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ADVANCED CONDUCTORS FOR FUTURE-ORIENTED OVERHEAD LINES

ABSTRACT

A highly sophisticated conductor for high-voltage overhead lines has been launched on the power transmission sector since several years. This fully-locked conductor integrates one or more concentric layers of formed wires having the shape of a “Z”. The outer layer, which is virtually smooth, has small helical grooves created between the upper edges of the Z-shaped wires with carefully chosen lay, depth and pitch. The characteristics of these conductors are more interesting than those of traditional stranded conductors with round wires.

The proposed compact conductor is homogeneous, all wires being produced from Aluminum Alloy and the advantages are both electrical and mechanical:

- Less Corona and Joule losses
- More ampacity
- Improved corrosion protection
- Better self-damping and reduced probability of galloping phenomenon
- Better behavior in ice and snow climates
- Better aerodynamic properties – reduced drag coefficient

Keywords: Compact Conductors, Aero-Z, Formed Wires, OHL uprating

1 INTRODUCTION

The AERO-Z® conductor has one or more outer layer(s) in aluminium or aluminium alloy (AlMgSi = Almelec = AMS = AGS) made up of profile Z-shaped wires.

The AERO-Z® cables and conductors have at least the last layer of strands composed of Z-shaped profiled wires which overlap each other, the bottom of one wire being placed under the top of the adjoining wire. This gives them an almost cylindrical outer surface, ribbed with helical grooves of a characteristic pitch and depth.

In the late sixties, the CABLERIES DE DOUR started the design and planning of “smooth” conductors made up of z-shaped profiled wires.

Indeed, since 1970, a great number of overhead lines have been built with fully locked (compact) conductors, and have formed the subject of many studies.
The first “smooth” conductors were installed for specific applications. The characteristics of these AERO-Z® conductors were more interesting than those of traditional stranded conductors with round wires. Indeed, with those traditional conductors, an oscillatory instability phenomenon could be risked, which means a risk of galloping at great range and at low wind speeds.

2 CHARACTERISTIC OF AERO-Z CONDUCTORS

2.1 Line Losses

AERO-Z® conductors have an outer area that inclines towards a “smooth” surface. The CORONA effect is thus all the lower because, due to the absence of deep valleys, dust is more easily eliminated by natural rainfall. The dirt which accumulates with the passage of time will therefore be less than with a traditional conductor.

Because of these reasons line losses will be reduced.

2.2 The Capacity of Amperage (Ampacity)

A better distribution of temperature inside AERO-Z® conductors allows a greater amperage capacity. Due to the density of the conductor, the inner and outer temperatures of the AERO-Z® are very close. The gain in temperature can be as much as 15°C at normal charge and 10°C at overload charge.

2.3 Internal Corrosion

Due to overheating during service, traditional conductors are subject to a displacement of the protection grease from the inner to the outer layers. In some cases, the grease can even flow out of the conductor. This causes a reduction in the protection of the conductor against internal corrosion and an increase of the frictional force between the wires. Therefore, abnormal wear and premature breaking can occur.

This phenomenon is quite different with an AERO-Z® conductor: the outer belt, which is formed by “Z” profiled wires firmly overlapped into each another, forms a hermetic casing which avoids the oozing of the grease into the outer layers of the conductor. This provides a perfect protection against internal corrosion and a lesser wear of the wires over the years.

Tests made on AAAC/ AERO-Z® and on traditional conductors installed in 1970 and removed in 1988 (because of a modification in the lay-out of the line), clearly proved that the weight of the grease on the AERO-Z® conductor remained similar to the initial weight, whereas the traditional conductor lost 28% of its grease. The prototype of the fully locked conductor was wired in 1970 from laminating rollers providing steel AERO-Z® conductors, and therefore the contact at the level of the noses of the “Z” wires was not perfect.

For the first conductor crossing of the Scheldt, Z-profiles were tied up against one another. After a study made on both the classical and the AERO-Z® conductors installed in 1970, the following conclusions could be reached:

- The dirt, which accumulates with the passage of time, was greater on the traditional conductors than on the AERO-Z® conductors. This was especially the case in the valleys between the wires.
- After removal of the outer layer, it could clearly be seen that a lot of impurities, which could be abrasive, infiltrated trough the outer layer of the traditional conductor. This was not the case with the AERO-Z® conductor, despite the fact that the “Z” profiled wires were hardly contiguous.
- Finally, the final two layers were removed from the inner layer and it was found that the grease in the traditionally stranded conductor had completely disappeared, wherever it was still completely present in the “smooth” AERO-Z® conductor. Even steel stripping could be noticed on the layers of the traditional conductors.
- On the inner layer, a similar phenomenon was noticed:
- No grease at all was left on the traditional conductor whereas all of it was still present on the AERO-Z® conductor;

- Significant steel stripping was found on the traditional conductor whereas none of it was found on the AERO-Z® one.

2.4 Shock Absorption

High voltage overhead lines conductors (617mm² AAAC traditional, 617mm² AAAC/ AERO-Z® and 593mm² ACSR were put through several oscillation tests at different sites in Belgium and France. The conclusion of these tests was that the shock absorption of AERO-Z® conductors happens twice as fast as that of traditional conductors. Improved shock absorption was also reached when the same tests were performed at different wind speeds.

2.5 Gallop

Wind tunnel tests and observations made on site have shown that the galloping of AERO-Z® conductors - without frost and at great range - occurs only at considerably higher wind speeds. This means that the probability of this type of gallop on an AERO-Z® line is much less, and if gallop does occur, its extent will be considerably less. The characteristic of the inner shock absorption of overhead line conductors is an important factor in the galloping behavior of these conductors.

The two most frequent types of gallop are:

1. “DEN HARTOG” gallop: this is an instability due to the aerodynamic lift and drag coefficient of a conductor covered with coats of ice. This instability often occurs with a very thin coat of ice and often on a single conductor. The inner absorption in vertical motion increases the speed at which the gallop occurs.

2. The “floating” gallop (wavering gallop – ex. TACOMA bridge): it consists of a dangerous connection between the vertical motion and the torsional motion and leads to new possibilities of instability, especially on beam conductor lines. The inner absorption in torsional motion takes a significant part in the starting and the extent of the galloping problem.

According to different tests performed, it could be concluded that AERO-Z® conductors have very well vertically absorption and improved torsional absorption qualities.

The AERO-Z® conductor therefore provides significant improvement in galloping problems.

Moreover, the shock absorption of an AERO-Z® conductor is made more rapidly, especially at low frequencies, and any damage that gallop may cause to the support equipment is therefore minimized.

2.6 Coats of Ice and Frost

AERO-Z® conductors provide solutions to the problems caused by frost and the formation of coats of ice around traditional conductors. Traditional overhead conductors have a very low torsional coefficient. This means that a very small amount of snow on the lateral face of the conductor is enough to make it twist on itself. In this case, the twisting of the conductor is the main mechanism leading to the formation of cylindrical coats of ice. On the other hand, on a rigidly fixed conductor, the snow deposit grows along the axis and the snow falls as soon as the eccentric mass is sufficient, which is the case with a fully locked AERO-Z® conductors, which are thus of particular interest for Electricity Companies who are subject to very bad weather on their territories.

Both ICELAND and CZECHOSLOVAKIA were supplied with AERO-Z® conductors. In Iceland, every year a great number of overhead lines break because of an overload of snow. The Icelandic Electricity Company (RARIK) installed an AERO-Z® conductor (536mm²) running parallel to an ACSR conductor of equal diameter in the north of the country. On both lines they recorded ice weights and duration tests on the formation of coats of snow. This experiment was carried out between March and July 1992.
It could be noticed that there was a coat of snow around the AERO-Z® conductor, but it was smaller and broke off more rapidly than on a traditional conductor. This experiment showed that an AERO-Z® conductor offers a better resistance to the formation of coats of ice due to snow.

The Czech experiment also shows that AERO-Z® conductors offer a better resistance to the formation of coats of ice due to frost. Frost forms around the conductor and turns into ice. This ice is heavier or lighter according to the number of bubbles of air confined inside it. This determines the density of the conductor.

Observations made during the winter:
- The AERO-Z® conductor accumulated little ice.
- The all-steel ground cable accumulated ice and its sag had increased and lowered the line at a dangerous level.
- The traditional conductor broke down due to the weight of the ice.
- This experiment concluded that AERO-Z® conductors are 1.5 to 3 times more resistant to frost than traditional conductors. Moreover, in all cases, the coat of ice breaks off more rapidly.

Tests performed in laboratory revealed also that ice weight on AERO-Z® is 12% less than for classic conductors.

![Figure 1. Coats of Ice and Frost (AERO-Z® conductor and traditional conductor)](image)

2.7 Drag Coefficient

The CABLERIES DE DOUR made tests with the collaboration of Professor OLIVARI from the VON KARMAN Institute in order to study the aerodynamic characteristics of traditional conductors and AERO-Z® conductors. Mainly influences of AERO-Z® strains on its aerodynamic behavior were examined. The tests showed that, for an equal diameter, the strain at high wind speeds was less on AERO-Z® conductors than on traditional conductors. This reduction can be as much as 40%. (Please keep in mind that the drag coefficient of a classical conductor is equal to 1).

During the last few years, it was also proved that the AERO-Z® design was also adaptable to other requirements of customers regarding to the shape of the Cx curve, in function of wind speeds (development for RTE/EDF – French 220 kV network).

Moreover, a 2002 study with finite elements made in collaboration with the Montefiore University of Liège (Belgium) (specialist in damping theoretical studies) has shown that the AERO-Z® conductors have a much better behavior in the case of a turbulent wind in such a way that he reduces dramatically the mechanical efforts on the anchoring strings, and this up to 30% thanks to the smaller excitation of the Aero-Z® conductor. This conductor will therefore extend the expected life duration of the dead ends and of the suspensions chains and will less strain the towers in the case of turbulent winds of hurricane.
3 ECONOMICAL ASPECT

As described previously, the installation of Aero-Z conductors brings a series of advantages in OHL operation like reducing the maintenance works on phase conductor, increase line security and reliability, longer lifetime.

A major impact on environment is created using this type of conductor because of Joule losses reduction, which will decrease the emission of CO2 for a given generated power.

A comparison between the classic ACSR 490/65 and compact AAAC-Z 648 is presented in the following table:

<table>
<thead>
<tr>
<th>Description</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductor Structure</td>
<td></td>
<td>7x3.4-54x3.4</td>
</tr>
<tr>
<td>Nominal Cross section</td>
<td>mm²</td>
<td>48955</td>
</tr>
<tr>
<td>Calculated cross section</td>
<td>mm²</td>
<td>553.8</td>
</tr>
<tr>
<td>Total</td>
<td>mm²</td>
<td>608.55</td>
</tr>
<tr>
<td>Calculated breaking load</td>
<td>kN</td>
<td>15.285</td>
</tr>
<tr>
<td>Overall diameter</td>
<td>mm</td>
<td>38.6</td>
</tr>
<tr>
<td>Total weight</td>
<td>kg/km</td>
<td>18.64</td>
</tr>
<tr>
<td>Max. DC resistance at 20 °C</td>
<td>Ohm/km</td>
<td>0.859</td>
</tr>
<tr>
<td>Young's elastic modulus</td>
<td>GPa</td>
<td>78</td>
</tr>
<tr>
<td>Lines expansion coefficient</td>
<td>10^{-11}°C</td>
<td>19</td>
</tr>
<tr>
<td>Capacity between 4°C and 1°C (0.866; 1100W/m²,</td>
<td>A</td>
<td>7.46 @ 78</td>
</tr>
<tr>
<td>Linearity of the conductor</td>
<td>W/m</td>
<td>9.68</td>
</tr>
<tr>
<td>Joule losses of 375 A (50% ACSR capacity)</td>
<td>W/m</td>
<td>8.255 (15% loss)</td>
</tr>
</tbody>
</table>

Figure 2. Comparison between the classic ACSR 490/65 and compact AAAC-Z 648

Having more conductive cross-section, AAAC-Z will heat-up less than ACSR for a given current. The economy resulted from reduction of Joule losses is shown in the next figure.

Figure 3. Economical Efficiency (AAAC-Z vs. ACSR)

For example, considering an annual average line load of only 30% and 60 Euro/MWh the cost of energy, for a single circuit OHL with 50 km line route length, equipped with 2-bundle conductor, an economy of 78 kEuro/year conductor will be realized.
4 CONCLUSION

Initially designed to solve the cases of long spans across rivers, a compact conductor has been developed in Belgium since 1970. This was the origin of the AERO-Z® conductor, whose general characteristics and notably its higher ampacity and lower drag coefficient vis-à-vis conventional stranded conductors recommend it.

At an equal diameter, under normal permanent operation, there is an increase in current carrying capacity of 8 to 17% and, as a corollary, a 12 to 25% decrease in Joule losses. Secondly, the drag coefficient for compact conductors was decreased by 25 to 50% compared with conventional conductors when subjected to high wind velocities. As a matter of fact, the higher is their diameter; the lower is the wind velocity beyond which they become more aerodynamic. The mechanical strength, joining ability and stringing ability are also satisfactory. The susceptibility to aeolian vibrations is at times strongly reduced, at worst equivalent to classic conductors. Lastly, although this is a point that was not formally verified, one could expect that the compact conductors are subject to less ice accretion due to the fact that they exhibit greater torsional stiffness and shed ice more easily owing to their smoother outer layer. As their technical and economic interest has been validated, these conductors are a reliable solution for new OHLs.