Temperature and frequency effects on cable resistance

Snapshots on multi-materials power cable linear resistance

INTRODUCTION

The influence of certain parameters is often better understood in the case of conductors consisting of single material. It becomes more complicated when the conductor consists of multiple materials. AESA Resistance bridges are integrated devices taking into account the common uncertainties of metrology. Questions occur regarding the simplifications introduced by the norms and are addressed here.

TEMPERATURE COEFFICIENT OF RESISTIVITY

Metal resistivity ρ varies essentially linearly with the temperature. The relation can be given as follow (linear approximation):

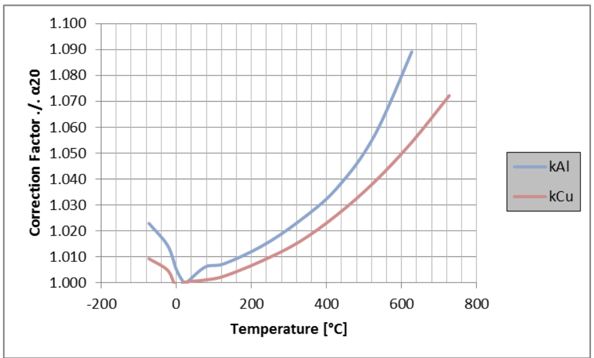
$$\rho(T) = \rho_0\big(1 + \alpha(T - T_0)\big)$$

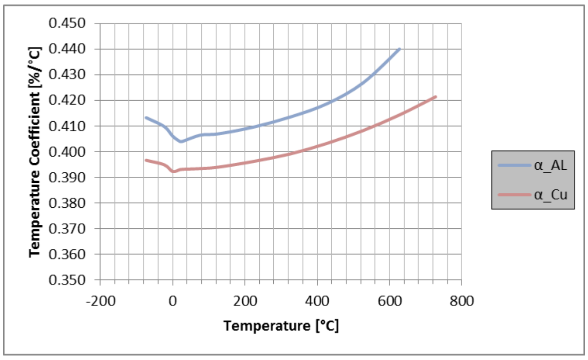
Where α is the temperature coefficient 1/°C and T_0 the temperature of reference. Usually this temperature is 20°C.

According to the norms IEC 60889 and 60028, the values generally admitted for the temperature coefficient α at 20 °C is 0.393 %/°C for copper and 0.403 %/°C for aluminium.

In reality, some linearity errors appear in particular at (very) low and high temperatures, where a correction is needed.

Knowing the resistivity ρ(T), it is then possible to determine the temperature coefficient in function of the temperature. The temperature correction factor k and the temperature coefficient α are given in the graphs below.





MULTI-METAL CONDUCTORS

In overhead lines (OHL), often utilized for long haul electricity distribution, aluminium tends to get preference for economic reasons. Because of its ductility, the cable is equipped with a core of different material to achieve the mandatory mechanical strength.

Different types of materials are used inside the core, like steel or composite. The most common material is steel (ACSR – steel-reinforced conductor). But more and more composite are used (ACCC – composite core conductor). The composite has the advantage of being lighter than steel.

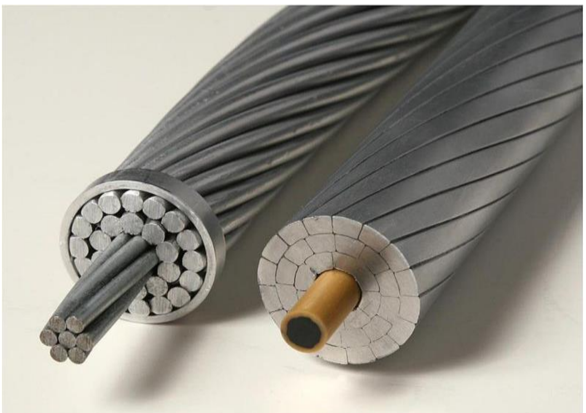


Figure 1 : Example of ACSR and ACCC Conductors

TEMPERATURE INFLUENCE ON DC RESISTANCE

AESA Cortaillod provides Resistance measuring bridges to measure the widest range of conductors including such power cables. The test systems are integrated, meaning they manage different uncertainty factors. One can thus introduce the temperature coefficient corresponding to the conductor under test.

What happen if the conductor is made with different materials like ACSR, copper-clad aluminium (CCA) and the like?

Let's take for example a conductor ACSR of 795 kcmil (400mm²) with the following structure:

- 7 wires of steel
- 54 wires of aluminium

Material	Section [mm²]	Resistivity [Ωm]
Aluminium	350	$2.653\ 10^{-8}$
Steel	50	$13.8\ 10^{-8}$

The linear resistance at 20°C is given by the formula:

$$\frac{R}{l} = \frac{\rho}{S}\left[\frac{\Omega}{m}\right]$$

We have for:

Aluminium	$R_{AL} = 75.8\,\mu\Omega/m$
Steel	$R_{ST} = 2.76\ m\Omega/m$

We can theoretically consider all wires to be in parallel, and thus these two resistances are in parallel. The resulting cable linear resistance is:

Cable	$R_{Cable} = 73.77\,\mu\Omega/m$

How will this linear resistance change with the temperature? Let's say at 30°C. The linear resistance of a cable is given by the following formula:

$$R(T) = R_0\big(1 + \alpha(T - T_0)\big)$$

Where R_0 is the linear resistance at the reference temperature T_0 (usually 20°C). If the cable would be of pure aluminium, the temperature coefficient of 0.403 %/°C (according to IEC 60889) would apply and the linear resistance would become:

Cable 100% Al at 30°C	$R_{Cable\ AL\ 30°} = 76.75\,\mu\Omega/m$

In reality, knowing that the temperature coefficient of steel is approximately 0.45 %/°C (according to IEC 60287), we obtain:

Aluminium at 30°C	$R_{AL\ 30°} = 78.85\,\mu\Omega/m$
Steel at 30°C	$R_{ST\ 30°} = 2.88\,m\Omega/m$

The cable linear resistance is:

Cable at 30°C	$R_{Cable\ 30°} = 76.76\ \mu\Omega/m$

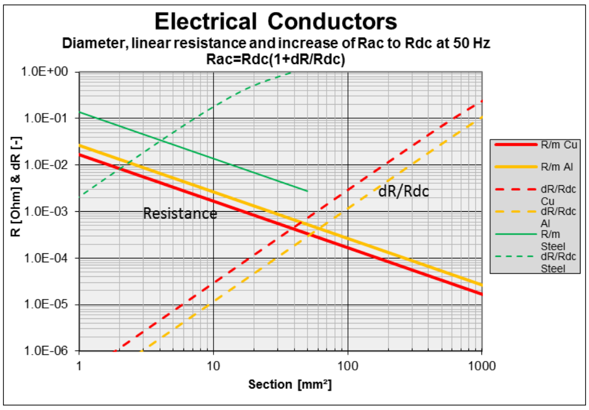
That means, by taking the aluminium temperature coefficient for both materials, we introduce an error of 0.01 %. Of course this result is dependent of the steel purity used as core, but moreover this calculation is related to the coefficient used. One find a wide range of different values depending of the sources, thus for steel, the temperature coefficient is given between 0.4 to 0.6 %/°C. But even with a temperature coefficient of 0.6 %/°C, the error will be at maximum 0.05 %. In most cases, including for Copper-Clad Aluminium (CCA), this simplification error will be negligible.

INFLUENCE ON AC RESISTANCE

At 50 Hz for example, due mostly to the skin effect (at high frequency, the current tends to flow only near the surface of the conductors), the linear resistance will increase more or less depending on the metal. In reality, we should also take into account the proximity effect due to the other wires in the conductor.

For conductors with combined material, in particular ACSR, this different behaviour may have to be taken into account in the evaluation of the linear resistance.

Let's take the same conductor as here above constituted by 7 mm² wires. The DC linear resistance at 20 °C is 73.77 µΩ/m.



The AC linear resistances at 20°C and 50 Hz are (according to IEC 60287):

Aluminium	$R_{AL\ DC} = 75.8\ \mu\Omega/m$	+1.4 %
	$R_{AL\ AC} = 76.87\ \mu\Omega/m$	
Steel	$R_{ST\ DC} = 2.76\ m\Omega/m$	+ 126%
	$R_{ST\ AC} = 6.24\ m\Omega/m$	

The conductor resulting AC linear resistance is:

Cable	$R_{Cable\ DC} = 73.77\ \mu\Omega/m$	+2.93 %
	$R_{Cable\ AC} = 75.93\ \mu\Omega/m$	

Neglecting the frequency influence produces an error of 2.93 [%] compare to the DC resistance. This result is valid if we consider the cable as a class 1 conductor. This hypothesis is correct for the Steel core as it would also be with Copper cable, but for aluminium, due to the oxide layer, we can consider that all wires are isolated from each other. Then the increase of the AC linear resistance $R_{AL\ AC}$ is only $6x10^{-6}$. So only the steel core will have an impact. The resulting AC linear resistance is 74.89 [μΩ/m], it means a difference of 1.51 [%] with the DC linear resistance. We see here the importance of the cable design on the resulting AC resistance.

CONCLUSION

The error on the DC resistance measurement of aluminium combined conductors (e.g. ACSR), using only the temperature coefficient of aluminium, is usually negligible. The error on the AC resistance measurement compare to the DC resistance is more strongly influenced by the construction of the conductor and the utilised material.

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References

- J. Phys. Chem. Ref. Data, Vol. 12, 1983
- Norms IEC 60028 / IEC 60287 / IEC 60889