Electric Power Systems Research 133 (2016) 36–41

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Review of high current rating insulated cable solutions

Roberto Benato [a,*], Luigi Colla [b], Sebastian Dambone Sessa [a], Marco Marelli [b]

[a] *Department of Industrial Engineering, University of Padova, Via Gradenigo, 6/A, 35131 Padova, Italy*
[b] *Prysmian Power Link, Milan, Italy*

ARTICLE INFO

Article history:
Received 12 January 2015
Received in revised form 5 October 2015
Accepted 6 December 2015
Available online 5 January 2016

Keywords:
Insulated cables
Current ratings
Ampacity

ABSTRACT

Current rating computations for HV- and EHV-insulated cables play a crucial role in the planning phase of a new line for both an entirely underground cable link and a mixed or hybrid (cascade connection of overhead and cable line) one. The paper gives a wide overview of the technical solutions which allow very high current ratings in undergrounded insulated cables. These solutions are examined from a theoretical standpoint and practical applications are shown and explained. The paper demonstrates that in underground insulated cables, current rating up to 2500 A can be reached.

Contents

1. Introduction

Current rating computations for insulated cables play a crucial role in the planning phase of a new line for both an entirely underground cable link and a mixed or hybrid (cascade connection of overhead and cable line) one. MV and LV insulated cable current ratings are often given by manufacturer catalogues in terms of tables.

Electrical engineers using manufacturer catalogues are sometimes not aware of the computation complexity and hypotheses which lie beneath current rating values.

For HV and EHV levels, the current ratings ought to be computed on a case-by-case basis by means of suitable calculation methods as the one developed by Neher and McGrath [1] and subsequently adopted by IEC in the development of International Standards IEC 60287 [2].

The current ratings or current-carrying capacities (in American electrical jargon, the term is often substituted by ampacity which is the combination of ampere–capacity) depend not only upon the electrical and thermal parameters of the cable itself but also upon the thermal parameters of the soil where it is laid. It is well known

* Corresponding author. Tel.: +39 0498277532; fax: +39 0498277599.
E-mail addresses: roberto.benato@unipd.it, roberto.benato@dii.unipd.it (R. Benato).

http://dx.doi.org/10.1016/j.epsr.2015.12.005
0378-7796/

that the different thermal resistivities of the soil (chiefly depending upon the density and moisture content) may strongly vary along the route [3] and, unless there is an extensive measurement campaign, they cannot be known with great detail.

It is also worth remembering the uncertainties on the forecast of the soil temperatures, for both the environmental parameters variations and the possible presence of external heat sources nearby the route [4]. This justifies the fact that current rating of a cable is not a unique value but it is more properly a range as it is shown in the next section.

2. Current rating of a cable system

As already mentioned, the current rating of insulated cables is generally computed according to IEC 60287 series of standards [2]. By the method provided in this standard, the cable current rating is computed for the steady state continuous load.

It should be noted that underground cables are characterized by a high thermal time constant: this means in practice that an emergency overload lasting up to some hours may be tolerated (IEC standard 60853-2 provides a method for the calculation of the cyclic and emergency current rating of cables).

In practice, any current rating calculation by solving the heat balance equations involves the computation of the following quantities:

- Losses in the cable conductors, screens, armour and insulation;
- Thermal resistances of cable layers and surrounding environment.

The current rating is given by the well-known formula:

$$I_a = \sqrt{\frac{\Delta\vartheta - W_d \cdot [0.5 \cdot T_1 + n \cdot (T_2 + T_3 + T_4)]}{R \cdot T_1 + n \cdot R \cdot (1+\lambda_1) \cdot T_2 + n \cdot R \cdot (1+\lambda_1+\lambda_2) \cdot (T_3+T_4)}} \tag{1}$$

where,

$\Delta\vartheta$ is the conductor temperature rise above the ambient temperature (K);

R is the alternating current resistance per unit length of the conductor at maximum operating temperature (Ω/m);

W_d is the dielectric loss per unit length for the insulation surrounding the conductor (W/m);

T_1 is the thermal resistance per unit length between one conductor and the sheath (K m/W);

T_2 is the thermal resistance per unit length of the bedding between sheath and armour (K m/W);

T_3 is the thermal resistance per unit length of the external serving of the cable (K m/W);

T_4 is the thermal resistance per unit length between the cable surface and the surrounding medium (K m/W);n is the number of load-carrying conductors in the cable (conductors of equal size and carrying the same load);

λ_1 is the ratio of losses in the metal sheath to total losses in all conductors in that cable;

λ_2 is the ratio of losses in the armouring to total losses in all conductors in that cable.

By applying some simplifications (e.g., neglecting the dielectric losses, the temperature coefficient and λ_1, λ_2, which in order to get a first estimate could be acceptable for unarmoured single core cables with perfect cross-bonding of the metallic screens) and aggregations (e.g., $T_{eq} = T_1 + T_2 + T_3 + T_4$) it is possible to write (1) as in (2):

$$I_a = \sqrt{\frac{\Delta\vartheta S}{\rho_{20^\circ C} T_{eq}}} \tag{2}$$

where, more simply:

$\Delta\vartheta$ is always the conductor temperature rise above the ambient temperature (K);

S is the cable cross-section (mm^2);

$\rho_{20^\circ C}$ is the conductor electric resistivity at 20 °C (Ω mm^2/m);

T_{eq} is an equivalent thermal resistance including internal and external thermal resistances (i.e., $T_{eq} = T_1 + T_2 + T_3 + T_4$) (K m/W).

Eq. (2) is extremely useful in order to understand on which parameters the power system expert can act in order to increase the current ratings. In fact, strengthening and widening of transmission network might require insulated cable links with bulk power transmission capabilities. Therefore, cable systems with high current rating can be obtained by means of (with reference to (2)):

- reducing T_{eq}, i.e., by reducing the burial depth, by increasing the cable spacing, by using thermally controlled backfill with very low thermal resistivity or with natural or forced cooling;
- increasing S, i.e., by using a cross-section equal to 3250 mm^2;
- reducing R (which is held implicitly in (2) but explicitly in (1)), i.e., with the use of insulated wire Milliken-type conductor;
- increasing $\Delta\vartheta$, i.e., with the use of an insulation material with better thermal performances which can reach higher maximum operating temperature.

3. AC resistance in cable systems and current rating range

The main parameter affecting the losses in cable conductors is its AC resistance R which can be determined by means of analytical calculations, numerical computations or measurements. In fact, many construction parameters influence the AC conductor resistance R: conductor design, surface condition of the wires, compaction degree, strain due to mechanical assembling of the sectors, pressure on the conductor due to the insulation, etc. An exact analytical solution is fully applicable for solid cylindrical conductors and important developments have been recently achieved [5] for more complex designs. The complexity of the design implies the need to verify with experiments the applicability of calculation results.

By considering the influence of the R value in current rating calculation, the R measurement may justify a specific interest, especially for larger conductors. A method for AC resistance measurement has not been standardized yet. A method for the measurement of power cables AC resistance which was proposed in [6] and included in [7] has been in use for several years.

With regard to the computations, IEC 60287-1-1 [2] provides skin (k_s) and proximity effect (k_p) coefficients which can be used in cable current rating calculations. Such values allow determining the AC resistance value by means of:

$$R = R'(1 + y_s + y_p) \tag{3}$$

where, R' is the dc resistance of conductor at maximum operating temperature (Ω/m);y_s is the skin effect factor;y_p is the proximity effect factor.

It should be noted that values of k_s and k_p suggested in IEC 60287-1-1 for Milliken-type (or M-type) conductors apply to conductors having four segments and cross sectional areas lower than 1600 mm^2.

A very good work has been published by Cigré [7] with measured values which confirm that in some cases the value of k_s and k_p suggested in IEC are optimistic.

Table 1 reports the current ratings computed between 800 and 2500 mm^2 for copper single-core cross-bonded cables directly buried at a burial depth of 1.5 m in a soil with ρ_{th} = 1.0 K m/W and temperature equal to ϑ_g = 20 °C. The factors assumed in the computations of Table 1 are k_s = 0.435 and k_p = 0.37 which correspond to a