BENEFITS OF USING PLASTIC CRIMPED STEEL-ALUMINUM CABLES (ASHS, ASHT) AND GROUND-WIRES (MZ AND OKGT) IN COURSE OF RECONSTRUCTION AND NEW CONSTRUCTION OF HV LINES.

The complex of products proposed for high-voltage power transmission lines (HVL) – is the fully domestic development starting from the technology, raw materials and fittings to the process of manufacturing and is aimed at provision of higher reliability, reduction of life and HVL construction costs by using the most cost-efficient technologies. Products have passed **not less than two** complete test cycles (not accounting for the certification tests) jointly with fittings providing efficient operation in any conditions, including extreme ones. All products are certified.

Plastic deformation process provides for increase of the filling ratio to 92–97 %, which results in a significant improval of strength and cross-section for the same cable diameter, reduction of aerodynamic load (20–35 %) and icing (25–40 %). Closed design ensures additional corrosion protection of internal steel layers (near the core wire).

The **process itself is more simple, which means substantially cheaper** compared to any analogous product, meanwhile performance values obtained are **at least** the same (see Table 1).

Maximum efficiency (including increase of spans by up to 30 %) is reached by integrated use of our cables and ground wires (or OKGT) in course of new construction. However even in other applications (transitions, expansion of the old HVL transmission capacity etc.), each of the products provides solution to a variety of problems.

1. High strength steel-aluminum cable (hereinafter referred to as ASHS, common grades of Al are used). Higher mechanical strength and compact design allows as follows: to use cables of substantially lower diameter and weight for the same HVL span length or to increase the distance between supports (for the same cable cross-section) for at least 20–30 % without changing the HVL transmission capacity, and to increase the ultimate allowable current value at the same maximum allowable temperature. For the same mechanical strength the transmission capacity is 15–25 % higher. For **identical** electromechanical performance values ASHS cable price is comparable with AS cables.
2. High temperature steel-aluminum cable (ASHT). The alloy (with minimal addition of Zr to increase the ultimate allowable operating temperature of these cables from 90 °C to 210 °C), developed in cooperation with RUSAL, along with design of the cable and fittings allowed for rapid increase (compared to our ASHS cable) of the transmission capacity (up to 100 %), **without significant cost rise**.
3. Ground wire M3 as per TU-062 (in operation since 2008, 14,000 km supplied) – is the only cable, which withstands the complete cycle of **successive** tests for lightning current effect, aeolian vibration, dancing and for resistance to short circuit current using a single cable sample, which maintains its **initial** mechanical properties **after passing all the exposures.**.
4. OKGT retains the properties of M3. Number of optical fibers in serial production items – 8–96.

Based on the analysis of climatic zonation maps, many regions are located in the most severe climatic effect areas. H More than 50 % territory is occupied with regions, which belong to group III and higher in terms of wind pressure and icing, to 40 hours and higher group in terms of thunderstorms, extended areas with frequent and intense dancing are present. Our products shall maintain the operational efficiency in any conditions, including extreme ones, as they have been initially created for that purpose.

Challenging operating conditions are nothing new for us. In our practice we have already faced the need, working in cooperation with the manufacturer factory, to develop and supply special-purpose cable products for deep headframes operating at extremely low temperatures in highly agressive chemical conditions with ultimate mechanical loads and high wear rate, as well as to supply critical cable-stay load-bearing structures for cable bridges and other complex structures, e.g. for the Ostankino tower.

Irrespectively of the conditions, major engineering goals are the same for all HVLs:

1. High transmission capacity;
2. Reduction of losses for transmission of electric power from the power source to the consumer;
3. High operational reliability in specific operating regions within the total service life period under influence of the entire spectrum of actual loads (icing, wing, lightning strikes, short-circuit, agressive operating media).

All the goals listed above shall be reached with minimal expenses and in accordance to the applicable regulatory requirements.

Energoservis, LLC team in cooperation with Redaelli CCM introduces the following products for HVL applications: high-strength cables (ASHS), high-temperature cables (ASHT), ground wires for HVL protection from lightning strikes (TU062) and optical cable OKGT integrated to the ground wire (TU113).

Detailed description of the design, processes and testing of ground wire is provided in the reference documents [1–6], that is why here we will only list its major benefits verified by testing:

1. Completely proof to lightning strikes of maximum power.
2. Proof to successive load cycles: lightning strikes – vibration loads (aeolian vibration, dancing).
3. High mechanical strength.
4. High resistance to the combination of tension-bending loads (tension – aeolian vibration).
5. Minimum corrosion resistance of Zn coatings of OZH group +5 %,
6. Ultimate linear elasticity modulus E for stranded cable products.
7. Minimal tolerance for the ultimate tensile strength value and product weight (less than 1 %)

Based on the results of all tests performed, no samples have been damaged or destroyed, and the ultimate tensile strength value did not change from the manufacturer determined value.

All above benefits are also applicable to our OKGT cables (TU113). The design difference includes replacement of the core wire by an optical module with variable number of fibers, placed inside of the module using the filler gel.

At this time positive operational experience of ground wire TU062 makes up 6 years, many new HVLs rated from 35 kV to 750 kV have been equipped with more than 13,000 km of cable during this time. However, for the purpose of reconstruction of obsolete HVLs, despite the acting prohibition, regular steel wires as per R.ST. WIRE 3062, 3063 are oftenly used as ground wires without applicable certification. In such a case it is usually appealed that "old" supports are not capable to withstand the weight and tension of our products. Set aside the fact of intolerable transgression against the principal technical regulation of Rosseti JSC and let us go through the technical aspect of the problem that allows us to come up with the following conclusions:

1. Maximum overweight of ground wires as per TU062 compared to steel cables of the same nominal diameter per 1 meter of uniformly distributed load due to its weight actually equals 20–30 grams. Thus, this value may be disregarded as being the minor value of much higher order compared to values of other vertical loads, e.g. icing.
2. Tension is certainly a much stronger argument, but solution to this problem is clearly shown by the below tension and sag calculation example for the Enisei – Itatskaya HVL 500 kV. Support force limitation for the project is as low as 6118 daN, which for the ground wire TU062 diameter 11.0 mm makes up only 44 % of the ultimate tensile strength. See initial data for calculation (Table 1), loading cases (Table 2), and tension and sag change modes shown in Fig. 1.

Table 1. Project-defined conditions for sag calculation.

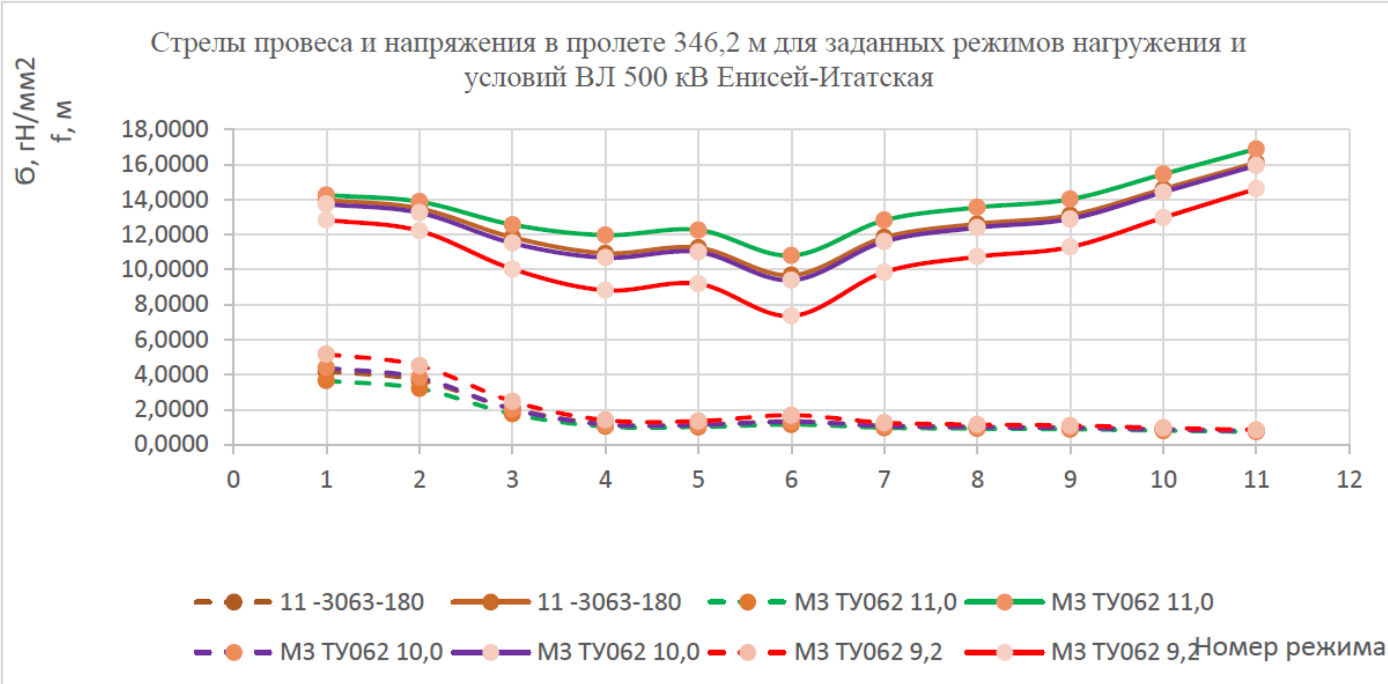
t_{-}, °C	t_{g}, °C	t_{e}, °C	t +, °C	t_{gr}, °C	$b_e = b_u$, mm	q_4, daN/mm^2	q_5, daN/mm^2	H_{pr}, m	f_{gab}, m
-60	-5.0	-0.8	38	15	20	80	18	17.7	14

Calculated span for the steel cable as per 11.0-R.STANDARD WIRE 3063 made up 346m with standard climatic load ratios.

Table 2. Loading cases (load combinations) for the Enisei – Itatskaya HVL 500 kV at normal conditions.

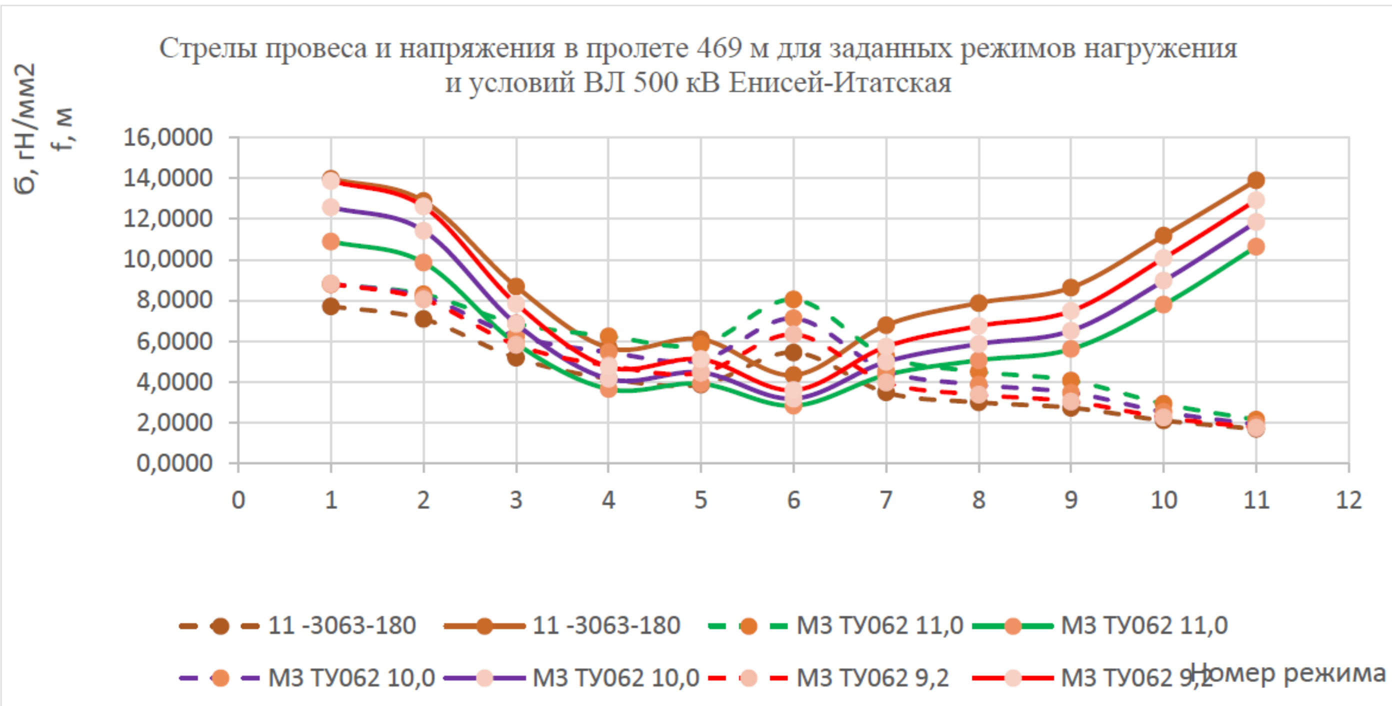
Mode number	Temperature	Wind	Ice-slick, mm	Specific Load
1	-5.0	q5	20	ϒ7
2	-5.0	q4 = 0	20	ϒ3
3	-5.0	80	0	ϒ6
4	-0.8	q4 = 0	0	ϒ1
5	15	q6 = 0,06*q4	0	ϒ9
6	-60	q4 = 0	0	ϒ1
7	38	q4 = 0	0	ϒ1
8	70	q4 = 0	0	ϒ1
9	90	q4 = 0	0	ϒ1
10	150	q4 = 0	0	ϒ1
11	210	q4 = 0	0	ϒ1

Figure 1 sag and tension in the span of 346.2 m for given loading conditions and the conditions of 500 kV Yenisei - Itatskaya



Calculation results clearly prove that taking into account considerable limitations applied to cable tension forces acting to the supports, application of ground wires as per TU062 with lower diameter compared to conventional steel cables as per R.STANDARD WIRE 3062, 3063 even allows to reduce the sag of the ground wire. For the HVL in the above example, usage of ground wire as per TU062-2008 diameter 10.0 mm instead of the steel cable as per R.STANDARD WIRE 3063 having diameter of 11.0 mm, would have increased the span length by 4 % and reduced the cable weight. For the same initial data and operating modes a rather different result is obtained when allowable support forces exceed or are equal to the ultimate tensile strength of the ground wire as per TU-062 (fig. 2).

Figure 2 sag and tension in the span of 469 m for given loading conditions and the conditions of 500 kV Yenisei - Itatskaya



In such a case span value for the steel cable 11.0 as per R.STANDARD WIRE 3063 already makes up 469 m, however such a R.STANDARD WIRE 3063 cable may be replaced at the same span by our ground wire TU062 diameter 9.2 mm with a tension group of 190 kg/mm^2.

Calculation results may be summarized in recommendations as follows:

1. It may be definetly recommended to use ground wire as per STO 71915393-TU062-2008 for reconstruction and regular replacement of ground wires at HVLs with a diameter one step lower compared to steel cables as per R.STANDARD WIRE 3063, e.g, 11.0 mm (R.STANDARD WIRE 3063) shall be replaced by 10.0 mm (TU062) and 9.1 mm (R.STANDARD WIRE 3063) shall be replaced by 8.0 mm (TU062). Such a replacement allows for reduction of weight and sag of ground wires without increase in horizontal tension forces applied to supports of old HVLs and not impairing its thermal capability.
2. In case of a minor reduction of requirements applied to thermal resistance of ground wires at sections with low probability of short circuit or having low SC current values, it may be recommended to use ground wire as per STO 71915393-TU062-2008 for replacement of ground wires at old HVLs with a diameter two steps lower compared to steel cables as per R.STANDARD WIRE 3063, e.g, 11.0 mm (R.STANDARD WIRE 3063) shall be replaced by 9.2 mm (TU062), which may significantly reduce the sag and load applied to supports.
3. For the new construction minimum effect of sag reduction is obtained by using the same diameter ground wires as per STO 71915393-TU062-2008 instead of steel cables as per R.STANDARD WIRE 3063. Maximum effect of weight and load to supports reduction in such a case may be obtained for areas with low possibility of a short circuit, by replacing the steel cable as per R.STANDARD WIRE 3063 by ground wire as per TU062 having diameter one step lower but identification group higher.

Obviously, maximum value of span between the supports is the priority for construction of new HVLs. Resolving of this issue requires an integrated approach to engineering of transmission lines. In terms of our products that means unconditional usage of our cable design in combination with our ground wires and OKGT. In the above example the main cable used is AS 500/64 with our high strength ground wire tied-in to its already calculated span.

Below an ASHS 128/37 cable span calculation is provided for an HVL 110 kV compared to cables of almost the same cross-sections and diameters: AS 120/27; TACSR 120; AS120/19. Tension and sag values for all other cables are calculated for the span equal to our cable. Tables 3, 4 and fig. 3 list the initial conditions, loading cases and tension and sag change modes:

Table 3. Project-defined conditions for sag calculation.

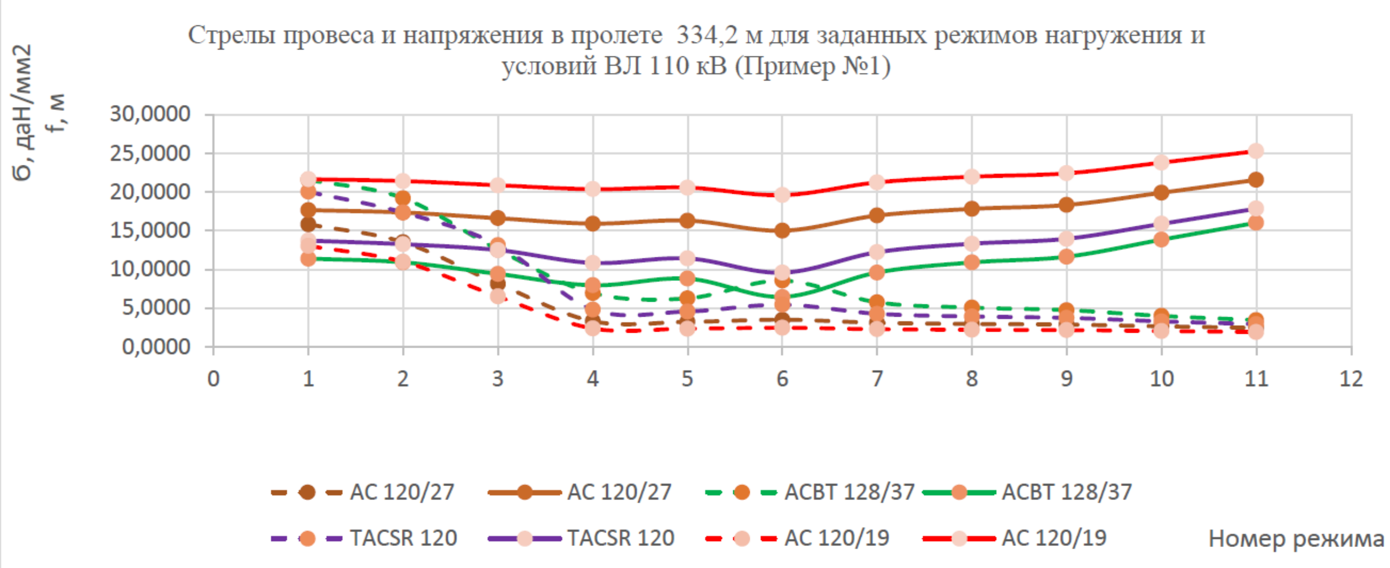
t_-, ºC	t_g, ºC	t_e, ºC	t +, ºC	t_{gr}, ºC	$b_e = b_u$, mm	q_4, daN/mm^2	q_5, daN/mm^2	H_{pr}, m	f_{gab}, m
-55	-10.0	-10	35	15	20	80	20	9.9	11.7

Calculated sag for the cable ASHS 128/37 made up 334.2 m at maximum allowable heating temperature 90 °C.

Table 4. Loading cases (load combinations) for calculation of the HVL 110 kV (Example No. 1) at normal conditions.

Mode number	Temperature	Wind	Ice-slick, mm	Specific Load
1	-10.0	q5	20	ϒ7
2	-10.0	q4 = 0	20	ϒ3
3	-10.0	80	0	ϒ6
4	-10.0	q4 = 0	0	ϒ1
5	15	q6 = 0,06*q4	0	ϒ9
6	-55	q4 = 0	0	ϒ1
7	35	q4 = 0	0	ϒ1
8	70	q4 = 0	0	ϒ1
9	90	q4 = 0	0	ϒ1
10	150	q4 = 0	0	ϒ1
11	210	q4 = 0	0	ϒ1

Figure 3. sag and tension in the span of 334,2 m for given loading conditions and the conditions of 110 kV (Example No. 1)



We managed to increase the span value in the above example by 27 % due to usage of ASHS 128/37 compared to the AS 120/27 cable. It is worth notice that with higher steel content (ratio 3.45 compared to 4.3 for AS 120/27) our cable has almost the same diameter at 10 % higher transmission capacity. Obviously, comparing performance values of our ASHS cable to AS 120/19 (ratio 6.1), span increase with the same sag will make up almost 40 %.

Similar results are obtained when comparing our ASHS and ASHT cables make I and II as per STO TU 120 to analogous AS cables with Al to steel cross-section ratio equal to 4.3. Thus, our cables may be recommended as the replacement of mentioned AS cables for applications in climatic regions with icing and wind conditions starting from group III, as using our cables it is possible to obtain 20–30 % longer design span, to reduce the number of intermediate supports of the HVL and to reduce the construction cost.

Effect of ASHS (ASHT) cable type 371/106 usage instead of the cable 300/204 (Al to steel ratio 1.4) at transitions also seems intriguing. At the same sag and span we may obtain approximately 30 % of weight reduction and 24 % of cable transmission capacity increase.

Cables ASHS and ASHT designed as per group III at ultimate conditions allow for up to 25 % higher transmission capacity at the same tensile load and lower weight compared to AS cables. At present conditions, it is the same weight and 20 % better transmission capacity. A similar comparison has been performed for AS cables with Al to steel ratio 4.3.

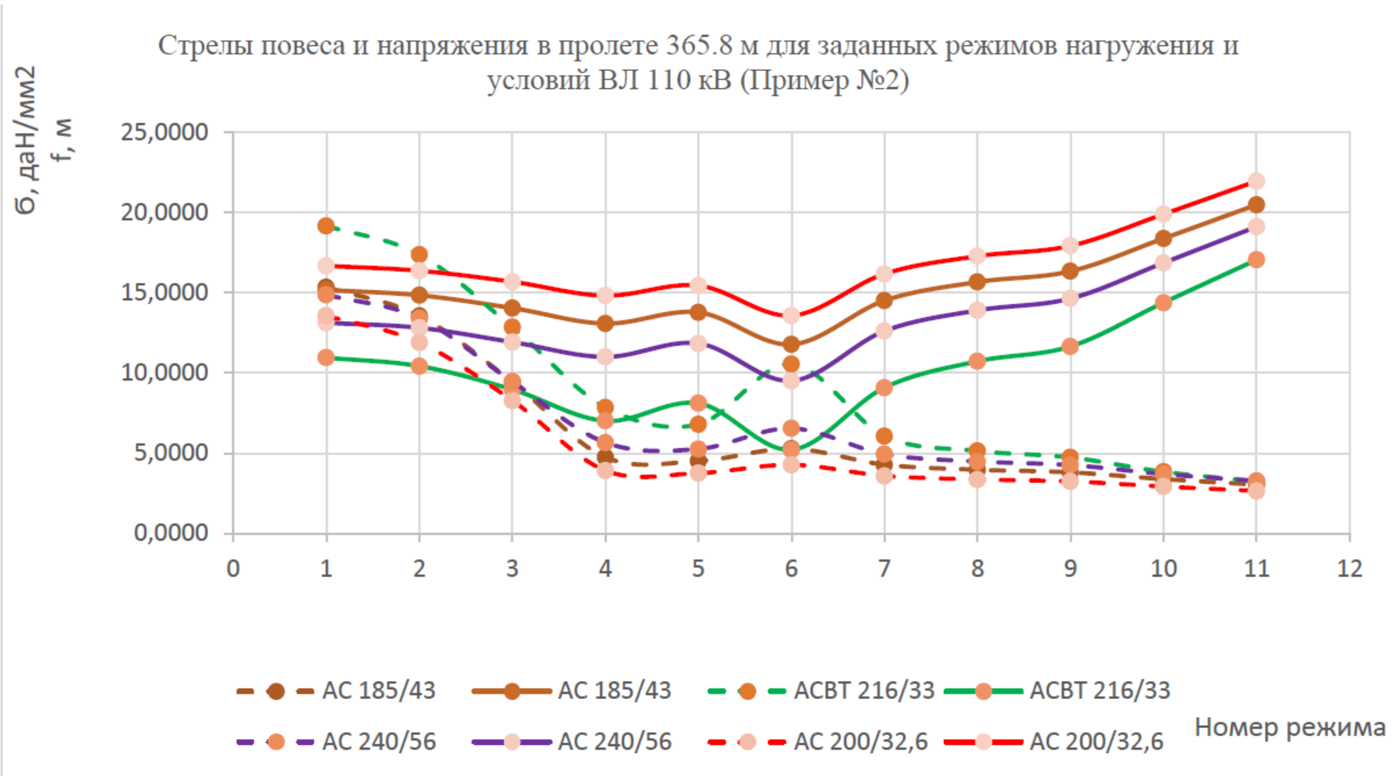
The nearest developments are aimed at creation of high-strength core design with a lower steel cross-section, which shall allow for significant weight reduction at the same tension as for AS cables and to increase the transmission capacity by 20–30 % at the same outline dimensions.

Table 5 and fig. 4 list the major performance values of the pilot cable sample produced in frameworks of group IV cables development – ASHS 216/33 compared to similar AS cables, along with tension and sag change modes: Specified conditions and loading cases are identical to conditions and modes analyzed for the HVL 110 kV, Example No. 1 (Tables 3, 4).

Table 5. Performance values of cables AS 185/43, ASHS 216/33, AS 200/33, AS 240/56.

Cable designation	S Al/S core ratio	S Al, mm^2	S core, mm^2	Weight of 1 km, kg	Cable diameter, mm	Ultimate tension, daN
AS 185/43	4.292	185	43.1	846	19.6	7776.7
ASHS (ASHT) 216/33	6.565	216	32.9	820	18.5	10600
AS 240/56	4.281	241	56.3	1106	22.4	9825.3
AS 200/33	6.135	200	32.6	805.6	19.82	7013.4

Figure 4 sag and tension in the span of 365,8 m for given loading conditions and the conditions of 110 kV (Example No. 2)



Data provided prove that application of the cable ASHS 216/33 for VL 110 kV analyzed in Example No. 2 compared to AS 185/43 allows for increase of span by 20 % and transmission capacity by 17 % at even lower cable weight. Compared to the cable AS 200/33 it is possible to increase the span by 27 % at better transmission capacity and almost the same weight. Provided the transmission capacity drop by 10–11 % is acceptable, replacement of the wire AS 240/56 may increase the span by 13 % with a significant, almost 35 % weight reduction at 20 % lower diameter.

Certainly, operability all design benefits of our cables and ground wires may be obtained only in optimal joint operation of the ground wire, cable and the core in the mounting arrangement (junction). In our case this task has already been resolved by Elektrosetstroyproekt, CJSC, which has developed specially for our cable design mounting arrangements and spiral joints that have jointly passed all the required certification testing cycles.

Plastic crimped cables type ASHS and ASHT proposed for application at HVLs differ from the conventional cables with plastic crimping of the core after stranding; the same operation is performed for current-conducting layers. In the first case regular grade Al is used, while in the second case a specified amount of Zn is added to increase the ultimate allowable operating temperature from 90 °C to 210 °C.

Performance values of all our products required for reference and calculations, along with its its appearance, list and some results of qualification testing are specified in the reference documents and at our web-site http://w.w.w.energoservise.com -

High temperature cables is the brand new class of products, thus its application is not covered by any regulatory documents. The main purpose of these cables is to increase the transmission capacity and ultimate allowable current value by means of increasing the Al recrystallization temperature and to increase the cable maximum operating temperature.

Table 6 [5] includes comparison of performance values for cables type AS (ACSR), AERO-Z produced by NEXANS and cables type ASHT produced by Redaelli CCM.

Table 6. Cables performance values comparison

Trademark	Ø, mm	Breaking force, kg	Weight, kg/km	Continuous carry , A
AS 240/56	22.4	98,253 (100 %)	1106 (100 %)	610 (100 %)
AERO-Z 346-2Z	22.4	111,320 (113 %)	958 (87 %)	852 (140 %)
Lumpi-TACSR	22.4	86,260 (88 %)	957 (87 %)	861 (141 %)
J-Power Systems GATACSR	22.4	110,000 (112 %)	1100 (99 %)	860 (140 %)
ASHS 277/79	22.4	163,940 (167 %)	1399 (127 %)	753.8 (123 %)
ASHS 258/73	21.6	151,553 (154.2 %)	1296.5 (117 %)	717.70 (118 %)
ASHT 277/79	22.4	163,940 (167 %)	1399 (127 %)	1199 (197 %)
AS 400/93*	29.1	173,715 (100 %)	1851 (100 %)	860 (100 %)
ASHS 477/66*	27.5	175,910 (101.3 %)	1860 (1.01 %)	1075.0 (125 %)

Note. Values for AS cables are assumed as 100 %.

ASHS and ASHT cables have higher strength than any of the cables listed in Table 6. ASHS cables have higher transmission capacity compared to AS cables, and the ASHT cable has transmission capacity twice higher than that for AS cables and 1.5 times higher that that for AERO-Z cables of same diameter. Increase in weight compared to the AS cable is compensated by higher strength of the ASHS and ASHT cables. In other words, ASHT cables allow to increase the span and to ensure for higher transmission capacity at lower diameter compared to AS cables.

Reasonable approach to the cable selection shows that ASHS and ASHS cables, ground wires TU062-2008 and OKGT TU113-2013 allow to expand the conventional HVL engineering frameworks and to set goals that used to be unachievable or such an achievement was challenging, and provided a specific technical assignment or requirement is available, it is possible to produce these items with predefined properties.

Major benefits of ASHS and ASHT cables listed in the report as compared to standard AS cables as per R.STANDARD WIRE 839-80 are listed below:

1. Higher mechanical strength and compact design allow for: usage of the same cable diameters at distances between the supports at least 20–30 % higher without changes in the transmission capacity of the HVL. Upon increase of the core strength and reduction of the cable diameter at same transmission capacity it is possible to reduce its weight by 30 % and to increase the span by up to 20 %.
2. At identical mechanical strength of products, the transmission capacity is increased by 20–30 % and the ultimate allowable current value is increased at same maximum allowable temperatures.
3. Lower construction cost and higher operational reliability of cables used in junction with ground wires or OKGT for regions, which belong to wind pressure or icing group III or higher.
4. High resistance to the combination of tension-bending loads (tension and aeolian vibration). Obtained by using thee patented process, combining linear stranding of core wires and current-conducting layers and plastic deformation of the core and the entire product.

Breakthrough feature of our cables is the combination of current-conducting Al and load-bearing steel layers single-direction stranding with plastic deformation of steel layers and the entire product. That not only provides the lightning strike resistance and increase of the useful cross-section in the easiest and streamlined way, but consciously provides all the structures with the highest resistance to bending and vibration loads.

As verified by calculations made in the Volgograd Institute of Technology [7], such a solution not only add nothing to the total electric losses, but vice versa, reduces such losses by eliminating the contact points.

Steel cables as per TU 062 may also be used as "anchor wires" for HVL supports to replace obsolete regular steel cables as per R.STANDARD WIRE 3063, 3064. Such a comparison proving the principal possibility of such a replacement is provided in table 7.

T. 7. Performance values of steel cables as per Standard wire and steel cables as per STO 71915393-TU062-2008.

Cable	Diameter,	Cross-		Identificatio	Galvanizing	Ultimate

designation	mm	section, mm²	Weight, kg	n group, kg/mm²	group	tensile strength, kN
R.STANDARD WIRE 3063	13	101.7	873	140	S, Zh	124.5
TU062	10	70	575	190	OZh	124.1
TU062	11	83.6	695	180	OZh	141.1
R.STANDARD WIRE 3064	14	116.9	993.6	140	S, Zh	135.5
TU062	11	83.6	695	180	OZh	141.1
R.STANDARD WIRE 3064	15.5	141.4	1200	140	S, Zh	164.0
TU062	12.5	108	890	180	OZh	182.5
R.STANDARD WIRE 3064	17.0	168.2	1425	140	S, Zh	195.5
TU062	13	118.6	982	180	OZh	200.3
R.STANDARD WIRE 3064	18.5	197.3	1685	140	S, Zh	229.5
TU062	14	135.9	1125	180	OZh	229.5
R.STANDARD WIRE 3064	22.5	298.5	2550	140	S, Zh	347
TU062	17	201.6	1670	180	OZh	340.5
TU062	17	201.6	1670	190	OZh	360.2

Cables suggested as a replacement to R.STANDARD WIRE cables listed in the table above are highlighted with green.

Conclusion:

It may be recommended for HV lines to replace the anchor wires as per R.STANDARD WIRE 3063 and 3064 by steel cables as per STO 71915393-TU062-2008 with approximately equal or higher ultimate tensile strength value. Such a replacement allows to reduce the weight, to reinforce the supports and to increase its service life, to substantially reduce the aerodynamic load applied to supports due to lower diameter, to increase the HVL reliability and to reduce the cost of these load-bearing elements of the supports.

Conformity testing requirements of Germany (DIN & IEC), confirmed by SAG Deutschland - Versuchs- und Technologiezentrum

STATEMENTS

1. It is not allowed to use steel cables as per R.STANDARD WIRE 3062, 3063, 3064 as ground wires at HVLs in course of new construction, reconstruction and at planned replacement. Actual use of standard

cables as per R.STANDARD WIRE 3062, 3063, 3064 as ground wires is the gross violation of the technical regulation of Rosseti, JSC and may not have any technical justification. The report (page 5) includes sufficient recommendations for replacement of regular steel cables by ground wires as per TU062 both for new HVLs and for old supports during the planned replacement.

2. Steel cables as per TU 062 may also be used as "anchor wires" for HVL supports. Replacement options suggested in table 7 allow to reduce the weight, to reinforce the supports and to increase its service life, to substantially reduce the aerodynamic load applied to supports due to lower diameter, to increase the HVL reliability and to reduce the cost of these load-bearing elements of the supports.

3. Application of ground wires as per TU062 and OKGT as per TU113 allows to make use of all exclusive benefits to increase the HVL operational reliability and life cycle.

4. Major capabilities of new ASHS and ASHT cables are shown, which allow for, compared to analogous AS cables and depending on the specific application, as follows: at the same mechanical strength to increase the cable transmission capacity by up to 30 % and to reduce its weight by up to 35 % and at the same transmission capacity to increase the span between supports by 30 to 40 %.

5. Usage of the suggested cable design provides additional resistance of the cable – mounting assembly system to bending (vibration) loads thus increasing its operational reliability.

6. Integrated and correct usage of ASHS and ASHT cables on conjunction with ground wires aas per TU062 or OKGT TU113, taking into account all the benefits listed in the report, along with usage of spiral fittings specially developed by Elektrosetstroyproekt, CJSC, for construction of new and reconstruction of old HVLs may significantly increase its reliability under influence of the entire spectrum of climatic loads, add to its transmission capacity and reduce the cost.

7. Change of the stranding direction has almost no effect to the amount of heat produced and to losses occuring in the components of steel-aluminum cable, while the **plastic deformation** process forming high-conductivity contacts between the wires leads to absence of magnetizing inside the cable and provides an additional effect of heat generation reduction in the core by 10 %.

8. **Additional reduction of the wind load to ASHS (ASHT) cable compared to standard AS cable by 25–40 % and icing reduction by 25–30 %.**

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