Factors Affecting Current Ratings for Underground and Air Cables

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***Abstract*—**The aim of this paper is to present a parametric study to determine the major factors that influence the calculations of current rating for both air and underground cables. The current carrying capability of the power cables rely largely on the installation conditions and material properties. In this work, the influences on ampacity of conductor size, soil thermal resistivity and ambient soil temperature for underground installations are shown. The influences on the current-carrying capacity of solar heating (time of day effects and intensity of solar radiation), ambient air temperature and cable size for cables air are also presented. IEC and IEEE standards are taken as reference.

***Keywords*—**Cable ampacity, underground cable, IEC standard, air cables.

I. Introduction

THE current ratings of power cables are primarily affected by the installation conditions, material characteristics and cable design.

In this work, a parametric study of the factors that affect the current carrying capacity is shown. All calculations are based on the IEC standard, and this standard consisted of several parts as shown in [1]-[7]. For buried cables, IEEE standard 835-1994 [8] presents comparable results for the IEC standards. For the air cables, the difference between IEC standard and IEEE standard is more noticeable. At the same time, both IEEE standard and IEC standard depend on the Neher-McGrath method [9].

The effects of the following parameters on the current carrying capacity of air cables are studied: Solar radiation's intensity, time of day effects, the surrounding air temperature, the size of cable, and groups of cables. Similarly, the effects of the following parameters on the current carrying capacity of buried cables are studied: The type of conductor (copper or aluminum), native soil's thermal resistivity, size of the conduit, surrounding temperature, size of the cable, dry zone and bonding type.

This paper aims to focus on the numerical technique for ampacity computation. All simulations were carried out using ETAP program to calculate the ampacity.

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II. Common Parameters

The following assumptions have been applied for calculations:

- Ambient air temperature is 45 °C
- Burial depth is 1 m
- Max. Conductor temperature is 90 °C
- Ambient soil temperature is 30 °C
- Thermal resistivity for the native soil is 1.2 °C.m/W
- Thermal resistivity for the dry soil is 3 °C.m/W
- Thermal resistance for the PVC conduit is 6 °C.m/W
- Thermal resistance for the metal conduit is 0 °C.m/W
- Solar absorption coefficient for the cable sheath (σ) is 0.8
- Solar heating is 'ON'
- Time of day is 12.00 AM
- The season type is summer
- All cases are balanced
- Load factor is 1
- Diffusion of solar radiation is 'OFF'

The appendix displays all the details regarding installations and cables used for the parametric study.

III. Air Cables

A. Conductor Sizes Effects

The conductor sizes have been varied for a wide range from 50 to 500 mm^2. Cables are installed and spaced from a wall on a tray in trefoil formation.

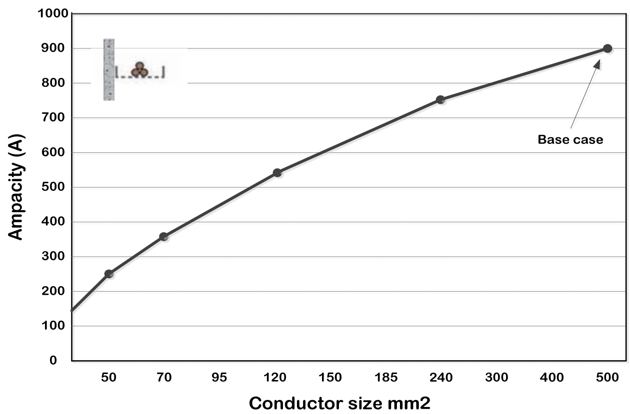

Fig. 1 Ampacity ratings verses conductor size for air cables.

As seen in Fig. 1, the ampacity (or current carrying capacity) increases with increases in the size of the conductor. Furthermore, the proximity and skin effects of alternating currents contribute to the resistance of the conductor resistance, especially for large conductors where these effects are crucial. Moreover, single-point bonded and two-point bonded cables are greatly affected by both the eddy and the circulating currents.

B. Solar Radiation Intensity Effects

Exposure to direct solar radiation leads to increments in temperature and thus reduces the current carrying capacity of cables installed in air. In addition to that, solar intensity relies on the geographical location (that is latitude and longitude). In other words, according to IEEE standard, the intensity of sunlight relies on the type of atmosphere.

TABLE I
INFLUENCE OF SOLAR RADIATION INTENSITY ON AMPACITY WHEN SURFACE ABSORPTION COEFFICIENT IS 0.8

Conditions of the Sun	Ampacity (A)
SUN ON	882
SUN OFF	955

Table I shows that the current carrying capacity (ampacity) is reduced in the presence of sun heating. Furthermore, it is noticed that the surface absorption coefficient for not shaded installation relies on the material type for the outer sheath of the cable.

C. The Time of Day Effects

The position of the sun is a function of the solar deflection, which is based on the height of the sun is based on the day of the year, the hour angle of the sun is based on the time of day, and latitude and longitude. Along with, the time period applied to locate the position of the sun during the day is set between (10:00 AM to 2:00 PM) according to IEEE. However, the time of day has less of an effect on the solar intensity, which means that the impact on the current carrying capacity is also less (as presented in Fig. 2). Thus, the impact on the current rating was observed to be only about 26 Amperes.

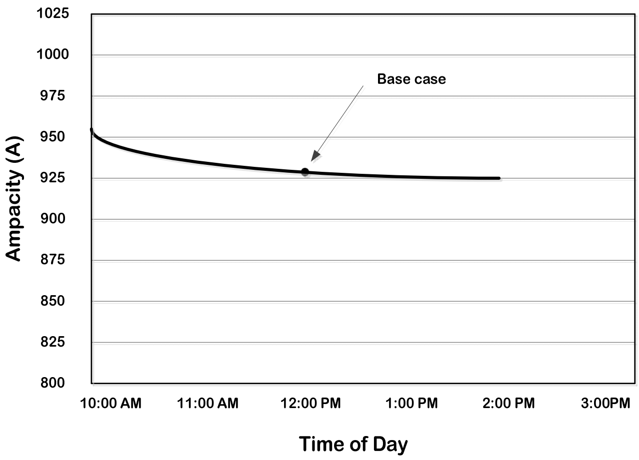

Fig. 2 Ampacity ratings verses the time of day

D. Ambient Air Temperature Effects

To determine the current carrying capacity, the air temperature factor plays a major role, especially for air cables. This factor is primarily considered in both IEC and IEEE standards.

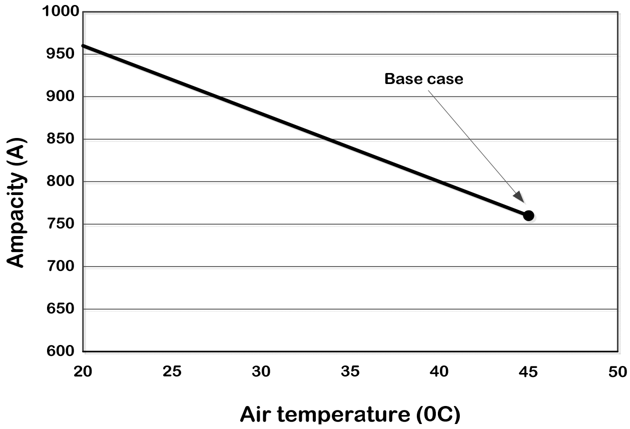

Fig. 3 Ampacity ratings verses air temperature

The influence of air temperature on the ampacity ratings is shown in Fig. 3. It can be observed that with increase in air temperature, the current carrying capacity reduces almost linearly. Furthermore, it is also noticed that the relation curve appears to a line with fixed slope.

E. Enclosed in Conduit

The current-carrying capacity of the cables installed in the air enclosed inside a conduit is lower compared to those without conduit as shown in Fig. 4.

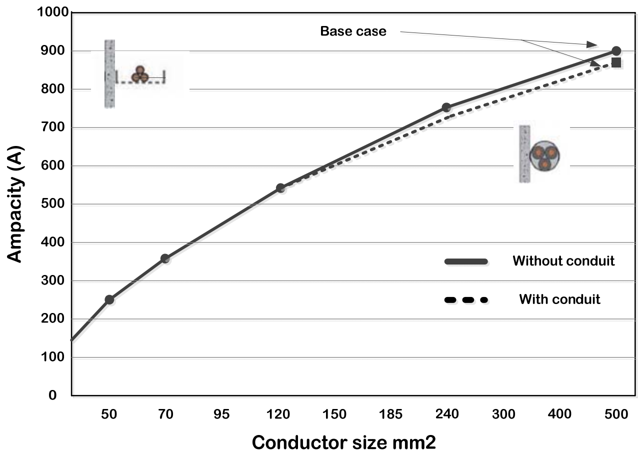

Fig. 4 Ampacity ratings verses conductor size for both cables (with and without conduit)

It is noticed that ampacity ratings of the cables inside conduit reduce more than ampacity ratings of the cables without conduit. It is also noticed that decreases in the ampacity are caused by the added thermal resistance of the conduit wall and the raised temperature of the enclosed air. One can see that large cable sizes have a strong influence on the ampacity ratings.

F. Groups of Cables

As seen in Fig. 5, cables are generally installed in groups. The hottest cable's current carrying capacity will be lesser than the same cable installed in isolation. This decrease is attributed to the mutual heating mechanism.

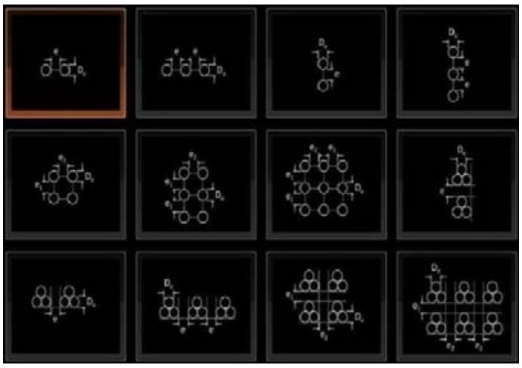

Fig. 5 Standardized arrangement of cables

The influences of grouping on the current carrying capacities are based on the ratio of the cable diameter (D) as well as the distance between circuits (e). If the distance between groups overrides the critical ratio of e/De then the thermal proximity effect, which causes correcting of the circuit, can be ignored. The relationship between ampacity ratings and distance of groups is shown in Fig. 6.

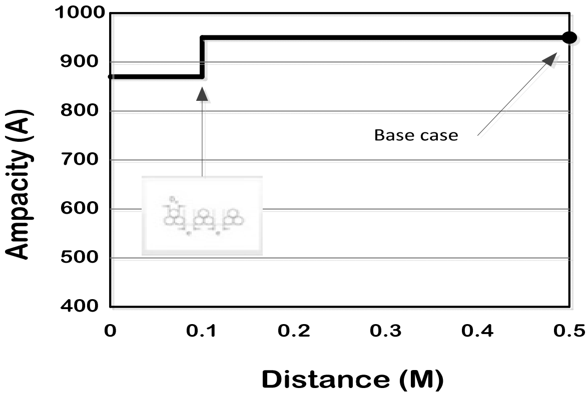

Fig. 6 Ampacity ratings verses distance between trefoils

G. Wind Speed Effects

Wind speed is a crucial factor that affects the current carrying capacity determination. The relationship between the ampacity rating and wind speed is shown in Fig. 7.

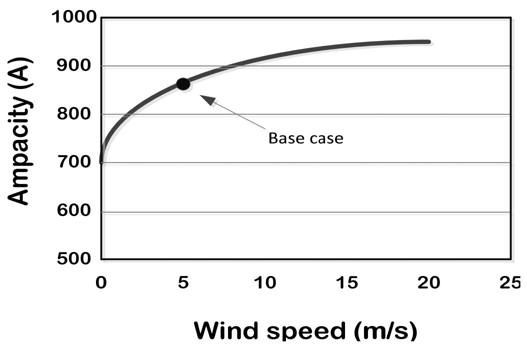

Fig. 7 Ampacity rating verses wind speed

It is observed that with the rise in wind speeds, the ampacity rating also increases. The rise in the wind speed between 0 and 5 m/s has a major influence on the ampacity rating.

IV. Buried Cables

A. Surrounding Soil Temperature

For buried cables, the surrounding soil temperature is a major factor that affects the ampacity ratings. Seasonal changes usually determine the surrounding soil temperature. Measuring devices are employed to determine soil temperature around the cable. This can also be achieved by taking meteorological data from relevant sources. Applicable international standards are employed to determine the surrounding soil temperature for calculating cable ratings.

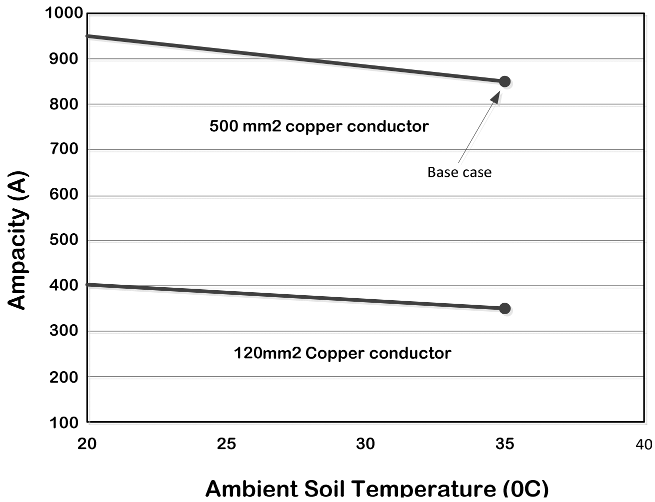

Fig. 8 Ampacity ratings verses ambient soil temperature

Fig. 8 shows that the rise in the surrounding soil temperature reduces the current carrying capacity in a nearly linear manner. It can be observed that the decrease in the ampacity rating for large cables is more than small cables because of the surface area for the large cables.

The surrounding soil temperature can be computed based on the following data.

- Burial depth
- Diffusivity of soil
- Annual average temperature
- Maximum seasonal temperature (or annual)
- Time of year.

B. Soil Thermal Resistivity

In the case of underground cables, the native soil's thermal resistivity is the most important factor that can influence the ampacity ratings. For the cables installed in flat and touching arrangement Thermal resistivity of the soil was varied from 0.4 to 4.0 (^{0}K-M/W).

Fig. 9 shows that the increase in thermal resistivity of the native soil considerably reduces the current carrying capacity (or ampacity). It is also observed that the soil thermal resistivity has a similar property of hyperbolic function.

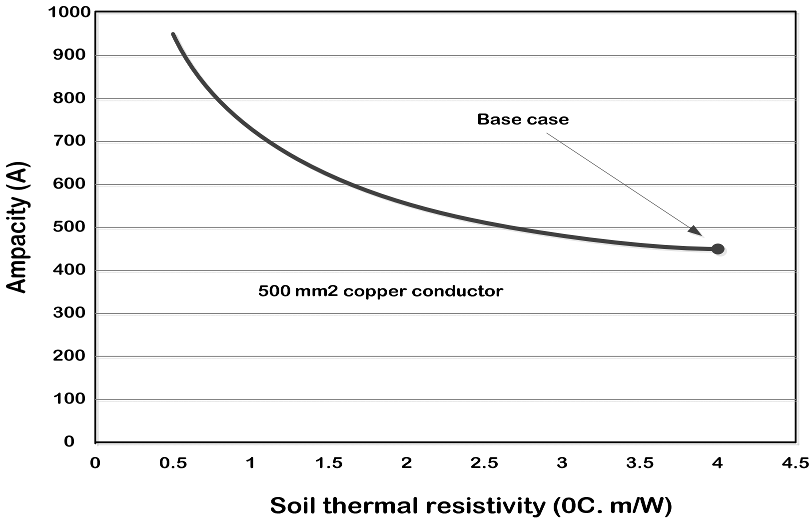

Fig. 9 Ampacity rating verses soil thermal resistivity

C. Depth of Burial

Thermal resistance impact for the soil surrounding around the cable usually increases with increasing the burial depth. And thus, the current carrying capacity (ampacity) reduces as the cable is buried deeper in the soil.

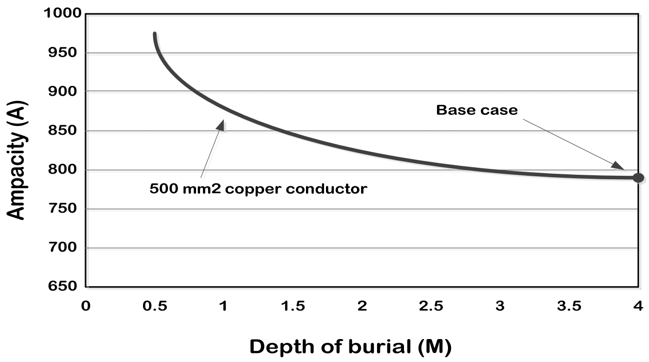

Fig. 10 Ampacity rating verses depth of burial

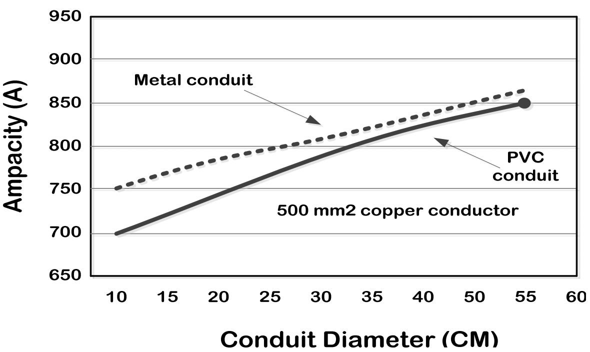

Fig. 11 Ampacity rating verses conduit diameter

Fig. 10 shows that the current carrying capacity decreases with increasing depth of burial as expected. One can see that cables buried at greater depths have a major effect on the ampacity rating of the cable.

D. Conduit Size

The diameter of the conduit varied from narrow to large sizes with cables installed inside the conduit in the native soil.

As shown in Fig. 11, the increase in internal diameter of the conduit led to the rise in the current carrying capacity of cables. It was found that a PVC conduit had a greater impact on the ampacity rating when compared with metal conduit.

E. Conductor Material

Usually, aluminum conductors have a greater resistance than copper conductors. Therefore, the ampacity ratings of aluminum conductors are generally lower as shown in Fig. 12.

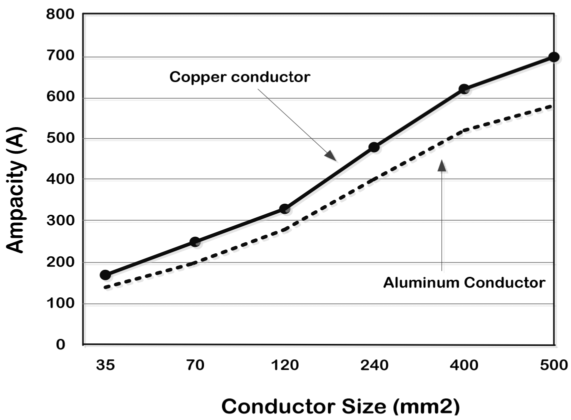

Fig. 12 Ampacity rating verses conductor size for both (aluminum and copper conductors)

F. Spacing between Phases

Fig. 13 demonstrates that the spacing between phases increases with the ampacity rating. The reason is that mutual heating effect between phases is reduced.

Increasing the spacing between phases has the following positive and negative effects: In the case of single-point bonded cables, a substantial increase in the current carrying capacity could be seen. At the same time, the sheath standing voltage also increased due to the rise in mutual inductances between the sheath layer and conductors.

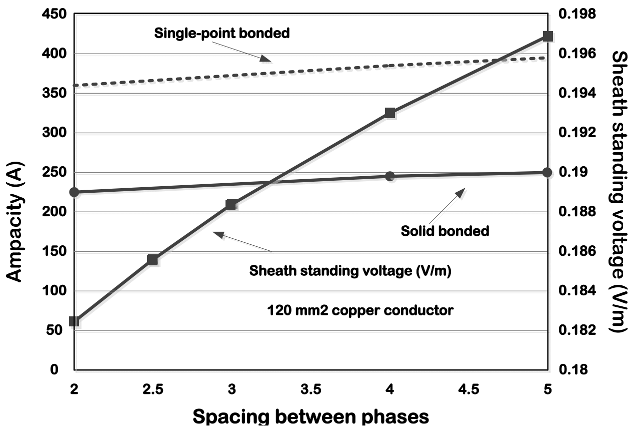

Fig. 13 Ampacity rating and sheath standing voltage vs. spacing between phases

For Solid bonded cables – the current carrying capacity decreased because of increased circulating currents. This happens when the influence of increased circulating currents is larger than the reduction of mutual heating. However, there is a point where the influence of increased circulating currents becomes lower than the reduction of mutual heating effects and the ampacity slightly increases.

G. Varying Cable Size with Soil Dry-Out

Cross-sectional area for the conductor sizes varied from 50 mm^2 to 500 mm^2 using 3-flat directly buried cables in the native soil.

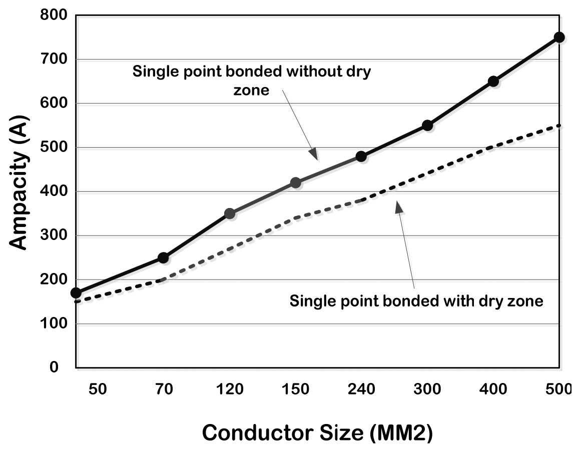

Fig. 14 Ampacity rating verses conductor size (before and after dry zone)

Fig. 14 presents the complex impact on ampacity rating due to moisture migration. It can be observed that cables with large sizes have a greater impact on the ampacity ratings.

H. Varying the Dimensions of the Backfill

In this work, the two dimensions (first and second) of the backfill were evaluated (as shown in Fig. 15).

The first dimension included 1×1.5 M (area=1.5 m^2) and the second dimension had 1.2×2 M (area=2.4 m^2). The thermal resistivity for the native soil varied from 0.4 to 4 K.m/W. The relationship between the ampacity rating and the backfill dimensions is presented in Fig. 16.

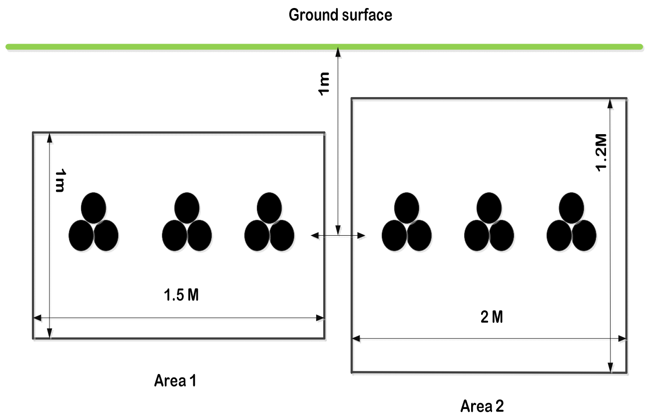

Fig. 15 Dimensions of backfill

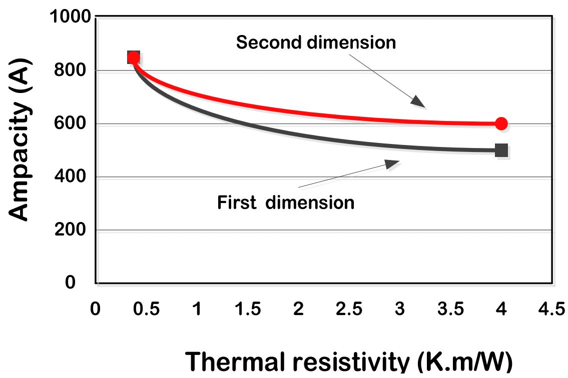

Fig. 16 Ampacity rating verses the backfill dimensions

It was observed that the ampacity rating reduced with backfills containing greater areas and vice versa.

V. Conclusions

One of the most important factors to provide an economic cost, safe design and functional setup is achieved by determining the cable ratings. It is imperative to get access to huge and insightful software tools for the calculation of cable ratings.

A. Air Cables

In these cables, the surrounding air temperature was found to have a major impact on the current carrying capacity. Additionally, the size of the conductor and material used has significant influences on the current carrying capacity in addition to the sheath bonding arrangement. Direct exposure to solar radiation had considerable impact on the current carrying capacity of cables, even those that were enclosed inside conduits.

B. Buried Cables

Again, the size of the conductor and material used had considerable impacts on the ampacity rating in addition to the sheath bonding arrangement. The ampacity ratings were also affected by both the thermal resistivity for native soil and surrounding temperature. To a lesser extent, spacing between phases would impact the ampacity rating. For single-point bonded cables, spacing had an impact on the sheath standing voltage, which is also a significant safety-related aspect.

APPENDIX

Cable components are required for modelling in ETAP program. The following cable parameters are taken from the Olex HV cable catalogue [10].

Fig. 17 Cross-sectional area for the 11KV cable

TABLE II
STRUCTURAL PARAMETERS OF CU 120 MM² CABLE

Physical Quantity	Values (mm^2)
Nominal conductor diameter	13.1
Conductor screen thickness	0.55
Insulation thickness	3.4
Semi-conductive insulation screen thickness	0.8
Copper screen wire thickness	1.35
PVC sheath thickness	2.05

TABLE III
STRUCTURAL PARAMETERS OF CU 500 MM² CABLE

Physical Quantity	Values (mm^2)
Nominal conductor diameter	26.5
Conductor screen thickness	0.7
Insulation thickness	3.4
Semi-conductive insulation screen thickness	0.9
Copper screen wire thickness	1.35
PVC sheath thickness	2.55

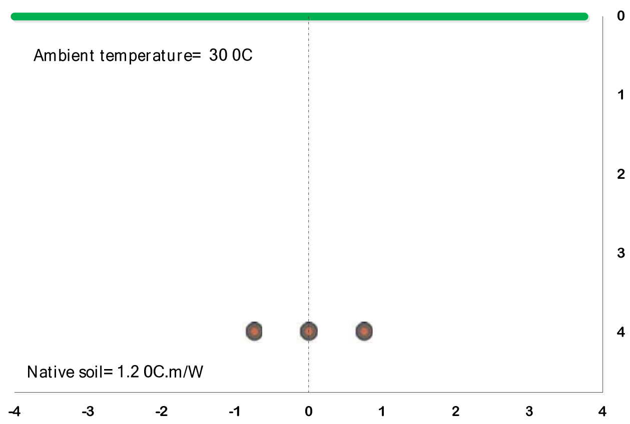

Fig. 18 Flat formation installation

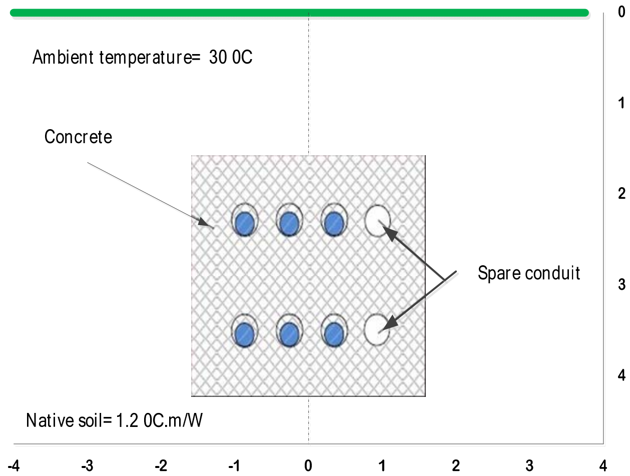

Fig. 19 Duct bank Installation

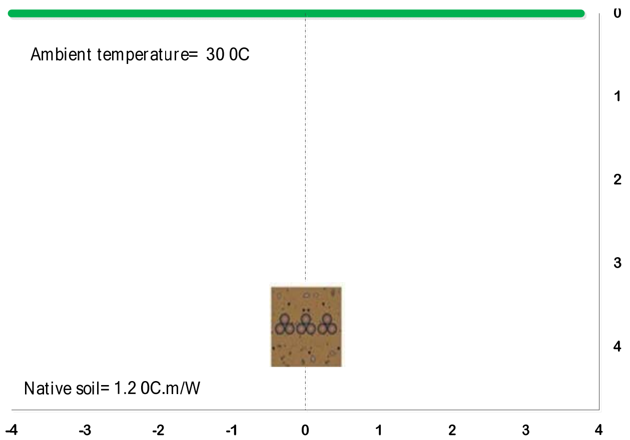

Fig. 20 Three trefoils directly buried in the soil

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