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D.2.11. Performances thermiques des câbles en régimes permanent et cyclique en présence de migration d'humidité dans le sol environnant

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D.2.11. Thermal performance of underground power cables with constant and cyclic currents in presence of moisture migration in the surrounding soil

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Abstract

A numerical methodology for thermal analysis of buried power cables in presence of heat and moisture migration in the surrounding soil is presented. The governing equations are solved via a finite volume methodology and both cable and soil are incorporated in the problem formulation. The developed program is versatile and user-friendly, and was implemented in a personal computer. Results are presented for constant and cyclic loads, stressing the importance of moisture migration in power cable design.

Introduction

The high-voltage electrical power distribution in urban areas in general makes use of underground cables. In presence of electrical current those cables generate heat that has to be dissipated through the surrounding soil in order to keep the cable temperature at safety levels. The cable operating temperature depends upon the soil ability to dissipate this heat. Since the operating temperature is dictated by the current carrying capacity of the buried cable, in presence of favorable conditions for heat transfer from the cable to the soil, smaller cables can sustain higher currents. Considering the high cost of underground systems, there is a great interest in accurate methods for predicting the thermal behavior of buried cables. This is a complex phenomenon that involves several mechanisms of heat and moisture transfer.

Several approaches have been adopted to establish current ratings of buried cables. The classic procedures are based on constant values of the soil thermal conductivity and the solution of the heat conduction equation. All standards available nowadays for current ratings are to some extent based on the aforementioned simplification. The International Electrotechnical Commission has recommended solution procedures for thermal analysis of power cables that include daily variation of power demand and a simplified model for dealing with a dry-out zone that may develop around the cable due to moisture migration away from the cable. The simplest case treated by IEC 287 [1] is of a constant and uninterrupted current, taken as the maximum expected value along the cable life. According to this procedure the cable is designed assuming that the maximum daily peak in current would apply all day along. For this case the soil is taken to be uniform with constant properties. Usually the power consumption decreases during the night and this cyclic variation in current is taken care by IEC 853-2 [2]. Also predicted by the International Electrotechnical Commission is the occurrence of a dry-out zone in the surrounding soil in consequence of moisture migration away from the cable. In presence of unfavorable conditions the heat flux causes moisture migration which significantly reduces the thermal conductivity of the soil around the cable, The IEC 287-2 [3] adopt a two-zone model: moist soil is assumed to have uniform thermal conductivity and the boundary between dry and moist soil is assumed to coincide with a stated critical isotherm. For soil temperatures above the critical isotherm the soil is assumed to have a uniform thermal resistivity equal to that of dry soil. It is a common practice to adopt the critical isotherm 30 °C above the ambient soil temperature.

The aforementioned procedure recommended by the available standards are easy to implement but oversimplifies the problem. Due to the high cost associated to underground power cables there has been an increasing demand for more elaborated models. Despite the recognition that moisture migrates under the presence of thermal gradients and that the soil thermal conductivity is greatly affected by the soil moisture content [4], several contributions available in the recent literature still present thermal analysis models based on the heat conduction equation without considering moisture migration. Examples include [5-7]. Those models apply for limiting situations involving certain types of soils and may be viewed as a first approximation of the problem.

The influence of moisture migration in designing underground power cables has been incorporated into the thermal models through different approaches. In [8] an analytical expression is given for the soil thermal resistivity as a function of soil porosity, moisture saturation degree, and thermal resistivity of the soil components: grain, water and air. The conditions governing soil hydrological equilibrium are then investigated and expressed in terms of an applied thermal gradient and the soil saturation degree. In [9] a similar approach as that adopted in [8] was used to derive a sufficient condition for drained unsaturated soil near warm impermeable source. Under steady conditions the vapor flux away from the cable due to the existence of the temperature gradient must be balanced by liquid flux that is brought to the cable by capillary. Equating both fluxes Ewen [9] showed that the susceptibility of soils to dry can be measured by a soil property called the critical temperature difference. Drying will take place if a temperature difference greater than the critical temperature difference is maintained between any two points in the soil.

A more comprehensive analysis of the problem was undertaken by Hartley and Black [10]. The coupled energy and mass conservation equations were solved for a one dimensional unsteady situation and the temperature and moisture content field around a cylindrical heat source was determined. From the results the authors were able to predict the thermal stability of the soil, correlating, for a given soil (specified porosity and initial moisture content), the surface heat transfer per unit length with the onset of drying adjacent to the heat source. The time for drying two cylindrical sources subjected to the same conditions were shown to be related to the square of the diameters. From this finding the authors were able to recommend a methodology for determining thermal instabilities of buried cables using the thermal probe [11]. The theory of Hartley and Black was corroborated by