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TOP 5 SOLUTIONS FOR YOUR MDM ABYSS

Microalloyed Copper Overhead Line Conductors

BY FERNANDO NUÑO, EUROPEAN COPPER INSTITUTE

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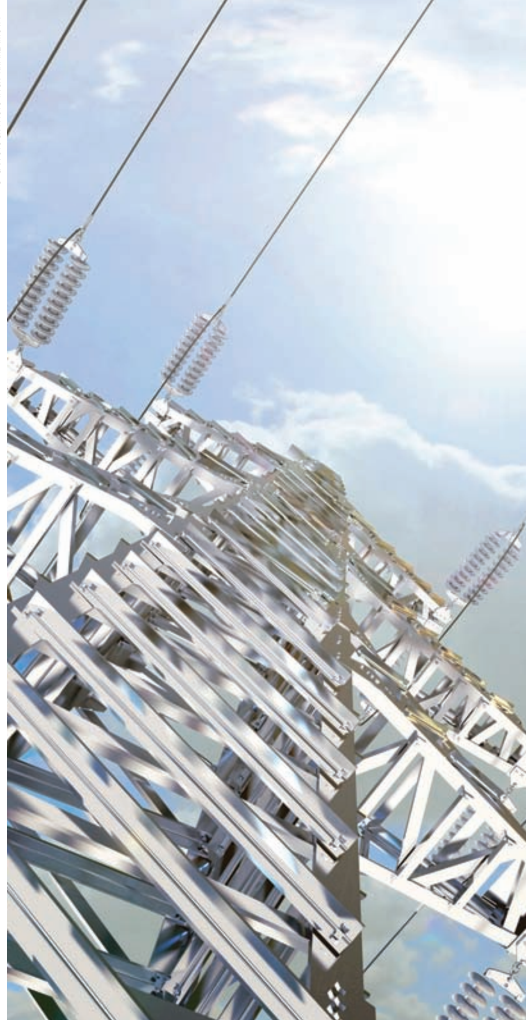

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The energy landscape is in full transition. Changing market structures combined with increasingly distributed, variable and unpredictable types of power generation complicate electricity grid management. Transmission network operators face several substantial and even contradictory challenges.

Renewable energy power stations often are in remote areas. New lines must be built to connect them to the main grid and transport their production to demand centers.

The increasingly high share of renewable energy in power generation creates a highly variable supply. The grid is an important part of the solution to cope with this variability because it enables an exchange of electrical energy from regions with temporary supply surpluses to regions with temporary peaks in demand. This new type of energy exchange requires grid reinforcement.

Resistance against the construction of new overhead lines, however, has never been so high. The construction of such lines in heavily populated areas always has been a challenge. Today, the uncertainty concerning the impact of electromagnetic radiation and increasingly stringent local regulations add to this challenge. In less populated areas, the process to gain permission for new overhead lines can be even more complicated because of visual impact on the landscape.

Because of the variable and unpredictable profile of renewable electricity production, transmission system operators often are forced to run transmission lines at capacity limits. Their jobs would be easier if some spare capacity was available for their use from time to time. They are limited, however, by the maximum operational temperature of the line conductor. Above this maximum temperature, the conductor material shows excessive creep, and the mechanical integrity of the cable no longer can be guaranteed.

Adding to the difficulty, there is an increasing focus on transmission line energy efficiency. After improving efficiency at the supply and demand sides, it is time to focus on energy that is lost in between. According to the International Energy Agency (IEA), the world consumes more than 20,000 TWh of electricity annually, of which 7 percent (or 1,400 TWh per year) is lost in the wires. Any improvement in energy efficiency

CROSS SECTION OF CAC FOR OVERHEAD LINE IN CIRCULAR AND TRAPEZOIDAL WIRE 1

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makes us less dependent on fossil fuels and reduces the associated carbon dioxide (CO_2) emissions.

Reducing transmission line losses by one-third would reduce annual CO_2 emissions by 250 million tons—the equivalent of taking 50 million cars off the road. Such an energy efficiency improvement also would replace the need for 60,000 MW of new generation capacity, which represents breathing space in the transition to a renewable energy economy.

It would increase the entire electricity system's energy and financial efficiency. For those reasons, regulators are paying more attention to the energy efficiency of overhead lines and are shifting their main goal from minimizing the investment cost to minimizing the life cycle cost (LCC) of the lines. This, however, creates more challenges for transmission network operators.

To cope with these simultaneous challenges, network operators need a conductor that can replace old conductors on existing rights of way and that increases the energy efficiency, capacity and overload capacity of the line: the microalloyed copper conductor (CAC).

Overhead line conductors are traditionally a domain for aluminium, using either steel reinforced aluminium or aluminium alloys. Using copper for overhead lines might surprise some people because it is a substantially heavier material. Weight, however, is not the most crucial characteristic of the conductor.

TYPES OF OVERHEAD LINE CONDUCTORS

DNV GL (formerly DNV KEMA) analyzed the technical and financial differences between two types of steel reinforced aluminium conductors (ACSR) and the CAC. The three conductors in Figure 2 have approximately the same current-carrying capacity at 80 C.

From left to right, the initial investment cost for the conductor rises, but the energy losses decrease. The basic technical characteristics of those three types of conductors are in Figure 3.

The CAC has a much smaller cross section for a similar level of current-carrying capacity at a certain operating temperature. CAC has sufficient mechanical strength without steel reinforcement.

Combined with the higher electrical

THREE TYPES OF OVERHEAD LINE CONDUCTORS 2

ACSR-Hawk LA 280 | ACSR Eagle LA 350 | Copper Conductor CAC 185

630 A at 80 C

700 A at 80 C
Higher Investment
Lower Losses

700 A at 80 C/1115 A at 150 C
Higher Investment
Lower Losses

BASIC CHARACTERISTICS OF ACSR AND CAC OVERHEAD LINE CONDUCTORS 3

	ACSR Hawk	ACSR Eagle	CAC 185
Cross section (mm2)	280	350	185
Current capacity at 80 C (A)	630	700	700
Current capacity at 150 C (A)	-	-	1115
Weight (kg/km)	982.3	1301.8	1652
Electrical resistance (Ohm/km)	0.1195	0.103	0.09
Tensile strength (kN)	85	123.6	93
Elasticity (kN/mm2)	77	81	50
Thermal expansion (1/°C)	0.0000189	0.0000178	0.000017
Max operational temp (°C)	80 C	80 C	150 C

conductivity of copper, this results in a smaller conductor section for the same line capacity.

This capacity per cross section is enhanced further because of the reduction of the skin effect. In the CAC conductor, an insulating coating is applied to each separate wire inside the conductor, resulting in an equal current that flows through the central wires as through those outside the conductor.

The higher conductivity of copper and lower skin effect also result in reduced energy losses. The maximum operating temperature of the CAC is much higher than that of its ACSR counterparts.

At first sight, the higher weight and lower elasticity of the copper conductor could be seen as disadvantages. In practice, this is not the case because:

- The strength of the towers for overhead lines is not so much determined by the weight of the conductor but more by resistance against forces created by wind and ice. The smaller the cross section of the conductor, the lower these forces will be.
- The high annealing temperature of copper (greater than 300 C) makes it easier to apply surface coating on the copper conductor without being concerned about a potential change of the material's mechanical properties. Certain types of surface coating can make the conductor hydrophobic, preventing ice load.

As a result, the CAC becomes a technically feasible and financially attractive alternative to ACSR conductors.

The ability to apply coating on the copper conductor also brings another advantage: It enables a surface treatment that reduces Corona losses, as well as the related energy losses and noise levels.

Especially in wet climates, Corona losses can become a substantial source of irritation for passers-by, adding to the negative image of high-voltage overhead lines. It prevents corrosion, as well.

Copper is much less affected by environmental corrosion than aluminium. In addition, if a coating is applied on each strand of the copper conductor, corrosion practically disappears.

ECONOMIC ANALYSIS

New lines with reduced life cycle cost (LCC). As mentioned, European grid regulators have a growing intention to reduce energy losses. Their focus is shifting from minimizing the investment cost of new lines to minimizing the entire LCC of the line. This LCC consists of five parts:

1. Towers and foundations (supply and install);
2. The conductor;
3. The stringing of the conductor;
4. Operational maintenance; and
5. Energy losses.

The DNV GL feasibility study calculated those five parts for several types of conductors and scenarios. In all scenarios, the energy losses represent the largest share of the LCC. Their share ranges between 40 and 80 percent, depending on the type of conductor, duration of the life cycle, load profile and electricity price.

Assume the following conditions:

- Load profile:
  - 100 percent of the load during 25 percent of the time;
  - 80 percent of the load during 20 percent of the time;
  - 40 percent of the load during 55 percent of the time.
- Electricity price: 5 cents per kWh
- Life cycle duration: 20 years

The CAC is some three times more expensive than the ACSR conductors, but the conductor price represents only a small share of the total LCC.

This higher investment cost is largely compensated for by the lower cost of energy losses (a reduction by at least 20 percent). As a result, the higher cost of the conductor is paid back in less than five years. The costs of stringing the conductor, of supplying and installing the towers, and of operational maintenance are of a similar order of magnitude for all three conductor types. The total LCC of the CAC is reduced by 14.3 percent compared with the ACSR Hawk.

Note that the energy losses in the conductor also can be reduced by increasing the cross section of the ACSR conductor, as is the case with the ACSR Eagle compared with the ACSR Hawk. The loss reduction, however, is not as substantial as with the CAC, and nearly all the investment gained this way is lost because of the higher cost of towers and tower foundations. The larger conductor cross section results in higher wind and ice loads, requiring tower reinforcements.

Taking all the advantages of the CAC into account, it proves particularly suitable for linking new large-scale wind power generation parks with the main grid.

First, an LCC philosophy normally is applied when assessing the economic feasibility of wind parks.

Second, the small cross section of the copper conductor make it a preferred choice in windy regions because it limits the wind load and avoids the need to reinforce the towers on the line.

Last, that copper conductors can be submitted to capacity overloads of up to 60 percent is a major advantage for transporting the variable output of the wind park to the main grid.

COMPETITIVE UPGRADE OF EXISTING LINES

For the refurbishment of an existing line with new conductors, the LCC consists only of four parts:

1. The conductor;
2. The stringing of the conductor;
3. Operational maintenance; and
4. Energy losses.

In a second study by DNV GL, this LCC for a line upgrade was calculated for different scenarios.

As could be expected, the energy losses represent an even larger share of the total LCC in the case of a new line, ranging between 85 and 95 percent, depending on the type of conductor, duration of the life cycle, load profile and electricity price.

Assume again the following conditions:

- Load profile:
  - 100 percent of the load during 25 percent of the time;
  - 80 percent of the load during 20 percent of the time;
  - 40 percent of the load during 55 percent of the time; and
- Electricity price: 5 cents per kWh; and
- Life cycle duration: 20 years.

The conductor losses of the CAC are more than 10 percent lower than those of the ACSS Hawk. As a result, although the initial investment is some 70 percent higher, the LCC of the refurbishment with copper conductor is 8.5 percent lower compared with the refurbishment with an ACSS Hawk conductor. Other conductor cross sections, load profiles, electricity prices and life cycle durations lead to slightly different results but with similar conclusions.

UNIQUE TECHNICAL SOLUTIONS

Advantage of a higher maximum operating temperature. One of the most interesting features of the CAC for overhead lines is the higher maximum operating temperature compared with ACSR conductors.

ACSR conductors have a maximum operating temperature of around 80 C to avoid excessive creep of the conductor material. Copper has a much higher temperature resistance against creep and can be heated to at least 150 C trouble-free.

Although the nominal capacity will keep the conductor temperature at 80 C, the cable can take occasional short-term overload currents without any danger or lasting implication. For instance, the ACSR Eagle aluminium conductor and the CAC 185 both have nominal currents of 700 A at 80 C. The ACSR Eagle conductor, however, cannot be overloaded to avoid higher temperatures but the CAC 185 can be loaded with up to 1115 A, heating the conductor up to 150 C. The latter corresponds with an overload of more than 60 percent.

Such an overload should be short-term because of the higher energy losses compared with the nominal situation, but it can help transmission network operators during emergency situations. For instance:

- Complying with the N-1 safety criteria. A network should be able to cope with the sudden breakdown of one line or power station without evolving into a blackout. In such a condition, other lines must take over the power that was transported over the line that broke down or other power stations farther from the centers of consumption must take over from the power station that broke down. In both cases, the functioning power lines receive additional power to create a new equilibrium.
- To ensure that in such a situation certain lines do not become overloaded and breakdown, new lines are built to provide spare capacity. Peak generation plants also are built to ensure local supply. In addition, phase-shift transformers are installed to direct the power toward lines with spare capacity. The use of CAC can

COPPER CONDUCTOR SAMPLES (SURFACE HYDROPHOBIC COATING IN VARIOUS COLORS) 4

avoid these kinds of investments.

- Transporting short-term peak productions from wind farms. What should be the capacity of transmission lines connecting remote wind farms with the grid? Such a wind farm will generate its maximum output only during a short time of the year. Is it economically worthwhile to choose the nominal capacity of the transmission line according to this maximum output? This dilemma can be solved using CACs. Although the nominal capacity of this line can be set at a lower value, it still will be able to supply the occasional maximum output to the grid. This can be crucial for ensuring the economic feasibility of a wind farm.

CAC offers an interesting alternative to steel reinforced aluminium conductors for high-voltage overhead lines.

BETTER PERFORMANCE IN EXTREME WEATHER

International standard EN 50341 – 1:2001 prescribes four categories of extreme weather conditions for which the performance of overhead lines should be tested:

- **LC 1a:** Extreme wind at design temperature (10 C);
- **LC 1b:** Wind at minimum temperature (minus 20 C);
- **LC 2c:** Unbalanced ice loads, different ice loads per span (minus 5 C); and
- **LC 3:** Combined wind and ice loads (minus 5 C).

CACs have an advantage over ACSR conductors in all four categories.

Thanks to the smaller diameter of the conductor, it will catch less wind.

Thanks to the high annealing temperature of copper, several types of coating can be applied on the conductor without a potential change of the material's mechanical properties.

Coating can make the conductor hydrophobic and significantly reduce the risk on ice load.

These characteristics make CAC particularly suitable for overhead lines in cold, humid and windy climates.

REDUCTION OF CORONA LOSSES

The Corona losses on high-voltage line conductors represent only a minor share of the energy losses, but they result in a noise many people find irritating.

Corona losses are particularly high in humid environments. Thanks to the high annealing temperature of copper, an anti-Corona coating can be applied on the CAC in an uncomplicated way, reducing the Corona losses to a level hardly perceived by the human ear.

This can be an important element for the acceptance of high-voltage overhead lines in densely populated areas in a humid climate.

CONCLUSION

CAC offers an interesting alternative to steel reinforced aluminium conductors for high-voltage overhead lines.

Although copper is heavier, the CAC does not require a reinforcement of the overhead line towers. Its mechanical strength makes a steel core superfluous.

More important, the smaller cross section combined with a hydrophobic coating result in a much lower wind and ice load, a decisive factor for determining required tower strength.

This makes the copper conductor particularly suitable for overhead lines in cold and windy climates.

The lower electrical resistance of copper combined with a reduced skin effect result in significantly lower energy losses compared with ACSR conductors.

Those energy losses compose the main part of the LCC, especially for the refurbishment of a line, but also for new lines.

Consequently, although the copper conductor requires a higher investment cost (some 70 percent), its LCC in many cases will drop beneath that of ACSR conductors.

One of the most interesting features of the CAC for overhead lines is the higher maximum operating temperature compared with ACSR conductors.

This makes it possible to charge the conductor with overloads of at least 60 percent without compromising the mechanical properties.

Such an overload should be short-term because of the much higher energy losses compared with the nominal situation, but it can help transmission network operators comply with the N-1 safety criteria and cope with short periods of high renewable energy production.

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