



SOFTWARE PACKAGE FOR POLYMERIC POWER CABLE SYSTEM

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المخلص

تعرض هذه الورقة تطوير مجموعة برامج بلغة البيسك المرئي تعمل على حساب اقل مساحة لموصل الكابل المستخدم لتصميم خط نقل أو منظومة توزيع صناعية أو داخل مدن مأهولة بالسكان، ويعمل البرنامج على حساب السعة التحميلية للكابل، وحساب الجهد المستحث في الغلاف المعدني للكابل وأيضا حساب القيمة المسموح بها لدائرة القصر لهذا الكابل المستخدم في التصميم حسب شروط العمل في منطقة ما. ويمتاز هذا البرنامج بأنه يعيد حساب تلك العوامل بناء على أي تغيير يحدث في شروط العمل أثناء التخطيط الميداني لتصميم هذا النظام. وأنه يساعد المهندسين المختصين في هذا العمل من حيث تدليل الصعوبات واختصار الوقت لتكرار المعادلات لحساب تلك العوامل حسب الشروط الجديدة..

ABSTRACT

This paper present the develop software package for visual basic to calculate the minimum cross section area for the used cable to plan the power system design, industrial distribution system or in urban areas. This work to calculate exact ampacity, induced voltage and permissible value short circuit current for the used cable in system design according to the living conditions in any region. It should not be ignored that this program re-calculates the above factors while changing the conditions laying which occur during planning this system design. This work helps the specialist engineers to decries difficulties and to shortcut equations repetition to calculate those factors according to the new conditions.

1. INTRODUCTION

Selecting the kind and size of the cable required to carry certain given power does not only depend on the cross-sectional area of the conductor but also on many other important factors. Cable ampacity is determined and based on the maximum temperature allowed on operation, thermal properties of the cable itself, the surrounding environment, methods of earthing the metallic sheath of the cable, arrangement of the cables, and number of cables in a group. This means that it depends on the rate of cooling the generated heat in the cable to the surrounding environment calculating the ampacity of the cable without considering all of above

factors will lead to wrong figure led to damaging the cable.[1]

The packages is built to find the minimum cross section area of a given cable to be installed in pre-defined conditions. The package will give the most accurate results regarding the cable ampacity whether the cable is exceeding the induced voltage limit according to IEC or not. The package finds not only the most economical cable size but also the safety of the cable and installation, in addition to the cable laying methods, cable arrangement or cable bonding system may be forced to change during cable laying. This could happen due to unexpected ground conditions specially when cables are laid in old towns and cities.



The software package will help to calculate the effect of changing the design of parameters on the cable ampacity and induced voltage, and the software package uses adiabatic or non-adiabatic method of S.C calculation when the a given cable is fit to be used in a given class of voltage or not also the permissible short circuit current.

2. METHODOLOGY

The main procedure followed in designing software for **Polymeric Power Cable System (PPCS)** can be divided into three steps. All steps are obtaining the system of equations from the IEC standard. The power cable design software is designed to assist the user to find the most appropriate cable size to be used to transmit a given amount of power, considering climatic conditions, bonding and earthing methods and all aspects that may affect cable ampacity. The software designed to be friendly used and tailored to different engineer's needs, such as a quick estimation to the cable size for a given load and laying conditions, exact cable ampacity when cable parameters, construction, laying methods and bonding techniques used all are known. The software also designed to recalculate cable ampacity when laying conditions change during cable laying (i.e. forced to change due ground obstacles such as other services, narrow corridor, soil changesi.e). [2]

PCSS as detailed in the Flow chart of the main software shown in figure (1) designed to operate at the following steps.

2.1. Step1 (Calculate current carrying capacity "Ampacity").

As this step aimed at calculating the exact Ampacity of a cable, all necessary information about cable construction has to be available. Some thing about the coming flow chart is shown in figure (2).

Ampacity is a term given by Del Mar in 1951 to the current-carrying capacity of

cable. Ampacity in underground cable system is determined by the capacity of the installation to extract heat from the cable and dissipate it in the surrounding soil and atmosphere.

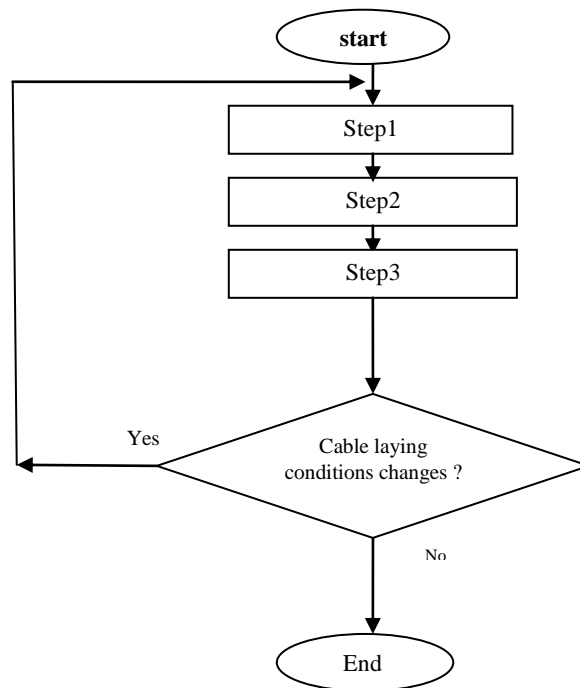


Fig. 1 Flow chart of the main software

The maximum operating temperature of a cable is a function of the damage that the insulation can suffer as a consequence of high operating temperatures. The insulation withstands different temperatures as function of the duration of the current circulating in the conductors. There are three standardized Ampacity ratings: steady state, transient (or emergency) and short-circuit.

The temperature rise in the cable is due to the heat generated in the conductor (I^2R), in the insulation (Wd) and in the sheath and armour (λI^2R) with allowance being made by multiplying each of these by the thermal resistance of the layers through which the heat flows (T).

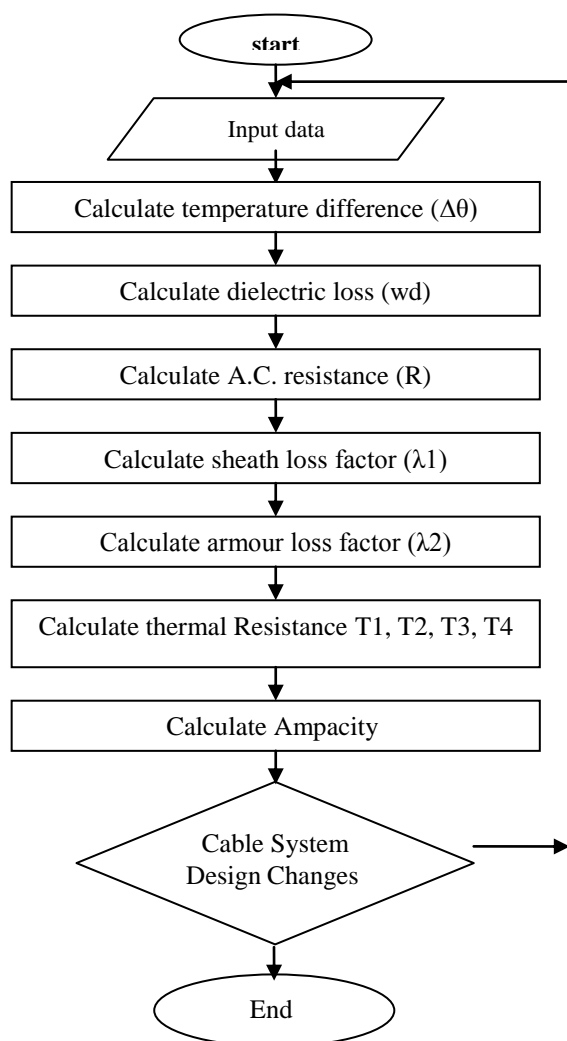


Fig. 2 flow chart of the step1

Ampacity computations of power cable require solution of heat transfer equations which define a functional relationship between the conductor current and temperature within the cable and in its surroundings. The heat is transferred through the cable and its surroundings in several ways.

Both methods employ the application of thermal equivalents of Ohm's and Kirchoff's Laws to a simple thermal circuit. In this program the method covered in the IEC 287 was used. When the conductor is energized, heat is generated within the cable. This heat is generated due to the I^2R losses of the conductor, the dielectric losses in the insulation and losses in the metallic component of the cable. The ampacity of the

cable is dependent on the way this heat is transmitted to the cable surface and ultimately dissipated to the surrounding. Thermal Electrical equivalent shown figure (3) the cable materials and soil represent a series circuit of thermal resistances. The thermal resistances control heat dissipation from the conductor. [6]

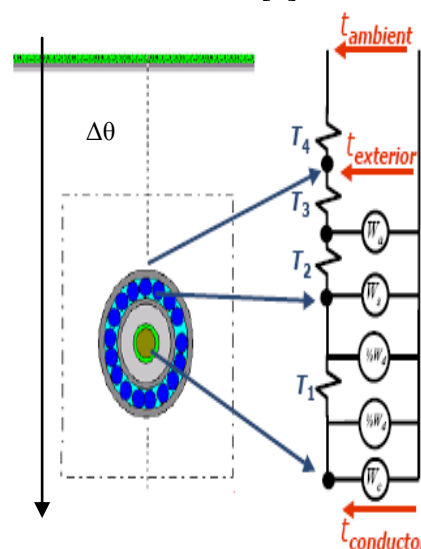


Fig. 3 Thermal Electrical Equivalent

The normal maximum continuous rating of the cable is dependent on a number of factors. Of these the one that is most important is the maximum permissible conductor temperature. The maximum permissible current rating is the loading in amperes which, applied continuously until steady conditions are reached, will produce the maximum allowable conductor temperature. Steady state is reached when the rate of heat generation in the cable is exactly equal to the rate of heat dissipation from the surface of the cable. This steady state is the only condition considered when calculating the maximum permissible continuous current rating. [6]

By applying the thermal equivalence of Kirchoff's and Ohm's law to the circuit shown in figure(3), equation(1) is obtained.

$$\Delta\theta = H * T \quad (1)$$



The temperature different between cable conductor and ambient given by equation (2) from equivalent circuit

$$\therefore \Delta\theta = \Delta\theta_1 + \Delta\theta_2 + \Delta\theta_3 \quad (2)$$

Where: $\Delta\theta$ is the conductor temperature rise above the ambient temperature.

H is the flow of heat in watts.

T is the thermal resistances in thermal ohm.

Application of equation (1) on the precedent equivalent circle.

$$H_1 = I^2 R + 0.5Wd$$

$$\therefore \Delta\theta_1 = H_1 * T_1$$

$$\therefore \Delta\theta_1 = I^2 RT_1 + 0.5WdT_1$$

Where:

H_1 is the heat flow in one core cable in thermal watts.

I is the current per conductor in ampere.

R is the ac resistance of each conductor in ohms at maximum temperature.

Wd is the dielectric losses in (watts/ phase).

$\Delta\theta_1$ is the temperature difference between conductors and sheath.

The expression (1) can be rewritten by substituting cable parameters and gives equation (3).

$$\therefore \Delta\theta = I^2 R [T_1 + n(1 + \lambda_1)T_2 + n(1 + \lambda_1 + \lambda_2)(T_3 + T_4)] + Wd[0.5T_1 + nT_2 + nT_3 + nT_4] \quad (3)$$

from equation (3) a formula can be obtained for the Ampacity as given in equation(4)

However, this equation has to be ac (4) for catering to the effect of intensity of radiation, for cases of cables laid in free air and directly exposed to the solar radiation. [5]

$$\therefore I = \left[\frac{\Delta\theta - Wd[0.5T_1 + n(T_2 + T_3 + T_4)]}{RT_1 + nR(1 + \lambda_1)T_2 + nR(1 + \lambda_1 + \lambda_2)(T_3 + T_4)} \right]^{0.5}$$

The last equation contents many factors, these factors shown in the flow chart in

figure(2); however, these factors can be calculate by following sections.

2.1.1 Calculate temperature difference ($\Delta\theta$).

This is the maximum permissible difference of operating temperature (between the cable and the ambient temperature). The maximum operating temperature varies according to the type of insulation used. The ambient temperature is usually taken as 30⁰ C for above ground installations and 20⁰ C for underground installations.

2.1.2 Calculate dielectric loss (wd).

The dielectric loss per unit length in each phase is given by equation (5).[5]

$$W_d = \omega \times C \times V_o^2 \times \tan \delta \quad (W/m) \quad (5)$$

where the electrical capacitance and the phase-to-to-ground voltage are obtained from equation(6).

$$C = \frac{\epsilon}{18 \ln \left(\frac{D_i}{d_c} \right)} \times 10^{-9} \quad F/m. \quad (6)$$

The dielectric constant ϵ and the loss factor $\tan \delta$ are taken from IEC standard.

2.1.3 Calculate A.C. resistance (R).

When considering steady conditions there is no longitudinal heat flow in the cable, so that it is immaterial what length of the cable is considered when calculating the rating. It is convenient to use 1m.

The a.c. resistance per unit length of the conductor at its maximum operating temperature is given in equation (7).

$$R = R' (1 + Y_s + Y_p) \quad (7)$$

where the dc value R' at θ 0C (ohm/m) is obtained from IEC 60287 by equation(8).

$$R' = R_o [1 + \alpha_{20} (\theta - 20)] \quad (8)$$



Where R_o is the DC resistance of the conductor at $20C_o$ (Ω/m) by equation(9)

$$R_o = \frac{\rho_{20}}{A} \quad (9)$$

where ρ_{20} is the electrical resistivity of the conductor material at $20C$ is listed in the IEC 60287 standard, also α_{20} : is the temperature coefficient of resistance at $20C$ listed in the IEC standard.

The factor Y_S , Y_P are called skin effect and proximity effect factors, respectively the ratio R/R' is usually close to unity at power frequency, and may be a few percent above unity for large diameter conductors.[1]

2.1.4 Calculate sheath loss factor (λ_1).

It is convenient to express sheath/screen losses as a fraction of the conductor losses, as both are dependant on the square of current.

The power loss in the sheath or screen consists of losses caused by circulating current (λ_1') and eddy current (λ_2'') and is given in equation (10).[1]

$$\lambda_1 = \lambda_1' + \lambda_2'' \quad (10)$$

For single core cables with sheath bonded at both ends of an electrical section, only the loss due to circulating current in the sheath needs to be considered. An electrical section is defined as a portion of the route between points at which the sheath or screens of all cables are solidly bonded.

2.1.5 Calculate armour loss factor (λ_2)

The armour loss represents the power loss occurring in the armour as a factor of total power losses in all conductors.[1]

The calculation of loss factor depends on the type of the armour. (i.e. Non-magnetic or Magnetic armour)

* Non-Magnetic Armour

The general procedure is to combine the calculation of loss in the armour with that of

the sheath. In place of sheath resistance, a parallel combination of sheath and armour can be used (The root mean square value of sheath and armour diameter replaces the mean sheath diameter).[1]

* Magnetic armour

For the magnetic armour λ_2 is calculated according to the armour type (i.e. steel wire or steel tape) and the number of cores in the cable.[1]

2.1.6 Calculate Thermal resistances

The heat path from the cable conductor(s) to the “sink” of heat, traverses the following items in turn.

Insulation \longrightarrow Metallic sheath \longrightarrow
Bedding \longrightarrow Armor \longrightarrow Outer Serving
Ground or air.

The thermal resistances of metallic portion of this heat path are so small in comparison with others. Therefore they can be neglected and the list now reduces to,

Insulation(T1) \longrightarrow Bedding (T2) \longrightarrow Outer
Serving (T3) \longrightarrow Ground or air(T4).[6]

The total thermal resistance consists of resistances partly in series and partly in parallel, so that it is necessary to figure out the values of these so called partial thermal resistances. Each partial resistance can be split up into two factors, one being essentially the thermal resistivity of the material and the other a function of the material through which the heat passes (The latter factor being called the geometric factor).

The dimensions of the cable affect the thermal resistance, and calculations can be made in the case of single core cables, as the heat flow is radial to the core.

However, multicore cables offer a very complex problem owing to the distortion of the lines of heat flow. This problem has been resolved by the use of geometric factors. The calculation of these factors T1, T2, T3 is dependant on the cable materials and cable type. [6]

With cables buried in the ground the heat transmitted through the cable passes into the surrounding soil. No conclusive evidence is available regarding the nature of heat flow in the soil, but the basis used for calculation accepts the theory that the ground surface above the

cable is plain isothermal of ambient temperature, so that all the heat generated is ultimately transmitted to the ground surface, which remains at constant temperature.

In general soil having a higher percentage of moisture will have a lower thermal resistivity and consequently the best heat dissipating qualities.

Porous or well-drained soils have a higher thermal resistivity. In this program type of soil have been considered according to the different weather conditions. If there is a variation in soil resistivity over a period of twelve months, the current rating should be based on the highest value of soil thermal resistivity observed.

With cables carrying a heavy load continuously, some drying out of the soil immediately surrounding the cable may occur, increasing the value of soil thermal resistivity. But in the program it is considered that soil drying out does not occur and the value of soil thermal resistivity remains constant during the operation of the cable. The value of T_4 is calculated considering all these factors.

2.2 Step2 (Calculate Induced Voltage).

Using metallic sheath in cables is inevitable due to the benefits gained from an existence of metallic sheaths in the cable. Metallic sheath as subjected to the magnetic field setup by the conductor current which cases an induced current flow at any the sheath, in other had voltage also induced in metallic sheath; this chapter discusses in details the induced voltage and induced current and the methods used for their limit. [2]

The induced voltage V_s within a cable system depends on the mutual inductance between core and sheath, the conductor current and finally on the cable length to decrease the induced voltage and current,

2.2.1 Both-end Bonding.

Both ends of the cable sheath are connected to the system earth. With this method no standing voltages occur at the cable ends, as shown in figure (4) induced voltage distribution at both-end bonding, this fig explains the maximum induced voltage by mid distance between bonding, which makes it the most secure regarding safety aspects. On the other hand, circulating currents may flow in the sheath as the loop between the two earthing points is closed through the ground. These circulating currents are proportional to the conductor currents and therefore reduce the cable ampacity significantly making it the most disadvantageous method regarding economic aspects. [7]

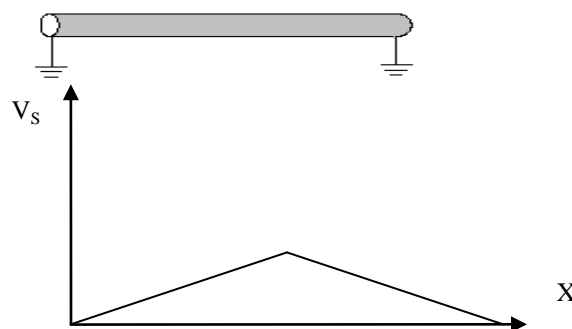


Fig.4 Induced voltage distribution at both-end bonding

2.2.2 Single-ended Bonding.

One end of the cable sheath is connected to the system earth, so that at the other end (“open end”) the standing voltage appears, which is induced linearly along the cable length as shown in figure (5). In order to ensure the relevant safety requirements, the “open end” of the cable sheath has to be protected with a surge arrester. In order to avoid potential lifting in case of a failure, both earth points have to be connected additionally with an earth continuity wire. The surge arrester (sheath voltage limiter) is designed to deflect switching and atmospheric surges but must not trigger in case of a short-circuit. [7]

2.2.3 Cross-Bonding.

This earthing method shall be applied for longer route lengths where joints are required due to the limited cable delivery length. A cross-bonding system consists of three equal sections with cyclic sheath crossing after each section.

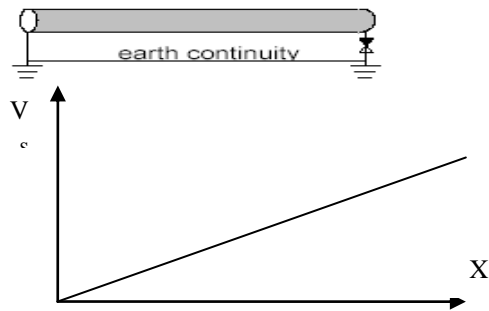


Figure (5) Induced voltage distribution at single-end bonding

The termination points shall be solidly bonded to earth. Along each section, a standing voltage is induced. In ideal cross-bonding systems the three section lengths are equal, so that no residual voltage occurs and thus no sheath current flows. Induced voltage distribution at cross-bonding As shown in figure(6).

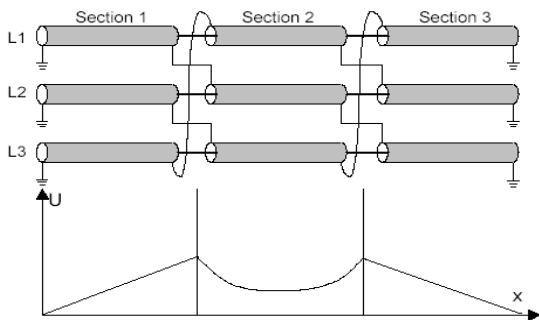


Figure (6) Induced voltage distribution at cross-bonding

The sheath losses can be kept very low with this method without impairing the safety as in the two-sided sheath earthing. Very long route lengths can consist of several cross-bonding systems in a row. In this case, it is recommended to maintain solid bonding of

the system ends in order to prevent traveling surges in case of a fault. In addition to cross-linking the sheaths, the conductor phases can be transposed cyclicly. This solution is especially suited for very long cable lengths or parallel circuits.

Any conductor (p), laid parallel with a set of three conductors carrying balanced three-phase currents will have a voltage gradient V_p induced along its length, given by Equation (11):[7]

$$V_p = j\omega I_p \times 2 \times 10^7 \times \left[\frac{1}{2} \log_e \left(\frac{S_{ap} \times S_{cp}}{S_{bp}} \right) + j \frac{\sqrt{3}}{2} \log_e \left(\frac{S_{cp}}{S_{ap}} \right) \right] V/m \quad (11)$$

Where :

- I_p = current (A) in conductor p r.m.s value.
- ω = angular frequency of the system ($2\pi f$).
- S_{ap} = axial spacing of the parallel conductor and phase “a” conductor.
- S_{bp} = axial spacing of the parallel conductor and phase “b” conductor.
- S_{cp} = axial spacing of the parallel conductor and phase “c” conductor.

And these spacing may be in any convenient common unit. It is assumed that the phase rotation is such that.

$$I_a = a \cdot I_p \quad \text{and} \quad I_c = a^2 \cdot I_p$$

$$\text{Where :} \quad a = -\frac{1}{2} + j \frac{\sqrt{3}}{2}$$

$$I_p = I_0 (1+j0)$$

I_0 = magnitude of load current

Clearly, as the spacing of the parallel conductor increases in relation to the mutual spacing of the group of the cables the induced voltage tends to zero. Similarly, if the three cables of the group are regularly transposed at even intervals, the induced voltages in the parallel conductor sum to zero over a complete cycle of transposition.



The voltage gradient induced in a cable sheath may be considered as a special case in which the parallel conductor is a sheath at a spacing from the conductor that it embraces equal to the mean radius of the sheath. When no other current-carrying conductor is in the vicinity, the three-sheath voltage gradients for a group of cables in any formation carrying balanced three-phase conductor currents are then given by:

*** Trefoil Formation Single Circuit**

For cables in trefoil where $S_{ab} = S_{bc} = S_{ac}$ these equations are reduce to the following equations (12,13,14): [7]

$$V_a = j\omega I_b (2 \times 10^{-7}) \times \left(-\frac{1}{2} + j \frac{\sqrt{3}}{2} \right) \log_e \left(\frac{2S}{d} \right) V/m$$

$$V_b = j\omega I_b (2 \times 10^{-7}) \log_e \left(\frac{2S}{d} \right) V/m$$

$$V_c = j\omega I_b (2 \times 10^{-7}) \times \left(-\frac{1}{2} - j \frac{\sqrt{3}}{2} \right) \log_e \left(\frac{2S}{d} \right) V/m \quad *$$

Flat Formation Single Circuit

For the other common formation of cables laid flat in which the axial spacing adjacent cables = S, the sheath voltage gradients are given by the equations (15,16,17): [7]

$$V_a = j\omega I_b (2 \times 10^{-7}) \times \left(-\frac{1}{2} \log_e \frac{S}{d} + j \frac{\sqrt{3}}{2} \log_e \frac{4S}{d} \right) V/m \quad (15)$$

$$V_b = j\omega I_b (2 \times 10^{-7}) \log_e \left(\frac{2S}{d} \right) V/m \quad (16)$$

$$V_c = j\omega I_b (2 \times 10^{-7}) \times \left(-\frac{1}{2} \log_e \frac{S}{d} - j \frac{\sqrt{3}}{2} \log_e \frac{4S}{d} \right) V/m \quad (17)$$

2.3 Step3 (Calculate Permissible Short-circuit Current).

Short-circuit ratings can be calculated using either the adiabatic method, which assumes that all of the heat generated remains trapped within the current carrying component, or non-adiabatic method, which allow for heat absorption by adjacent materials.

The adiabatic method may be used when the ratio of short-circuit duration to conductor

cross-sectional areas is less than 0.1 s/mm². On smaller conductors such as screen wires, as the short-circuit duration increases the loss of heat from the conductor becomes more significant. In such cases the non-adiabatic method can be used to provide a significant increase in permissible short-circuit current. [4]

2.3.1 Adiabatic Method.

By ignoring heat loss an equation can be derived which equates heat input (I²RT) to heat absorbed into the current carrying component (product of mass, specific heat and temperature rise).

The adiabatic temperature rise formula given in IEC 724 by equation (18): [4]

$$I_{AD}^2 = K^2 * S^2 * \ln \left(\frac{\theta_f + \beta}{\theta_i + \beta} \right) / t \quad \text{Where} \\ \text{:IAD} \\ =$$

short-circuit current calculated on an adiabatic basis

t = duration of short circuit (second)

K=constant for the material of the conductor

S = area of conductor (mm²)

θ_f = final temperature (°C)

i = initial temperature (°C)

β=reciprocal of the temperature coefficient of resistance (α) of the conductor (per degree Celsius at 0⁰ C)

In the above, 'conductor' refers to the current carrying component. The constants for the usual metals (K) are given in standard IEC and calculated by equation (19).[4]

$$K = \sqrt{\frac{\sigma_c (\beta + 20) \times 10^{-12}}{\rho_{20}}} \quad (19)$$

Where : σ_c = volumetric specific heat of the current carrying component at 200 C

(J/K.m³) given in standard IEC

ρ₂₀ = electrical resistivity of the current carrying component at 200 C (Ω.m) given in standard IEC.



2.3.2 Non-adiabatic Method.

IEC 949 gives a non-adiabatic method of calculating the thermally permissible short-circuit current allowing for heat transfer from the current carrying component to adjacent materials. The non-adiabatic method is valid for all short-circuit durations and provides a significant increase in permissible short-circuit current for screens, metallic sheaths and some small conductors.

The approach adopted is to calculate the adiabatic short-circuit current, using equation (18), and a modifying factor which takes into account the heat lost to adjacent materials. The adiabatic short-circuit current is multiplied by the modifying factor to obtain the permissible non-adiabatic short-circuit current.

The equations used to calculate the non-adiabatic factor are given in IEC 949. for conductors and spaced screen wires fully surrounded by non-adiabatic materials the equation for the non-adiabatic factor (ε) is given by equation (19): [4]

$$\varepsilon = \left[1 + X(t/S)^{1/2} + Y(t/S)^{1/2} \right]^{1/2} \quad (19)$$

where :

X and Y are given in standard IEC 949 for sheaths, screens and armour the equation for the non-adiabatic factor is given by equation (20) : [4]

$$\varepsilon = 1 + 0.61M\sqrt{t} - 0.069(M\sqrt{t})^2 + 0.0043(M\sqrt{t})^3$$

where :

$$M = \frac{\left(\sqrt{\frac{\sigma_2}{\rho_2}} + \sqrt{\frac{\sigma_3}{\rho_3}} \right)}{2 * \sigma_1 * \delta * 10^{-3}} * F$$

σ_1 = volumetric specific heat of screen, sheath or armour (J/K.m³)

σ_2, σ_3 = volumetric specific heat of materials each side of screen, sheath or armour (J/K.m³)

δ = thickness of screen, sheath or armour (mm)

ρ_2, ρ_3 = thermal resistivity of materials each side of screen, sheath or armour (K.m/W)

F = factor to allow for imperfect thermal contact with adjacent materials, the contact factor F is normally 0.7, however there are some exceptions. For example, for current carrying component such as a metallic foil sheath, completely bonded on one side to the outer non-adiabatic sheath, a contact factor of 0.9 is used. Thermal constants for common materials are shown in Table from IEC standard. [4]

3. RESULTS AND DISCUSSION

It is required to feed a load of 47 MVA from 30 kV systems by a copper core, XLPE cable, buried in flat or trefoil at 0.8 m where the temperature is 20⁰ C. The cable is used in Tripoli area. Feeding the above data to PPCS will yield that the minimum size of the conductor that should be used is (514.75 mm²). The used available size should be 630 mm². Using steps to calculate ampacity, induced voltage and short circuit capacity for this cable during 1sec to cable laying in Tripoli for installation method in direct buried ground:

- 1- Depth of laying 0.8 m
- 2- Ambient ground temperature=20⁰ C
- 3- Laying trefoil configuration
- 4- Single point bonding
- 5- The dimension of cable used in this example is shown in fig (7).

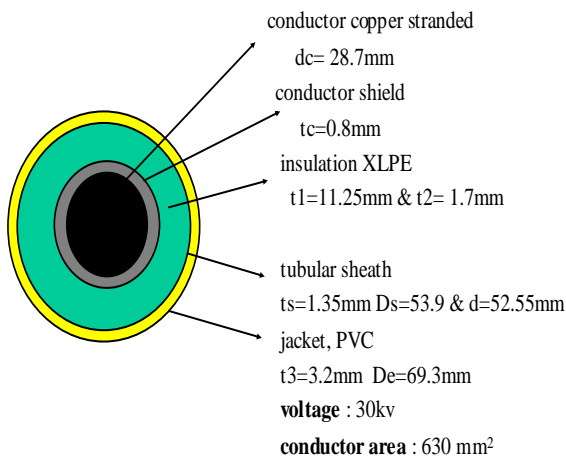


Fig. 7 Used Cable Construction

Value of ampacity and induced voltage for characteristics of the cable and ambient, then changing in arrangement laying in Tripoli from trefoil to flat at S=200mm distance between phase in table (1) And fig (8) show the induced voltage at 500 m.

The value of permissible short circuit current for the cable during non-adiabatic heating is (91.01 kA).

Ampacity is affected by changing of soil from region to another in Libya. Therefore General Electrically Company of Libya undertakes to study the thermal resistivity of soil in Libya regions. Therefore the effect of soil changes on ampacity is as shown in the example:

Is it good for city to transfer the cable from it to another, for example (Tubruq, Sebha,) at same voltage and work conditions or not?

Through general electrical company specifications it is found that finds the thermal resistivity of soil is different from city to another, which has effects on ampacity. This ampacity and induced

voltage at conditions laying in cities Tubruq and Sebha are given in table (2).

Table (1) results of cable characteristics laying in Tripoli

30kv single core 630 mm ²	arrangement	Permissible current rating Ampacity (A)	Maximum Induced voltage at 500 m	Maximum Induced voltage at 1000m
Copper conductor	trefoil	1262.86	Va=Vb=Vc= 80.5	Va=Vb=Vc= 160.97
Copper conductor	Flat	1259.6	Vb =80.27 Va=Vc= 101.54	Vb = 160.93 Va=Vc= 203.07

Notes: The cable when laid in Tubruq city carries slightly less ampacity (26%) than cables laid in Tripoli city, because in Tubruq city the soil thermal resistivity greater 125% than in Tripoli city, also the cable when laid in Sebha city carries slightly less ampacity (16%) than cables laid in Tripoli city, because in Sebha the soil thermal resistivity greater 66.6% than in Tripoli city.

Table (2) results the ampacity and induced voltage at conditions laying in cities

City	30 kv single core cable "flat" arrangement	Ampacity (A)	Induced voltage at 500 m	Soil thermal resistivity (k.m / w)
Tripoli	Copper conductor	1262.86	80.49	1.2
Tubruq	Copper conductor	944.731	60.21	2.7
Sebha	Copper conductor	1060	67.56	2.0



4. CONCLUSION

From the results obtained by using different models of PPCS on different cable system arrangements, laying methods, bonding method of single and double circuits. The following conclusions can be written:

- * Cable Ampacity decreases when increases in soil thermal resistivity.
- * Cable Ampacity decreases when increases in depth laying.
- * Cable Ampacity increases when there is no circulating current in sheath.
- * Cable Ampacity changes by changing underground medium (duct, backfill , direct buried).
- * As induced voltage increases by distance, single point bonding should not be used for long lengths.

Increasing the distance between phases in a single cable circuit decreases the ampacity of the cable.

- * Induced voltage is high when cables are laid flat and single point bonded when compared to trefoil formation, but the difference becomes lower if cables are cross bonded.

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