Heat Transfer Modeling of Power Cables in Tunnels

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Abstract

Electric power, in cities or for power plant outflow, is most often transmitted through underground cables laying just below the road surface. Due to increased electricity demands more and more power suppliers make large investments to house these cables in deep or shallow tunnels (kilometers long and 2-3 meters wide, see Figure 1) which offers several advantages:

-- Allows large power to be transmitted
-- Easy maintenance
-- Optimum security from severe weather conditions

The main factor to be dealt with is the cooling of the cables. The conductor temperature must be kept below 90°C to ensure long term operation. That condition limits the transmitted power allowed.

To design these structures, a thermal analysis of the tunnel environment is needed. Currently two empirical models are in use, IEC (International Standard) and the work from CIGRE (International Council on Large Electric Systems).
The thermal environment is usually complex, with several different kind of cables placed in different configurations, transmitting different powers. These differences are hard to take into account accurately, so CFD / Thermal simulations using COMSOL Multiphysics® software are undertaken to measure the inaccuracy of the empirical models and get clues for improvements.

The Conjugate Heat Transfer interface is used and three models are developed:

-- 2D models of a circular tunnel with several cable configurations in free air (see Figure 2)
-- 2D axisymmetric model of a circular tunnel with a single cable in the middle in a forced flow. k-ε and Low Reynolds turbulence models are tested against an empirical international standard
-- 3D models of a tunnel mock-up (1/6th) of three cables in forced flow with a classic k-ε model. (Figure 3)

Steady state solutions are reached for every simulation and the temperature profiles checked with published standard empirical models. For free air models, a transient calculation is done and fed in a steady one to help the convergence.

The COMSOL Multiphysics® simulations in free convection showed that several hypotheses,

while accurate for a single cable, are completely wrong in more complex ones and lead to underestimation of the hottest cable temperature.

For forced flow simulations, the k-ε model lead to an error of 80% with the empirical model. Using a Low Reynolds model with a longer geometry lowers the error down to 15% (Figure 4)

These studies highlight the limitations of the current design tools for underground power lines that can lead to power lines premature aging at best, COMSOL Multiphysics® simulations helped locate an interesting possibility for improvement: the heat transfer correlations used in the design engineering tools, especially at the cable surfaces, which are too inaccurate.

In order to complete and help design more accurate correlations, a mock-up and academic studies are planned. Experimental data will be obtained and cross checked with simulations to have a precise modeling.
Ground test on a real site is under discussion to try new developed model on a full scale structure.

Reference

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Figures used in the abstract

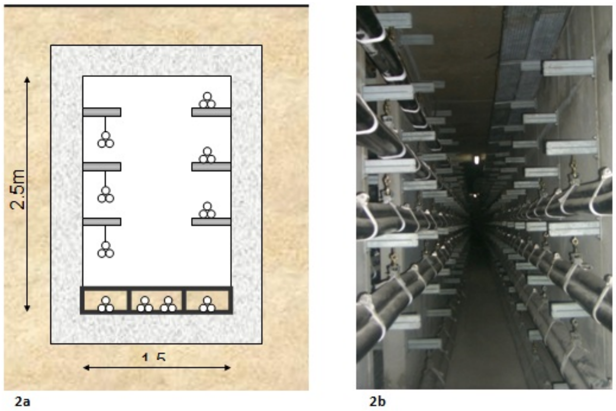

Figure 1: Tunnel installation.

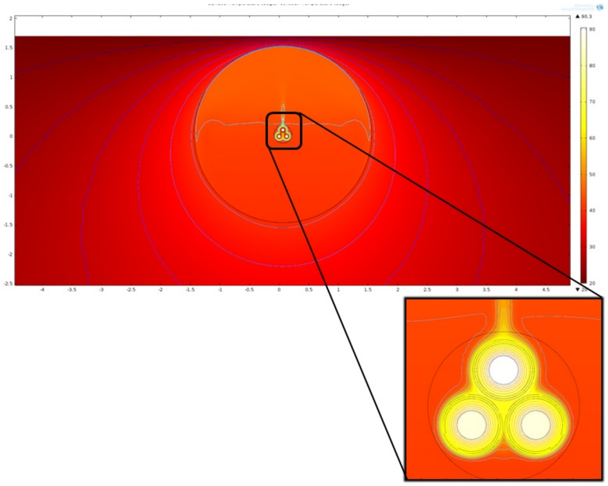

Figure 2: 2D model - Free air Temperature Results with isothems.

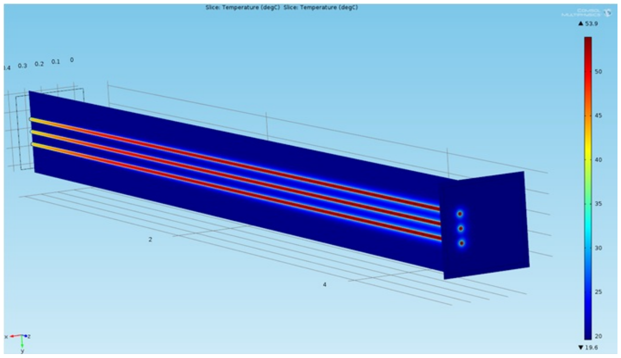

Figure 3: 3D model - Forced convection temperature results.

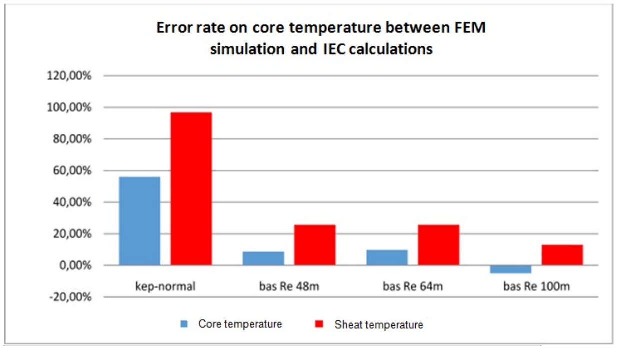

Figure 4: Turbulence models error rate comparison.