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

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Underground cable installations in porous backfill material can experience moisture migration, the movement of moisture away from a heat source, which can severely limit the load transfer capacity of the system. There has long been discussion about whether a critical temperature rise or heat flux is the most important driver for moisture migration when modelling the thermal environment in terms of an equivalent two-zone separation of moist from dry conditions, for which references will be given. Full solution of the equations that model the coupled water and vapour transport mechanisms in porous media subject to temperature and hydraulic gradients, usually utilising the Philips and de Vries equations, have been accomplished by research groups that will be duly referenced in the full paper. Although such detailed analyses tend to remove the dilemma between critical temperature rise vs. heat flux, there is still room for methodologies that are computationally light for real time temperature prediction based on current measurements and a thermally relevant modelling of the cables in their thermal environment.

The authors have previously developed real-time two-zone methodology based on a critical radius r_x that corresponds to a critical temperature rise that delineates dry from moist. This paper presents a formulation that defines the critical radius in terms of a critical heat flux (that itself can have moisture and temperature dependence for a given backfill) and imbeds it in an existing cable temperature prediction algorithm. Although the algorithmic context of the new development will be briefly outlined in this paper, it is fully expounded in previous work by the authors.

The methodology utilises hypothetical steady state target conditions to which the response at every time increment tends. The steady-state equation for the solution for the critical radius in terms of the critical heat flux, q_x is:

$$r_x(q_x) = \frac{\theta_i - \theta_o}{q_x \cdot W_0\left(\dfrac{\left(\dfrac{r_0}{r_i}\right)^{\frac{\rho_{dry}}{\rho_{dry}-\rho_{wet}}} \cdot (\theta_i - \theta_o)}{q_x r_o (\rho_{dry} - \rho_{wet})} \right)(\rho_{dry} - \rho_{wet})}, \tag{1}$$

where θ_i, r_i, θ_o and r_o are the temperatures and radii at the inner and outer nodes (between which the critical heat flux occurs) of the equivalent thermal circuit that models both the cables and their installed environment. $W_0(x)$ is a special (real) solution of the Lambert W function, which is approximated by a polynomial expression in the algorithm, and ρ_{wet} and ρ_{dry} are the thermal resistivities (K m / W) of the moist and dry regions.

Equation (1) with its derivation and the previous solution in terms of critical temperature rise will be compared, seeing which method comes closest to predicting the measured temperatures of a cable-scale heating tube installed in graded sand backfill at Aalto University, subject to a time-varying load profile that causes moisture migration.