Leakage current behaviors under high electric field in polymer minicables

Dimitri **CHARRIER**, Quentin **EYSSAUTIER**, Nexans France, (France), dimitri.charrier@nexans.com, quentin.eyssautier@nexans.com

Gabriele **PEREGO**, Nexans Italia (Italia), gabriele.perego@nexans.com

Christian **FROHNE**, Nexans Deutschland Gmbh, (Germany), christian.frohne@nexans.com

Markus **JARVID**, Nexans Norway AS, (Norway), markus.jarvid@nexans.com

ABSTRACT

For a long time now, leakage current measurements in insulation systems stressed at high electric field are performed to deduce the electrical conductivity. Moreover, recent decades were dedicated to design new polymer materials to be more resistive thanks to an appropriate cleanliness, chemical and physical design. Here we report different families of leakage current behavior that were observed in model cables under different test regimes.

KEYWORDS

Direct current, cable, electrical resistivity, apparent conductivity, leakage current, isothermal, thermal cycles, thermal runaway, long term stability.

INTRODUCTION

In the context of material development dedicated to power transmission with extruded cables, the assessment of electrical performances is required through different relevant and complementary test methods.

In high voltage direct current (HVDC) cables, power transmission is ensured by the flow of direct current I in conductor and the applied voltage V between the conductor and the outer screen. It means that when the current load I is switched-off, an electric field can still be concentrated in the insulation.

In real use, the electric field is completely distorted by thermal gradients and by space charge injections mainly coming from the interfaces. Thus, the electric field can locally be significantly higher than the average field.

Consequently, the leakage current at stabilization can only give an ‘apparent’ electrical resistivity or conductivity of the insulation system with an average electric field. The ‘real’ local conductivity is obfuscated by the inhomogeneous distorted electric field, also coming from the geometry. It deals with a black box issue, where only the leakage current leaving out of the cable is read.

Analytical expressions of electric fields exist for isothermal situations with an insulation free of space charges [1]-[2]. Some finite element modelling requires input data which are, most of the time, not available when assessing new materials. Therefore, an empirical approach on the leakage current appears to be a perfect compromise for determining an analytical expression.

The standard approach is to extract an apparent DC conductivity in S/m (or resistivity in Ω.m) for one applied temperature, one given average electric field in kV/mm and one insulation system, consisting of the insulation and the connected electrodes. The comparison works if all the test objects and test methods are identical. Otherwise, electric field distortions are not comparable. For instance, the leakage current in an insulation system is influenced by the electrical and thermal history.

Therefore, instead of looking for resistivity after calculation, we propose here to focus on at the raw data of leakage current measurements, which can give more reliable information about long term stability of the material.

The tiny leakage current measured in the insulation does not necessarily impact the power transportation which is, in the end, our final goal. It is rather an indicator of long term performance of the insulation system.

Power losses come in majority from the electrical resistivity of the conductor. A voltage drop $\Delta V = V_{station} - R_{cable} I$ is created between the voltage at the power station $V_{station}$ and the end of cable $V_{end} = R_{cable} I$. The power loss coming from the conductor results in a heat flow from the conductor (heat source) across the insulation to the environment (heat sink). This heat flow across the insulation (and the surrounding cable layers), together with the heat flow into the environment results, in rising the temperature of the conductor and creates a temperature gradient across the insulation. This temperature gradient is a function of the heat flow (ohmic losses in the conductor), the insulation properties and the geometry.

In addition to the heat generated by ohmic losses of the conductor, the leakage current creates additional losses in the insulation, which also dissipate to the environment. According to its magnitude, it contributes to an additional temperature increase of the conductor. Since conductivity of the insulation increases with temperature, the risk of thermal impact from leakage current is higher, the more the cable is current loaded. Depending on the possibility of heat dissipation to the environment, the electric conductivity of the insulation, and the dependency of electric conductivity from temperature, the cable system can experience a thermal instability resulting in a failure caused by overtemperature, often referred to as “thermal runaway”.

Plates of insulation as test objects for conductivity measurement have the advantage of offering the possibility to apply homogeneous electric field and homogeneous temperature. Leakage current on plates is standardized [3] although dimensions (plate diameter or thickness) and conditionings are not fully specified.

Model cables (small scale cables consisting of a metal conductor and metal screen separated by coaxial layers of semiconductive and insulating material) offer the possibility to apply a radial electric field and thermal gradients, similar to the conditions in real high voltage cables.

In table below plates and model cables are compared with their possibility to represent electrical and thermal stresses.