Simulation of stochastic wind action on transmission power lines

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Abstract

The paper presents FEM analysis of the wind action on overhead transmission power lines. The wind action is based on a stochastic simulation of the wind field in several points of the structure and on the wind tunnel tests on aerodynamic coefficients of the single conductor consisting of three wires. In FEM calculations the section of the transmission power line composed of three spans is considered. Non-linear analysis with deadweight of the structure is performed first to obtain the deformed shape of conductors. Next, time-dependent wind forces are applied to respective points of conductors and non-linear dynamic analysis is performed.

Keywords: FEM, wind action, overhead transmission power lines, wind tunnel, stochastic simulation of wind field

1. Introduction

Large modernization works of 110 kV and 400 kV overhead transmission power lines are conducted in Poland. One of the main loads acting on this kind of structures is the wind load. Consideration of the wind load requires time consuming non-linear dynamic calculations. In the literature several different approaches to the wind action can be found. For example the FEM model of the overhead power line consisting of two spans were used in [1] to analyze dynamic coupled response of lines and towers to wind action. Field measurements on three long transmission lines together with FEM analyses were presented in [2].

The FEM modeling of the section of power line consisting of conductors composed from the group of three wires is presented here. Time dependent wind field is simulated as the stochastic process in time and space. Aerodynamic coefficients are based on the wind tunnel measurements.

2. FEM model of transmission power line

In this work, a section of the 400 kV high-voltage overhead transmission power line consisting of two anchor poles Y52O and two straight-line poles Y52P are presented. The section is limited to three spans, each of 450 m. The structure is located in the first wind zone, in the open terrain (category I), and in the first icing zone. The section of the line is presented in Figure 1.

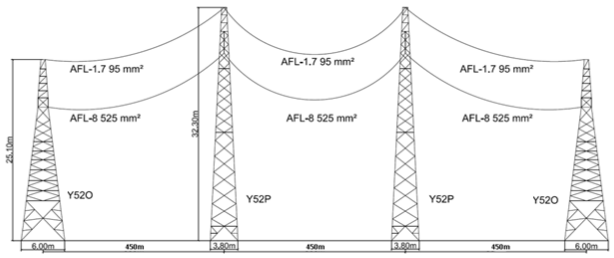

Figure 1: Section of the overhead power line

In the FEM model a group of 3 AFL-8 525 conductors arranged in a triangle with a vertex directed downwards is used as the phase conductor. The total cross-section area is equal to 586.9 mm^2, the calculated breaking force is equal to 159.86 kN. Phase conductors are modeled as non-linear truss elements with initial elongation of 0.15%.

3. Simulation of stochastic wind field

The non-linear dynamic analysis of the wind action was preceded by the non-linear analysis of the line under the effect of deadweight only. The deformed form of the power line was obtained in this way.

For the purpose of the dynamic analysis 68 points located every 20 m along the power line were chosen. The simulation of the stochastic wind speed field was performed in these points. Two components of the wind speed u, w – horizontal (along axis y) and vertical (along axis z) perpendicular to the line – in every point were generated at each time step. The space coordinates of points were determined for deformed construction under the influence of deadweight. The Figure 2 shows a half of the power line with points where the wind speed field was generated.

The following main parameters of the wind speed simulation were assumed: the number of time steps – 8272, the time step – 0.01 s, the time shift due to time required for the non-linear analysis related to the deadweight – 80 s. The total time of simulation was equal to 162.72 s. The average wind speed at 10 m was equal to 25 m/s. Weighted Amplitude Wave Superposition (WAWS) method was used in simulation.

An example of the wind speed components u and w in point 23 (in the axis of the straight-line pole) is shown in the Figure 3.

4. Estimation of wind forces

The resultant wind speed V_w on the basis of two components was determined. The angle of the resultant vector against the line was also determined. For every angle of wind attack repective aerodynamic coefficients were assumed on the basis of wind tunnel tests performed on the section model of the group of three wires (Figure 4).

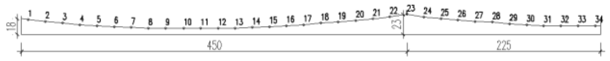

Figure 2: Points of stochastic wind field generation

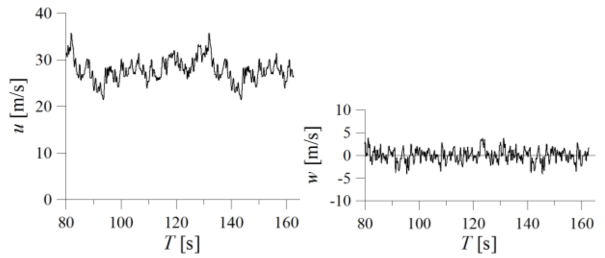

Figure 3: Wind speed components *u* (left), *w* (right) in point 23

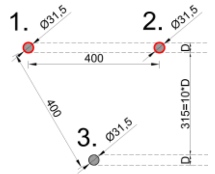

Figure 4: Group of 3 wires in single conductor in wind tunnel

The aerodynamic coefficients $C_y(\varphi)$, $C_z(\varphi)$, $C_m(\varphi)$ were determined in wind tunnel tests. The aerodynamic coefficient C_y for windward wires No 1 and No 3 was constant and equal to 0.95. The aerodynamic coefficients C_z and C_m were close to zero for these wires (C_z = -0.02, C_m = 0.01). The aerodynamic coefficients $C_y(\varphi)$, $C_z(\varphi)$ in the function of the angle of wind attack for the leeward wire No 2 are shown in Figure 5.

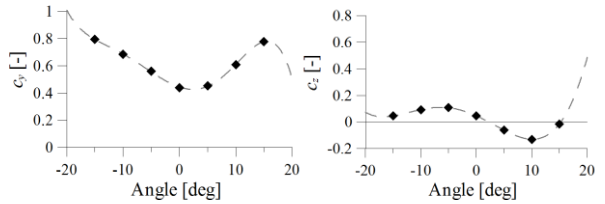

Figure 5: Aerodynamic coefficients for leeward wire No 2 in the function of the angle of wind attack, a) $C_y(\varphi)$, b) $C_z(\varphi)$

The following aerodynamic forces depending on the angle of wind attack can be estimated:

Drag force: $F_n(\varphi) = 0.5\rho V_w^{\,2} d C_y(\varphi)$ (1)

Lift force: $F_c(\varphi) = 0.5\rho V_w^{\,2} d C_z(\varphi)$ (2)

In above equations ρ is the air density, *d* is the cross-section dimension in the direction perpendicular to the wind action.

Wind forces were calculated in selected points on the basis of instantaneous wind speeds. The forces were again decomposed in two components F_y and F_z. In every point the forces were applied to the three wires forming single conductor. The example of wind forces in point 23 is presented in Figure 6.

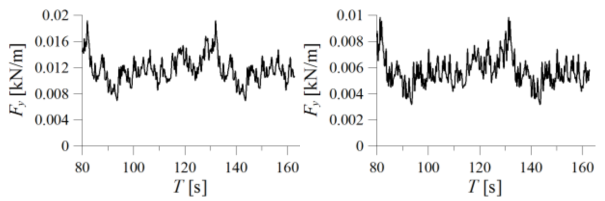

Figure 6: Time history of F_y in point 23 for windward wire (left), leeward wire (right)

The example of displacements of the whole phase conductor and the examples of displacements in the point at suspension of the phase conductor on the straight-line pole (point 23) and in the middle of the span between two straight-line poles (point 34) are presented in Figure 7 and 8, respectively.

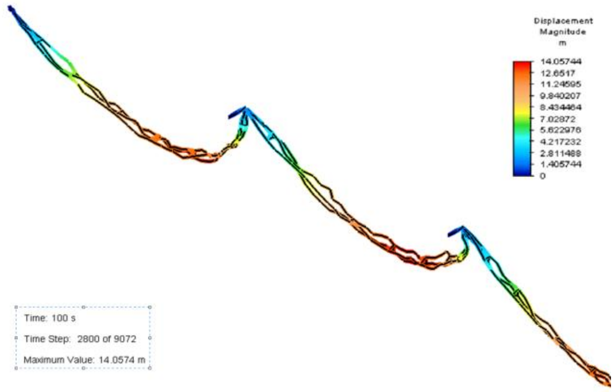

Figure 7: Displacements of the conductor in time t = 100 s

a) b)

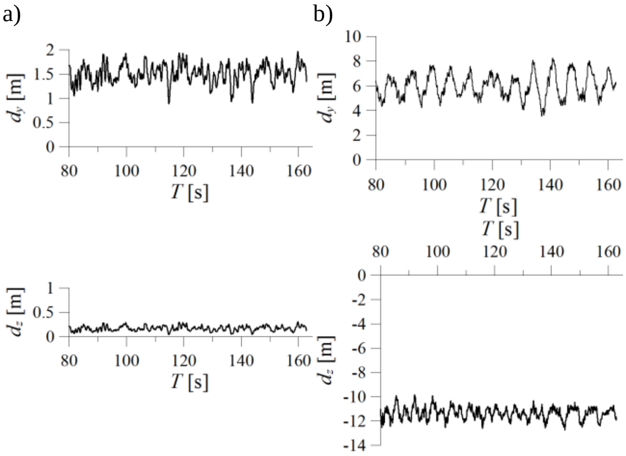

Figure 8: Time history of displacements a) in point 23 at the windward wire, d_y (top), d_z (bottom), b) in point 34 at the windward wire, d_y (top), d_z (bottom)

5. Conclusions

On the basis of the non-linear analysis of the wind action on the section of power line composed of the conductor consisting of three wires the following conclusion can be formulated:

- vertical displacements do not exceed 13.2 m,
- horizontal displacements do not exceed 8.1 m,
- the axial forces in the AFL-8 525 conductor reaches 100 kN. This is a safe value because the nominal RTS tensile strength in this type of conductors is 160 kN.

References

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