Current rating of power cables based on a temperature limit at the interface with native soil to avoid soil dry-out

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ABSTRACT

To avoid soil dry-out, underground cables are sometimes rated to limit the temperature at the interface between the native soil and the cable installation's most outer element. Depending on the installation, it could be the jacket, duct, pipe or backfills/duct bank boundary. This paper presents two methods to rate cables with the purpose of avoiding soil dry-out. The first one applies to direct buried cables and uses an optimization algorithm to maximize the total ampacity of the cable system whereas the second one is a new finite element based approach to cables installed in duct banks or backfills that limits the duct bank/backfill temperature.

KEYWORDS

Soil dry-out, moisture migration, ampacity rating, cable rating optimization, cable rating, underground cables

INTRODUCTION

For environmental reasons, there is an increasing interest in accounting for the phenomenon of soil moisture migration when rating underground power cables. Actually, soil dry-out may result in instability and changes in the thermal and environmental properties of the native soil which can become irreversible; not to mention that it can de-rate significantly the cables' ampacity and lead to their failure. As a result, it is not uncommon anymore to rate cables with the purpose of avoiding soil dry-out. In such case, the objective is to limit the temperature at the interface between the native soil and the cable installation to the critical temperature θ_{crt} above which moisture migration occurs.

The purpose of the two methods presented in this paper is to provide a new ampacity rating approach for which the temperature limit is set at the interface between the cable installation boundary and the native soil. For direct buried installations, the interface can be the jacket, duct or pipe. For backfill or duct bank installations, the interface is the backfill/duct bank boundaries. This is in contrast with typical practices for which the rating of cable installations is based on the conductor temperature and insulation properties. For this reason, the usual equations and numerical approaches which are adopted to find the optimal ampacity rating of underground installations need some modifications.

In this paper, the Barrier Optimization algorithm [1] is used to find the maximum total current distribution for direct buried cable installations. In contrast with the application of this method presented in [1], the constraint is to limit the interface temperature instead of the conductor temperature. Therefore, the objective function and the optimization constraints have to change, which leads to a new formulation of the algorithm. Unlike a typical ampacity rating problem, all cable types have the same temperature constraint applied to the most external layer. This is because the critical temperature above which soil dry-out happens is a property of the native soil which is the same for all cables in the installation.

The external surface of a cable can be considered as an isotherm. Therefore, as shown later, in the case cables are buried directly underground, the number of unknown currents equals the number of independent equations written for the temperature at the surface of the hottest cable of each circuit. Therefore, a direct or optimization approach to the solution for current distribution can be employed. However, for cables installed in backfills or duct banks, there is only one point with the highest temperature on the duct bank/backfill boundaries with possibly many unknown circuit currents. Moreover, during the iterative approach to obtain the unknown current distribution, the position of the hottest point can change. Due to the inherent differences, the direct buried and backfill\duct bank installations are considered separately.

In the following section, the ampacity solution is presented for cables laid directly in the native soil and then cables laid in backfill and/or duct banks are considered. The final section presents results of numerical examples for both types of installations.

IEC REPRESENTATION OF THE CABLE INSTALLATION

In accordance with the IEC Standard 60287 [2], the thermal model for the steady-state analysis of a given cable installation is represented by an equivalent electrical network presented in Figure 1, also referred to as a ladder network. Here the same model and terminology as in the IEC Standard 60287 are used.

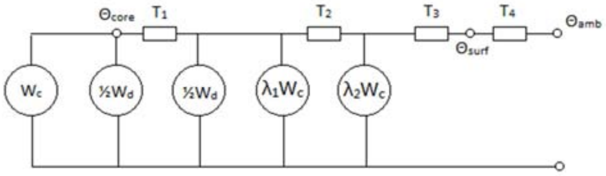

Fig. 1: Ladder network - Thermal model of a cable

W_c: joule losses of the cable, W/m.
W_d: dielectric losses of the cable, W/m.
λ_1: loss factor associated with the cable sheath.
λ_2: loss factor associated with the cable armour.
T_1, T_2, T_3: Internal thermal resistances, K.m/W.
T_4: Self portion of the external thermal resistance, K.m/W.
Θ_{core} temperature of the cable conductor, °C.
θ_{amb} ambient temperature, °C.

The nodes of the ladder network represent the average