Model-based predictive control for use in RTTR temperature sensing systems of high voltage cables

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ABSTRACT

This study presents an adaptive method for the transient calculation of buried power cables for use in fiber optic distributed temperature sensing (DTS) systems with real time thermal rating (RTTR). The accuracy of an RTTR system depends heavily on highly uncertain parameters: correct modeling of the soil with thermal resistance and thermal capacity, and accurate estimation of the ambient temperature. In order to eliminate these uncertainties, a novel modeling approach is used, which allows using model-based predictive control to determine and adapt the soil parameters and ambient temperature from the temperature measurement data.

KEYWORDS

Real time thermal rating, Model-based predictive control, Distributed temperature sensing.

INTRODUCTION

RTTR Measurement System

Overview

The load capacity of buried energy cables can be significantly optimized thanks to the large thermal inertia of the cable-earth system using an RTTR system. For this purpose, the temperature is measured and recorded along the cable route at defined positions with a DTS. The resolution of this temperature measurement with a glass fiber as a temperature sensor is about 1°C every 1 meter and a measurement takes place every 10 to 15 minutes.

The measured temperature is sent to the RTTR software together with the current and any other parameters measured by the SCADA (Supervisory Control And Data Acquisition) system. From these measurements and the laying arrangement (position of the cables, thermal soil resistance, soil type, operating voltage, etc.) the RTTR software calculates the current conductor temperature of the cable and, if necessary, the temperature of further layers in the cable and the soil.

Problem

A DTS is more likely to be used on longer cable systems, the route of which usually runs through different terrain with varying environmental parameters. In different sections, the laying depth may change, or even the type of laying as a whole. Examples of this are road crossings, underpasses of railway lines, controlled horizontal wells for crossing waterways, or micro-tunneling.

Therefore, it is necessary to divide a cable route into numerous zones with their own thermal model. Even with constant laying, the operator usually defines a maximum length of the zones. For example, the cable system examined for verification and presented at the end of this paper has a mean zone length of 167 m. There are also systems with more than 400 zones. After each temperature measurement, all zones are recalculated.

As a consequence, a short computation time is an important prerequisite, which is difficult to achieve in numerical computations using the finite element method (FEM), but not for analytical calculations. For the development of an RTTR software, the authors therefore relied on analytical methods right from the start.

Calculations according to IEC

Formulas

Load capacity calculations of electrical cables for steady-state load are usually calculated analytically according to an IEC formula set [1, 2]. The cable is modeled with thermal resistors T_1 for the insulation, T_2 for the bedding between sheath and armour, and T_3 for the cable jacket. The environment, consisting of the cable conduit (optional) and the soil, is modeled with an additional thermal resistance T_4. The influence of other cables and heat sources is considered by the mirror charge principle.

For transient load capacity calculation, another IEC formula set is used [4]. The cable is extended by thermal capacities and converted into a two-port network, for which analytical formulas can be applied. The influence of the soil and external sources is solved analytically by means of a diffusion equation. This parabolic differential equation is solved by means of an integral exponential function.

Applicability

Steady-state calculations of power cables are typically done using the formula set from the IEC 60287 standard. The authors developed a software in Python which is capable of solving arrangements with several different and interacting cable systems in fractions of a second.

Dynamic calculations of power cables are often done using the formula set from the IEC 60853 standard and according to [5], most of the existing dynamic RTTR calculation systems are also based on this standard. The routines to extend the transient calculation according to this standard proved to be extremely cumbersome. In particular, the consideration of mutual heating is complicated because the methodology cannot be feasibly converted into the state space representation, which is probably the best known form of the system description for dynamic transmission and heat conduction systems. In addition, publication [5] stated the inadequate performance of this modeling for real-time applications.

The authors concluded that implementing an RTTR measurement system using [4] was not effective and an alternative approach had to be found.