Evaluation of thermal resistances T3 and T4 for touching formations in IEC 60287-2-1

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ABSTRACT

The formulas in IEC for the external thermal resistance T_4 in touching formations should utilize the temperature contribution from adjacent cables, instead. The factor of 1.6 used for T_3 in trefoil formation should be unity. The grouping in IEC; metal sheathed/non-metal sheathed (= copper wire screen) is not a necessary condition.

In IEC, a discontinuity of T_4 exists when going from non-touching to touching formations. This discontinuity could be smoothed out by a "thermal proximity factor" for all type of configurations. Only the temperature contribution approach for all types of formations could then be used, making the thermal calculations improved.

KEYWORDS

jacket thermal resistance T_3, external thermal resistance, T_4, touching formations

INTRODUCTION

The standard IEC 60287-2-1[1] describes three ways of calculating the external thermal resistance T_4 for equally loaded cables in trefoil and flat formations:

1) Cables are *non-touching*
2) Cables are *touching*
   a. *Metal sheathed*
   b. *Non-metal sheathed (Cu-wire screen)*

The formulas for *non-touching* formations are easiest to understand since the related formulas are based on the temperature contribution from adjacent cables to the hottest cable in the formation. However, there are some conditions that must be fulfilled when utilizing the temperature contribution approach:

a) The metal sheath *and* the jacket of *hottest* cable in the configuration are *treated* as isotherms according to IEC,
b) the adjacent cables are *non-materialized,* i.e. they possess the same thermal properties as the surrounding soil,
c) the adjacent conductors are treated as line sources with a distance s to the hottest cable conductor.

Using the above conditions, it is quite straightforward to derive the formulas in IEC for *non-touching* formations. The basic approach is to calculate the external thermal resistance as:

$$T_4 = \underbrace{\frac{\rho_e}{2\pi} ln\left(u + \sqrt{u^2 - 1}\right)}_{T_{4-hottest}} + T_{4-mutual} \quad [1]$$

If $u > 10$ the ln -expression may be written as $ln(2u)$ where $u = \frac{2L}{D_e}$. It is also possible to calculate the temperatures individually in the actual formation since all cables (normally two or three) are treated as individuals with a unique location in the soil.

A soon as the distance s equals the diameter D_e, IEC uses the *touching* formation approach. However, there exists an unphysical discontinuity in the value of T_4 when going from infinitesimally separated cables to touching cable. The rationale for this discontinuity is not explicitly explained in IEC.

By using the touching formation approach in IEC, all cables in the formation are now *not* treated as individual cables, but rather as a *group* of cables, virtually placed at the same location in the soil, having a combined virtual diameter for all cables in the group.

The main reason behind, is most likely to average the effect that the heat flux from the conductors is not creating perfect isotherms, i.e. the cables in the same formation are thermally disturbing each other. The premise in IEC is though, that the metal sheath can be regarded as an isotherm. Our understanding of the meaning of IEC is for example that the calculation of T_1 for the insulation system, is not possible without accepting the metal sheath as an isotherm. But we will see that this is not a necessary condition for T_3 and T_4, either.

To summarize: the following conditions apply in IEC for metal sheathed cables in *touching* formations:

a) The metal sheath *only* must be treated as an isotherm, i.e., the metal sheath should have a *high* thermal conductivity,
b) two or three cables are positioned at the same location in soil. The *group* of cables have therefore the same (average) temperature.

In general, the formulas for *touching* formations in IEC 60287-2-1 [1] could be written as:

$$T_4 = n\frac{\rho_e}{2\pi}(ln(2u) - \delta) \quad [2]$$

The factor n may be either 2 or 3 for the number of cables and the factor δ depends on the formation selected:

- *trefoil* touching: $\delta = 0.630, n = 3$
- flat touching (*dual*): $\delta = 0.451, n = 2$
- flat touching (*triple*): $\delta = 0.760^1, n = 3$

)[1], Eq. (2) for triple formation is written in another form than in IEC. However, if writing the formula in the form of IEC the factor is 0.346. Thus, the formulas are equivalent if using 0.760 as above.

Note that for Eq. (2), the short-form of the ln -expression is used. Consequently, the touching formulas have some minor limitations on the factor u.

It will later be shown that the only formula of real significance to calculate the external thermal resistance T_4, is to use the temperature contribution approach in § 2.2.3.1 in IEC 60287[1], irrespective of if the cable are touching/non-touching or metal sheathed/non-metal