Determination of the minimal cable trench width for HVDC cable systems laid in air filled protection pipes

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ABSTRACT

This paper gives an extensive overview of the influence of the laying in HVDC cables inside protection pipes on the thermal rating of the system. First, the governing equations to determine the involved thermal resistances are presented. Then, with the validated model, the necessary spacing between the cables and therefore the minimum trench width is determined for two different soil characteristics. Here, it is shown that depending on the soil characteristics, the laying of the cables inside protection pipes can (but need not) require more spacing than the directly buried configuration.

KEYWORDS

Cable ampacity rating, HVDC cable systems, air filled protection pipe, minimum cable trench width

1. INTRODUCTION

Due to civil engineering reasons, high voltage power cable systems are often laid in air filled protection pipes. In comparison to a direct laying, this laying condition leads to supplementary thermal resistances between the cable outer jacket and ground surface, leading to a possible reduction in ampacity rating of the cable system or to an increase of the trench width.

If, however, the current carrying capacity is a fixed design parameter of a power cable system, the supplementary thermal resistances from the air-filled protection pipe can be compensated by a wider geometrical spacing of the single cables in the trench or a soil replacement for better thermal condition. Nonetheless, the trench width has a strong influence on the costs of construction, so that an exact determination of the necessary spacing between the cables is vital for a cost-efficient construction of cable routes.

Against this background, the minimal spacing of an HVDC cable system, laid in air filled protection pipes, will be determined in the framework of the proposed contribution. This will be done by the help of a finite element modelling, as the current IEC standard 60278 does not cover the impact of air-filled protection pipes for cable systems with a diameter larger than 10 cm.

Hence, the correct implementation of the three heat transfer mechanisms within the protection pipe – namely conduction, convection and radiation – will be verified comparing the results from the modelling with semi empiric analytical expression. Furthermore, the impact of the pipe diameter as well as the position of the cable inside the pipe will be examined.

With the numerical model validated, it will be used to provide a further understanding of the mutual heating of the single cables inside one trench and the impact of the cable spacing on the general ampacity rating of the complete system. The latter will be studied with respect to different soil properties such as the thermal conductivity and the critical temperature, indicating a possible drying out.

2. THEORY

In the following, the fundamentals of the involved heat transfer mechanisms between the cable outer jacket and the inner wall of the protection pipe will be presented. This is not only vital to ensure the validity of the numerical simulations that will follow afterwards, but also helps to derive the fundamental influences on the overall results. But before delving into details, it is helpful to recall the concept of thermal resistances, on which the cable ampacity calculation is based upon.

2.1 The concept of thermal resistance

The concept of thermal resistances (as a simplification of general thermal quadropoles [1]) is best explained by pointing out the analogy between the equations of the stationary electric current field and the conductive heat transfer within solid matters. Therefore, the temperature drop across an object through which heat flows can be described the same ways as the voltage drop by the ohmic law:

$$\triangle T = R_{\mathrm{th}} \cdot q \tag{1}$$

Where:

$\triangle T$: Temperature difference in K

R_{th}: Thermal resistance in K·W^{-1}

q: Flow of heat in W

With regard to the heat equations in energy cable systems, the symmetry in longitudinal direction can be used to express equation (1) in terms of quantities per unit length, hence:

$$\triangle T = R'_{\mathrm{th}} \cdot q' \tag{2}$$

With:

R'_{th}: Thermal resistance per unit length K·m·W^{-1}

q': Flow of heat per unit length in W·m^{-1}

Where the flow of heat describes the losses per unit length of the cable which enter the surrounding soil perpendicularly from the cable outer jacket.

By applying equation (2) to a directly buried single cable, its temperature rise $\mathrm{d}T_{\mathrm{cab}}$ above the reference temperature T_{ref} in stationary conditions can be calculated using an equivalent circuit that is shown in Figure 1 (top): -Here, the losses per unit length P'_{V} of the cable flow across the thermal resistances of the cable elements and the sourrunding soil (denoted $R'_{\mathrm{th,cab}}$ and $R'_{\mathrm{th,soil}}$ and weightend according to the local generation of the total losses within the cable), leading to a temperature drop $\mathrm{d}T_{\mathrm{cab}}$.