a thermal step through the dielectric of the characterized full size cable, the duration of the measurement has to be increased when up scaling from model to full size cable. For instance, when the "two temperature source" model is used for data processing, the duration of the measurement is increased from 200 s on model cables to up to 1000 s on full size cables.

CONCLUSION

In the present paper, a brief review of some of the different dielectric tests and characterizations included in the Cigré TB-496 from plate samples to full size cables in the frame of research and development has been done.

Furthermore, a presentation of the undergoing development at Nexans to adapt the thermal step method to full size cables has been performed.

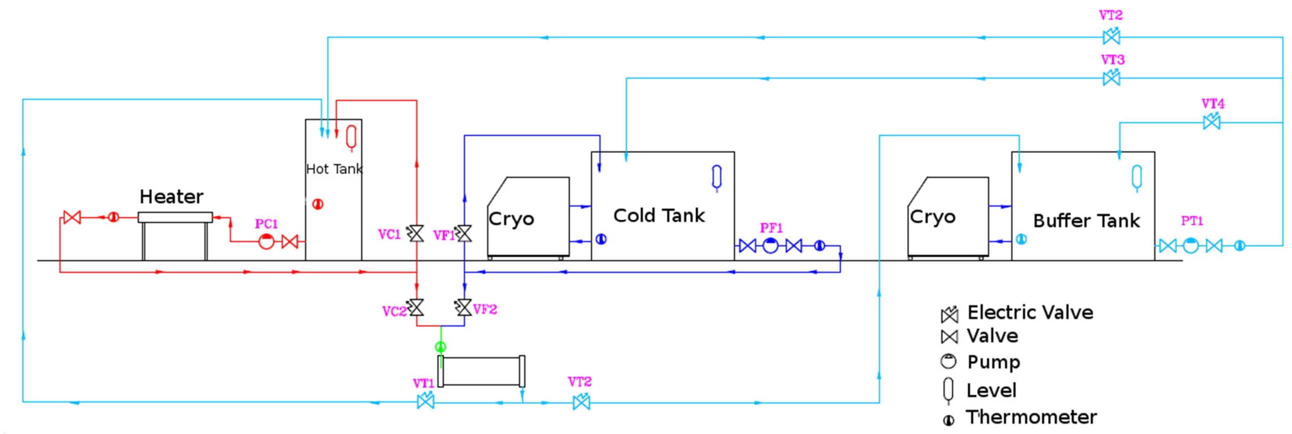

Figure 6: Block diagram of the TSM bench adapted to full size cables.

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