COMPARATIVE ANALYSIS OF POWER LINE TOWER ACCORDING TO SERBIAN AND EUROPEAN STANDARDS

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Summary: *This paper presents the result of the study of our standars in the area of designing overhead power lines and their comparison with the European standards (EN). The emphasis in this paper is placed on the load analysis on tower as the most important structural element of power line. Considering that our standars (Pravilnik) do not consider load conditions with a combined action of the wind on ice-covered conductors, which are required by EN, in this paper are presented an algorithm for calculation this load case. Results of calculation are presented on lattice tower height of 41.5m.*

Keywords: *power line tower, European standars, Pravilnik*

1. INTRODUCTION

Overhead power line is designed as a system made of components such as supports, foundations, conductors and insulator strings. This approach enables the designer to coordinate the strengths of components within the system and recognizes the fact that a power line is a series of components where the failure of any component could lead to the loss of power transmitting capability. It is expected that this approach should lead to an overall economical design without undesirable mismatch.

As a consequence of such a system design approach, it is recognized that line reliability is controlled by that of the least reliable component. An overhead transmission line can be divided into four major components as shown in Figure 1. Subsequently, each component may be divided into elements, [1].

This paper gives a detailed view of the load analysis on the overhead suspension tower according to *Pravilnik o tehničkim normativima za izgradnju nadzemnih elektroenergetskih vodova nazivnog napona od 1kV do 400kV*, hereinafter Pravilnik, [2].

This paper is a continuation of work “Proračun dalekovodnog nosivog stuba 2D4 prema Evropskim Normama”, [3]. In previous paper was presented load analysis on power line tower according to European standards and comparison of the obtained results with results obtained according to the Pravilnik, [2]. Considering that there have been significant

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differences already in the load analysis according to the two standards, it was considered necessary to repeat the calculation of the load analysis according to the Pravilnik.
After conducting the analysis, it was concluded that the reason for the difference obtained according to two standards is the result of the fact that our standars do not consider load conditions with a combined action of the wind on ice-covered conductors. On the other hand this influence is required according to EN [4] and as it shown in [3] caused the maximum impacts in tower. Considering the differences among the standarads in paper is presented algorithm for calculation of loads of simultaneous action of wind and ice on conductors and ground wire that is made by combining the recommendations given in [2] and [4].

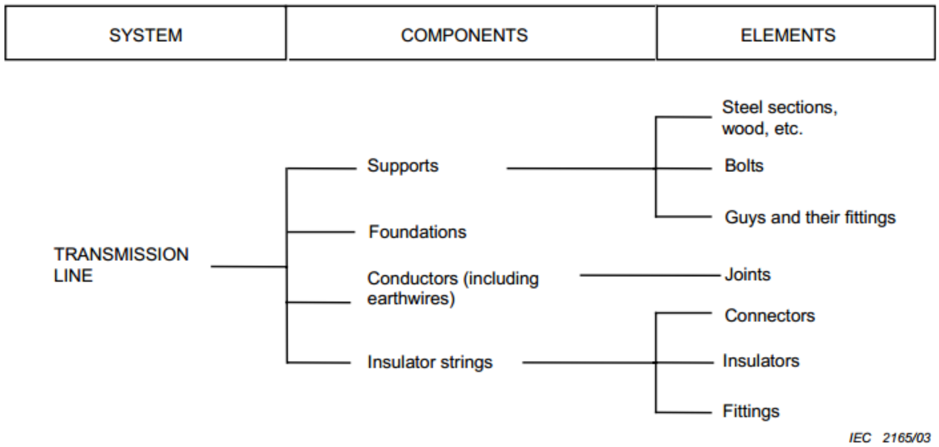

Figure 1. Diagram of a transmission line

Representations and analysis of the results are given for lattice steel tower type “dunav” voltage level of 110 kV. The analyzed power line tower is the height 41.50m, calculated with the wind speed of 25m/s, with the wind span up to 350m and with the gravity span of up to 800m. Design of tower is calculated according to Evrocode 3 [5] and the recommendations contained in [4, 6 and 7].

2. CLIMATIC LOAD ANALYSIS ACCORDING TO SERBIAN STANDARDS

Load on tower is in direct function of necessary equipment and climatic areas in which the tower is located. This section gives an overview of the main characteristics of calculation of climatic loads on towers of overhead power lines according to our standars, [2, 8]. Our standars differs normal and extraordinary loads, with no consideration of simultaneously effect of additional load (caused by deposition of frost, ice and snow) and wind on the conductors and earthing wires.

Considering the limited space, this paper does not display a detailed load calculation, but provides an overview of the basic parameters of climatic impacts as wel as obtained values of load on tower.

2.1 WIND LOAD

Wind load is calculated according to the formula:

$$S_w = A \cdot p \cdot k \cdot \sin\alpha \left[daN\right] \tag{1}$$

where A [m^2] is surface area exposed to the wind, p [daN/m^2] is wind pressure, k is the coefficient of the wind and α is the angle between wind direction and longitudinal axis of the lattice cross-arm.

Coefficient of the wind on lattice tower has value, [2]:

$k = 1.0$ for conductors and ground wires
$k = 2.6$ for rectangular cross-section lattice steel tower

Unlike European standars in which the load of the wind changes with height above the ground (as shown in [3], tables 3, 4 and 5), according to our standars wind pressure is adopted as constant up to a certain height above the ground [2], Table 1.

*Table 1. Wind pressure **p** deppending on maximum wind speed **v** and height above the ground **H***

Wind speed	**Wind pressure *p* [*daN/m²*]**	
***v* [*m/s*]**	**0m < *H* < 40m**	**40m < *H* < 80m**
Zone 1 - 20	60,00	75,00
Zone 2 – 25	75,00	90,00
Zone 3 – 30	90,00	110,00
Zone 4 – 35	110,00	130,00
Zone 5 > 35	130,00	150,00

According to table 1 and adopted wind speed of $25\,\text{m/s}$ wind pressure on tower and conductors is

$$p = 75\,daN/m^2$$

while wind pressure on ground wire is

$$p = 90\,daN/m^2$$

2.2 ICE LOAD (ADDITIONAL LOAD)

An additional load is the load on conductor and ground wire caused by deposition of frost, ice or snow and by our standards is calculated according to the formula:

$$q_{dt} = k_{dt} \cdot 0.18\sqrt{d} \quad [daN/m] \tag{2}$$

where d is conductor and ground wire diameter in [mm] and k_{dt} is ice coefficient. Coefficient k_{dt} depends on climatic conditions, and have **1.6** value in this analysis.

2.3 COMBINED WIND AND ICE LOADING

The combined wind and ice loadings treated in this subclause relate to wind on ice-covered conductors. This loading case was obtained by a combination of recommendations given in European standards [4] and by our standards [2].

- Vertical loading (weight of ice-covered conductors) was obtained according to member 68a.1 of Pravilnik, [2].
- Horizontal loading on conductor and ground wire due to wind blowing horizontally, perpendicularly to conductor direction, is given by

$$V_{x5} = 0.4 \cdot L_{SR} \cdot p \cdot \left(d_p + 2b_p\right) \tag{3}$$

$$Z_{x5} = 0.4 \cdot L_{SR} \cdot p \cdot \left(d_z + 2b_z\right) \tag{4}$$

where L_{SR} is wind span, $d_{p(z)}$ is the diameter of conductor (ground wire) and $b_{p(z)}$ is the thickness of the ice on coductor (ground wire). The value of the coefficient of **0.4** in the previous formulas was adopted in accordance with the recommendations given in the [4].

The thickness of ice was calculated on the basis of the value of additional loads, obtained by equation (2), according to formula:

$$q_{dt} = \left(D^2 - d^2\right) \cdot \frac{\pi}{4} \cdot 9000 \quad [N/m] \tag{5}$$

where D [m] is diametar of ice-covered conductor (ground wire), and d is diametar of conductor(ground wire) in [m].
From the previous expression follows:

$$b_{p(z)} = \frac{1}{2}\left(\sqrt{\frac{4 \cdot q_{dt,p(z)}}{\pi \cdot 9000} + d_{p(z)}^2} - d_{p(z)}\right) \quad [m] \tag{6}$$

Table 2 present load cases obtained according to our standards [2, 3] in combination with European standars [4]. Load cases 1 to 4 were obtained according to members 68a and 69a.1 from Pravilnik, while load case 5 was obtained as defined in section 2.3.

Tabela 2. Load cases for suspesion tower according to Pravilnik with EN

Load case			Conductor [KN]			Ground wire [KN]			Tower [KN/m^2]	
			V_x	V_y	V_z	Z_x	Z_y	Z_z	S_x	S_y
68a	1		-	-	V_{z1}	-	-	Z_{z1}	-	-
	2		V_{x2}	-	V_{z2}	Z_{x2}	-	Z_{z2}	S_x	-
	3		-	V_{y3}	V_{z3}	-	Z_{y3}	Z_{z3}	-	S_y
69a. 1	4	P_p	-	0,5 V_{y4}	V_{z1}	-	-	-	-	-
		N_{ep}	-	-	V_{z1}	-	-	Z_{z1}	-	-
		P_z	-	-	-	-	0,5 Z_{y4}	Z_{z1}	-	-
		N_{ez}	-	-	V_{z1}	-	-	-	-	-
	5		V_{x5}		V_{z5}	Z_{x5}		Z_{z5}	S_x	

Symbols used in the table 2:

P, Z	conductor, ground wire
Pp, Pz	broken conductor, broken ground wire
Nep, Nez	unbroken conductor, unbroken ground wire

3. LOAD ANALYSIS RESULTS AND COMPARISON WITH EUROPEAN STANDARDS

Figure 2 shows static silhouette of lattice tower as well as model of tower obtained in the Radimpex software package Tower, [9], which is employed as an example for analysis in this study. Characteristics of the power line tower as well as selected equipment are shown in [3].

Load calculation results obtained according to recommendations defined in section 2 are presented in Table 3.

Tabela 3. Load calculation results for suspesion tower according to Pravilnik with EN

Load case			Conductor [KN]			Ground wire [KN]			Tower [KN/m^2]	
			V_x	V_y	V_z	Z_x	Z_y	Z_z	S_x	S_y
68 a	1		-	-	20.02	-	-	14.88	-	-
	2		5.75	-	9.02	5.04	-	5.66	2.6x0.75	-
	3		-	1.44	9.02	-	1.26	5.66	-	2.6x0.75
69 a. 1	4	P_p	-	12.71	20.02	-	-	-	-	-
		N_{ep}	-	-	20.02	-	-	14.88	-	-
		P_z	-	-	-	-	10.70	14.88	-	-
		N_{ez}	-	-	20.02	-	-	-	-	-
	5		5.13		20.02	5.47		14.88	2.6x0.75	

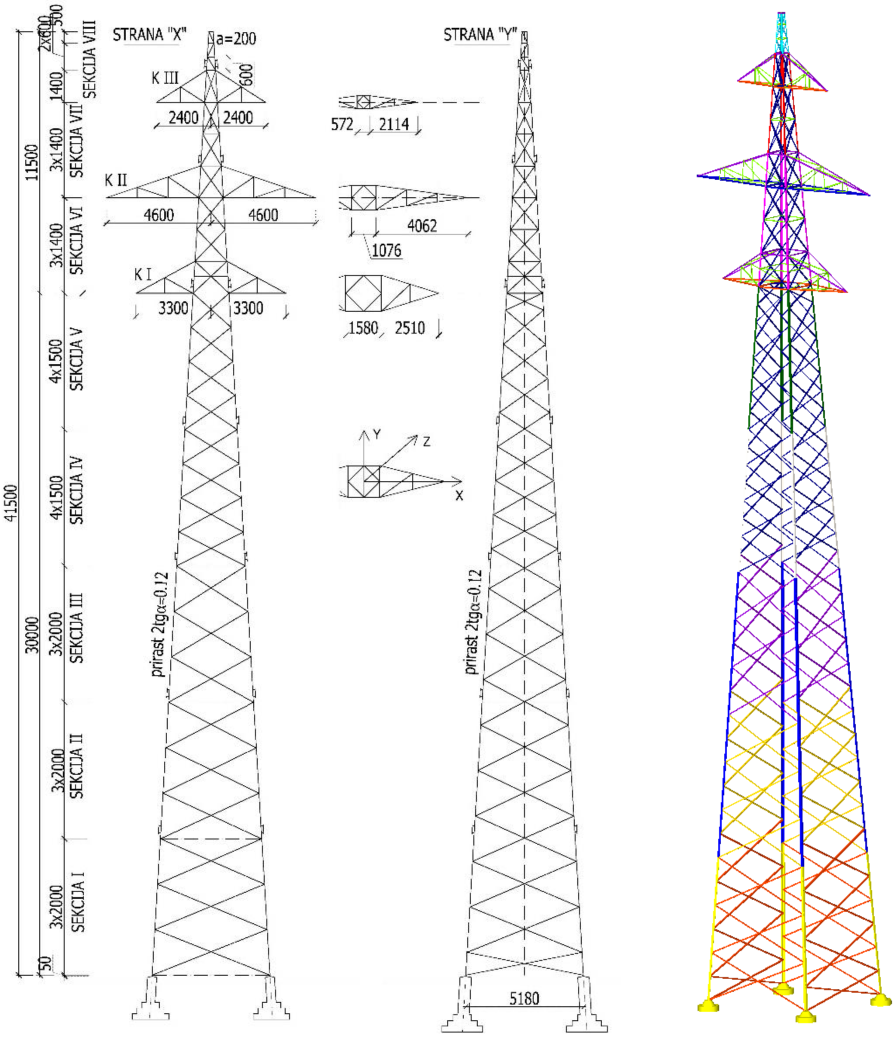

Figure 2. Static silhouette and model of lattice tower

Considering that the structural elements will be designed according to Eurocode 3, [4, 5], partial factor were adopted according to the recommendations given in [3, 4], and are shown in Table 4.

Table 5 presents load cases for suspesion tower according to EN [4]. Table 6 presents the results of the load analysis according to EN [4, 6, 10] in order to compare with results shown in Table 3. In Tables 5 and 6 are shown only load cases that are similar according to both standards. Unlike our standards according to EN were analyzed and influences from the effects of wind at an angle of 45˚ to the line (load cases N2, N4, E1.2 and E2.2 from table 5). Load case E2.2 was obtained according to Table 5 with wind at an angle of 45˚ and gave maximum impacts in the structural elements (Table 7, column EN).

Tabela 4. Partial factors for actions, ultimate limit states

Load case			Partial factor
1,2,3	normal loads	Wind	1.35
		Ice	1.35
		Deadweight	1.10
4	extraordinary loads	Wind	1.00
		Ice	1.00
		Conductor tension	1.00
		Deadweight	1.10
5	combined wind and ice loads	Wind	1.35
		Ice	1.35
		Deadweight	1.10

Tabela 5. Load cases for suspesion tower according to European standards

Normal Working Load Cases	
N1, N2	• Deadweights, Wind on tower, accessories and conductors
N3, N4	• Deadweights, Ice loads, Reduced wind on tower, accessories and iced conductors
Exceptional Loading Cases	
E1 Broken Wires	• Deadweights, Ice loads, one sided reduction of conductor or earthwire tension (both under wind and ice load condition) by 50% for phase conductor and 65% for earthwire acting at any one attachment point
E2 Cascading	• Deadweights, Ice loads, one sided reduction of conductor or earthwire tension (both under wind and ice load condition) by 20% for phase conductor and 40% for earthwire acting at attachment points simultaneously

Tabela 6. Load analysis results for suspesion tower according to European standards

Load case	N1			N3		
	Vx	Vy	Vz	Vx	Vy	Vz
Lower phase	3.79	-	7.18	2.96	-	15.86
Middle phase	3.94	-	7.18	3.08	-	15.86
Upper phase	4.08	-	7.18	3.19	-	15.86
Ground wire	2.87	-	4.52	2.58	-	11.32
Load case	**E1.1**			**E2.2**		
	Vx	Vy	Vz	Vx	Vy	Vz
Lower phase	2.96	12.72	15.86	1.14	6.22	15.86
Middle phase	3.03	12.72	15.86	1.18	6.27	15.86
Upper phase	3.19	12.72	15.86	1.22	6.31	15.86
Ground wire	2.58	13.9	11.32	0.91	9.47	11.32

Load cases shown in Tables 3 and 6 should be multiplied by coefficients from Table 4. As can be shown in Tables 3 and 6 the results of the load calculation are different. The reason for that is higher load of wind and higher additional load according to Pravilnik in regard to EN. On the other hand according to EN were considered the influences that are not considered according to our standards.

4. STRESSES IN THE MEMBERS OF THE TOWER AND DISCUSSION

The results of cross-section forces calculation on tower according to analyzed standards are shown in Table 7, where column Pravilnik+EN shows results according to Pravilnik with simultaneously effect of additional load and wind and column EN shows results according to European standards. Cross-section forces shown in Table 7 are the maximum and as can be seen the values of axial forces by both standards are very close. A little higher value of axial force is obtained according to the European standards (except in section VI) because of cascading load case which are not considered according to Pravilnik.

Tabela 7. Load analysis results for suspesion tower according to European standards

Tower section	Angle profile	Pravilnik + EN			EN		
		N [kN]	My [kNm]	Mz [kNm]	N [kN]	My [kNm]	Mz [kNm]
I	L 110x110x10	-320.68	-0.130	0.097	-320.44	0.167	-0.099
II	L 100x100x10	-297.47	-0.123	0.055	-302.22	-0.187	0.017
III	L 100x100x10	-272.20	-0.113	0.046	-279.79	-	-
IV	L 90x90x9	-244.79	-0.081	0.020	-248.79	-	0.030
V	L 80x80x8	-208.24	0.073	-0.024	-210.79	-	0.043
VI	L 70x70x7	-131.56	-0.150	0.041	-127.41	-	-0.102
VII	L 60x60x6	-49.94	-0.046	0.029	-55.81	0.016	-0.034
VIII	L 40x40x4	-26.26	0.043	-0.026	-36.81	-0.037	0.015
KII	L 65x65x7	-68.04	0.223	-0.212	-68.58	0.232	-0.199

Table 8 shows the results of design of the structure elements with cross-section forces shown in Table 7 according to *ultimate limit state* (Eurocode 3). In column 1 are shown results of calculation of resistance of cross section, in column 2 are results of calculation of buckling resistance of compression member while in the column 3 are results of calculation of buckling resistance of compression member with bending. Column 4 and 5 shows results of calculation according to Pravilnik (without simultaneously effect of additional load and wind) and *maximum stress theory*.

Cross-section profiles were adopted according to Pravilnik and *maximum stress theory*. As can been seen in Table 8 some profiles do not satisfy stability requirements according to Eurocode 3. The reason for that are greater cross-section forces obtained according to Tables 3 and 6, in comparison to Pravilnik [2].

Tabela 8. Results of design of the structure elements

Tower section	Angle profile	Pravilnik + EN			EN		Pravilnik / JUS	
		1	2	3	1	2	4	5
I	L 110x110x10	0.644	0.940	0.978	0.651	0.951	0.69	0.94
II	L 100x100x10	0.659	1.042	-	0.67	1.058	0.70	1.03
	L 100x100x12	0.558	0.883	0.917	0.567	0.898		
III	L 100x100x10	0.603	0.953	0.987	0.613	0.968	0.63	0.91
IV	L 90x90x9	0.672	0.931	0.961	0.683	0.946	0.69	0.90
V	L 80x80x8	0.720	1.083	-	0.73	1.095	0.73	1.01
	L 80x80x10	0.587	0.885	0.924	0.695	0.897		
VI	L 70x70x7	0.596	0.745	0.858	0.577	0.722	0.59	0.71
VII	L 60x60x6	0.307	0.773	0.857	0.349	0.880	0.29	0.69
VIII	L 40x40x4	0.363	0.560	0.772	0.509	0.787	0.43	0.63
KII	L 65x65x7	0.333	0.730	1.036	0.335	0.736	0.25	0.37
	L 70x70x7	0.310	0.610	0.864	1.04 *	0.867 *		

** refers to the results of the calculation of buckling resistance of compression member with bending*

Results of the design of the tower elements with loads obtained according to the recommendations given in section 2 and according to EN, [3], are very close. Based on the results of the calculation can be concluded that the load on the power line towers can be calculated by our standards with the recommendations that have been introduced in this paper.

5. CONCLUSIONS

Analyzing our standards and European standards in the area of designing overhead power lines, a significant difference in proposed climatic impacts on tower been noticed. Our standards (Pravilnik) do not consider simultaneously effect of additional load (caused by deposition of ice, frost and snow) and wind on the conductors and ground wires, which are required by EN. Considering that these phenomena are not excluded in our region they should be taken into consideration. Hence, this paper points to the weaknesses of our standards and provides recommendations and guidance for determining simultaneous loads of wind and ice on conductors and ground wires.

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УПОРЕДНА АНАЛИЗА ДАЛЕКОВОДНОГ СТУБА ПРЕМА СРПСКИМ И ЕВРОПСКИМ СТАНДАРДИМА

Резиме: *Овај рад приказује резултат изучавања домаћих прописа у области пројектовања надземних електроенергетских водова и њихово поређење са Европским стандардима (ЕН). Акценат у раду је стављен на анализу оптерећења стуба као најзначајнијег структуралног елемената електроенергетског вода. С обзиром да наши прописи (Правилник) не разматрају услове оптерећења са комбинованим дејством вјетра на залеђене проводнике, који су обавезни према ЕН, у овом раду је приказан алгоритам прорачуна овог случаја оптерећења. Резултати прорачуна су приказани на решеткастом стубу висине 41.5м.*

Кључне речи: *далеководни стуб, Европски стандарди, Правилник*