WOOD POLE OVERHEAD LINE STRENGTH PROBLEMS UNDER EXTREME WEATHER LOADS

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Abstract. The present paper considers mechanical strength problems of wood pole electricity distribution overhead lines. The problem of supplying power economically is also discussed from the various aspects including comparison of different conductors for overhead lines (OHL). In the present work more detailed CAD models and finite elements as well as finite volume methods, realized in CAE software and vastly verified in engineering practice, are used to obtain more accurate results. Firstly, simulations of air flow in cases of different shape of forest cutouts are conducted to evaluate wind loads acting on OHL components as well as on conifer and foliage trees grown along OHL footpath. Thermo and ice loads of the conductors are also taken into account. Two conductor types are analyzed: bare cables consisting of stranded aluminium wires and reinforced aluminum cables with a steel core which are typically used in medium voltage OHL. To obtain results with the appropriate computer resources, the equivalent characteristics (elastic modulus, etc.) of wires are identified by conducting physical experiments on a testing machine as well as by solution of a nonlinear contact problem for conductor consisting of a steel core and stranding aluminum wires. Buckling analysis of different types of trees and OHL poles as well as frequency analysis are performed.

Keywords: wood pole overhead lines, strength, metamodeling, finite element method, finite volume method.

Introduction

In recent years serious problems were observed in Latvian rural areas in the medium voltage electricity distribution networks. Due to global climate changes the extreme weather loads are the cause of frequent failures and electricity interruptions for rural consumers. In the winter 2010 – 2011 OHL damages (Fig. 1) were caused by the combination of many weather conditions at the same time such as snow, rain at negative temperatures, frequently changing direction of strong wind, icing and others.

Fig. 1. **Ice-covered trees hang on OHL (left) and damages of OHL (right) in Latgale region**

Till now mechanical calculations of OHL were implemented in accordance with appropriate state standards, using analytical methods based on classical OHL calculation theory and appropriate hypotheses [1; 2]. The theoretical results could be rough and strength of OHL could be overstated. In this work another strength analysis approach is considered based on the 3D models, finite element method (FEM) and finite volume method (FVM). Modern CAD/CAE software gives an opportunity describing the mechanical models with distributed masses accurately and also taking into account such parameters like material thermo expansion stresses, wind loads, materials friction and nonlinear properties. As a result the calculations could be more accurately and could be done for the specific Latvia weather.

Simulations of air flow in cases of different shape of forest cutouts

Determination of the wind loads on the OHL and the surrounding forest is an actual problem [3; 4]. Probability of trees falling on the OHL could be also analyzed. Conifer and mixed conifer-foliage trees are two more common types of the forests in Latvia. The forest models are shown in Fig. 2b and Fig. 2d respectively. The FVM is used by SolidWorks (SW) Flow Simulation for solution of the Navier-Stokes equations. The wind flow is shown (Fig. 2a) by arrows acting in normal direction to the OHL axis. As calculations indicate the conifer-foliage mixed forest absorbs wind energy more effectively. The velocity of wind close to OHL decreases essentially. It is also possible to make cutouts of the forest near OHL (Fig. 2c). Comparing Fig 2b with Fig 2c, the velocity of wind near OHL is less in the cutout case, the trees also have more possibilities to fall in the side directions (not normal to the OHL axis) if the wind direction is changing. In the forest cutout case the wind velocity on OHL in areas, where trees are farthest from the OHL, is reduced by 72 %, but in regions, where trees are closest to the line, the wind velocity drops by 86 %.

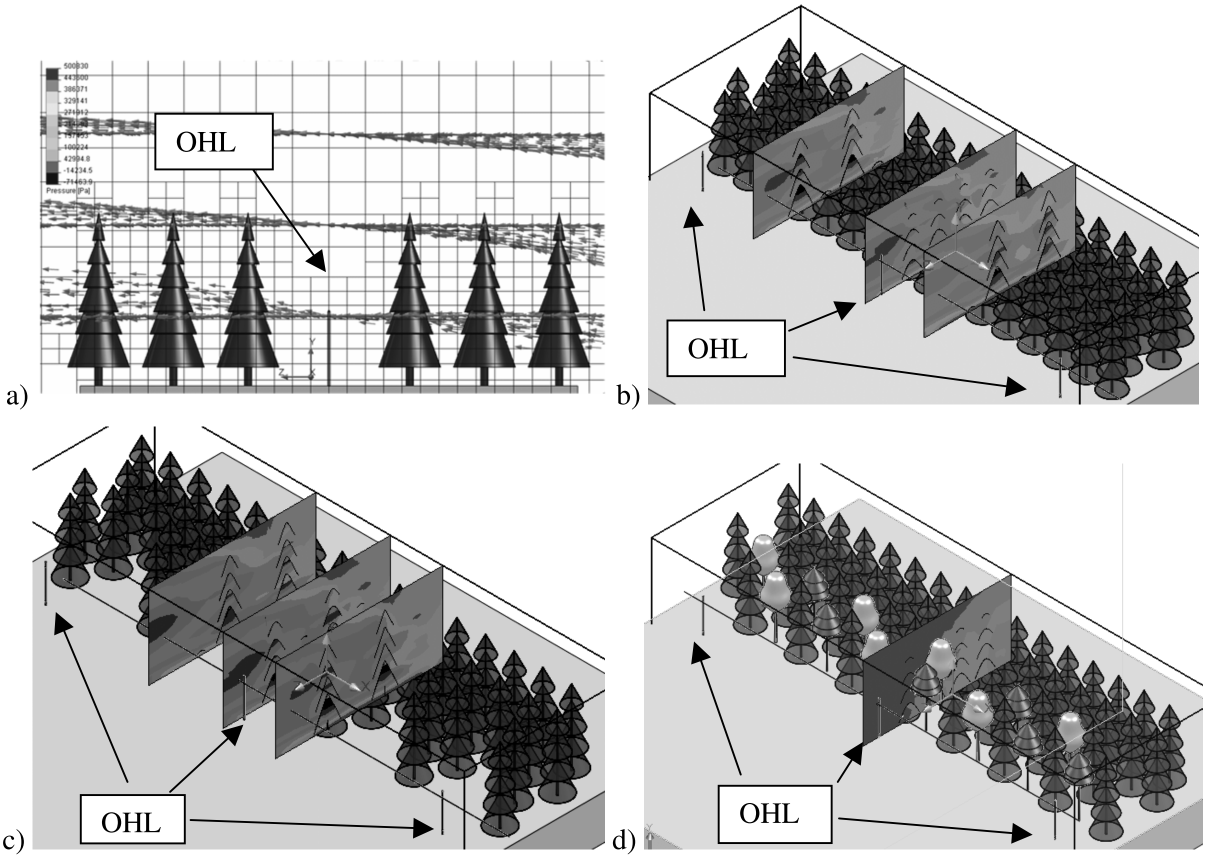

Fig. 2. **Simulations of wind loads:** a – d**iscretization of** model and wind flow (side view); b – wind flow in spruce (picea abies) forest without cutouts; c – spruce forest with cutouts; d – birch (betula pendula) and spruce mixed forest

The results are very much dependent on the forest structure (tree type and height, forest density, etc.). The obtained wind loads are used in the strength analysis of the wires and individual OHL wood poles. Additional analyses are necessary for the thorough assessment of the cutouts shape effect. For the cutouts shape optimization the nonparametric metamodeling approach using [5 – 7] is planned.

Strength of wood pole

The basic 20 kV OHL model consists of the conductors in two span lengths supported by three poles (Fig. 3a) with appropriate armature. One of the considered geometric models of a pole is given in Fig. 3b. The pole and armature parameters are taken from [8; 9]. The calculations with different sizes of FE are done (Fig. 4) to determine the accuracy of the results. FE with average size 140 mm in comparison with the size 20 mm gives difference of the maximal pole displacement 4.8 %, but with average size 120 mm – only 2.9 %. So the latter size of FE is used in the computations.

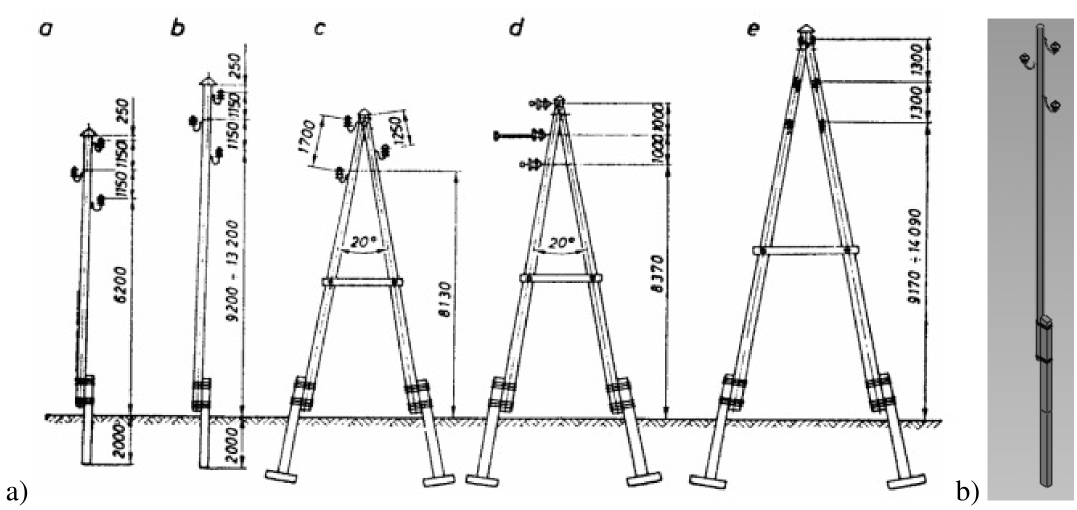

Fig. 3. **20 kV wood pole frequently used in Latvian rural areas**

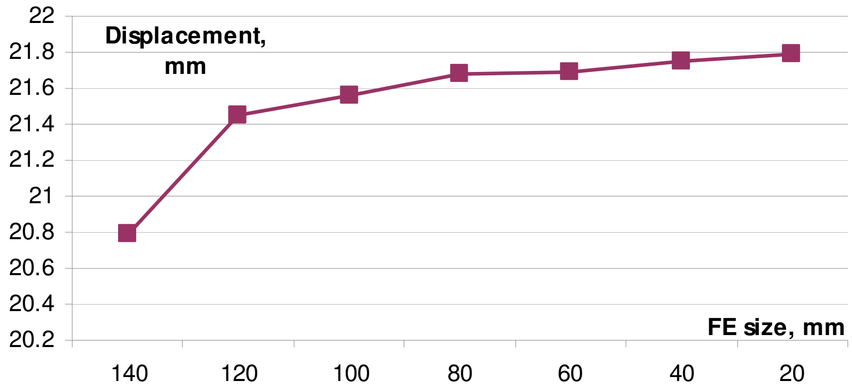

Fig. 4. **Pole maximal displacement dependence on FE average size**

The maximal von Mises stress in the pole is 8.9 MPa and maximal displacement ~22 mm (Fig. 5a) due to the wind load 336 N·m^{-2} that is corresponding to the II wind region of Latvia with reduction of 16 % [11]. As we can see in Fig. 5.b and 5c the pole construction is safe from the considered wind load and it could not be damaged without any additional loads (from falling trees, extreme icing).

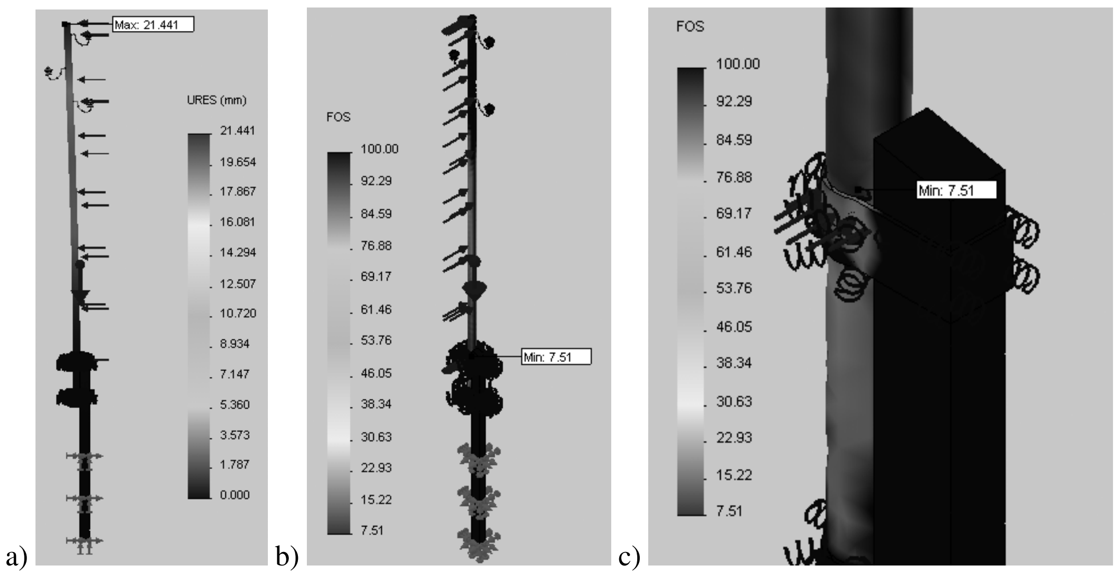

Fig. 5. **FE analysis of wood pole strength:** a) Displacements from wind load, b) FOS and c) Place with minimal FOS

The obtained results could be used in dynamics calculations because throbbing wind could create vibration at the OHL axis and can cause significant fluctuations in wires.

Mechanical strength of conductors

From all the variety of conductors used in OHL only the most common types are investigated, especially, bare cables stranding from seven aluminum wires as well as aluminum cables with a steel core. They are sufficiently complex objects. So initially behavior of a short length cable with one or few turns of wires is evaluated in order to analyze the physics of deformation and get the equivalent parameters for simplified models of long span cable. The aluminum wire with a steel core is particularly actual.

Firstly, the strength of aluminum and steel-aluminum wires is tested on the pulling machine Zwick Roell [11]. From the experiments the constants of wires with different service life are obtained. For example, the cable AT50 components (from Latgale region OHL) pulling charts are presented in Fig. 6. The obtained properties of aluminum wire: tensile strength $\sigma = 160$ MPa; density $\rho = 2705$ kg·m^{-3}; modulus of elasticity $E = 69000$ MPa; thermal expansion coefficient = = $2.39 \cdot 10^{-5}$ (ºC)$^{-1}$; Poisson ratio $\nu = 0.33$. The steel wire properties: tensile strength $\sigma = 1280$ MPa; density $\rho = 7700$ kg·m^{-3}; modulus of elasticity $E = 210000$ MPa; thermal expansion coefficient = = 1.3·10-5 (ºC)$^{-1}$; Poisson ratio $\nu = 0.28$. The convolution step of the cable AT50 wires stranding is 21.2 cm. Next, the cable AT50 FE model is created and a nonlinear contact problem (Fig. 7) is analyzed. The obtained equivalent characteristics are tensile strength $\sigma = 304.4$ MPa; density ρ = = 3900 kg·m^{-3}; modulus of elasticity $E = 84850$ MPa; thermal expansion coefficient of $1.92 \cdot 10^{-5}$ (ºC)$^{-1}$; Poisson ratio $\nu = 0.28$.

The cable model with equivalent material characteristics and simplified geometry is used for the 60 m length of span analysis. The standard tension force 1463 N of the bare cable at the temperature -5 ºC as well as the loads from wire icing are taken into account. The extra loads on the cables and OHL are defined by the icing layer thickness that could reach 20 mm at the extreme weather condition [8]. The results are presented in Table 1. As we can see, AT50 wire can sustain up to 50 mm icing at -5 ºC.

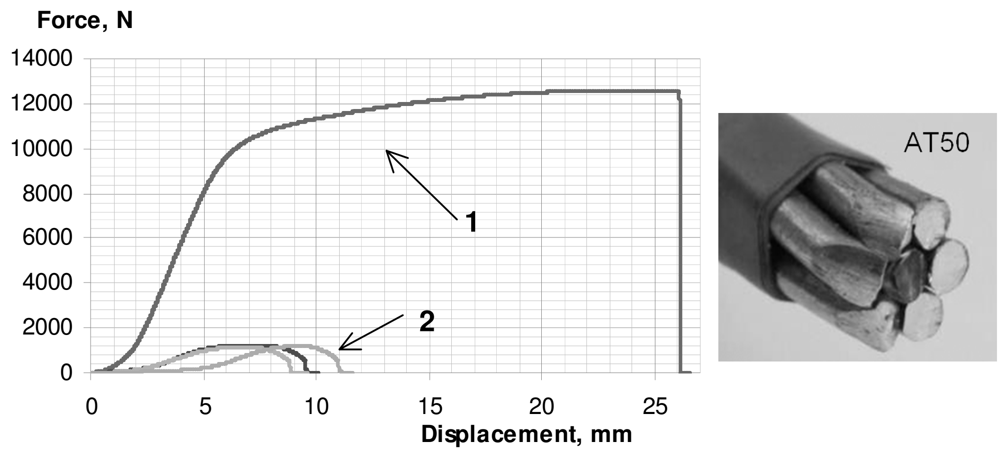

Fig. 6. **Pulling charts of components of conductor AT50:**
1 – steel core wire; 2 – aluminum wires of stranding

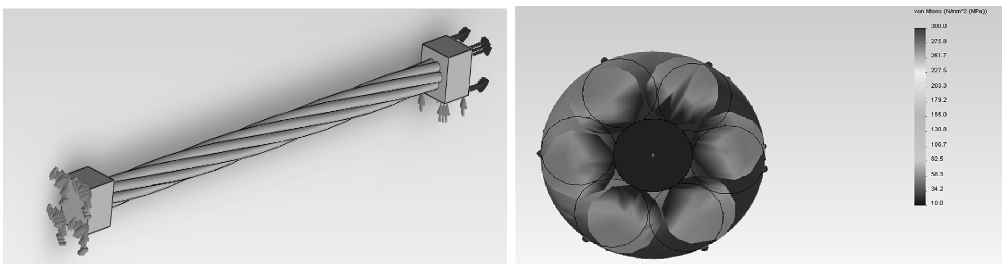

Fig. 7. **Model of cable AT50 for FE strength calculation (left) and von Mises stress distribution in cross-section of cable for nonlinear contact problem model (right)**

Table 1

Characteristics of cable AT50 with 60 m span at different thickness of icing at -5 ºC

Wire icing layer thickness, mm	Ice weight kg·m^{-1}	Wire maximal displacement, m	Loads from icing, N	Wire tensile stresses MPa	Wire tension force N	FOS
0	0.00000	0.654	0.0	23.2	1305.3	13.10
15	1.06303	1.220	625.7	85.0	4776.1	3.58
30	3.42244	1.738	2014.5	171.0	9608.6	1.78
50	8.58490	2.249	5053.1	309.0	17371.0	0.99

Cable frequency analysis

The 4 first natural frequencies for the cable AT50 are obtained using the FE analysis (Table 2). The cable with 60 m span between the poles is analyzed and the standard tension force 1463 N of the cable at the temperature -5 ºC is taken into account [10].

Table 2

Cable AT50 natural frequencies

Mode No.	Frequency, Hz
1	4.298
2	8.597
3	12.896
4	17.198

Buckling analysis of different types of trees

In literature a variety of models for tree stability [12; 13] are considered. In this work FEM models are used and calculations for two types of trees – spruce and birch are performed. Firstly, snow distribution and the icing loads are defined (Fig. 8a; 8b). The characteristics of live wood are obtained from the source [14]. Buckling analysis of birch and spruce is performed for the loads that take into account the extreme weather conditions over the investigated period of time. The crown of the tree branches load, equivalent to the icing with 2.2 cm thick layer of ice is assumed. Stability of the individual tree with the trunk diameter at the base of 30 cm and height of 15 m is calculated (Fig. 8c). It is shown that the birch will lose stability from the ice load 1331 kg, but the spruce from 2930 kg will not lose stability.

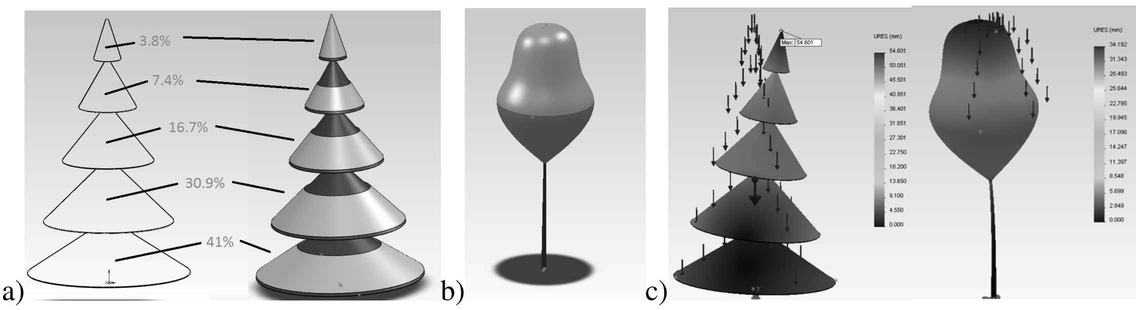

Fig. 8. **Buckling analysis:** a – model of spruce and snow distribution; b – model of birch with snow; c – FE analysis of trees

Conclusions

FEM calculations of strength of the OHL wood poles show that they have sufficiently large safety factors. The cables used in OHL have a sufficient reserve of strength and meet the LEK 015 standard [10], especially those with a steel core (cable AT50). The OHL elements have enough strength to stand strong winds (with the velocity 25 m·s^{-1}). The cable AT50 has enough strength and could not be broken from standard tension and static icing loads observed in Latgale region. As a result, any significant extra load (extreme icing with more than 20 mm, falling trees) must be applied to the cable or to OHL construction in the winter conditions to cause serious damages. The stability of the trees is affected by snow load more seriously than a short sudden gust of wind.

Acknowledgments

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