ESTIMATION OF THE THERMAL RESISTIVITY OF BACKFILL MATERIALS USING A PRACTICAL APPROACH

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ABSTRACT

The ampacity of buried cables depends on both cable construction and laying conditions, and in particular the thermal resistivity of the surrounding soil. In this work a model for thermal conductivity (inverse of resistivity) with only geotechnical index properties as input parameters is presented. The model is compared to transient- and steady-state measurements in laboratory on a common backfill material, providing less than ±10% difference between calculated and measured values. The model can thus provide estimated values for thermal resistivity and thermal dry-out curves.

KEYWORDS

Thermal resistivity, backfill, ampacity.

INTRODUCTION

The increased focus on utilization and security-of-supply of the electric power system, calls for more accurate methods of calculating the highest current carrying capacity (ampacity) in cable systems. As calculation tools are becoming more available and accurate, the importance of accurate input parameters increases and uncertainty in these can impede optimal utilization.

The ampacity of buried cables depend on both cable construction and laying conditions, in particular the thermal resistance of the surrounding soil which accounts for 50-75% of total thermal resistance for a cable system [1]. A significantly better utilization of both new and existing installations can be achieved by providing accurate values of the thermal properties of backfill materials.

The thermal resistivity can be measured in field or laboratory by applying e.g. transient thermal probe method [2, 3]. However, such instruments have substantial economic cost and requires skilled and experienced personnel to assure reliable measurements. The consequence for most cable owners is that standard tabulated values from national or international standards [4] are applied. Experience have shown that there are large variations in the measured thermal resistivity of commonly used backfill materials, often due to improper compaction or poor grading.

In this work, a method for estimating the thermal resistivity of common backfill materials without the need for special instrumentation is presented. The method relies on an empirical model of thermal conductivity (inverse of resistivity) of soils, where input parameters are collected by characterization of the backfill, i.e. dry density and porosity, and information found in the Declaration of Performance (DoP) that should follow all building materials in the European Union. To confirm the method, comparison with measured thermal resistivity in the laboratory is made.

THERMAL RESISTIVITY OF SOILS

Over the time numerous models for calculation of thermal conductivity have been developed which are widely used for engineering applications [5, 6]. These models calculate the thermal conductivity of a given soil material as a logarithmic function of water content or as a power function of dry density. Farouki [7] conducted a comprehensive review of thermal conductivity models and gave a conclusion that the model by Johansen [5], based on normalized thermal conductivity approach, gives the most precise estimation of thermal conductivity for the entire range of dry density for fine and medium sized natural soils.

The normalized thermal conductivity is expressed as:

$$\lambda_r = \frac{\lambda - \lambda_{dry}}{\lambda_{sat} - \lambda_{dry}}, \qquad [1]$$

where λ_r is normalized thermal conductivity, λ is the actual thermal conductivity of soil (W/m·K), λ_{dry} and λ_{sat} is the thermal conductivity (W/m·K) at dry and saturated conditions, respectively. Johansen [5] related λ_r to a soil specific function of degree of saturation and defined empirical equations for λ_{dry} and λ_{sat}.

The model proposed by Johansen [5] was limited to natural soils and did not consider the thermal conductivity of soil particles as an influencing parameter.

Côté and Konrad [8] further developed the normalized thermal conductivity model to be applicable to different soil types. They generalized λ_r as follows:

$$\lambda_r = \frac{\kappa S_r}{1 + (\kappa - 1) S_r}, \qquad [2]$$

where κ is an empirical parameter to account for the different soil types in the unfrozen or frozen conditions. For unfrozen natural and crushed sand κ is 3.6 and 4.5, respectively. S_r is the degree of saturation, and can be calculated as

$$S_r = \frac{w}{100} \cdot \frac{\rho_d}{n \cdot \rho_w}, \qquad [3]$$

where w is water content (g), ρ_d (g/cm^3) is dry density, ρ_w (g/cm^3) is density of water and n (no unit) is porosity. n can be found as:

$$n = 1 - \frac{\rho_d}{\rho_s}, \qquad [4]$$

where ρ_s (g/cm^3) is the density of solid particles. Thermal conductivity at saturated conditions can be calculated using a simple geometric mean:

$$\lambda_{sat} = \lambda_s^{1-n} \lambda_{w,i}^{n}, \qquad [5]$$

where λ_s is the particle thermal conductivity (W/m·K), $\lambda_{w,i}$ is