Computationally light two-zone moisture migration modelling for underground cables – critical temperature vs. critical heat flux

Robert John **MILLAR**, Merkebu **DEGEFA**, Matti **LEHTONEN**, Jussi Ekström**;** Aalto University, Finland, john.millar@aalto.fi, merkebu.degefa@aalto.fi , matti.lehtonen@aalto.fi, jussi.ekström@aalto.fi

Heinrich **Brakelmann;** BCC Cable Consulting and University of Duisburg-Essen, Germany, heinrich.brakelmann@uni-due.de

ABSTRACT

This paper discusses, formulates and demonstrates a development in the 2-zone approach for modelling moisture migration, the tendency of net moisture content to move away from a heat source once a combination of critical conditions has been reached. The main development is to delineate dry from wet regions with a critical heat flux rather than the traditional critical isotherm. The results, based on measurements in a graded sand backfill surrounding a cable-scale heating tube indicate that, at least for the experimental setup, the critical heat flux produces slightly better results. Real-time methodology developed by the authors some years ago is utilised.

KEYWORDS

Ampacity, cable rating, moisture migration

INTRODUCTION

The standard method [1] for the cyclic rating of cables is based on a lumped parameter (equivalent R-C thermal circuit) for the cables and the solution for a line source in a semi-infinite environment, attenuated by an attainment factor, which accounts for the heat stored in the cables during a transient [2], and generally involving a negative heat source the same distance above the earth surface as the cables are buried [3], in order to create an isotherm at the earth surface. The approach the authors of this paper have suggested and utilised, involves using an equivalent thermal circuit for the entire installation, cables and environment. Such methodology has also been developed in [4] and [5].

The reason we have used the method is to simplify the modelling of moisture migration. A thermal circuit gives nodal temperature solutions, including the interface between cables and backfill, which can be used to approximate the location of a physical or virtual boundary between dry and wet regions when moisture migration is occurring. The use of the word virtual acknowledges that moisture migration (a complex process involving heat induced liquid and vapour transport from hot to cold and return from wet to dry), is a more complex process than an instantaneous or time-delayed total drying out of a moist region. Nevertheless, the temperature rise of the cables, which are of foremost interest in establishing the load transfer limits of cable connections and forecasting their ability to cope with contingencies, can be adequately modelled with such a simplification. This is especially valid for installations in partially moist porous environments, which is precisely the situation where such modelling, simplistic or otherwise, is called for.

The question addressed in this paper is, "What is the best (simple) parameterisation that delineates the moist from dry regions in real time: a critical temperature rise, or a critical heat flux?" This paper compares the two, commencing in the next section with the derivation of the location of a critical heat flux, before illustrating the same in a real-time algorithmic context in the subsequent sections.

METHODOLOGY

The context for the work covered in this paper is a real-time algorithm based on an equivalent thermal circuit, where the coefficients and time constants of the driving exponential functions have moisture content (expressed as saturation degree h) and critical radius (r_x) dependence. This work and the derivation of the critical radius in terms of critical temperature rise (above ambient) have been detailed in [6]-[8]. The thermal ladder circuit for the heating tube consists of 6 loops, the first of which includes the heating tube itself, modelled as a thermal capacitance (1900 J / m K) and a thermal resistance of 0.05 K m / W). The heating tube is located at a typical cable burial depth (1.1 m) in a graded sand backfill of typical trench dimensions (0.4 x 0.4 m), but there is no concrete trough separating the backfill from the native soil. This, and the fact that the sand backfill was not machine compacted, means that the environment is very susceptible to moisture migration. What is more, the fact that our heating tube is of thermally light construction makes its temperature response very sensitive to moisture migration, as the PT100 temperature sensors are on the tube surface and the heat source, a power regulated DC source fed through a Teflon insulated resistance wire, is just below the surface, which consists of a light 0.5 mm aluminium sheath. There are no sheath or armour losses typical of a real cable installation. The overall diameter of the 6 m heating tube is 70 mm. The arrangement is ideal for testing algorithms that attempt to rise to the challenge of modelling moisture migration in real time.

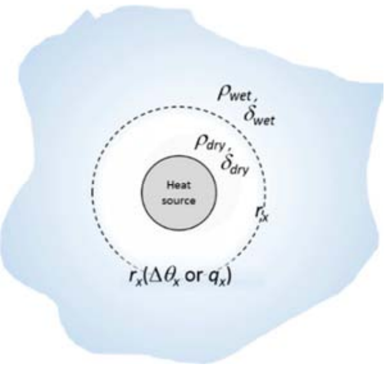

Fig. 1: Delineation of dry from wet regions around a cylindrical heat source