Newly patented innovative high-efficiency wires for power transmission lines in energy grids

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Innovative wire, high-voltage power lines, loss of power and energy, economic efficiency, compacted wire
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Abstract

To meet the ever increasing power demand, we must continue to improve existing technology with active participation of equipment manufacturers, research institutions, etc. This paper discusses a new configuration of compacted wire, recently patented in Germany, which research has found to have significant advantages over existing compacted wires. The paper will start by comparing different wires of compaction and twisting and their main characteristics such as: strength, lower electrical resistance, less electrical loss, higher current, higher temperature, next it shows the results of a computer experiment which examined the relative effects of wind on compacted versus round wires showing clear advantages of reduced dancing in compacted wires, next it prognoses a creep, and finally developed the software.

1. Introduction

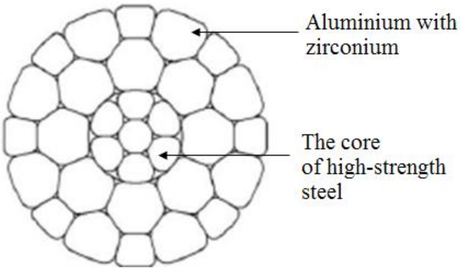
During the last few decades, some new problems have arisen in Electric Power Transmission, which has led to a variety of novel trends in overhead line projecting and construction, causing major corresponding changes in the wire requirements and designs [1]. Power failure analysis of the Russian Overhead Lines' elements [2] shows that the malfunctions related to failures of the conductors and ground wires are ranging from 40 % to 55 % of all malfunctions registered, while they are increasing by ≈ 3-5 % annually. The main causes of damage are ice load (overweight, wind), fatigue due to Aeolian vibration and dancing, as well as damage from corrosion and the conductors' burns after flashovers and lightning shocks. Therefore, optimization of the wires structure is necessary to address not only the current-carrying capacity and operating loss (heating conductors due to their DC resistance, the cost of reversal magnetization of the steel core, eddy currents and corona losses), but also their exploitation applicability and stability in a variety of sharply different climatic conditions in Russia.

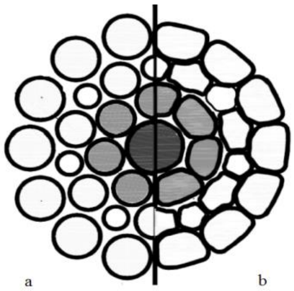
The practice of leading power grid companies suggests that a promising direction in solving the problem of increasing the capacity of transmission lines is the development of new structural materials for wires and transmission lines capable of long-term operation at temperatures of 100-200 ºC.

Russian engineers have developed a new high-efficiency wire for power transmission lines in energy grids. In 2016, a German patent [3] was received for the construction and production of this technology. This innovative design addresses multiple problems in the industry as the wires are stronger, can handle a higher current, and have less resistance and electrical loss, thereby saving money. The new wires have already caught the attention of German Bundesnetzagentur, who are considering using these wires in the future. At the 79-th General assembly of the International Electrotechnical Commission (IEC) in Minsk in 2015 at a meeting are also interested in the wires, and are currently discussing how to develop a new international standard for overhead messenger wires for railways using the same technology.

2. Design of Innovative wires for power transmission lines

There are new trends in both design and materials in the production of wires. Russia is manufacturing a fundamentally new type steel-aluminum non insulated high temperature wires (ASHT) and steel-aluminum non insulated high strength wires (ASHS). New wires have structurally the same design which consisting of a core and twisted compacted wires made of heat resistant aluminum-zirconium alloy which is shown in figure 1. The different between ASHT and ASHS wires is only including some zirconium in ASHT wires. Innovative wires brand ASHS and ASHT are intended for transmitting electric power through overhead transmission lines with high voltage lines 35-1150 kV. The main difference between standard steel-aluminum wires and wires brand ASHT and ASHS is shown in figure 2, a – standard steel-aluminum twisted wires are the round, b – the space between compacted wires is reduced but more metal is used with the same diameter (see table 1).





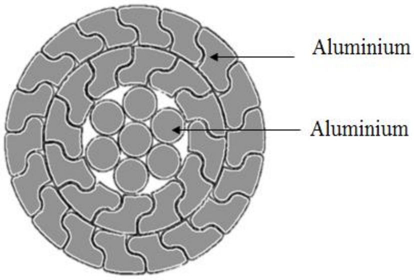


Figure 1. Wires brands ASHT, ASHS Figure 2. Types of wires a) Round b) Compacted Figure 3. Wires brands AERO-Z

Figure 1 shows a new class of compacted conductors with increased strength and capacity. These are compacted or plastically deformed high-strength conductors brands ASHT, ASHS [4, 5]. They have been approved by the interdepartmental commission of JSC "FGC UES" and have a significantly higher mechanical strength and current carrying capacity.

Table 1. - Comparison of diameters and cross-sections of standard steel-aluminum wire and the new ASHT, ASHS wires

Parameters of the conductors to be compared	AS 150/24	ASHT, ASHS 162/47	
	value	value	Change in percent to AS
Core cross section, mm^2	24,2	47,3	+90
Al part cross section, mm^2	149	162,3	+8,9
Diameter, mm	17,1	17,1	0,0

The deformation of the aluminum wire contributes, by increasing the fill factor of the working section to increase the useful current-conducting section of the wire. The obtained external surface is smoother and alter than that of round wires, and can reduce the load against climatic influences and significantly reduce aerodynamic drag and the dance of wires [4].

Other manufacturers use Z-shaped wire which is shown in figure 3 and used in the wire of the brand AERO-Z [13].

This compacted wire differs from the any constructions, because after twisting the core, it is subjected to raising its density over the cross section by compression, and then a similar procedure is applied to the conductive layers after their blending and twisting, see an example of such design in figure. 4. The cross section of the new Ground wire unidirectional twisted, with separate wires plastically deformed is shown in figure 5.

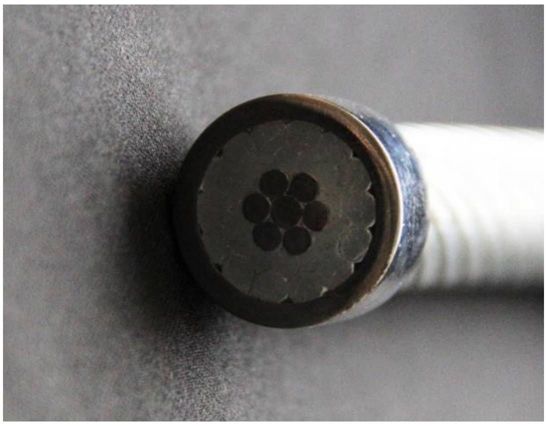


Figure 4.

Figure 5.

Figure 4. A Model of the new wires unidirectional twisted (the three conductive layers, core)

Figure 5. The cross section of the new ground wire unidirectional twisted, with separate wires plastically deformed.

Plastic deformation with a 8-9% reduction of distance between wires the cross-section prevents unwinding of the conductor and the mutual displacement of its elements under tensile forces, and due to mechanical hardening, the strength of the aluminum wires increases up to 1,5-2 times, while the difference in conductivity of the soft and the cold-hardened aluminum is less than 1% [6]. The costs of conductors ASHT, ASHS and refurbishment of overhead line with these conductors are slightly higher than similar costs of the ordinary conductors, but increasing the capacity (a few tens of percent for ASHS, up to 80-100 % for ASHT) covers additional costs, reduces the load on the towers, reduces tensile force, wind and sleet loads and, eventually, it should increase the reliability of the Overhead Line, as far as the fatigue strength of the new conductors improves considerably. The smaller diameter of the conductors ASHS, ASHT compared to the same of ordinary conductors AS with lower strength would provide

reduction: aerodynamic drag and, consequently, wind-induced loads; the level of internal corrosion in the conductor; the intensity of ice and snow build-up on the conductors outer surface; dancing amplitudes of wires.
The wire has a high resistance to the effects of lightning impulse the value of which is determined by the area of the suspension.

3. Important characteristics

Parameters of the new wires important for the overhead lines designed do exceed greatly than those for ordinary ones. But the new wires are little heavier, they would fit excellent for the new Line to be built in the regions with excessive wind or ice loads or for long River crossings.

3.1 Strength

Due to their innovative design, ASHS wires have more than 1.5 times the strength of standard Al-Steel wires. The breaking force is much higher than all competitors. The increased strength is a result of the compaction of the Aluminum –zirconium wires, and the high-strength steel core.

Table 2. – Comparison of breaking force of different wires

Type	Diameter, mm	Breaking force, kg
Standard AL-Steel 240/56	22,4	98253(100%)
AERO-Z 346-2Z	22,4	111320 (113%)
Lumpi -TACSR	22,4	86260 (113%)
J-Power Systems GATACSR	22,4	110000 (113%)
ASHS 277/79 Energoservise	22,4	163940 (167%)
ASHS 258/73 Energoservise	21,6	151553 (154,2%)
Standard AL-Steel 400/93	29,1	173715 (100%)
ASHS 371/106 Energoservise	26,0	225001 (122,79%)
ASHT 277/79 Energoservise	22,4	163940 (167%)

The values for Standard AL-Steel 240/56 conductors (serially used now) are assumed as 100 %.

3.2 Lower electrical resistance

As there is a higher quantity of metal in the cross section of both ASHS and ASHT, the electrical resistance is much lower than competitors' wires.

Table 3. - Comparison of weight and resistance of different wires

<table>
<tr><th>№</th><th>Company manufacturer</th><th>Conductor</th><th>Ø, мм</th><th>Weight, kg/км</th><th>Resistance, Ом/км</th></tr>
<tr><td>1</td><td rowspan="3">Standard steel-aluminum wire</td><td>AS 240/32</td><td>21,6</td><td>921</td><td>0,121</td></tr>
<tr><td>2</td><td>AS 300/39</td><td>24,0</td><td>1 132</td><td>0,098</td></tr>
<tr><td>3</td><td>AS 400/51</td><td>27,5</td><td>1 490</td><td>0,075</td></tr>
<tr><td rowspan="4">4</td><td rowspan="4">Energoservise</td><td>ASHT461/64</td><td>26,9</td><td>1 802</td><td>0,063</td></tr>
<tr><td>ASHT 371/106</td><td>26</td><td>1882</td><td>0,0776</td></tr>
<tr><td>ASHT 277/79</td><td>22,4</td><td>1400</td><td>0,1040</td></tr>
<tr><td>ASHS 277/79</td><td>22,4</td><td>1400</td><td>0,1040</td></tr>
<tr><td>5</td><td>Lumpi-Berndorf</td><td>TACSR/HACIN 212/49</td><td>21</td><td>939</td><td>0,1283</td></tr>
<tr><td>6</td><td>Lumpi-Berndorf</td><td>TACSR/ACS 212/49</td><td>21</td><td>914</td><td>0,1283</td></tr>
<tr><td>7</td><td>J-Power Systems</td><td>GTACSR 217/49</td><td>20,3</td><td>1015</td><td>0,136</td></tr>
<tr><td>8</td><td>Nexans</td><td>AERO-Z 366-2Z</td><td>23,1</td><td>1014</td><td>0,092</td></tr>
<tr><td>9</td><td>ZM</td><td>ACCR 405-T16</td><td>20,1</td><td>684</td><td>0,129</td></tr>
</table>

Electrical loss is directly correlated with electrical resistance. As ASHS and ASHT have lower resistance, they also have lower electrical loss.

3.3 Higher current

The higher quantity of metal in the cross section allows for a higher possible current. The current capacity for ASHS is slightly higher than AERO-Z, whereas the capacity for ASHT is more than twice that of AERO-Z and Standard Steel-Aluminum wires as well (see table 4). If the increase in the support load is not desirable, it is suitable to replace the AS 300/67 conductor ASHS 317/47, has less weight and heat losses, higher bandwidth compared with the AS300/67 with almost equal tensile strength (125 kN) . With the new construction of overhead lines with increasing distance between the supports and the low current loadings on line is possible to use ASHS 277/79, and when it is necessary to significantly increase the capacity of the line - that ASHS 389/59. Conductor ASHS295/44(116 kN) is more suitable for the replacement of AS240/56 (98 kN) conductors for overhead lines, where a slight increase in weight and load on the bearing is permissible, with the need to increase bandwidth, while lowering heat loss.

Table 4. - Comparison of maximal current of different wires

№	Company manufacturer	Conductor	Ø, мм	Maximal current, A
1	Standard steel-aluminum wire	AS 240/32	21,6	605
2		AS 300/39	24,0	710
3		AS 400/51	27,5	825
4	Energoservise	ASHT461/64	26,9	1668
		ASHT 371/106	26	1476
		ASHT 277/79	22,4	1199
		ASHS 277/79	22,4	862
5	Lumpi-Berndorf	TACSR/HACIN 212/49	21	861
6	Lumpi-Berndorf	TACSR/ACS 212/49	21	871
7	J-Power Systems	GTACSR 217/49	20,3	840
8	Nexans	AERO-Z 366-2Z	23,1	732
9	ZM	ACCR 405-T16	20,1	1059

So using innovative wires may be considerably increasing the capacity of high voltage lines as compared with standard conductors.

3.4 Higher temperature

Leading power grid companies are looking for materials for wires and transmission lines capable of long-term operation at temperatures of 100-200 ºC. The ASHT wires are resistant to the thermal effects of short-circuit currents arising in the event of operation of single-phase and two-phase earth fault. Experimentally confirmed operating temperature for wire brand ASHT is 150°C, the maximum allowable of 210°C.

3.5. Less creep

The correct definition of the conductors creep has recently become one of the important requirements arising from the Exploitation organizations in Russia, as it turned out that the capacity of many of the overhead Lines may not be fully utilized due to increased, after many years of service, sag of the wires [9].

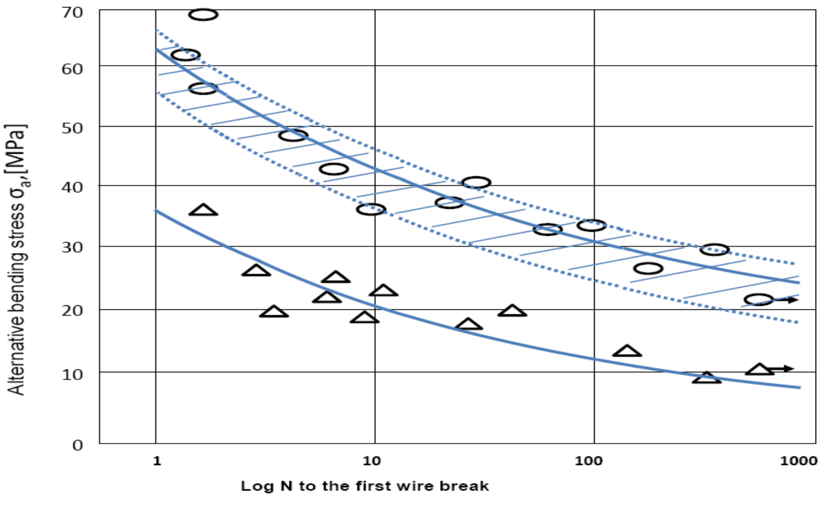


Figure 6. Prognosis of creep for the ASVP, ASVT conductors (shaded area). The results of computer modeling for single-layer (ellipses) and multi-layer (delta) wires AS are reproduced on the basis of data [8].

To avoid this problem with new wires in future, special attention to the creep tests is addressed. Quite recently, tests of creep (hood) of the OPGW type have been initiated, to provide the normalized input data for the Project engineers. The tests was carried out under a constant load of T_{eds} = 20% of RBS in the experimental stand. The results obtained at 20 ± 2 ^{0}C are shown in the graph of figure 7. So far, the test was carried out at constant and strictly controlled conditions, and the results obtained may be described in rather a simplified form. By this moment, we have an approximate expression for creep as: $\varepsilon_{creep} = at^{b}$; where a = 0,0278, b = 0,0511.

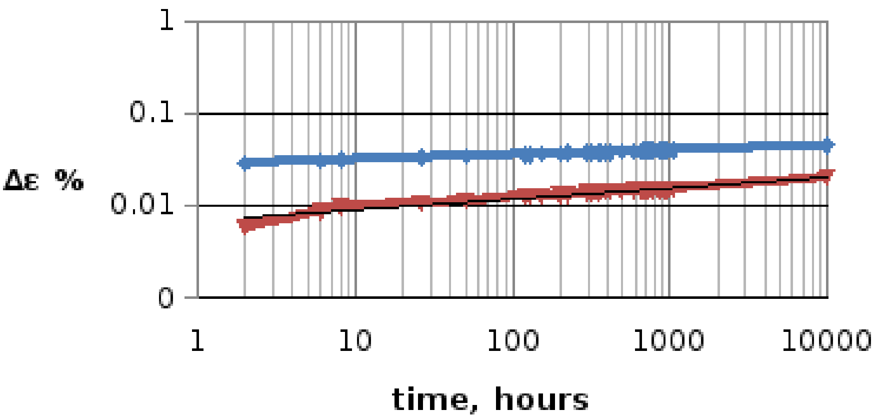


Figure 7. Creep results for the wires produced on the basis of the new technology of unidirectional twisting (Ø11,0 mm).

In the future, by extending the baseline of our tests, we expect to obtain more reliable creep characteristics of the samples. By changing tension and temperature during experiments, we would have chances to generate a more comprehensive polynomial digital description of new wires creep.

Table 5. Comparison of standard AS and the innovative compacted wires

Parameters of the conductors to be compared	AS 150/24	ASHT, ASHS 162/47	
	value	value	Change in percent to AS
Diameter, mm	17,1	17,1	0,0
Rated Breaking strength, daN	5227,9	9882,4	+89,0
Max current load, A	554	590,5 (822)	+ 6,6 (+ 48,4)
Span length of OHL at one and the same sag, m	280	364	+ 30
Towers on the 10 km of OHL	37	27	- 27
Specific losses of electricity at the same current load (150 A), MWh/km per year	41,7	36,4	- 12,7
Conductor temperature expansion coefficient, 10^{-6} 1/ °C	19,2	16,7	- 13
Conductor elasticity modulus, E*10-3, N/mm2	82,5	88	+ 6,7
Sag at the highest air temperature (+40 °C), m, for the spans: 250 m / 300 m	6,29 9,26	3,32 4,87	- 47,2
Sag at ambient temperature - 5 ° C in the 3rd region of the wind and ice load, m: 250/300	6,66 9,63	4,41 6,04	- 33,8
The electric field of the corona onset at dry weather, kV/cm	34,04	40,0	+17,5
DC Resistance (20 ^{0}C), Ohm/km	0,2039	0,1780	-12,7
Preliminary conductors' relative costs estimation	100 %	110-120 %	

3.6 Climatic conditions

3.6.1 Wind and ice accretion

We have been used for modeling the license software package of COMSOL Multiphysics capable to solve the differential equations in private derivatives, with the CFD Module intended for modeling of dynamics of liquids. By means of COMSOL CFD Module it is possible to carry out simulations of the squeezed current and thus to solve problems for subsonic, transonic and supersonic speeds. Functions of the solution of problems of a laminar or turbulent stream are available to the user of the application.

For implementation of an assessment of wind influence on wires with various form of cross sections the two-dimensional model which geometry is represented in figure 8 has been used.

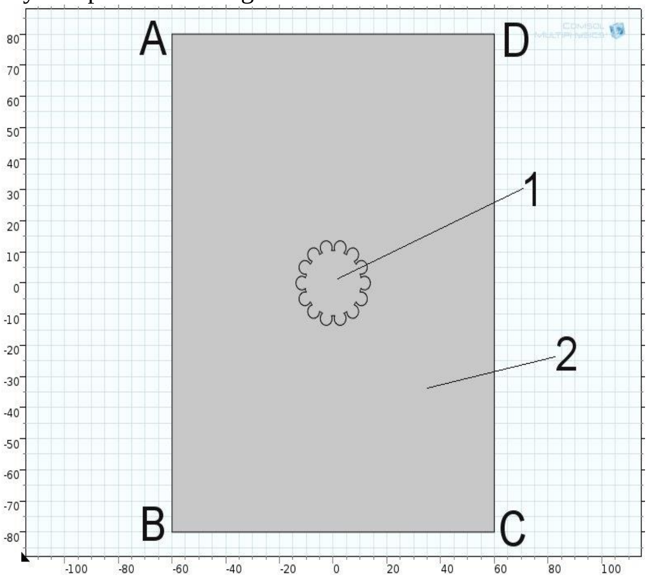


Figure 8. Geometry of the model used in this research: 1 – wire section, 2 – the air moving with the set speed

Inside the model Navier-Stokes's equation has been used (1):

$$\rho(\mathbf{u}\cdot\nabla)\mathbf{u} = \nabla\cdot\left[-P\mathbf{I} + (\mu+\mu_T)\left(\nabla\mathbf{u} + (\nabla\mathbf{u})^T\right) - \frac{2}{3}(\mu+\mu_T)(\nabla\cdot\mathbf{u})\mathbf{I} - \frac{2}{3}\rho k\mathbf{I}\right] + \mathbf{F}, \quad (1)$$

$$\nabla\cdot(\rho\mathbf{u}) = 0,$$

$$\rho(\mathbf{u}\cdot\nabla)k = \nabla\cdot\left[(\mu+\mu_T\sigma_k^*)(\nabla k)\right] + P_k - \rho\beta_0^* k\omega,$$

$$\rho(\mathbf{u}\cdot\nabla)\omega = \nabla\cdot\left[(\mu+\mu_T\sigma_\omega^*)(\nabla k)\right] + a\frac{\omega}{k}P_k - \rho\beta_0\omega^2,$$

$$\mu_T = \rho\frac{k}{\omega},$$

$$P_k = \mu_T\left[\nabla\mathbf{u} : \left(\nabla\mathbf{u} + (\nabla\mathbf{u})^T\right) - \frac{2}{3}(\nabla\cdot\mathbf{u})^2\right] - \frac{2}{3}\rho k\nabla\cdot\mathbf{u},$$

where u – air speed, v – the operator Nabla, c – air density, μ – dynamic viscosity, k – kinetic energy of a turbulent stream, w – the specific speed of dispersion, a, σ_ω^*, σ_k^*, β0, β_0^*, I – intensity of a turbulent stream.

The following boundary conditions have been chosen: on the verge of AB value of wind speed of has been established:

$$\upsilon_{AB} = \upsilon_0,$$

which is directed perpendicular to side Avna a wire;

on sides of BC, CD and AD pressure is equal to zero:

$$p = 0,$$

borders of a wire section represent not deformable walls.

Modeling has been carried out at various values of speed. The wind loading operating on a wire perpendicular to its axis paid off as the sum of projections of pressure upon a wire on an axis x:

$$F = \int \mathbf{n}\cdot P dl,$$

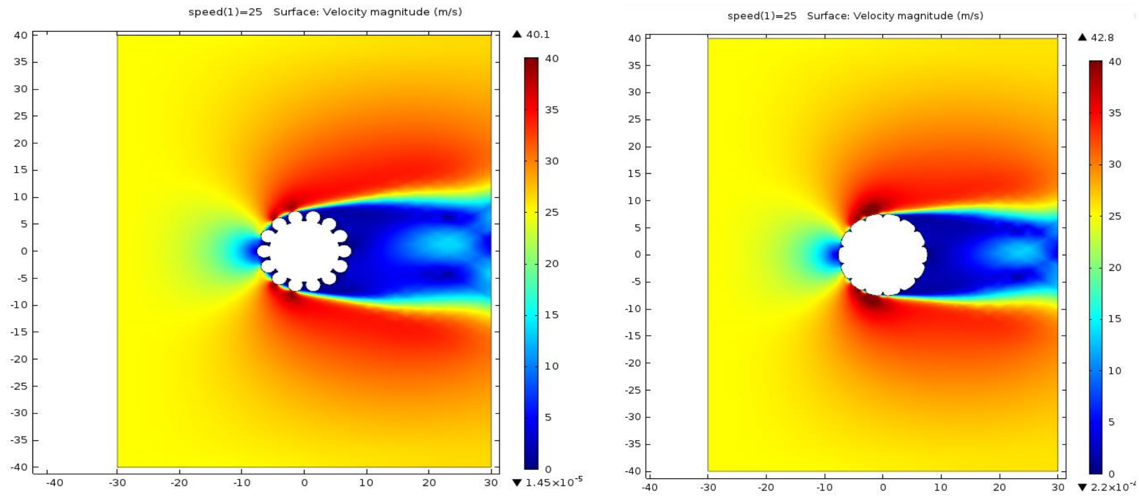
where P – pressure, n – a single vector along an axis x. The calculated wind loading differs from standard wind load of wires and cables F^{H}_{w}, as are not considered:

Change of wind pressure on height depending on district type; Influence of length of flight on wind loading;

Unevenness of wind pressure on flight of overhead lines.

Use of it, "cleared" from influence of various, not depending on a design of a wire factors, allows is more white accurately to define a wire contour contribution to change of wind loading.

Visualization's examples of the carried-out calculations of speed's distribution in an air stream and pressure at interaction of wind with wires with various contour of cross section (without ice cover) are given in figure 9.



a b

Figure 9. Speeds' distribution in an air stream, at a wind speed of 25 m/s (the area downwind I): a - AS 120/19; b - ASHS 128/37.

Average decrease in wind loading of a wire of ASHS (ASHT), rather standard the EXPERT makes 25-40%.

Table 6. Values of forces operating on wires with various contour of cross section depending on the air stream speed.

Speed υ_{AB}, м/с	The wind loading operating on wires of the following brands					
	ASHS 128/37	AL-Steel 120/19	ASHS 277/79	AL-Steel 240/56	ASHS 477/79	AL-Steel 400/64
25	3.65	4.80	5.18536	7.00026	6.37887	8.048
32	5.90	7.87	8.39748	11.48598	10.31608	13.21725
60	20.80	28.45	29.78561	41.59838	36.49622	47.89583

In the case of the new wires application at large crossings, it is possible to reduce the height of the terminal anchor supports of the crossing up to 25-30 %, subject to the standardized dimensions of the support Towers; this in turn will lead to considerably lower cost of all the crossing. In addition, with a reduction in height of the support Towers their inductance decreases, correspondingly reduces probability of direct lightning strokes and probability of back flashover to the overhead line. Moreover, it is necessary borne in mind that the unique technological solutions in the production of new wires allow to offer a significant reduction in price relative to other wires with the same characteristics.

By using new wires is increased breaking strength and decreased Specific loss of electricity at the same current load, aerodynamic loadings (till 35%) and formation of ice (till 25%), conductor temperature expansion coefficient (15%) only due the constructional design. In case of application for repair or upgrading works at the old overhead lines some other (less weighty – with the thinner core) new wires may be advised [7].

3.6.2 Lighting

The results of tests by lightning discharge of the ground-wires of different types of one and the same diameter is shown in table 7.

Table 7. The results of tests on stability to lightning discharge of the ground-wires of different types of one and the same diameter

No	Design, Material	Impulse value Coulombs	The Percent of all Discharges[9]	Mech. strength after Stroke	The Sample condition
Competitor 1	7 wires of Al-clad Steel, usual design	80	≈85%	0,4…0,5 RBS	Figure 10
Competitor 2	19 galvanized wires, usual design	85	≈90%	0,5…0,6 RBS	Figure 11
Competitor 3	19 galvanized wires, unidirectional twist, compacted	110…140	> 99 %	1,0 RBS	Figure 12

Figure 10. The Sample condition of Competitor 1

Figure 11.The Sample condition of Competitor 2

Figure 12.The Sample condition of Competitor 3

Aluminum coating of rods allows additional reduction of temperature, but its use is associated with a number of negative factors: low corrosion resistance of aluminized coating in the area of contact with stainless tube of optical module; low resistance of ground wires with aluminum coating. When selecting a type of protective coating for steel rods it is necessary to consider not only possible change of temperature field in wires at similar values of short-circuit current, but also dependence of its value on specific resistance of ground wire.

4. Software

Calculation of wires parameters and final Selection of Optimal Wires for Part of the Overhead Line (SOWfPOL) calculated automatically by the special research software. The windows of software shown in figure 13.

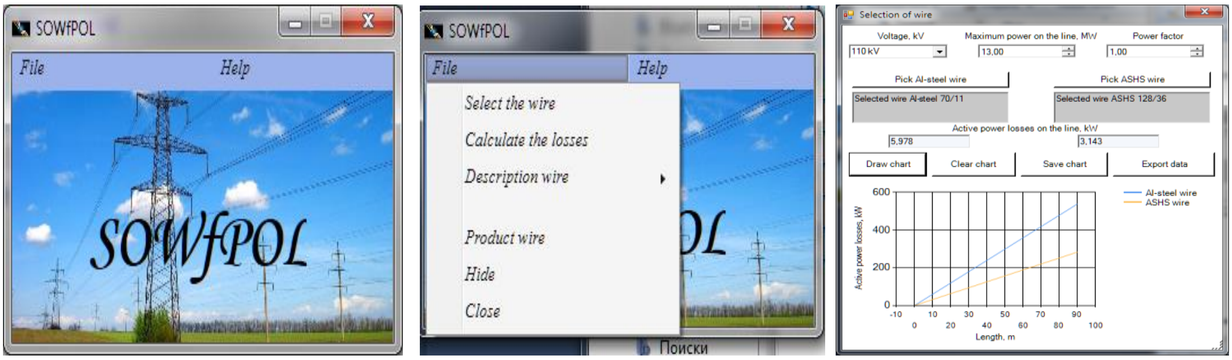


Figure 13. Window of software to choose the correct wires with the best parameters and final selection of optimal wires for part of the overhead line. a – interface of program, b – menu file, c – selection of wire

The menu file include next sections: select the wire, calculate the loss, description wire, product wire, hide, close. The program can calculate a current of overhead line; to show the product wire using in energy grids; to show the technical characteristics of wires; making experimental comparisons of different wires; to calculate technical loss on the transmission line, making figures electrical loss; export the results in Excel and saving all information.

5. Conclusion

The innovative technology of overhead line wires unidirectional twisted and compacted has been proposed and successfully implemented. It provides important and prospective advantages of the new innovative wires – much greater strength and the higher current of Power transmitted. In addition to the advantages enumerated above, the new wires have already revealed superior stability at lightning strokes; also, all the new products would surely have a very promising feature – the good fatigue stability at Aeolian vibrations and other kinds of dynamic impacts.

Comparative estimation of parameters of steel-aluminum wires of various types and mechanical durability calculations in various modes of environmental conditions demonstrated that steel-aluminum compacted brand ASHS wires allow flexibly solving design and construction problems of power transmission lines in energy grids.

Mathematical modeling techniques with subsequent series of experiments were used to demonstrate the falsity of the established opinion that it is necessary to apply steel-aluminum wires with an even number of layers of aluminum wires, twisted in the opposite directions in order to decrease electric power loss due to magnetic reversal of steel cores.

The transmission capability of high voltage lines in energy grids can be increased due to application of ASHS wires by a magnitude of several tens up to several hundreds of percent in comparison with standard wires [3].

Smaller diameter of ASHS, ASHT wires as compared to standard wires with the same transfer capability allows the reduction of the support load and slack of wires.

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10. Biographies

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