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Increasing transmission potential of 110 kV alternating current lines

***Abstract**. Construction of new power lines is a complicated and long-lasting formal and legal process. The duration of the investments is extended by trade arrangements, public consultations in order to delimit line corridor, time required to obtain necessary decisions, permits, analyses and opinions necessary to implement an enterprise. The main goal of this publication is to conduct an analysis and present the variants of possibility of rebuilding of a power network in the aspect of increasing transmission potential of existing 110kV lines, taking technical and financial aspects into account.*

Streszczenie.** Budowa nowych linii elektroenergetycznych to skomplikowany i długotrwały proces formalno – prawny. Czas realizacji inwestycji wydłużają prowadzone uzgodnienia branżowe, prowadzone konsultacje społeczne w celu wytyczenia korytarza linii, oczekiwania na pozyskanie koniecznych decyzji, pozwoleń, analiz i opinii niezbędnych do realizacji przedsięwzięcia. Głównym celem publikacji jest przeprowadzenie analizy oraz przedstawienie wariantów możliwości przebudowy sieci elektroenergetycznej w aspekcie zwiększenia zdolności przesyłowych istniejącej linii 110kV z uwzględnieniem zagadnień technicznych oraz finansowych. (Zwiększenie zdolności przesyłowych linii 110 kV prądu przemiennego***).*

Keywords: High Temperature Wires, Wire capacity, Adaptive works, AFL, ACSR, ACSS/TW.
Słowa kluczowe: Przewody wysokotemperaturowe, Obciążalność przewodu, Prace dostosowanie, AFL, ACSR, ACSS/TW.

Introduction

Construction of new lines is very expensive and problematic investment. New column structures, wires and additional equipment make costs of investment extremely high. Apart from financial aspect, there is also formal and legal battle connected with making land of the lines available and with obtaining relevant permits. These adversities make potential investors discouraged to build new modern power lines. Within last 15 years, there was a view of the so-called thermic modernization of existing lines. Thanks to application of the new generation of wires, HTLS (*High Temperature Low Sag*), significant change of structural solutions of old lines is unnecessary. This view is legitimate because in most of the lines built several dozen years ago, operating and static wires along with insulators and required equipment must be urgently replaced. New generation of HTLS allows not only to increase current parameters of load of the lines, but also improves resistance to wind and effects of icing of the wires.

Older lines of the National Power System were designed to capacity limit temperature of 40ºC [1-3]. Tests and analyses conducted by CIGRE (*Conseil International des Grands Réseaux Électriques*) showed that most of non-European and European power networks have different limit temperatures of the wires in the lines. For steel and aluminium wires in the United States temperature between 50 and 115 ºC are used, in Canada 75 ÷100 ºC, in the Great Britain and Ireland 50 ÷75 ºC, in the Scandinavian countries 50÷90 ºC [3, 5]. The possibility of replacement of current steel and aluminium wires with high-temperature wires has become very attractive and apart from financial costs, there are no additional problems of legal and ownership character.

The goal of this publication is to conduct an analysis for the variants of rebuilding of power network illustrated with an example of existing 110 kV lines, taking technical and financial aspects into account. Four variants of adaptive works in the existing 110kV lines, which will allow to increase their transmission potential, were presented in this article. For each presented variant, time to do adaptive works and their cost were estimated.

Modernization of high-voltage overhead power lines

In the years 2017–2021, Polish Power Grids spent nearly PLN 6 billion for construction and modernization of transmission lines and stations. Within last 4 years, about 2700 km of tracks of 400 kV lines, 80 km of tracks of 220 kV lines and 6 new system substations were built. Until 2030, the following actions are planned [14]:

- 172 investments,
- 3 597 km of new 400 kV lines,
- modernization of 1 643 km of 400 kV lines,
- calculated total value of expenditure is PLN 14 billion.

Performing duties of a transmission system operator, PSE are currently running more than 110 various investments. Above all, they include construction, expansion and modernization of high-voltage power lines and stations. Their goal is to ensure safe functioning of the National Power System and stable supply of electric energy to all consumers in a long-term perspective. Expansion and modernization of a transmission grid should be aimed at: creating safe working conditions of the National Power System, increasing security of supplying the areas of large urban agglomerations, increasing the role of transmission system in the National Power System, improving potential in the National Power System and voltage adjustment, power evacuation from connected sources, as well as expansion of interconnections [4, 6].

Among others, it requires substantial development of a structural transmission grid, structural changes of supply systems in crucial parts of Poland, allowing sources of energy of different production technology and various parameters to cooperate with each other, as well as photos of transmission functions with 110 kV distribution network, which takes place in many regions of Poland [7]. Among others, it requires substantial development of a structural transmission grid, structural changes of supply systems in crucial parts of Poland, allowing sources of energy of different production technology and various parameters to cooperate with each other, as well as photos of transmission functions with 110 kV distribution network, which takes place in many regions of Poland [10].

Modernization of overhead high-voltage power lines is mainly connected with increasing their thermal capacity and includes the following actions [8, 11, 16-18]:

- application of high-temperature low sag (HTLS),
- construction of new or additional track of the lines,
- application of the systems of monitoring and forecasting permissible current-carrying capacity of the lines,

– modernization works.

Out of actions mentioned above, quick increasing of thermal-carrying capacity of overhead lines with no significant changes in structural solutions of old lines can be achieved by using high-temperature wires. The necessity to increase capacity results from the fact that large number of the overhead lines 110 kV in Poland was designed to work in design temperature of a wire of +40°C, which with ambient temperature +30°C and wind velocity 0,5 m/s guarantees to maintain permissible distances to the objects below the line [9].

In some studies, designed lines had design temperature of a wire of +60°C, and even +80°C. Assuming design temperature +80°C for AFL6-240 allows, under summer conditions, to load it with current of 645 A [12]. Such current, due to its invariability in time is called static current, whereas, maximum current determined based on actual weather conditions is commonly called dynamic current. Using dynamic capacity of the lines allows for better, more effective use of transmission potential of the lines. For example, for 6 m/s wind blowing perpendicularly to a line, capacity of the lines is increasing by 50% [13, 15].

Technical analysis of possibility of increasing current-carrying capacity of 110 kV lines

The comparison of ACSR and ACSS/TW phase conductors

For many years, phase conductors commonly applied in the National Power System have been AFL wires of ACSR type (*Aluminium-conductor steel-reinforced)*. They are made of one or more concentric layers of a bearing steel wire and one or more conductive, reinforced layers of deformed aluminium wires. The requirements that such wires must meet made it necessary to develop diverse types of the wires in terms of diameters and relation of sections of steel to aluminium. For example, there are AFL-6 185mm^2, AFL-6 240mm^2 and AFL-8 525mm^2. Due to constant growth of electric energy demand, phase conductors of this group are becoming insufficient. High mass of the wires and permissible operating temperature of +80°C translate into permissible current-carrying capacity of the lines. An alternative to this solution, more and more popular in the National Power System has become application of ACSS (*Aluminium Conductor Steel Supported*) high-temperature wires of low sag. They are wires of similar structure to ACSS/TW (*Aluminium conductor steel-Supported /Trapezoidal Wire*) made of profile wires. Structure of a wire consists of a steel core in the braid of one or many layers of the wires, which allows increasing the degree of filling the section and increase current-carrying capacity while maintaining diameter of a wire similar to the one from ACSR family. ACSS/TW can work in a constant way, without damages in high temperature of +200°C with no loss of mechanical properties. Annealed aluminium applied in the wires makes it more elastic and most of the loads rest on steel core, which has supporting function of ACSS.

An equivalent of AFL-6 240mm^2 ACSR is ACSS/TW Hawk 242-AL0/39-MEHST. Diameter of ACSS/TW is lower than ACSR with a similar section. Structure and materials that ACSS is made of allow to reach lower mass of a wire in comparison with traditional ones. Resistance of ACSS/TW Hawk 242-AL0/39-MEHST is much lower than resistance of AFL-6 240mm^2 ACSR. It means that their application in modernized and newly built lines will result in lower losses and reduction of CO_2 emission connected with losses. Parameter that we should pay attention to is modulus of elasticity (Young modulus), which for ACSR is more than 2,5 times higher than for ACSR [19]. Young modulus is a very significant parameter in construction of the wires that determines elasticity of the wires and sags of the wires in the spans of the lines. Table 1 shows the comparison of technical parameters of the examples of ACSR and ACSS/TW Hawk.

Table 1. The comparison of technical parameters of AFL-6 240 and ACSS/TW Hawk

Wire	Diameter	Total cross-section	Weight	Breaking force	Diameter Al	Diameter Fe	Resistance 20°C	Number of wires Al	Number of wires Fe	Al:Fe	Young modulus
	[mm]	[mm^2]	[kg/km]	[kN]	[mm^2]	[mm^2]	[Ω/km]	pcs.	pcs.	-	[N/mm^2]
AFL-6 240	21,70	276,14	965,4	84,6	236,06	40,08	0,1223	26	7	5,89	74594
ACSS/TW Hawk	20,03	281,34	976,2	84,40	242,0	39,34	0,1178	18	7	6,15	190000

Most of 110kV power lines in the National Power System, operating temperature of phase conductors max. +40°, +60° or +80°C. ACSS, due to its special structure and parameters, allows to increase permissible operating temperature of the lines up to even +200°C, making it possible increasing flow of current in a line while maintaining similar sags of the wires in the spans in comparison with ACSR working in maximum temperature of +80°C.

In order to determine current-carrying capacity of ACSR AFL-6 240mm^2 and ACSS/TW HAWK 242-AL0/39-MEHST, assumed ambient temperature in summer conditions was +30°C and in winter: +20°C. Sun exposure of the wires in summer: 1000 W/m^2, in winter: 770 W/m^2. Emission factor and absorption coefficient of a wire - 0,5. Wind velocity - 0,5 m/s perpendicularly to a wire. Table 2 shows relation between the value of sag of the wires and temperature of the wires

Table 2. ACSR wire load capacity AFL-6 240mm^2 and ACSS/TW HAWK 242-AL0/39-MEHST

Temperature of wire [°C]	ACSR AFL-6 240mm^2		ACSS/TW HAWK 242-AL0/39-MEHST	
	Current-carrying capacity [A]			
	Summer	Winter	Summer	Winter
40	131	364	143	374
60	450	557	462	569
80	609	686	622	700
100	-	-	739	802
120	-	-	833	886
140	-	-	913	958
160	-	-	983	1023
180	-	-	1046	1082
200	-	-	1104	1136

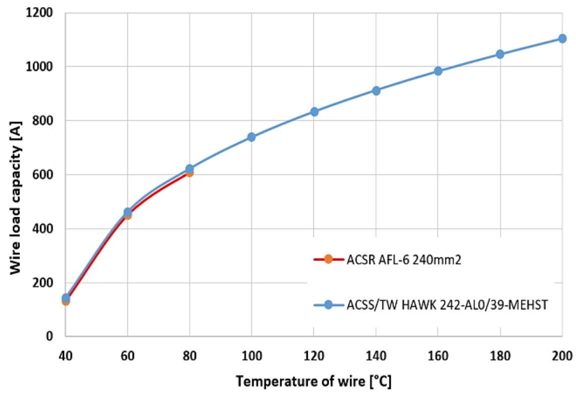

Fig.2. Chart of capacity of the wires – summer period

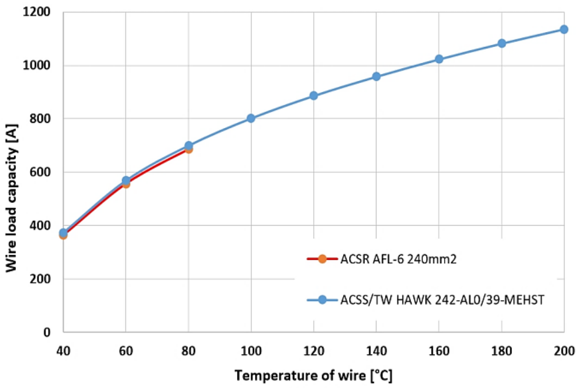

Fig.2. Chart of capacity of the wires - winter period

Charts of capacity of ACSR AFL-6 240mm^2 and ACSS/TW HAWK, relations were presented on figure 1 and 2.

Increasing maximum current-carrying capacity gives the possibility of modernization of existing 110 kV lines, that is, replacement of existing ACSR with ACSS without the necessity of replacement of columns and foundations with new ones. For 300 meter span and weather conditions assumed while determining current-carrying capacity, the values of sag of the wires to temperature of a wire were determined in Table 3.

Table 3. The value of sag for ACSR AFL-6 240mm^2 and ACSS/TW HAWK 242-AL0/39-MEHST

Span 300 m	Values of sag [m]	
Temperature of wire [°C]	ACSR AFL-6 240mm^2	ACSS/TW HAWK 242-AL0/39-MEHST
-25	5,47	4,3
-20	5,67	4,35
-15	5,85	4,41
-10	6,04	4,47
-5	6,23	4,53
0	6,41	4,6
5	6,6	4,66
10	6,78	4,73
15	6,96	4,93
20	7,14	5,12
30	7,49	5,52
40	7,84	5,92
50	8,18	6,32
60	8,51	6,71
70	8,84	7,09
80	9,15	7,46
90	-	7,8
100	-	7,95
110	-	8,1
120	-	8,25
130	-	8,4
140	-	8,55
150	-	8,71
160	-	8,87
170	-	9,02
180	-	9,18
190	-	9,34
200	-	9,49

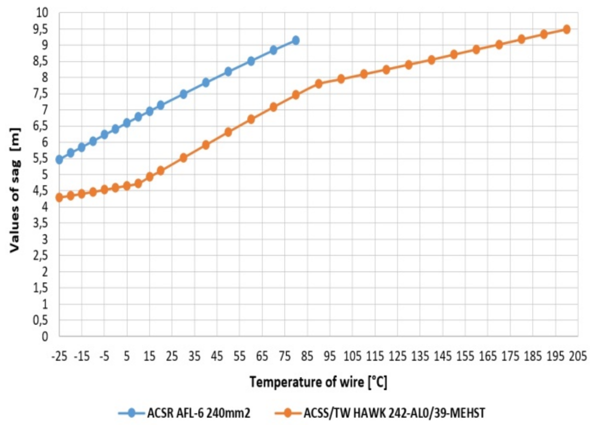

Fig.3. Chart of relation between the value of sag of a phase conductor and temperature

The value of a sag of the wires depending on temperature of ACSR AFL-6 240mm^2 and ACSS/TW HAWK, the relations are presented on figure 3.

The values of the sags of ACSS/TW HAWK 242-AL0/39-MEHST phase conductors in maximum operating temperature of +200°C are comparable with the sags of ACSR AFL-6 240mm^2 phase conductors in permissible temperature of +80°C. It is important because in replacement of phase conductors with ACSS in the existing lines will not reduce existing, normative distances between phase conductors and the ground and remaining alternately used objects.

Replacement of ACSRs with ACSS/TW high-temperature wires

An analysis of replacement of the wires includes assessment of possibility of increasing current-carrying capacity of high-voltage lines illustrated with an example of existing 110 kV overhead line, which is 12,67 km long. The scope of analysis includes preparing and modelling of existing state of 110 kV lines in a specialist software for designing overhead lines, PLS-CADD (*Power Line Systems - Computer Aided Design and Draft*). Input data to software along with geodesic measurements of existing state of the lines were entered in order to prepare a model of lines. Using this software, existing state of the lines was reconstructed and existing stress in the phase conductors and static wires was determined. Then, the scope of adaptive works to do depending on assumed value of current-carrying capacity of the lines was determined. While preparing a list of necessary adaptive works, the possibility of doing the following works was checked in the first place:

– shortening suspension strings in order to increase distance from alternately used objects inside the span,
– possibility of adjustment of sags of existing wires,
– making columns higher through assembly of catalogue insert making the bottom part of a column higher.

The possibility of replacement of single columns and replacement of existing ACSR AFL-6 240mm^2 with ACSS high-temperature wires was considered. Final effect of the analysis shows adaptive works that are necessary to reach required current-carrying capacity of 110 kV lines depending on accepted variant. Financial aspects were considered while preparing such variants. Time estimated to do specific adaptive works, device required to do such works and cost estimate for each variant were prepared.

Existing 110 kV line was designed and built so as not to exceed maximum operating temperature of phase conductors, that is, +40°C. In such temperature, phase conductors can be loaded with current not exceeding:

– in the summer period, for ambient temperature (T_o= +30°C), wind velocity (V = 0,5m/s), sun exposure (P_s=1000W/m^2) — 131A,
– in the winter period (T_o = +20°C, V=0,5m/s, P_s=770W/m^2): — 364A.

Increasing transmission potential is possible through adjustment of the phase conductors to operating temperature of +80°C or replacement of existing wires with a new, high-temperature ACSS. However, it requires modernization of the lines. Therefore, there were the following assumptions – 4 variants of modernization depending on accepted current-carrying capacity. For each variant, all required adaptive works will be presented that need to be done due to required normative distances to the ground and alternately used objects.

Variant 1

Adaption of existing AFL-6 240 mm^2 ACSRs to work in maximum temperature +80°C. Target current-carrying capacity of the wires: summer – **609A**, winter – **686A**.

Variant 2

Replacement of existing ACSR AFL-6-240 mm^2 phase conductors with new ACSS/TW Hawk 242-AL0/39-MEHST high-temperature wires, adapted to operating temperature of +80°C. Target current-carrying capacity of the wires: summer – **622A**, winter – **700A**.

Variant 3

Replacement of existing ACSR AFL-6-240 mm^2 phase conductors with new ACSS/TW Hawk 242-AL0/39-MEHST high-temperature wires, adapted to operating temperature of +120°C. Target current-carrying capacity of the wires: summer – **833A**, winter – **886A**.

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Steady-State Thermal Rating
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IEEE Standard 738-2006 method of calculation

Weather Conditions
------------------
Air temperature:              20.000 (deg C)
Wind speed:                    0.500 (m/s)
Wind to conductor angle:      90.000 (deg)

Solar Conditions
----------------
Measured solar radiation:           770.000 (Watt/m^2)

Conductor Properties
--------------------
Description: ACSS/TW Hawk 242-AL0/39-MEHST
Azimuth:                         90.000 (deg)
AC resistance at 20.0 (deg C):   0.1134 (Ohm/km)
AC resistance at 200.0 (deg C):  0.1978 (Ohm/km)
Solar absorptivity:               0.500
Emissivity:                       0.500
Outer diameter:                  20.030 (mm)
Outer strand diameter:            0.000 (mm)
Outer strand layers:                  0
Outer surface finish:            Smooth
Outer heat capacity:              0.000 (Watt-s/m-deg C)
Cable is thermal bimetallic:       True
Core diameter:                    0.000 (mm)
Core heat capacity:               0.000 (Watt-s/m-deg C)
Elevation above sea level:        0.000 (m)

Analysis Results
----------------
Current:                           1136.975 (Amps)
Conductor temperature               200.000 (deg C)
Convective cooling:                 187.210 (Watt/m)
Radiative cooling:                   76.200 (Watt/m)
Solar heating:                        7.712 (Watt/m)
Equivalent global solar radiation:  770.000 (Watt/m^2)
Final solar absorptivity:             0.500
Final emissivity:                     0.500
Final wind to conductor angle:       90.000 (deg)
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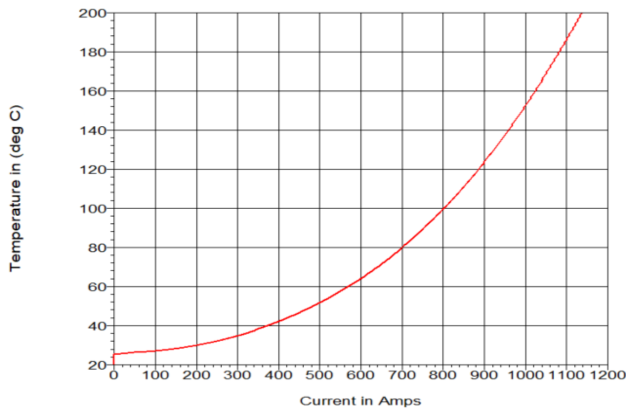

Fig.4. Determining current-carrying capacity of ACSS/TW Hawk 242-AL0/39-MEHST in PLS-CADD

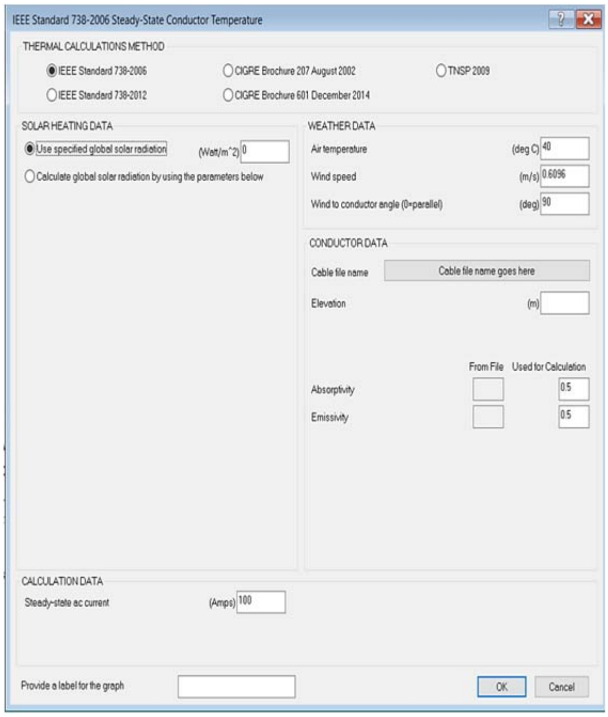

Fig.5. Panel of PLS-CADD to enter weather data and capacity of the lines in order to determine temperature of the wires

Variant 4

Replacement of existing ACSR AFL-6-240mm^2 phase conductors with new ACSS/TW Hawk 242-AL0/39-MEHST high-temperature wires, adapted to maximum operating temperature of +160°C. Target current-carrying capacity of the wires: summer – **983A**, winter – **1023A**.

An example of determining current-carrying capacity of ACSS/TW Hawk 242-AL0/39-MEHST was presented on fig. 4.

Based on:

– Geodesic measurement (location of the columns, span length, how high are wires hanged, size of sags),
– Conditions during measurements (measured air temperature, wind velocity and direction, specific level of sun exposure),
– Momentary value of load current of the lines, accepted emission factor and absorption coefficient.

Temperature of the wires at the moment of taking geodesic measurements was determined. Temperature of the wires was generated in PLS-CADD after entering data mentioned above. Figure 5 shows a panel of entering data of PLS-CADD.

Actual stress in the wires was determined based on a spatial model and calculated temperature of the wires that measurement of this model was made. Based on that, in PLS-CADD, existing stress in the wires was determined. In accordance with PN-E-05100-1:1998 „Overhead power lines. Design and construction. Alternating current lines with bare operating wires", the highest permissible stress in steel and aluminium phase conductors or aluminium-alloy ones may not exceed 40 % resistance to normal stretching. While determining maximum stress in the wires in a given pull-off section, we must consider:

- permissible strength of applied wire, in which maximum tension in the wires may not exceed in no point 40% of RTS (rated power tearing off a wire),
- conditions that column was designed for, which are specified in the specification sheets of columns.

While determining permissible stresses in AFL-6 240mm^2 phase conductors, three examples were analysed:

Example 1 – Maximum stress/tension in the wires due to strength of structure of the of columns

In the analysed 110 kV line, S24 lattice columns were applied, which in accordance with specification sheet, columns were adapted to hanging on AFL-6 240mm^2 phase conductors with a stress of 100MPa in -5Sn condition (temperature -5° with additional load with normal hoar frost). In accordance with specification sheet, AFL-6 240mm^2 has a diameter of 21,7mm and total section s = 276,2mm^2, rated power tearing RTS off = 84600 N. Stress in AFL-6 240mm^2 (s =276,2mm^2) is 100MPa, which gives the value of tension:

$$100\text{MPa} \cdot 276{,}2\text{mm}^2 = 276200\text{N (in -5Sn condition)}.$$

Therefore, different wire of similar parameters can also be hanged, but with an assumption that in -5Sn condition, the value of tension of a new wire does not exceed the value of tension of 276200N like for AFL-6 240mm^2 in -5Sn condition.

Example 2 – Maximum stress for AFL-6 240mm^2 due to strength of a wire

In accordance with PN-E-05100-1:1998, permissible tension in the phase conductors of pull-off section may not exceed 40% RTS of a wire, that is:

$$84600\ \text{N} \cdot 0{,}4 = 33840\ \text{N},$$

which gives power of tension of the wires

$$F = 33840 \div 276{,}2 = 122{,}5\ \text{MPa}$$

That is, „normal" stress for AFL-6 240mm^2 due to stretching is 122,5 MPa. Therefore, permissible stress due to strength of a column: 100 MPa and permissible stress due to strength of a wire: 122,5 MPa. That is, as a value of „normal" stress in AFL-6 240mm^2 we accept lower value from the ones above, that is, 100 MPa.

Example 3 – „Reduced" stress for AFL-6 240mm^2

In accordance with PN-E-05100-1:1998, permissible „reduced" tension in the phase conductors of pull-off section may not exceed 28% RTS of a wire, that is:

$$84600\ \text{N} \cdot 0{,}28 = 23688\ \text{N},$$

which gives power of tension of the wires

$$F = 23688 \div 276{,}2 = 85{,}7\ \text{MPa}$$

That is, the value of „reduced" stress in AFL-6 240 mm^2 is assumed as 85,7 MPa. To sum up, we assume the following stresses for AFL-6 240 mm^2:

- „Reduced" stress ─ 85,7 MPa,
- „Normal" stress ─ 100 MPa.

Determining permissible stresses in ACSS/TW Hawk 242-AL0/39-MEHST phase conductors, example no. 4 was analysed.

Example 4 – „Reduced" stress for ACSS/TW Hawk 242-AL0/39-MEHST

ACSS/TW Hawk 242-AL0/39-MEHST, in accordance with specification sheet, has a diameter of 20,03mm and total section s = 281,3 mm^2, rated power tearing RTS off = 84400 N. While designing a new wire, we should assume that stress of ACSS in -5Sn condition -does not exceed tension of 276200N, like for AFL-6 240mm^2. It means that the value of normal stress is:

$$F = 276200 \div 281{,}34 = 98{,}2\ \text{MPa}$$

In accordance with PN-E-05100-1:1998, permissible „reduced" tension in the phase conductors of pull-off section may not exceed 28% of RTS of a wire, that is:

$$84400 \cdot 0{,}28 = 23632\text{N},$$

which gives

$$F = 23632 \div 281{,}34 = 84\ \text{MPa}$$

The value of „reduced" stress in ACSS/TW Hawk 242-AL0/39-MEHST is assumed as 84 MPa. To sum up, we assumed the following stresses for ACSS/TW Hawk 242-AL0/39-MEHST:

- „Reduced" stress ─ 84 MPa,
- „Normal" stress ─ 98,2 MPa.

Existing 110 kV line with 45 spans was modelled in PLS-CADD and permissible operating temperature of phase conductors and permissible current-carrying capacity of the lines were determined. Table 4 shows the values of maximum temperature that phase conductors can work in the existing state, that is, without doing any adaptive works. Red color was used to distinguish the spans, in which phase conductors do not reach required operating temperature of +40°C before adaptive works, because there are no required normative distances from the ground and alternately used objects.

Table 4. A list of spans allowing the work of phase conductors of the lines in temp. +80°C

Span	Colliding object	Maximum operating temperature phase conductors in the existing state
1-2	ground	+41°C
2-3	linie LV	+35°C
3-4	ground	+59°C
4-5	ground	+60°C
6-7	ground	+66°C
10-11	ground	+68°C
11-12	ground	+79°C
13-14	ground	+74°C
16-17	ground	+66°C
17-18	ground	+56°C
18-19	ground	+63°C
19-20	ground	+67°C
20-21	ground	+64°C
21-22	ground	+60°C
22-23	linie MV	0°C
23-24	linie LV	+52°C
24-25	linie LV	+55°C
25-26	ground	+44°C
26-27	ground	+75°C
27-28	ground	+60°C
28-29	building	+25°C
29-30	linie LV	0°C
30-31	ground	+77°C

31-32	ground	+75°C
33-34	ground	+66°C
34-35	ground	+74°C
35-36	linie LV	+25°C
37-38	ground	+69°C
39-40	ground	+74°C
40-41	ground	+77°C
41-42	ground	+35°C
42-43	ground	+30°C
43-44	ground	+75°C
44-45	linie MV	+45°C

Based on the results obtained in Table 4, it was found that 110 kV line in the existing state can't work in temperature that it was designed for, that is, +40°C. In the spans no. 2 – 3, 22 – 23, 28 – 29, 29 – 30, 35 – 36, 41 – 42 and 42 – 43, there are no required normative distances from alternately used objects. In the spans no. 22 – 23 and 29 – 30, maximum operating temperature of phase conductors is 0°C, which means that line should be disconnected because it is dangerous for safety of people. Adaptive works must be immediately done. In the existing state, to maintain normative distances between phase conductors and the ground and alternately used objects, phase conductors can work in temperature of 0°C. As it results from calculations for design temperature of a wire, that is, 0°C, capacity of the lines is 0 [A]. It results from obvious fact that wire heats up to such temperature only from solar energy.

In order to determine operating temperature of phase conductors for specific current-carrying capacity, the following operating weather conditions of the lines are assumed:

- in the summer period, for ambient temperature (T_o= +30°C), wind velocity (V = 0,5m/s) of perpendicular direction to a wire, sun exposure (P_s=1000W/m^2), emission factor and absorption coefficient of a wire, each by 0,5,
- in the winter period, for ambient temperature (T_o=+20°C), wind velocity (V= 0,5m/s) of perpendicular direction to a wire, sun exposure (P_s=770W/m^2), emission factor and absorption coefficient of a wire, each by 0,5,

Table 5 shows the comparison of maximum value of current-carrying capacity of lines depending on type of a wire and maximum operating temperature of conductors.

Table 5. Comparison of the maximum current carrying capacity of the line

Wire	Current-carrying capacity [A]		Maximum temperature of a wire in the least favourable case
	Summer	Winter	
AFL-6 240mm^2	131	364	+40°C
AFL-6 240mm^2	609	686	+80°C
ACSS/TW Hawk	622	700	+80°C
ACSS/TW Hawk	833	886	+120°C
ACSS/TW Hawk	983	1023	+160°C

For current-carrying capacity of the wires presented in Table 5 , simulation was made in PLS-CADD determining the works that must be done in 110 kV line for phase conductors to work in specific temperature. To meet the requirements of 4 variants of capacity, a list of required adaptive works and their cost were presented in Table 6.

Table 6. A list of adaptive works for variant 1, 2, 3 and 4

Actions	Example 1		Example 2		Example 3		Example 4	
	Span section	Position	Span section	Position	Span section	Position	Span section	Position
Adaptive works to adjust the sags of phase conductors	1-5, 22-29, 29-30, 37-44, 44-45, 45-46,	—	—	—	—	—	—	—
Adaptive works to adjust the sags of static wires	37-BR	—	37-BR	—	37-BR	—	37-BR	—
Replacement of phase conductors with ACSS/TW Hawk	—	—	BR-1, 1-5, 5-6, 6-11, 11-18, 18-22, 22-29, 29-30, 30-44, 44-46, 46-BR	—	BR-1, 1-5, 5-6, 6-11, 11-18, 18-22, 22-29, 29-30, 30-44, 44-46, 46-BR	—	BR-1, 1-5, 5-6, 6-11, 11-18, 18-22, 22-29, 29-30, 30-44, 44-46, 46-BR	—
Raising a column +2m	—	17, 21	—	—	—	21	—	13, 17, 21
Raising a column +2,5m	—	2, 4, 7, 10, 19, 24, 26, 34, 36	—	36	—	2, 7, 18, 25, 29, 31, 34, 36	—	2, 3, 4,7,8, 15, 18,19, 25, 27, 31, 33, 34, 36
Raising a column +5m	—	23		23		23		11, 23
Replacement of 3XŁPA strings	—	12, 13, 14, 28, 31, 32	—	—	—	—	—	—
Replacement of S24 column with tubular column M1	—	29		29		29		29
Financial comparison	1 998 658, 57 PLN		1 757 224, 47 PLN		2 283 098, 76 PLN		2 880 946, 85 PLN	

Conclusions

ACSSs have, due to its structure, to a large extent flat sag depending on temperature and after exceeding the so-called knee point, growth of temperature causes very low growth of sag, which allows to fully use its potential in high temperatures. Special structure of a wire makes it possible to reach much higher capacity of the lines in comparison with AFL-240mm^2 ACSRs. Moreover, as it was shown in the comparison of AFL-6 240mm^2 with ACSS/TW Hawk 242-AL0/39-MEHST, ACSS high-temperature wires generate the lowest losses working in increased temperature, with the same load like in ACSR wires. The main parameter is much lower resistance of ACSS. Therefore, it can be said that reduction of transmission losses will make investment cost-effective after a few years.

Conducted technical analysis based on existing WN 110 kV power line showed that by the application of ACSS high-temperature wires allowed to significantly increase its transmission potential without interference to structural solutions of existing lines. Replacement of phase conductors from typical ACSR AFL-6 240 mm^2 with ACSS made it necessary to do required adaptive works such as: reinforcing and raising existing supporting constructions and in one case, the necessity to replace a column. After completion of the works mentioned above, 110 kV line will be able to work in temperature of even +160°C. It will allow to reach the following current-carrying capacity of the wires: summer – 983 A, winter – 1023 A, where in the existing state, line could work only in temp. +40°C and maximum load: summer – 131 A, winter – 364 A.

Increasing transmission potential through modernization of existing objects is much more attractive solution in financial terms than construction of new lines. As it was shown in the analysis, reasonable solution is replacement of commonly applied ACSRs with ACSS high-temperature wires because they are one of the cheapest high-temperature wires available on the market.

A significant aspect of all modernization works is cost connected with adaptation of 110 kV lines to type of the operating wires. There is a cost estimate for each of four variants, which differs significantly depending on a variant of scope of adaptive works. Final result of a cost estimate was presented in the article and it was found that modernization of 110 kV lines with ACSS/TW Hawk 242-AL0/39-MEHST adapted to operating temperature of +80°C is cheaper by more than 12% than adaptation of existing AFL-6 240mm^2 ACSRs to work in maximum temperature of +80°C. Another proposed variants with ACSS/TW Hawk 242-AL0/39-MEHST adapted to operating temperature of +120°C and +160°C, are solutions that are by 30% and 64% more expensive in comparison with the best financial variant, however their target current-carrying capacity of the wires is much higher. When this parameter will be a determinant, proposed solutions can be applied because an alternative is construction of a new line, which is much more expensive.

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