ADOPTION OF HIGH CAPACITY LOW SAG CONDUCTORS ON HIGH VOLTAGE POWER LINES

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ABSTRACT

Nowadays the new high voltage distribution overhead line authorization procedures have become a challenge: it can last up to two years. In the last two decades, new conductors called High Temperature Low Sag conductors (HTLS) are on the market providing better performance compared with traditional Aluminium Conductor Steel Reinforced (ACSR) conductors. The technical features of these conductors allow increasing the ampacity thus the power transmission capability of existing lines and providing a reserve in case of contingency in new lines (n-1 condition). The study evaluates the HTLS technology compared to traditional ACRS conductors. Said that, the topics Enel wanted to deep analyze were very important:

-How worthy is the adoption of HTLS versus the traditional high voltage conductors

-Which scenario is preferable for the application of this technology

To explore these topics with an as far as possible quantitative approach, the company studied the exploitation of these conductors with an innovative approach called Design to Shared Value (DSV), to evaluate their use in two different scenarios:

1) *repowering of existing line*
2) *construction of new lines*

INTRODUCTION

For the repowering of the existing lines, the result of the DSV analysis assigns a considerable advantage to the HTLS conductors (Singlewire or multiwire core) compared to the ACSR conductor, confirming what is common accepted in the industry that HTLS conductors are the best solution to face the repowering of an existing line. In addition, the results give us a prove of the DSV methodology accuracy.

On the other hand, for the construction of new lines, the DSV values of the solutions considered are close together, it must be noted that the cost of a new line could vary depending on the orography of the territory, the operating needs of the line, the result of the tenders, etc.
Thus, for each new line to be built, Enel will update the analysis with the specific costs of the project without discarding the HTLS solution a priori.
In addition, as the cost of energy is rising and will continue this trend over next years, together with the foreseen decrease of the cost of HTLS technology over time due to the widespread of its application, the construction of new lines during next years will gain value and almost certainly exceed the value of the standard solution.

CONDUCTORS' COMPARISON - TRADITIONAL VERSUS HIGH CAPACITY: MECHANICAL AND ELECTRICAL FEATURES

The conventional transmission line of Enel Grids consists of Aluminum Conductor Steel Reinforced (ACSR) or of All Aluminum Alloy Conductor (AAAC) deployed at the beginning of the 20th century.

ACSR	AAAC	HTLS
Aluminum steel conductor	*All aluminum conductor*	*Aluminum conductor carbon fiber core*

Fig.1 overhead line bare conductors technologies

When conductor current is increased to meet the demand, the lines will heat up and elongate due to thermal expansion in the steel material and aluminum wires, causing sag. AAAC conductors have excessive sag from thermal expansion and creep in the aluminum wires. The Knee Point Temperature (KPT) is defined as the temperature above which the aluminum strands are no longer carrying tension in the conductor. In ACSR conductor, where the aluminum wires are hard aluminum types with high strength, the high tension carried by aluminum wires results in relatively high thermal knee point (~120 °C or higher), well above the annealing temperature of hard aluminum wires, therefore, it is impossible to leverage thermal knee point in ACSR conductors. If all the conductor constituent materials can support high temperature operation (from high ampacity), the problem of thermal sag and ampacity limitations can be overcome by replacing conductors from the conventional types to high temperature low sag types (HTLS) deployed at the beginning of 21st century.

Nowadays on the market there are many HTLS conductors; inside the Enel Grids global standard the follows technologies are considered:

1) Aluminum conductor polymeric matrix composite core (single carbon fiber wire core or multiple carbon fiber wires core)
2) Aluminum conductor metal matrix composite core
3) Aluminum Conductor Steel Supported (ACSS)
4) Gap type conductor

Technology Type	Material for core	Material for envelope wires
Aluminum Conductor PMC Core	Polymer Matrix Composite Core (single or multi-wires)	Fully annealed Aluminum or thermal resistant aluminum Alloy wires
Aluminum Conductor MMC Core	Metal Matrix Composite Core wires	Thermal resistance Aluminum Alloy wires
Aluminum Conductor Steel Supported	Zn95Al5 Coated Steel wires	Aluminum fully annealed trapezoidal wires
GAP Type conductor	Al Clad Steel Core wires	Thermal resistance Aluminum Alloy trapezoidal & round wires

Table 1 HTLS conductors technologies

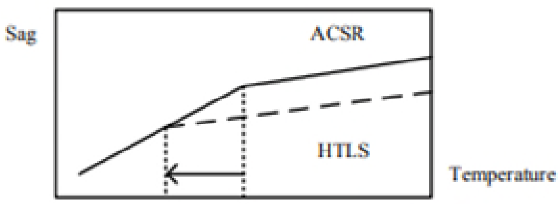

Fig.2 Sag-temperature diagram

Figure 2 shows the drop in KPT. The slope after thermal knee point is directional proportional to the thermal expansion coefficient of the core material. The steel wires in ACSS or gap conductors will exhibit the same slope as ACSR above knee point due to higher thermal expansion in steel.

The aluminum conductor polymer matrix composite core conductor was introduced to the market featuring fiberglass and carbon hybrid core, with desirable weight, low thermal expansion, and high strength, and annealed aluminum wires. The annealed aluminum wires readily creep and do not carry significant tension, resulting in attractive thermal knee point (low). This, combined with low thermal expansion (about 1/7th of steel) of the fiberglass carbon core, result in attractively low thermal sag.

The recent advancement in polymer matrix composite conductor with aluminum encapsulation for pre-tensioned carbon core is quite encouraging. This conductor leverages the pre-tensioning in carbon core to address the vulnerability in compressive stress and bending associated with prior generation glass fiber carbon core conductors, while also completely shielding the composite core from environment for life. The thick aluminum encapsulation around the carbon core enables robustness and mistake tolerance in conductor field handling during installation, while facilitating compatibility with standard work practice.

About the electrical features of the HTLS conductors there are two methods to reduce the electrical resistance:

1) Use of high conductivity material to manufacture the outer layers of conductor (aluminum-zirconium alloy)
2) Use of special shape for the outer layers to maximize the conductor cross section (trapezoidal)

In this way, using the HTLS conductor, we can reduce the power losses of the line when operating at standard temperatures of 75 °C. The best HTLS conductors should facilitate two paradigm shifts in traditional conductors, a) leveraging highest conductivity aluminum without sacrificing conductor strength; b) packing the most aluminum without conductor weight penalty. In the same types of HTLS conductors, like the ones with core encapsulated in aluminum featuring highest strength and lightest weigh carbon composite core, this additional aluminum cross section can further help the outer layers to raise the total conductive cross section.

DESIGN TO SHARED VALUE PILLARS: INTRINSIC SAFETY, SUSTAINABILITY, PERFORMANCE, GROSS- MARGIN

Enel Grids Engineering & Construction Function, adopted the methodology named “Design to Shared Value”, inspired by the Steven Eppinger and Karl T. Ulrich [2] approach, in order to lead choices related to the path of technological convergence and standardization.

Enel Grids, to overcome the classical procedure, has developed the new approach in which the main innovation consists of attributing equal dignity to Sustainability and Intrinsic Safety issues, compared to the usual engineering dimensions: Performance and Cost. Thus, Safety and Sustainability gain relevance in the process of making the choice of one technical solution over others.

The DSV methodology allows Enel Grids to make objective choices between different component/solutions by means of a value analysis, which aims to maximize a

set of characteristics (x, y, z ...) of a Value Function and systematically reduce its cost.
The DSV Value is defined as the following ratio:

$$\text{DSV VALUE} = \frac{DSV\ functionality}{Cost}$$

The functionalities placed in the numerator are the set of characteristics and performance, attributed to the component/solution to evaluate.
The denominator is the cost (or total cost of ownership) of the component/solution.

According to the Enel Grids interest in making choices related to the path of technological convergence and standardization of the grid, four variables were defined as functions, or "Dimensions":

- Intrinsic Safety;
- Sustainability;
- Performance;
- Gross Margin.

All these have been weighted, based on the Company strategy, prioritizing Intrinsic Safety over Performance. This last one in turn was ranked over Sustainability and Gross Margin that have equal weight.

This methodology has been tested in relevant cases studies throughout years 2021 and 2022 and allowed Enel Grids to develop medium/long-term strategies aimed to maximize the value of new grid solutions, ensuring a multidimensional approach, according to technical performance, economic features (such as competitiveness, economies of scale, Opex and Capex), sustainability requirements (environmental, social) and safety values, also incorporating aspects relating to purchasing strategies (competitiveness, supplier response, market risk, climate change, resilience, material scarcity).

STUDY CASES

The extension of Enel Grids grid in various countries and continental regions where legal and technical regulations may be substantially different made it advisable to incorporate Intrinsic Safety and Sustainability criteria in the evaluation of the suitable multiple solutions existing on the market.

The initiative refers to the choice of conductors for the High Voltage lines (voltage>66 kV), used in the Enel countries. The DSV analysis compares traditional ACSR conductors (**Aluminium Conductor Steel-Reinforced**) with the type of high-capacity conductors CFCC (**Carbon Fiber Composite Core**), in the case of new constructions and in the case of reconductoring.

Main objective of the analysis was the Value definition of the two conductors in order to define the more suitable solution for Enel Grids grid development.

The analysis was developed on two main scenarios:
Scenario 1: the case of repowering of an existing HV line with an increase of at least 50% of the capacity of the line to be re-powered;
Scenario 2: the construction of new HV lines using rather CFCC or ACSR conductors with the same power transported;

SCENARIO 1 : Repowering of existing line

The goal was to increase capacity of and existing line by the replacement of the conductor with another with the same external diameter. The replaced conductor is ACSR-380 (337-AL1/44-ST1A). For the conductors change, three options had been studied, two HTLS conductors to be used on the same structures and a new ACSR that provide the same capacity than HTLS alternatives but using new/refurbished structures:
HTLS conductors are ACCC® Dove and TS® Dove, ACSR conductor is ACSR-824 (727-AL1/97-ST1A) with equivalent maximum capacity.

SCENARIO 2 : Construction of a new line

The goal was to choose the best long-term alternative for the conductor of a new line where new structures and right of way must be managed.
Studied conductors are:
a) ACSR-380 (337-AL1/44-ST1A)
b) ACCC® Dove
c) TS® Dove

DSV Results

In this analysis for ACSR and CFCC technologies, the DSV methodology do not evaluates the Intrinsic Safety dimension due to the similarity of the activities involved.
For the other dimensions of the DSV method, functions and subfunctions evaluated on both study cases are those indicated on Table 2.
Every dimension of the DSV method is prioritized using the Significance factor showed on Table 2.

Function / Significance		
Sustainability / 3		
	Performance Efficiency	Green House Gas (GHG) Reduction
Performance / 4		
	Grid Performance	Losses
		N-1 Capacity. *
	Installation	
	Interoperability	
	Modularity	Mechanical features

Gross Margin / 3	
Total Cost Ownership	30-year TCO
Market Risk	
Installation time (h)	Installation time
	Permitting

Table 2

* Capacity of the grid when one element is not in operation.

Values assigned for every conductor alternative are represented in the following Table 3.

Reconductoring of existing line			
	ACSR	**ACCC®**	**TS®**
GHG Reduction	5	3	3
Losses	5	3	3
N-1 Capacity.	5	5	5
Installation	1	3	4
Interoperability	4	3	3
Mechanical features	-	-	-
30-year TCO	5	3	3
Market Risk	4	3	3
Installation time	1	3	4
Permitting	1	3	3
Construction of a new line			
	ACSR	**ACCC®**	**TS®**
GHG Reduction	3	5	5
Losses	3	5	5
N-1 Capacity.	3	5	5
Installation	4	3	4
Interoperability	4	3	3
Mechanical features	3	5	5
30-year TCO	3	5	5
Market Risk	4	3	3
Installation time	4	3	4
Permitting	0	0	0

Table 3

DSV functionality value (Significance*Adequacy) for every conductor in both study cases, is depicted in Table 4

Reconductoring of existing line			
	ACSR	**ACCC®**	**TS®**
Sustainability	15	9	9
Performance	60	56	60
Gross Margin	33	36	39
DSV functionality	**108**	**101**	**108**
Construction of a new line			
	ACSR	**ACCC®**	**TS®**
Sustainability	9	15	15
Performance	68	84	88
Gross Margin	33	33	36
DSV functionality	**110**	**132**	**139**

Table 4

Finally, the budget for the installation of each conductor is estimated using the value of the budget needed for the installation of ACSR as 100% of the cost. The ratio between total DSV functionality value and cost shows the DSV Value of every conductor for the case study, as shown in Table 5.

Reconductoring of existing line			
	ACSR	**ACCC®**	**TS®**
Cost	100	40	35
DSV functionality	108	101	108
DSV Value	**1,08**	**2,53**	**3,09**
Construction of a new line			
	ACSR	**ACCC®**	**TS®**
Cost	100	119	113
DSV functionality	110	132	139
DSV Value	**1,10**	**1,11**	**1,23**

Table 5

CONCLUSION

SCENARIO 1 : REPOWERING

The use of CFCC conductor allows:

- Maintain the existing construction solution (pylons) with savings in:
  - Time of work realization
  - Project costs
  - Less complexity of the authorization process due to the replacement of some towers of the existing line
- Less sag: with the increase in temperature, the CFCC conductor offers less sag compared to ACSR conductor.
- Increased capacity, limited by the maximum CFCC conductor diameter that can be supported by existing supports.

The use of ACSR conductor:

- It does not allow to maintain the existing constructive solution (towers/pylons) and therefore requires a redesign of the line: modification of the track, pylons, permits, etc ;
- It implies the adaptation of the conductor section to the necessary increase in flow rate.
- For the new designed line there will be lower electrical losses, due to the greater section of the chosen conductor. The result is less CO2 emitted.

SCENARIO 2 : NEW LINE

The use of CFCC conductor implies:

- Lower electrical losses, due to the greater useful section given by the compacted trapezoidal wires. The result is less CO2 emitted.

- Construction solution (pylons) identical to that of the ACSR standard conductor. Depending on the orography of the area, the solution could be less expensive;
- Less sag in the event of an increase in the load on the line, compared to ACSR conductors.
- The electrical overload can be increased by 1.8 times (compared to the nominal flow rate) thanks to the increase in conductor temperature.
- A higher price (up to 2.8 times) compared to ACSR, affecting the construction costs of a new line from +8% up to +30%. It depends on the type of CFCC conductor (type b) or c));
- Increased installation times up to +30%, depending on the conductor (type b) or c));
- Regulatory issue: there are concrete possibilities for applying the technology in the various countries.

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