ADVANCED MEASUREMENT OF AC RESISTANCE ON SKIN-EFFECT REDUCED LARGE CONDUCTOR POWER CABLES

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ABSTRACT

The increasing demand for HV/EHV cables with very high ampacity results in conductors with large cross sections. Furthermore, cable conductor designs with low impact of skin effect become indispensable to minimize additional losses caused by the conductor AC resistance and/or to reduce the conductor cross section.

The measurement of the skin effect or AC resistance is difficult to apply on full size cables under practical conditions. At the moment, the relevant standard IEC 60228 gives no advice how to properly perform AC resistance measurements. To utilize the full abilities of reduced skin effect conductors and to ensure the quality during production well defined measuring techniques are needed, which should be easy to apply and deliver accurate as well as reproducible results.

This paper proposes an advanced but easy to handle measurement procedure to determine the AC resistance of conductors with large cross sections on production lengths of power cables.

KEYWORDS

XLPE cables, AC, alternating current, AC resistance, large conductors, skin effect, eddy current losses, k_s factor, Milliken, oxidized wires, enamelled wires

INTRODUCTION

The current rating of AC cables depends on the AC resistance of the conductor. The AC resistance R_{AC} is higher than the DC resistance R_{DC} due to the skin effect. The skin effect is based on the behaviour of the eddy current depth depending on frequency f, conductivity σ and permittivity μ and causes eddy current losses δ.

$$\delta = \frac{1}{\sqrt{\pi \ f \ \sigma \ \mu}} \qquad (1)$$

These AC losses, caused by the skin effect, can be reduced by the use of optimized conductors e.g. so called Milliken conductors having insulated conductor strands, oxidized or enamelled wires. Further more the construction of conductors in terms design, stranding direction of the segments and special manufacturing details are of great importance optimizing conductors in order to reduce AC losses [4-30].

The formulae to determine the AC resistance from the DC resistance are given in international standard 60287-1-1 [1]. They were extended to segmental conductors, introducing empirical coefficients from measurements performed on 1600mm² 4 segments oil-filled cables. For practical reason the physical behaviour is normative described by a so called skin effect factor y_s.

$$y_s = \frac{x_s^4}{192 + 0{,}8\, x_s^4} \qquad (2)$$

The formulae represent approximations of Bessel's functions and solving Maxwell's equation in solid round conductors. Formula (2) is valid in a range of $0 < x_s < 2.8$. The above formula is accurate providing x_s does not exceed 2.8:

$$x_s = \frac{8\pi f}{R_{DC}'(\upsilon)} 10^{-7} k_s \qquad (3).$$

Values for the k_s factor are given in Table 2 of the standard IEC 60287-1-1 [1].

For solid conductors with a circular cross section the skin effect factor y_s can exactly be calculated. The solution provides a k_s factor of 1 for solid conductors. Other k_s factors represent measures in order to reduce the skin effect.

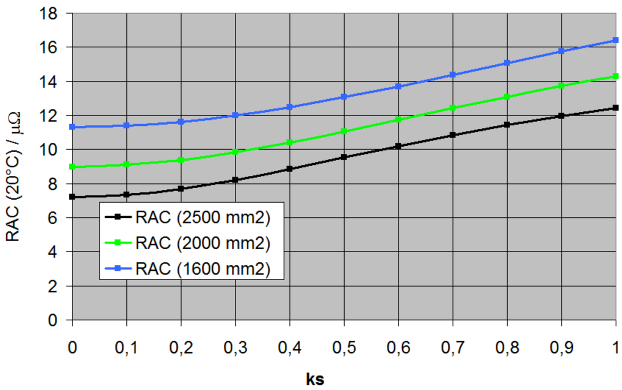

Fig. 1: Development of R_{AC}(20°C) for different conductor cross sections

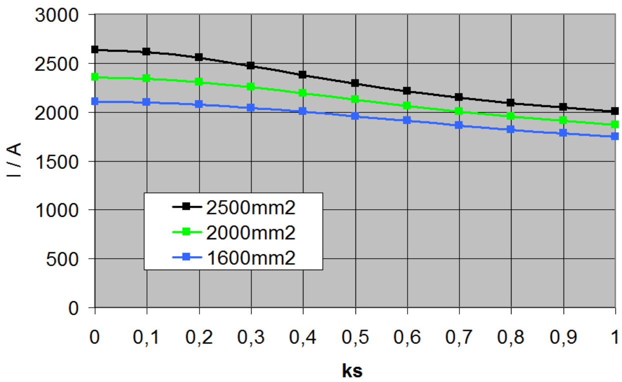

Fig. 2: Ampacity calculation: maximum current @ 50W/m conductor losses

The k_s factors becomes zero for f=0 representing DC current conditions.