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Research of steel - aluminium plastically compacted conductors for overhead lines (OHL)

V. KURYANOV, L. GYREVICH, L.TIMASHOVA, V. FOKIN
NRU "Moscow Power Engineering Institute", Volgograd State Technical University
"R&D Center "FGC UES", JSC, "Energoservis", LLC
Russian Federation

SUMMARY

This paper discussed the problems associated with the usage of new types of high-strength and high temperature wires for OHL, the methods of their installation, standardization and operational efficiency calculation. The focus of the paper is the technology of production and operation of the plastically compacted conductors for OHL combined with the analysis of power losses due to streamer discharge, aerodynamic and ice loads.
Steel-aluminum plastically compacted conductors have an almost smooth outer surface it looks like conductors made of segmented omega-or z-shaped wires, but it's much easier and cheaper.
Comprehensive tests conducted under the supervision of VDE Testing and Certification Institute from Germany have shown that the use of such wires on 110-220 kV OHL in some cases can increase the length of the spans of OHL to 140% in compared with classical wires. In some cases it is possible to reduce aerodynamic ~ 20% and icy loads ~ 25% while maintaining the dimensions and capacity of reconstructed OHL.

KEYWORDS

Plastic compaction, wind and ice load on steel-aluminum wires, corona discharge.

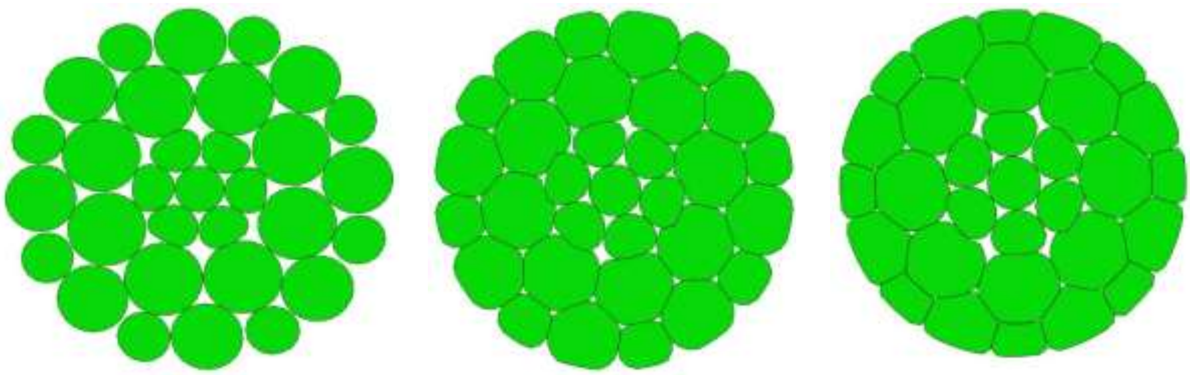
Vek077@yandex.ru

INTRODUCTION

The invention and mass introduction of new types of non insulated high temperature wires showed that one the promising areas of improvement of their characteristics is compaction [1].
The first mention of the technology of plastic compression of conductors when considering ways to increase the technical resource of steel ropes in the book by M.A. Bukstein “Production and use of steel ropes” in 1973 in Moscow Publishing house “Metallurgy”.
Plastic compression technology is applicable to strands of round wire and is necessary to give them a greater density and smooth surface which helps to increase the contact area. Such ropes were made in the USSR since 1970 years of last century.

I. COMPACTION

The use of circular - radial plastic compression of the conductors improve several characteristics at once: to increase the accuracy of manufacturing strands in diameter; to seal the to eliminate the possible unevenness of the tension of the conductors is shown of Fig.1, elimination of various unevenness of wire tension, formation of strip contact between strands and minimization of binding stresses.
Reducing the size of the wire is achieved by using plastic deformation not only of the outer layer, but also pre-compression of the steel core. Due to the use of compaction, the effect of concentrating a larger material in the same diameter is achieved, so the structural strength and current carrying capacity are increased.
Fig. 1. Changing of the profile of aluminum strands of external layer and density of filling of the steel-aluminum wire ASHS 216 / 33 at various degrees of compaction: a - after winding ø19, 2 mm; b, c - after compressions to ø17,8 and ø16,2 mm respectively.



a b c

The linear touch of the strands is achieved with a twist in one direction and the point touch is achieved with the opposite twist.
The efficiency of plastic compression is achieved only with the help of linear contact of the strands. In the case of point contact of the strands in areas of strand’s contact the wire is deformed that reduces its reliability at operation [2].
The outer surface of the conductors obtained with the use of such technology is smoother and smoother than the conductors made from round wires, which allows

reducing the load from climatic influences, significantly reduce aerodynamic drag in some operating modes [6, 7].

Theoretical and numerical simulations were performed to compare the interaction of wind with steel-aluminum wires with different cross-section contours, but with a similar diameter: ASHS128/37 и ACSR 120/19; ASHS 277/79 и ACSR 240/56; ASHS 477/79 и ACSR 400/64. For modeling, the COMSOL Multiphysics software package was used, which allows solving partial differential equations. The model was based on the Navier-Stokes equation. Computer modeling of the behavior of the air flow near the wire showed that a smoother contour and a smaller diameter of the ASHS type wires can reduce the wind load, reduce the diameter and therefore reduce the wind load. The simulation results are summarized in table 1.

Reducing the wind load allows you to reduce the load on the transmission line supports and install wires with greater capacity on existing supports during major repairs.

Table 1. Values of wind load on wire of ACSR and ASHS types with different contour of cross section depending on speed of an air stream

Speed υ_{AB}, m/s	Wind load acting on wires of the following brands, N / m					
	ASHS 128/37	ACSR 120/19	ACHS 216/32	ACSR 240/34	ASHS 277/79	ACSR 240/56
25	3.6	4.8	4.9	6.9	5.2	7.0
29	4.9	6.5	6.6	9.3	7.0	9.4
32	5.9	7.9	7.8	11.4	8.4	11.5
36	7.5	10.0	10.2	14.4	10.9	14.6

The modified wire geometry of the wire as a result of the application of plastic deformation technology theoretically and experimentally improves the properties of such a wire and gives a number of technical advantages:

- increase the wire fill factor to 92-97% with comparing of maximal fill factor of ACSR to 78%;
- reduction of aerodynamic load ~ 20%;
- reduction of icing ~ 25% [6] and reduction of wire stretching several times.

Thus, compaction allows to achieve improvement of operational characteristics of wires in comparison with classical steel-aluminum wires of similar diameters.

Intensive icy-wind load is one of the actual problems of the electric grids in countries with icy-wind operating conditions.

The close to smooth outer surface of plastically deformed conductors of the ASHS type, similar to the profile of the outer layer of wires from segmental, Ω-and Z-shaped aluminum wires what allows the ASHS wire use similar properties of Ω-and Z-shaped wires, including the adhesion of snow and ice [6,7].

At the same time, even in comparison with conductors from segmental, Ω - and Z-shaped aluminum wires, ASHS wires should have greater torsional rigidity, better self-damping, since, in contrast, they have a developed contact surface of adjacent strands not only within one layer of a single strands but also between layers. This further reduces the possible size of the ice wall. The closed design of the core and the wire as a whole construction for ASHS and ASHT wires prevents seasonal changes in the vibration mode associated with the ingress of moisture into the wire, which is especially significant in winter.

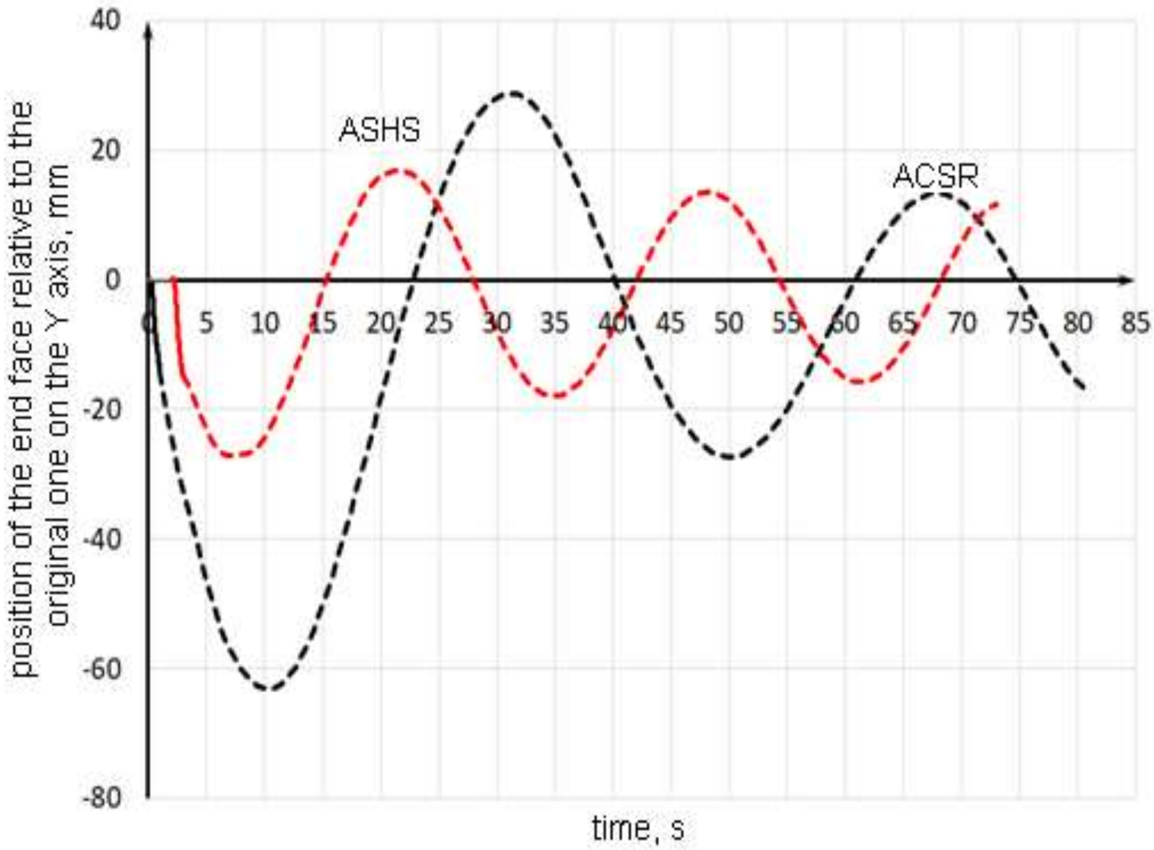
The dancing and vibration after the disturbing effect is extinguished due to the expenditure of energy on the internal friction between the strands. The ACSR wires have small contact between each other strands, so the friction losses are not so much. Compacted wires have a well-developed contact surface due to their special profiles, but each strand moves easily relative to the underlying layer and the layer above it. In wires that are compacted due to plastic deformation, developed contact areas are obtained both inside the layer and they enter the empty space in neighboring layers, so the displacement of the layers relative to each other is difficult. This does not apply to cases where the layers are compacted as they are wound, i.e. the steel core separately, and then the aluminum layer additionally. Plastic deformation of wires not only significantly increases the mechanical strength, but also reduces the elongation several times during operation.

The behavior of steel-aluminum wire of traditional design ACSR and plastically compressed ASHS with close areas of steel and aluminum wires is compared by computer modeling in the software complex SIMULIA/Abaqus.

In the simulation, a single pulse bending action was applied to the cantilever-pinched wire segment, and then a change in the amplitude and frequency of the damped oscillations was recorded.

The ASHS wire 128/36 due to the closer contact of the single strands, the initial amplitude and period of oscillation is approximately 1.7 times less than that of the ACSR wire 120/27 at the same dialed speed of the bent conductor under impulse action and shown on Fig. 3.

Fig. 3. Change in time of a vertical coordinate of a free end face of a piece of ASHS 128/36 and ACSR 120/27 wires at damping fluctuations.



For traditional ACSR wires characterized by a significant change in the geometry of the wire in the process of oscillation with the formation of large distances between the

strands, and the increase in the external size of the wire occurs both in the plane of oscillations and perpendicular to it.
The contact between the single strands of whole wire is plastically compacted ASHS conductors is maintained even at points of extrema.

II. COMPARISON OF WIRES AND TEST METHODS

During the tests of the new compacted high-temperature steel-aluminum wire, both mechanical and electrical properties were checked in accordance with current European norms and standards [8].
In accordance with IEC 61284 also DIN EN 50189, DIN EN 50540, DIN EN 62004 standards, complete mechanical and electrical tests have been carried out:

- Single-Wire Tests;
- DC resistance of the conductor;
- Tensile fracture strength of the conductor;
- Tensile fracture force of the nucleus after stress-strain test;
- Stress-Strain Testing (Wire & Core);
- Thermal Expansion Coefficients (Conductor & Core);
- Creep;
- Continuity Temperature Behaviour / Transition Point;
- Installation testing;
- Tensile test with Grip;
- Tensile test with the credits and connectors spirals;
- Radio interference voltage test;
- Corona inception/extinction voltage.

The mechanical tests of the wire rope, including the appropriate fittings fig. 4, were performed by Spie/SAG in Peterstrasse 44, Langen in Germany, land of Hesse, shown in figure 4.
FGH Engineering & Test GmbH in Mannheim in Germany was commissioned with the electrical tests.
The VDE Testing and Certification Institute carried out this project Germany, Offenbach, 28 Merian street accompanied this project and was responsible for its overall management. The tests have been successfully completed.
The General conclusion according to the final paper drawn up by VDE, SAG and FGH, for the ASHS and ASHT wires are recognized as conforming to European and IEC standards. VDE and SAG conducted an inspection of the quality control system of the manufacturer.

Fig. 4. Testing area in Germany, Langen, land of Hesse

Possibilities of solving the main problems of OHL construction and operation through the joint use of high temperature and high strength compacted wires are shown in Table 2.

Table 2.Possibilities of solving the main problems of OHL construction and operation through the use of compacted conductors

Problem	Solution based on compacted wires application	Confirmation
Reducing corona losses and noise level, without increasing conductor's diameter	+	Experimental confirmation of "R&D Center "FGC UES" [9], JSC and VDE (Germany)
Increasing lightning protection and resistance to short circuit currents	+	Experimental confirmation of "R&D Center "FGC UES", JSC and VDE (Germany)
Significant reduction of elongation in operation	+	Experimental confirmation of "R&D Center "FGC UES", JSC
Reducing vibration, galloping and oscillations selfdamping while keeping wire diameter	+	Experimental and computational confirmation of VSTU [2, 3], JSC "VNIIZHT" and MPEI
Increasing span length and or sags, without increasing wire's diameter	+	Design solutions [9]
Replacing the wire on the existing transmission poles, decreasing the load on all elements of overhead line and (or) increasing its transmission capacity	+	Design solutions [9]
Decreasing wind pressure while keeping wire diameter	+	Computational confirmation of VSTU and MPEI [2, 3, 5]
Replacing the conductor in the ring networks and decreasing conductor diameter	+	Design solutions [9]

Reduction of icing, while keeping conductor diameter	+	Computational confirmation of VSTU [2, 3] and MPEI
Keeping transmission capacity in areas with high air temperatures and solar activity, without increasing wire's diameter	+	Design solutions and computational confirmation of VSTU and MPEI [2, 3, 5]

III. TESTING OF CORONA DISCHARGE OCCURRENCE AS A FUNCTION OF VOLTAGE

An important point when using conductors with less diameter is the risk of electrical losses from corona and increase the acoustic noise level.

Testing laboratory of electrical equipment of high-voltage electrical grids according to the requirements of electromagnetic compatibility of JSC Scientific R&D Center FGC UES located at Russia, Moscow, Kashirskoe shosse 22, building 3, and then the Institute of the Association of electrical engineering VDE Testing and Certification Institute in Germany conducted four studies for testing this problem.

At the first stage, two wires of the same diameter 18.8 mm were taken for comparing and studying corona discharge.

Conductor samples were taken directly from the drum when testing in FGH Engineering & Test GmbH laboratory.

As to the tests of R&D Center FGC UES laboratory, the surface of wire samples was additionally cleaned of dirt and small defects related to the transportation and unwinding that could cause corona discharge. It was done for studying immunity of new ASHT 19.6-216/33-1 wires to corona discharge inception.

The tests were carried out in accordance with IEC 61284 recommendations.

Based on comparative tests results obtained at R&D Center FGC UES, it was established that ASHS 197/55 wire manufactured by compacted technology has corona discharge voltage 142.2 kV by 5.7% higher than ACSR 185/29 conductor 134.5 kV with the same diameter 18.8 mm [9].

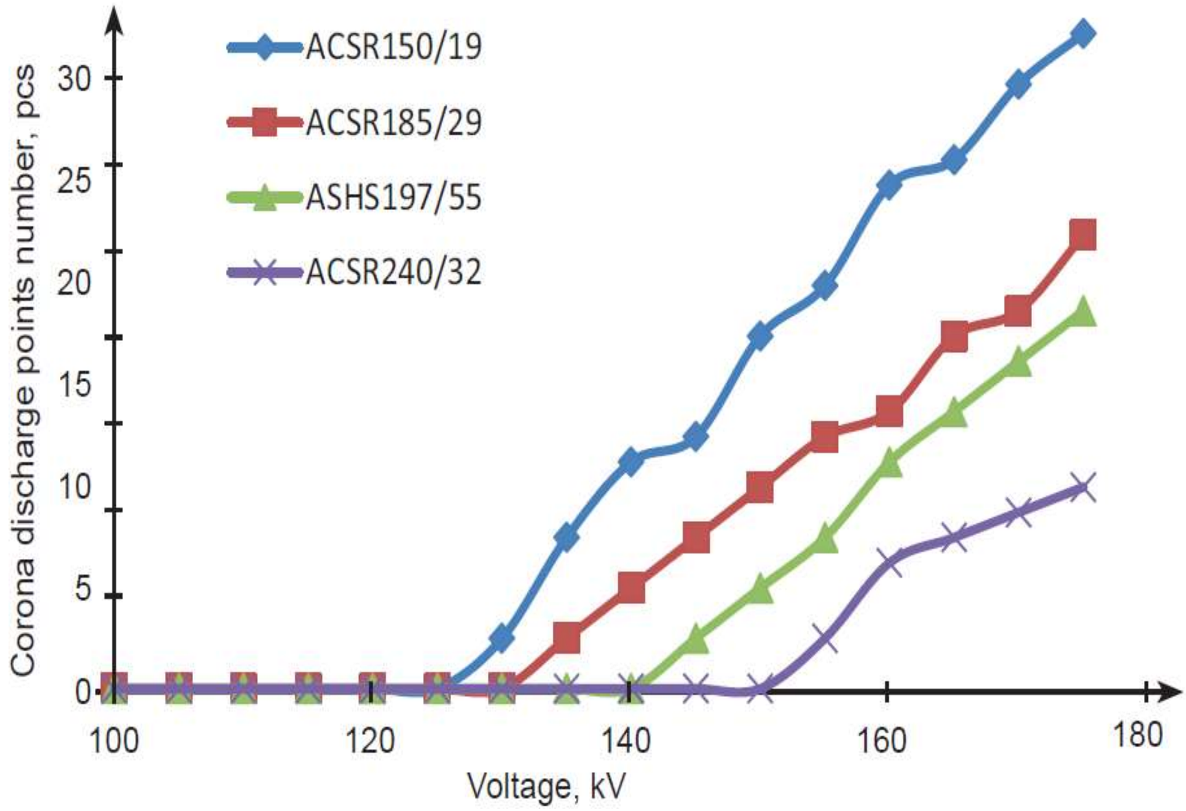
However, continuous permissible current of the wires being compared differs significantly 605 A for ACSR 240/32 wire and 689 A for ASHS 216/33 wire t = 70 °C, and 1040 A for ASHT 216/33 wire t = 150°C.

Similar tests were carried out for ASHS 216/33 and classical ACSR 240/32 wires with different diameters. Based on comparative tests results ACSR 240/32 wire 21.6 mm in diameter and ASHS 216/33 wire 18.5 mm in diameter have the same corona discharge voltage.

The test voltage for inspecting visible corona on 220 kV OHL was determined by FGH Engineering & Test GmbH laboratory as 167.7 kV phase voltage and R&D Center FGC UES, JSC laboratory as 160.0 kV phase voltage. The slight difference in results is due to the difference in climatic conditions when testing samples.

Voltage levels and registered results when testing visible corona are shown in Fig 5.

Fig. 5. Dependence of corona discharge points number on voltage



According to the tests results obtained by the laboratories, it was determined that streamer inception of corona discharge for ASHT 19.6-216/33-1 wire is at the level of 139.7–150 kV phase voltage. Based on corona discharge level, this conductor is recommended for use in domestic and foreign 110, 115, 138 and 150 kV electrical grids. In calculation cases, the wires can be used in higher voltage grids. R&D Center FGC UES calculated the specific losses per crown for good weather, the data are presented in tables 3, 4.

Table 3. Calculated specific corona losses in good weather for 220 kV overhead line

Phase construction (wire model; wire diameter)	Annual average losses change
ACSR 240/32, Ø 21,6 mm	26,67%
ACSR 300/39, Ø 24,0 mm	0,00%
ACSR 330/43, Ø 25,2 mm	−13,33%
ASHS 317/47, Ø 22,3 mm	−13,33%

Table 4. Calculated specific corona losses in good weather for 330 kV OHL with split phase consisting of 2 conductors with 40 cm spacing

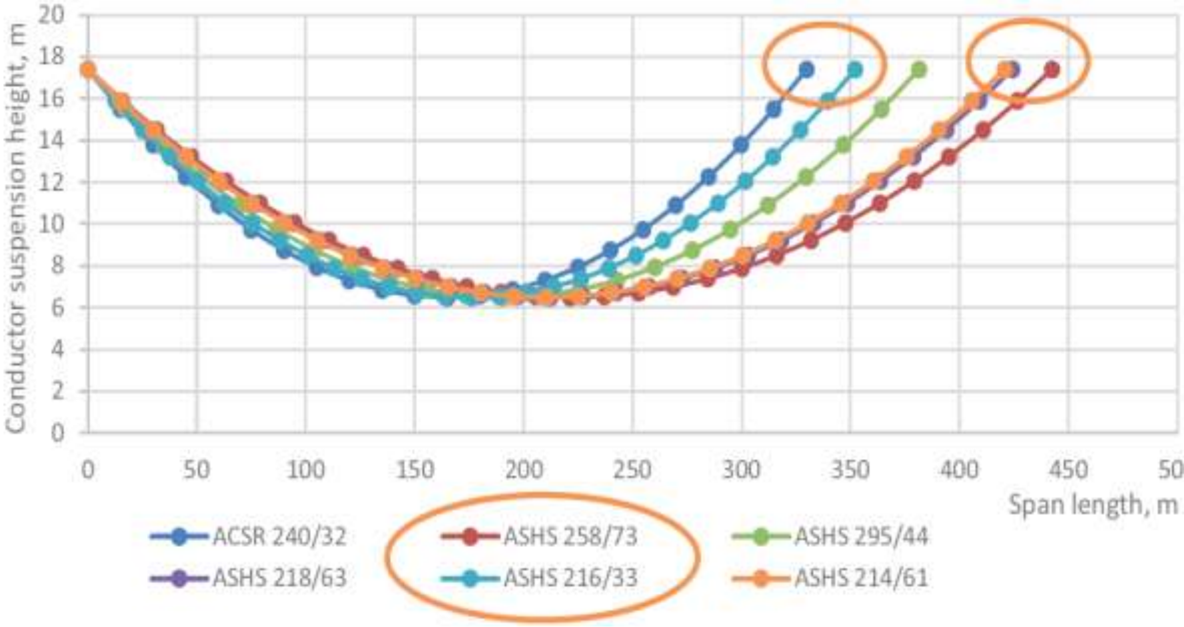
Phase construction (wire model; wire diameter)	Annual average losses change
2 × ACSR 300/39, Ø 24,0 mm	18,52%
2 × ACSR 400/51, Ø 27,5 mm	0,00%
2 × ASHS 317/47, Ø 22,3 mm	−7,41%

It has been experimentally confirmed that ASHS wires have advantages in terms of lower corona losses compared to ACSR wires the same diameter.

Also, ASHS wires have comparable corona losses in regard to ACSR conductors with larger diameter and similar electrical and mechanical characteristics.

IV. INCREASE OF SPAN LENGTH WHEN CONSTRUCTING NEW FACILITIES

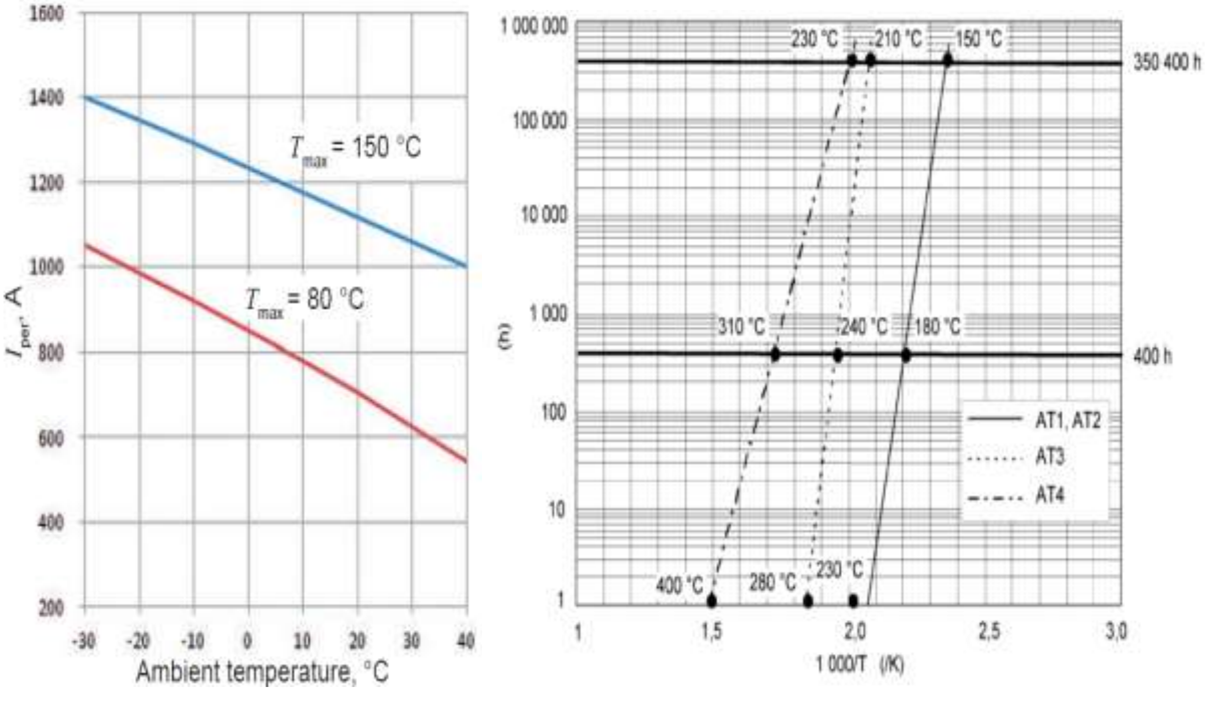
The plastically compression, compacted ASHS and ASHT wires allow engineers to increase the distance between overhead line poles up to 40% of the standard span in the absence of restrictions related to line route. It is an urgent task when constructing new overhead lines. For example, the comparative analysis of the span length for ASHS 128/37 wire mounted on 110 kV overhead line and ACSR 120/27, ACSR 120/19 conductors having the same cross-section and diameters has been fulfilled.
Because of ASHS 128/37 wire application the span length can be increased from 212 to 294 m compared with ACSR 120/27 wire.
ASHS 128/37 conductor has a higher content of steel. The ratio between aluminum and steel cross-section area is 3.45 for ASHS 128/37 wire and 4.3 for ACSR 120/27 conductor, an equal diameter 15.2 mm, and increased transmission capacity by 8% higher. An example of ASHS/ASHT wires application efficiency is the initial project of 150 kV Murmanskaya OHL in Russia. Analyses of data are shown in figure 6.
In its turn, ASHS 216/33 wire is the optimal option when reconstructing OHL and replacing wires on existing power transmission poles.
220 kV OHL project developed by "FGC UES" R&D Center is also an illustrative example.
Fig. 6. Calculated spans for 150 kV Murmanskaya overhead transmission line



Proper use of developed compacted wires in combination with ground wires of TU 062-2008 or fiber-optic ground wires of TU 113-2013 for new construction and reconstruction of 35–750 kV overhead lines can:
- significantly increase their transmission capacity,
- reduce capital and operating costs,
- enhance reliability when exposing entire range of climatic loads.

V. SUPPORTING TRANSMISSION CAPACITY OVERHEAD LINES IN THE REGIONS WITH HIGH AMBIENT TEMPERATURE

Due to its design features, ASHT high-temperature wire is cheaper by several times regarding to analogs with a long-term permissible temperature of 150 °C. Characteristics and features of ASHT wire are confirmed during the Russian-German tests. According to existing Electrical Installations Code, permissible current is determined taking into account the highest conductor's temperature equal 70°C.
It should be noted that, according to the regulatory documentation, classical wires are allowed to operate when their temperature is up to 90 °C. The permissible temperature for ASHT wires is 150 °C.
Fig. 8 represents the dependence of permissible current load on the air temperature and wind speed is 1.2 m/s for ACSR and ASHT wires in conditions of the maximum operating temperature of 80 °C and 150 °C, respectively.
Continuous permissible current for high-temperature conductor is 30-35% higher than the value for standard conductor of the same diameter. The calculation of the limit currents at the temperatures below 45°C can be produced ignoring the influence of solar radiation. Absorbed solar radiation in the middle latitudes can heat conductors by 2–3 °C for wires operating in the temperature range of 60–70 °C and above. The difference in permissible load for the compared conductors is 5%. The temperature of ASHT conductor is lower comparing to ACSR conductor, when increasing current load.
The temperature difference around 5–7% is especially noticeable at high currents.
Fig. 7. Dependence of current load on ambient temperature for ACSR and ASHS conductors with the same diameter at a wind speed of 1.2 m/s on the left and experimental validation on the right.



Thus, compacted conductor can be used when significant enhance of transmission capacity, without increasing the cross-section, is required. Also, the compacted conductor can be implemented in the areas with high ambient temperatures [9].

CONCLUSION

The design features of compacted plastically compressed wires reduce the load on all overhead line elements when replacing wires on existing power transmission poles. Tests conducted in two independent research laboratories in Germany have shown a number of technical advantages:

– increase the filling factor of the conductor to 92-97%;

– reduction in aerodynamic loading ~ 20%;

– reduction of icing ~ 25% and reducing the tension for several times.

A comprehensive proper usage of plastically compacted wires for the new construction and reconstruction of OHL 35-750 kV can significantly increase their reliability when exposed to the entire range of climatic loads, increase throughput, reduce capital and operating costs.

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