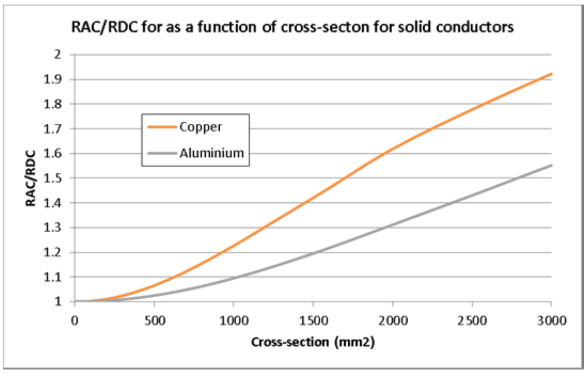
Challenges in the measurement of the AC linear resistance of electrical conductors

INTRODUCTION

With the soaring needs for electric power transportation capacities, the conductor cross-sections of power line have not ceased to increase over the last decades. This greatly impacts the sensitivity of the cable linear resistance to the skin effect present in alternative current (AC) conditions. As a consequence, measurement of the AC linear resistance of conductors is required to properly qualify large cross-section conductors.

STANDARDS

Linear conductor resistance is usually specified by its direct current (DC) value (IEC 60228) which is used to rate the maximal transmission ampacity. For large cross-section conductors (typically > 1000mm2), skin effect (i.e. the tendency of an electrical AC to become non-uniformly distributed within the conductor) at power frequencies of 50Hz or 60Hz becomes non-negligible and affects the maximal allowed transmitted power. Additionally, this transmitted power is limited by maximum operating temperature of the cable and hence directly related to Joule losses. For illustration, a plot of the ratio of AC to DC linear resistance as function of cross-section is shown below for solid conductor:



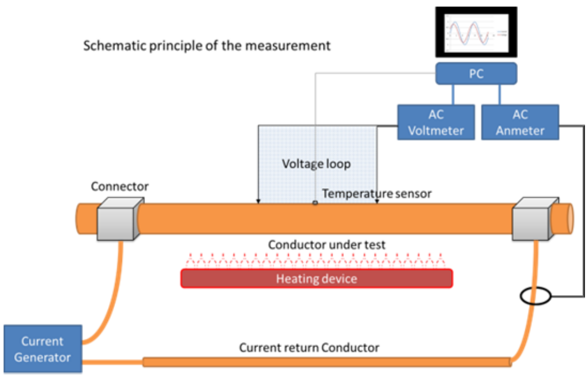
A four point bridge (Kelvin) method is traditionally used to measure the DC resistance, taking into account correction for temperature effects (variation of the resistivity of the material) and parasitic voltages as recommended in IEC 60468.

For AC measurements, the technical brochure of CIGRE TB272 indicates some potential approaches and defines a correction factor, k_s, that allow making an estimation of the AC resistance of a conductor given its DC value and its design.

Nevertheless, up to now, no standardized experimental method for measurement of AC linear resistance of conductors has been defined and a new CIGRE working group is presently preparing recommendations to carry that type of measurement. For information, this CIGRE working group is being chaired by AESA.

CHALLENGES

A schematic of the measurement principle is shown below:



Although similarities can be found with DC linear resistance measurements, such as an adequate electrical connection of the conductor to achieve steady current distribution, additional specific considerations are necessary for an accurate AC measurement, i.e. :

- Picking up the voltage at the surface of the conductor is not sufficient given that the generated magnetic fields around the conductor are part of the contribution to the voltage drop to be measured. An appropriate voltage loop or measurement method which picks up the electrical field generated by the conductor, but remains independent of external perturbations, has to be devised.
- Only the active power (and no the reactive power) must be considered and thus, phase difference, ϴ, between current and voltage has to be determined.
- The measured AC resistance depends on skin effect which in turns depends on the contact resistance between the wires forming the conductor, which further might, depending on the cable design, be affected by the mechanical strain on the conductor and thus, its temperature. Hence, temperature correction is not straightforward and measurement at high temperature (usually 90°C) is needed to assess the final ampacity of the electrical power line.

Moreover, the required size of the measuring apparatus will directly be impacted by the following considerations:

- The distribution of the measuring current through the cross-section of the conductor must be steady for an accurate measurement. This is usually achieved by measuring long lengths of conductor or/and by welding the connection for current injection. AESA is relying on its patented axial injection scheme to improve the distribution over a short length.
- The precision of the measurement is directly linked to the precision of the distance between the voltage taps. AESA experience with measurement using sharp knives placed 1m apart will help reduce the total length of the device
- Return current must be placed far apart of the cable under test to avoid EMC perturbations. Alternatively, a coaxial design has to be chosen, which basically makes the installation of the conductor, as well as the voltage taps difficult. AESA is working on an original proprietary configuration to considerably ease the positioning of both the conductor and the voltage taps, including thermometer.
- Measurement at high temperature will be affected by temperature gradient present at cable ends. A large conductor length would limit this effect if the complete system is not put in an oven.

The ergonomics of the apparatus which shall allow simple manipulations and provide fully temperature and parasitic voltage compensated results are part of AESA's targets in the development of a dedicated AC system. This system will follow the upcoming publication of the Technical Brochure of CIGRE about recommendations on AC measurement techniques.

The unquestioned experience of AESA in the DC linear resistance measurement of large conductors will help reaching the highest repeatability and accuracy, along with ease of use.

All the corrections needed for proper interpretations of the measurement will be directly integrated in a dedicated software.

The system will be sold as a new measurement apparatus. Services linked to AC resistance measurements (testing, calibration, training …) will also be proposed.

Boris Dardel, R&D Director, AESA Cortaillod