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# Evaluation of Thermal State for Underground Power Cables in Nasiriya City

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## Abstract

Due to the increase in demand for electric power and increasing population density in different regions, the application of underground cables has become widely used in transmission and distribution networks. In this paper, the thermal behavior of underground cables was studied numerically. Four types of underground cables were selected copper conductor cables with (95 mm$^2$) and (240 mm$^2$) and aluminum conductor cables (95mm$^2$) and (240mm$^2$), which are used in the power networks in Iraq. The study was carried out based on the conditions surrounding such as the ambient temperature, the thermal properties of the soil and the current capacity, its effect on the thermal behavior of the cables. The results of the numerical simulation showed that the surrounding factors and loading capacities have a direct effect on determining the temperature of the cable. In addition, the type and size of the conductor cable material have an effect on determining the current-carrying capacity of the cable where the conductor cable with a nominal cross-sectional area 240mm$^2$ has a temperature higher than the conductor cable with nominal cross-sectional 95mm$^2$by (8.96%) for the copper conductor and (13.68%) for the aluminum conductor at current 500A.

**Keywords**: Thermal state, Current-carrying capacity, Underground cables, Saturated soil, IEC 60287.

## NOMENCLATURE:

| | |
|---|---|
| k | Thermal conductivity (W/m.K). |
| A | Cross-sectional area of conductor (mm$^2$). |
| q | Heat Source term (W/m$^3$). |
| T | Temperature (K). |
| x | Coordinate (m). |
| y | Coordinate (m). |
| L | Physical length of the conductor (m). |
| I | Current (A). |
| R | Resistance (Ω/m). |
| $T_a$ | Ambient temperature (K). |
| $T_s$ | Soil temperature (K). |

Abbreviation

| | |
|---|---|
| Al | Aluminum. |
| Cu | Copper. |
| IEC | International Electrotechnical Commission. |
| 2D | Two- Dimensional. |
| XLPE | Cross-Linked Polyethylene. |
| PVC | Polyvinyl Chloride. |
| CFD | Computational Fluid Dynamics. |

## 1- Introduction:

Power cables are used in transmission and distribution networks, although overhead lines are usually favored for power transmission, underground power cables are preferred to the safety of life, aesthetic appearance, and safe operation in densely populated areas. Cables are either simple structure to complex structure depending on the mechanical, environmental and thermal stresses when increasing the level of energy and voltages [1]. In addition, operation of the systems available at the highest capacity is important and required, this requires studying the thermal behavior of the cables for maintaining the cable and increase cable life. In order to achieve this, there are many analytical, numerical and experimental methods to determine the thermal state of cables where the experimental methods are expensive and require a long time. Analytical methods are implemented using IEC60287 (International Electrotechnical Commission). This method is used when the conditions are simple [2] but when it becomes more complicated, numerical methods are more preferred.

Many researchers studied the thermal behavior of underground cables using theoretical and experimental methods such as:-

**Anders and Brakelmann (2004) [3]** presented analytical improved current capacity calculations for cables. They used theoretical methods for estimating conductor temperature and cable losses. These methods were used to calculate the conductor temperature and losses by determining the current values and calculating the thermal resistance by Neher/McGrath procedure. The current values were used from (0 to 966) A for a three-conductor armored insulated with XLPE(Cross-Linked Polyethylene). Their results showed that the conductor of the temperature obtained from the analytical methods gives approximate results with which were measured by the sensors that were proved on the cables or pipe surface to measure the temperature.

**Dafalla (2008) [4]** experimentally investigated possible ways to improve the thermal resistance of the soil surrounding high voltage cables located in desert areas. They used sand available in the city of Riyadh located in Saudi Arabia because of repeated failures of cables in Riyadh and surrounding regions, especially during summer time. Cement was added to improve thermal resistance and the conditions examined for dry sand testing are in case moisture content is 0%, the moisture content is 5%, the moisture content is 0% and cement is 5%, the moisture content is 5% and cement is 5%. Their results showed that white sand is better than natural sand and adding cement without moisture where little improvement in the thermal resistance of the soil, adding moisture to the sand with the cement improves the thermal resistance of the soil. In addition, the soil improvement method is affected by the nature of the number of cables. If the number of cables is two inside the trench, the natural sand can be used and the added water is 10%. If the number of cables inside the trench is three cables, the crushed sand or natural sand can be used with the addition of 10% of water for brushes and if the number of cables four cables inside the trench is used white sand with the addition of water.

**Papagiannopoulos et al. (2013) [5**] studied the thermal behavior of buried cables under the soil and used numerical and experimental methods. Numerical simulations were performed using COMSOL. In their study, they used the numerical solution to solve the conduction equation in the unsteady state. The experimental method was performed by using a box filled with sand to measure the temperature of the cable insulated with PVC used thermocouple. The used loads are (45,50) A and the cable temperature is measured at these loads. Through their results, it was found by calculating the temperature of the cable that there is a great correspondence between the data taken by numerical simulation and the experimental data. Also, their results showed that at the beginning thermal resistance in the soil surrounding the cables will be few, but after a period found that the thermal resistance of the soil will increase.

**Chen et al. (2014) [6**] presented a numerical investigation about the effect of forced ventilation of the cables inside the tunnel on calculating the ampacity. They used the software COMSOL to compute the temperature of cables that it was numerically calculated using the finite element method. They studied some of the factors that affect the current capacity of the cables in the tunnel exposed to forced ventilation such as the inlet air velocity, the inlet air temperature and the length of the channel. Their results showed that the use of tunnel ventilation for cables improves the possibility of underground cables. Also, their results indicated that increasing the speed of the air entering a tunnel increases the current capacity. Conversely, increasing the temperature of the inside air in the channel reduces the load capacity and current capacity decreases with increasing the length of the tunnel ventilation.

**Ocùoñ et al. (2015) [7]** presented numerically the thermal behavior of buried cables under the soil in the Polish power plant. Three cables were used in the pipes that were placed directly in the soil or by the thermal backfill. In their study. They used the finite element method using Matlab and carried out numerical calculations of the stable state. Three different cases are considered in the first case the cables inside the pipe filled with sand-bentonite mixture and placed in the thermal backfill and buried in the soil, in the second case put the cables inside the pipes filled with sand-bentonite mixture and buried with the soil and the third case the cables inside pipes filled with dry sand and buried with soil. Their results showed that the temperature of the cable is low when the cables inside the pipes filled with the sand-bentonite mixture and placed these pipes with the thermal backfill, the temperature rises significantly if the cable inside the pipes filled with dry sand.

**Ocłoń et al. (2016) [8]** studied experimentally and numerically improved the performance of the underground power cable system with adding materials has high thermal conductivity. The material was used as an additive to the thermal backfill material (Gruntar$^{TM}$) to improve the thermal conductivity of the soil. The additions were 5%, 10%, and 15% the thermal conductivity of the thermal backfill was measured at these additions. They used in their numerical study the model consisting of three high voltage cables arranged in a flat arrangement consisting of copper conductor and insulator of XLPE where each cable is placed inside a sand-filled pipe then placing it in the soil. The two-dimensional model is used to solve the heat conduction equation with Matlab code using the finite element method. The results showed that the addition of 15% of the material (Gruntar$^{TM}$) works to improve the thermal conductivity and thus raise the loading capacity of cables from 10A to 12A. Also, in their numerical study the increasing the dimensions of the thermal backfill area leads to low-temperature cable power and thus higher capacity.

**Rerak and Ocłoń (2017) [9]** presented a numerical study on the effect of thermal conductivity of soil and thermal backfill on the distribution of underground cable temperature. The heat conduction equation for underground cables was solved using the MATLAB program to calculate the heat transfer of underground cables. Two-dimensional modeling was carried out for three flat-shaped cables buried in the ground at a depth of 2m. They studied the effect of change the thermal conductivity of the soil on thermal behavior underground cables. The thermal conductivity of the soil was used (0.5-1) W/m.K and thermal conductivity of backfill is 1.54

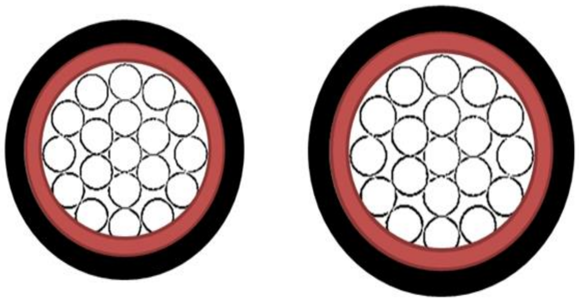
W/m.K. Also, they studied the effect of the change in the thermal conductivity of the backfill from (1-3) W/m.K and the thermal conductivity of the soil 0.554W/m.K. Their results showed that the thermal conductivity of the soil and the backfill has a significant role in the design of the cables where high thermal conductivity of the soil reduces the temperature of the conductor cable. Also, they found that replace mother ground with backfill material reduces the cable temperature with 14ºC.

In this paper, the effect of some properties related with the cable is (the size of the cable and the type of conductor material) add to the effect of the weather conditions such as ambient temperature, current capacity and thermal conductivity of soil on the thermal behavior of cables studied numerically depending on the weather conditions in the city of Nasiriya.

## 2. Problem description

The selected underground cables for thermal state evaluation are copper conductor cables with (95 mm$^2$) and (240 mm$^2$), aluminum conductor cables with a cross-sectional area (95mm$^2$) and (240mm$^2$) which are widely used in Iraqi electrical networks. Figure (1) represents the real geometry of the cables consisting of a set of wires and insulation XLPE and jacketing PVC. Figure (2) represents a computational model of the cables. For the purposes of modeling, the cables were described as three circles of (aluminum conductor or copper conductor), insulation XLPE and jacketing PVC. The computational domain consists of the soil domain and the cable section. Using two-dimensional modeling, the soil domain dimensions are (3m*3m). The computational domain scheme is as in Figure (3).

The cables used according to International Standard (IEC 60502) as shown in table (1) and table (2), both tables describe the physical and electrical properties of the cables. According to these specifications, the maximum temperature of the cables is 90ºC.



a-Aluminum or copper conductor cables
A= 95 sq.mm.

b-Aluminumor copper conductor cables
A= 240 sq.mm.

Figure.1 The real geometry of the cables

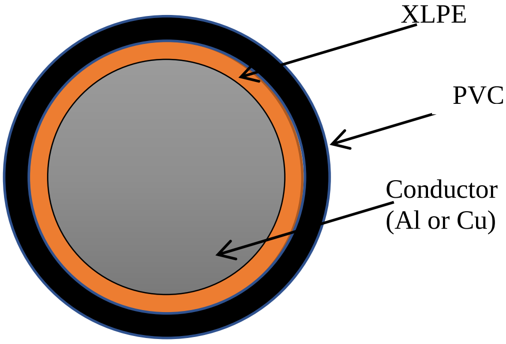


Figure.2 The computational model of the cables.

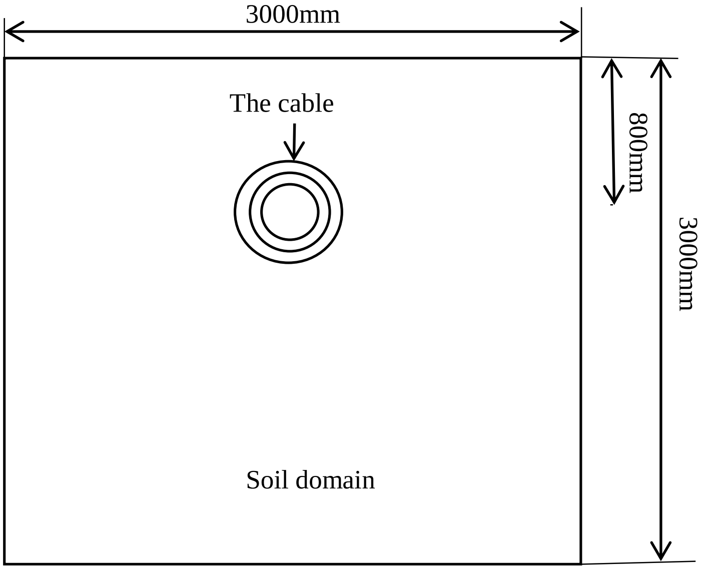


Figure.3 Schematic of the computational domain.

Table 1. Cu cables based on IEC 60502 [10].

| Nominal Cross Section | Nominal Insulation Thickness | Nominal Sheath Diameter | Approx. Overall Diameter | Approx Cable Weight | Max DC Resistance at 20ºc |
|---|---|---|---|---|---|
| mm$^2$ | mm | mm | mm | Kg/km | Ohm/km |
| 95 | 1.1 | 1.5 | 16.7 | 980 | 0.193 |
| 240 | 1.7 | 1.7 | 25.5 | 2410 | 0.0754 |

Table 2. Al cables based on IEC 60502 [10]

| Nominal Cross Section | Nominal Insulation Thickness | Nominal Sheath Diameter | Approx. Overall Diameter | Approx Cable Weight | Max DC Resistance at 20ºc |
|---|---|---|---|---|---|
| mm2 | mm | mm | mm | Kg/km | Ohm/km |
| 95 | 1.1 | 1.5 | 17.8 | 445 | 0.3200 |
| 240 | 1.7 | 1.7 | 27.5 | 1070 | 0.1250 |

## 3- Governing equations:-

The governing equations used to solve the model are heat conduction equation with the steady-state for two-dimensional underground power cable system which can be written as follows [7]:

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)=-q^{\cdot} \qquad \dots(1)$$

For determining the heat generated rate due to the electric current passing through the conductor cable.

$$q^{\cdot}=\frac{I^2R}{A\,L} \qquad \dots.(2)$$

These losses are calculated for conductor without insulation, where the loss of insulation is very minor can be neglected. Also, Insulation losses are considered when operational with high voltage cables [1].

## 4- Boundary conditions:-

Boundary conditions are used to complete the model are as follows;

The soil was considered as a solid medium. From the numerical simulation of the thermal condition of the underground cables. The temperature is set at the top and bottom of the computational domain, Where the top part is the ambient temperature ($T_a$) and the bottom part of the computational domain is the soil temperature ($T_s$) corresponds to the temperature of the soil, which is measured at a depth of 3m in southern Iraq.

The boundary conditions are set on the right and left sides of the computational domain a zero heat flux.

The heat generated from the cable is calculated for the conductor as a joule loss. This value used in the numerical modeling of underground cables as a thermal source and considered as source terms.

## 5. Numerical solution

The model solved numerically by the governing equations and boundary condition using (FVM) Finite Volume Method. The heat transfer between the cable and the soil was done by using computational fluid dynamics modeling. (CFD) Computational Fluid Dynamics is a technique used widely in heat and mass transfer investigations where these models can be easily applied to estimate the thermal state of the main components of electrical distribution networks such as underground cables, overhead conductors and transformers [11].

The FLUENT /ANSYS software used to solve the problem and obtain numerical results. The convergence criterion was defined by the residual value $10^{-12}$ for energy to control the numerical solution.

Table3.The thermal and physical properties for components of the cable [12].

| Material | Density (kg/m3) | Specific heat (J/kg.. k) | Thermal conductivity (W/m..k) |
|---|---|---|---|
| Copper | 8978 | 381 | 387.6 |
| Aluminum | 2719 | 871 | 202.4 |
| XLPE | 950 | 3750 | 0.333 |
| PVC | 1600 | 1500 | 0.25 |

Table 4. The thermal and physical properties for different types of soil [13].

| Type of soil | Density (kg/m3) | Specific heat (J/kg. k) | Thermal conductivity (W/m. k) |
|---|---|---|---|
| Dry soil | 2050 | 1840 | 0.52 |
| Moist soil | 1470 | 1553 | 1 |
| Saturated soil | 1500 | 880 | 1.4 |

## 6. Results and discussions

To verify the accuracy of the calculated results of the model underground cables compared with other model presented in [14] consists of a single cable underground, where the cross-section of conductor 630mm$^2$, insulation XLPE and oversheath. The computational domain used is 1600mm*1600mm, ambient temperature and soil temperature in summer are 288K and 298K respectively either soil temperature and ambient temperature in winter are 283K.

Table (5) shows the comparison between the numerical results of the present model with the numerical results in [14] to calculate the temperature of the cable. The table illustrations there is an acceptable agreement between the calculated results of the presented model and the numerical results in [14]. The average error of the winter season with current 470A is 0.89%, the summer season with current 470A is 0.82%, the winter season with current

940A is 1.13% and the summer season with current 940A is 1.18%.

Table 5. Comparison between the results of the present model and the results in [14]

| Condition | Current (A) | The temperature of the conductor (K) | |
|---|---|---|---|
| | | Results in [14] | Results of the present model |
| Base case winter | 470 | 293.43 | 290.79 |
| Base case summer | 470 | 304.95 | 302.44 |
| Base case winter | 940 | 317.77 | 314.17 |
| Base case summer | 940 | 334.74 | 330.76 |

**Fig.4** indicates the contours of temperature cables for aluminum and copper cables when soil temperature and ambient temperature (Ts=299.3K, Ta=308K) and current capacity 500A. From these figures, one can see that the maximum temperature of the conductive material and the high heat generated due to the losses of Jules from the passage of current through the conductor, which contributes to the high temperature of the conductor and other parts of the cable. Also, The aluminum cable with a cross-sectional area 95mm$^2$ is higher than the other cables due to increase the thermal resistance, the cable lowest temperature is the copper cable with a 240mm$^2$ enables it to carry more current capacity. In addition, it can be noted that there is a difference in the temperature of the cables due to the type of conductor material and the cross-section of the cable.

**Fig.5** describes the variation of conductor temperature with ambient temperature for the aluminum conductor cables with nominal cross-section 95mm$^2$ in Fig.5a and nominal cross-section 240 mm$^2$ in Fig.5b under different current and (Ts=299.3K). From these figures, it can be seen that the temperature of the conductor cable increases with increasing ambient temperature due to increase ambient temperature reduces the heat dissipation produced by cable. Also, increasing current and ambient temperature will result in a high temperature cable and thus lower energy transferred through cable because both factors contribute to the high temperature of the cable. In addition, it can be perceived that nominal cross-section cable 240 mm$^2$ has the lowest temperature because the cables have higher conductivity and therefore the loss of power is reduced.

**Fig.6** shows the variation of conductor temperature with ambient temperature for the copper conductor cables with nominal cross-section 95mm$^2$ in Fig.6a and nominal cross-section 240 mm$^2$ in Fig.6b under different current and (Ts=299.3K). It can note from these figures that, the temperature of the conductor cable increase with increasing ambient temperature. Also, from Fig.6a it can be found that at low current, the temperature conductor cable does not exceed the permissible limits though high ambient temperature, but at high load capacity it exceeds the thermal limits, from Fig.6b, the temperature of the copper conductor cable does not exceed the permissible limits even at the high load capacity with high ambient temperature and thus can increase the loading capacity with high ambient temperature.

**Fig.7** shows the variation of conductor temperature with the current for the aluminum conductor cables when ambient temperature 308K and soil temperature 299.3K. From this figure, it can be noted that the conductor temperature increases with increasing current because the resistance of the cable causes loss of power and thus loss convert into heat energy that causes heating the cable. Also, it can be observed that the aluminum conductor cable with nominal cross-section 240 mm² has a temperature lower than the aluminum conductor cable with nominal cross-sectional area 95 mm² due to increase cross-section increases the rate of heat dissipation production from the cable.

**Fig.8** displays the variation of conductor temperature with the current for the copper conductor cables when ambient temperature 308K and soil temperature 299.3K. One can be perceived that the conductor temperature increases with increasing current due to Jule losses resulting from the passage of the current through the conductor cable that causes the cable heating. From the other side, it can show that copper conductor cable with nominal cross-section 240 mm² has a temperature lower than the copper conductor cable which has a nominal cross-sectional area of 95 mm² therefore, the cable temperature with cross-section of 240 mm² does not exceed the thermal limit allowed at high-loading capacities.

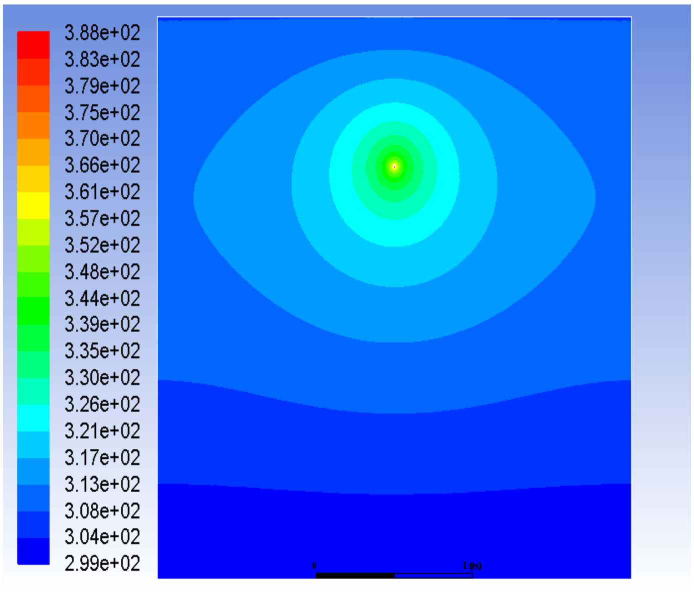
**Fig.9** describes the variation of conductor temperature with ambient temperature for the aluminum conductor cables with nominal cross-section 95mm$^2$ in Fig.9a and nominal cross-section 240 mm$^2$ in Fig.9b for different soil types and (Ts=299.3K). From these figures, it can be seen that the temperature of the conductor cable increases with increasing ambient temperature for all soil types. Also, the temperature of the cable differs depending on the type of soil where the cable has the highest temperature in the dry soil followed by the moist soil, then the saturated soil because of the change in the thermal conductivity where changes the heat transfer rate, high thermal conductivity contributes to faster heat transfer thus reduces the temperature of the cable. In addition, it can find the cable temperature with a cross-section of 95mm² exceed the thermal limits allowed even saturated soil.

**Fig.10** illustrates the variation of conductor temperature with ambient temperature for the copper conductor cables with nominal cross-section 95mm$^2$ in Fig.10a and nominal cross-section 240 mm$^2$ in Fig.10b for different soil types and (Ts=299.3K). It can be perceived that the temperature of the conductor cable increases with increasing ambient temperature for all soil types. Also, it can be noted that the cable conductor has the lowest temperature when the soil saturated compared with other types of soil because the saturated soil has low thermal resistance and thus increase the heat dissipation of the cable. In addition, the cable temperature with a cross-section of 240mm² when saturated soil and moist soil with high ambient temperature do not exceed the thermal limits, but the soil is dry with the ambient temperature rising thus the cable temperature exceeds the permissible limit.

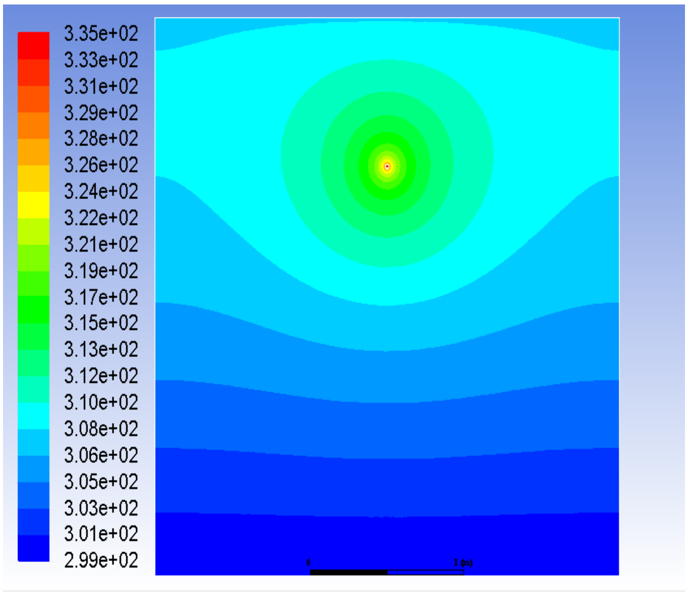
**Fig.11** displays the variation of conductor temperature with the current for the aluminum conductor cables for different soil types with ambient temperature 308K and soil temperature 299.3K. From these figures, it can find that the conductor cable temperature increases with an increasing current for all soil types because of the loss of power transmitted through the conductor which raises the cable temperature. Also, the conductor cable temperature is higher in the dry soil due to the low moisture content which contributes to increased thermal resistance and thus decreases in heat dissipation resulting from the cable. In addition, the aluminum conductor cable with a cross-sectional 240mm$^2$ has a temperature less than the cable that has a cross-sectional 95mm$^2$ for all soil types and thus higher current.

**Fig.12** shows the variation of conductor temperature with the current for the copper conductor cables for different soil types with ambient temperature 308K and soil temperature 299.3K. From these figures, one can be noted that the conductor cable temperature increases with an increasing current for all soil types. Also, it can be seen that the temperature of the conductor cable decreases in the soil is saturated due to increased moisture content which increases heat dissipation. In addition, at low current, the conductor cable temperature is converted to all types of soil, but with an increasing current capacity, the difference in temperature between the soil types increases depending on the nature of the soil.

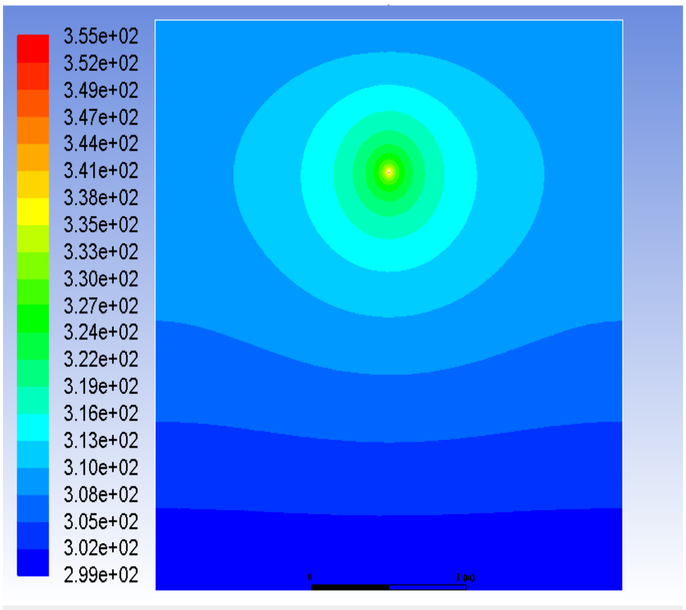
**Fig.13** shows the maximum cable temperature in the conductor in various cables with a load capacity of 500A, ambient temperature 308K and soil temperature 299.3K for different types of soil. From this figure, it can be seen that the maximum temperature of the cable that is the aluminum conductor with cross-sectional 95mm$^2$ because it has high resistance compared to other cables, in addition, the dry soil has a low thermal conductivity compared to moist soil and saturated soil. Also, the difference in temperature between the cables returns to the size of the conductor, the type of conductive material and the type of soil contributes significantly to determining the thermal behavior of the cables. In addition, the aluminum conductor cable with a cross-sectional 95 mm$^2$ exceeds the permissible thermal limit (363K) with (6.6%), (13.55%) and (34.80%) for saturated, moist and dry soil respectively. This means that the current cannot be increased, especially in the dry soil, which should be reduced to maintain the cable. The aluminum conductor cable with a cross-sectional 240mm$^2$ exceeds the permissible thermal limit with (2.4%) for dry soil, this small increase in case dry soil does not affect the safety of cable operation, but it means cannot increase the load capacity. The copper conductor cable with a cross-sectional 95mm$^2$ exceeds the permissible thermal limit with (1.7%), and (14.53%) for moist and dry soil respectively. Finally, the copper conductor cable with a cross-sectional 240mm$^2$ has the lowest temperature due to its high conductivity and cross-sectional area compared to the other cables so the cable temperature is less the permissible limits for all soil types, thus increasing the current capacity.



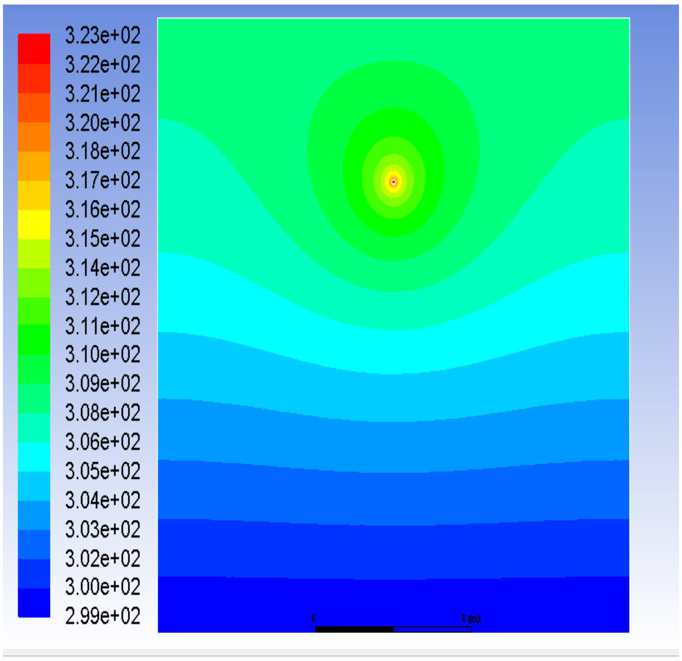
a- Aluminum conductor cable nominal cross section 95 sq.mm.



b- Aluminum conductor cable with nominal cross section 240 sq.mm.

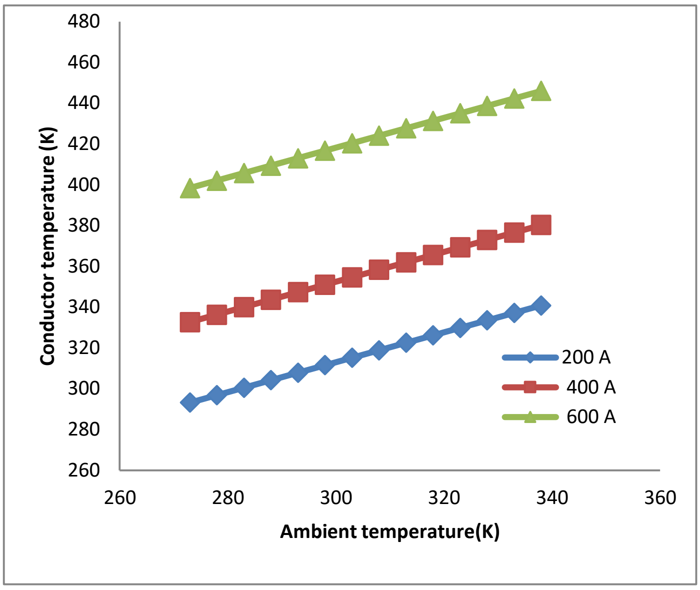


c- Copper conductor cable nominal cross section 95 sq.mm.

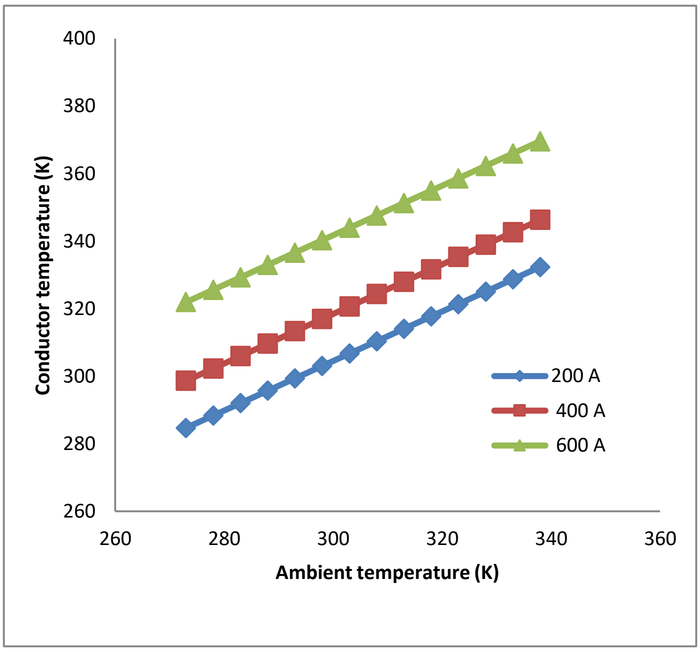


d- Copper conductor cable nominal cross section 240 sq.mm.

Fig.4 Cross section of static temperature, contour (K) for the underground cables with soil temperature and weather conditions ($T_s$=299.3K, $T_a$=308K) and current capacity 500A.

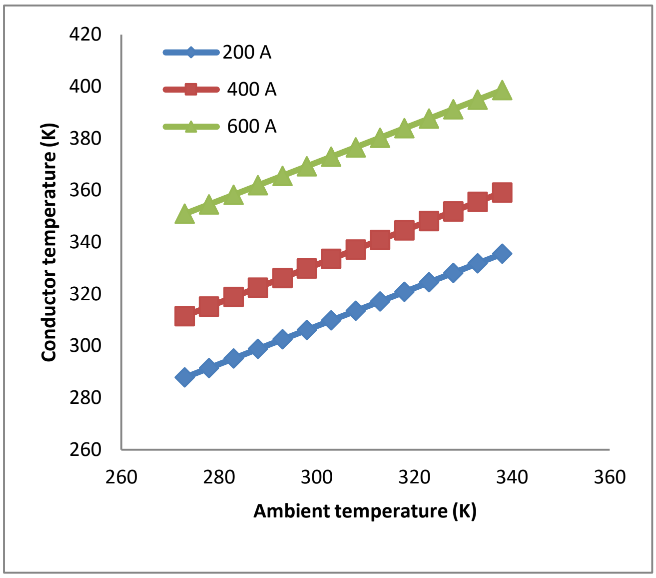


a- nominal cross section of a conductor A=95 sq.mm.

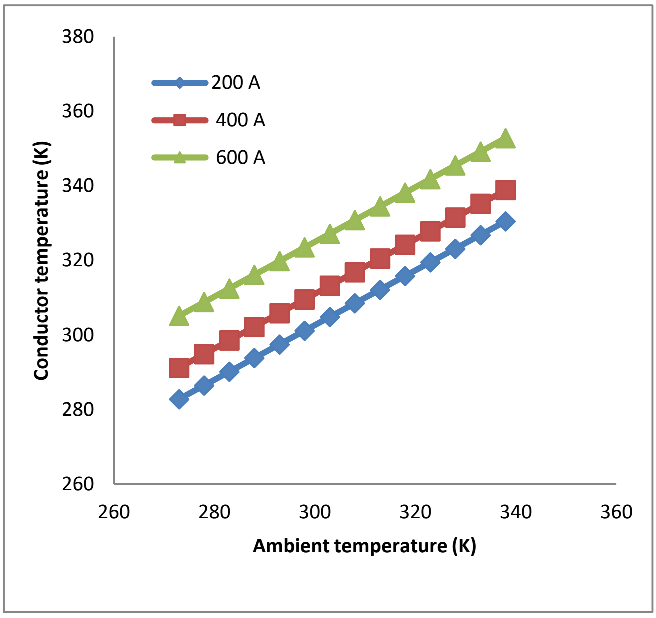


b- nominal cross section of a conductor A=240 sq.mm.

Fig.5 Variation of conductor temperature with ambient temperature for aluminum conductor cable.



a- nominal cross section of a conductor A=95 sq.mm.



b- nominal cross section of a conductor A=240 sq.mm.

Fig.6 Variation of conductor temperature with ambient temperature copper conductor cable.

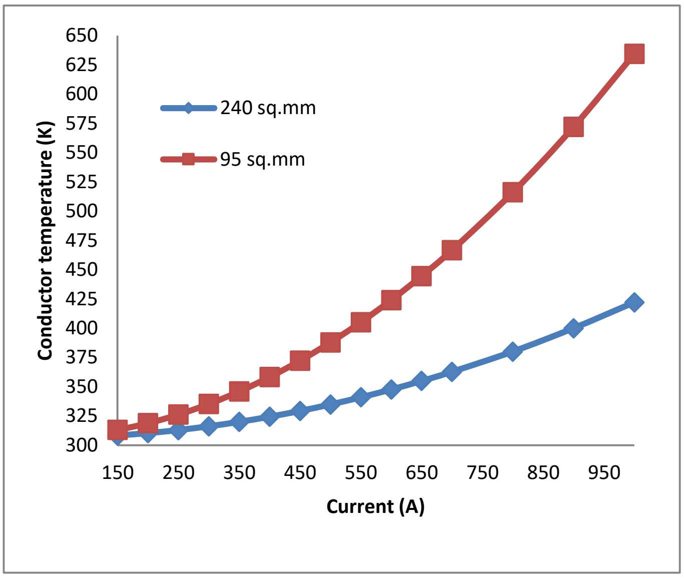


Fig.7 Variation of conductor temperature with current for aluminum conductor cable.

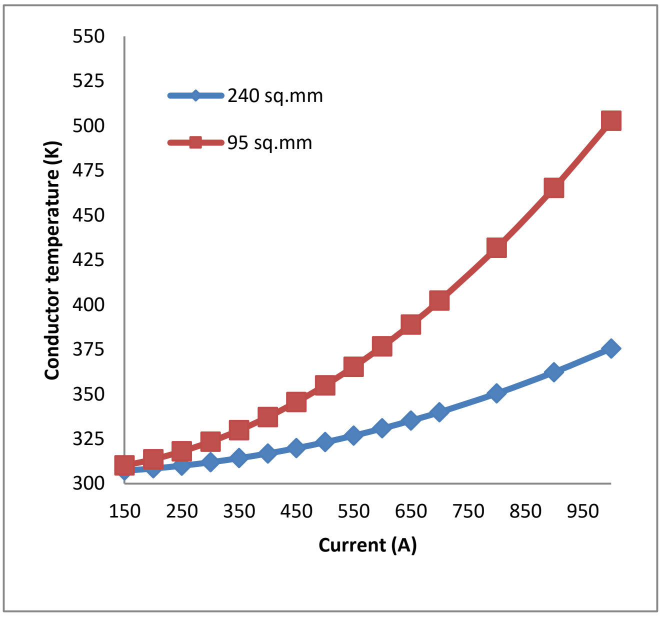
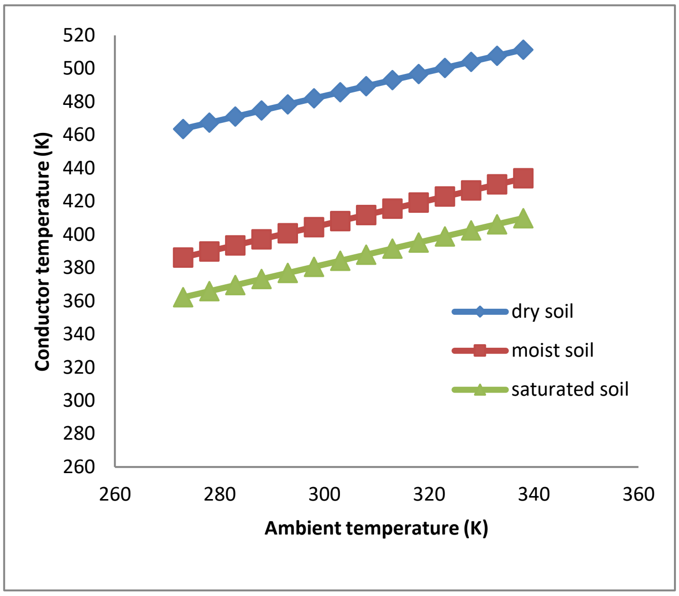
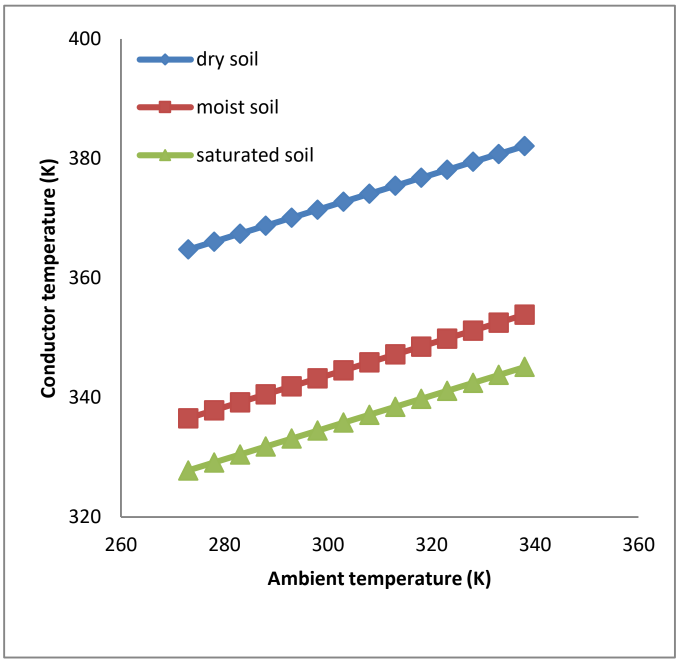


Fig.8 Variation of conductor temperature with current for copper conductor cable.

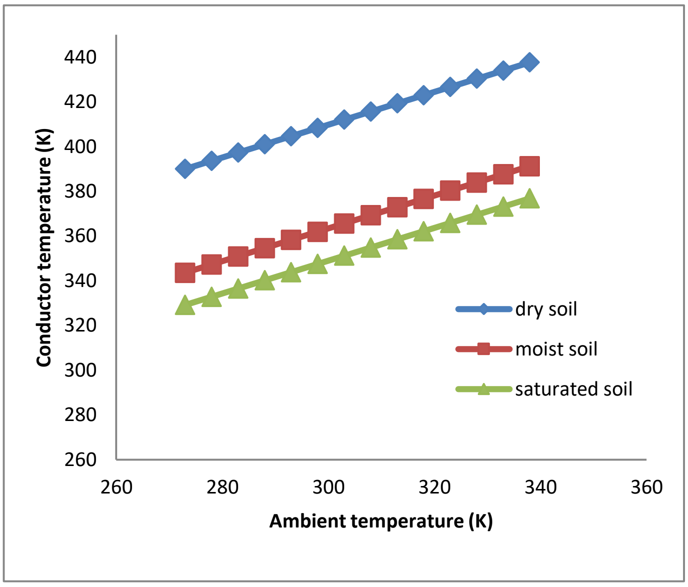


a- nominal cross section of a conductor A=95 sq.mm.

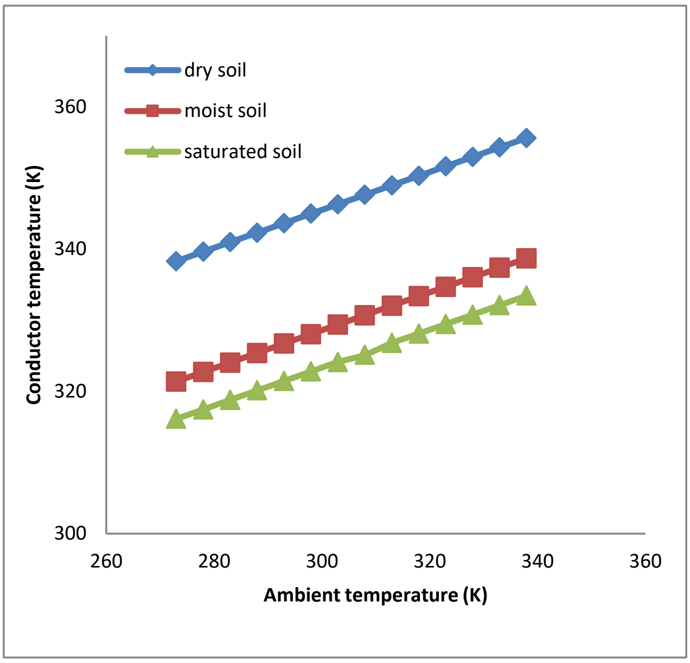


b- nominal cross section of a conductor A=240 sq.mm.

Fig.9 Variation of conductor temperature with ambient temperature for aluminum conductor cable.

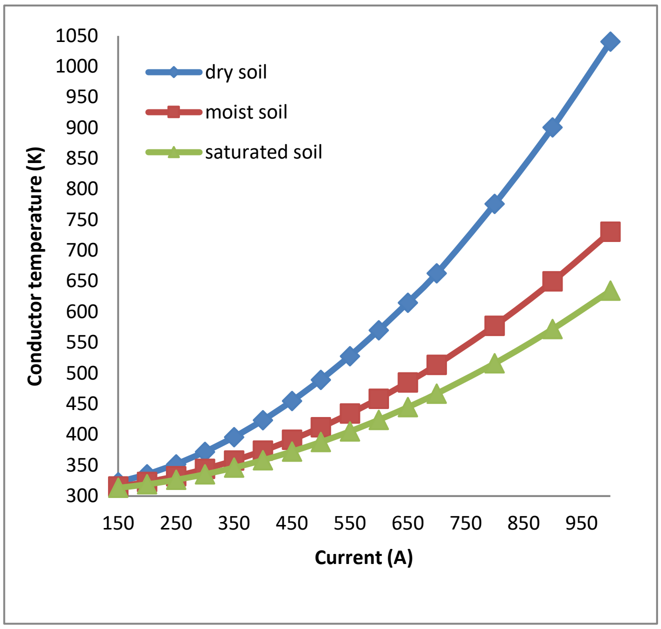


a- nominal cross section of a conductor A=95 sq.mm.

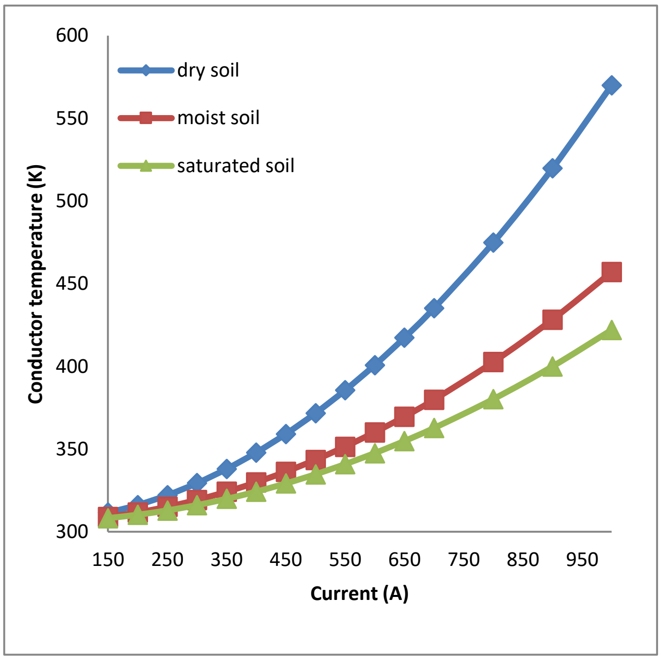


b- nominal cross section of a conductor A=240 sq.mm.

Fig.10 Variation of conductor temperature with ambient temperature for copper conductor cable.

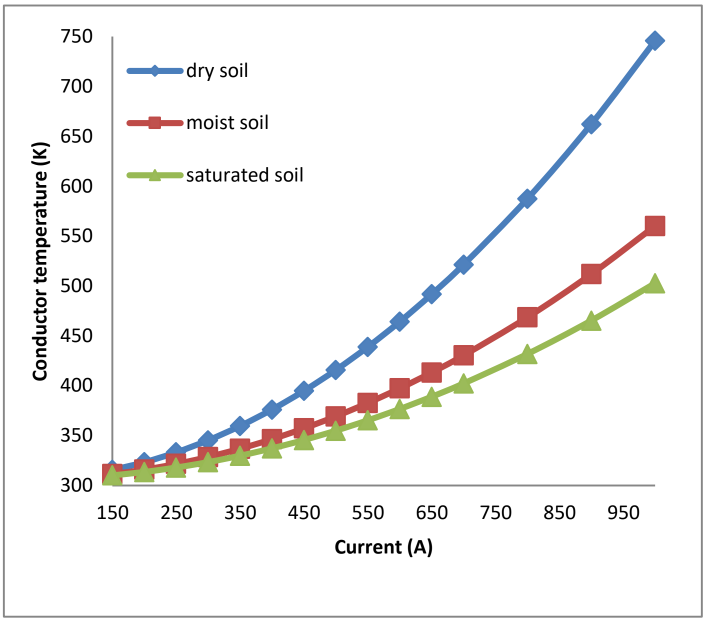


a- nominal cross section of a conductor A=95 sq.mm.

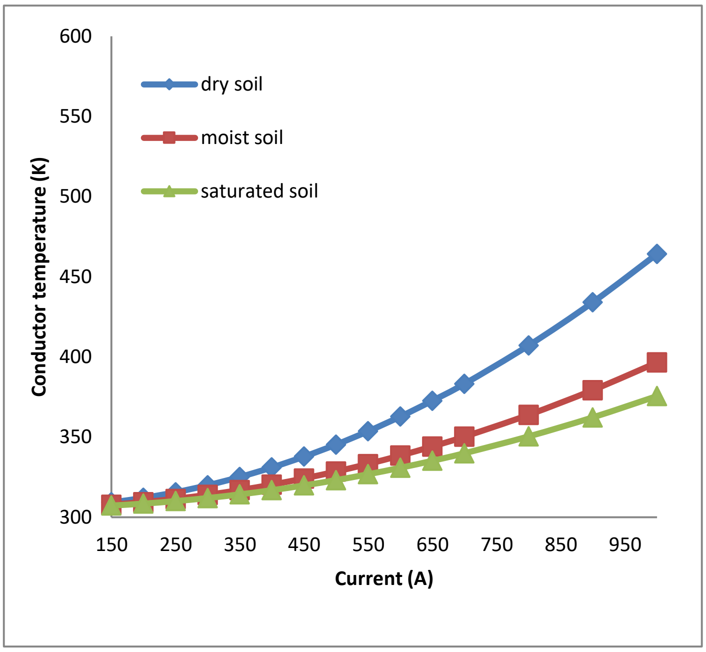


b- nominal cross section of a conductor A=240 sq.mm.

Fig.11 Variation of conductor temperature with current for aluminum conductor cable.



a- nominal cross section of a conductor A=95 sq.mm.



b- nominal cross section of a conductor A=240 sq.mm.

Fig.12 Variation of conductor temperature with current for copper conductor cable.

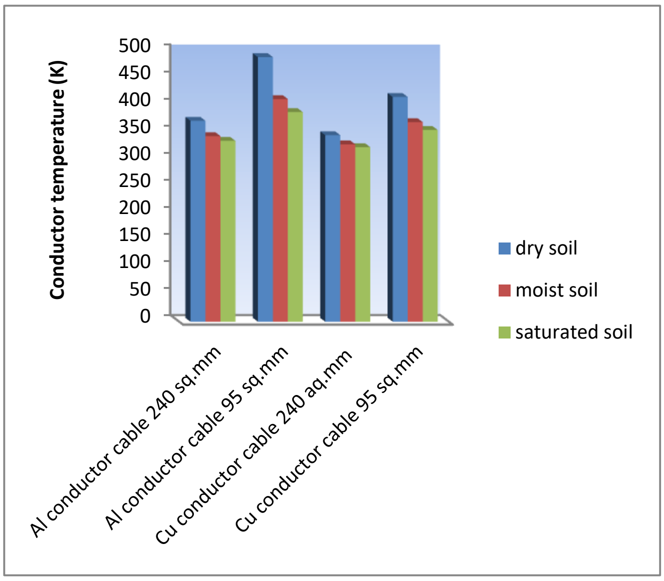


Fig.13 The maximum cable temperature in the conductor in various cables at different types of soil.

## 7- Conclusions:

In this paper, the thermal behavior of underground cables has been studied based on changing the surrounding conditions such as ambient temperature, the thermal conductivity of soil and loading capacities, their effect on determining the thermal behavior of cables. From the results obtained it can conclude the following:-

1- Increasing the current capacity leads to an increase the temperature of the cable.

2- Increasing the ambient temperature has a significant impact on increasing the temperature of the cable and thus less current capacities.

3- Increasing the thermal conductivity of the soil increases the heat dissipation resulting from the cable, Therefore, the loading capacity is higher. As the Nasiriyah soil is saturated soil, the underground cable system is very suitable to have soil good thermal properties compared to other types of soil.

4- Copper conductors have load capacities higher than aluminum conductors at the same cross-section area.

5- Increasing the cross-section area of the conductor increases the ability of the conductor to carry higher current, thus increases the power transmitted across the line.

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