Endowing a configurable and computationally light underground cable temperature prediction algorithm with real-time rating capabilities

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ABSTRACT

A computationally light temperature prediction algorithm for underground cables utilizing a thermal circuit for the cable in its installed environment was developed some years ago. The algorithm lacked rating abilities, however, and this paper indicates how this particular algorithm and more significantly, a dramatic simplification of the algorithm, can be so endowed. Without temperature measurement in or on the cable of concern the extension is trivial, but with temperature measurement, the methodology succeeds in accounting for variation in ambient temperature, which can include the effect of external heat sources, and goes some way towards accounting for moisture content variation and moisture migration.

KEYWORDS

Moisture migration, real-time rating, underground cable temperature prediction.

INTRODUCTION

Real-time state estimation algorithms are becoming increasingly necessary to prevent the unnecessary curtailing of loads and generation sources, and more accurately but still safely utilise network components such as underground cables e.g., [1]-[4]. While one important and equally challenging discipline is load flow prediction in the era of difficult-to-forecast renewable energy integration in the networks, this paper is confined to the thermal-modelling aspect of the real-time rating of underground cables. The real-time temperature prediction of underground cables is but one building-block in this endeavour. The ability to predict how long an increase in load flow can be sustained or how much it can be increased for a given time is even more useful, and is what motivated the developments in this paper. Specifically, the paper details a first attempt to approximate the error between a nominal temperature response profile vs. a measured set of measurements in order to be able to extrapolate an error expression into the near future for rating purposes.

The core methodology behind this work has been extensively detailed in [5] and [6], and involves a thermal analysis that eventually yields a summed set of exponential equations with dependency on r_x, the critical radius for moisture migration, and h, the ambient moisture content, for a *given installation*. It assumed that the moist and dry thermal resistivities and diffusivities and their dependencies on moisture content, as well as the critical temperature θ_x or heat flux q_x for moisture migration are known for the *given installation*. The main strength of the methodology was that the exponential expressions suit a recursive computation that requires very little memory, and avoid the limitations of superposition of non-linear systems by utilizing hypothetical steady-state target conditions and temperatures, which are recalculated at every time interval. The drawback is the amount of pre-processing required to deliver the necessary dependencies to the real-time algorithm.

If the installed environment of the cable is known to a high degree of accuracy, the algorithm can run blind, i.e., without any temperature measurement other than the ambient temperature relevant to the cable of concern. If a rigorous thermal analysis and knowledge of thermal externalities are not available, or if the installation defies analytical methodology but can be numerically simulated, a set of nominal exponential expressions can be reverse engineered from the step response. Failing that, the step response of the cable itself or the scaled step response of a thermal probe in the same installation conditions as the cable system, could be used to measure a step response, and a curve fitting algorithm used to generate the exponential equations.

It would seem prudent, however, to keep any online algorithm on track with temperature measurement, and the installation of distributed temperature sensing (DTS) systems on major cable connections is becoming more common [7]. Whether or not DTS systems can be continuously monitored, they can be used to identify hot spots, which can be remedied if possible, and monitored with local temperature measurement if not. It is reasonable to say that if a utility wishes to safely run cables up to their thermal limits, they must identify hot spots along the route and equip these locations with surface-mounted temperature sensing. This is easier said than done!

Thus, whatever means are used to ascertain the step response of a cable, a feedback loop, whereby a temperature measurement is compared with the estimated temperature from the exponential expressions, updates a linear error function to provide more accurate rating into the future. A linear function is chosen at this stage of development, as it is more suited for extrapolation than higher order polynomials.

This implies a dramatic simplification in earlier methodology developed by the authors, in that it is assumed that the change in shape of the step temperature response will not be that significant over a forecasting period of up to, e.g., 48 hours. Whilst it is acknowledged that the shape of the temperature responses at each node are to some extent changed by the migration of moisture and ambient changes in moisture content, the changes are not so significant as to produce unacceptable error in forecasting for relatively short times into the future based on adding an extrapolated error function to the nominal response. Of course the algorithm is intended to work as a rolling window, but the point established in this paper, is to see whether the approach can operate blindly into the near future with sufficient accuracy. The Methodology section will detail this modelling, and how it can be integrated into a real-time rating algorithm. The results compare the computed prediction results with the measured response of a cable-scale heating tube that is extremely responsive to changes in the thermal environment.