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Research paper

Underground electric cables a correct evaluation of the soil thermal resistance

Ferdinando Salata*, Fabio Nardecchia [1], Andrea de Lieto Vollaro [2], Franco Gugliermetti [3]

DIAEE, Area Fisica Tecnica, "Sapienza" University of Rome, Via Eudossiana, 18, 00184 Rome, Italy

HIGHLIGHTS

- Optimal installation of electrical buried cables.
- Proper evaluation of the thermal resistance of the soil.
- Influence of the geometric parameters of the trench.
- Mutual influence of multiple conductors in the same excavations.
- Correction of design formulas provided by regulations.

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ABSTRACT

Nowadays companies supplying medium/high voltage electric energy, near residential areas, tend to use underground cables laying. Hence the design engineer is required to estimate the thermal resistance around the underground cable to perform a right dimensioning of the cables; as a matter of fact what it should be avoided is the overheating determined by a bad heat dissipation due to the Joule effect.

IEC rules provides a formula for the evaluation of the soil thermal resistance which is easy to apply. But from an experimental point of view, as the bibliography shows, it was discovered it tends to underestimate the problem when dealing with very dry soils in particular.

Thanks to an experimental system, some useful data were collected for the validation of a 2D FEM model of an excavated area with a linear heat source reproducing the underground conduit. The numerical model presents a variation of both the geometrical parameters of the excavated area and the distance characterizing other cables (hence heat sources) located in the same site of installation examined. In this way two dimensionless coefficients, useful to correct the values of the thermal resistance furnished by the current regulations, were determined.

1. Introduction

It can be noticed how, in the past few years, near residential areas in particular, there was a tendency to use underground power cables supplying energy through medium/high voltage alternating current. The data [1] confirm that this solution is not widely used yet: when the voltage is very high (380 kV) the percentage of the underground electric network, respect to the total value, presents the following variations: 0.4% for countries such as United States and Spain, 0.3% in Germany and Holland, 0.1% in Sweden and Canada. Other countries, France and Switzerland, are characterized by lower values, 0.2%. In Italy the underground electrical power grid, with a voltage of 380 kV, equals to 25 km out of 10,700 km (0.2% of the total), whereas the one with a voltage of 220 kV and 132–150 kV is 950 km out of 52,000 km (1.8% of the total).

There are many reasons why there is a tendency to prefer underground cables, one is the possible electromagnetic pollution determined by overhead conduits. Underground cables imply extra costs which, according to the valuation performed by European managers grid, is 10–13 times more the price of a traditional 132–150 kV overhead line and 12–17 times more the very high voltage power lines. Such difference is due to the fact that with

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* Corresponding author. Tel.: +39 0644585661; fax: +39 064880120.
E-mail addresses: ferdinando.salata@uniroma1.it (F. Salata), fabio.nardecchia@uniroma1.it (F. Nardecchia), andrea.delietovollaro@uniroma1.it (A. de Lieto Vollaro), franco.gugliermetti@uniroma1.it (F. Gugliermetti).

[1] Tel.: +39 0644585685; fax: +39 064880120.

[2] Tel.: +39 0644585720; fax: +39 064880120.

[3] Tel.: +39 0644585429; fax: +39 064880120.

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123–150–220 kV power lines, underground cables are able to transfer the same amount of power of overhead cables, whereas for 380 kV power lines we need a doubling of the line. These costs are determined by the necessary equipments for the exertion of underground cables requiring stations at regular intervals. Other costs, caused by underground lines management, are determined by the maintenance of the cables during their exertion, which is more complicated and expensive. From a statistical point of view the unavailability of the power line, in those sections affected by a damage, varies from the typical values characterizing an overhead line (about a few hours) to values that can reach 25 days (for underground cables) like in Refs. [2–4]. The fact that the cables are installed underground does not mean that they are immune from damages and malfunctioning, actually we have the opposite situation. As a matter of fact the problems caused by the disposal of heat produced by the cables, due to the Joule effect, are well-known.

Thus the cables laying is a solution which can be easily applied to those sections where the power line has a high voltage, but not very high, especially when there are external factors, such as areas located near highly urbanized zones. Thanks to the environmental benefits of the exposed population, it is still possible to have underground cables at 132–150–220 kV with reasonable costs [5]; if we are dealing with peripheral lines in particular, since they do not belong to the group of the main high-voltage power lines, and where failure may be more easily tolerated by the electrical system.

During the planning phase of the long-distance power line, it is necessary to estimate the soil thermal resistance to verify the heat disposal. Such value is provided by the IEC 287-2-1 regulation through Formula (1), which is easy to apply:

$$R_{IEC} = \frac{1}{2\pi}\rho_T ln\left(u + \sqrt{u^2 - 1}\right) \tag{1}$$

where:

- ρ: soil thermal resistivity (from 0.7 K m/W, for very humid soils, to 3.0 K m/W, for very dry soils);
- u: (2L/D);
- L: distance from the center of the cable respect to the ground level [mm];
- D: outside diameter of the underground cable [mm].

It is clear that an underestimated valuation can cause serious problems during the exertion of an underground conductor. A bad disposal of the heat generated by the surrounding soil determines phenomena which quicken the aging process of the insulation layer of the cable. They are deeply affected by the maximum temperatures of exertion that the electric cable must endure even for short time intervals as shown by Ref. [6]. Hence, furnishing the design engineers with something reliable about soil resistance [7], in order to avoid damages and malfunctioning which always lead to a lower reliability and higher extraordinary maintenance costs respect to overhead cables, is very important.

2. Material and method

In this case study the focus is on the soil thermal resistance of very dry soils [8] which present hard conditions of exertion for underground conduits.

From the experimental analysis performed in the laboratory, through the equipment here described in the paragraph 2.1 (whose results were previously published [9,10]), it can be noticed how the value of the resistivity experimentally measured in the first attempt is higher than the value provided by the Equation (1). In particular, for the geometric configuration, taken as a point of reference and which corresponds to the experimental one (with just one conductor cable), the value of the resistance estimated has an underestimation of the 70% respect to the one measured experimentally. These results were later confirmed by the numerical simulations performed through a validated FEM model [11]. The regulations IEC 287-2-1, to make the estimation easier, provide the Equation (1) to calculate the soil thermal resistance. It does not take into consideration though that for very dry soils this equation underestimates the problems of heat disposal caused by the underground electric cable due to the Joule effect demonstrated in Ref. [12].

In this work, it was also taken into consideration how the shape of the excavated area and the positioning of the cable in the excavated area can nullify the value calculated through the formula provided by the current regulations. The regulations [13], concerning underground cables installation (called the “M1 type”), define the minimum depth of the cable laying based on its category: category zero and 1:0.5 m; category 2:2:0.6 ÷ 0.8 m; category 3:1.0 ÷ 1.2 m. As a matter of fact the depth, width and the bed of sand where the electric cable must be positioned and the backfill of the excavated area are all factors affecting the thermal resistance of the soil thus presenting different values respect to those assumed by the regulations [14].

Even the presence of many cables in the same excavated area determines a thermal field affecting, in a negative way, the heat disposal of those cables installed individually [15]. In order to make a more accurate evaluation of the actual thermal resistance of the soil the choice was to suggest corrective coefficients of the Formula (1) provided by the IEC regulation [16]. The purpose was to identify two corrective factors (f_1 and f_2, dimensionless) in order to have a better approximation of the actual value of the soil resistance as shown in Refs. [17–19] and reach this type of relation:

$$R_{FEM} = f_1 \cdot f_2 \cdot R_{IEC} \tag{2}$$

where:

- f_1: dimensionless factor affected by the variation of the geometrical parameters of the excavated area;
- f_2: dimensionless factor affected by the presence of other cables in the installation area.

Hence the FEM software modeled different geometrical configurations [20] of the excavated area, and afterward different positioning for two more cables installed near the disturbed cable, in the same installation area where the cables are positioned. The FEM model was validated experimentally thanks to a scale model of an excavated area reproduced in a laboratory [9,21].

2.1. Experimental measurements

In order to be able to study the thermal effects of an underground power cable in the surrounding soil it was reproduced a scale model (Fig. 1) in a laboratory. A wooden box (whose plant presents the following dimensions: length 1.9 m, width 1.5 m and depth 0.35 m) was insulated from the surrounding environment through polystyrene panels. The inside was covered with a waterproof enamel to avoid humidity exchanges between the soil and the surrounding environment. Then it was realized a trench (width: 0.008 m), representing the section of the excavated area with the underground cable, with the axis of symmetry of the longest side included between the ground level and a depth of 0.15 m. Inside this trench, at its midpoint, at a depth of 0.135 m and above a sand bed, it was positioned a pipe made of steel. The pipe, which on scale