Enhanced adoption of the two-zone model to implement the drying out of soil in ampacity calculations of directly buried cable systems for different types of soil

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ABSTRACT

The description of the thermal conductivity of the bedding by a two zone model is widely used to implement the drying out of soil in ampacity calculations. The adoption of this model to the great variety of natural soils as well as the implementation of cohesive soils has proved to be difficult. Therefore, the presented work proposes to use a continuous function to describe the dependency of the thermal conductivity of the soil on the temperature within the bedding. The method is based on the numerical solution of the constitutive equations, which have been solved for stationary, periodic and transient time dependencies, as well as on laboratory and field tests.

1. INTRODUCTION

As the heat injection from directly buried underground power cables into natural soils trigger a redistribution of moisture within the bedding, their thermal properties can change significantly during operation of the cable. The relevance of this “drying out” of the bedding for the ampacity rating of the cable system has been assessed numerous times – both experimentally and by simulations.

In order to implement the drying out of soil in ampacity calculations, application of the two zone model is today’s best practice [1]. It is based on the assumption that the redistribution of moisture within the soil leads to two distinctive zones: a “dry” zone with very low moisture content around the cable as well as a “wet” zone with ambient moisture content. The boundary between these two zones coincides with an isothermal, which is often defined as the difference to ambient temperature and therefore denoted as “critical temperature rise”.

Hence, three parameters of the bedding must be specified when the two zone model is applied: The thermal conductivity of the bedding in “dry” and “wet” conditions, denoted as λ_{dry} and λ_{wet}, as well as the value of the critical temperature rise, dT_{crit}. As an example, German standard [2] assumes the following values for stationary conditions::

$$\lambda_{dry} = 0.4 \ \frac{W}{m \cdot K} \qquad \lambda_{wet} = 1 \ \frac{W}{m \cdot K} \qquad dT_{crit} = 15 \ K \qquad (1)$$

With the help of these parameters, the two zone model offers tangible and safe results that are easily implemented in common heat calculations via a temperature-dependent thermal conductivity of the bedding material.

However, being an approximation on the safe side, natural soils may have higher critical temperatures or thermal conductivities than given in equation (1), resulting in higher possible current ratings. Yet, the adaption of the aforementioned parameters to a specific bedding material poses some problems. While the two conductivities may easily be determined via measurements, the critical temperature rise cannot be directly specified. [1] provides a formula to determine the value of T_{crit} as a function of the ambient water content Θ_a, the so-called critical water content Θ_{crit} (which marks the saturation, below which hydraulic as well as thermal conductivity of the bedding decline drastically), and a parameter η, which is calculated from the diffusion coefficients D_Θ and D_T, see Eq. (2). But rather rough approximations and negligence of the temperature dependencies of the diffusion coefficients are involved in the proposed calculations, leading to uncertain results when it comes to find the value of dT_{crit} for a specific soil. The authors themselves point out that more sophisticated methods exist for the calculation of drying out of different soils, but for reasons of practicality, the use of the prespecified values is recommended. It is also in this sense that the considerations according to [1] are focussed on stationary conditions.

Hence, existing knowledge offers only limited use in adopting the two zone model to specific soils. To fill this gap, an interdisciplinary project has been launched that aims at improving the current ampacity calculations of a German distribution system operator by its adoption to the variety of existing natural soils. In the framework of this project, the validated model of the involved soil physics has been implemented, which will shortly be recalled in chapter 2. In chapter 3, the necessary soil characteristics will be presented for three exemplary soils, which serve as an input to the simulation. Then, in chapter 4, moisture migration within these soils will be studied numerically under three different time regimes: stationary, periodic and transient boundary conditions. Finally, the derived thermal properties will be validated by a comparison of simulations and measurements from a test field, which is given in chapter 5.

As it was found, the calculations based on the derived soil specific characteristics lead to significantly better results than the application of the two zone model. Therefore, the actual temperature of cable systems can be predicted more precisely, which can subsequently be used to increase the transmission capacity of cable systems.

2. COMBINED HEAT AND MASS TRANSFER

The numerical calculation of possible moisture movements within soils is based on the formulation of Phillip and de Vries [3], which describes the interaction