COOLING ANALYSIS OF BUNDLED OVERHEAD POWER LINES

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1. Introduction

Bundled conductors are parts of the electricity supply system that provides transmission of electric power from location of power plant or distribution point to another location. Compared to classic simple electric conductors, bundled conductors provide increase in transmission power due to higher cross section of the phase conductors. In addition they reduce corona effect due to more homogenous distribution of the electric field intensity around the bundled conductor than it is in the case of single conductor of the same electric potential. It is also economic aspect to use bundle conductors than one conductor of greater cross section area because of its weight, mounting operations issues and mechanical behavior of the system.

Fig.1: *Power line equipped with bundled conductors (left), triple bundle (right).*

2. Thermal state of the power line conductors

For operation of the power lines it is necessary to know also the thermal operating state of the lines. Temperature of the electric conductors influences the electric parameters of the material − temperature dependent resistivity of steel and aluminium. Increasing these values with increasing temperature causes positive feedback due to Joule heat loses that depend on resistivity of the conductors. It means that maximum electric current transmitted by the power line is determined and limited by maximum allowed operating temperature of the conductors. Moreover, the thermal expansion of the conductor materials ensures the extension of the conductors with increasing temperature. Under high temperature conditions the mechanical tensile stress in the conductors decreases and final sag of the line increases. During critical thermal state of the line the conductors can approach or reach the grounded elements under the overhead power line (e.g. trees or other vegetation) and so cause the short-circuiting the system. Therefore the thermal state of the power lines is one of the safety aspects for operating such systems.

The most used bundle conductors are: twin bundle, triple bundle and quadruple bundle, see Fig. 2.

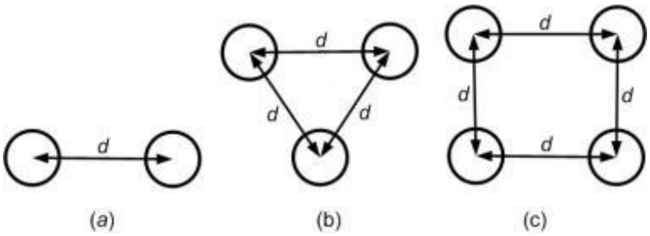

Fig.2: *Types of bundled conductor: twin- (a), triple- (b) and quadruple-bundle (c).*

3. Geometric and discretized model

We prepared numerical simulation of cooling process of the triple bundle conductor system loaded by steady electric current. Due to simplification of the model we created only the cross section part of the bundle with surrounding air area with dimensions that ensure correct air flow development around the bundle, see Fig. 3.

Distance between the conductors of the bundle was set to d = 0.4 m. Firstly, we consider only free convection around the bundle due to the rise of air temperature caused by Joule heat in the conductors. Space for free convection was considered as enclosed box with boundary walls set to the value of ambient temperature t_{amb} = 25 °C.

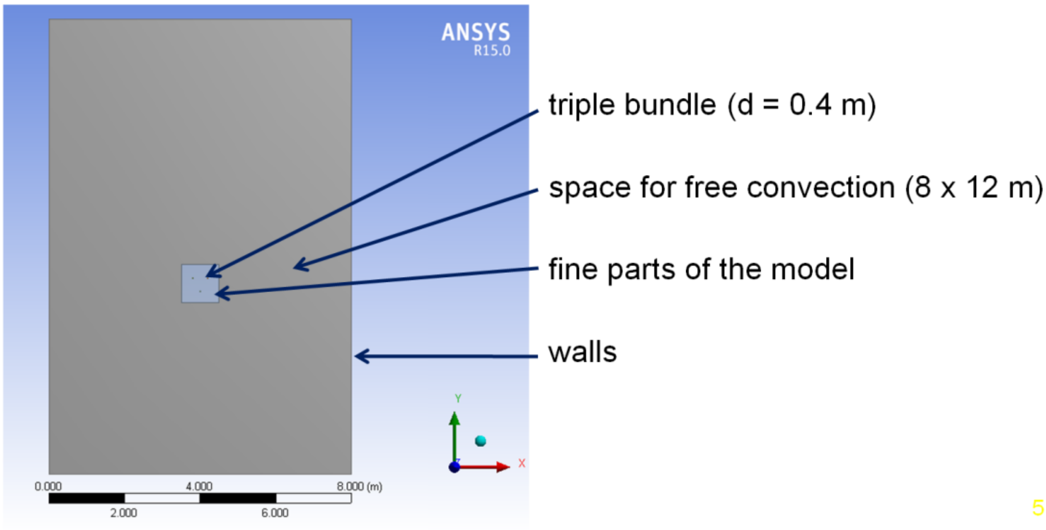

Fig.3: *Geometric model for numerical simulations.*

Fig. 4 shows discretization of the geometric model to finite volumes. The area near the solid conductors has fine mesh, also the air parts near the solid surface and near the walls are meshed more perfectly. Number of elements was 19 637.

Electric current that heats up the bundled conductors by Joule heat was I = 680 A per conductor.

The Computer Fluid Dynamics simulation (CFD) was performed in ANSYS CFX software that provides fluid-thermal analyses. Calculation process was multi-core and iterative where thousands of iterations were necessary to reach convergent results.

Also cooling processes using combined free-and-forced air flow were performed. Fig. 5 shows boundary conditions applied to such model where inlet air velocity and outlet average pressure were prescribed.

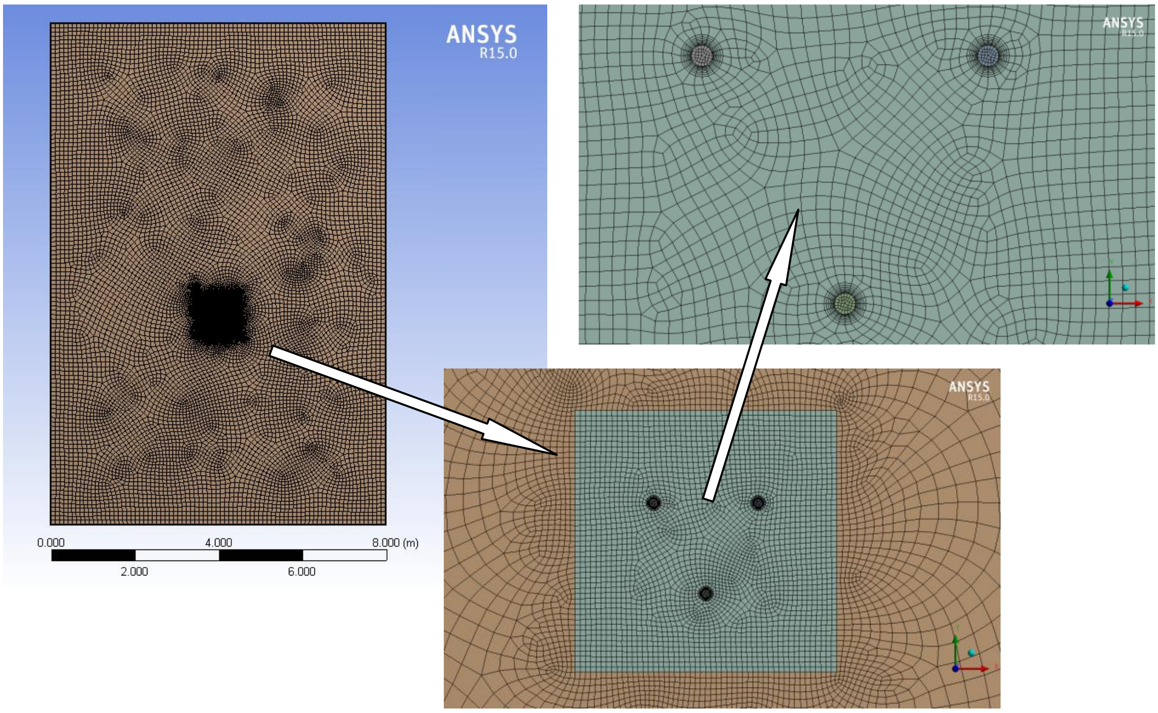

Fig.4: *Meshed model: full model (left), detail of the fine part (bottom), bundle (right).*

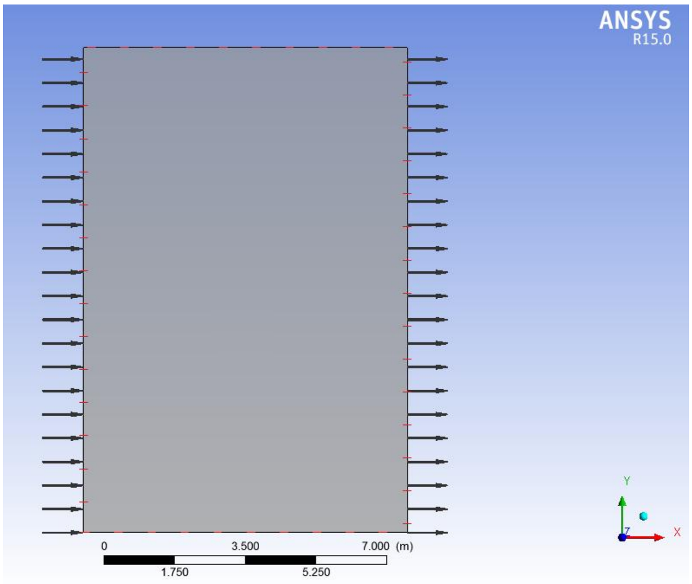

Fig.5: *Boundary conditions for forced air flow simulation.*

4. Fluid flow and thermal results

Temperature of the individual conductors of the bundle and temperature distribution of heated air around them is shown in Fig. 6. We can see that there is almost none thermal influence between the conductors under free convection conditions in the case of triple bundle (numbering of the conductors is shown in the figure).

Fig. 7 shows the combined free-and-forced cooling process of the bundled conductors. Prescribed air velocity was $v = 0.3\ ms^{-1}$ in this case (direction from left to right). Fig. 8 shows air velocity distribution near the conductors. We can see that there is notable thermal influence between the windward and leeward conductors. Leeward conductor is flowed off with air of lower velocity and also the temperature of that air is higher than ambient temperature (air heated by the windward conductor).

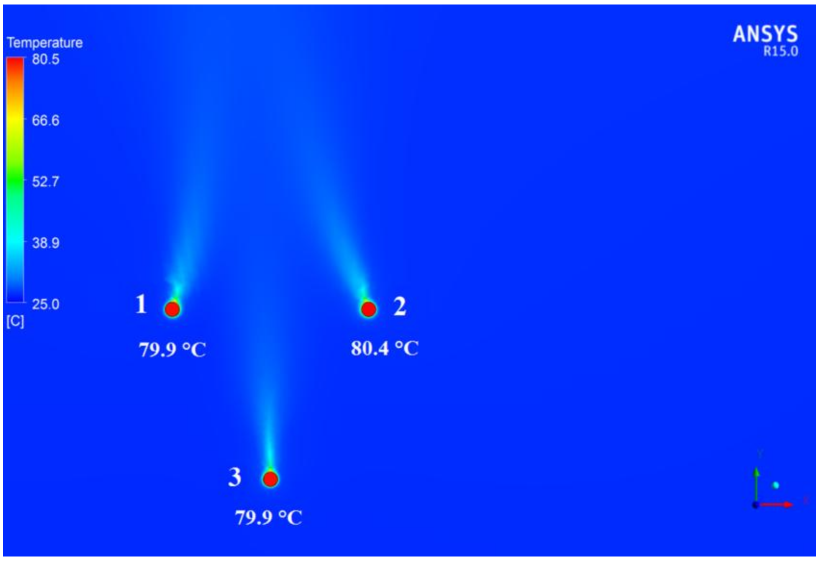

Fig.6: *Temperature distribution for free convection around bundle.*

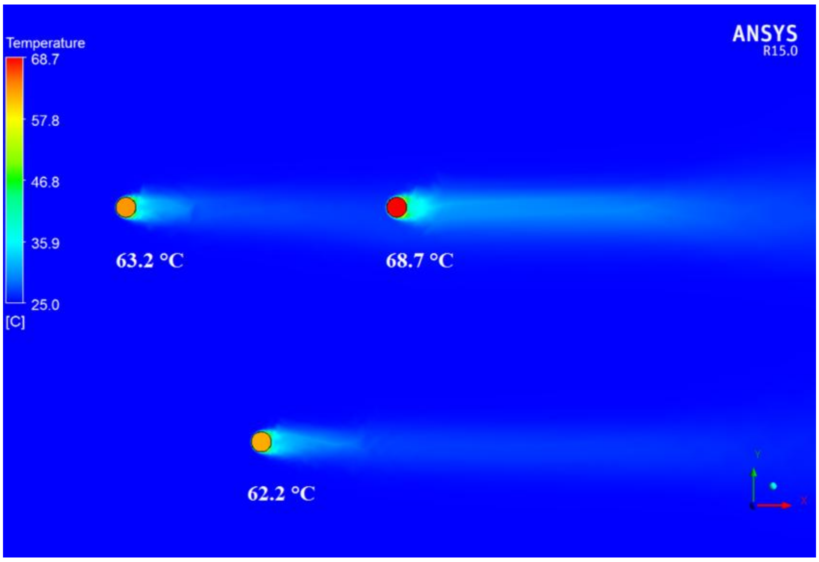

Fig.7: *Temperature distribution for forced convection around bundle.*

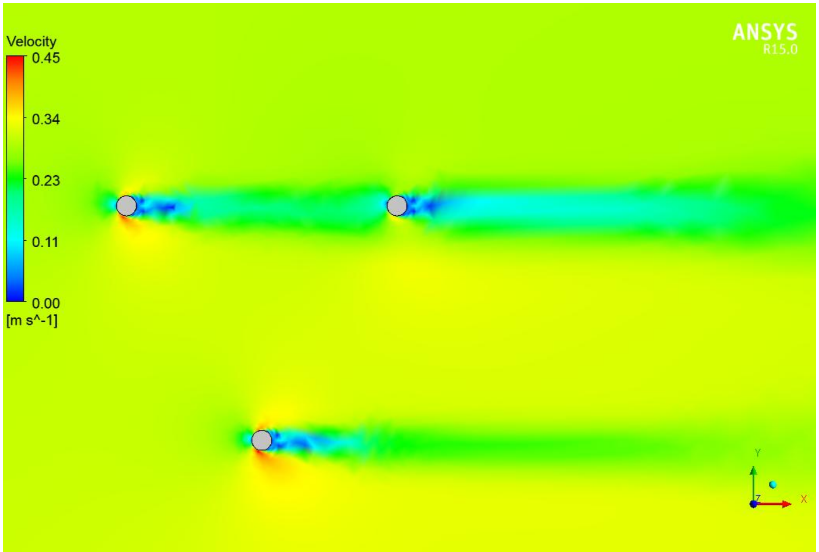

Fig.8: *Air velocity for forced convection around bundle.*

The model was calculated for different inlet air velocities (wind speeds). Final temperatures of individual conductors of the triple bundle for calculated wind speeds are shown in Tab. 1 and in Fig. 9. We can see that thermal influence is significant only in cases with low forced air velocity. Moreover, critical thermal state for cooling the conductors of the bundle is in the case of free convection (the highest temperatures of the conductors) where no thermal influence between the conductors is observed.

Tab. 1. *Temperatures of the conductors in bundle as function of wind speed.*

wind speed [ms^{-1}]	conductor #1 [°C]	conductor #2 [°C]	conductor #3 [°C]
free convection	79.9	80.4	79.9
0.2	73.6	76.1	69.1
0.3	63.2	68.7	62.2
0.5	54.4	58.6	53.9
0.8	49.0	51.6	48.7
1.0	46.4	48.1	46.2
1.5	43.3	44.6	43.2
2.0	41.3	42.3	41.2
3.0	39.1	39.8	39.1
5.0	36.9	37.5	36.9
7.5	35.3	35.9	35.3
10.0	34.3	34.6	34.3
15.0	32.9	33.0	32.9
20.0	31.9	31.8	31.9
30.0	30.7	30.2	30.7

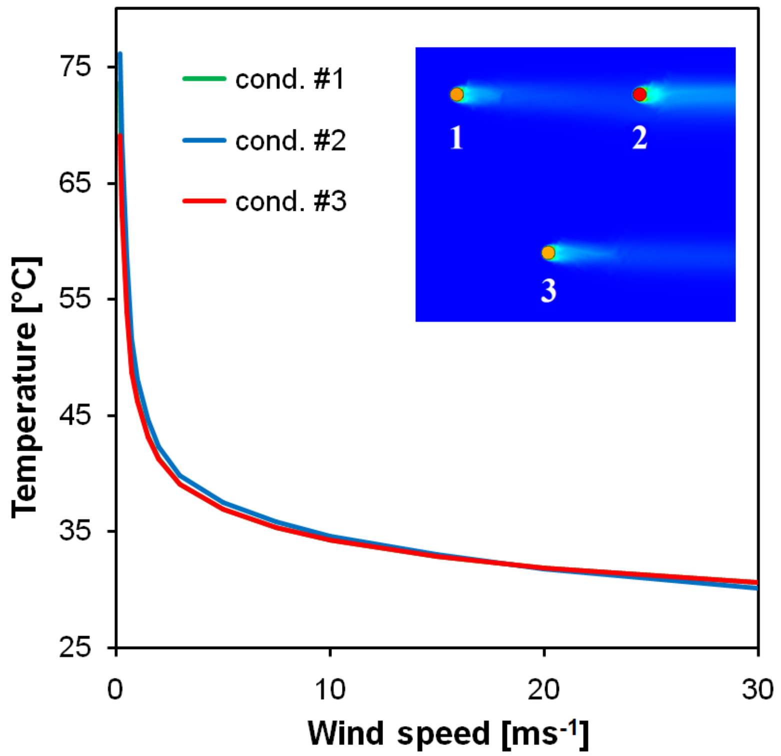

Fig.9: *Temperatures of the conductors in bundle as function of wind speed.*

5. Conclusion

Investigation of the thermal state of the power line bundled conductors is important due to limitation of transmitted electric power and safety reasons. Thermal influence between individual conductors of the bundle is significant only under low wind speed conditions whereby free convection conditions, with no mutual thermal influence in case of triple bundle, are critical. Temperature of the conductors rapidly decreases under higher wind speed conditions.

Acknowledgement

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