High Voltage Power Cable Current Ratings

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***Abstract* - Power cables are used for both ac and dc high voltage power transmission throughout the world. Technological advances, particularly those relating to jointing, has meant that cables can reliably be utilised at ever-increasing voltages and for a broader range of applications and installation conditions than ever before. A better understanding has been gained of the thermal behaviour of high voltage power cables, through application experience and development (which is ongoing) of better theoretical models, which has led to more accurate calculation of current ratings. This latter point is reflected by relatively recent amendments of the pre-eminent international standard on the topic which is International Electrical Commission (IEC) 60287.**

Accurate determination of cable ratings is important for providing an economical, functional and safe electrical design. The site specific installation conditions and conductor configurations of high voltage power cables have a most severe impact on their current rating. The required numerical calculations are complicated, thus it is imperative that engineers have access to versatile computer modelling tools so they may perform them with relative ease and confidence. For engineers employing computer modelling tools for these calculations, or even (perhaps especially) if they are not, it is important to understand and in turn be able to effectively manipulate and to even harness the effects of changes of the major factors on the current rating. It is the intention of the author of this paper to provide such a useful reference source on that basis.

***Index Terms*—Current rating, High voltage, Power cable, IEC Standard, Power engineering computing, CableCALC HV.**

I. INTRODUCTION

The current rating of cables is affected by the installation conditions and the cable design and materials. In this report a parametric study of the factors which affect current ratings is presented. All calculations are in accordance with the IEC 60287 and the Neher-McGrath methods. Modelling was performed using the commercially available software package called CableCALC High Voltage Tm (HV).

For cables in air the effect on the current rating of the following parameters is studied: conductor size, sheath bonding arrangement, enclosing in conduit, exposure to direct solar radiation and groups of cables.

For buried cables the effect on the current rating of the following parameters is studied: conductor size, soil dry-out, conductor material, sheath bonding arrangement, enclosing in conduit, phase separation, soil thermal resistivity, conduit size and soil ambient temperature.

CableCALC HV can be used to model cables from 400 V up to 500 kV (5 kV dc). In this study the cable modelled was extruded 11 kV cross-linked polyethylene (XLPE) insulated and screened. The fundamental principles demonstrated in this parametric study apply for power cables of any ac voltage level.

The calculated current ratings have been compared with and validated by those published by the cable manufacturer [5].

II. COMMON PARAMETERS

The following common parameters are used for modelling of the cables:

Load factor = 1.0
Ambient air temperature = 40 ˚C
Ambient soil temperature = 25 ˚C
Maximum conductor temperature = 90 ˚C
Depth of burial = 0.8 m
Native soil thermal resistivity = 1.2 ˚C.m/W
Dry soil thermal resistivity = 2.5 ˚C.m/W
Cable sheath solar absorption coeff. = 0.8
PVC conduit thermal resistance = 6 ˚C.m/W
Metal conduit thermal resistance = 0 ˚C.m/W

The details for the 11 kV cable used in the parametric study are included in the Appendix.

III. CABLES IN AIR

A. *Varying conductor sizes*

The conductor size has been varied from 35 mm^2 up to 500 mm^2. Cables are modelled as installed spaced from a wall on tray in trefoil arrangement.

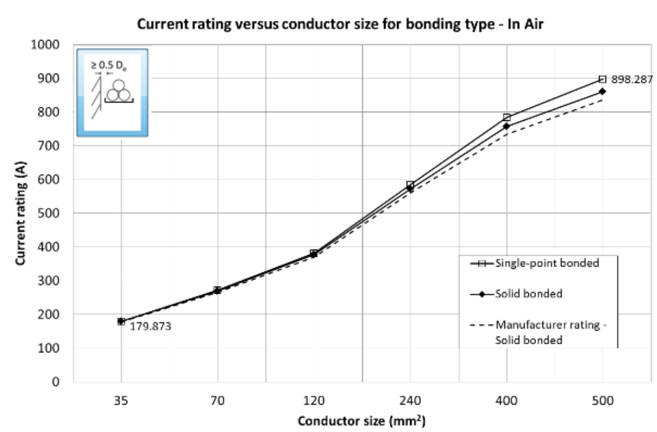

Fig. 1, Current rating vs conductor size – cables in air.

Fig. 1, shows current rating increases with an increase in conductor size. The dc resistance of a conductor is inversely proportional to conductor size; however, doubling of the conductor size does not double the current rating. This is because for ac currents the contribution of the skin and proximity affect is proportional to conductor size and especially for large conductors is significant.

The larger the conductor size the larger the circulating current losses (significant for solidly bonded cables) and eddy current losses (significant for single-point bonded cables) in the metallic sheaths and screens. Circulating current losses are generally much larger than eddy current losses hence the current rating for solidly bonded cables is lower than for single-point bonded cables.

B. *Enclosed in conduits in air*

The current rating of cables installed in air enclosed in conduits is reduced compared with those which are unenclosed. This can be seen by comparing Fig. 2 with the previous Fig. 1 and is caused by the added thermal resistance of the conduit wall and the raised temperature of the enclosed air.

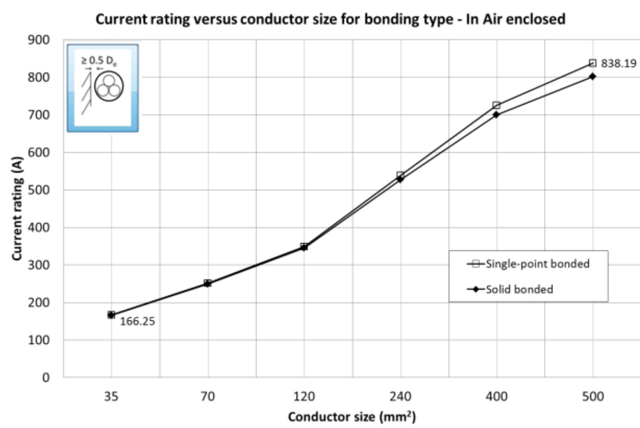

Fig. 2, Current rating vs conductor size for bonding type – cables in air enclosed in conduits.

C. *Exposed to direct solar radiation*

Exposure to direct solar radiation increases the temperature and hence reduces the current rating of cables installed in air. Fig. 3 shows that the current rating is reduced more for larger (greater surface area) cables than smaller (less surface area) cables.

The solar radiation intensity depends on the geographical location (latitude and longitude) and the day of the year and hour of the day. The surface absorption coefficient depends on the material type of the outer cable sheath.

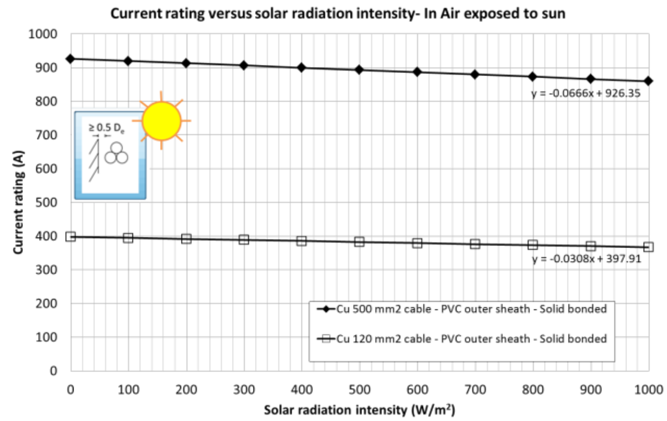

Fig. 3, Current rating of 120 mm^2 and 500 mm^2 cables exposed to varying solar radiation intensity.

D. *Groups of cables*

When cables are installed in groups as shown in Fig. 4 the rating of the hottest cable will be lower than in the case when the same cable is installed in isolation. This reduction is caused by mutual heating.

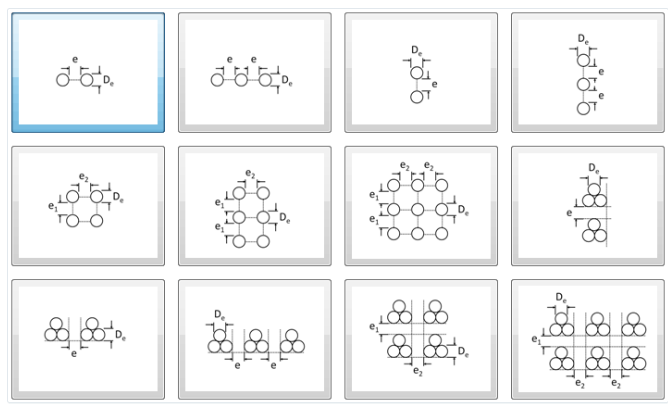

Fig. 4, Cables installed in groups – standardised arrangements as defined in IEC 60287-2-2 [3].

The effects of grouping on current ratings are dependent on the ratio of the cable diameter (D_e) and the separation between circuits (e). If the separation between groups exceeds the critical ratio of e/De then the thermal proximity effects which cause de-rating of the circuits can be neglected.

Fig. 5 depicts the relationship between separation of groups and current rating.

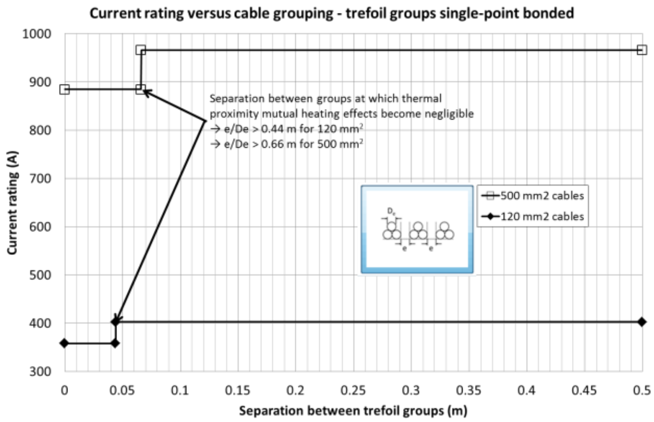

Fig. 5, Current rating vs separation between trefoil groups.

IV. Buried Cables

A. *Varying conductor sizes and soil dry-out*

The conductor size has been varied from 35 mm^2 up to 500 mm^2. Cables are modelled as direct buried in flat and touching arrangement. Fig. 6 shows the current rating for buried cables is lower than for cables in air.

Soil thermal resistivity is not constant and is highly dependent on soil moisture content. As soil heats up from the presence of cables then moisture may tend to migrate away from the cable surface. A dried-out zone of soil can develop around the cables in which the thermal resistivity is increased. This in turn tends to increase the temperature of the cables which reduces their ratings.

The significant effect of moisture migration on cable ratings as shown in Fig. 6 are quantified by a two-zone model for the soil surrounding loaded cables [4]. The concept of the model is summarised as follows. Moist (native) soil is assumed to have a uniform thermal resistivity; however if the heat dissipated from a loaded cable and its surface temperature are raised above a certain critical temperature then the soil immediately surrounding the cable will dry out resulting in a zone which is assumed to have a higher uniform thermal resistivity.

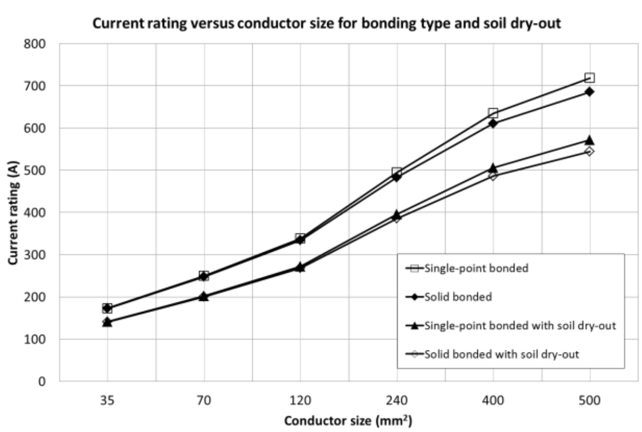

Fig. 6, Current rating vs conductor size – cables direct buried.

B. *Conductor material*

The resistance of aluminium conductors is greater than the equivalent sized copper conductors hence the current rating is lower as shown in Fig. 7.

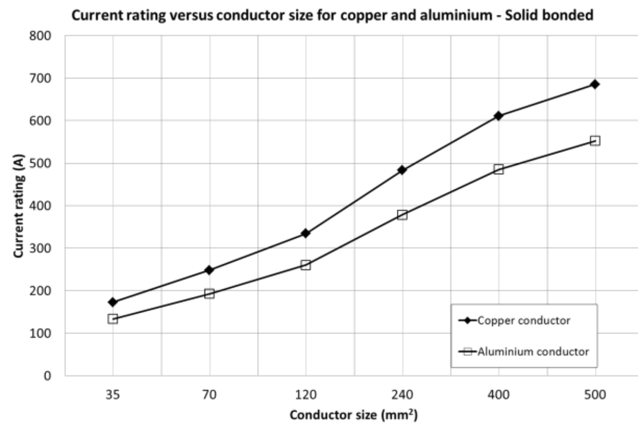

Fig. 7, Current rating vs conductor size for copper and aluminium conductors – cables direct buried.

C. *Soil thermal resistivity*

The thermal resistivity of the native soil for direct buried cables laid in flat and touching arrangement was varied from 0.4 up to 4.0 ˚C.m/W.

Fig. 8 shows the current rating of cables is highly dependent on and reduces significantly (more for larger cables) with increasing soil thermal resistivity and follows a hyperbolic function.

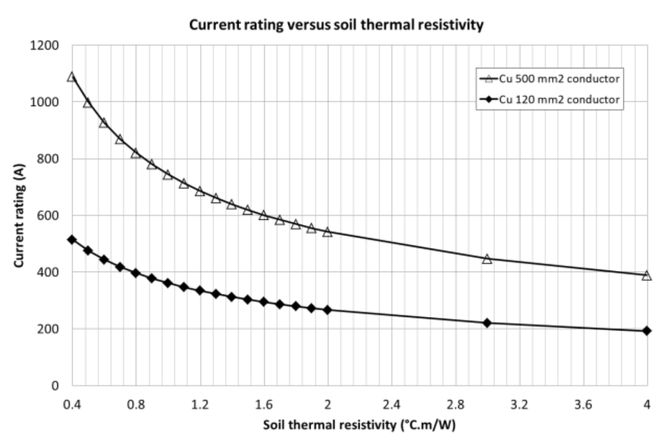

Fig. 8, Current rating vs native soil thermal resistivity.

D. *Spacing between phases*

Fig. 9 shows that as the spacing between phases is increased the current rating also increases. This is due to a reduction in the mutual heating affects between phases.

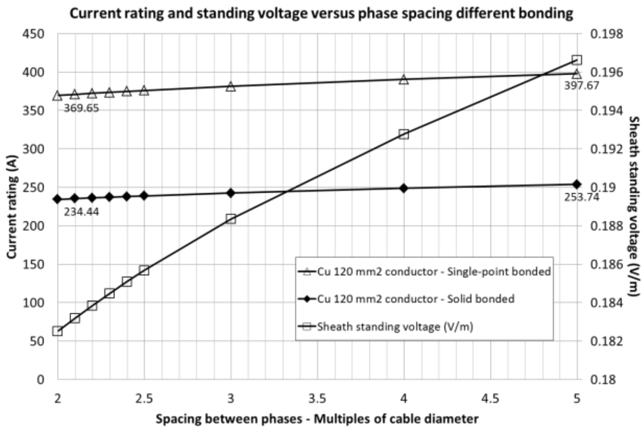

Fig. 9, Current rating and sheath standing voltage (single-point bonded cables) vs spacing between phases.

Increasing the phase spacing has the following effects:

Single-point bonded cables – current rating increases often significantly; and sheath standing voltage is increased due to increased mutual inductances between sheath and conductor.

Solid bonded cables – current rating reduces due to increased circulating currents. This occurs while effect of increased circulating currents is greater than the reduction of mutual heating. However, there is a point where the effect of increased circulating currents becomes less than the reduction of mutual heating effects and the current rating slightly increases.

E. *Conduit size*

The diameter of conduit for cables buried in native soil in combined conduits was varied from a tight fit up to a very large size.

Fig. 10 shows that current rating increases with conduit internal diameter. Also because the thermal resistivity of the metal conduits is relatively so much less than that of PVC conduits the current rating of cables installed in metal conduits is greater.

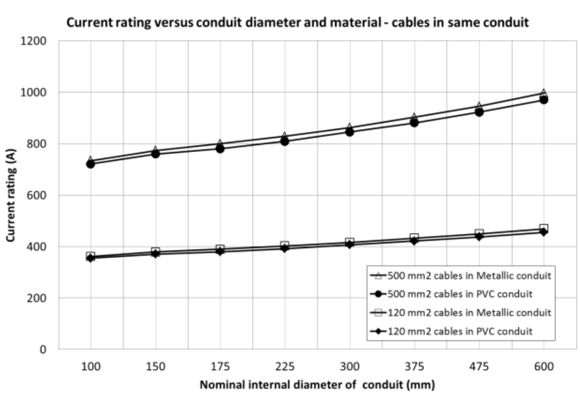

Fig. 10, Current rating vs conduit diameter.

F. *Ambient soil temperature*

The ambient soil temperature affects the cable rating and is dependent on climatic factors as well as installation specific factors. The ambient soil temperature can either be measured or taken from relevant meteorological data sources. Applicable national or international standards often explicitly state the ambient soil temperature at which cable ratings shall be calculated. Fig. 11 shows that as soil ambient temperature goes up cable current rating goes down linearly. The drop in current rating is greater for larger cables due to surface area than it is for smaller cables.

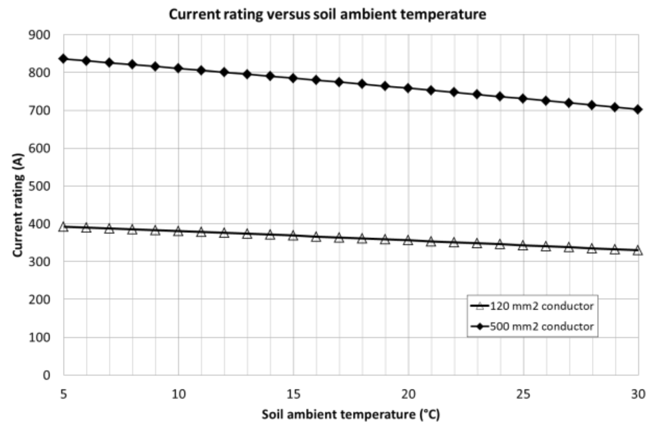

Fig. 11, Current rating vs soil ambient temperature.

It is often commercially advantageous, particularly when burying cables at depths greater than 1 metre, to consider and to propose to your client to use expected soil ambient temperature and not a conservative value such as 25 °C from the standards.

The expected average soil ambient temperature can be calculated based on the following data:

1. Annual average temperature.
2. Maximum annual temperature variation from average.
3. Soil thermal diffusivity (inertia).
4. Time of year.
5. Depth of burial.

Example, for a particular installation in a moderate climate the average annual temperature is 12 ˚C and the maximum temperature is 35 ˚C. Therefore the maximum annual temperature variation is 23 ˚C. The soil composition resembles wet sand hence the soil thermal diffusivity is 0.01 cm^2/s. The anticipated depth of burial of cables is 1 metre.

Fig. 12 shows that during summer at a depth of 1 metre the soil temperature is 21.64 ˚C. As can be seen, as depth of burial approaches infinity the soil ambient temperature approaches average ambient temperature.

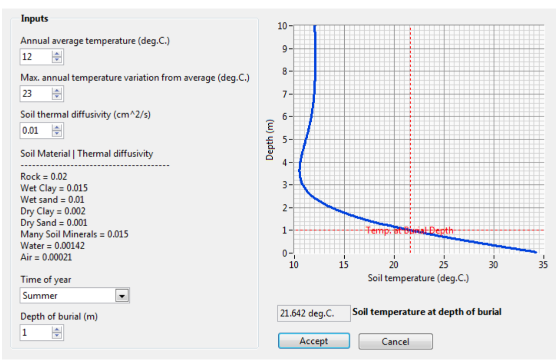

Fig. 12, Calculation of soil ambient temperature at a particular depth and time of year.

V. Conclusions

Accurate determination of cable ratings and performance is important for providing an economical, functional and safe design.

Access to powerful and insightful software tools for performing power cable rating calculations is useful.

A. *Cables in air*

The size and material of the conductor significantly affects current rating as well as the sheath bonding arrangement. The current rating of cables in air which are enclosed in conduits, in close proximity to other groups of cables or exposed to direct solar radiation are affected.

B. *Buried cables*

Again, the size and material of the conductor significantly affects current rating as well as the sheath bonding arrangement. The soil resistivity and soil ambient temperature both have a major effect on current ratings. To a lesser degree spacing between phases of buried single core cables affects current rating. For single-point bonded cables phase spacing affects the sheath standing voltage which is an important safety-related aspect in the design.

VI. References

[1] IEC 60287-1-1 Electric cables – Calculation of the current rating – Part 1-1: Current rating equations (100 % load factor) and calculation of losses – General

[2] IEC 60287-2-1 Electric cables – Calculation of the current rating – Part 2-1: Calculation of thermal resistance.

[3] IEC 60287-2-2 Electrical cables – calculation of the current rating Part 2-2: Thermal resistance – A method for calculating reduction factors for groups of cables in free air, protected from solar radiation.

[4] J.H. Neher and M.H. McGrath, “Calculation of the Temperature Rise and Load Capability of Cable Systems”, AIEE Transactions Part III – Power Apparatus and Systems, Vol. 76, October 1957, pp. 752-772.

[5] Olex High Voltage Cables Catalogue

VII. Appendix – Cable Data

Cable dimensions are required for modelling in CableCALC HV software. The following cable data was taken from the Olex HV cable catalogue [5].

Description:
6.35/11 kV Single Core Screened and PVC Sheathed.
Conductor material: Stranded copper or Aluminium

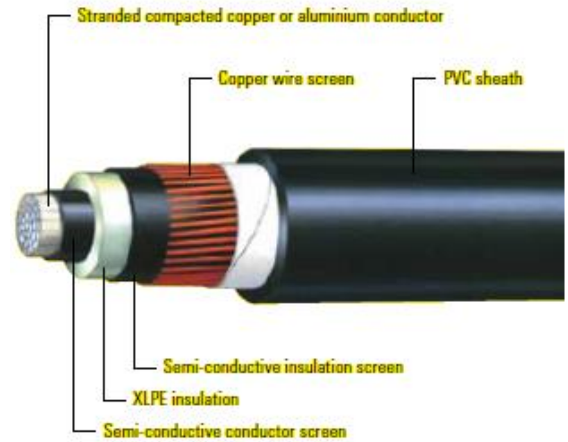

Fig. 13, Cross-sectional view of 11 kV cable modelled.

Table 1. Cable dimensions for modelling of Cu 120 mm^2 cable

Cable dimension (mm)	Value
Nominal conductor diameter	13.10
Conductor screen thickness	0.55
Insulation thickness	3.40
Semi-conductive insulation screen thickness	0.80
Copper screen wire thickness	1.35
PVC sheath thickness	2.05

Table 2. Cable dimensions for modelling of Cu 500 mm^2 cable

Cable dimension (mm)	Value
Nominal conductor diameter	26.50
Conductor screen thickness	0.70
Insulation thickness	3.40
Semi-conductive insulation screen thickness	0.90
Copper screen wire thickness	1.35
PVC sheath thickness	2.55