EVOLUTION OF SPACE CHARGE AND INTERNAL ELECTRIC FIELD DISTRIBUTIONS IN HVDC CABLE UNDER LONG TERM TESTING

Jérôme MATALLANA, Hakim JANAH, Pierre MIREBEAU, Nexans (France)
Bjørn SANDEN, Nexans (Norway)
Jérôme CASTELLON, Serge AGNEL, Petru NOTINGHER jr., Alain TOUREILLE, University of Montpellier (France)

e-mail : jerome.matallana@nexans.com

ABSTRACT

In spite of significant advances within the R&D community of HV cable technology, the definition of a suitable insulation design for extruded HVDC cables remains quite a challenge. It is widely agreed that the electric field distortions resulting from long-lasting space charge build-up over the insulation thickness govern the cable performance and its life expectancy. But because it is difficult to allow for unavoidable space charge build-up through comprehensible insulation design rules, the most pragmatic approach opening the way to space charge dynamics understanding is to measure them directly on cables subjected to long term DC testing. This has been achieved by means of an industrial facility based on the Thermal Step Method set up in a Nexans HV Competence Centre in close cooperation with the Electrical Engineering Lab of the University of Montpellier.

The aim of this contribution is to present the evolution of the electric field and/or space charge distributions as a function of time in HVDC trial cables under long term testing. Two aspects of the Thermal Step Method have been considered :

- *Measurements under high applied DC field to reach the actual internal field distribution under service conditions,*
- *Measurements under short-circuit condition to record the build-up and evolution of the steady residual space charge.*

The outcome of these experimental campaigns was found to be of great interest and led to decisive orientations for insulation selection and design.

KEYWORDS

Space charge – Electric field measurements – HVDC cables

INTRODUCTION

The design of HVDC extruded cables is one of the most challenging issues in the cable industry. It is today well established that the electric field distribution over the insulation thickness is strongly affected by space charges which somehow control the cable behavior and its life expectancy. Fortunately, some tractable calculations of the field and space charge distributions in steady state have been treated in many publications, e.g. [1-2]. Such approaches assume an intrinsic resistivity depending on both temperature and field through a Poole-Frenkel type mechanism. These considerations are commonly used by engineers to design HVDC cables under loaded condition. However, from a R&D standpoint, one cannot be satisfied by such a restricted understanding, mainly for two reasons. The first one is that the conduction mechanisms involved in the insulation under service conditions are considerably more complex and governed by charge trapping/de-trapping and injection through semi-conductive screens. The second one is that a measurement facility is required to assess or not considered hypotheses directly on cables under test. This alternative has been exhaustively examined by manufacturers and researchers, e.g. [3-5], and is currently the most reliable alternative to determine the capability of an insulation system to withstand HVDC application throughout its lifetime.

This paper relates Nexans approach to study their developed HVDC cable insulation. The space charge dynamics over long testing durations has been investigated through electric field measurements on cable by means of an industrial facility based on the Thermal Step Method.

EXPERIMENTAL FACILITY

Theoretical background

The technique is based upon the Thermal Step Method (TSM) in double capacitor configuration, exhaustively described in [6]. Compared with the classical TSM – carried out on a single short-circuited cable sample – the double capacitor technique consists of using a “compensation cable”, placed oppositely to the "cable under test" (both cables are assumed to be identical). By connecting one side of the compensation sample to a current amplifier and the other one to the measured specimen via an electrode, a “double capacitor” is obtained. A voltage can then be applied to the cable core, and a thermal step to the measured sample. The TSM current will be recorded via the “compensation sample” (see on Figure 1). By the “outer cooling technique” the TSM current is given by the expression :

$$I_{TSM}(t) = -\alpha \frac{C}{2} \int_{R_E}^{R_I} E(r) \frac{\partial \; \Delta T(r,t)}{\partial \; t} \, dr \qquad (1)$$

where $\alpha = \frac{1}{r}\frac{dr}{dT} - \frac{1}{\varepsilon}\frac{d\varepsilon}{dT}$ is a constant of the material, C is the electrical capacitance of the cables, R_I and R_E the inner and outer radii of insulation layer, $E(r)$ is the radial electric field distribution, and $\Delta T(r,t)$ is the relative temperature distribution in the area of the cable subjected to the thermal step : $\Delta T(r,t) = T(r,t) - T_0$.

Using two identical cables offers the considerable advantage of compensating the polarization and conduction currents which can flow across the insulation under high DC field. Theoretically, the measured current is solely due to the internal field of the measured sample. In practice, a slight imbalance between both cable samples always exists and a