Study of the behaviour of a n-metal cable screen subject to an adiabatic short-circuit

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ABSTRACT

This paper presents a method to calculate the effects of a short circuit under adiabatic conditions in a cable screen which is connected in parallel with other conductor components with close concentric geometry, such as metallic armours or metallic barriers for radial obturation.

KEYWORDS

Short-circuit calculation, cable screen, IEC 60949, cable design.

INTRODUCTION

The standard IEC 60949 *"Calculation of thermally permissible short-circuit currents, taking into account non-adiabatic heating effects"* considers only one current carrying component to determine the admissible fault current and duration for a given cable design, as can be seen in the expression found in its clause 3 (page 9 of the document). The Amendment 1 of this standard indicates the possibility of taking into account several carrying conductor components when they are connected in parallel, distributing the fault current among them in inverse proportion to their resistances.

This presents a problem whose resolution is not obvious, since components made of metals with different electrical resistivities, temperature coefficients and heat capacities will grow their respective temperatures and resistances at diverse rates. Consequently, during the fault time the proportion of current carried by each single component will be in constant evolution, leading the whole screen to a situation that will diverge from that obtained assuming fixed current ratios.

The lack of a clear procedure showing how this calculation should be made leads very frequently to dimension one of the components to withstand alone the entire fault current. This results into cables that are more expensive, and also a little heavier than necessary. Additionally, a design optimisation would reduce the power losses when the cables are installed in solid-bonding configurations, due to smaller induced currents in the screen.

This study first shows that the expression of the clause 3 of the standard can be deducted from physical laws. And then it proposes using the same physical laws to solve the case of several conductor components working in parallel. The result is an analytical expression whose exactitude has been checked with a numerical algorithm that generates a sequence whose limit is the exact solution of the problem. The equation found in the point 3 of the standard is a particular case of the solution of the "n-metal" problem.

The main limitation to this study is the assumption of concentricity between all the components involved in the calculation, so it should not be used for taking into account the common armour of three core cables, for instance. This is due to the fact that the mutual inductances between the conductor and the screen and other components connected in parallel have not been considered, and in an eccentric configuration they will not be compensated, thus altering the distribution of the current between the different metallic components.

EXPRESSION IN POINT 3 OF IEC 60949

The expression found in the standard for the calculation of the effects of an adiabatic short circuit on a single current carrying component can be deducted from physical laws.

Taking:

- The equation of the adiabatic rise of temperature in a conductor due to the Joule's law (energy balance):

$$I^2 R' = S \times 10^{-6} \times \sigma_c \frac{d\theta}{dt}$$

  where:
  - o t is the time (s)
  - o I is the short-circuit current (A)
  - o R' is the DC resistance per unit of length of the conductor component (Ω/m)
  - o S is the geometrical cross-sectional area of the conductor component (mm²).
  - o σ_c is the volumetric specific heat of the conductor component at 20°C (J/K·m³). It is assumed that this parameter do not experience relevant variations in the range of temperatures studied.
  - o θ is the temperature of the conductor component.
- The expression that links the resistance of a conductor component (per unit of length) with its temperature:

$$R' = \frac{\rho_{20} \frac{\theta + \beta}{20 + \beta}}{S \times 10^{-6}}$$

  where:
  - o ρ_{20} is the electrical resistivity of the conductor component at 20°C (Ω·m).
  - o β reciprocal of temperature coefficient of resistance of the conductor component at 0 °C (K).
- And the definition of the parameter K taken from point 3 of IEC 60949:

$$K = \sqrt{\frac{\sigma_c(\beta + 20) \times 10^{-12}}{\rho_{20}}}$$

A system of equations is obtained, and its solution is:

$$I_{AD}{}^2 t = K^2 S^2 \ln\left(\frac{\theta_f + \beta}{\theta_i + \beta}\right)$$