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B2 - OVERHEAD LINES
PS 1 / CHALLENGES & NEW SOLUTIONS IN
DESIGN AND CONSTRUCTION OF NEW OHL

Plastically compacted steel - aluminium wires for new overhead lines

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SUMMARY

Climate change may constrain future electricity supply adequacy by reducing electric transmission capacity and increasing electricity demand. The carrying capacity of overhead power lines decreases as ambient air temperatures rise; similarly, during the summer peak period, electricity loads typically increase with hotter air temperatures due to increased air conditioning usage. As atmospheric carbon concentrations increase, higher ambient air temperatures may strain power infrastructure by simultaneously reducing transmission capacity and increasing peak electricity load. We estimate the impacts of rising ambient air temperatures on electric transmission ampacity. During assess the impact of climate change on electricity load by using historical relationships between ambient temperature and utility-scale summertime peak load to estimate the extent to which climate change will incur additional peak load increases. By middle of century 2040–2060, increases in ambient air temperature may reduce average summertime transmission capacity by 1.9%–5.8% relative to the 2000–2020 reference period. At the same time, peak per-capita summertime loads may rise by 4.2%–15% on average due to increases in ambient air temperature and changes in the consumption structure itself, shift of load peaks of power from winter to summer. In the absence of energy efficiency gains, demand-side management programs and transmission infrastructure upgrades, these load increases have the potential to upset current assumptions about future electricity supply adequacy.

Paper discusses the problems associated with the use of new solutions related to the use of high-temperature wires of a new design for high-voltage power transmission lines 35-750kV, installation methods, standardization and calculation of operational efficiency. The main part of the research is connected with plastically compressed wires for high-voltage power transmission lines with the analysis of power and energy losses as well as corona losses due to streamer discharge, aerodynamic and ice loads, and the example of the design and construction of a new 6 kV transmission line with a capacity of 6 MW are presented.

Steel-aluminum plastically compacted overhead wires have an almost smooth outer surface and are manufactured using modern competitive technology, in terms of the cost of the final product. Plastically compressed conductors have a number of advantages that are usually characteristic of more expensive conductors made of profiled wires. Such advantages are the reduction of vibration loads and self-damping of vibrations. Intensive ice formation leads to icy loads of 6-750 kV overhead transmission lines and is one of the urgent problems of the electric power industry in countries with appropriate weather conditions. Due to the almost smooth outer surface, close to the conductors of segmented Ω- and Z-shaped aluminum wires, vibration and galloping of the conductors, as well as ice coating can be reduced. At the same time, high-strength conductors ASHS conductors have greater torsional rigidity, lower probability of galloping, increased vibration resistance and self-extinguishing ability even compared to conductors made of segmented Ω- and Z-shaped aluminum wires, since high-strength conductors have a developed contact surface of adjacent wires not only inside one layer of wires, but also between layers. Plastic deformation of conductors not only significantly increases the mechanical strength, but also reduces the elongation several times during operation.

Calculation of limit currents at temperatures below 45°C is produced without taking into account the influence of solar radiation. Absorbed solar radiation in the middle latitudes can heat conductors by 2-3 °C, for conductors operating in the temperature range of 60-70 °C and above. In southern latitudes, standard wires operate in emergency mode even without loading. The ASHT wire is able to withstand a large load under equal environmental conditions compared to the ASCR wire. The difference in the permissible load for the compared high-temperature conductors to 100%. The temperature difference is especially noticeable at high currents - about 5-7%. This paper also shows the use of compacted wire when it is necessary to significantly increase the throughput without increasing the cross-section. Plastic deformation maximizes space filling with minimal cost.

KEYWORDS

High-strength wire; high temperature wires; plastically compacted wires for OHL; power losses; steel-aluminum plastically compacted conductors; overhead power lines; characteristics and features conductors; mechanical strength; permissible current load.

INTRODUCTION

Due to the increase in energy consumption in large cities and regions, there is often a problem of insufficient capacity of power transmission lines. In order to solve problems of this kind associated with an increase in demand for electric energy, especially in the summer, it is necessary to modernize or reconstruct distribution networks. In order to ensure reliable operation in the long term and to ensure a balance between electricity production and consumption, coordinated planning for the commissioning of new network infrastructure facilities is necessary. At the same time, the configuration of the load schedule is of great importance not only for the balance, the regime of power plants, but also for the normal operation of existing, reconstructed and newly designed overhead lines.

Changes in the maximum load in the southern regions of the world and the impact on the capacity of electric grids

The increase in energy consumption in southern regions around the world may be accompanied by high ambient temperatures throughout the year. For example, in the energy system of the South of Russia, new historical maximum of electric power consumption has recently been established, the load is 17,145 MW, which is 577 MW higher than the same indicator recorded in previous periods of time. Such indicators became the first example in the history of Russia when the historical maximum in the unified power system was exceeded during the summer load maxima. Previously, historical consumption peaks in all were recorded only in winter. The increase in energy consumption is primarily associated with a period of extremely high temperatures.

The temperature of the conductive cores is determined by weather conditions such as the sun, wind, air temperature and the magnitude of the load current, and the capacity of overhead power lines depends on the temperature of the conductive cores [1].

The carrying capacity of the conductor is determined on the basis of thermal calculation. Thermal calculation in the general case is reduced to determining the temperature of the conductive core, taking into account losses. This takes into account the thermal resistances of the wire and the environment, as well as fluctuations in ambient temperature due to seasonal temperature changes and extraneous heat sources. Figure 1 shows the value of the long-term permissible current of the wires. Throughput decreases with increasing ambient temperature. Based on this, it can be concluded that it is advisable to compare the wires of overhead lines used in the southern regions produced using modern technologies, including the use of plastic deformation technologies. An increase in air temperature, as well as exposure to solar radiation under current conditions, can lead to consumer shutdown modes in these conditions. Figure 1 shows that the values of the long-term permissible current of the compared wires of overhead lines, determined by taking into account solar radiation, have a significant difference under the same ambient temperature conditions.

Table 1 presents the comparative characteristics of several solutions. The ASCR wire is a classic conductor consisting of a steel core and aluminum wires twisted by the correct twist with the direction of twisting of adjacent twists in opposite directions. A feature of the ASHS conductors is the increased mechanical strength and compactness of the structure, provided by plastic deformation of the steel core and wires and their twists before twisting. This, in turn, makes it possible to use conductors of significantly smaller diameters in the same length spans of overhead lines or to increase the distances between supports up to 40% without changing the transmission capacity of overhead lines, as well as to increase the maximum permissible current value at the same maximum permissible temperatures.

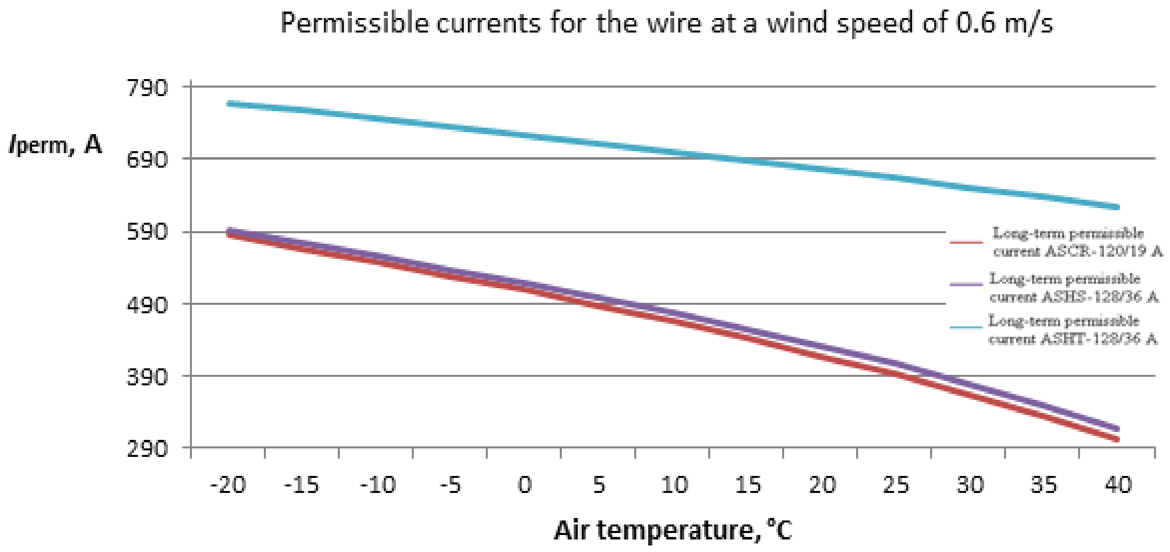

Figure 1 - Dependence of the long-term permissible current of wires on the ambient temperature.

The peculiarity of ASHT conductors is an alloy that increases the operating temperature of the conductors from 90 °C to 150 °C and the maximum permissible to 210°C, the wire design allows without changing the resistance of the wire, relative to ASHT, to achieve an increase in throughput without a significant increase in price.

Table 1 - Characteristics of the compared wires

Wire	ASCR aluminum wire with steel core	ASHS high-strength plastically compacted steel aluminum wire	ASHT high temperature plastically compacted steel aluminum wire
Core material	Steel	Steel	Steel
The material of the individual wires	Heat-treated aluminum alloy	Heat-treated aluminum alloy	Heat-treated aluminum alloy
Long-term permissible operating temperature, °C	90	90	150

The characteristics of the ASHT conductor display comparatively higher values of the long-term permissible current relative to the characteristics of ASCR 120/19, as well as ASHS-128-36. These indicators are due to the use of zirconium alloys, new sealing technology, as well as the innovative design of the core and the wire as a whole.

Comparative analysis of active power losses

Calculation the losses of active power in lines using wires such as ASCR, ASHS, ASHT. When calculating losses, we take into account the ambient temperature and heating of the wires by load currents [2, 3]:

$$\Delta P = \frac{3R_0(1+\alpha\Theta_{amb})I^2}{1-\frac{3R_0\alpha}{A}I^2}. \quad (1)$$

The numerator in this expression represents the losses reduced to the ambient temperature, and the denominator takes into account the increase in losses due to the heating of the wires by the load current. The coefficient A is determined by the following equation at the maximum allowable current I_{perm}:

$$A = \frac{3I_{perm}^2 R_0 (1+\alpha\Theta_{perm})}{\Theta_{perm}-\Theta_{amb}}, \quad (2)$$

where Θ_{perm} — maximum permissible wire temperature, °C; Θ_{amb} — ambient temperature, °C, to which the permissible current is reduced.
In table 2 shown the initial data for calculating power losses in the line.

Table 2 - Initial data for calculating power losses in power transmission lines

Name and designation of the parameter	Numerical value		
	ASCR-120/19	ASHS-128/36	ASHT-128/36
Reference linear active resistance at 20 °C, r_{20}, Ohms/km	0,249	0,225	0,2282
Linear active resistance at 0°C r_0, Ohms/km	0,22908	0,207	0,20994
Temperature coefficient of resistance α,°C^{-1}	0,0043		
Wire diameter d_W,м	0,0152	0,0152	0,0152
Permissible temperature Θ_{perm},°C	90	90	150
Ambient temperature Θ_{amb},°C	40	40	40
Maximum permissible current $Iperm$, A	302	318,62	624,95

The choice of high air temperature is due to the correspondence of the actual operating conditions of the wire temperatures. The data in Table 2 are obtained at the reference value of the permissible current, adjusted for ambient temperature. Table 3 presents the results of a comparative analysis of power losses of power transmission line wires. The calculations performed are valid for the stationary thermal regime.

Table 3 - Results of wire power loss comparison

Load current, *I*, relative units	Wire	Maximum permissible current, *Iperm*, A	Coefficient A	Losses of active power in the line, taking into account heating, Δ*P*, kW/km
0,4	ASCR-120/19	302	1739	12,05
0,6				28,01
0,8				52,19
1				86,94
The load current for the remaining wires is taken as a fraction of the permissible current of the wire ASCR-120/19 *I*, A				
120,8	ASHS-128/36	318,62	1749	10,86
181,2				25,16
241,6				46,64
302				77,12
120,8	ASHT-128/36	624,95	3679	10,85
181,2				24,84
241,6				45,02
302				72,17

The load current is expressed as a fraction of the permissible current of the brand wire ASCR-120/19.
Figure 2 presents the results analysis of wire power losses.

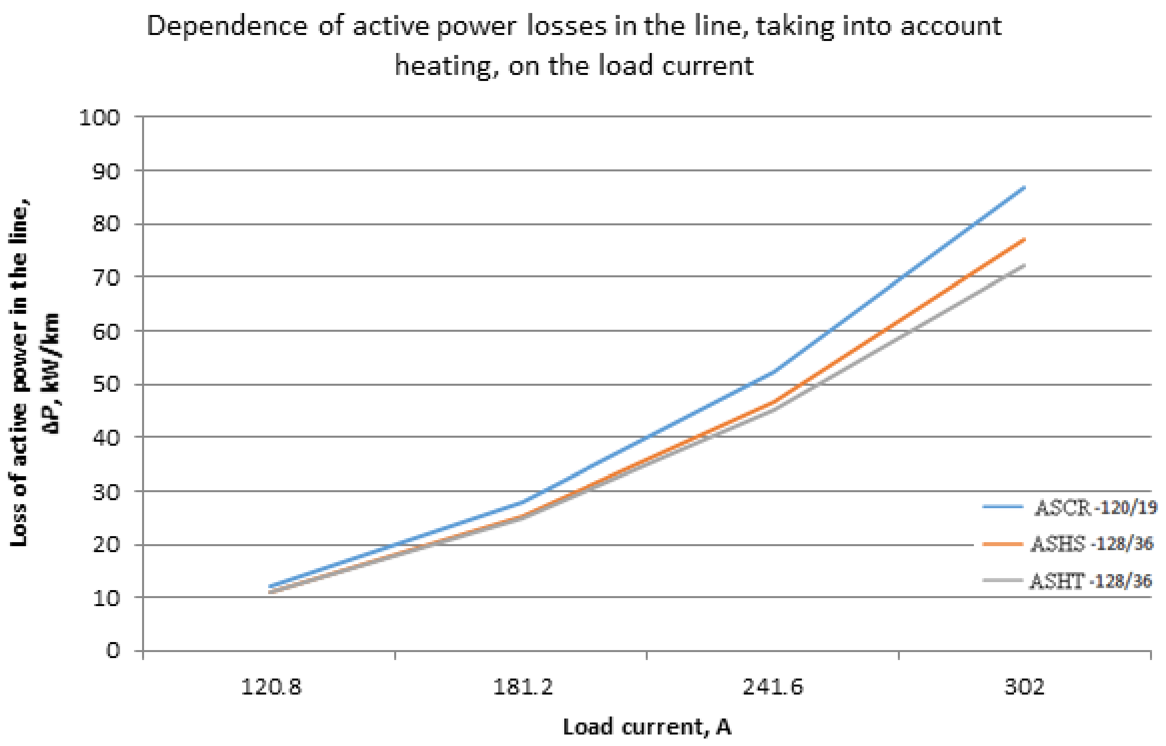

Figure 2 - Comparative analysis of wire power losses.

Summing up, the ASHS and ASHT type wires have significantly better characteristics relative to the ACSR wires in question under conditions of the same ambient temperature, as well as equal current load.

Reduction of operational exhaust

Plastic deformation not only significantly increases mechanical strength, but also reduces the extraction elongation several times during operation, regardless of the metal. The corresponding tests were carried out in JSC "VNIIZHT" and JSC "STC FGC UES" with products made of different metals - from steel to copper. In addition, the dependence of the wire on temperature is also reduced. Thus, the coefficient of thermal elongation at is 7% greater than AC 120/19 than that of ASHT 128/36.

As the temperature rises, the wires lengthen and the sag arrows increase. As a result, the dimensions of the overhead line and insulation distances may be violated, i.e. the reliability and safety of the overhead line operation are reduced. On a number of overhead lines, the throughput is limited by insufficient dimensions to the ground of intersected objects and interfacial distances due to temperature or operational changes in the sag arrows. This is especially important for overhead lines with difficult terrain, areas near tall buildings, on forest clearings, near high hills and in other places where overhead lines are closed from the influence of winds of prevailing directions, on overhead lines passing through territories with difficult terrain, on hilly and mountainous areas, in spans where the nature of the terrain changes dramatically, and the wires are closed from the action of the wind by various obstacles of natural or artificial origin. The prospect of an additional significant increase in throughput in ensuring the stability of gravity and dimensions [4]. Figure 3 shows the comparative analysis of the overall spans of wires for overhead lines 35-110 kV.

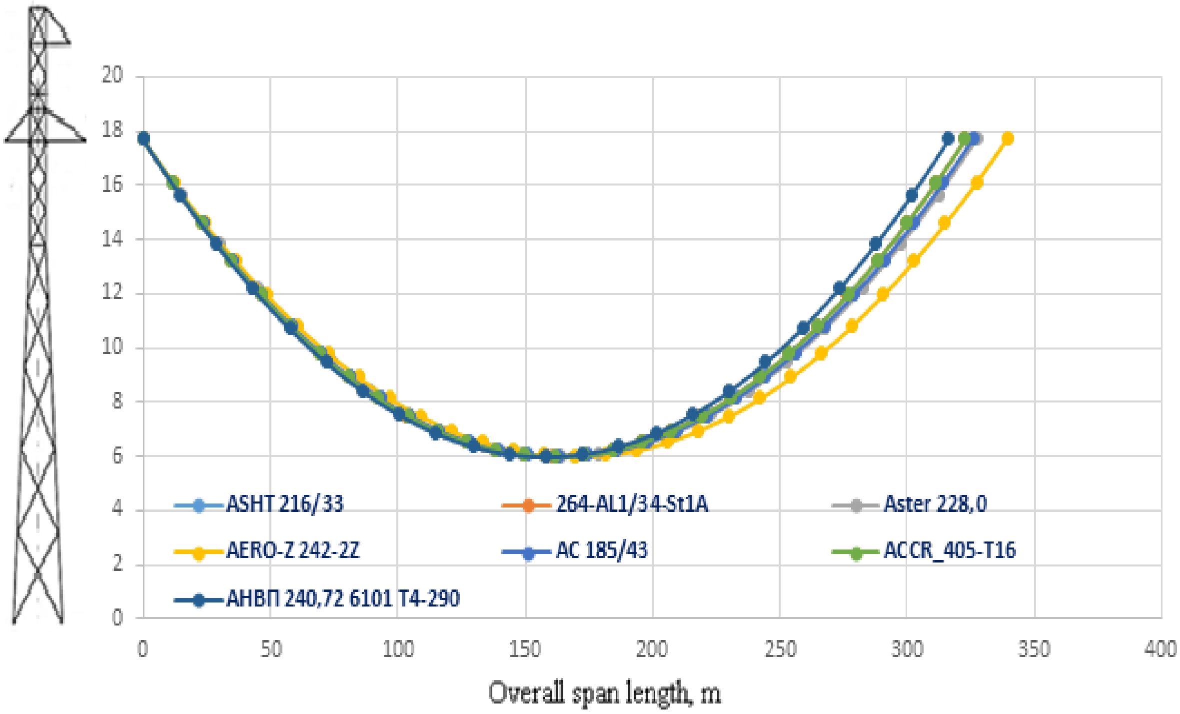

Figure 3 - Comparative analysis of the overall spans of wires for overhead lines 35-110 kV.

So based on tests conducted in Germany, the conductor ASHT 216/33 is comparable to wires of large diameters in terms of electromechanical characteristics. Which is experimentally confirmed by VDE.
When the maximum loads are shifted for a period of high air temperatures, the risks of limiting current loads increase. Strictly speaking, from the point of view of using high-temperature wire in areas with high air temperatures and solar activity, it provides a given throughput, because heating the wire by the sun to 60 ° C reduces the throughput by 40%. In this case, the use of high-temperature modification ASHT is promising, especially considering the cost comparable to ASCR. Figure 4 shows the comparative analysis of the overall spans of wires for overhead lines 6-35kV.
In ASHS and ASHT wires, the use of solutions to increase the throughput by limitation, without complex and expensive structures and alloys, which attracts both from a technical and economic point of view: Experimental confirmation of ASHS and ASHT features in test centers in Russia and Germany.
Thus, the use of unique technologies makes it possible to use a whole range of experimentally proven advantages:

1. Reduce the diameter of the wires, while maintaining the cross sections, which reduces wind, vibration and ice loads on the overhead line supports and their foundations;
2. Reduce aeolian vibration and splash due to increased contact between wires and layers;
3. Reduce icing as a result of increased torsional rigidity.
4. Reduce corona loss, increasing corona voltage can reduce corona diameter without increasing corona risk and noise level.

The design and use of high-carbon steels in a steel core, the mechanical characteristics of ASHS and ASHT wires, an example of reducing the cost of construction and operation of overhead lines, by reducing the number of supports while maintaining sag, while increasing the reliability of overhead lines. The operating temperature of ASHT-150C wires was experimentally confirmed, limiting - 210C without the use of alloys that worsen the conductivity and price.

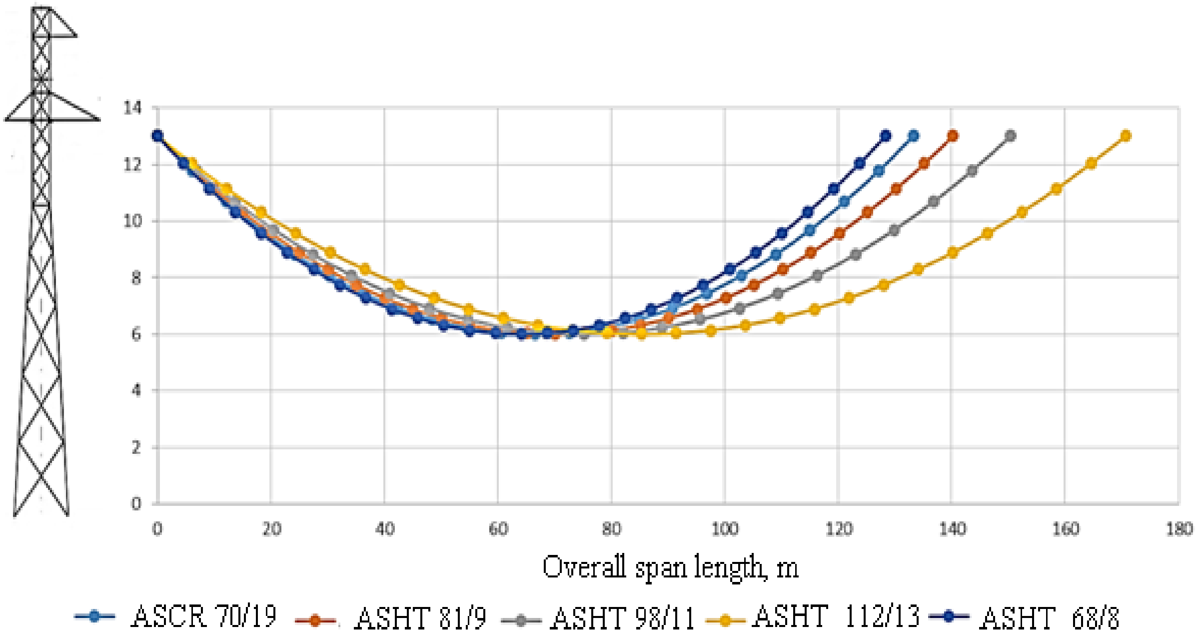

Figure 4 - Comparative analysis of the overall spans of wires for overhead lines 6-35kV.

Plastic deformation of wires not only significantly increases the mechanical strength, but also reduces the elongation several times during operation. Due to its design features, the high-temperature ASHT wires is several times cheaper than analogues with a long-term permissible temperature of 150 °C.

Results of the design and construction of a new 6 kV transmission line with a capacity of 6 MW

The power supply of the facility with a capacity of 6 MW was completed in 2021 by the construction of two 6 kV power transmission lines in the Volgograd Region of Russian Federation. As a result of a technical and economic comparison, a high-temperature wire ASHT 150/23 was chosen. Figure 5 shows the appearance of the constructed power transmission lines with an ASHT wire.


Figure 5 - Appearance of constructed power transmission lines with ASHT wire.

Steel-aluminum compacted wire have an almost smooth outer surface and are manufactured using modern competitive technology, in terms of the cost of the final product.

Figure 6 shows option with a plus tolerance for the diameter of aluminum wires. Nominal diameter Ø 13.5mm, Central wire - steel Ø4.0mm, five Aluminum wires Ø 5.60 mm.

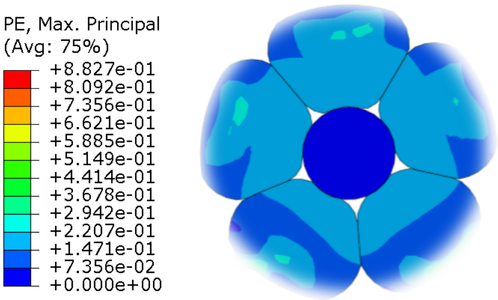

Figure 6 - Option with a plus tolerance for the diameter of aluminum wires.

The breaking force of the core, if necessary, can be changed, in agreement with the customer. Greater compression does not lead to a change in the design and diameter, nor to excessive stresses and deformations of the elements.

Figure 7 shows a specially designed device for connecting a high-temperature wire and a cable line suitable for it.

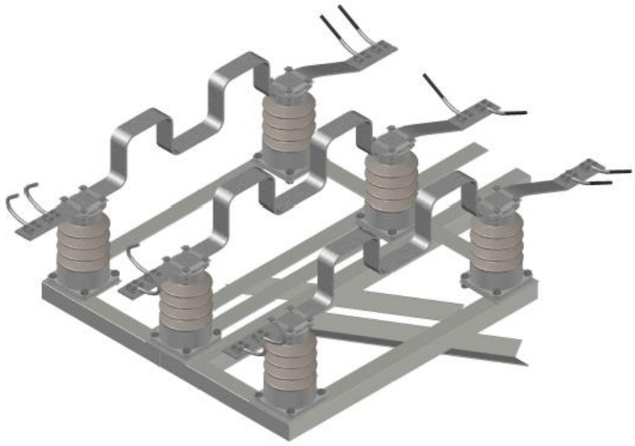

Figure 7 - device for connecting a high-temperature ASHT wire and a cable line.

Plastically compacted wires presented in table 4 have a number of advantages that are usually characteristic of more expensive conductors made of profiled wires. Such advantages are the reduction of vibration loads and self-damping of vibrations.

Table 4 - An example of an effective alternative to standard ASCR in new construction ASHS and ASHT 128/36 and reconstruction 112/13+ overhead lines

Wire	Breaking load, kN	Max. tensile, daN	Cross section Al, mm2	R, for 20 °C, Ом/км	Iperm, A (ASCR, ASHS)	Iperm, A (ASHS)	Ø. mm	Weight 1 km, kg	Span length, m
ASCR 120/19	**41,5**	**1868,4**	**118**	**0,244**	**418**	-	**15,20**	**471,0**	**299**
ASHS(T) 112/13+	**41,9**	**1970,2**	**123,09**	**0,234**	**453**	**613**	**13,50**	**433,4**	**312**
ASHS(T) 128/36	**77,1**	**3456,7**	**128**	**0,225**	**493**	**669**	**15,20**	**645,9**	**384**
ASHS(T) 98/11	31,4	1413,4	98,17	0,293	392	531	12,60	354,0	272
ANHS 118,55 6101 T4-290	33,9	1524,6	118,55	0,274	487	-	13,00	330,7	284

The permissible temperature for compacted wires of 150 °C is the dependence of the permissible current load on the air temperature for ASCR and ASHT wires under conditions of maximum operating temperature is 80 °C and 150 °C, respectively. The continuous permissible current for a high-temperature wire is 30-35% higher than the value for a standard wire of the same diameter.

CONCLUSION

Summing up, it has been shown that the researched wires in the new construction or reconstruction of overhead lines with the use of high-capacity wires allows you to provide a reserve of current load. The increase in the carrying capacity of the wires is provided by their higher operating temperature compared to conventional steel-aluminum wires. Due to increased resistance to temperatures above 100 °C, wires can carry a higher current load under normal conditions. The use of plastically compressed conductors is justified for the case with high ambient temperatures. In turn, the resulting effect in reducing technical losses allows us to talk, among other things, about decarburization and reduction of the carbon footprint, since it is required to produce less electricity in order to compensate for technical losses in electrical networks and as a result, emissions into the environment are reduced. Which together provides reliable solutions for the transition to low-carbon energy of the future within the framework of the Electricity 4.0 concept. The complex correct use of plastically compressed wires during the construction of new 6-750 kV overhead lines can significantly increase their reliability when exposed to the entire range of climatic loads, increase throughput, and reduce final capital costs.

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