The Mechanical Design Creation of the Overhead Transmission Line

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ABSTRACT: *We have created the overhead transmission line mechanical design with the help of the linear expansion of the thermal resistant conductors. These conductors are characterized by the regular current flows. We have recorded the thermal resistant conductor at various tension levels and temperatures. The experimental results have been posted with data at many transmission lines.*

Keywords: Overhead Transmission Lines, Super Thermalresistant Conductors, Mechanical Design, Continuous Current

Received: 3 October 2022, Revised 9 November 2022, Accepted 18 November 2022

DOI: 10.6025/tmd/2023/11/1/20-26

1. Introduction

The high-voltage overhead transmission lines are the backbone of the electric power systems. Their total length accounts for tens of thousands of kilometers. Building new power lines is a priority of each transmission system operator. On the other hand, engineers are looking for solutions to increase the power capability of the existing lines, since building new lines in private properties is extremely slow and complicated process. One of the possible solutions is the substitution of the old conductors with new ones, which have doubled transmission capacity by increasing the operation temperature from 70-90ºC up to 210ºC.

Figure 1 shows the dependence of the conductor sag from the working temperature [5]. The coefficient of linear expansion α of the classical aluminum-steel conductors (ACSR) is about 19.10 ºC^{-1}. The super thermal-resistant conductors ZTACIR, which are studied in the paper, are made of aluminumzirconium alloy, and are reinforced with nickel-iron alloy core (invar). They have α =15,8.10-6 ºC^{-1}, determined mainly by the linear expansion of the invar core [2]. Another important property when heating combined conductors is the so called knee point (stress transfer point) [3, 5]. When the conductor is heated above the knee point temperature, the resulting linear expansion coefficient decreases to the value of linear expansion of the invar core – about α = 3,5.10-6 ºC^{-1}. For ACSR and ZTACIR conductors this point is within the range 80-100 ºC. The other two conductor types shown in Figure 1 are designed to allow the different metals of the combined conductor to expand and shrink independently from each other. They are in turn more expensive and require special mounting hardware. However, due to their advantages they have found application in Europe [6,7].

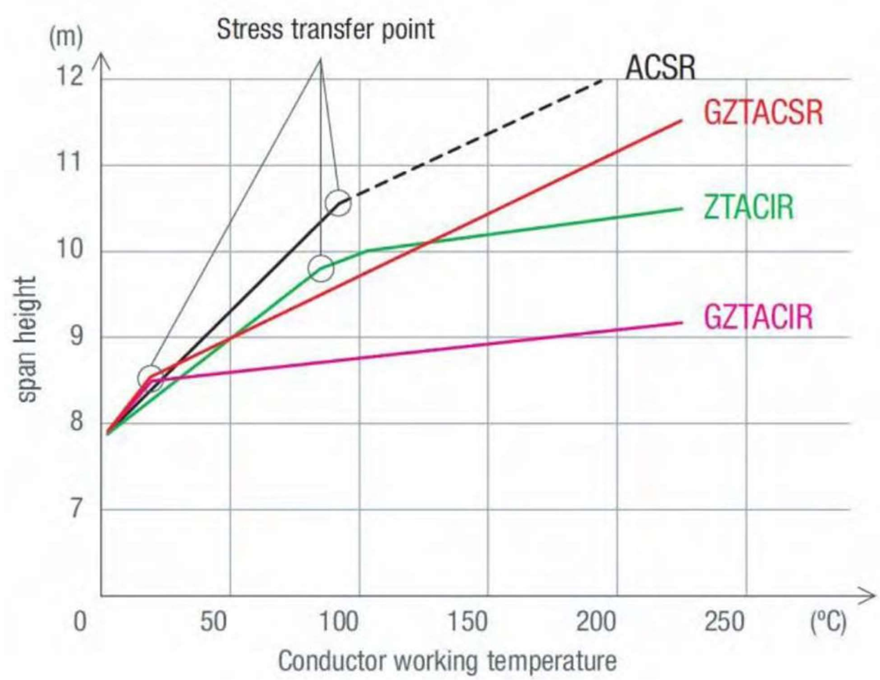

Figure 1. Temperature dependence of the conductor SAG

The design process of overhead transmission lines can be conditionally divided in a few stages, two of which are briefly explained in the following section.

1.1. Evaluation of the Input Data

First of all, it is necessary to know the climate region where the line will be built. For example, the climate regions in Bulgaria are five, classified depending on the degree of conductor icing. Another important factors are the max wind speed when there is no ice on the conductor, the max wind speed when the conductor is iced, max air temperature (40ºC for Bulgaria), min temperature (-30ºC, average annual temperature, temperature when conductor icing begins (-5ºC and air temperature at max wind speed (15 ºC Second of all, the mechanical properties of the conductors should be determined - cross-section, weight, modulus of elasticity, thermal coefficient of linear expansion α, ºC^{-1} and tensile strength – σ_p.

Based on the climate conditions and the mechanical specifications of the conductor, the so called specific loads of the conductors γ are evaluated. The loads are namely: γ_1 – load due to the conductor own weight; γ_2 – load due to the ice shell on the conductors; $\gamma_3 = \gamma_1 + \gamma_2$ – load due to the weight of the conductor and the weight of the ice; γ_4 – load from the max wind speed Vmax, acting on non-iced conductor; γ_5 – load from the wind acting on iced conductor, with max wind speed designated as V?; γ_6 – load resulting from the conductor's own weight plus the load from the max wind speed; γ_7 – load resulting from the load of the iced conductor plus the pressure from the $V_n$wind speed.

According to the Bulgarian regulations [1] the highest allowable tension of the conductors is evaluated as percentage of the conductors rated tensile strength. For overhead transmission lines and conductor cross-section above 95 mm^2, the allowable tension is 45 % from the rated value, when calculated for max conductor mechanical loading or for min temperature. In case the conductors are substituted with different type, the allowable tension must reconcile with the tensions initially evaluated for the power line.

1.2. Evaluation of the Maximum Mechanical Loading and the Maximum Sag of the Conductors

As it is known, the mechanical design of the conductors of overhead transmission lines is based on the theory of flexible and non-elastic fibers (catenary). The characteristic of the actually used conductors do not completely match the characteristics of the flexible and non-elastic fibers, but for practical computations the difference is considered insignificant. Based on this theory, an equation for the conductor position between two electric poles can be derived. For simplicity, the following is assumed: - the points where the both ends of the conductor are mounted are considered to be still, while the conductors are articulated to that points; - the conductors are uniformly loaded along the whole length. Under the stress of the loads the conductors "hang" like homogeneous heavy flexible fiber (catenary); - the flexible fibers are subject to tensile force only; - the shape of the span curve of the conductor do not depend on the length of the interpole distance.

For overhead transmission lines up to 400 kV and interpole distance up to 500 m, the hyperbolic equation can be simplified assuming that the conductor span curve is parabolic. Then the equation is the following:.

$$y = \frac{\gamma \cdot x^2}{2 \cdot \sigma_o}, \tag{1}$$

where σ_0 is the mechanical tension of the conductor at the point with the deepest sag within a horizontal interpole.

If x from the latter equation is substituted with the distance between one of the poles and the deepest sag point for horizontal interpole, the maximum conductor sag can be evaluated as follows:

$$f = \frac{\gamma \cdot l^2}{8 \cdot \sigma_o}, \tag{2}$$

where l is the interpole distance.

The length of the conductor between the two poles is:

$$L = l + \frac{\gamma^2 \cdot l^3}{24 \cdot \sigma_o^2}. \tag{3}$$

When changing the atmospheric conditions it is assumed that the state of the conductor is changed in steps. First, the air temperature is changed from t_m to t_n, which causes a change of the conductor length from L_m to L_{1m}. Immediately after that, the mechanical load of the conductor changes along with the conductor length from L_{1n} to L_n. After some slight simplifications the formula for the conductor length becomes as follow:

$$L_n = L_m \left[1 + \alpha\left(t_n - t_m\right) + \beta\left(\sigma_n - \sigma_m\right)\right]. \tag{4}$$

Based on (3) and (4) the following equation for changing the conductor operation conditions from "m" to "n" is derived [3,9,10]:

$$\sigma_n - \frac{\gamma_n^2 \cdot l^2 \cdot E}{24 \cdot \sigma_n^2} = \sigma_m - \frac{\gamma_m^2 \cdot l^2 \cdot E}{24 \cdot \sigma_m^2} - \alpha \cdot E \cdot \left(t_n - t_m\right) \tag{5}$$

The maximum mechanical tension σ_{max} is determined among the following two operation conditions: №1.1 maximum load operation ($\sigma_{\gamma 7}$, γ_7 and t=-5ºC) or №1.2 min temperature operation (σ_{tmin}, γ_1 and t=-30ºC). The deepest conductor sag is determined among the following conditions:

№2.1 iced conductors at no wind ($\sigma_{\gamma 3}$, γ_3 and t=-5ºC) or №2.2 min temperature operation ($\sigma_{\gamma 1}$, γ_1 and t=40ºC). There exist a critical interpole distance $l_{кр}$ and a critical temperature $t_{кр}$, such that the max tension σ_{max} and the max conductor sag are equal for the both operation conditions. This fact makes it easy to determine the necessary design operation conditions.

3. Experimental Results

Different input data is used to obtain full picture of the deviation of the max conductor sag when designing overhead transmission lines with ZTACIR Ø19,04 mm conductors [5,8]. Different data combinations are obtained by varying the climate region (the ice thickness around the conductor) and the max tension of the conductor σ_{max}. The σ_{max} tension smax values are selected according to the possibility for their realization when either a new line is designed or the aluminum-steel conductors of an existing line are changed with super thermal-resistant conductors ZTACIR Ø19,04 mm. In addition, the mechanical stress on the electric poles must not exceed the stress before the line reconstruction. Such conductor substitutions were realized for reconstruction of existing overhead lines in north-eastern Bulgaria [4].

The following parameters are assumed for the presented computations: max wind speed 35 m/s; max wind speed when the conductors are iced 17,5 m/s; ice density 900 kg/m^3; altitude 250 m; active height of the pole 16 m (max conductor sag 9,5 m).

The computations were made considering conductor temperature not exceeding the max allowable operation temperature of the super thermal-resistant conductors ZTACIR. Therefore, the variable coefficient of linear expansion α (knee effect) is accounted.

The tables below present results for:

$l_{кр}$ – critical interpole distance;

$l_{г}$ – dimensioning interpole distance (the distance for which the max allowed conductor sag is observed);

$t_{кр}$ – critical temperature;

$\Delta f_{210\text{-}15}$ – the difference of the conductor sag at temperature 210 ºC and 15 ºC;

$\Delta f_{210\text{-}40}$ - the difference of the conductor sag at temperature 210 ºC and 40 ºC.

The tables present the deviations $\Delta f_{210\text{-}15}$ and $\Delta f_{210\text{-}40}$, to determine the order of sag change due to heating from the continuous

l, m		Climate region			
		II	III	IV	I sp.
	$l_{кр}$, m	98	68	51	31
	$l_{г}$, m	261	226	197	155
	$t_{кр}$, ºC	26	35	41	49
200	$\Delta f_{210\text{-}15}$,m	1,84	1,48	1,17	0,75
	$\Delta f_{210\text{-}40}$,m	1,34	1,09	0,87	0,56
250	$\Delta f_{210\text{-}15}$,m	1,94	1,52	1,19	0,75
	$\Delta f_{210\text{-}40}$,m	1,43	1,13	0,89	0,56
$\approx l_{г}$	$\Delta f_{210\text{-}15}$,m	1,95	1,51	1,17	0,74
	$\Delta f_{210\text{-}40}$,m	1,44	1,12	0,87	0,55

Table 1. Conductor Sag Deviation at σ_{max} = 75MPa

operation current, compared to the sag determined for the dimensioning temperatures in Bulgaria (15ºC when two overhead lines intersect or the max air temperature).

The sag deviations are calculated for three different interpole distances – 200 *m*, 250 *m* and distance approximately equal to the dimensioning distance.

l, m		Climate region			
		II	III	IV	I sp.
	$l_{кр}$, m	124	87	64	39
	$l_{г}$, m	298	255	222	174
	$t_{кр}$, ºC	35	46	54	63
200	$\Delta f_{210\text{-}15}$,m	2,15	1,83	1,48	0,95
	$\Delta f_{210\text{-}40}$,m	1,57	1,34	1,09	0,71
250	$\Delta f_{210\text{-}15}$,m	2,32	1,89	1,50	0,95
	$\Delta f_{210\text{-}40}$,m	1,70	1,40	1,11	0,71
$\approx l_{г}$	$\Delta f_{210\text{-}15}$,m	2,43	1,90	1,49	0,95
	$\Delta f_{210\text{-}40}$,m	1,79	1,41	1,10	0,71

Table 2. Conductor Sag Deviation At σ_{max} = 95MPa

l, m		Climate region			
		II	III	IV	I sp.
	$l_{кр}$, m	163	114	84	52
	$l_{г}$, m	346	294	255	200
	$t_{кр}$, ºC	48	63	73	85
200	$\Delta f_{210\text{-}15}$,m	2,32	2,25	1,94	1,27
	$\Delta f_{210\text{-}40}$,m	1,77	1,65	1,42	0,94
250	$\Delta f_{210\text{-}15}$,m	2,69	2,41	1,98	1,27
	$\Delta f_{210\text{-}40}$,m	2,00	1,77	1,46	0,95
$\approx l_{г}$	$\Delta f_{210\text{-}15}$,m	3,10	2,49	1,98	1,27
	$\Delta f_{210\text{-}40}$,m	2,29	1,84	1,46	0,94

Table 3. Conductor Sag Deviation At σ_{max} = 125MPa

l, m		Climate region			
		II	III	IV	I sp.
	$l_{кр}$, m	196	137	101	62
	$l_{г}$, m	381	324	280	220
	$t_{кр}$, ºC	60	77	89	103
200	$\Delta f_{210\text{-}15}$,m	2,13	2,30	2,26	1,58
	$\Delta f_{210\text{-}40}$,m	1,72	1,78	1,67	1,16
250	$\Delta f_{210\text{-}15}$,m	2,67	2,69	2,38	1,55
	$\Delta f_{210\text{-}40}$,m	2,07	2,01	1,75	1,15
$\approx l_{г}$	$\Delta f_{210\text{-}15}$,m	3,54	2,95	2,41	1,57
	$\Delta f_{210\text{-}40}$,m	2,63	2,17	1,77	1,16

Table 4. Conductor Sag Deviation At σ_{max} = 125MPa

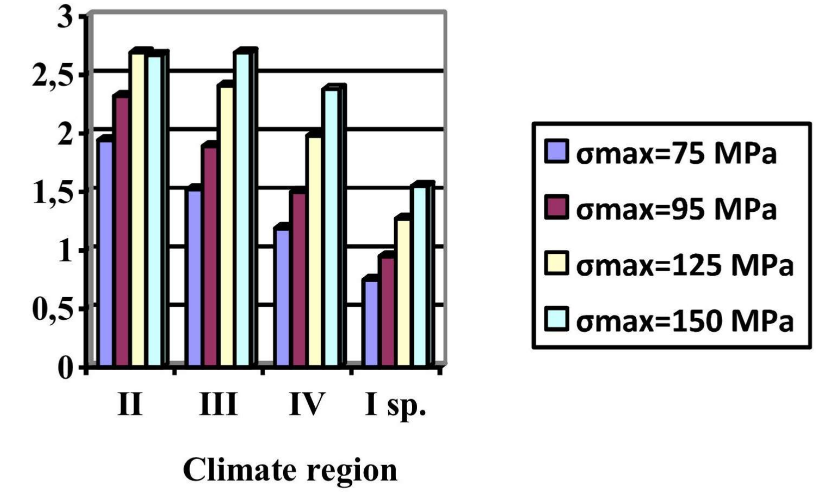

Figure 2. SAG deviation $\Delta f_{210\text{-}15}$ at l=250 m

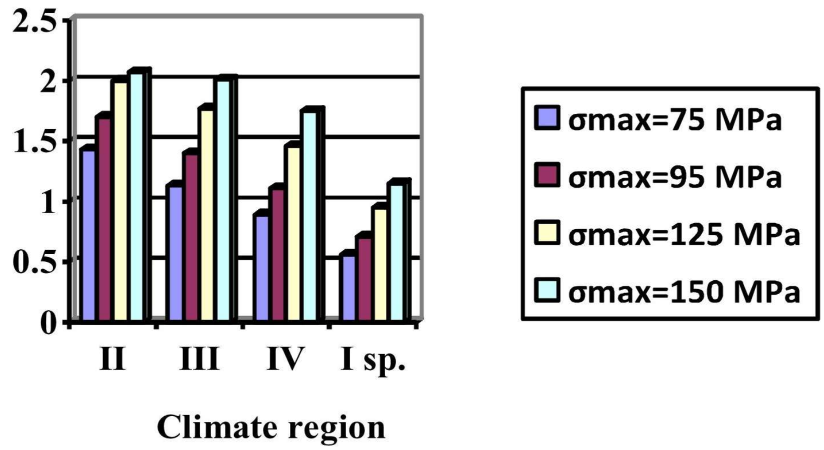

Figure 3. SAG deviation $\Delta f_{210\text{-}40}$ at l=250 m

From the results it is found that:

- The critical temperature in the most cases is higher than the max air temperature in Bulgaria (40 ºC), which means that if the conductor heating from the flowing current is not accounted the max sag condition is №2.1 (iced conductors without wind);

- $\Delta f_{210\text{-}15}$ and $\Delta f_{210\text{-}40}$ deviate within a wide range (from half up to more than three meters), which compared to the max allowed sag (9,5 m) is a significant deviation;

- $\Delta f_{210\text{-}15}$ approaches values above 3 m, which means that the insulation distance between two intersecting overhead lines could be violated (according to [1] the insulation distance is between 3 m and 5,50 m);

- At constant dimensioning interpole distance the deviations Δf do not change significantly (up to 1 m) with the change of the max tension;

- At nonviolent climate conditions (it corresponds to increased initial tension of the conductors at no load from ice or wind) the calculated deviations are higher (Δf).

4. Conclusion

Based on the obtained results, the following conclusions can be drawn:

1. Due to the significant sag deviations of the super thermal-resistant conductors, the heating from the flowing electrical current should be accounted when calculating the distance from the conductor to the ground (or to other facilities being crossed by the line);

2. When crossing existing overhead lines, accounting the additional sag due to the heating from the electrical current is determining;

3. Due to the different sag deviations for the different air temperatures and climate regions, each case should be considered individually rather than in a typical way.

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