Improving the energy efficiency of wide crossings of overhead power lines

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Abstract. The use of new generation wires in the design of wide spans of overhead power lines over water barriers and large gorges can increase their transmission capacity and increase reliability. However, when large currents flow, load losses in line also increase. Thus, it is necessary to obtain a methodology for technical and economic comparison of design options for overhead power lines over large crossings, which enables to determine the most cost-effective version of the project with high mechanical reliability. For comparative analysis, five options for wide spans of overhead power lines over the river with new-generation wires of Russian production were compiled: Aluminium Alloy Conductor Steel Reinforced, Z-type (high conductivity), Thermal-Resistant Conductor, Aluminium Composite Core Conductor, ASk2y. Option with Aluminium Conductor Steel Reinforced wire was taken as the source. For the first option, the crossing scheme E-A-A-E was selected, for the remaining options E-I-I-E scheme was considered. For the modes of maximum loads, minimum temperature and average annual conditions, the mechanical calculation of wires was carried out using the method of permissible stresses. The wire bending deflections were determined in accordance with the theory of the catenary curve. The method of integrated indicators was used to perform a technical and economic comparison of these options. The calculation results showed that among the proposed options, the most optimal is a crossing with the ACCC wire having minimum relative investment per 1 MW of transmitted electricity and minimal power loss. The transmission capacity of the line with this wire is increased by 1.8 times, and the cost of crossing is reduced by 16%. Due to the compact design of wire, the probability of ice formation on wire is reduced, and the reduced bending deflection reduces the probability of wire break due to natural environmental influences.

1 Introduction

The urgent task of the power engineering sector is to optimize design solutions for wide spans of overhead power lines (OHL) through large gorges and water barriers in order to increase their reliability and current transmission capacity. When designing wide spans of OHL, it is important to reduce the loads on transmission towers and foundations, to reduce the wire bending deflection, to reduce the probability of wire breaks and swinging during icing and squally winds [1, 2, 3]. These tasks are solved by using innovative types of wires with high electrical conductivity and high mechanical strength [4, 5, 6].

To assess the energy efficiency of line, it is important to evaluate the level of losses of the transmitted power.

The design of wide spans of overhead power lines is carried out in accordance with the requirements of the standard "Norms of technological design of overhead power transmission lines with a voltage of 35-750 kV" [7] and the provisions of the "Rules of Electrical Installations Design" [8]. The standard recommends to design the crossing in several ways. The final choice of options is based on a feasibility study.

In Russia, construction of wide spans through water barriers includes a practical experience of using high-temperature high-strength wires of the ACS (TACSR/ACS) brand with a steel core [9], clad with Aluminium manufactured by Lumpi-Berndorf (Austria) and EM-CABLE LLC (Russia), compacted wires with reinforced high-strength steel core AACSRZ (Lamifil LLC, Russia) [10,11,12].

2 Problem statement

The goal of this work is to increase the energy efficiency of a wide span of a 220 kV double-circuit overhead power line across the river. The length of the crossing is 2080 meters.

Climatic conditions are the following: II region in terms of wind (wind speed 29 m/s), III region in terms of ice (ice wall thickness $b = 20$ mm) [13].

The following tasks were set:

- To develop options for crossing of overhead line over the river using wires of a new generation of Russian production in order to increase energy efficiency;
- To select crossing schemes, types of transmission towers and wire brands;

- To perform a mechanical calculation of wires taking into account climatic conditions and a feasibility study of the developed options.

3 Development of options

Based on the experience of designing and construction a wide span of 220 kV OHL through the Kama Reservoir in 2009 [14, 15], five options for the crossing were proposed for consideration.

The first option: the crossing scheme E-A-A-E using crossing towers AT 133 and terminal towers K330-2+5K. The height of the AT 133 transmission tower is 154 m, the suspension height of the lower wire is 133 m (Fig. 1.). Aluminium Conductor Steel Reinforced ACSR 500/336 is used.

Fig. 1. The crossing scheme E-A-A-E.

The second option is using high-temperature high-strength wire TACSR/ACS 521-A20SA (Russia) with a gap between the steel wires of core and the wires of aluminium-zirconium alloys. The gap is filled with heat-resistant grease. The wire has not only increased electrical conductivity, but also increased corrosion resistance owing to the use of aluminium cladding technology.

The crossing scheme E-I-I-E (Fig. 2) was selected using intermediate towers PP330-2/79.5 and terminal towers K330-2+5K. The height of the PP330-2/79.5 tower was 104.4 m, the suspension height of the lower wire was 75.2 m.

Fig. 2. The crossing scheme E-I-I-E.

Other crossing options will be performed according to the same E-I-I-E scheme with replacement of wire types, which are listed below.

Third option: AACSRZ-527 (HC) - Aluminium Alloy Conductor Steel Reinforced, Z-type (high conductivity). The conductive part has a Z-shaped profile, which reduces the wind resistance. Reinforced high strength steel core enhances mechanical strength of wire.

Fourth option: Aluminium Composite Core Conductor ACCCTM - 527. The conductive part is made of trapezoidal wires of annealed Aluminium. Core is made from basalt and carbon fibers.

Fifth option: Ask2y-527 wire. The compacted wire is made of trapezoidal Aluminium wires and a high-strength steel core with zinc- Aluminium coating. Data for comparative analysis of the considered crossing options are given in table 1.

Table 1. Characteristics of wires of 220 kV overhead line.

Parameters	Meas.u.	Wire brand				
		AC SR	TAC SR	AAC SRZ	AC CC	ASk 2y
Options		1	2	3	4	5
Fc	mm ²	826.7	521.0	526.6	574.8	562.0
dc	mm	37.5	29.7	27.5	27.72	27.8
Gc	t/km	4.005	3.483	2.081	1.54	1.853
E	kN/mm ²	114.0	154.6	85.9	116.0	79.3
RTS	kN	467	666	312.4	159.1	175.6
α (TKLP)	10 ⁻⁶ /°K	15.5	12.6	17.39	1.61	18.1
Tower reference		AT 133	PP330-2/79.5			
Tower mass	kg	400	154.4			

4 Mechanical calculation

The mechanical calculation of wires and cables of wide spans is carried out according to the method of permissible stresses for maximum load conditions, minimum temperature and average annual conditions. The voltage at any point of wire is found from the equation [16]:

$$\sigma - \frac{\sigma}{\gamma\beta} \operatorname{ch} \frac{\gamma l}{2\sigma} \cdot \frac{1}{\frac{\sigma_m}{\gamma_m} \cdot \operatorname{ch} \frac{\gamma_m l}{2\sigma_m}} = \sigma_m - \frac{1}{\beta} - \frac{\alpha}{\beta} (t - t_m) \quad (1)$$

where σ , σ_m are voltage and permissible voltage in the material of wire or cable in one of the considered modes, respectively;

γ , γ_m are the specific mechanical load of wires, N/m · mm²;

β , α are the coefficients of elastic elongation and thermal expansion;

t, t_m are the temperatures typical for the calculated or known mode.

The overall bending deflections when crossing a large gorge or water barriers are determined in accordance with the requirements of the "Rules of Electrical Installations Design". For high-temperature wires, it should be determined at the maximum permissible wire temperature.

The wire bending deflection is determined in accordance with the theory of the catenary curve.

At different heights of suspension points, wire bending deflections corresponding to the large and small equivalent spans are determined by formulas (2) and (3):

$$f_1 = \frac{\gamma \cdot l_{eg1}^2}{8 \cdot \sigma_0}; f_2 = \frac{\gamma \cdot l_{eg2}^2}{8 \cdot \sigma_0}; \quad (2)$$

$$f_2 = -\frac{\sigma}{\gamma} \cdot \ln \cos \frac{\gamma \cdot x_0}{\sigma}; f_1 = f_2 + \Delta h. \quad (3)$$

Wire deflections in the span at different heights of suspension points are shown in Fig. 3 [17].

Fig. 3. Determination of wire deflections in the span for various heights of suspension points.

5 Results of mechanical and technical and economic calculations

The wire length in span L is determined taking into account the deflection f according to the formula:

$$L = l + \frac{8 \cdot f^2}{3 \cdot l}. \quad (4)$$

The integral effect I_e is taken as a criterion of profitability [18]:

$$I_e = \sum_{t=0}^T (R_t - Z_t) \cdot \frac{1}{(1+E)^t} - \sum_{t=0}^T K_t \cdot \frac{1}{(1+E)^t}, \quad (5)$$

where R_t is the income received at the t -th calculation step;

Z_t is the costs at the t -th calculation step;

T is the planning horizon, taken 13 years;

$\sum_{t=0}^T K_t$ is the cost of crossing, million rubles;

E is the discount rate;

t is the number of calculation step.

The results of calculation of the considered crossing options are given in Table 2.

Table 2. Characteristics of wires of the 220 kV overhead line crossing.

Parameters	Mea s. u.	Options				
		1	2	3	4	5
Bending deflection, f	m	145.6	86.0	66.1	49.0	62.4
Length of wire in span, L	km	12.74	12.0	12.60	12.51	12.61
Weight of wire in span	t	51.0	44.2	26.2	19.8	23.2
Cost of 1 t of wire	ths. rub.	175	525	525	700	350
Cost of wire in span	mln. rub.	8.93	23.2	13.8	13.9	8.11
The cost of crossing, K	mln. rub.	192.7	171.4	162.0	162.1	156.3
Cost reduction	%	-	11.0	16.0	15.9	18.9

An important indicator of effective functioning of an overhead power line is the minimum loss of electricity. To assess the technical efficiency of crossing, we introduce the concept of the energy coefficient K_e [19-22].

$$K_e = \frac{W_{re}}{W_{re} + \Delta W_L + \Delta W_{CL}}, \quad (6)$$

where W_{re} is the transmitted electricity,

ΔW_L is the load losses of electricity;

ΔW_{CL} is the corona electricity losses.

Maximum transmitted power is:

$$P_{max} = 1.05 \cdot \sqrt{3} \cdot I_{max} \cdot U_{rat} \cdot \cos \varphi. \quad (7)$$

where I_{max} is the maximum line current, A;

$\cos \varphi$ is the power factor, taken 0.9;

U_{rat} is the rated voltage of the network, taken 220kV.

Transmitted electricity per year W_{re} :

$$W_{re} = P_{max} \cdot T_{max}, \quad (8)$$

where T_{max} is the number of hours of maximum load use, taken $T_{max} = 6000$ h.

Load losses of electricity in line are:

$$\Delta W_L = 3 \cdot I_{max}^2 \cdot L \cdot r_0 \cdot \tau, \quad (9)$$

where τ is the maximum loss time, taken 4500 h.

The calculation results are presented in Table 3.

Table 3. Parameters of the 220 kV OHL crossing wires.

Parameters	Meas. u.	Options				
		1	2	3	4	5
t_{max}	°C	90	150	90	180	90
I_{all}	A	960	1344	979	1867	1360
P_{max}	MW	345.3	483.84	352.44	672.12	489.6
r_0 at 20 °C	kOhm/km	58.8	166.5	77.5	54.5	58.2
W_{re}	MW·h·10 ⁵	20.7	29.0	21.2	38.4	29.5
$\Delta W\Sigma$	MW·h·10 ⁵	0.14	0.75	0.20	0.46	0.29
K_e	%	99.3	97.4	99.0	98.8	99.0
I_e	bln. rub.	19,1	26.1	19.4	35.2	27.1
Relative capital investments	mln. rub./MW	0.56	0.35	0.46	0.24	0.32

The calculations show that among the proposed options, the most optimal is crossing with ACCC wire having minimum relative investment per 1 MW of transmitted power. The transmission capacity of line with this wire is increased by 1.8 times, and the cost of crossing is reduced by 16%. The smaller diameter of wire reduces the probability of ice formation on the wire, and the reduced bending deflection reduces the probability of wire break due to natural environmental influences.

6 Conclusions

The results of calculations of a wide crossing of 220 kV overhead transmission line over the river showed that the use of modern types of wires can solve the problem of both increasing the transmission capacity of overhead power lines and increasing their reliability.

The cost of span construction is reduced by 11-19% due to the possibility of using towers and foundations of lower material consumption.

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