CAC, COPPER ALLOY CONDUCTOR IN CORROSIVE ENVIRONMENTS

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ABSTRACT: *Copper Alloy Conductors (CAC) offer a solution for overhead lines located in corrosive environments, as it has been proved through the experience acquired in a 25 kV line refurbishment in Spain. Historically, the UK has always used copper for small conductors within 10km of the coast due to the heavy salt corrosion of aluminium. Samples of copper and aluminium conductors were collected and further analysed; quantifying the degradation suffered during their service, which in the aluminum case show a significant loss of electrical and mechanical properties. An economic analysis has also been included, providing an estimation of the necessary investment.*

KEY WORDS: Copper, CAC, corrosive environments, La Farga, overhead lines, a CAC-50-Pica d'Estats-UHC.

1. INTRODUCTION

La Farga is a **copper manufacturer** with more than **200 years** of **history**, its large experience covers a **wide range** of **copper products** used in different sectors: railways, tubes, electrical wiring, automotive, etc.

The extensive knowledge of copper alloys and the ability to adapt to the needs of each sector has given to La Farga great inventive skills to develop **innovative solutions** for **efficient energy transport**.

Among these innovative solutions emerged the **CAC conductors**, as a solution for the blackouts experienced during snow or wind storms. Through the observation of the fast ice accretion around the conductors, it was possible to conclude that a reduced conductor's diameter could be achieved by means of using copper instead of aluminium, improving the safety against the breakage of the conductor or the supports of the overhead lines.

2. CAC FEATURES

CAC (Copper Alloy Conductor) is a **microalloyed copper conductor specially designed for low, medium and high voltage allowing an efficient energy transport due to its high electrical and mechanical properties**.

Thanks to the copper microalloy, it can operate at high temperatures without creeping, thus increasing its capacity. La Farga has designed 5 different copper alloys in order to satisfy different cases, specially the most demanding ones:

- UHC (Ultra High Conductivity)
- HC (High Conductivity)
- STD (Standard)
- HS (High Strength)
- UHS (Ultra High Strength)

As well as these characteristics, copper also has the inherent advantage that it does not suffer from vibration fatigue as badly as aluminium. It has a significantly higher EDS (Every Day Stress) limit than aluminium. Typically, in the UK, copper lines are traditionally strung at 33%UTS at 5°C compared with aluminium conductors at 18-20%. Ground clearances are thus easier to achieve and maintain (due to the lower creep) and longer spans can be used, thus saving on poles and pole hardware (crossarms, insulators, fittings and the labour in fitting them) with fewer poles needed per kilometer. Alternatively, re-conductoring an existing aluminium line with CAC copper can allow increased power transfer due to the higher conductivity of copper and its ability to operate at higher temperatures without excessive sags (as demonstrated in the example in the next section).

One of **CAC**'s characteristics is its **high corrosion resistance**. The copper microalloy coupled with the anticorrosive coating; make CAC especially suitable for saline environments as it does not suffer from the problems of electrolytic cell formation between aluminium strands that occur in AAAC and the loss of galvanizing of the steel core in ACSR.

In addition, every wire from a CAC conductor is isolated independently using the coating, which due to its dielectric properties **reduces the skin effect losses**. Likewise, this property reduces the electric field at the conductor's surface and consequently the **corona effect** losses and its audible noise.

Table 1

	CAC-50-Pica d'Estats-UHC	ACSR LA-74	Cu-50	ACSR LA-56
Diameter	9.10	11.00	9.00	9.45
Section	49.4	73.5	48.3	54.6
Weight [kg/km]	450	254	441	189.1
Breaking strength [kN]	20.2	21.7	19.8	16.3
Electrical resistance DC 20ºC [ohm/km]	0.368	0.455	0.376	0.613
Electrical resistance AC 25ºC [ohm/km]	0.375	0.525	0.429	0.708
Maximum operating temperature [ºC]	150	80	80	80
Ampacity [A]	435	252	265	208

Furthermore, one of the main characteristics of CAC is its hydrophobic coating, which reduces the ice accretion on the conductor's surface, consequently reducing the ice and wind loads, characteristic which proves to be especially efficient for wet snow icing phenomena.

CAC conductors are available in aluminium and black color avoiding thefts or camouflaging it into the landscape.

It can be said that **CAC conductors** represent a **technological improvement** in comparison with other standard conductors.

3. BUSINESS CASE

In January 2015 **La Farga installed** a **CAC-50-Pica d'Estats-UHC** in the surrounding area of a potash salt mining company, in order to provide a solution to conductors' corrosion problem occurred by a saline atmosphere.

The refurbished line is located 326 meters above the sea level and it operates at a nominal tension of 25 kV. The topographical study commissioned prior to installation provided only the presence of an ACSR LA-74 conductor, nevertheless during the laying off; sections of ACSR LA-56 and Cu-50 were collected.

The mechanical and electrical specifications of the existing conductors have been compared with the specifications of the CAC-50-Pica d'Estats-UHC:

- **<u>CAC-50-Pica d'Estats-UHC vs ACSR LA-74:</u>**
  As it can be seen in the table above, the current carrying capacity of the CAC-50-Pica d'Estats-UHC is **1.7** times larger than the ACSR LA-74, which was taken as a reference in the conductor selection stage. It also **reduces the power losses by 28.6% due to Joule Effect** compared with the ACSR LA-74.

- **<u>CAC-50-Pica d'Estats-UHC vs ACSR LA-56:</u>**
  Analogously, the CAC-50-Pica d'Estats-UHC conductor increases **2.1** times the ACSR LA-56 capacity. It also **reduces by 47% the power losses due to Joule Effect** of the ACSR LA-56 conductor.

- **<u>CAC-50-Pica d'Estats-UHC vs Cu-50:</u>**
  It is important to notice that CAC conductors also improve the performance of ETP copper conductors, as it can be observed the CAC-50-Pica d'Estats-UHC increases **1.6 times** the capacity of the Cu_50, thanks to its ability to operate at high temperature. **The power losses are also reduced by 13%** by means of isolating each wire using the dielectric coating.

4. CORROSION ANALYSIS

In order to analyze the effects of corrosion on copper and aluminum conductors, samples of ACSR LA-56 and Cu-50 were characterized.

4.1 ACSR L-56

It could be appreciated with a simple visual inspection that corrosion has significantly deteriorated the ACSR LA-56 conductor, 4 from the 6 aluminium wires were found broken in several places, exposing the steel core. It can also be noted that a surface layer of salt is adhered to aluminum wires increasing their weight and diameter:

Figure 1: Salt adhered to the ACSR LA-56 conductor

The characterization of the ACSR LA- 56 conductor has been done by taking measurements of breaking strength and electrical resistance on the aluminum wires and the steel core. In addition, an estimation of the loss of mechanical and electrical features has been analyzed considering also the breakage of 4 from the 6 aluminum wires that constituted the ACSR LA-56 conductor. The obtained results have been compared with the reference values specified in the norm UNE-EN 50182:

Table 2

LA-56 Degradation			
Material	**Sample (no broken wires)**	**Sample (4 broken wires)**	**UNE-EN 50182**
Composition	1+6	1+2	1+6
Aluminium diameter [mm]	3.32	3.32	3.15
Steel diameter [mm]	3.15	3.15	3.15
Total diameter [mm]	10.73	10.73	9.45
Breaking strength [kN]	9.4	6.5	16.3
% Decrease of breaking strength	**-42.6%**	**-60.3%**	-
Electrical resistance DC 20ºC [Ω/Km]	0.684	1.952	0.613
% Increase of electrical resistance	**+11.6%**	**+218.5%**	-

If no broken wires are considered, it can be observed that the LA-56 has suffered a 42.6% decrease of tensile strength (value well above the 5%, which the UNE-EN 50182 considers as the maximum acceptable loss of strength after stranding an AL1, ST1A cable) and 11.6% increase of the electrical resistance.

However, the losses of the LA-56 conductor could be further increased if the breakage of the constituting wires is considered. As it can be seen at the table above, where the breaking strength has decreased a 60.3% and the electrical resistance has increased a 218.5%, which will certainly lead to a poor electrical performance with hot spots at the breaking points due to the high resistivity of the potash chloride.

4.2 Cu-50

A first visual inspection shows that the copper conductor has been much less corroded than the ACSR LA-56 conductor; there weren't any broken wires and it hadn't lost the characteristic flexibility of the cable. It could be seen that there was a copper oxide layer on the conductor surface; which protects the underlying metal and gradually limits the rate of penetration of corrosive agents[1].

In order to quantify the degradation suffered by the cable, an analogous procedure has been realized comparing the results with the minimum breaking strength and resistivity values according to the diameter of the wires, as detailed in the UNE 207015:

Table 3

Cu - 50		
Material	**Sample**	**UNE 207015**
Breaking strength [kN]	18.7	19.8
% Decrease of breaking strength	**-5.6%**	
Electrical resistance DC 20ºC [Ω/Km]	0.390	0.376
% Increase of electrical resistance	**+3.8%**	

4.3 Aluminium vs Copper comparison

It can be considered that the Cu-50 conductor **hasn't lost its mechanical and electrical characteristics after 40 years** of service in a highly corrosive environment. In contrast the LA-56 conductor has increased

[1] *Overhead conductor corrosion study* by Jacques Calitz. Tshwane University of Technology, South Africa, October 2004.

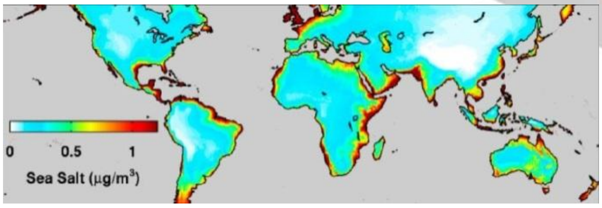
considerably the line's power losses and decreased the safety against its breakage after only 10 years of service.

Table 4

Aluminium vs Copper comparison		
Material	**LA-56**	**Cu-50**
Time of service	10 years	40 years
Breaking strength [kN]	9.4 to 6.5	18.7
% Decrease of breaking strength	**-42.6% to -60.3%**	**-5.6%**
Electrical resistance DC 20ºC [Ω/Km]	0.684 to 1.952	0.390
% Increase of electrical resistance	**+11.6% to +218.5%**	**+3.8%**

This is in line with UK experience of salt corrosion of medium voltage lines close to the coast. As the world sea salt map below shows[2] the UK is one of the world's worst places for sea salt corrosion. But UK standards assume a 60 year lifetime for copper conductors because of their ability to withstand corrosion.

Figure 2: density of sea salt fraction of PM 2.5 from aerosol optical depth (AOD) for period 2004-08



If the obtained results are taken into account in the case of the ACSR LA-56 conductor, it can be estimated that the real EDS was between 1.74 and 2.52 times the design EDS.

It can be concluded that copper conductors have a higher corrosion resistance compared with aluminum conductors. The corrosion protection offered by the CAC conductor's coating, increases more than 20 years the life cycle of bare copper conductors, which entails that the life cycle of CAC conductors in this corrosive environment is superior to 60 years.

Figure 3: Copper vs aluminium conductor

5. ECONOMIC ANALYSIS

An economic analysis has been performed considering a time horizon of 60 years and taking into account the costs associated with the line's refurbishment:

Table 5

Economic analysis		
Item	**LA-74**	**CAC-50-Pica d'Estats-UHC**
Conductor price [€/km]	2,948	10,753
Labour, fittings, Engineering [€/km]	19,375	19,375
Total investment [€/km]	**22,323**	**30,128**
Life cycle	10 years	60 years
TOTAL after 60 years [€/km]	**133,938**	**30,128**

It can be concluded that **CAC conductors are perfect candidates for corrosive environments**; taking advantage on the **higher corrosion resistance** of copper which **prevents the fast degradation** suffered by the aluminium conductors. Furthermore, CAC's copper microalloy and its coating improve the mechanical and electrical properties of bare ETP copper, giving a new and efficient solution for low, medium and high voltage overhead lines.

[2] Phillip S, Martin R V et al, *Global Chemical composition of ambient particulate matter for exposure assessment* Environmental Science and Technology, Vol 48 pp 13060-68, 2014