HURRICANE SIMULATION ON POWER TRANSMISSION LINE

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Abstract. *- The hurricane winds are characterized by high speeds, at which the « drag crisis » regime of flow around cable is achievable. That is why, in the calculation of the wind-induced movement of the overhead transmission line during hurricane, it is important to represent the cable aerodynamic drag as Reynolds-dependent. In order to assess the behaviour and fatigue resistance of the transmission line conductor under hurricane conditions, the Reynolds-dependent drag coefficient was introduced in the SAMCEF Mecano finite-element software. To represent the hurricane wind loading, the turbulent, spatially non-uniform wind model was used. Results of comparative study of the smooth cable AERO-Z and the classical multistrand cable, including the percentage of load reduction offered to supporting structure, are presented.*

INTRODUCTION

Following known observation statistics, every 50 years the hurricanes of mean velocity 30 to 40 m/s occur in many coastal areas of Europe [7]. Since the gusts in such cases are of even greater velocities, and the impact on structures is hard, it is important to properly assess the response on hurricane, especially the buffeting response. The technique of simulating the behaviour of the transmission line conductors follows the general approach [2, 10]. This approach relies on two aspects: the correct modelling of cable aerodynamic plus an adequate model of wind.

In what follows, the application issues of both models will be discussed and illustrated on basis of comparative study, done jointly by ULG and Nexans/Benelux. This study aimed to assess the effect of equipping the line, susceptible to the hurricanes, with a smooth conductor. As the latter we studied AERO-Z (made of fully-locked Z-shaped external strands), and as the classical analogue, Aster570 conductor. The response analysis was done in time domain with the aid of finite-element software SAMCEF Mecano/Cable [12].

CABLE AERODYNAMICS

Given ρ the air density (kg/m^3), D the conductor's diameter (m), and the drag coefficient C_D, the aerodynamic load per unit length of the cable is defined by the general expression:

$$F_D = \frac{\rho V^2}{2} D C_D \qquad \text{(N/m)} \qquad (1)$$

Here, the instant wind velocity V (m/s) is found from the relationship

$$\mathrm{V} = \mathrm{U} - \mathrm{V}_c \qquad (2)$$

$\mathbf{V}_c$ being the vector of relative cable velocity (m/s);

U is the vector of the wind speed (m/s), which is defined after the model described below.

In hurricane winds, the particular importance should be paid to representing the dependency of the cable drag coefficient, C_D, on the Reynolds number, $\mathcal{Re}$. When the turbulence in the flow begins to develop in the boundary layer on cable surface[1] (*critical* state or *drag crisis*), C_D drops sharply (see the curve for smooth cylinder, Fig. 1). It is known [1], that with the rougher cable surface, the critical Reynolds number ($\mathcal{Re}$) is lower. The dependencies $C_D(\mathcal{Re})$ for the studied conductors, obtained from wind tunnel tests are shown in Fig. 1. With the diameter of conductors about 30 mm (quite characteristic for transmission line) and hurricanes about 30 and 40 m/s, we obtain $\mathcal{Re}$= 60.e3 and 80.e3 correspondingly. Thus, in hurricane the „critical" values of C_D are easily reached for both classical and smooth conductors.

Again, the performed wind-tunnel tests demonstrated, that the surface roughness also influences the rate of C_D decrease. Therefore, the effect of critical and supercritical flow on aerodynamic loading of the cable becomes less noticeable on classical conductors.

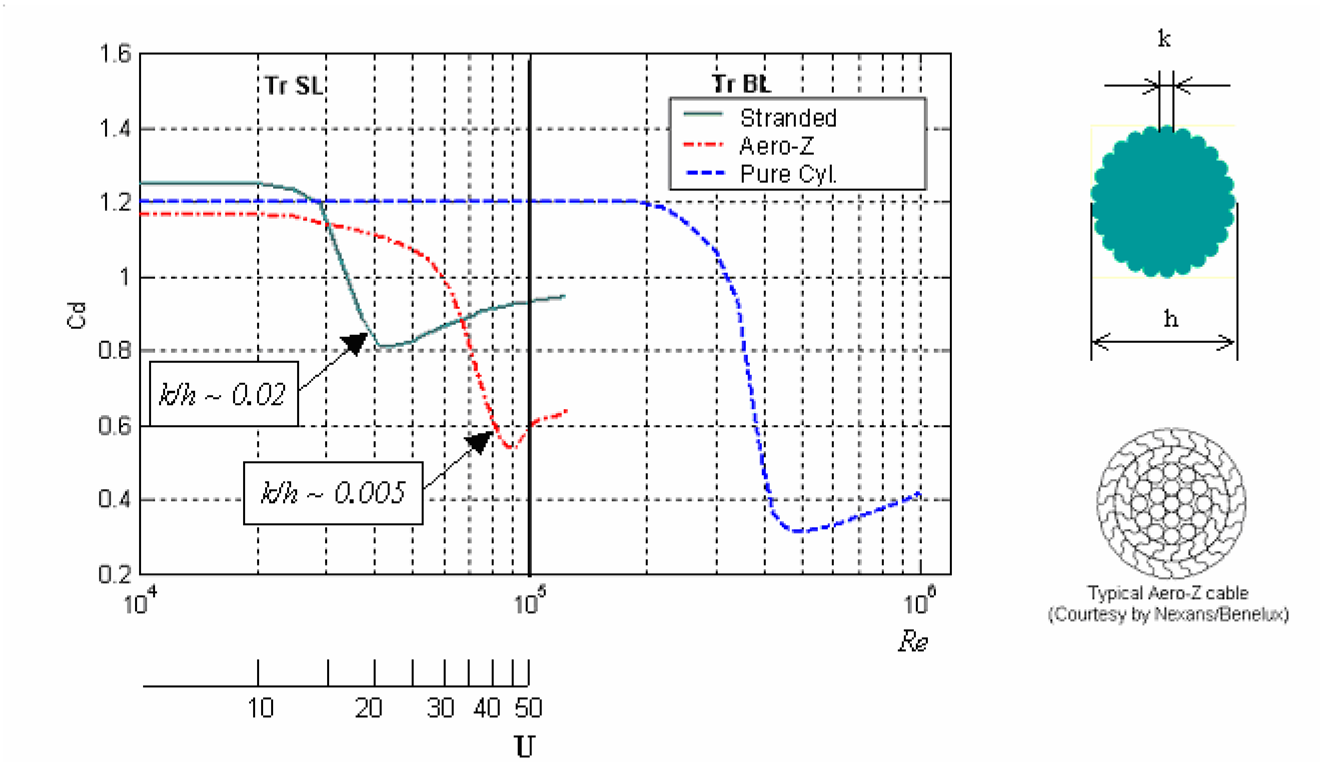


Fig. 1. Drag crisis curves for smooth and classical stranded conductors, compared to the pure cylinder. *k/h* indicates the equivalent surface roughness. Below the cross-section of typical conductor Aero-Z is shown.

MODEL OF WIND

In expression (2), the parameter U stands for the turbulent wind speed. The latter is due to the turbulence of very different scale, being produced in the atmospheric boundary layer near the Earth surface. After the basic approach, U value is considered as the sum of mean and fluctuating

[1] Firstly observed on spheres by Constanzi and Eiffel in 1912, this phenomenon was then obtained on cylinder by Taylor in 1916 and Fage in 1928 for similar conditions [10].

components:

$$U(x,y,z,t) = \bar{U}(z) + u_{wind}^{fluct}(x,y,t) \tag{3}$$

Here, $\bar{U}(z)$ defines the mean wind speed defined after power or logarithmic law with respect to the height over ground, z;

$u_{wind}^{fluct}(x,y,t)$ defines the time-dependent, space-correlated wind fluctuations. Of several statistical models of turbulent wind, (Davenport, Harris, Von Karman and others) the choice depends on the range of main excitation frequencies, but also on the formulation of turbulence scales. In particular, the Counihan's empirical model of turbulence scale (as was our case) is explicitly included into Von Karman spectrum:

$$\frac{\omega S(\omega)}{\sigma^2} = \frac{\dfrac{\omega L_u(z)}{\pi \|\mathbf{U}_{wind}(z)\|}}{\left(1+\left(\dfrac{4.2065\omega L_u(z)}{\pi \|\mathbf{U}_{wind}(z)\|}\right)^2\right)^{\frac{5}{6}}} \tag{4}$$

Here,

$S(\omega)$ is the fluctuating component's power spectrum density ($m^2 s/rad$);

ω is the cyclic frequency of the wind fluctuation (rad/s),

U_{wind} is the mean wind speed (m/s),

L_u is the turbulence scale (m) in the direction of the mean horizontal wind speed, giving idea of the eddy size. In this analysis, it was defined after Counihan's model;

σ is the standard deviation of the wind speed fluctuations (m/s).

U_{wind} and L_u are function of vertical coordinate z , but they do not depend on the ground roughness.

The parameter σ may be found by two ways, depending on the field measurements. The first way consists in experimental definition after the basic expression

$$\sigma^2 = \int_{-\infty}^{+\infty} S(\omega) d\omega \tag{5}$$

Another approach (used in our analysis) permits to define σ from the value of the reference wind speed, $\|U\|_{wind}^{ref}$, and the turbulence intensity I (in percent):

$$\sigma = I \cdot \|U\|_{wind}^{ref} .$$

The spanwise correlation of the turbulent wind was introduced into the model via the coherence function over the discrete wind samples, defined with respect to the central fluctuation frequency. As the latter, we used the basic eigenfrequency of transmission line span (0.18 Hz).

Two samples of resulting fluctuating components of the wind are shown in Fig. 2, (a) and (b). The initial Von Karman spectrum is shown in Fig. 2, (c) together with the spectrum recovered after SAMCEF simulation.

The ensemble of time-dependent, spanwise-correlated samples of wind velocity is illustrated in Fig. 3.

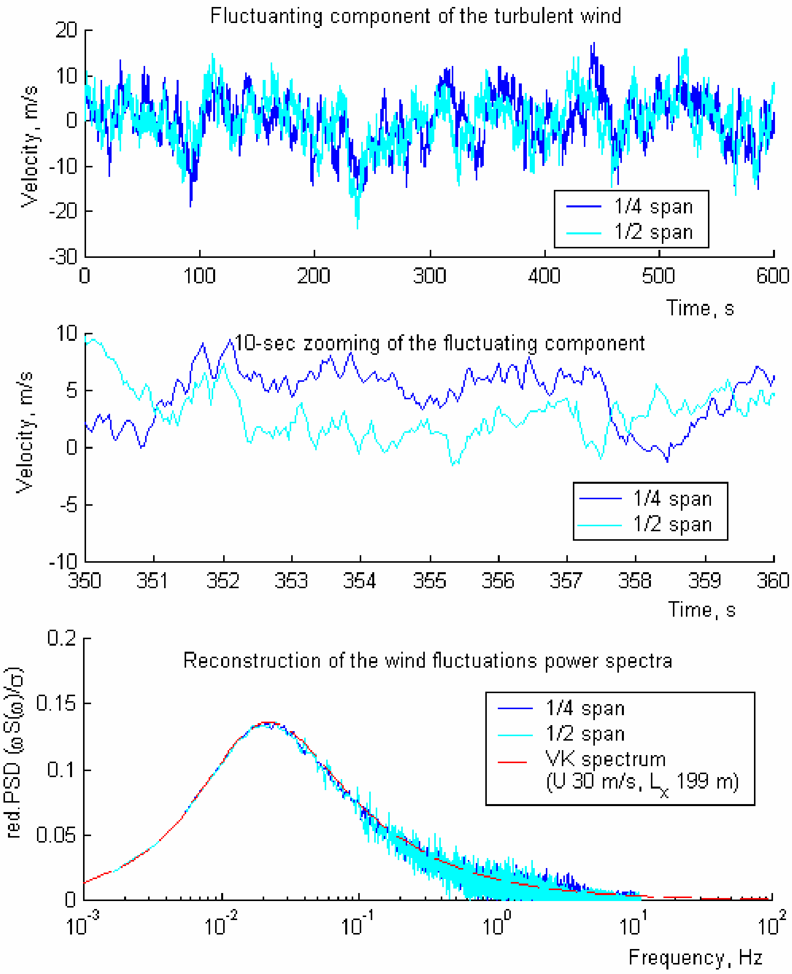


Fig. 2. Modelling the fluctuating wind in SAMCEF: (a) typical wind sample, (b) 10 sec. zooming of the above, (c) FFT recovery from the wind sample compared to the basic Von Karman spectrum

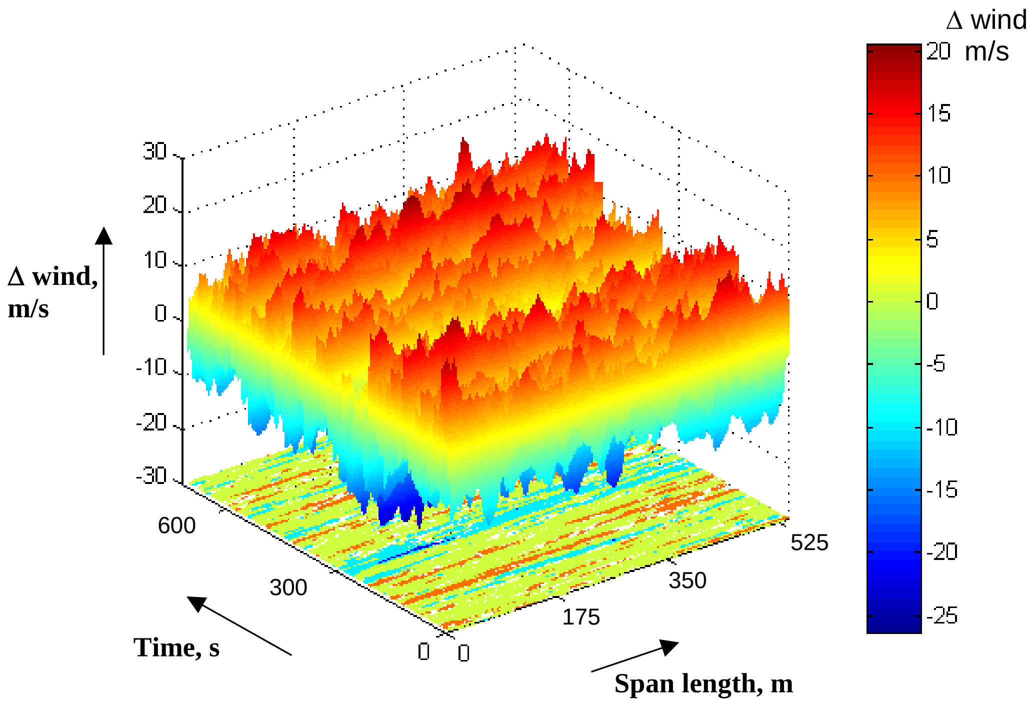


Fig. 3. Wind fluctuations across the span. Mecano simulation of the Von Karman spectrum

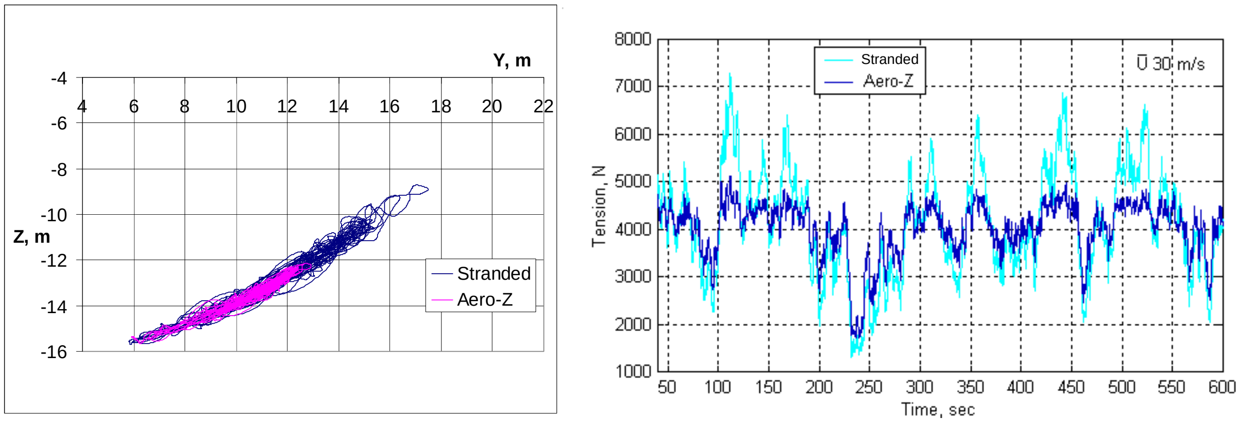
ANALYSIS RESULTS

The analysis was made over a 525 m long span of transmission line. The cable tension was 33.6 kN (for classical conductor) and 39.14 kN (for smooth conductor). These tensions ensure the same initial sag at zero wind (16.5 m) for both types of conductors.

Several analysis cases with different mean wind speeds (30 m/s and 40 m/s) were considered. The simulation was done over 10 min. interval – this duration is imposed by the standard wind recordings and is retained in the models of the wind fluctuations.

In all analysis cases, the smooth-surfaced cable was excited significantly less than the classical multistrand analogue. The tension variation (T_{max} - T_{min}) in Aero-Z is by 44 to 52 % less than in the classical cable, which means the better fatigue resistance. The fatigue problem during hurricane is not related to many cycles (due to limited hurricane duration), but to very high amplitude of conductor movement (“oligocyclic fatigue”). In our analysis, the displacement amplitudes of Aero-Z were by 29 to 43% less (Fig. 4, b).

For mean wind speed $\bar{U}$=30 m/s , variations of the tower loads ΔR_y from the smooth cable were by 34% less than from the classical analogue. At $\bar{U} = 40\,m/s$ the gain from Aero-Z was especially significant in the mean R_y (up to 46%).



(a) (b)

Fig. 4. (a) Mid-point evolutions of the cable AERO-Z and the classical multistrand cable (mean wind speed: 30 m/s).
(b) Variations of the tower load n the wind direction, Ry, for the cable AERO-Z and the classical multistrand analogue. Mean wind speed: 30 m/s.

Such gain of Aero-Z in the wind-excited response is, above all, due to its aerodynamic. All other parameters, such as slightly higher inertia, also add to the lower response on the wind fluctuations, however, their contribution is much less. As the wind speed reaches the corridor between 30 and 40 m/s, the drag coefficient of the classical multistrand cable does not vary too much, making the drag force free to fluctuate. On another hand, C_D of AERO-Z fluctuates inverse proportionally to the wind fluctuations (Fig. 5, a), causing the drag force on Aero-Z to remain quasi-constant in the range of speeds between 30 and 40 m/s (Fig. 5, b). Thanks to such stagnation, beyond the critical state the drag force on smooth cable is strongly reduced as compared to the stranded cable. The latter has analogical effect but at lower wind speeds and with the smaller decrease of C_D (see Fig. 1). As a result, effect of drag force stagnation on stranded cable is not so noticeable.

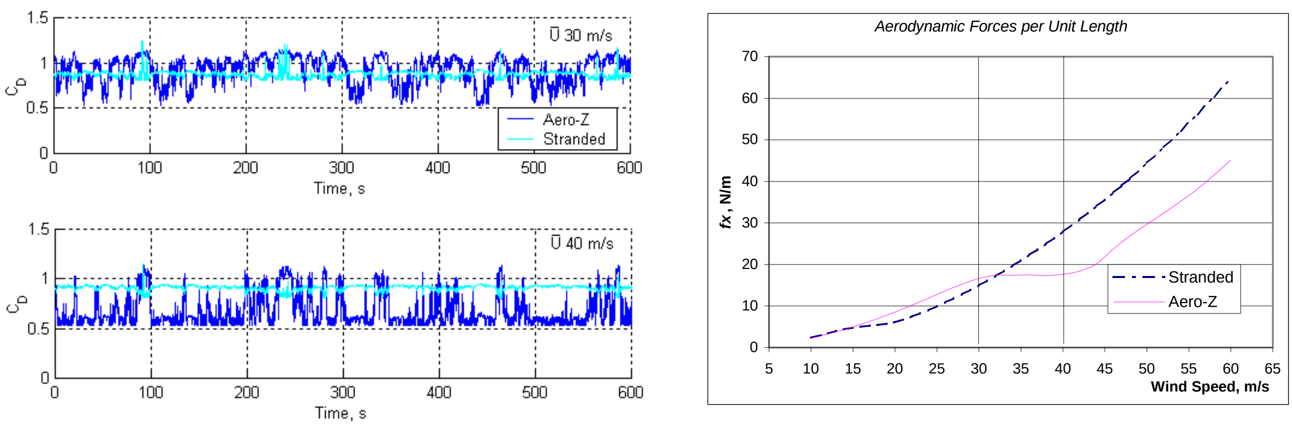


Fig. 5. (a)Variations of the drag coefficients of cable AERO-Z against the classical multistrand cable
(top: mean wind speed U= 30 m/s, bottom: U= 40 m/s)
(a) Variation of drag force per unit length (1) vs. wind speed

CONCLUSIONS

The present analysis has confirmed theoretical and experimental estimations about effectiveness of some smooth conductors in the hurricane wind conditions. The significant reduction in dynamic response of AERO-Z, compared to the classical stranded cable, is due to its low-drag properties. Such

conductor is, therefore, less susceptible to the fatigue effects and imposes lower loads (up to –40%) on the other components of the transmission line (pylons, insulators etc.)
In [9] it has been already shown that reaching of critical regime brings positive effect not only in the transmission line, but also in stay-cables. In that case, the stay-cable roughness should be increased to ensure the critical regime at lower Reynolds numbers than for convenient, smooth cables. The stay-cable becomes then less susceptible to the rain-wind vibrations and is less loaded under medium winds. In case of transmission line we demonstrate, that smooth conductors are less loaded, and are much less prone to the wind gusts, under hurricane winds.

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