Modeling of the Thermoelectric Performance of a ±320 kV HVDC Underground Cable System

Andreas I. CHRYSOCHOS, Nathanail CHYTIRIS, Konstantinos PAVLOU, Konstantinos TASTAVRIDIS, Georgios GEORGALLIS; Cablel® Hellenic Cables S.A., Greece, achrysochos@fulgor.vionet.gr, nchytiris@fulgor.vionet.gr, kpav- lou@fulgor.vionet.gr, ktastavridis@cablel.vionet.gr, ggeorgali@cablel.vionet.gr
Dimitrios CHATZIPETROS, Cablel® Hellenic Cables S.A., Greece, School of Electronics and Computer Science, Electrical Power Engineering Group, University of Southampton, UK, dchatzipetros@fulgor.vionet.gr

ABSTRACT
The thermoelectric performance of a ±320 kV HVDC underground cable system is examined by means of analytical and FEM modeling. Both cable and joint geometry are investigated under steady-state and transient conditions, analyzing the different phases of a PQ test. Results facilitate the theoretical assessment of the cable system actual performance prior to the real PQ test.

KEYWORDS
Electric field, field inversion, HVDC cable system, PQ test.

INTRODUCTION
HVDC solutions gain increasingly more ground in solidly insulated transmission lines because of their higher cost-effectiveness than the respective HVAC ones, particularly for long distances. Thanks to Voltage Source Converter (VSC) technology, XLPE insulated cable systems have already been installed and are currently in operation.

In the present study, focus is made on the theoretical evaluation of the combined thermoelectric performance of a ±320 kV underground cable system. First, the electric field distribution is considered in the cable, under a given temperature drop across the XLPE insulation layer. Due to its resistive nature, HVDC field is substantially different than the respective HVAC ones, particularly for long distances. Thanks to Voltage Source Converter (VSC) technology, XLPE insulated cable systems have already been installed and are currently in operation.

The transient electric field distribution can be described by the following equations:

\[ \nabla \cdot \mathbf{J} = \frac{\partial \rho}{\partial t} \]  
\[ \mathbf{J} = \sigma \mathbf{E} \]  
\[ \dot{\mathbf{E}} = -\nabla \mathbf{V} \]  
\[ \nabla \cdot (\varepsilon \mathbf{E}) = \rho \]  

where \( \mathbf{J} \) the current density, \( \mathbf{E} \) the electric field, \( \rho \) the space charge density, \( \mathbf{V} \) the voltage potential, \( \sigma \) the dielectric conductivity, and \( \varepsilon \) the dielectric permittivity.

Due to the absence of any comprehensive theoretical model for the conduction in polymeric materials, the dielectric conductivity is usually described by the following empirical expression [1]:

\[ \sigma = \sigma_0 e^{\alpha T + \beta E} \]  

where \( \sigma_0 \) the dielectric conductivity at reference temperature \( T_{ref} \) and electric field \( E_{ref} \), and \( \alpha, \beta \) the temperature and field coefficient of dielectric conductivity, respectively.

In order to calculate temperature \( T \) in (5), the heat transfer problem must be solved, which for transient conditions in solid medium is given by:

\[ dC_p \frac{\partial T}{\partial t} + k \nabla^2 T = Q \]  

where \( d \), \( C_p \) and \( k \) the material density, heat capacity at constant pressure and thermal conductivity, respectively, while \( Q \) the external heat source including also the resistive heating by leakage current on dielectric medium.