Impact of Laying Conditions on Temperature Distribution in HVDC Cables Based on Numerical Simulations

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ABSTRACT

The importance of HVDC transmission has increased in recent years. In particular, the number of extruded HVDC cables has risen significantly. The electric field distribution in HVDC cables differs from that in AC cables since it depends on the electrical conductivity of the insulating medium. The electrical conductivity is strongly, non-linear depending on temperature. In order to increase the model accuracy of HVDC cables, the thermal analysis of the system components is of particular interest. For this reason, this publication describes the influence of laying conditions both on the conductor temperature and on the resulting temperature difference in the dielectric.

KEYWORDS

thermal modelling, HVDC cables, laying conditions, conductor temperature, temperature difference.

INTRODUCTION

High-voltage direct current (HVDC) transmission is a key technology, whose expansion is increasingly accelerated in the course of the energy system extension [1]. On the basis of legal requirements, HVDC links are more and more to be designed entirely or partially as cable links in Germany [2]. As a consequence, the installed cable lengths increase, which requires a deeper understanding of their insulation systems. A large part of today's HVDC cables are designed as extruded cables using polymers, such as cross-linked polyethylene (XLPE) as the insulating medium [3]. However, the electric field stress in HVDC cables differs significantly from that in alternating current (AC) cables, because the field-determining factor under DC load is the electrical conductivity of the insulating media. The electrical conductivity of polymeric insulation materials is multifactorially influenced. In addition to the electric field itself, the temperature of the insulating medium and particularly the temperature difference in the dielectric are the predominant influencing factors on the electrical conductivity and thus on the electric field distribution in the HVDC cable [4] [3]. As a consequence, the calculation of the temperature distribution is an important aspect to improve the accuracy of HVDC cable modelling.

While in [5] and [6] a numerical model is presented which enables the calculation of the temperature distribution in the HVDC cable exposed to air and a cable covered by a thermally insulating foam, in this publication a model implemented in Comsol Multiphysics is presented which allows the thermal calculation of buried HVDC cables. Initially, this publication presents a comparison of analytical calculation methods with the results of numerical simulations. Subsequently, the influence of the heat generating current, the installation geometry and the thermal properties of the soil and of special thermally stable laying materials on the conductor temperature is illustrated. The impact of these factors on the resulting temperature difference in the dielectric is finally shown.

THERMAL MODELLING METHODS OF BURIED CABLES

Several methods are available to determine the temperature distribution in buried HVDC cables. In the following, two frequently used methods will be presented, compared and distinguished from each other. On the one hand, this involves an analytical estimation of the temperature in the cable and, on the other hand, the calculation of the temperature distribution on the basis of numerical simulations.

Analytical Approach

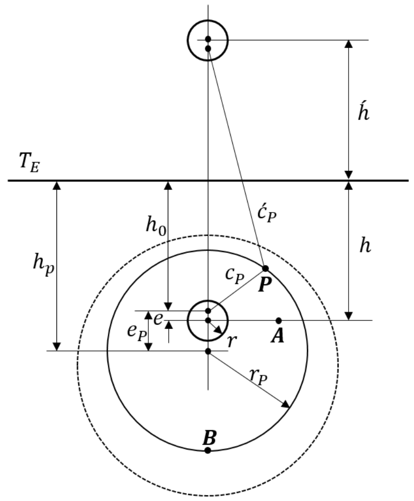

Fig. 1: mirror theory according to [7]

The predominant heat transport mechanism in the cable is the heat conduction. By underground cables, this type of heat transport continues in the soil. When the cable is installed in the soil with the thermal conductivity λ_E, the dissipated heat generated in the cable is transferred to the atmosphere via the soil and the surface of the soil, with the surface temperature T_E. For the analytical calculation of the temperature distribution in an underground cable, it is assumed, as shown in that a second cable (sink) located mirror-inverted to the surface of the soil absorbs the heat $\dot{Q}$ generated in the underground cable (source) [7] [8] [9]. In this arrangement, the temperature at point $\boldsymbol{P}$ (T_P) in relation to the soil surface temperature is defined as:

$$T_P - T_E = \frac{\dot{Q}}{2\pi l \lambda_E} \ln\left(\frac{\acute{c}_P}{c_P}\right). \quad (1)$$

Point $\boldsymbol{P}$ and $\boldsymbol{B}$ are located on an isotherm, i.e. on a line with constant temperature. From this, using the geometric parameters from Fig. 1 the geometric constant of the isotherms is determined by [7]:

$$k_P = \frac{\acute{c}_P}{c_P} = \frac{2h_0 + e_P + r_P}{e_P + r_P}. \quad (2)$$

The eccentricity of the isotherm is calculated by [7]:

$$e_P = h_P - h_0, \quad (3)$$