**INNOVATIVE 11-25KV ALUMINUM-STEEL OVERHEAD CONDUCTOR**

**ABSTRACT**

During the last decade the cost of copper and aluminium base metal has risen and challenged Energy Utilities in developing alternative cost-effective technological solutions. Enel SpA, together with Cesi Ricerca SpA and two accredited manufacturers (Tratos Cavi SpA and De Angeli Prodotti SpA), engineered an innovative MV overhead bare conductor made of annealed aluminium, extruded around a supporting steel core. In this paper we will illustrate the new conductor with the more traditional overhead conductor types and its economical and environmental benefits and drawbacks.

**INTRODUCTION**

Enel SpA serves more than 30 million customers nationwide with an asset of 2,000 substations, 200,000km of MV lines (excluding underground cables), and 752,000km of LV lines. The total annual power consumption is approx. 340 TWh. Transmission and distribution networks evolve and expand along with communities demanding and deserving quality and reliability. Consequentially it is critical to aim, consolidate and maintain network flexibility, adopting modern, feasible and sustainable engineering solutions. These objectives may require ad hoc technologies and therefore a synergic multidisciplinary approach from utilities, manufacturers and researchers. In this context of continuous evolution, our project team developed an innovative MV ACSS bare overhead conductor (referred in this paper as AACSS) that combines simplicity with improved performance adding significant value to Enel’s mission.

**AACSS TECHNICAL DATA**

In 2008, Enel SpA erected more than 260km MV overhead power lines. This figure accounts for networks expansion, maintenance, refurbishment and replacement of end-of-life line components including those caused by act of vandalism and copper conductors thefts. Numbers and volumes involved, copper price curve fluctuating trend, network reliability, sustainability concerns and will to improve conductors performance, were the driving forces behind the project.

The AACSS represented schematically in Figure 1, has a stranded supporting steel core tightly surrounded by a layer of annealed aluminium, extruded so that the desired electrical characteristics are obtained. Dimensionally, the AACSS conductor cross-section able to satisfy the predefined criteria was the 60mm².

AACSSs material selection, correct dimensioning and manufacturing techniques led to interesting results, especially in terms of line heat losses (Joule law). It has been evaluated that compared to a 35AAAC and a 25Cu conductors type, the heat losses of a 60ACSS are respectively 50% and 30% less. In other words, the new AACSS directly contributes to lessen the power line carbon footprint.

It has been estimated that the annual carbon emission reduction of a 60AACSS power line juxtaposed to the standard 25Cu or a 35AAAC, is respectively between 350 and 600 tons of CO₂ per kilometre of line.

Table 1 highlights another interesting feature: the AACSS higher working temperature adds on to the line carrying capacity flexibility.
ENVIRONMENTAL AND ECONOMICAL ASSUMPTIONS

The Life cycle (LC) environmental and economical comparative evaluation analysis between the 60AACSS and the standard type conductors were carried out assuming a functional unit of 1 kilometre long 24kV overhead line, erected on a straight flat and uniform land characterised by 30 years maximum installation life span. To count for the expected network expansion within the length of time set, a provision for a linear ampacity increase (from 70A up to 140A) was made.

Mechanical line design calculation indicated as the most suitable pole, a 14m long conical steel pole with 34.5cm equivalent base diameter, 1.5cm/m conicity factor complete with a square 1.2x1.2m outcropping concrete basement, 1.6m deep. The insulators assumed were the hanging single composite 42cm long strings type, complete with relative accessories.

Table 2 shows required number of poles per kilometre of line, for each type of conductor examined.

<table>
<thead>
<tr>
<th>Conductor</th>
<th>Number of Poles [n/km]</th>
</tr>
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<tbody>
<tr>
<td>25Cu</td>
<td>9.62</td>
</tr>
<tr>
<td>35Cu</td>
<td>7.35</td>
</tr>
<tr>
<td>35AAAC</td>
<td>8.47</td>
</tr>
<tr>
<td>60AACSS</td>
<td>8.70</td>
</tr>
</tbody>
</table>

Table 2 – Pole Density

COMPARATIVE LC ENVIRONMENTAL IMPACT EVALUATION

The environmental impact analysis for each conductor type was carried out using the Life Cycle Assessment (LCA) technique, ISO 14040 series compliant. Inventories and environmental impact calculations were executed using the TEAM PW&C software. Finally, for the LCAs evaluation we have adopted the from cradle to grave approach.

The LCA functional unit, represented schematically in Figure 2 is subdivided in the following main phases:

(a) Manufacturing: including those of conductors, poles and accessories; acquisition transportation and use of base row material;
(b) Transport and Installation: including transportation of all overhead power line components from place of origin to site, line erection labor and machineries fuel consumption for installation purposes;
(c) Use: including energy dissipated throughout the line heat losses (Joule Law), estimated applying the predefined line ampacity increase value;
(d) End-of-life accounting for:
   - Line dismantling and transportation of obsolete components to a suitable waste collector site;
   - Recycle of metals with a closed loop mass efficiency ≥95% carefully avoiding to include base materials;
   - Silicon rubber incineration with energy recovery;
   - Reinforced fiberglass resin insulators, concrete and metal scraps, landfill.

LCA evaluation data assumed reflects the present National scenario and were executed according the latest relevant Best Practices. No cut-off criteria was applied.

The impact categories selected for the LCA critical flow comparison are:

1. WH – Hazardous Waste Production
2. WT – Total Waste Produced
3. TEP – Total Primary Energy Consumption
4. EL – Electricity Consumption
5. DEP – Depletion of non-renewable resources
6. GWE – Greenhouse effect over 20 years
7. AA – Air Acidification
8. EUT – Eutrophication
9. XTX – Human Toxicity
10. OLD – Ozone Layer Depletion (average value)
11. POF – Photochemical Oxidant Formation (average value)

The environmental sustainability profile analysis lead to the following conclusions:

- Line heat losses load up the total environmental LCA impact and have to be balanced by a mixed production of an equal amount of electricity from which derive carbon emissions and waste that are the major contributors (excluding depletion due to non renewable resources) of all LC impacts (99%).
- Impact due to manufacturing processes, including the depletion of non renewable resources (i.e. metals), is less than 2%;
- End-of-life management partially compensate the base material acquisition phase. However this compensation is diminished by the recycling energy consumption;
- Overall on the conductor sustainability profile, the Transportation and Installation phases account for less than 4%;

Figure 3 shows the 25Cu line conductor phase impacts
expressed in unit values of impact during the LC assumed.

Figure 3 - 25Cu line LC impacts

The bar graph in Figure 4 shows the LCA environmental phase impact for each type of conductor understudy, expressed per unit value of the ACSS impact. At first glance it can be clearly seen that the 60AACSS conductor has the best environmental performance. In contrast due to its lighter physical weight the 35AAAC conductor has the most environmentally friendly phase impact (see Figure 5).

Figure 4 - Line sustainability profiles

Figure 5 – Manufacture phase line comparison profiles

COMPARATIVE LC ECONOMICAL

EVALUATION

The economical feasibility assessment was based on three categories: construction, operational and dismantling costs.

Construction costs

Construction costs comprise costs of line components (conductor, poles and accessories) and costs of line erection labour. Table 3, reports the single items actual costs per 1 kilometre of line build using one of the four type of conductors examined, expressed per unit value.

<table>
<thead>
<tr>
<th>Conductors</th>
<th>Conductor [€/km]</th>
<th>Poles [€/km]</th>
<th>Accessories [€/km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>25Cu</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>35Cu</td>
<td>1.4</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>35AAAC</td>
<td>0.3</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>60AACSS</td>
<td>1.0</td>
<td>0.9</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Table 3 – Costs of line components in p.u.

Line erection costs resulted to be similar and depended only on the number of poles required per km of line; they ranged from 7990 €/km for the 35AAAC type to 8850 €/km for the 25Cu type. The 60AACSS type line components costs value resulted to be intermediate (8350 €/km).

As it can be seen from the above graphic bars about half the costs of construction are related to labour (line erection). The 60AACSS and the 25Cu line costs distribution values resulted similar.

Operational costs

The two main items included in the operational costs were maintenance and heat losses. In line with what noticed for the erection costs, line maintenance costs do not substantially differ: they range from 1637€/km for the 35AAAC type to 2260€/km for the 35Cu, while the 60AACSS conductor set to an intermediate value of 1914€/km.

On the contrary, significant differences are attributable to line losses. Figure 7 shows cumulated line losses costs,
evaluated considering the predefined installation life span (30 years), a linear line carrying capacity increase (from 70A to 140A) and an inflation rate of 7%.

The load curve has been approximated according Enel Specification, assuming a total peak ampacity flow of 2,545 hours per year. The 60AAACSS conductor type line shows together with the 35Cu type, the best performance.

Even in this instance, dismantling costs between the type conductors studied do not substantially differ. Being the cost actualised over a 30 years period, the influence on the LC cost is marginal and ranges from 685€/km for the 35 Al type to 790€/km for the 25Cu type.

**LC costs**

Summing up all costs over the entire LC, Figure 8 reports the cumulated conductors expenditure. The 60AAACSS conductor showed as expected, the best performance confirming the soundness of the project although the 35Cu type demonstrated to be highly competitive.

Due to its peculiar physical properties, the ACSS conductor has also the advantage to contain thefts and vandalism acts. Although the economical impact of conductors theft appears negligible (preliminary evaluations indicate an economical impact of theft around 2000€/km over its entire lifecycle), it is important to inhibit this malicious practice.

**CONCLUSIONS**

In synthesis benefits deriving from the installation of the new 60mm² AACSS MV overhead bare conductor are:

- Possibility to be installed in place of all others Enel’s standard conductor type (25Cu, 35Cu and 35AAAC) thus minimizing material logistic and management issues;
- Reduction of new power line total costs (including material manufacture, line operation and end of line dismantling);
- Possibility to cover for increased power demand, seasonal power peaks and backups of faulty feeders thus improving network flexibility;
- Inhibition of line thefts and acts of vandalism.

The major ACSS conductor drawback resides on its inability to absorb line vibrations as well as traditional stranded conductors. After many pilot line test failures, the installation of line dumpers solved the inconvenient completely. However even if minor, the increased number of line accessories adds up on line maintenance, components and dismantling costs.