NUMERICAL ANALYSIS OF SOME HEAT TRANSFER MODELS IN HIGH/MEDIUM VOLTAGE CABLES AND SURROUNDING AREA

Gerda Jankevičiūtė, Mečislavas Meilūnas, Natalija Tumanova

EUREKA project E!6799 POWEROPT "Mathematical modelling and optimization of electrical power cables for an improvement of their design rules"

EUREKA project E!6799 POWEROPT "Mathematical modelling and optimization of electrical power cables for an improvement of their design rules"

Current IEC standards consider only standard electrical cables and the safety factors are large, that can result in 50–70 % usage of actual resources. Simulation results of heat distribution in/around electrical cables in time are necessary to optimize the usage of electricity transferring infrastructure. It is important to determine:

- maximal electric current for the cable;
- optimal cable parameters in certain circumstances;
- cable life expectancy and other engineering factors.

Cable Structure

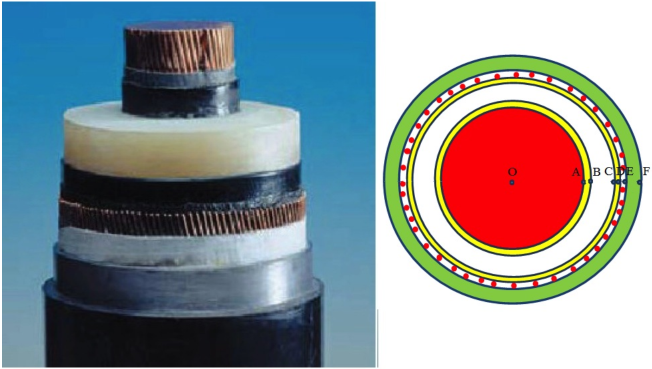


Figure : Typical high-voltage (110 kV) cables: OA– copper conductor; AB – conductor screen XLPE; BC, SC – insulation layers XLPE, DE – metallic shielding, EF – outer covering PVC;

Layout Topologies

Types of installation:

- Cables directly buried;
- Cables in pipe (pipe directly buried);
- Cables in air;

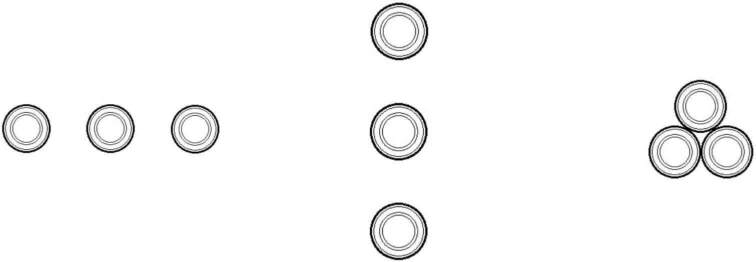
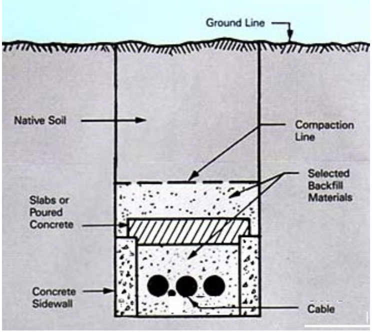
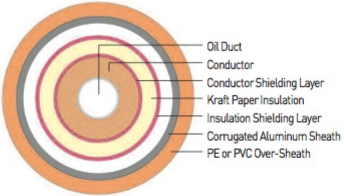


Figure : Examples of cables layout topologies: three single core cables arranged horizontally; three single core cables arranged vertically; three-core cable.

Forced Cooling

- Cooper or aluminum stab is under or over the cables;
- Plastic / aluminum pipes filled with water are laid alongside underground cables;
- Special duct with fluid (oil) flowing along the cable is installed in the cable itself.





Heat Transfer in Underground Cables

$$\begin{cases} c\rho\dfrac{\partial T}{\partial t} = \nabla\cdot(\lambda\nabla T) + q, & t\in[0,t_{max}], x\in\Omega, \\ T(x,0) = T_0(x), & \text{when } x\in\Omega, \\ T, \lambda\nabla T \ \text{ are continuous}, & \text{when } x\in\Omega, \end{cases} \quad (1)$$

here $x = (x_1, x_2)$, $T(x,t)$ is temperature, $\lambda(x) > 0$ – thermal conductivity coefficient, $q(x,t,T)$ – the source function. $\partial\Omega$ is Ω domain contour. $\rho(x) > 0$ – mass density, $c(x) > 0$ – specific heat capacity.

c, ρ, λ are piece-wise continuous only.

Boundary Conditions

- $T(x,t) = T_b$, when $x \in \partial\Omega$, where $\partial\Omega$ is Ω domain contour.
- $T(x,t) = T_{b1}$ for the upper boundary, $T(x,t) = T_{b2}$ for the lower boundary, $\frac{\partial T}{\partial x_1} = 0$ for left and right boundaries is applied for modelling conditions in winter ($T_{b1} = T_{b2}$) or summer ($T_{b1} > T_{b2}$).
- Boundary condition of third type $\lambda\frac{\partial T}{\partial x_2} = \alpha(T(x,t) - T_{air})$ is applied on the upper boundary to evaluate the environment influence, i.e. cooling effects of wind ($\alpha = \alpha(x)$) or sun radiation ($\alpha = \alpha(T)$).

Heat Transfer in Air

- Cable in air;
- Cable in pipe, pipe directly buried.

Single Cable in Air

- Model of heat conduction (1) is valid. The heat transfer equation must be solved only in the area of cables cross-section.
- Boundary condition on cable contour:

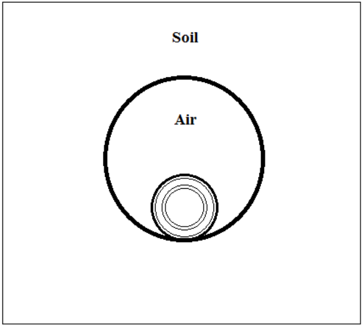
$$\lambda \frac{\partial T}{\partial \nu} = \alpha(T(x,t) - T_{air}), \text{when } x \in \partial\Omega,$$

here ν is the external normal to the surface of the cable, the averaged form of the convective coefficient α is:

$$\alpha = \left[0.1254 \left(\frac{1}{d} \right)^{1/2} + 1.0932 (T(x,t) - T_{air})^{1/6} \right]^2,$$

where d is the diameter of the cable.

Cable in Pipe



Laminar flow model for air:

$$\nabla \cdot \mathbf{u} = 0,$$

$$\rho \frac{\partial \mathbf{u}}{\partial t} + \rho \mathbf{u} \nabla \cdot \mathbf{u} - \nabla \cdot (\eta \nabla \mathbf{u}) = - \nabla p - \rho \alpha \mathbf{g} (T - T_0),$$

Heat transfer equation:

$$\rho c \left(\frac{\partial T}{\partial t} + \nabla \cdot (\mathbf{u} T) \right) - \nabla \cdot (\lambda \nabla T) = q,$$

where $\rho(x) > 0$ is the density of material in particular area, $\mathbf{u}(x, t)$ is velocity of the flow, p is the pressure, η is the dynamic viscosity, α is the thermal expansion coefficient.

Numerical experiments: Single Cables Arranged Horizontally

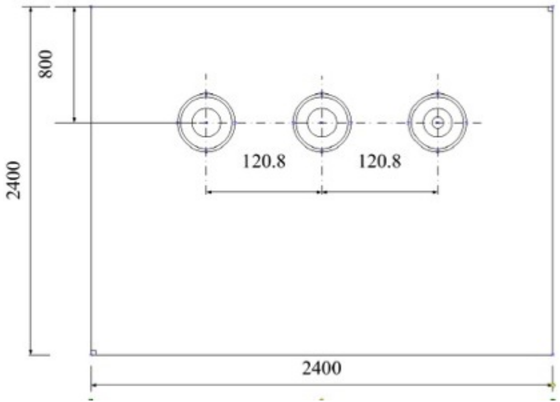


Figure : The computational domain used for investigation of the thermal state of a group of underground cables placed in a row (flat formation)

Different Types of Soil for Different Seasons

Type of soil	Density	Heat capacity	Thermal conductivity
Moist soil	2100	2000	1,11
Average moisture	1900	830	0,833
Dry soil	1400	800	0,408

Single Cables Arranged Horizontally

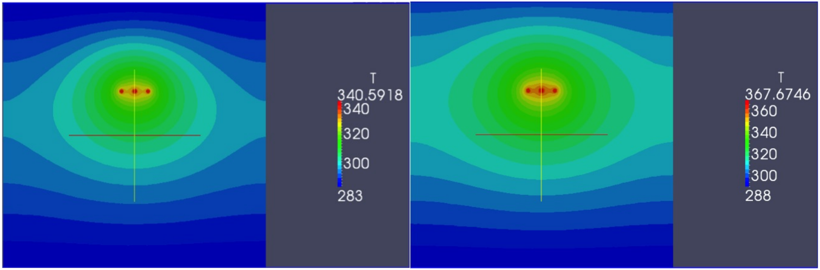


Figure : Temperature distribution around the cables with the transferred current of 940 A under the winter and summer conditions

Trefoil Cable

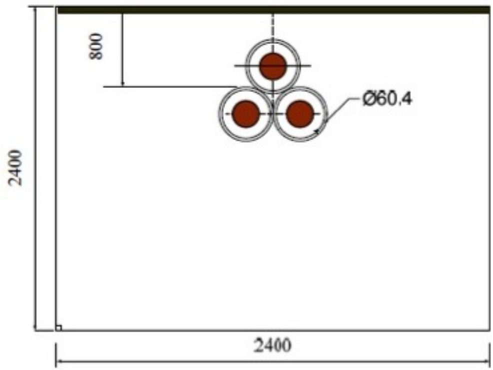


Figure : The computational domain with cables buried in the trefoil formation

Trefoil Cable

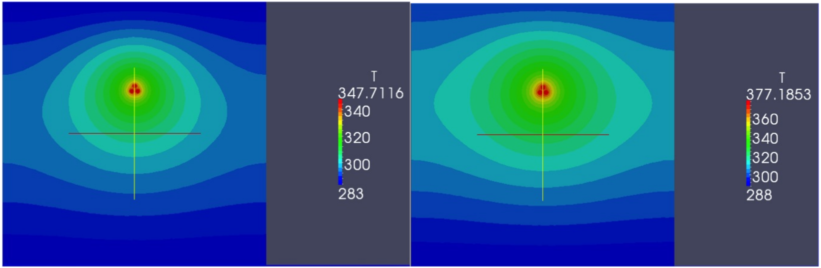


Figure : Temperature distribution around the cables with the transferred current of 940 A under the winter and summer conditions

Single Cable in Pipe

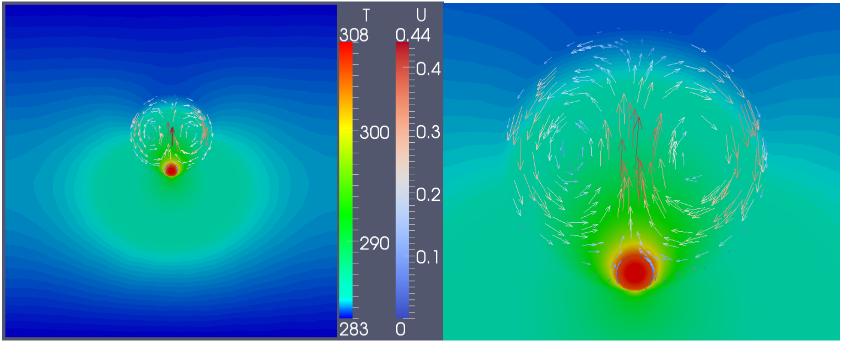


Figure : (a) Temperature and velocity flow for the single cable in pipe with the transferred current of 470 A under the winter condition; (b) zoomed part of Figure (a)

Soil Drying Models: The Simplest Approach

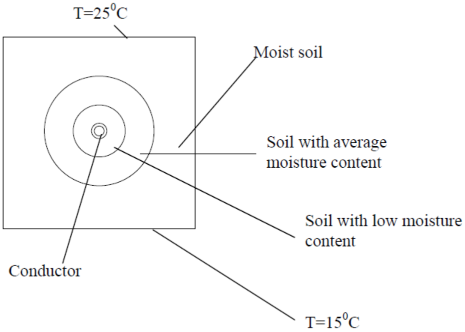


Figure : Computational domain for the case with the combined soil

Heat and Water Transfer in Porous Medium

The porous medium is considered to be rigid and unsaturated. Two phases are present: liquid (water) and (water vapor and air). The temperature of solid, liquid and gas phases are considered: $T^s = T_l = T^g = T$. Richards flow equations is obtained from the mass conservation equation for liquid phase and Darcy law, assuming relation for capillary pressure $p^c(S^l) = p^g - p^l$ ($p^g = const$):

$$\varepsilon \frac{\partial}{\partial t}(\rho_w S^l) + \nabla \cdot [-\rho_w \mathbf{K} \frac{k^l_{rel}(S^l)}{\mu_w}(-\nabla p_c(S_l) - \rho_w \vec{g})] = 0,$$

where ε – porosity of the porous medium, S^l – saturation of the liquid phase ($S^l + S^g = 1$), $\mathbf{K}$ – permeability tensor of the porous medium, $k^l_{rel}(S^l)$ – relative permeability of liquid phase, μ_w – viscosity of the water, $\vec{g}$ –vector gravitational acceleration.

For the description of the heat transfer, the energy conservation is used:

$$(\rho c)_{eff}\frac{\partial T}{\partial t}+\left[\rho_w c_w \mathbf{K}\frac{k^l_{rel}(S^l)}{\mu_w}(\nabla p_c(S_l)-\rho_w\vec{g})\right]\cdot\nabla T=\nabla\cdot(\lambda_{eff}\nabla T)+q,$$

where: $(\rho c)_{eff}=(1-\varepsilon)\rho^s c^s+\varepsilon(S^l\rho_w c_w+S^g\rho^g c^g)$ is effective heat capacity, c^s, c_w, c^g denote the specific heat capacity of the solid phase, the liquid phase (water), gas phase, respectively. λ_{eff} - effective heat conductivity.

Thank you for your attention!