Comparison of ACSR, ACCC and AAAC Conductors for Overhead Transmission Lines

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Abstract – **The goal of this paper is to perform comparison of three types of conductors for transmission overhead lines: Aluminium Conductor Steel Reinforced-ACSR, All Aluminium Alloy Conductors-AAAC and Aluminium conductor Composite Core-ACCC. The paper at beginning summarizes the constructive and technological characteristics of the conductors. Their physical, mechanical and electrical specified parameters are compared in table. Applicative part of the paper presents comparison of ACSR, AAAC and ACCC conductors on one tension field of 110 kV overhead transmission line. Three design solutions of tension field are presented, with usage of standard design calculations for overhead transmission line.**

Keywords – **Conductors, overhead transmission line.**

I. INTRODUCTION

The replacement of classical ACSR phase conductors with other ones from the same type, but with greater cross section (greater transmission capacity), leads to replacement or mechanical reinforcement of support constructions for conductors (towers, consoles, insulator chains etc.) [1]. This type of reconstructions on existing overhead transmission lines (OHTL) is very expensive and inefficient. Namely, if existing phase conductors are replaced with new types of conductors which will have greater ratting current, lower sag on higher working temperatures, smaller mass, and lower electrical resistance, then on very effective and more economical way transmission capacity of the OHTL will be increased [2]. If reconstruction of an existing OHTL results in double transmission capacity, the price of reconstruction is much lower than construction of new OHTL with the same transmission capacity [3]. Construction and application of new types of conductors with better characteristics than existing ones, has become challenge for many companies in the field of manufacturing conductors for transmission of electricity.

The paper presents two types of conductors as an alternative of ACSR conductors. The first one is ACCC (Aluminum Conductor with Composite Core) conductor which for the first time was introduced on the world market in 2005 [7]. This conductor is constructed from aluminium and has circle or trapezoidal shape. It has core produced from polymer composite materials.

There are several companies mainly in USA which commercially produce ACCC conductors and they are becoming serious competition of standard ACSR conductors.

The second conductor is AAAC (All Aluminium Alloy Conductors). This conductor is produced with heat-treatable magnesium silicon type aluminum alloys. The alloys referred to have higher strength but lower conductivity than pure aluminium. Being lighter, alloy conductors sometimes have advantage compared to the more conventional ACSR, having lower breaking loads than the later. Also their use becomes particularly favorable when ice and wind loadings are low.

The paper is consisted of five sections. Section II summarizes the constructive and technological characteristics of the conductors. Their physical, mechanical and electrical specified parameters are compared in table. Section III presents the applicative part of the paper. Comparison of ACSR, AAAC and ACCC conductors is performed on one tension field of 110 kV OHTL. Three design solutions of tension field are presented, with usage of standard design calculations for OHTL. Several conclusions and further work possibilities about this matter are presented in section V.

II. COMPARISON OF ACSR, ACCC AND AAAC CONDUCTORS

Overrating load current at OHTL with conductors containing steel core, can cause elongation of conductors and spans sag increase to values which will affect the safety clearance. The company CTC Co. (USA) at 2005 produced composite core with a very high ratio of breaking load (force)/weight and small coefficient of thermal expansion. The replacement of steel core with composite one, for conductor with equal outer diameter provides almost doubling of transmission capacity, higher working temperature and significant decrease of sags in spans. Figure 1 depicts the design of conductor with composite core ACCC/TW (trapezoidal wires) compared with ACSR conductor.

Composite core is a result of a process of pultrusion. During the pultrusion process, continuous unidirectional (0^0-axis) carbon fibers form a cylindrically shaped solid core

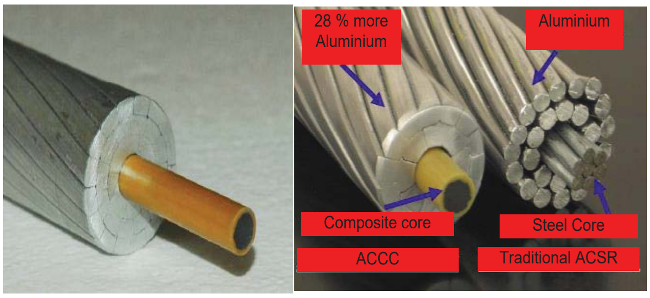

Fig. 1. ACCC/TW conductor and comparison of ACCC and ACSR

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while a layer of similarly oriented E-glass fibers, is placed as a shield. The bundled fibers are wet out with a high-temperature toughened epoxy. The fiberglass layer serves two purposes: first, it separates the carbon from the conductive aluminum wires to prevent galvanic corrosion. Second, it counterbalances the more brittle carbon and improves the flexibility and toughness of the core. The one-piece rod composite core lead to a core with a greater cross-sectional area, but a smaller diameter which implies larger loading with reduced tensile stresses over that of the steel core subjected to the same loads.

Fully annealed (soft), H0 (O') tempered 1350 aluminum trapezoidal wires with conductivity of 63% IACS are helically wrapped in one or more layers around the composite core. The use of trapezoidal wires yields compact conductor with less void area than ACSR. The compact trapezoidal wires, coupled with a smaller composite core, result in an ACCC/TW conductor that has approximately 28% more aluminum cross-sectional area than ACSR and ACSS with round wires and same outer diameter. Thermal properties of composite core and soft aluminum wires enable high operating temperatures of ACCC/TW, continuously up to 180 ^{0}C. The greater aluminum content in ACCC/TW with high electrical conductivity, combined with the capability to work at high operating temperatures, can double the ampacity of an existing OHTL with ACSR conductors.

ACCC/TW conductors are produces with standard dimensions with current rating capacity in range from 300 to 3500 A [3]. Although the price of ACCC/TW conductors is three times higher than ACSR conductors with same diameter, the replacement of ACSR conductors with equivalent ACCC/TW and doubling of transmission capacity is three times cheaper than construction of new line with same capacity as the existing one with ACSR conductors. [3].

AAAC conductor is high strength Aluminum-Magnesium-Silicon Alloy conductor. It was developed to replace the high strength 6/1 ACSR conductors. This alloy conductor offers excellent electrical characteristics with a conductivity of 52.5% IACS, excellent sag-tension characteristics and superior corrosion resistance to that of ACSR. Service life of AAAC is around 60 years, twice as durable as ACSR. It is superior to ACSR conductors when used in distribution lines [1]. Figure 2 depicts the design of AAAC conductor.

Comparison of physical, mechanical and electrical specified parameters is performed between ACSR 240/40 conductor as traditional standard at 110 kV OHTL and compatible alternatives ACCC/TW conductor Glasgow and AAAC/TW 300 conductor. Data for ACCC conductors can be found in [4] and [7], for ACSR 240/40 conductor is taken from [5], and for AAAC in [6].

Fig. 2. AAAC conductor

Table 1 summarizes mechanical and electrical characteristics of mentioned ACSR 240/40, ACCC Glasgow and AAAC 300 conductor types. It can be concluded that ACCC conductors, for approximately same diameter and cross section as ACSR 240/40 conductor, have: lower weight and mass, higher tensile strength of conductor (achieved with replacement of steel core with composite one), lower coefficient of linear expansion, lower modulus of elasticity, significantly higher working temperature, smaller electrical resistance and higher ratting current. Lower specific weight and smaller coefficients of linear expansion and modulus of elasticity lead to significantly smaller sags even at higher working temperatures.

TABLE I
COMPARISON OF CONDUCTORS

Mechanical and electrical characteristics	**Type of conductor**		
	ACCC Glasgow	**AAAC/ TW 300**	**ACSR 240/40**
Cross section Al/core (mm^2)	236.7/ 47.1	323.98	243/ 39.5
Total cross section (mm^2)	283.8	323.97	282.5
Diameter (mm)	19.53	21.7	21.9
Mass of conductor (kg/km)	731.3	893	987
Weight of conductor (daN/m)	0.717	0.876	0.968
Specific weight 10^{-3} (daN/m,mm^2)	2.526	2.704	3.426
Specific weight of normal ice load 10^{-3} (daN/m,mm^2)	2.803	2.588	2.981
Coefficient of linear expansion 10^{-6} (^{0}C^{-1})	17.1	23	18.9
Modulus of elasticity (daN/mm^2)	6700	6800	7700
Tensile strength (daN)	11500	9560	8640
Normal tension (daN/mm^2)	16.2	12	13
Tension (daN/mm^2)	30.4	22	24.5
DC resistance at 20 ^{0}C (Ω/km)	0.1184	0.1022	0.119
Rated current at 80 ^{0}C (A)	570	775	530
Rated current at 100 ^{0}C (A)	692	951	648
Rated current at 180 ^{0}C (A)	1027	-	-
Maximum working temperature (^{0}C)	180	90	80
Price (Euro/m)	10	6	4

AAAC/TW 300 conductor versus ACSR 240/40 have: lower weight and mass, higher tensile strength of conductor, smaller electrical resistance and higher ratting current. Maximum working temperature of the conductor is 90 ^{0}C.

III. STUDY CASE

The development of new regulations for OHTL in many countries in Europe is ongoing process. Almost all European countries have adopted standard for the design of OHTL EN 50341-1. Most of them developed national normative aspect of the standard taking into account special features characteristic for the country. Macedonia has adopted the standard EN 50341-1, but still has no national normative aspect. The design and construction of OHTL is done by Regulation of technical standard for construction of OHTL with voltage 1 kV to 400 kV [1]. For determining loads purposes, all load combinations are calculated with maximum working tension (stress) of the wire. The maximum working stress is usually calculated at -5 ^{0}C with normal ice load or at -20 ^{0}C without ice load, depending on which combination gives governed value [1].

Design replacement comparison of ACSR 240/40 conductors with proposed conductors ACCC/TW Glasgow and AAAC/TW 300 is shown on a tension field of 110 kV existing OHTL. The length of tension field is 1600 m and the terrain is relatively flat and regular (Figure 3).

Climate parameters on the terrain are: wind pressure 75 daN/m^2, coefficient of normal ice load 1.0 and coefficient of extra ice load is 2.0. Maximum working tension (stress) of conductors ACSR 240/40 is 9 daN/mm^2. Grounding wire type Fe III 50 mm^2 is used with maximum working tension 26 daN/mm^2. The OHTL is designed with steel towers type S for suspension supports (towers) and type A-150 for angle tension (strained) towers. Table II summarizes tower spotting list on the terrain (X- is tower position on the terrain on X-axis and Y is tower position on Y-axis. Ruling span of the tension field is 320.79 m.

TABLE II
TOWER SPOTTING LIST

No	Tower type	Tower height	Span (m)	X (m)	Y (m)	Difference in height (m)
1	A-150	15	280	0	130	0
2	S	17.8	310	310	138.13	9.21
3	S	16.8	300	610	145.89	6.86
4	S	16.8	330	940	153.43	7.71
5	S	17.8	335	1275	150	-2.43
6	A-150	18	325	1600	152	3.65

Using the same tower spotting solution, replacement of conductor ACSR 240/40 with ACCC/TW Glasgow and AAAC/TW 300 will be proposed. Glasgow conductor is designed with maximum working stress of 9 daN/mm^2, and AAAC/TW 300 7.8 daN/mm^2, because it has greater cross section than ACSR 240/40.

Figure 3 depicts the tower spotting and catenary curves of OHTL with all three types of conductors for maximum sag temperature +40^{0}C [1].

Several parameters important of OHTL design with each of used conductors are shown in Table III. It can be notified that all three conductors have lower critical span than the ruling span of the tension field. This fact implies that maximum working tension will appear on temperature -5^{0}C+ normal ice load. Critical temperature for all conductors is lower than 40^0 C, what leads to maximum sag appearance on +40^0 C. It is obvious that conductors ACCC/TW Glasgow and AAAC/TW 300 have higher catenary parameter than ACSR 240/40. This means that these conductors will have lower sags than ACSR 240/40.

This is shown with sag and tension (stress) curves calculated for full range of temperatures from -20^0 C to 100 ^{0} C. Figures 4 and 5 depict sag and tension curves for ruling span of the tension field appropriately. It can be easily concluded from Figure 4 that conductor ACCC/TW Glasgow has lowest sags, significantly lower than other two conductors. Namely Glasgow has in average 2 m lower sags compared with ACSR 240/40. The situation is the same in each span of the tension field. Conductor AAAC/TW 300 has lowest tensions in the full range of temperatures, because it is designed with maximum working tension 7.8 daN/mm^2. Glasgow has lower tension than ACSR 240/40.

Table V summarizes forces table for support tower number 4 which type is S and has highest weight and wind span. The calculation is performed according to loading cases defined in articles 68 and 69 from [1]. It can be notified that mechanical loading of towers in all three axes is lowest when ACCC/TW Glasgow conductor is used. This conductor can be also calculated with maximum working tension 8 daN/mm^2 and in this case has also lower sags than other two conductors. Similar results for tables of forces are obtained for angle strain tower type A-150.

TABLE III
SPECIFIC PARAMETERS FOR OTL DESIGN WITH EACH CONDUCTOR

Parameter	ACCC Glasgow	AAAC 300	ACSR 240/40
Critical span (m)	150.5	156.8	137.1
Critical temperature (^{0}C)	36.3	19.4	23.8
Maximum working tension (daN/mm^2)	9	7.8	9
Tension on 40^{0}C (daN/mm^2)	4.19	3.62	4.54
Catenary parameter 40^0 C (m)	1660.3	1338.8	1324.3

TABLE IV
TABLE OF FORCES FOR SUPPORT TOWER 4 TYPE S

Loading case		ACCC/TW Glasgow			AAAC/TW 300		
		Vx	Vy	Vz	Vx	Vy	Vz
Art. 68_1	A	-	-	628	-	-	683
	B	487	-	318	511	-	361
	C	-	122	318	-	128	361
Art. 69_1	PP	-	1277	628	-	1253	683
	NP	-	-	628	-	-	683
	PZ	-	-	-	-	-	-
	NZ	-	-	628	-	-	683

Loading case		ACSR 240/40		
		Vx	**Vy**	**Vz**
Art. 68_1	**A**	-	-	733
	B	546	-	409
	C	-	137	409
Art. 69_1	**PP**	-	1271	733
	NP	-	-	733
	PZ	-	-	-
	NZ	-	-	733

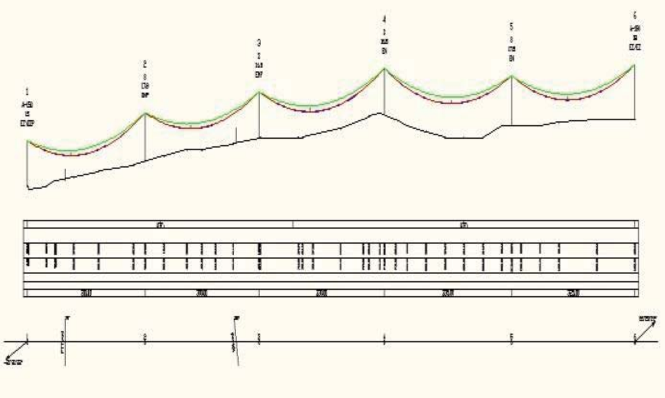

Fig. 3. Tower spotting and catenary curves with each conductor

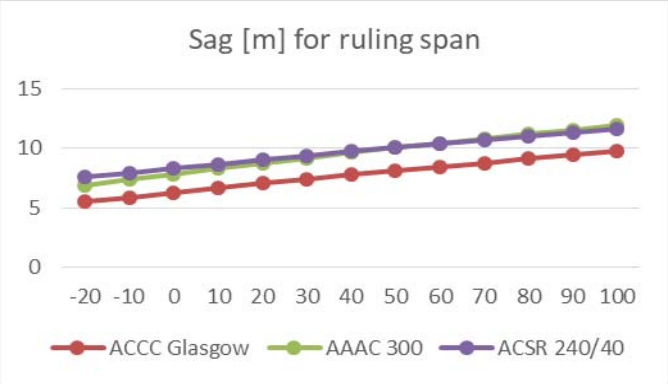

Fig. 4. Sags for ruling span for full range of temperatures -20 ^{0}C to 100 ^{0}C

Fig. 5. Tensions for ruling span for full range of temperatures -20 ^{0}C to 100 ^{0}C

IV. CONCLUSION

ACCC conductors are new technology conductors for transmission of electricity, which are becoming a serious competition of mostly used ACSR conductors. ACCC conductors for approximately same diameter and cross section as ACSR 240/40 conductor, have: lower weight and mass, higher tensile strength of conductor (achieved with replacement of steel core with composite one), lower coefficient of linear expansion, lower modulus of elasticity, significantly higher working temperature, smaller electrical resistance and higher ratting current.

AAAC/TW 300 conductor compared to ACSR 240/40 has lower weight and mass, higher tensile strength of conductor, smaller electrical resistance and higher ratting current. The maximum working temperature of the conductor is 90 ^{0}C.

According to the presented results in the paper, it can be concluded that replacement of existing ACSR 240/40 conductor with new one ACCC/TW Glasgow or AAAC/TW 300 leads to significantly: lower sags and stresses in full range of temperatures, lower towers loading, higher ratting current for higher operating temperature and lower electrical resistance meaning losses decrease in transmission of electricity in the OHTL.

The price of ACCC/TW conductors is one of the main disadvantages. However with technology development of this type of conductors, it is reasonable to expect that the price will go down and ACCC will become more competitive versus ACSR. In meanwhile AAAC are good alternative for ongoing projects for conductors replacement during reconstructions of OHTL and increasing transmission capacity. MEPSO (Macedonian Transmission System Operator) is implementing AAAC/TW 300 conductor on several 110 kV OHTL in the ongoing process of reconstruction and network revitalization.

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