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Graduation project

Buried Underground Cable

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Hebron – Palestine

May, 2016

جامعة بوليتكنك فلسطين

الخليل – فلسطين

كلية الهندسة والتكنولوجيا

دائرة الهندسة الكهربائية

إسم المشروع

Buried Underground Cable

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بناء على نظام كلية الهندسة والتكنولوجيا وإشراف ومتابعة المشرف المباشر على المشروع وموافقة أعضاء اللجنة الممتحنة تم تقديم هذا المشروع إلى دائرة الهندسة الكهربائية وذلك للوفاء بمتطلبات درجة البكالوريوس في الهندسة تخصص هندسة تكنولوجيا الطاقة الكهربائية

توقيع المشرف

توقيع اللجنة الممتحنة

توقيع رئيس الدائرة

1

Chapter one

Introduction

1.1 Overview.

1.2 Motivation.

1.3 Problem statement.

1.4 Related work.

1.5 Budget

1.6 Time schedule

1.1 Overview

The electrical distribution system is used to transfer the power through several distances. It can be classified for several levels. These are the high voltage transmission system, Medium voltage distribution system, and Low voltage distribution system. The electrical power can be distribute and transferred between the several levels by cables. These cables can be divided into two types. First one is overhead line and the other one is underground cables. However, at Palestine usually used the underground cables to deliver medium voltages [1].

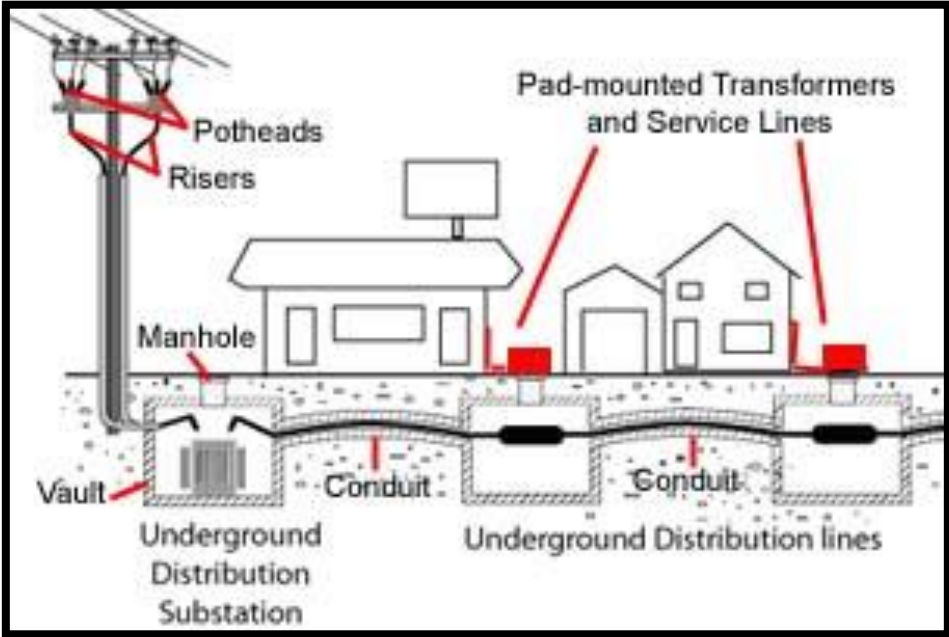


Fig (1.1) Underground distribution system [1]

The power engineering should be studies the principle of operation, design and thermal behavior of underground cable, because of that underground cable will be the future of electrical power transferred in Palestine to solve the problems of overhead transmission lines.

1.2 Motivation

Due to the increase use of underground cable, it's essential to deliver the power continuously to the customer with satisfied behavior, so the buried system of the cables must detect and initiate the correct action.

So there are several things that insure the importance of our project and some of these:

- 1) Analysis the thermal behavior of underground cables.
- 2) Investigated the appropriate methods to buried underground cable to decrease losses in power cable.
- 3) The related economic aspects.
- 4) The increasing awareness of buried underground cable.

1.3 problem statement

The project statement is to investigate the appropriate methods to decrease the effect of heat generated inside the cable is the result of the current passing through the cable (Ohm losses, I^2R), insulation losses and heat form surrounding soil. This heat decreases the accuracy of transferred current and withstanding insulation.

Thermal characteristics of the materials around of the cable (soil, ducts, concrete,) and environmental condition, all of these conditions effect to the current through the cables.

1.4 Related works

Ampacity¹ of underground cable has been proposed in the literature for analysis an effect of the heat on the ampacity. El-Kady in [2] proposed the calculation of the sensitivity of power cable ampacity to variation of design and environmental parameters.

Al-Saud said, the heat transfer analysis of underground power cable investigates under different loadings using experimental to analyze the behavior of underground cable directly buried in sand and soil, then simulate using finite element tools, and he conclude that a good correspondence between both experimental and simulation results. The effect of load overheating on the adjacent soil, on boundary losses was highlighted, and parameters investigation was performed of each case loading [2].

There are many factors affect cables performance and aging such as cable resistivity, ampacity, length, load, soil thermal resistivity for underground cables and different type of insulation. The thermal effects are part of these factors and affect the performance of cables in different aspects especially for underground cables because there are many parameters involved such as the atmosphere temperature, soil thermal resistivity and the power dissipate from the cable in form of heat [2].

Ampacity is a term given by Del Mar in [3] to the current carrying capacity of a cable. Ampacity calculation techniques are as the cables themselves. George Ander has summarized the history of ampacity calculation in his [3] book. Carlos Garrido in [4] proposed theoretical model to calculate steady-state and transient ampacity and temperature, he present mathematical model which solves the heat diffusion equation cylindrical coordinates inside the cable and in Cartesian coordinate in surrounding soil. Francisco de León in [5] proposed the calculation of underground cable ampacity he introduce the heat transfer mechanisms in underground cable installation and analyze the available solution methods of diffusion equation, using the Neher-MacGrath method.

The heat transfer mechanism underground cable is conduction. The heat is produced when a high current passes through the cable causes the copper molecules to collide in very high rate producing heat that is transferred from one layer of the cable to another until reaches the cable's surface out to the soil [5].

¹ Ampacity is the current carrying capacity in the cable.

1.5 Budget

Table (1.1) the budget of the project

Tools	Price NIS
Sandy soil	330
Limestone soil	150
Wooden box	400
Data logger	12500
Current source	Used in company
15 kv XLPE cable	Used in company
Other	700
Total	14080

1.6 Time schedule

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Task 1	■	■														
Task 2			■	■	■	■	■	■	■							
Task 3									■	■	■	■	■	■		
Task 4													■	■	■	■
Task 5																■

Task 1: Coordination with the company to prepare the equipment's

Task 2: waiting the equipment's

Task 3: setup the experimental.

Task 4: analysis the result.

Task 5: write the graduation book.

2

Chapter two

Underground Cables

2.1: Distribution System.

2.2: Network Element.

2.3: Types of cables faults.

2.4: Cables used in the Jerusalem District Electricity Company (JDECO).

2.1: Distribution system

Power plant (power generation), transmission system and distribution system are the major components of an electric power system [6].

Electrical power is generated in power plants, after that it is rising the voltage to high voltage such as: (66 KV-132 KV) by using step-up voltage transformers, then the power flow through transmission lines. When access to the areas of energy consumptions, it is reduced the voltage to medium voltage (33 KV and 11 KV) by step-down voltage transformers. Later, the voltage reduced again to low voltage (up to 400 V).

2.2: Network Element

2.2.1: protection device

Faults and other abnormal conditions on power system cause:

- Damage to faulty equipment.
- Loss of synchronism between generation sources.
- Danger to personal.
- Voltage reduction (loss of supply).
- Potential damage to unfaulted equipment.

So protection devices used to detect faults and abnormal conditions, isolate faulty equipment and take remedial action.

There is many protection devices used in the network, such as Autoreclosers, Fuses, Surge Arrester, Isolators and Load Break Switch.

2.2.2: Distribution Transformers

The main function of the transformer is to transform the voltage to high voltage or low voltage. There are two types of transformers, Step up transformer and step down transformer. Step up transformer used in power plant to transform the voltage to high voltage, and the step down transformer used in distribution system to transform the voltage to medium voltage and low voltage (220V and 380V).

2.2.3: Transmission lines and Cables

Underground cables are a viable alternative to overhead transmission lines when proper consideration is given to the many details of using these types of systems. Cables, however, have different characteristics than overhead lines that must be factored into design, ratings, switching, reactive compensation, operation, maintenance and repair.

Electrical power can be transmitted or distributed either by overhead system or by underground cables. The underground cables have several advantages such as less liable to damage through storms or lightning, low maintenance cost, less chance of fault, smaller voltage drop and better general appearance.

However, their major drawback is that they have greater installation cost and introduce insulation problems at high voltages compared with the equivalent overhead system. For this reason, underground cables are employed where it's impracticable to use overhead lines. Such locations may be thickly populated areas where municipal authorities prohibit overhead lines for reasons of safety, or around plants and substations or where maintenance conditions do not permit the use of overhead construction [7-8].

The chief use of underground cables for many years has been for distribution of electric power in congested urban areas at comparatively low or moderate voltages. However recent improvements in the design and manufacture have led to the development of cables suitable for use at high voltages. This has made it possible to employ underground cables for transmission of electric power for short or moderate distances [8].

2.2.4: Underground Cables

The main component of an underground cable is one or more conductors which surrounded by cover of suitable insulation and by a protecting cover.

There are many types of cables that could be used; the function depends on the service requirements and working voltage. There are many important requirements that the cables must fulfill:

1. Aluminum of high conductivity or copper should be used on the cable.
2. The cable must carry the wanted load current without overheating and causes voltage drop within limit, which depends on the conductor size.
3. High degree of safety and reliability must be in the cable which achieved by the suitable thickness.
4. The cable must be protected with mechanical tools to be safe.
5. The factory of cables should use stable chemical and physical component.

2.2.4.1: Construction of cables

The fig2.1 shows the general construction of cable. There are several components of cables: [4]

1. Core or Conductor
One or several conductors could be in the cable according to the service intended. Tinned copper or aluminum should cover the cable to be flexible.
2. Insulation
Suitable thickness of insulation should be provided, which depend on voltage, impregnated paper, varnished cambric or rubber mineral compound support the insulation.
3. Metallic sheath
The protection from the environmental condition such as moisture, and acid or alkaline materials in the soil and weather.
4. Bedding
Fibrous materials are the component of the bedding layer along the metallic sheath to protect it from injury and corrosion.
5. Armoring
Contain one or two layers of galvanized steel wire or steel tape over the bedding, but some cables don't have Armouring protect cable from mechanical injury.
6. Serving
To protect Armouring layer from atmospheric condition, consist of fibrous as bedding. These components (bedding, armoring and serving) are only applied to cables for protection.

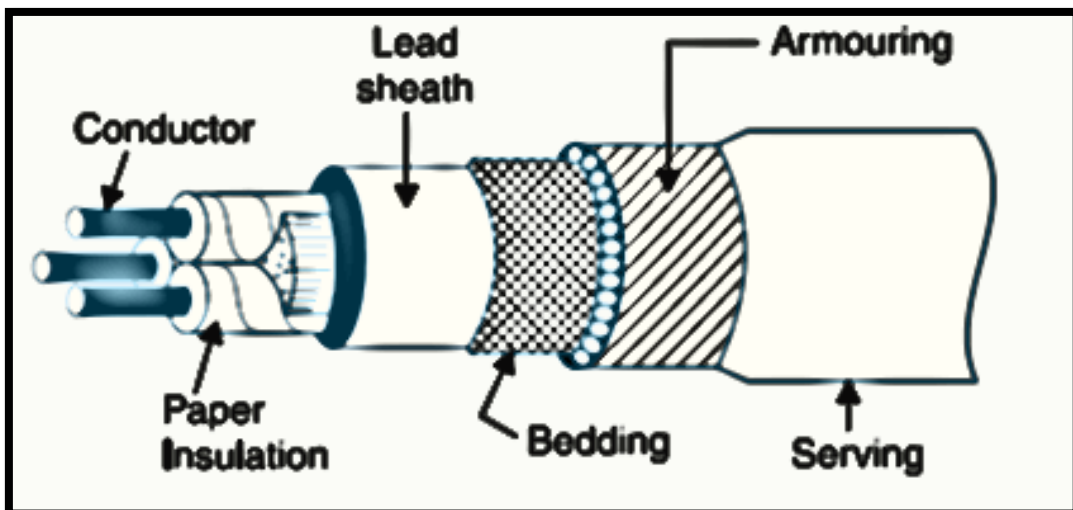


Fig (2.1) Construction of cables

2.2.4.2: Insulating materials for cables

The satisfactory operation of a cable depends to a great extent upon the characteristics of insulation used. Therefore, the proper choice of insulating material for cables is considerably important. In general, the insulating materials used in cables should have the following properties:

1. High insulation resistance to avoid leakage current.
2. High dielectric strength to avoid electrical breakdown of the cable.
3. High mechanical strength to withstand the mechanical handling of cables.
4. Non-hygroscopic i.e., it should not absorb moisture from air or soil. The moisture tends to decrease the insulation resistance and hastens the breakdown of the cable. In case the insulating material is hygroscopic, it must be enclosed in a waterproof covering like lead sheath.
5. Non-inflammable.
6. Low cost so as to make the underground system a viable proposition.
7. Unaffected by acids and alkalis to avoid any chemical action.

But not all above properties are available on the insulating material.

The principal insulating materials used in cables are: [9]

1- Rubber

Produced from oil products or from milky sap it has many properties such as relative permittivity and dielectric strength and resistivity of insulation is 10^{17} Ω .cm. Pure rubber couldn't be used as insulating material, because it readily absorbs moisture, and the safe temperature is low (about 38°C) in maximum, soft and liable to damage.

2- Vulcanized India rubber (VIR)

Mineral matter such as zinc oxide and red lead and (%3 - %5) Sulphur are mixed with pure rubber, then the product compound is rolled into thin sheets and cut into strips, then this rubber compound applied to the conductor heated to a temperature of nearly 150°C, this process known as Vulcanization., and the product known as Vulcanized India Rubber, which has greater mechanical strength and durability and wear resistant property than pure rubber, due to fast sulfur reaction with copper, therefore the cable with VIR insulation have tinned copper conductor. This kind is usually used for low and moderate voltage cables.

3- Impregnated paper

Chemically pulped paper made from wood chippings is the main component of this paper and then impregnated with some compound such as paraffinic or naphthenic material. It has many advantages such as low cost, and low capacitance, high dielectric strength and high insulation resistance, therefore it has almost superseded the rubber insulation. Although, it has many advantages, it suffers from hygroscopic which allow the absorption of moisture and so decrease the insulation resistance of the cable, due to this disadvantages paper insulated cables are always provided with some protective covering and are never left unsealed, they are used where the cable route has few joints, for example, they can be used for distribution at low voltages in areas where the joints are provided only at terminal apparatus. When the joints are required at number of places and the lengths are small, VIR cables will be less expensive durable than paper insulated cables.

4- Varnished Cambric

Varnish coated a cotton cloth, which also known as empire tape, the cambric is lapped on to the conductor in the form of a tape and then coated with petroleum jelly compound in order to allow for the sliding of one turn over other as the cable is bent. These cables are always provided with metallic sheath, because the varnished cambric is hygroscopic. Its permittivity is 2.5 to 3.8 and dielectric strength is about 4KV/mm.

5- Polyvinyl chloride (PVC)

The polymerization of acetylene produces this insulating material called PVC. It's compounded with certain materials known as plasticizers which are liquids with high boiling point, in order to obtain this material as cable insulation the plasticizers forms a gell and renders the material plastic over the desired range of temperature. PVC has high insulation resistance, good dielectric strength and mechanical toughness over a wide range of temperature. PVC considered as inert to oxygen and acids and alkaline. So, this type of insulation is preferred over a VIR in extreme environmental conditions, such as in cement factory.

PVC insulated cables are generally used for low an medium domestic light and power installations, because the mechanical properties of PVC are not so good as those of rubber.

6- Cross-Linked Polyethylene (XLPE)

Which composed of different chains of polyethylene, these chains connected together by cross linking, the main function for this linking is the prevention of melting or separating of the polymer at high temperature. So, XLPE can be used safely at elevated temperature application. XLPE has low dielectric losses, better ageing characteristics and resistance to water treeing. The temperature level limit is 250° C, and the normal operating from 90° – 110° C.

2.2.4.3: Classification of Cables

Cables for underground service may be classified in two ways according to:

- 1- The type of insulating material used in their manufacture.
- 2- The voltage for which they are manufactured.

However, the latter method of classification is generally preferred, according to which cables can be divided into the following groups:

- 1- Low-tension (L.T.) cables (up to 1KV).
- 2- High-tension (H.T.) cables (up to 11KV).
- 3- Super-tension (S.T.) cables (from 22 kV to 33 KV).
- 4- Extra high-tension (E.H.T.) cables (from 33 KV to 66 KV).
- 5- Extra super voltage cables (beyond 132 kV).

According to the type service for which it's intended, a cable may have one or more than one core, it may be single, two, three or four core.

For a three phase service, either 3-single core cables or three cables can be used depending upon the operating voltage and load demand.

Fig 2.2 shows the constructional details of a single core low tension cable. It consists of one circular core of tinned stranded copper or aluminum insulated by layers of impregnated paper. A lead sheath is surrounded the insulation which prevents the entry of moisture into the inner parts. Then overall serving of compounded fibrous material is provided to protect lead sheath from corrosion. Single core cables are not usually armored in order to avoid excessive sheath losses. The principal advantages of single core cables are simple construction and availability of lager copper section [10].

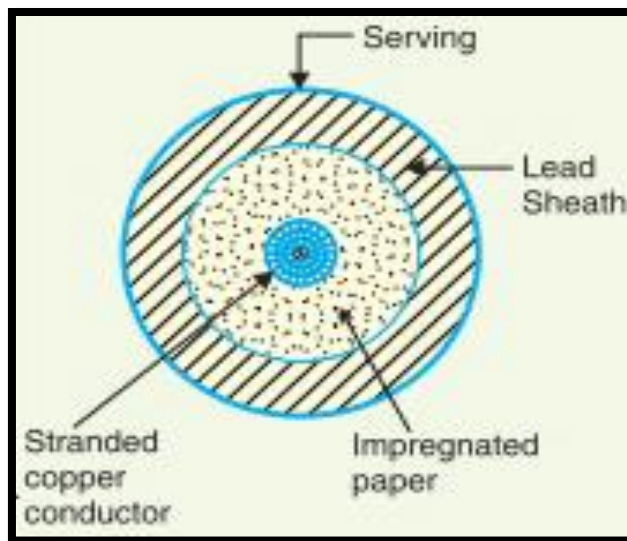


Fig (2.2) Single core low tension cable [10]

2.2.4.4: Cables for 3-phase service

In practice, underground cables are generally required to deliver 3-phase power. So, either 3-core cable or 3-single core cable may be used. For voltage up to 66 KV, 3-core cable (multi-core construction) is preferred due to economic reasons, but for higher voltage than 66 KV, 3-core cables become too large and unwieldy and so single core cables used.

The types of cables which used for 3-phase service: [10]

- 1- Belted cables (up to 11 KV).
- 2- Screened cables (from 22 KV to 66 KV).
- 3- Pressure cables (beyond 66 KV).

1- Belted cables

Used for voltages up to 11KV, but in extra ordinary cases, their use may be extended up to 22KV. Fig 2.3 shows the constructional details of a 3-core belled cable. The core is insulated from each other by layers of impregnated paper. Then there is layer of paper belt is wound round the grouped insulated cores. The fibrous insulating materials is filled the gap between the insulated cores to give circular cross section to the cable. The cores are stranded and may be of non-circular shape to make better use of available space. The lead sheath is covered with belt in order to protect the cable against ingress of moisture and mechanical injury. Armouring layers is covered the lead sheath.

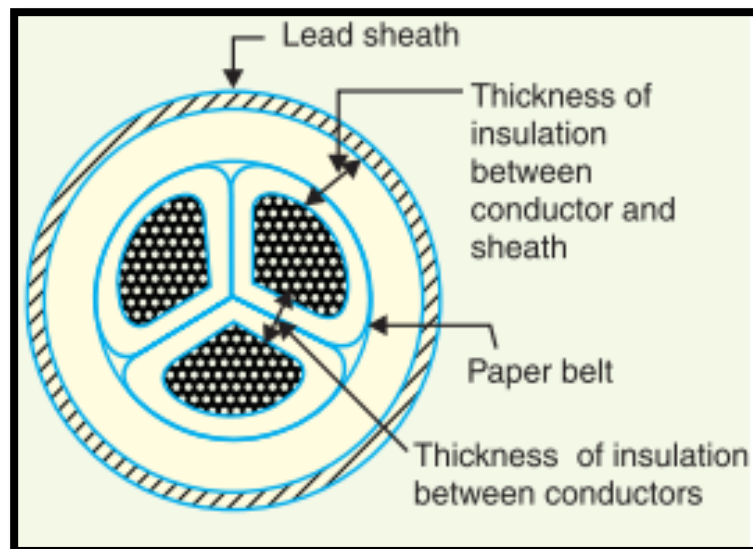


Fig (2.3) 3-core belled cable

The belted type construction is suitable only for low and medium voltages as the electrostatic stresses developed in the cables for these voltages are more or less radial. However, for high voltages (beyond 22KV), the tangential stresses also become important.

These stresses act along the layers of paper insulations. As the insulation resistance of paper is quite small stresses act along the layers. Therefore, tangential stresses setup, leakage current along the layers of paper insulation. The leakage current causes local heating, resulting in the risk of breakdown of insulation at any moment. In order to overcome this difficulty, screened cables are used where leakage current are conducted to earth through metallic screen.

2- Screened cables

These cables are suitable for use up to 33KV, but in special case their use may be extended to operating voltages up to 66KV. H type cables and S.L type cables are the two principal types of screened cables.

- a) H-type cables. This name due to the first designer H. Hochstadter. Fig 2.4 shows the constructional details of typical 3-core, H-type cable. Impregnated paper is insulated each core. A metallic screens which consist of perforated aluminum foil, is covered the insulation on each core. The cores are laid in such a way that metallic screens make contact with each other. An additional conducting belt is wrapped round the three cores. The cable has lead sheath, bedding, armouring but no isolating belt. Each core screen is in electrical contact with the conducting belt and the lead sheath. The electrical stresses are purely radial and consequently dielectric losses and decreased due to the lead sheath in are at earth potential.

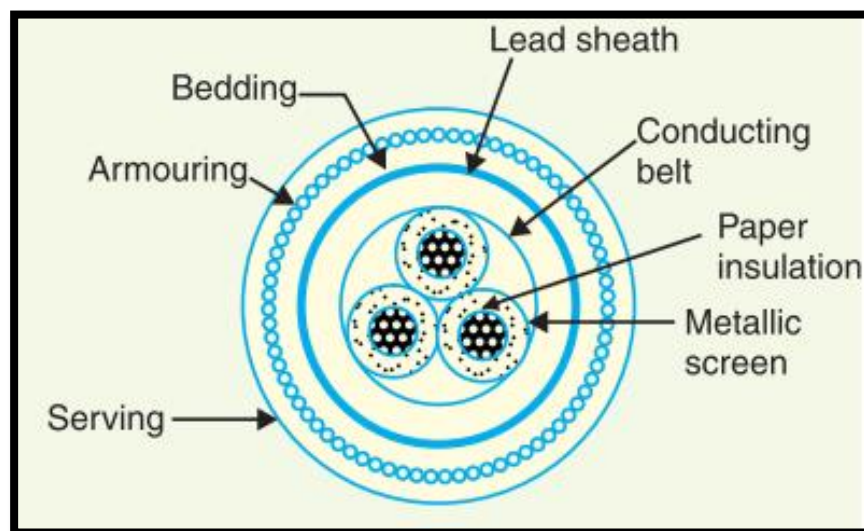


Fig (2.4a) Typical 3-core, H-type cable

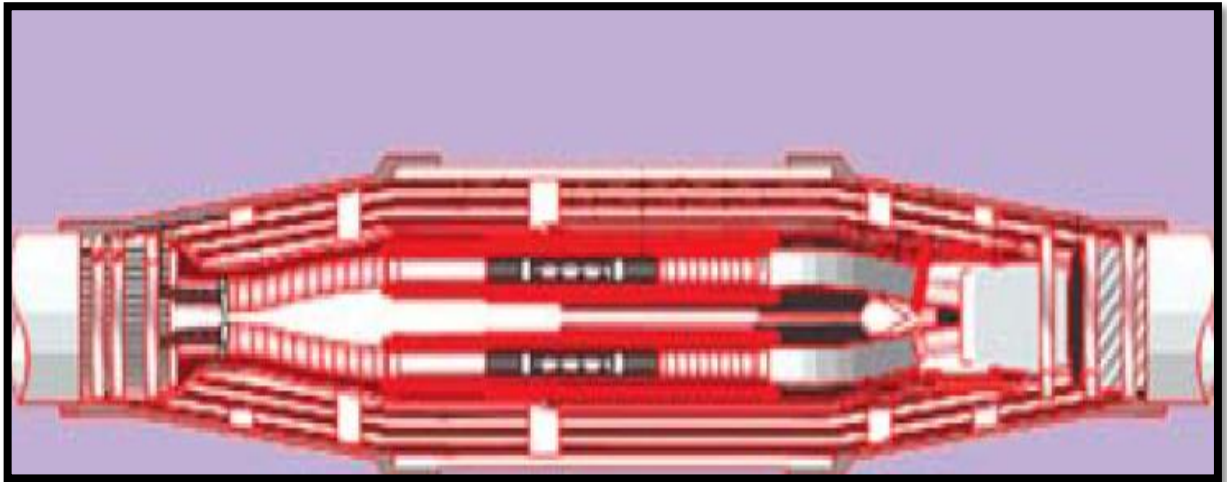


Fig (2.4b) H-type cable

There are two advantages for H-type cables. The possibility of air pockets or voids in the dielectric is eliminated due to the perforation in the metallic screens which assist in the complete impregnation of the cable with the compound. The voids if present tend to reduce the breakdown strength of the cable and may cause considerable damage to the paper insulation. Second advantages are increasing the heat dissipating power of the cable due to metallic screen.

- b) S.L type cables, basically it is H-type cable but the screen round each core insulation is covered by its own lead sheath. There is only armouring and serving are provided but there is no overall lead sheath. Fig 2.5 shows the constructional details of a 3-core S.L (separate lead).

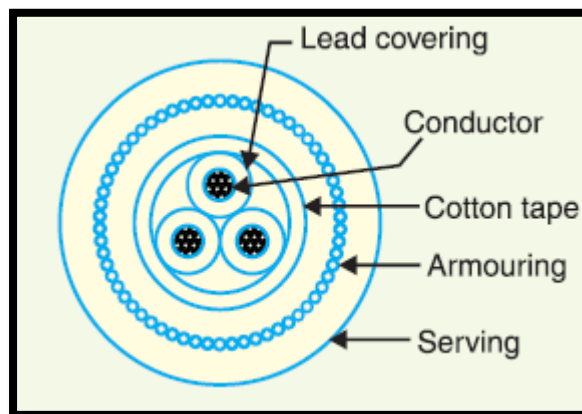


Fig (2.5) S.L type cable

There are two main advantages of S.L-type over H-type cables. First advantage is the separate sheath minimizes the possibility of core-to-core breakdown. Second advantage is the elimination of overall lead sheath therefore bending of cables become easy. But the disadvantage is that the three lead sheaths of S.L cable are much thinner than the single sheath of H-cable and therefore call for greater care in manufacture.

Limitation of solid type's cables:

All the cables of above construction are referred to as solid type cables because solid insulation is used and no gas or oil circulates in the cable sheath. The voltage limit for solid type cables is 66KV due to the following reasons:

- When the solid cable carries the load, its conductor temperature increases and the cable compound expands. This will stretch the lead sheath which may be damaged.
- If the load on the cable decrease then the conductor will cool and form a partial vacuum within the cable sheath, when pinholes are present in the lead sheath, it will draw the moist air into the cable.
- In the insulation of a cable, voids are always present. But the manufactures have resulted in void free cables due to modern techniques. Voids are formed due to the differential expansion and contraction of the sheath and impregnated compound. The voids breakdown strength is less than the strength of insulation. If the void is small enough, the electrostatic stress across it may cause its breakdown. The first voids breakdown which the nearest to the conductor permanent damage to the paper insulation caused due to the chemical and thermal effect of ionization.

4- Pressure cables

For voltages beyond 66KV, there is danger of breakdown of insulation due to the presence of voids, so solid type cables are unreliable, the preferred cable when the voltage is greater than 66KV, pressure cables are used. In such cables voids are eliminated by increasing the pressure of compound and for this reason they are called pressure cables. There are two types of pressure cables via oil-filled cables and gas pressure cables.

a) Oil filled cables

Oil circulation is performed by oil channels or ducts. External reservoirs keep the oil supplied to the channel, and those reservoirs placed at suitable distance (500m) along the route of the cable. Oil under pressure compresses the layers of paper insulation and is forced into any voids that may have formed between layers. Oil filled cables can be used for higher voltage due to the elimination of voids. The range of the voltage has been from 66KV up to 230KV. There are 3-types of oil filled cables, single core conductor channel, single core sheath channel and three core filler space channel.

Fig 2.6 shows the constructional details of a single core conductor channel, oil filled cable.

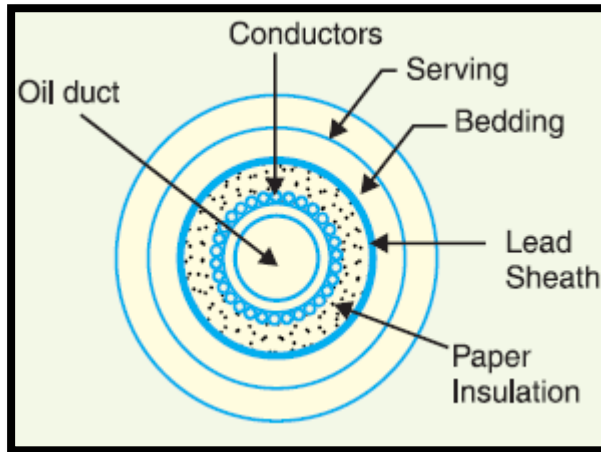


Fig 2.6 Single core conductor channel, oil filled cable

The oil channel is formed at the center by stranding the conductor wire around a hollow cylindrical steel spiral tap. External reservoir helps the oil under pressure to supply to the channel. The oil percolate between copper strands to the wrapped insulation due to the spiral steel tape which is the channel is made of prevention the possibility of void formation by the compression of the oil pressure in the layers of paper insulation. When the temperature of cable increase the oil gets expand then the extra oil collects in the reservoir, however, when the temperature decrease during light load condition, the oil from the reservoir flows to the channel.

Figure 2.7 shows the constructional details of a single core sheath channel oil filled cable. In this type of cable, the conductor is solid similar to that of solid cable and is paper insulated. However, oil ducts are provided in the metallic sheath as shown.

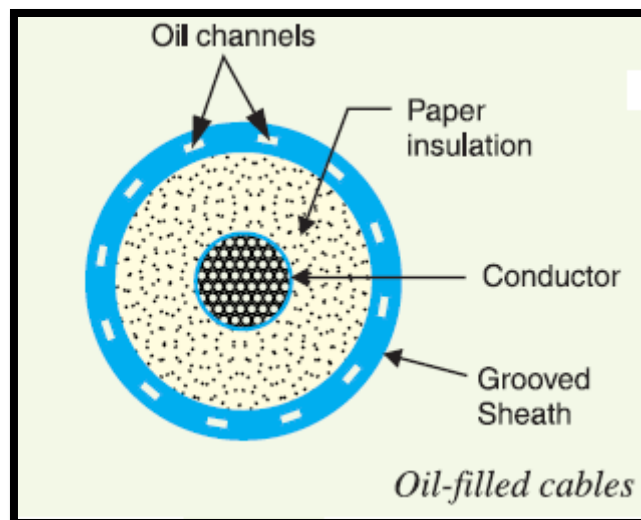


Fig 2.7 Single core sheath channel oil filled cable

In the core oil-filler cables shown in fig 2.8, the oil ducts are located in the filler spaces. These channels are composed of perforated metal-ribbon tubing and are at earth potential.

There are three advantages to the oil-filler cables:

- Prevent the formation of voids and ionization.
- Increased the allowable temperature range and dielectric strength.
- When the leakage happen, at first defect happened on the lead sheath and indicated and the earth faults possibility is decreasing.

But there is a major disadvantage is complicated system and high initial cost.

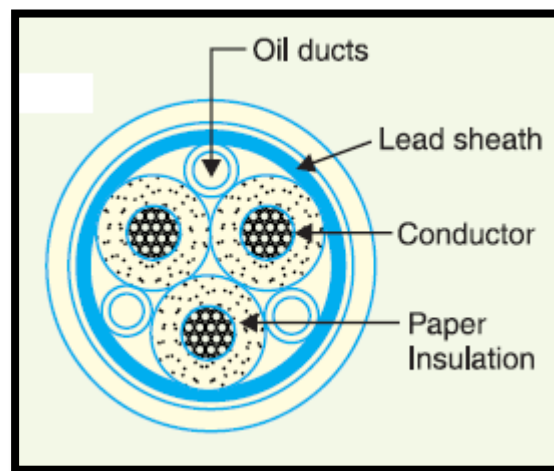


Fig 2.8 Oil-filler cables

b) Gas pressure cables

As the pressure increased, the voltage required to set up ionization inside a void is increased. The principle of gas pressure cables, if ordinary cable is subjected to a sufficiently high pressure, the ionization can be altogether eliminated. Radial compression will be produced when the pressure is increased which tends to close any voids. Fig 2.9 shows the section of external pressure cable designed by Hochstadter, Vogal and Bowden. There is a similarity between the construction of this cable and ordinary solid type expect that it is of triangular shape and thickness of lead sheath is %75 that of solid cable. The main reason of the triangular shape is that the shape acts as a pressure membrane, and this triangular section reduces the weight and gives low thermal resistance. The cable is laid in in a gas light steel pipe, and then the pipe is filled with nitrogen gas at 12-15 atmospheres. Radial compression produced by the gas pressure and closes the voids that may have formed between the layers of paper insulation. Such cables can carry more load current and operate at higher voltage than normal cables. Nitrogen gas helps in quenching any flame and the maintenance cost is small, these are the big advantages but the highly overall cost considered as disadvantage.

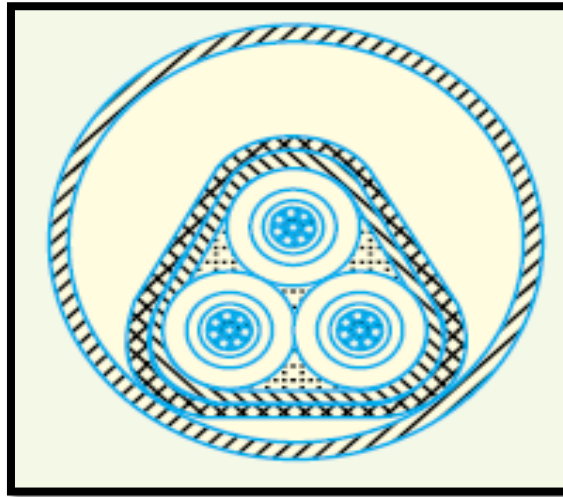


Fig 2.9 Pressure cable

2.2.4.5: Lying of underground cables

The reliability of underground cable network depends to considerable extent upon the proper laying and attachment of filling such as cable end boxes, branch connectors and joints. There are three main methods of lying underground cables (direct lying, draw in system and the solid system) [10].

1- Direct laying

Favored in modern practice. Simple and less expensive method. In this method a trench of about 1.5 m deep and 45 cm wide is dug, the trench is covered with a layer of fine sand (of about 10 cm thickness) and the cable is laid over the sand bed. The function of the sand is to prevent moisture entry from the ground to protect the cable from decay, then the cable is covered by another layer of sand of about 10 cm thickness. Then the bricks cover the trench, so help in the protection of the cable from mechanism injury. A horizontal or vertical inter axial spacing at least 30 cm is provided when more than one cable is laid on the same trench, in order to decrease the effect of mutual heating and to ensure that a fault occurring on one doesn't damage the adjacent cables. To provide a protection against corrosion and electrolysis, cables must have serving of bituminized paper and hessian tape. This method is simple and cheap and gives the best conditions for dissipating the heat generated in the cables, also clean and safe method these are the main advantages for this method, but it is also has disadvantages:

- Difficult alteration in the cable network.
- Expensive maintenance cost.
- Localization of fault is difficult.
- Not suitable for congested areas.
- The extension of load is possible only by a completely new excavation which may cost as much as the original work.

2- Draw in system

Along the cable route, conduit or duct of glazed stone or cast iron or concrete are laid in the ground with manholes at suitable position, then the cables pulled into position from manholes. Fig 2.10 shows sections through four-way underground duct line. Transmission cables are carried by the three of duct and the fourth duct carries really protection connection, pilot wires where the duct lines changes direction, depths, dips and offsets be made with a very long radius or it will be very difficult to pull a large cables between the manholes, so care must be taken. In order to simplify the pulling of the cables, the distance between the manholes shouldn't be too long. The cables laid in this way must provide with the serving of hessian and jute to protect them when being pulled into ducts. This way has many advantages:

- Repairs or alternation without opening the ground.
- As the cables aren't armored, therefore the joints become simpler and maintenance cost is reduced.
- Less chances of fault occurrence due to strong mechanical protect.

However, this way also has disadvantages of the initial cost is very expensive and the capacity of the cable is reduced due to the close grouping of cables and unfavorable condition for dissipation of heat. This method is suitable for congested area, and mainly used for short length cables route as in work shop.

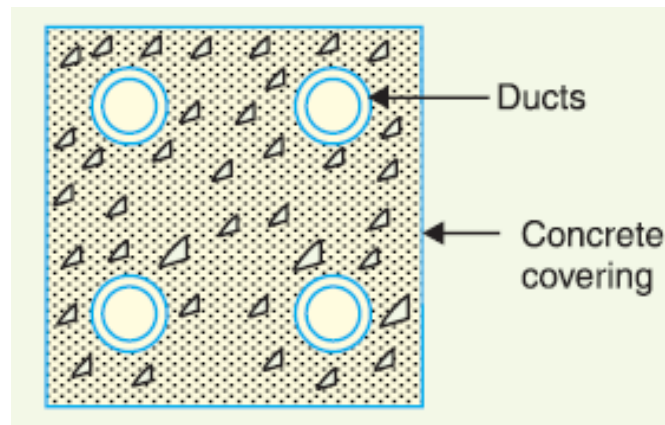


Fig 2.10 Four-way underground duct line.

3- Solid system

The cable is laid in open pits or troughs dug out in earth along the cable route. The troughing of stoneware, cast iron, asphalt or treated wood. As the cable is laid in position, bituminous or asphalt compound filled the troughing and covered over, cables are usually plain lead covered because troughing affords good mechanical protection. This system is more expensive than direct laid system, and required

skilled labour and favorable weather condition., the current carrying capacity is reduced due to poor heat dissipation, due to this disadvantages it is rarely used.

2.2.4.6: Insulation resistance of single core cable

The prevention of leakage current is prevented and avoided by the suitable thickness of insulating material in the cable conductor the path for leakage current is radial through the insulation. Insulation resistance of the cable is defined as the opposition offered by insulation to leakage current. The insulation resistance of the cable should be very high, due to satisfactory operation [4].

Considered the single core cable of conductor radius r_1 and internal sheath radius r_2 as shown in figure 2.11, let l is the length of the cable and ρ be the resistivity of the insulation.

Consider a very small layer of insulation of thickness dx at a radius x . The length through which leakage current tends to flow is dx and the area of X-section offered to this flow is $2\pi xl$.

- Insulation resistance of considered layer: [10]

$$= \rho \frac{dx}{2\pi xl} \quad 2.1$$

Where l : length of the cable.

ρ : resistivity of the insulation.

dx : very small layer of insulation of thickness.

x : radius of a very small layer of insulation.

Insulation resistance of the whole cable is [4]

$$R = \int_{r_1}^{r_2} \rho \frac{dx}{2\pi xl} = \frac{\rho}{2\pi l} \log_e r_2 \setminus r_1 \quad 2.2$$

Where r_1 : radius of the conductor.

r_2 : radius of the internal sheath.

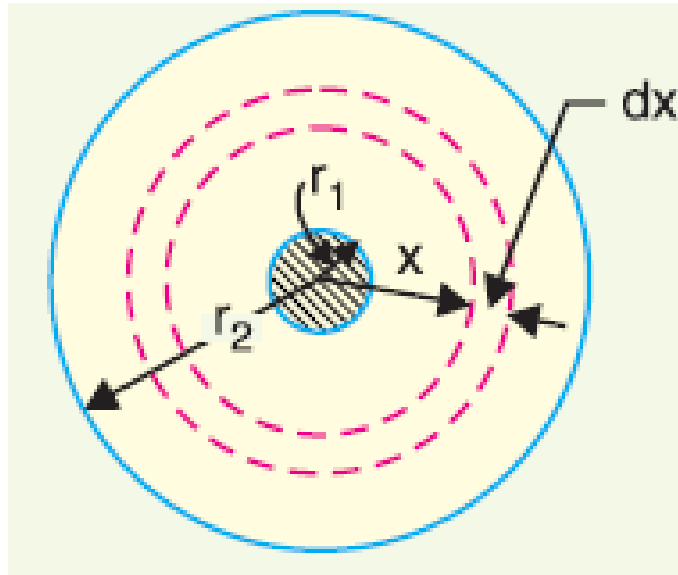


Fig (2.11) Single core cable

2.3: Types of cables faults

Cables are generally laid directly in the ground or in ducts in the underground distribution system. For this reason, there are little chances of faults in underground cables. However, if a fault does occur, it is difficult to locate and repair the fault because conductors are not visible. Nevertheless, the following are the faults most likely to occur in underground cables:

1- Open circuit fault

When there is a break in the conductor of a cable, it is called open circuit fault. The open-circuit fault can be checked by a megger. For this purpose, the three conductors of the 3-core cable at the far end are shorted and earthed. Then resistance between each conductor and earth is measured by a megger. The megger will indicate zero resistance in the circuit of the conductor that is not broken. However, if the conductor is broken, the megger will indicate infinite resistance in its circuit.

2- Short circuit fault

When two conductors of a multi-core cable come in electrical contact with each other due to insulation failure, it is called a short-circuit fault. Again, we can seek the help of a megger to check this fault. For this purpose, the two terminals of the megger are connected to any two conductors. If the megger gives zero reading, it indicates short circuit fault between these conductors. The same step is repeated for other conductors taking two at a time.

3- Earth fault

When the conductor of a cable comes in contact with earth, it is called earth fault or ground fault. To identify this fault, one terminal of the megger is connected to the conductor and the other terminal connected to earth. If the megger indicates zero reading, it means the conductor is earthed. The same procedure is repeated for other conductors of the cable.

2.4: Cables used in the Jerusalem District Electricity Company (JDECO)

Jerusalem District Electricity Company (JDECO) is a distribution power company in the state of Palestine, specifically, in the West Bank. It distributed the electrical power in several areas of the west bank such as Jerusalem city, Bethlehem city and Al-Aroub Camp.

In Jerusalem District Electricity Company (JDECO), it used certain types of underground cables to transmit and distributed the electrical power. It depends on the international standards IEC.

In this project, the focus will be on the medium voltage underground cables (from 11 KV up to 33 KV) and study the heat effect on the efficiency of underground cable through to find the fitting way to burial the cable.

The following cables are used in Jerusalem District Electricity Company (JDECO) :

2.4.1: N2XS (F) 2Y 18\30 KV

Conformable to international standard IEC 60502-2

1×150 mm² RM\25 single core copper cables: maximum operation voltage V_{max} = 36 KV – nominal voltage: 18\36KV – test voltage = 45 KV – insulation thickness = 8 mm – screen cross sectional area = 25 mm² – jacket thickness = 2.5 mm – outer Ø cable = 43 mm – weight of cable = 3000 kg\km – temperature range: during insulation up to -20 °C – maximum operating temperature at 90 °C – short circuit temperature at 250 °C – short circuit duration up to 5 second.

Construction of N2XS (F) 2Y 18\30 KV

Stranded copper or aluminum conductor – conductor screen of semiconducting compound – insulation of cross-linked polyethylene (XLPE) – screen of semiconducting compound – semi-conducting swellable tap – screen of copper wires and copper tape – separation tape – PE sheath – three stranded cable – minimum insulation temperature is $-20\text{ }^{\circ}\text{C}$ – maximum conductor temperature in service is $90\text{ }^{\circ}\text{C}$ – short circuit maximum conductor temperature is $250\text{ }^{\circ}\text{C}$ [for more details, find the appendix 1, 2, 3].

2.4.2: NA2XS (F) 2Y 18\30 KV

$1 \times 150\text{ mm}^2$ RM\25 single core aluminum cable: $V_{\text{max}} = 36\text{ KV}$ – test voltage = 63 KV – insulation thickness = 8 mm – diameter over insulation = 31.5 mm – sheath thickness = 2.5 mm – outer diameter = 43 mm – weight of cables = 1934 kg/km - max. Temperature $90\text{ }^{\circ}\text{C}$ – max. Operating temperature $70\text{ }^{\circ}\text{C}$ – temperature moved\during $(-20 - 70)\text{ }^{\circ}\text{C}$.

Construction of NA2XS (F) 2Y 18\30 KV

Aluminum conductor – Inner semi-conducting layer – XLPE DIX8 insulation – outer semi-conducting layer – semi-conducting swelling tape – copper wire screen – rubber inner sheath – PE outer sheath [for more details, find the appendix 3, 6, 7, 8].

2.4.3: N2XSEY 8.7\15 KV

According to standard No IEC 60502-2

$3 \times 120\text{ mm}^2$ three core copper cables: overall diameter = 63.5 mm – weight = 6364 kg/km – DC resistance at $20\text{ }^{\circ}\text{C}$ = $0.153\text{ }\Omega/\text{km}$ – AC resistance at $90\text{ }^{\circ}\text{C}$ = $0.196\text{ }\Omega/\text{km}$ – inductance = 0.312 mH/km – current-carrying capacity at $30\text{ }^{\circ}\text{C}$ in ground = 337 A – short circuit current at 1 second in conductor = 17.16 KA – short circuit current at 1 second in screen = 1.03 KA .

Construction of N2XSEY 8.7\15 KV

3 copper conductor – PVC filler – conductor screen – XLPE insulation – insulation screen – copper tape screen – ID tape – non hygroscopic tape – PVC inner sheath – PVC sheath .

Special features on request:

Oil resistance, UV resistance, flame retardant cat A,B,C – flam retardant non category – anti termite – anti rodent – low smoke zero halogen – nylon coated [for more details, find the appendix 3, 4, 5]

2.4.4: Construction Requirements

- **Conductor:**
The material of the conductor shall consist of plain annealed copper wires, stranded, compacted and circular.
- **Conductor Screen:**
The conductor screen shall be nonmetallic and shall consist of a layer of extruded cross linked semi – conducting compound.
- **Insulation:**
The insulations shall be XLPE
- **Non Metallic Insulation Screen:**
The semi conducting screen shall be applied directly over the insulation and shall consist of an extruded semi conducting layer.
- **Metallic Screen:**
Over the non-metallic insulation screen, a metallic screen shall be applied consisting of a concentric layer of copper wires and bounded together with a copper tape.
- **Outer Sheath:**
The outer sheath shall consist of polyethylene compound and the color shall be “Black” and marked with the manufactures name; N2XS (F) 2Y, 20.8/36 KV, the year of production, the property of (J.D.E.Co.) Each meter run should be numbered.

3

Chapter three

Thermal behavior and calculation of ampacity in the Underground cable

3.1 Introduction.

3.2 Heat source in the cable system.

3.3 Heat transfer in the underground cable installation.

3.4 The NEHER-MCGRATH METHOD.

3.5 Soil resistivity.

3.1 Introduction

Evaluation of the transient and steady-state temperature distributions and heat flows under buried electrical power cables is needed for several purposes including: [11]

- Determination of the maximum temperatures to be associated with different cable loading.
- Study of the effects of different trench geometry.
- Evaluation of the importance of different trench backfill and natural ground properties on temperature distributions and heat flow.
- Determination of the time require for establishment of thermal equilibrium following temperature change.
- Evaluation of the effects of weather and solar radiation on temperature distribution in the ground.
- Estimate of moisture movement in the round surrounding the cable.
- Study the effect of several buried materials.

3.2 Heat source in cable system

The heat source from the current in the cable can be divided into two groups:

- Heat in conductors.
- Heat in insulators.

The losses in metallic (conductors) element are the most significant losses in a cable and they are caused by:

- a- Joule losses due to impressed current, circulating current or induced (eddy current) losses
- b- Hysteresis losses in conductors that is also magnetic.

The following metallic component of a cable system produces heat:

- ❖ Core conductors.
- ❖ Sheaths.
- ❖ Concentric neutral.
- ❖ Armors.
- ❖ Skid wires.
- ❖ Pipes/ducts.

The losses in those components are functions of the frequency (f) and the temperature (T) of operation and proportional to the square of the current (I). The temperature and frequency is included in an equivalent ac resistance to express Joule law as:

$$W = R_{ac}(f, t) I^2 \quad 3.1$$

Insulating materials also produce heat. The heat produced in the insulating layers is only important under certain high voltage conditions. The following component could be considered:

- ❖ Main insulation
- ❖ Shields
- ❖ Screens
- ❖ Jackets
- ❖ Beddings/serving

The loss relationship is given by: [12]

$$W_d = \omega C V^2 \tan(\delta) \quad 3.2$$

Where

C : Capacitance.

V : Voltage applied.

δ : lose angle.

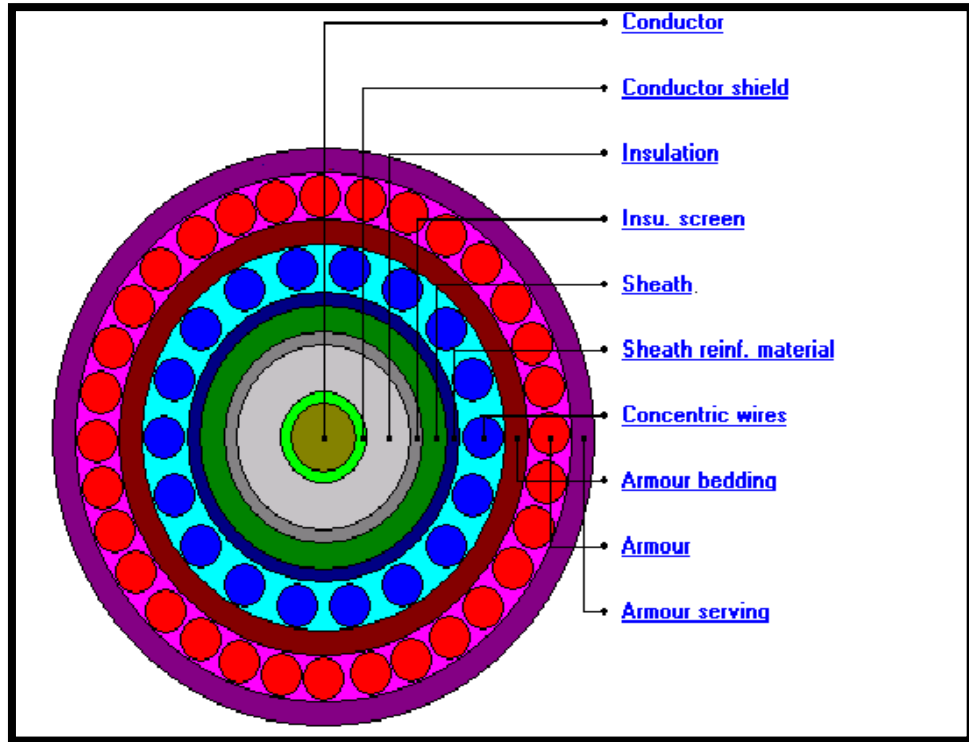


Fig 3.1 illustration of a cable construction [12]

3.3 Heat transfer in the underground cable installation

There are different source of heat in the cable that produce from losses that result of passing the current through cable, or dielectric losses or shield sheath or inductive current through cable conductors or the current produce from the closer cable.

There are three physical mechanisms for heat transfer:

- Convection
- Radiation
- Conduction

Convection is the mode of energy transfer between a solid surface and liquid or gas that is in motion, and it involves the combined effect of conduction and fluid motion. In absence of any bulk fluid motion, heat transfer between a solid surface and adjacent fluid is pure conduction. The presence of bulk motion of the fluid enhances the heat transfer between the solid surface and the fluid.

There are two type of convection, first is forced convection if the fluid is forced to flow in a tube or over a surface by external means such as fan, pump, or the wind. Second is called free convection if the fluid motion is caused by buoyancy forces. The heat rate of heat transfer by convection Q'_{conv} is determined from Newton's law of cooling, expressed as

$$Q'_{conv} = h A (T_s - T_f) \quad 3.3$$

Where

h : Is the convection heat transfer coefficient.

A : Surface area.

T_s : Surface temperature.

T_f : Bulk fluid temperature away from the surface

Radiation is the energy emitted by matter in the form of electromagnetic waves, as a result of change in the electronic configuration of atoms o molecules.

Unlike to convection and conduction the radiation does not require the presence of an intervening medium. Radiation is fastest and attenuation in vacuum.

All bodies at temperature above absolute zero emit thermal radiation. The rate of radiation that can be emitted from a surface at absolute temperature T_s is given by Stefan-Boltzmann, expressed as [8]

$$Q'_{emitt} = \varepsilon \sigma A T_s^4 (W) \quad 3.4$$

Where

A : The surface area.

$\sigma = 5.67 * 10^{-8} W/m^2$.

k_4 : Stefan-Boltzmann constant.

ε : The emissivity of the surface, whose value in range of $0 \leq \varepsilon \leq 1$, is a measure how closely a surface approximation a black body for which $\varepsilon = 1$.

Conduction is transfer energy from the more energetic particles to adjacent less energetic ones as result of interaction between the particles. It can take place in solid liquid and gases.

In liquid and gases conduction is due to collisions of molecules during their random motion.in solid, due to combination of vibration of molecules in a lattice and the energy transports by free electrons

$$Q^{'} cond = Kt A(\Delta T / \Delta x) (W) \quad 3.5$$

Where

$Q'cond$: The rate of heat conduction.

Δx : Layer of constant thickness.

ΔT : The temperature difference.

A : The area.

Kt : The thermal conductivity of the material.

In the limitation case of $\Delta x \rightarrow 0$, the equation above reduces to differential form [9]

$$Q' cond = Kt A (dT/dx) (W) \quad 3.6$$

This is known as Fourier's law of heat conduction.

In an underground cable system, the main heat transfer mechanism is by conduction. With exception of the air inside the conduits in duct banks or buried ducts installations all the heat is transferred by conduction. Since the longitudinal dimension of a cable is always much larger than the depth of the installation, the problem becomes a two-dimensional heat conduction problem [10].

In view of the complication of the ampacity problem, engineers found practical solutions by combining analytical solution to simplified geometries heuristic results. Neher and McGrath in [12] summarized the knowledge on the ampacity calculation field to that date, and today Neher-McGrath method is still being used and it is the base for IEEE¹ and IEC² standards [11-12].

¹ IEEE is institute electrical and electronics engineering

² IEC is international electrotechnical Commission

Amount of loaded conductors, geometric configuration between the cable, type of grounding of the metallic shields of the cable, thermal characteristic of the materials around of the cable (soil, ducts, concrete, backfill, etc.), effect of the typical variation of the environment (moisture and temperature in the land), and other interferences caused external of heat. The maximum temperature that XLPE insulation enduring is 90 C, so when the cable come to this temperature, the current in the cable core is cable ampacity.

There are two methods to calculate ampacity:

- 1- IEC 20287 standard cable ampacity.
- 2- The Neher-McGrath method.

There are many differences between two methods we can summarize in the table:

Table 3.1 difference between IEC 20287 and The Neher-McGrath method.

IEC 20287	The Neher-McGrath method
IEC equation use the metric system	Neher-McGrath used the imperial system
Detailed methodologies are given	Explicit equation for the transient rating
Eddy losses Includes flat formation as well	Only the Eddy losses for triangular
Magnetic armors are considered	Magnetic armors not considered
More insulation than Neher-McGrath	Less insulation than IEC

3.4 The NEHER-MCGRATH METHOD

This method based on the thermal-electrical analogy method due to Pashkis and Baker [13], which subdivided the area of layers, and then substitute the heat source by current source and the thermal resistance by electrical resistance and thermal capacitance by electrical capacitance, where the capacitance doesn't play part of steady state rating.

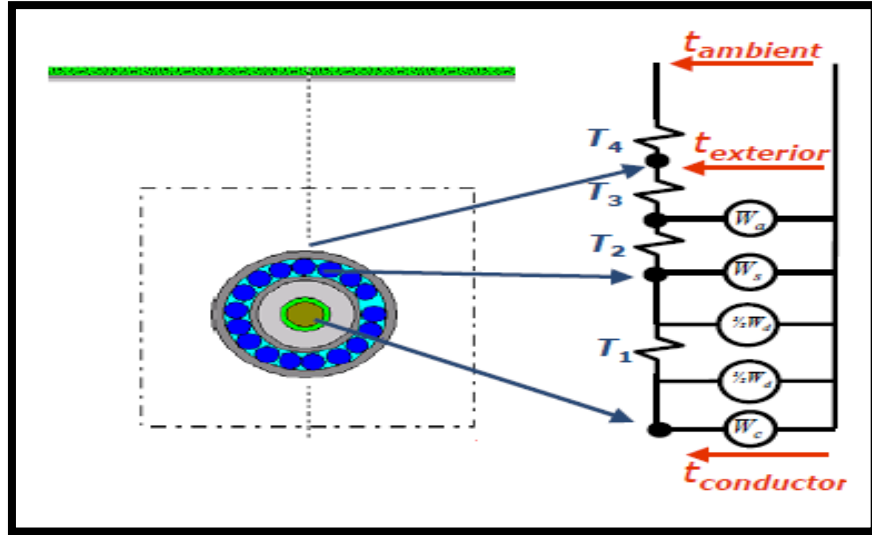


Fig 3.2 Thermal electric equivalent

To find the ampacity we first note that the potential of every node in the circuit is analog to the temperature of the regions between the layers, the potential difference between the terminals of the circuits and the innermost current source represents the temperature rise of the core of the cable with respect to the ambient temperature. Therefore the temperature of the cable's core is the ambient temperature plus Δt , as the fig (3.3) shown [13-23].

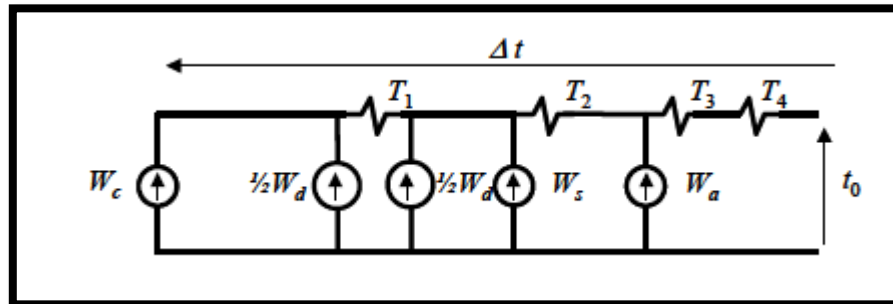


Fig 3.3 Electrical equivalent

The ambient temperature Δt is calculate by equation 3.8

$$\Delta t = \left(W_c + \frac{1}{2} W_d \right) T_1 + (W_c + W_d + W_s) T_2 + (W_c + W_d + W_s + W_a) (T_3 + T_4) \quad 3.7$$

The heat sources (electrical losses) W 's are expressed as proportion of the conductor losses. The conductor losses computed using the ac resistance and the current.

$$W_c = R_{ac} I^2 \quad 3.8$$

$$W_s = \lambda_1 W_c \quad 3.9$$

$$W_a = \lambda_2 W_c \quad 3.10$$

By substitution the following expression (3.9), (3.10), and (3.11) in 3.8 and re-arranging we have:

$$I = \sqrt{\frac{\Delta t - W_d \left(\frac{1}{2} T_1 + T_2 + T_3 + T_4 \right)}{R_{ac} T_1 + R_{ac} (1 + \lambda_1 + \lambda_2) (T_3 + T_4)}} \quad 3.11$$

Instead of calculate the:

T : Thermal resistance

λ : Loss factor

R_{ac} : ac Resistance

3.4.1 Thermal resistance (T)

As shown in fig 3.3, the layers divided to internal and external layers. First, internal layers of the cable (T_1, T_2, T_3) can be considered as tubular geometries and we can compute thermal resistance on it by basic principle as equation.

$$T = \rho \frac{1}{A} = \rho \ln \left(\frac{r_2}{r_1} \right) \quad 3.12$$

Where

ρ : Electrical resistivity, circular mil ambient earth.

r_1 : The radius of circle inscribed within the duct bank touching the sides.

r_2 : The radius of a larger circle embracing the four corners.

In the complicated geometries and external layers to the cable, such as three-core cables, duct banks, heuristics are used as equation

$$T = \frac{\rho}{2\pi} G \quad 3.13$$

Where

G : The geometrical factor is function of the shape and dimension of the particular geometry under analysis.

There are many of heuristics used in the calculation of thermal resistance such as equally and unequally loaded cables, touching or not touching cable, trefoil or backfill. The reader can find it in the reference [24-28]. Numerical method (finite element) has been used to determine extension to the geometrical factor when heuristics do not exist.

The external of the cable thermal resistivity is commonly computed assuming that the service of the earth in the neighborhood of the cable installation is an isothermal. Kennelly [7] made this assumption in 1893 and it's still being used. This assumption allows for application of image method to compute the external to the cable thermal resistance (T_4). The following expression results from the image method:

$$T = \frac{\rho}{2\pi} \ln \left(\frac{4L}{D_c} \right) \quad 3.14$$

Where

D : Diameter outside of conductor, inches

ρ : Electrical resistivity, circular mil ambient earth.

L : Depth of reference cable below earth's surface, inches

The thermal resistance layers external to the cable (T_4) must also include the duct when present, and the air inside. The duct itself is of tubular geometry and it very easy to module, however, the treatment of the air inside of a duct is a complex matter. The heat transfer is dominant by convection and radiation and not by conduction there exist simple formulas, which have been obtained experimentally and that work fine for the conduction tested.

3.4.2 Loss factor (λ)

Loss factor in equations (3.10), (3.11) related to the losses that metallic layers (sheaths, armors, etc.) produce in proportion to the losses of the cable core. These losses include circulating current and induced current (eddy current).

The bonding used for sheaths or (concentric neutrals) plays a very important role in the current intensity that circulates in them. Thus the losses are very much dependent on the bonding type and the geometrical arrangement of the cables (flat, triangular formation).

3.4.3 AC Resistance (R_{ac})

The operating resistance of a cable is function of the temperature and the frequency. The temperature variation is described by:

$$R(t) = R_0[1 + \alpha(t - t_0)] \quad 3.15$$

Where

R_0 : Resistance at a base temperature ($t_0 = 20^\circ C$)

α : Coefficient of variation with temperature

Using Bessel function. For the modeling of eddy current effects in cables, for low frequencies (50 and 60 Hz), there are very simple and accurate formulas adequate for ampacity calculation. The eddy effects are included by two factors. One considers the skin effect (y_s) and the other, the proximity effect (y_p). The mathematical expression to account for these losses is

$$R(f) = R_{dc}(1 + y_s + y_p) \quad 3.16$$

By combining equation (3.16) and (3.17)

$$R_{ac}(t, f) = R_0[1 + \alpha(t - t_0)](1 + y_s + y_p) \quad 3.17$$

The value for y_s and y_p are computed from simplified analytical expression particular to each cable core construction (solid, standard, segmented, etc.)

3.5 Soil thermal resistivity

The heat -that generated from losses I^2R of buried cable- dissipate through the surrounding soil. The rate at which this heat can be determines the temperature, that cable during any loading condition. Soil thermal resistivity consider one of the important values, that we must know to calculate the amount of current any particular cable can be allowed to carry [30].

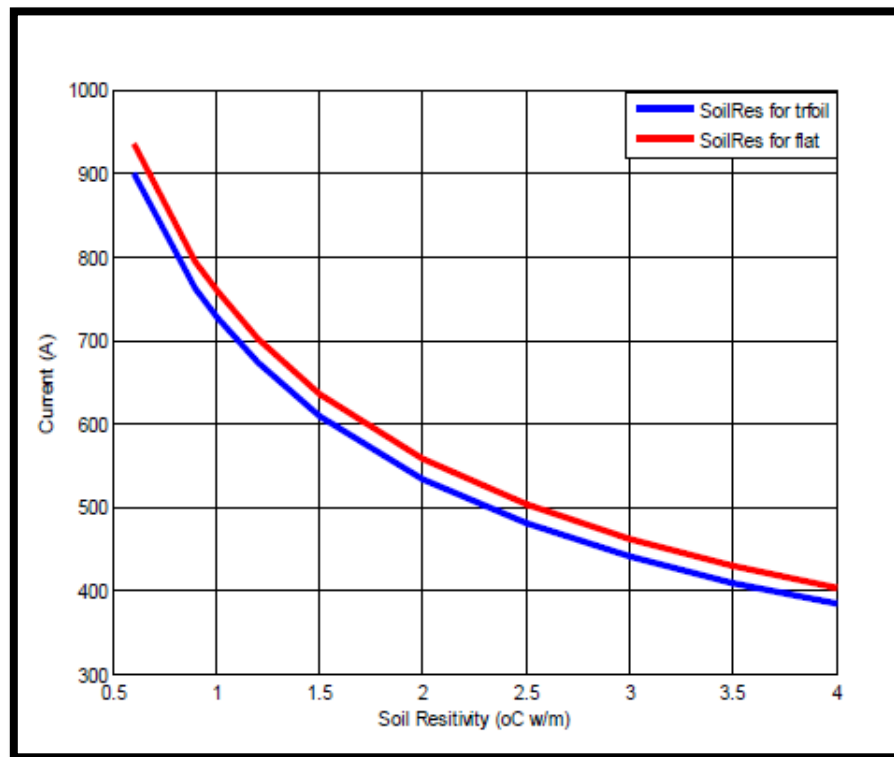


Fig (3.4) Variation of cable ampacity with soil resistivity [29]

3.5.1 Soil properties

Thermal resistivity is measure of the ability of material to resist the flow heat. The soil thermal resistivity is measured by inserting a heat generating thermal probe into the soil sample and soil resistivity is measured as described in IEEE standard. A known heat rate in W/cm is injected into the probe and plot is made of the temperature of the probe/soil interface versus time [30].

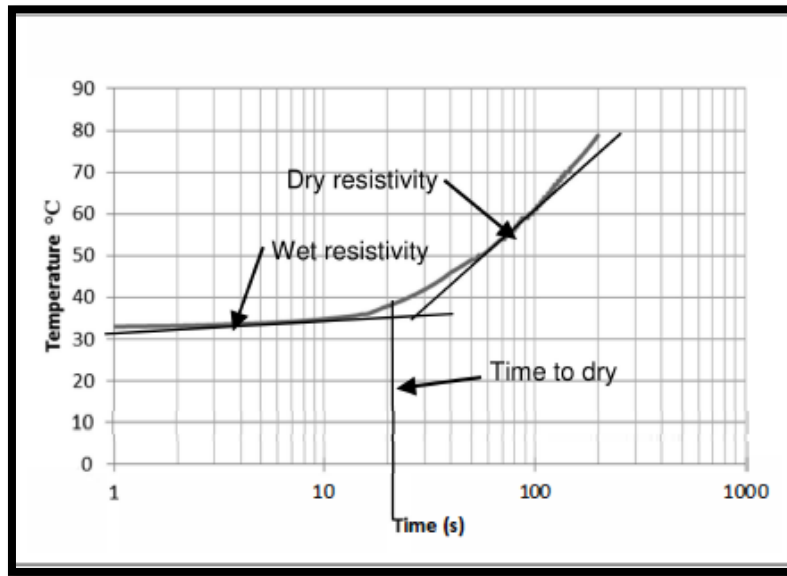


Fig (3.5) Soil curve versus temperature [30]

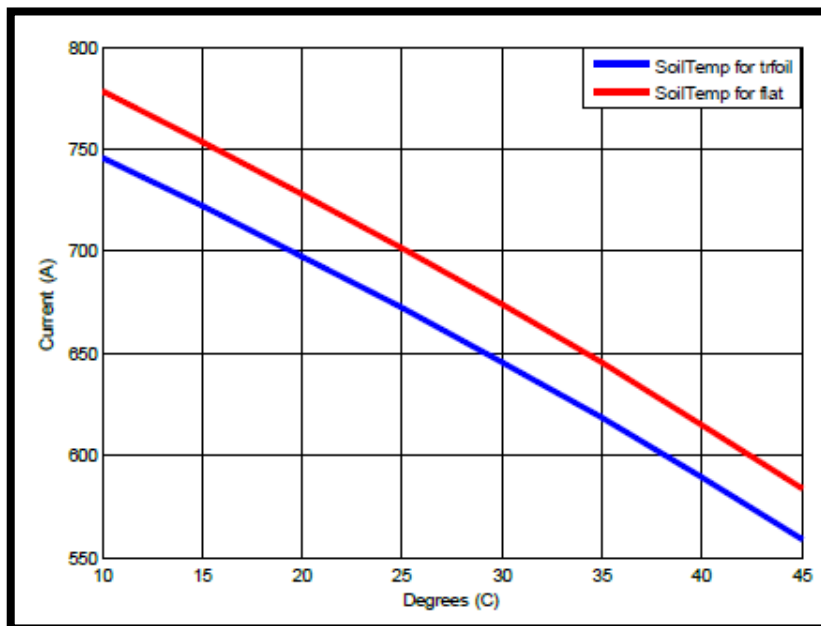


Fig (3.6) Effect of soil temperature on the ampacity of cable

3.5.2 Thermal soil stability

Soil is made of solid particles in contact with each other at relatively small contact point as shown in fig (3.7)

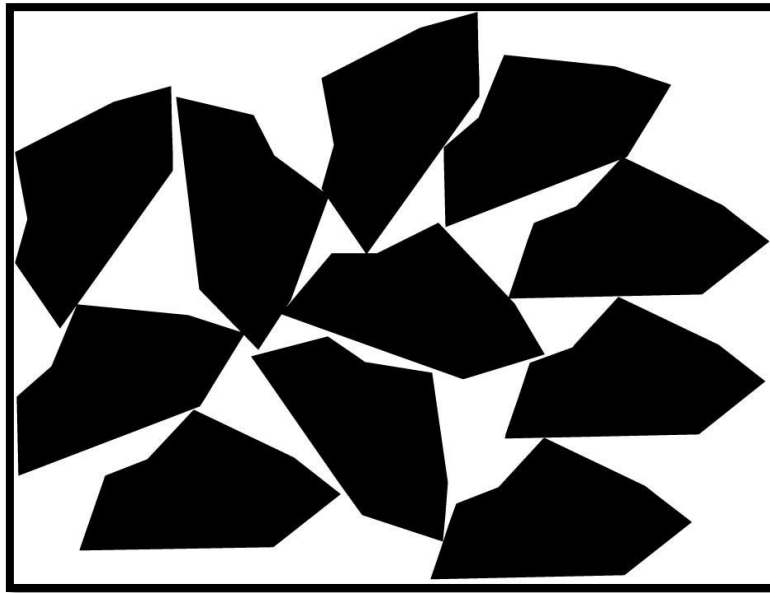


Fig (3.7) soil particles with voids [30]

The basis of thermal stability that may occur which may cause temperature of the cable to quickly increase until damage occurs: [31]

- The voids between the particles may contain either air or water. In dry soil the void between particles are filled with air.
- Some of heat is also conducted through the air which has much more resistance to heat flow than the soil particles.
- The increased of the water that fills in the voids, makes the conduction of heat will increase that causes decrease in soil resistivity.
- As the dry soil -by heat source such as a current carrying cable-, there resistivity will increase, causing the temperature of the cable increase.
- If the soil reaches some critical temperature it may dry condition, where the dry soil increases in resistivity causing the cable temperature to increase.

There are two mechanisms to move moisture away from heat source in soil:

- ❖ Movement in liquid form due to heat weakening surface tension between water and soil particles [32].
- ❖ Due to vapor movement through the soil and it will be considered as an effective enough mechanism to produce the type of drying seen in soils surrounding cable, because movement of moisture in the liquid state has been found to be a minor effect in temperature damage of cables [33-34].

The heat source heats the surrounding soil makes soil dries by evaporation, the water near the cable vaporized and the increased the pressure due to additional heating causes the vapor to move through the soil pores until it condenses in cooler location [36].

If the heat that enters to the soil is slow enough that the surrounding water can be replenish the water that migrates away, the soil resistivity will not change. If the heat is large enough that the water is vaporized and leaves the surroundings faster than the water can be replenished, then the soil will dry and increase the soil resistivity near the cable.

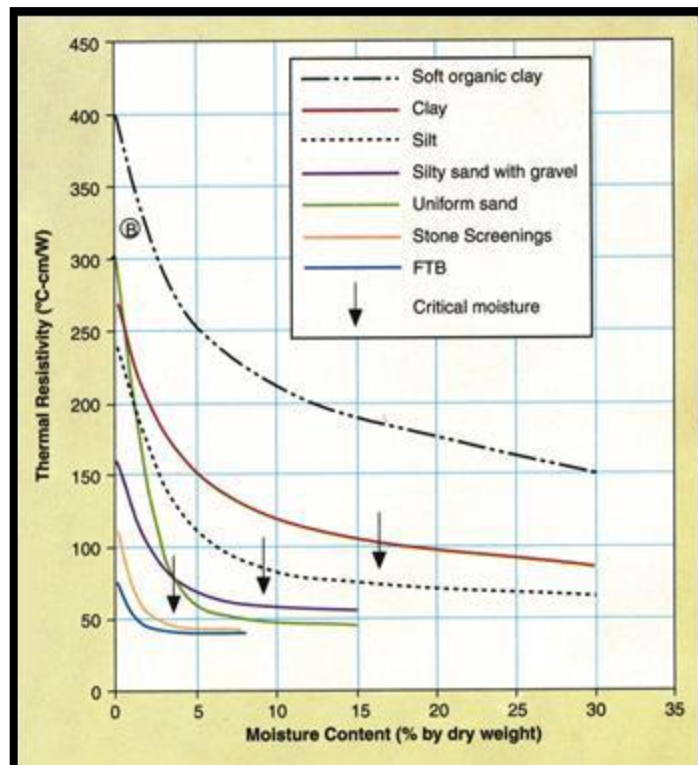


Fig (3.8) Relation between moisture and temperature [37]

Table 3.2 the Specific resistance to some types of components dry soil

Type of soil	thermal resistivity $C^{\circ} - cm/W$
Quartz 11	7.9
Quartz 1	14.9
Quartz “random orientation “	11
Quartz Glass	79
Granite	26-28
$CaCo_3$ 1 limestone	23.6
Limestone, dense	45
Sand stone	50
Shale(sound)	60
Shale (high friable)	200
Mica	170
Concrete	60-85
Organic	400-700
Ice	45
Oil(petroleum)	800
Air	4500
Plastic ducts	480

4

Chapter Four

Experimental of buried underground cable

4.1 Introduction.

4.2 Block diagram.

4.3 Procedure of experimental.

4.4 Equipment's of experimental.

4.5 location of the probe in Experimental.

4.6 Results

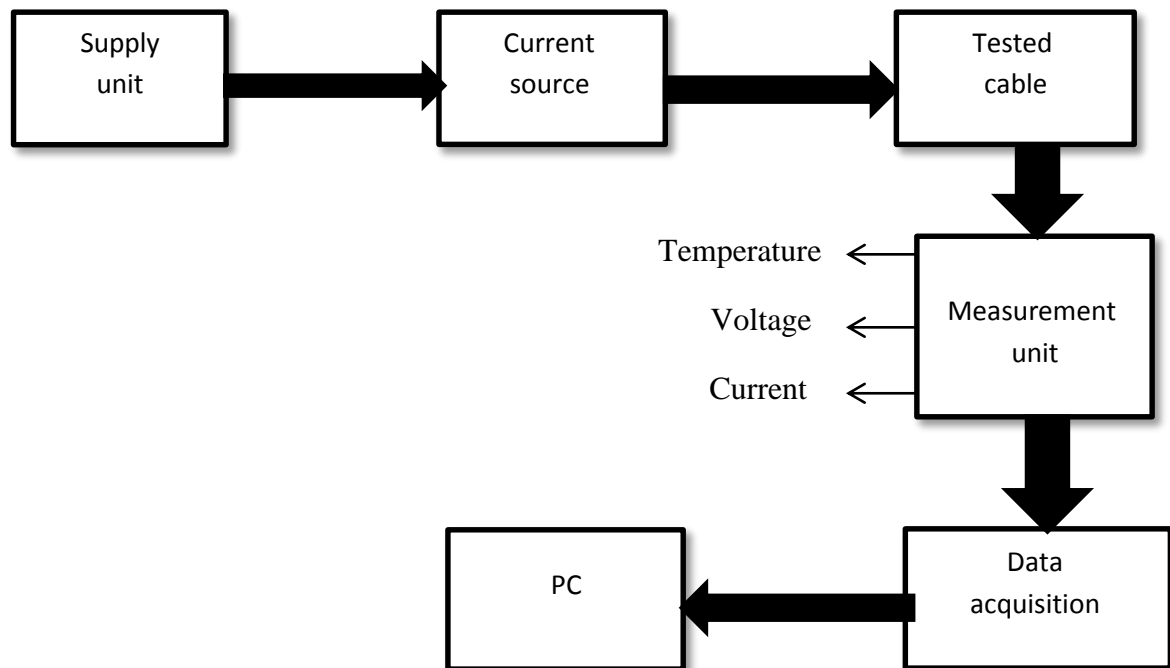
4.1 Introductions

In the previous chapter we talked about the determination of thermal behavior of underground cables, and their importance in the design and processes of the cables as the heat generated inside the cable may lead the cables breakdown thermally. It's necessary to know the temperature distribution around buried cables that can arise during use, as accurately as possible [38].

In this chapter, thermal behavior of 11kv underground power cable was investigated under different loadings using a full size experimental setup, finite model element was developed and used in order simulate the experimental model and the carried out results and compared with the experimental results [39].

4.2 Block diagram

The block diagram for experimental:



4.3 Experimental Procedure



Fig (4.1) Experimental

Firstly, we will setup the experimental equipment before start:

- The first step is installation the container in laboratory, that used to test the thermal conductivity.



Fig (4.2) installation the container

- Embedding the cable test into container, 75cm length from left, 60cm depth from the surface of the container as we see in fig (4.3).



Fig (4.3) embedding the cable test into container

- Instillation twelve probe of thermocouple k type, two grid – each grid has three probe- in the side of container that 50cm from cable to the right and to the left, two probe is 20cm from it to the right and left, two probe up 30cm from cable and down 20cm from it, one probe on the insulator of the cable, probe on the surface of the container and four probe in corner of box. fig (4.4).

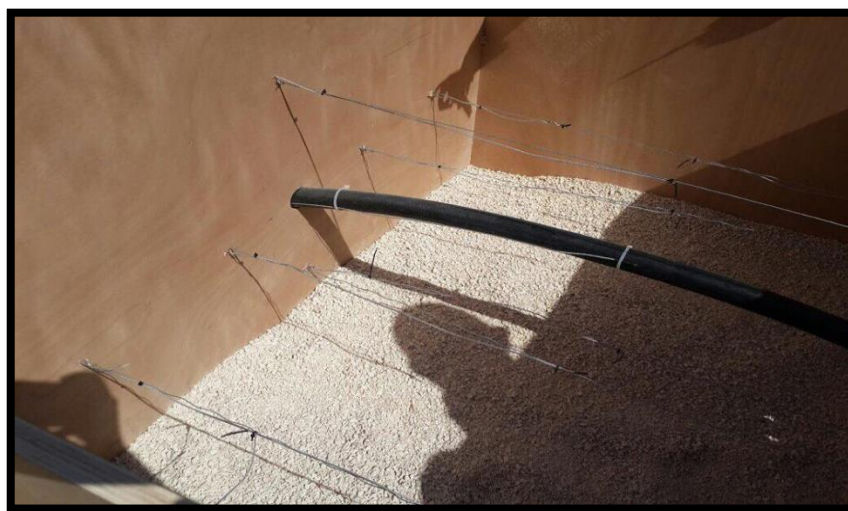


Fig (4.4) Location of thermocouple probe

- Filling types of soil sand, and limestone, one after one and record the temperature result for each type.



Fig (4.5a) sand soil



Fig (4.5b) limestone soil

- Connected the cable test as secondary side of current transformer and connect the supply to the primary side.

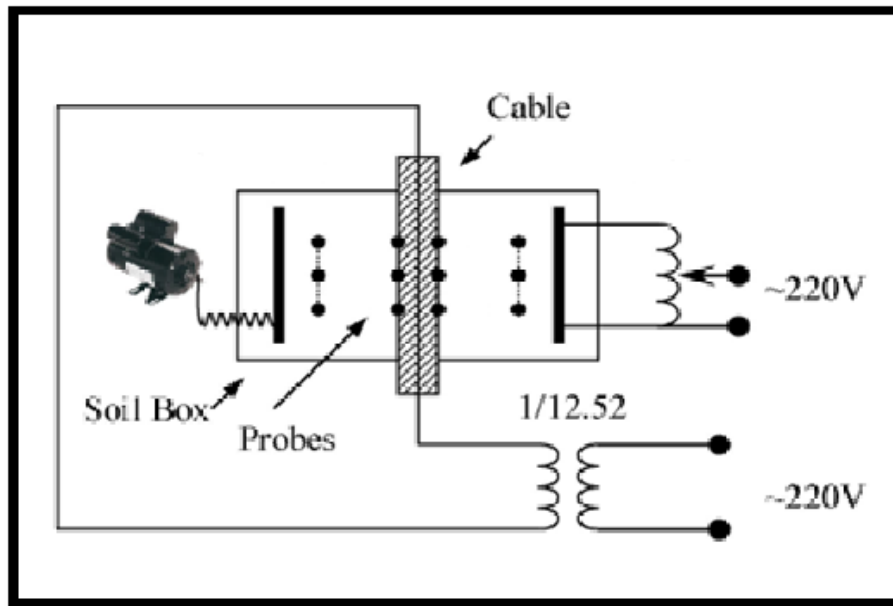


Fig (4.6) Experimental circuit [39]

- Connected data acquisition –data logger- to record heat around the cable.



Fig (4.7a) data logger connect to laptop



Fig (4.7b) Data acquisition

- We put a sign to alarm the human form the electricity



Fig (4.8) alarm sign

After setup the experimental for sand soil, load the cable 100A from current transformer, the cable insulation, cable surface, ambient and other grid probe temperature record continuously several time per a day over 120 hours before and after the steady state was achieved. After that load the cable again 450A then observed daily over 120 hours before steady state achieved. Then changed the soil to limestone and again the steps as sand soil.

Compare the result from the sand and limestone experimental to decide If we can use a substitute for limestone soil sandy soil –that used to bury cable in the Palestine- and that depends on speed and amount of the heat dissipation for everyone.

4.4 Equipment's of Experimental

A field test facilities were required to simulate the operation of buried electrical transmission cables include:

- The main unit is the container, that is wooden box having dimension of 154X111X 124 (W*H*D) designed to be portable, with a removable roof to allow accessibility to the internal contents as a fig (4.9).



Fig (4.9) Container 154X111X 124 (W*H*D)

- Actual cable sample of XLPE 15kv was laid out inside the container. Then the cable was placed in the soil filled container. Then the cable was subjected to a certain load (300A and 600A) in order to examine the thermal behavior inside the cable and at points surrounding the cable.

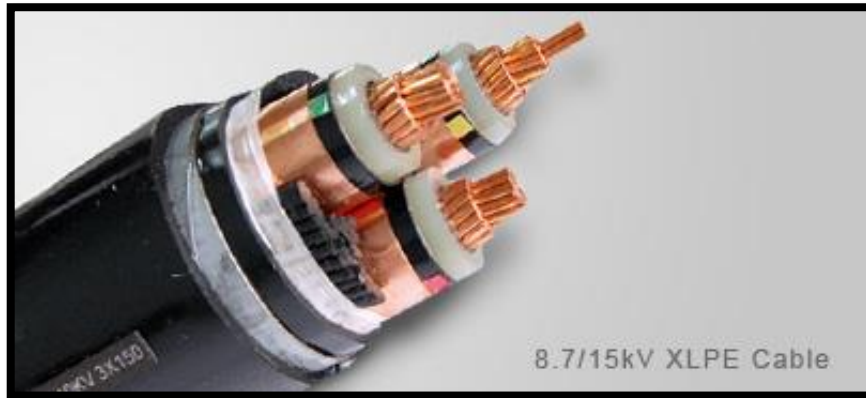


Fig (4.10) XLPE 15Kv cable

- The soil, placed in the container, and is with certain specification like humidity to dissipate the temperature result from cables through passes current, and temperature from atmosphere that affect to the soil.



Fig (11.a) sand soil

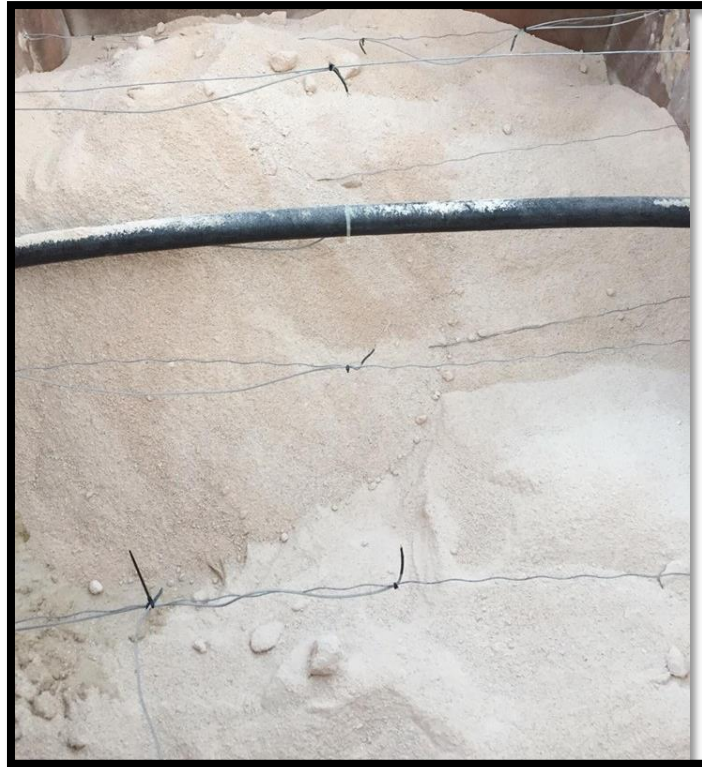


Fig (4.11b) limestone soil

- Thermocouple probes (12 probes) were used to record the temperature of specific points of the cable (external, surface, insulation) as well as the surrounding soil and ambient. The thermocouple probes were distributed around the cable inside the container.



Fig (4.12) thermocouple distributed in around the cable

- High current transformer, connected through circuit breaker was used to load the cable. The current transformer used to set up supply current to the required high current level (100A and 450A) needed to test the cable.



Fig (4.13) Current source Transformer

4.5 Location of the probe in Experimental.

In the Fig (4.14) and Fig (4.15) see the location of sensor probe that used in the project.

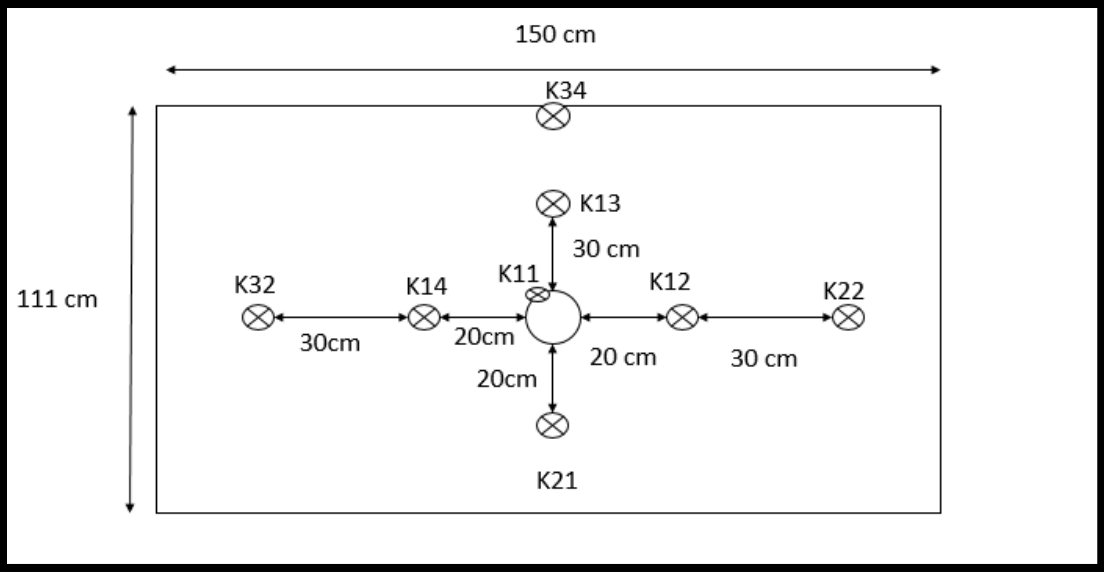


Fig (4.14) side view

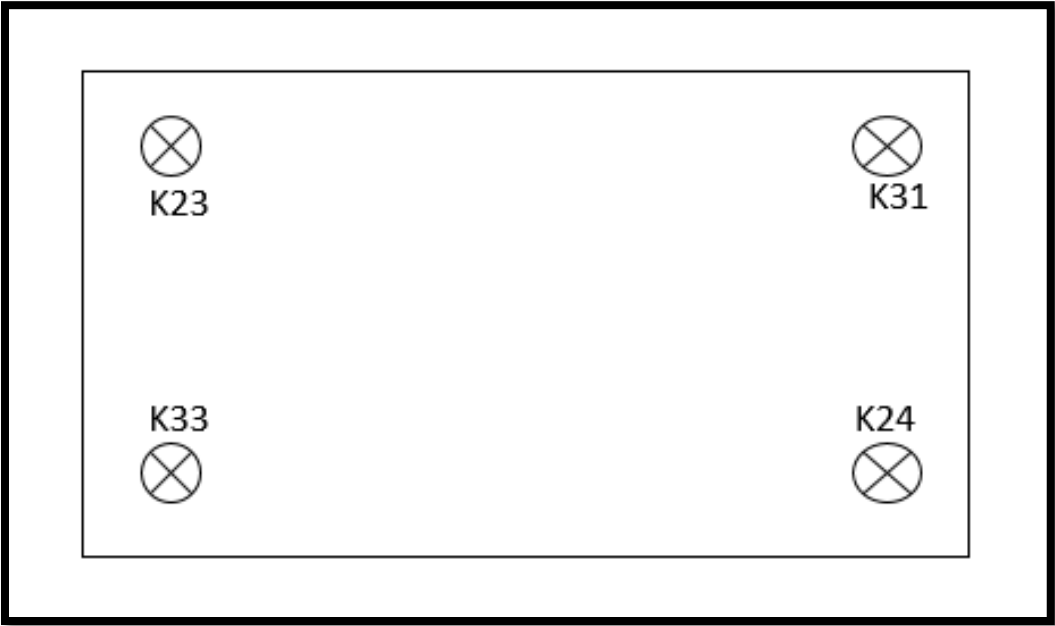


Fig (4.15) Top view

4.6 Results

Every sensor probe that seen in the design in previous section, read the temperature and send it to data logger to show it in the especial program used for it. And we talk the measurements and analysis by the average, curves and percentage of dissipation for each experimental.

Table 4.1 below show the time interval of the curve for each experimental:

Experiment	Time
Sand 100 A	4/4/2016 10:45Am -6/4/2016 10:45Am
Limestone 100A	3/5/2016 10:45Am – 5/5/2016 10:45Am
Wet Sand 450A	20/4/2016 10:20 Pm – 22/4/2016 10:05Am
Limestone 450A	26/4/2016 10:05 Pm – 28/4/2016 11:00Am
Wet limestone 450A	11/5/2016 1:10 Pm – 12/5/2016 10:35Am

- Wet Sand 450A:

Fig (4.16) shows the temperature at the surface of the cable for the case of using 450A and wet sand soil as buried material. It can be seen that the temperature is starts with almost 40 C° and increased gradually until it reached the steady state point at 56 C° during the night. And then, increased gradually during the midding. This is because, the weather temperature increased significantly during this period. However, the temperature is then reduced again to reach the steady state during the night.

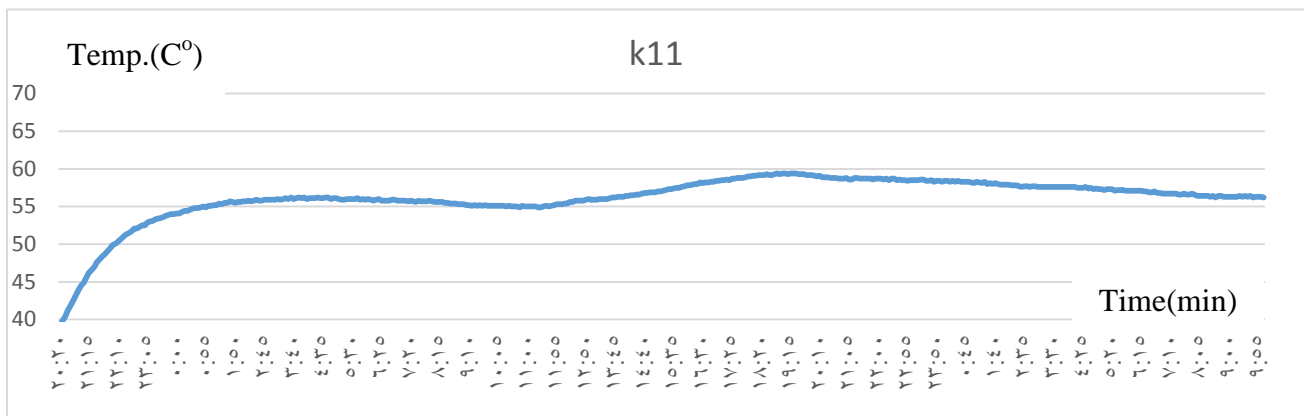


Fig (4.16) Relationship between time and temperature for K11 sensor

Fig (4.19) shows the temperature at 20cm left of the cable for the case of using 450A and wet sand soil as buried material. It can be seen that the temperature is starts with almost $36.1\text{ }C^{\circ}$ and decreased gradually until it reached $32.8\text{ }C^{\circ}$ during the night. And then, increased gradually during the midday until $44\text{ }C^{\circ}$. This is because, the weather temperature increased significantly during this period.

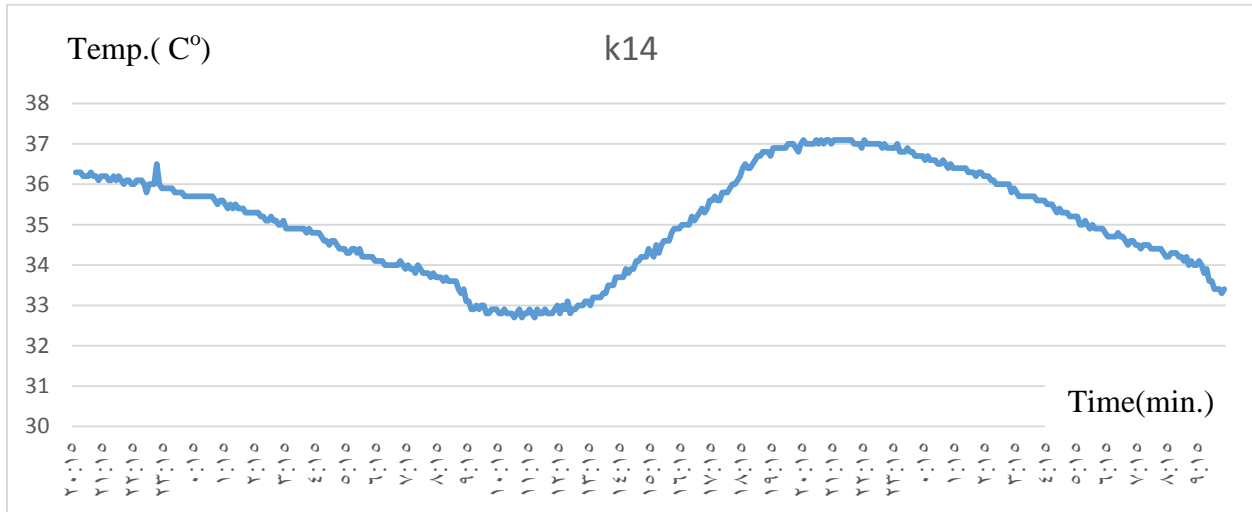


Fig (4.19) Relationship between time and temperature for K14sensor

Fig (4.20) shows the temperature at 20cm in the bottom of the cable for the case of using 450A and wet sand soil as buried material. It can be seen that the temperature is starts with almost $33.5\text{ }C^{\circ}$ and increased gradually until it reached $35\text{ }C^{\circ}$ then reach steady state for short time during the night. And then, decreased gradually during the midday $33.5\text{ }C^{\circ}$ then increased. This curve doesn't effect of the weather because it's under the cable.

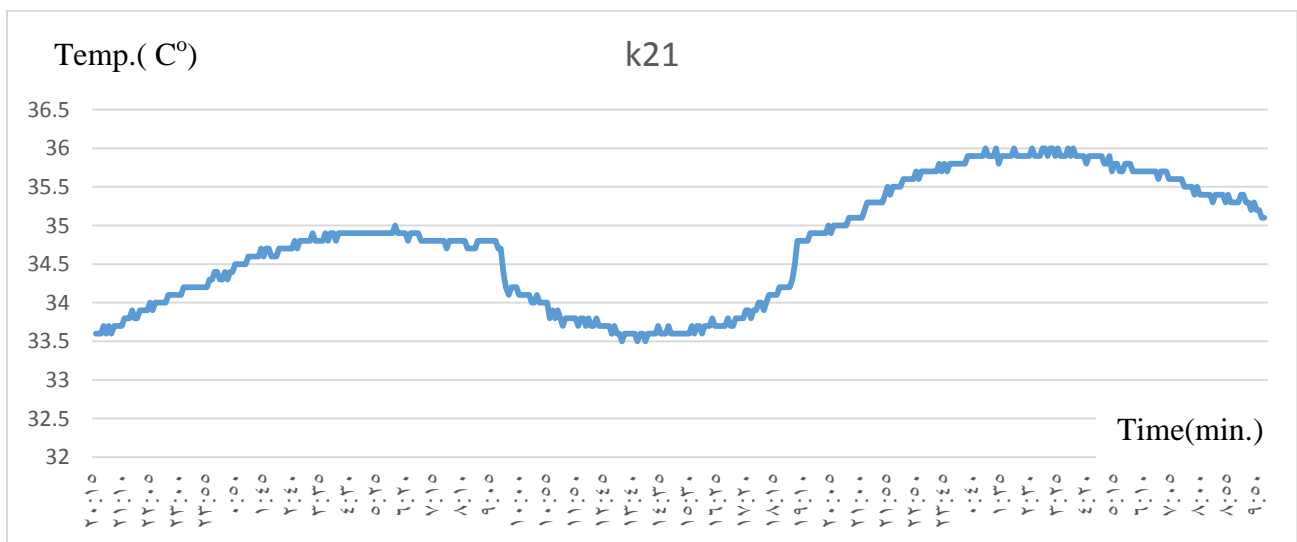


Fig (4.20) Relationship between time and temperature for K21 sensor

Fig (4.21) shows the temperature at 50cm from cable for the case of using 450A and wet sand soil as buried material. It can be seen that the temperature is starts with almost 39 C° and decreased gradually until it reached 30 C° during the night. And then, increased gradually during the midday for short time until 44 C°. This is because, the weather temperature increased significantly during this period.

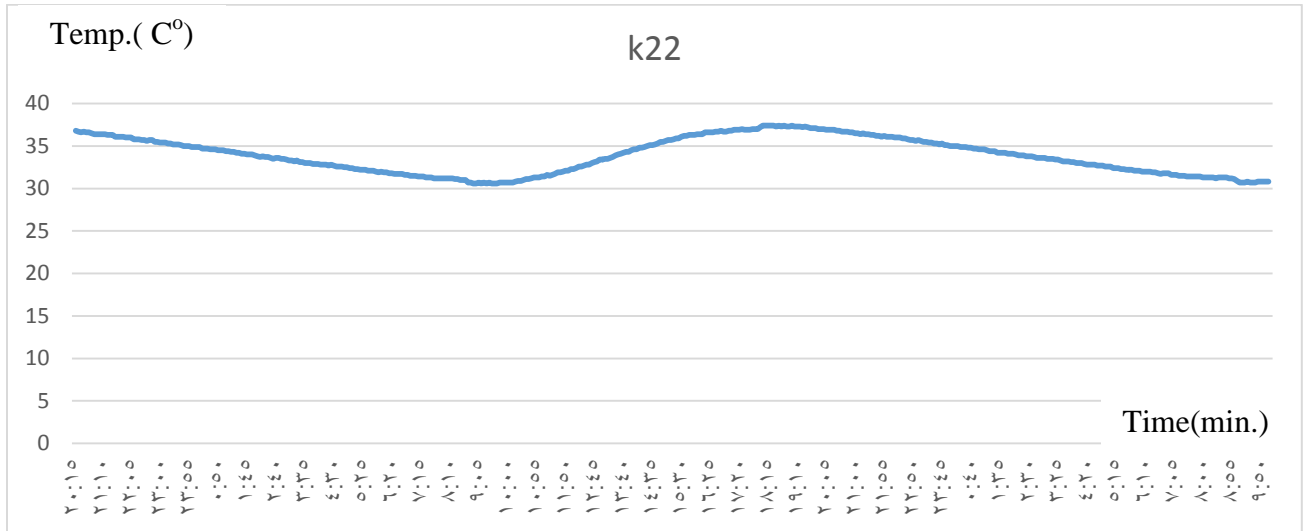


Fig (4.21) Relationship between time and temperature for K22 sensor

Fig (4.22) shows the temperature at the corner of the cable for the case of using 450A and wet sand soil as buried material. It can be seen that the temperature is starts with almost 37 C° and decreased gradually until it reached 30 C° during the night. And then, increased gradually during the midday until 37 C°. This is because, the weather temperature increased significantly during this period.

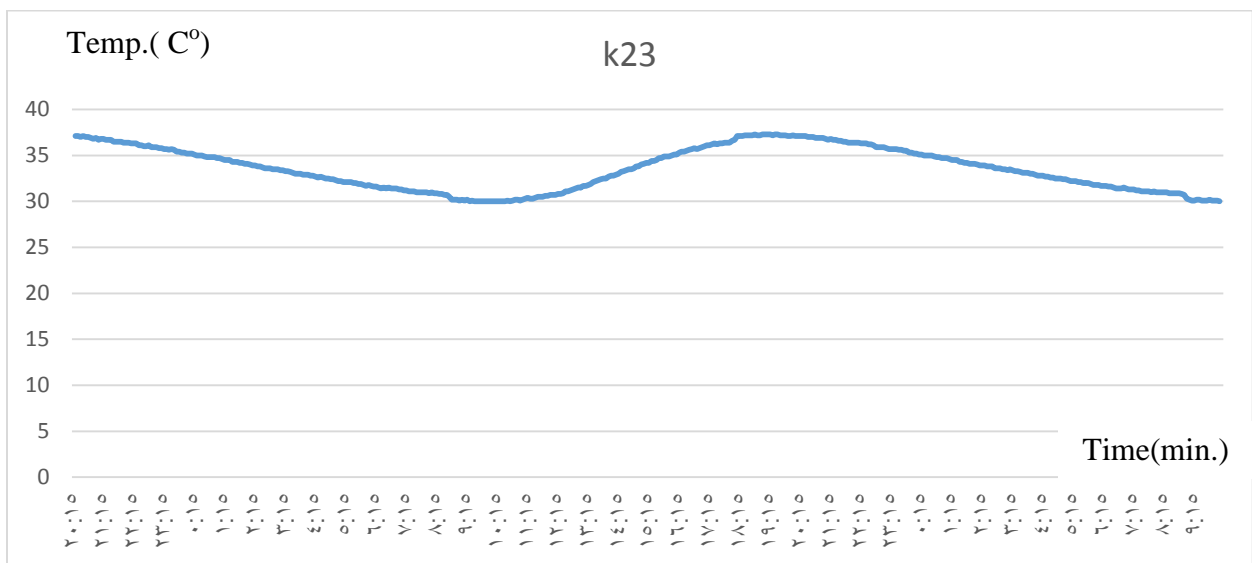


Fig (4.22) Relationship between time and temperature for K23 sensor

Fig (4.23) shows the temperature at the corner of the cable for the case of using 450A and wet sand soil as buried material. It can be seen that the temperature is starts with almost $37\text{ }^{\circ}\text{C}$ and decreased gradually until it reached $30\text{ }^{\circ}\text{C}$ during the night. And then, increased gradually during the midday until $38\text{ }^{\circ}\text{C}$. This is because, the weather temperature increased significantly during this period.

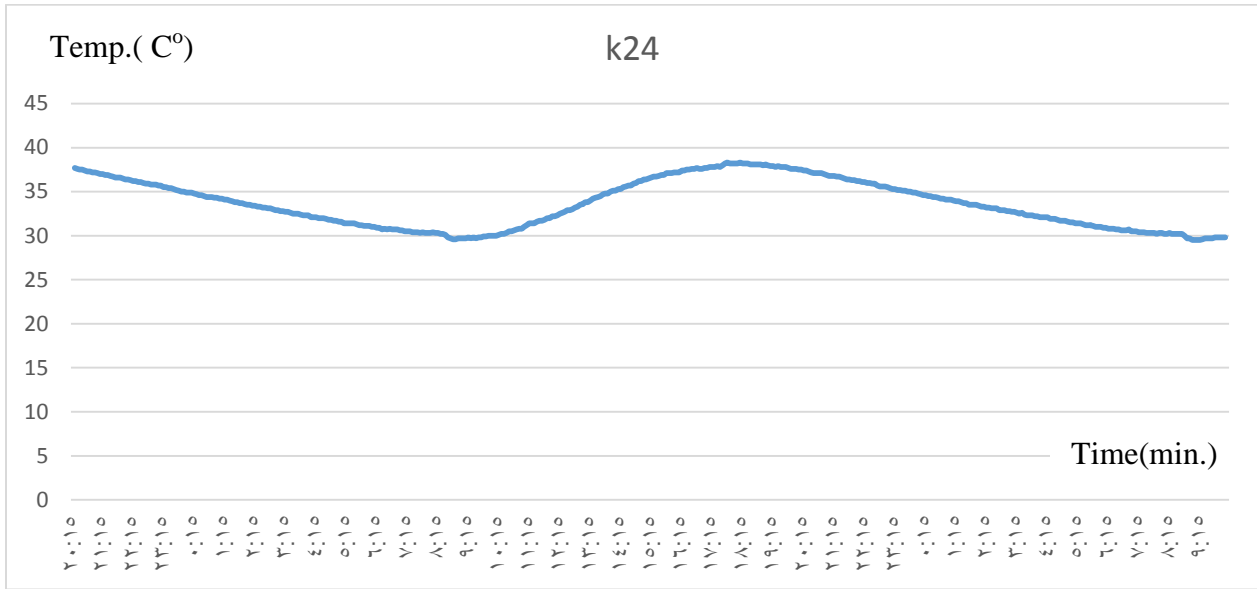


Fig (4.23) Relationship between time and temperature for K24 sensor

Fig (4.24) shows the temperature at the corner of the cable for the case of using 450A and wet sand soil as buried material. It can be seen that the temperature is starts with almost $30\text{ }^{\circ}\text{C}$ and decreased gradually until it reached $20\text{ }^{\circ}\text{C}$ during the night. And then, increased gradually during the midday until $49\text{ }^{\circ}\text{C}$ then stay at steady state for short time. This is because, the weather temperature increased significantly during this period.

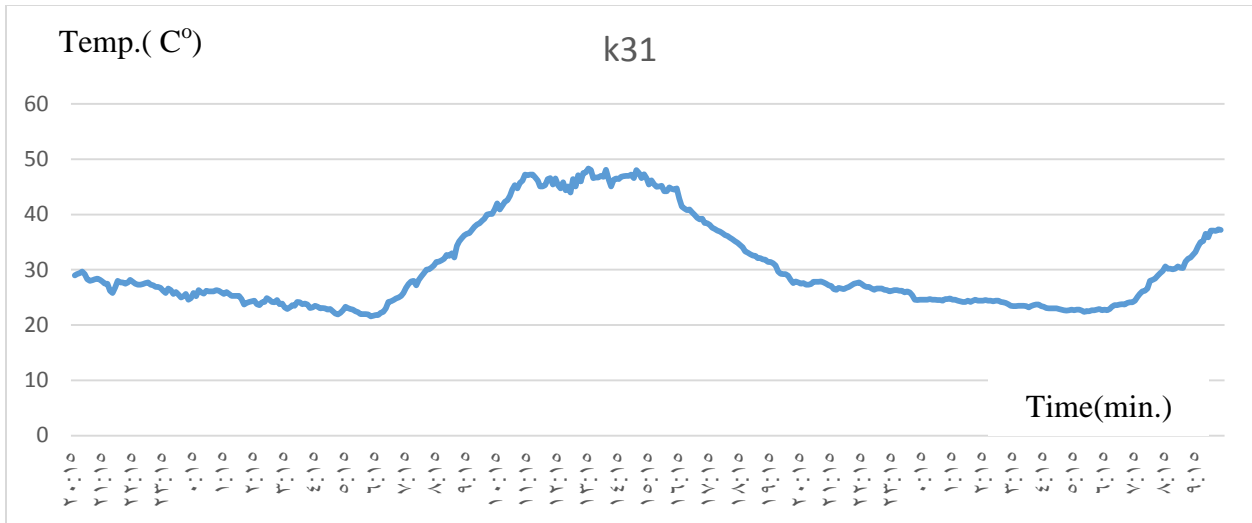


Fig (4.24) Relationship between time and temperature for K31 sensor

Fig (4.25) shows the temperature at 50cm to the left of the cable for the case of using 450A and wet sand soil as buried material. It can be seen that the temperature is starts with almost 37 C° and decreased gradually until it reached 30 C° during the night. And then, increased gradually during the midday until 37 C°. This is because, the weather temperature increased significantly during this period.

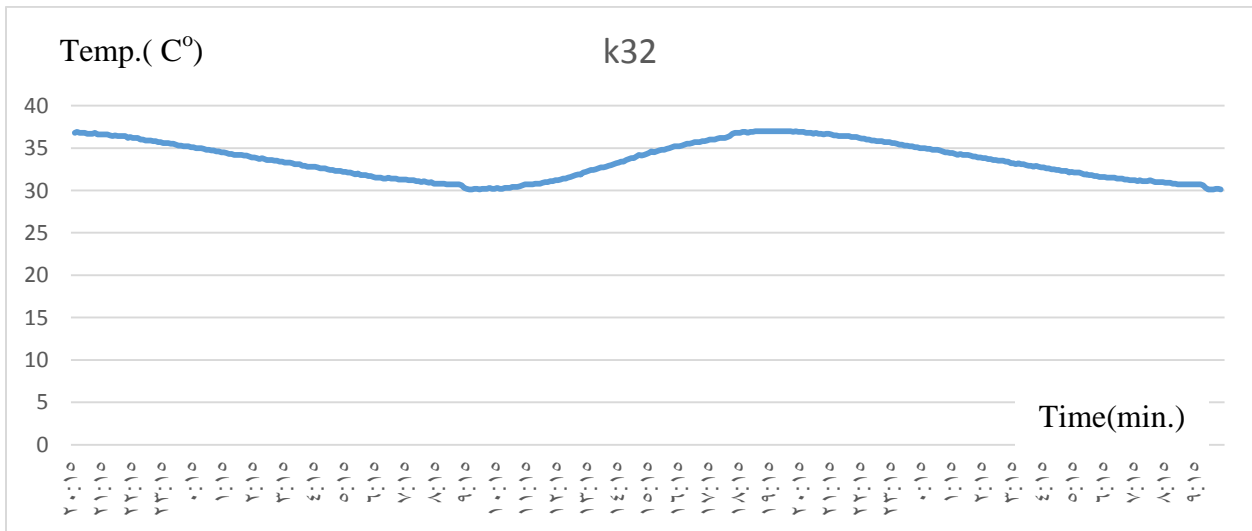


Fig (4.25) Relationship between time and temperature for K32 sensor

Fig (4.26) shows the temperature at the corner of the cable for the case of using 450A and wet sand soil as buried material. It can be seen that the temperature is starts with almost 37 C° and decreased gradually until it reached 30 C° during the night. And then, increased gradually during the midday until 37 C°. This is because, the weather temperature increased significantly during this period.

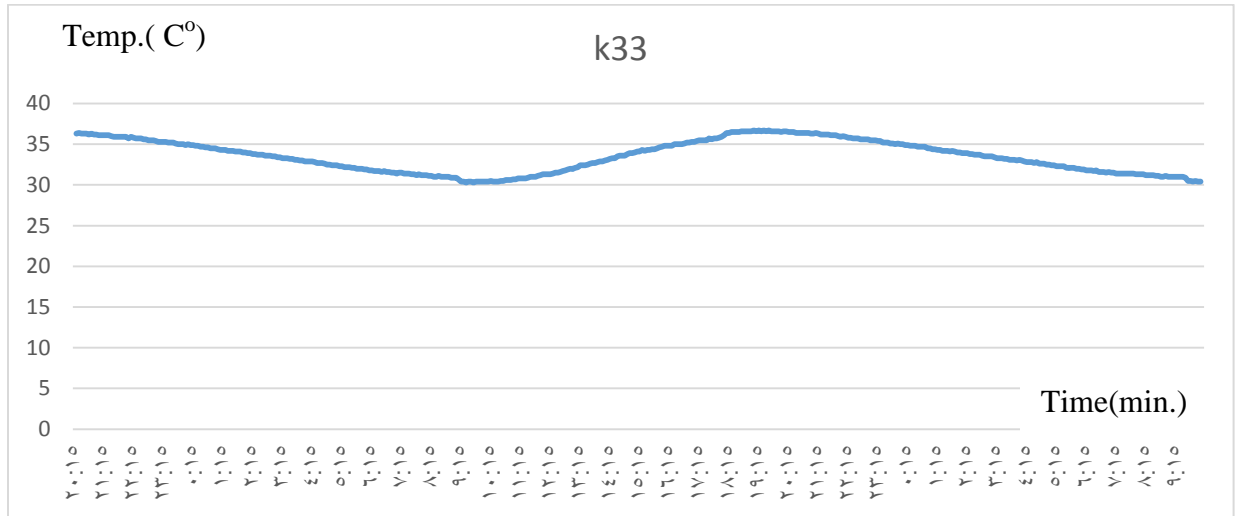


Fig (4.26) Relationship between time and temperature for K33 sensor

Fig (4.27) shows the temperature at the surface of box for the case of using 450A and wet sand soil as buried material. It can be seen that the temperature is starts with almost 37 C° and decreased gradually until it reached 30 C° during the night. And then, increased gradually during the midday until 38 C°. This is the weather temperature.

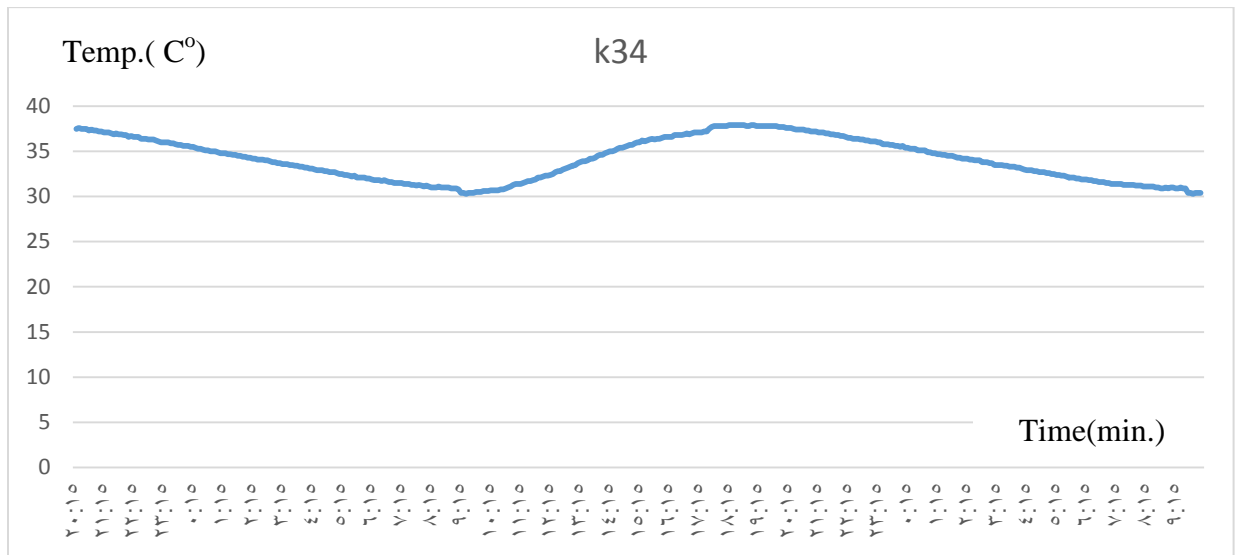


Fig (4.27) Relationship between time and temperature for K34 sensor

- **Limestone 450A:**

Fig (4.28) shows the temperature at the surface of the cable for the case of using 450A and limestone soil as buried material. It can be seen that the temperature is starts with almost 36 C° and increased gradually until it reached the steady state point at 60 C° then stay at steady state, this is because the heat from cable is affect more than weather temperature.

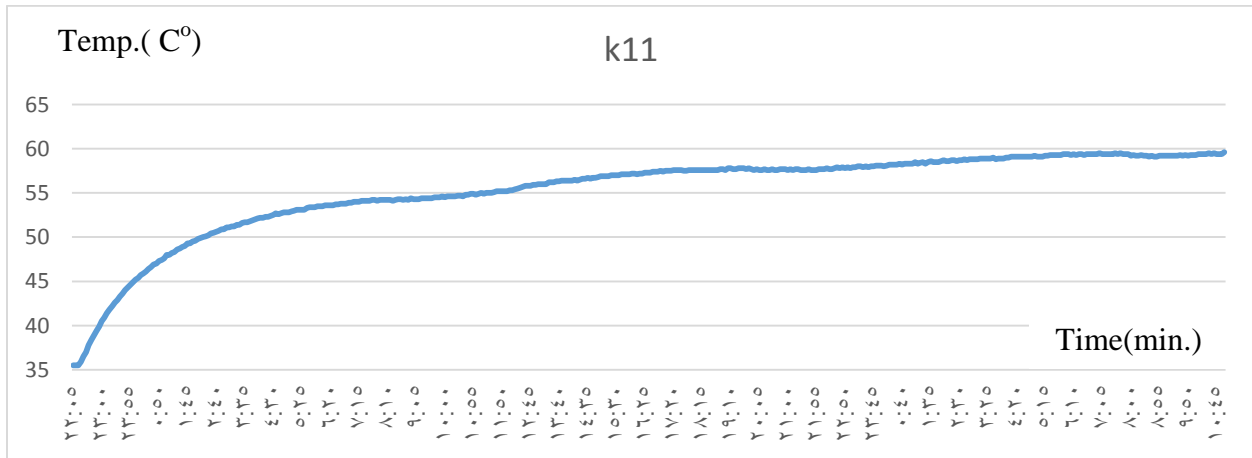


Fig (4.28) Relationship between time and temperature for K11 sensor

Fig (4.29) shows the temperature at 20cm to the right of the cable for the case of using 450A and limestone soil as buried material. It can be seen that the temperature is starts with almost 33 C° and increased gradually until it reached 37.5 C° and then stay at steady state, this is because the soil dissipate heat that out from cable.

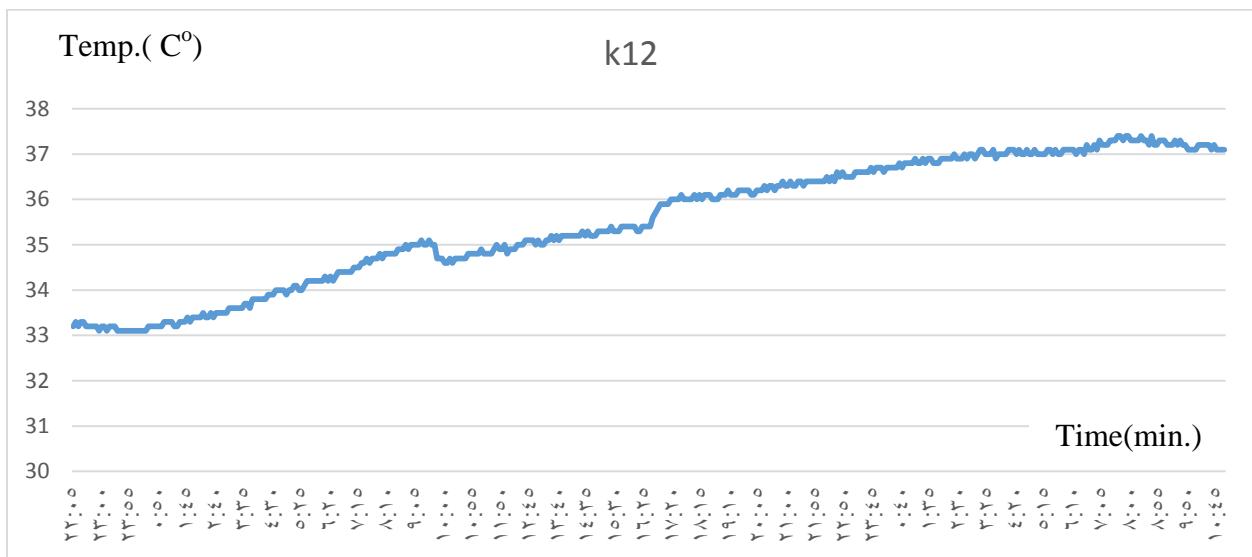


Fig (4.29) Relationship between time and temperature for K12 sensor

Fig (4.30) shows the temperature at 30cm at the top of the cable for the case of using 450A and limestone soil as buried material. It can be seen that the temperature is starts with almost 34 C° and decreased gradually until it reached 30 C° at night and then increased again at midday until reach 36 C°, this is because, the weather temperature increased significantly during this period.

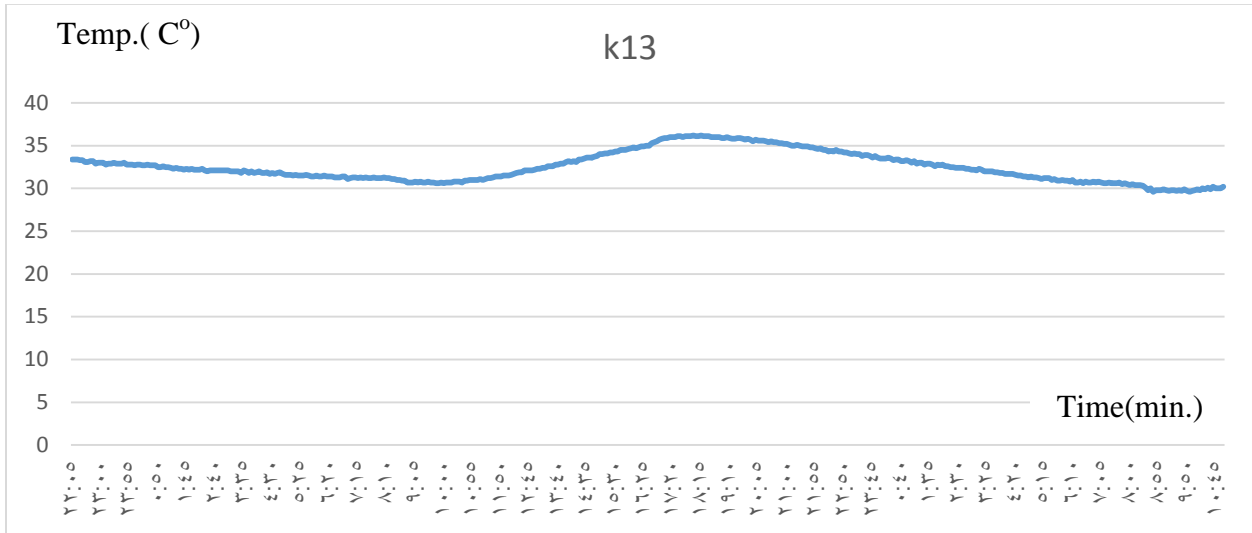


Fig (4.30) Relationship between time and temperature for K13 sensor

Fig (4.31) shows the temperature at 20cm at the left of the cable for the case of using 450A and limestone soil as buried material. It can be seen that the temperature is starts with almost 33 C° and increased gradually until it reached 37 C° then stay at steady state, this is because, the effect of the soil to the heat dissipation.

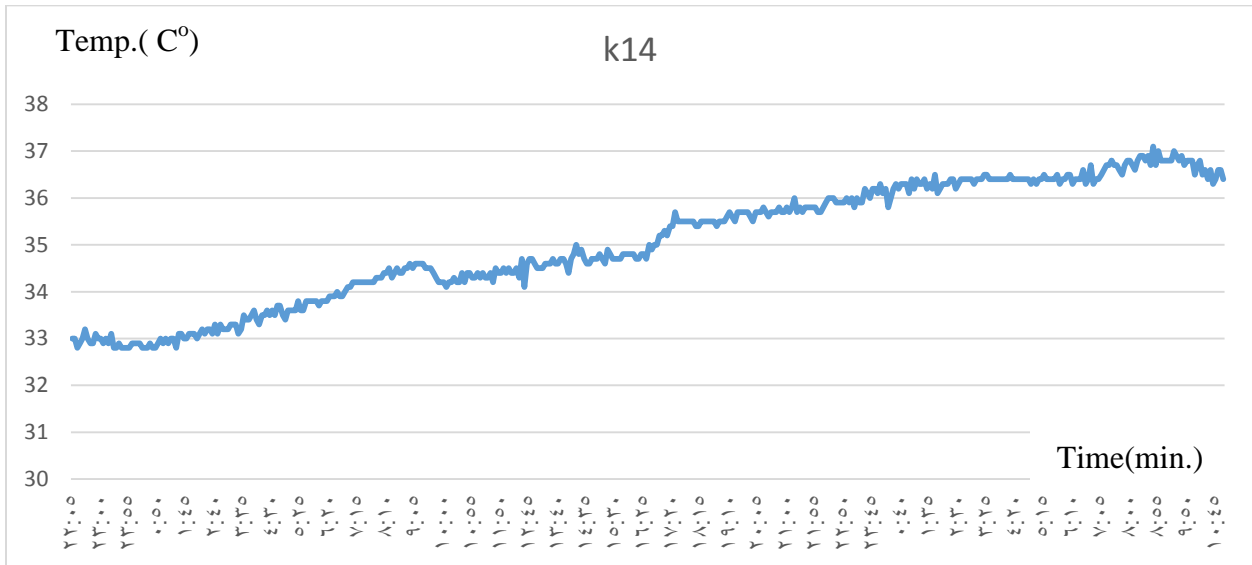


Fig (4.31) Relationship between time and temperature for K14 sensor

Fig (4.32) shows the temperature at 20cm at the bottom of the cable for the case of using 450A and limestone soil as buried material. It can be seen that the temperature is starts with almost 32 C° and increased gradually until it reached 32.5 C° at night and then decreased again at midday until reach 32.1 C° and then decreased again to each steady state, this is because, the weather temperature is ignored.

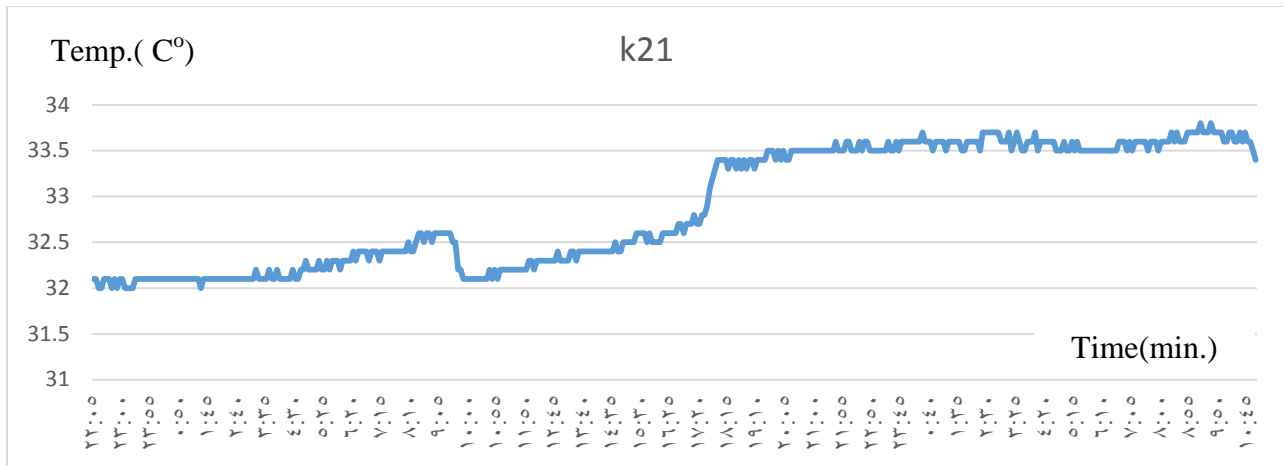


Fig (4.32) Relationship between time and temperature for K21 sensor

Fig (4.33) shows the temperature at 50cm at the right of the cable for the case of using 450A and limestone soil as buried material. It can be seen that the temperature is starts with almost 31 C° and increased gradually until it reached 31.9 C° then return to steady state and then decreased to 31 C° and increased again at midday until reach 33 C°, this is because the weather temperature during this period.

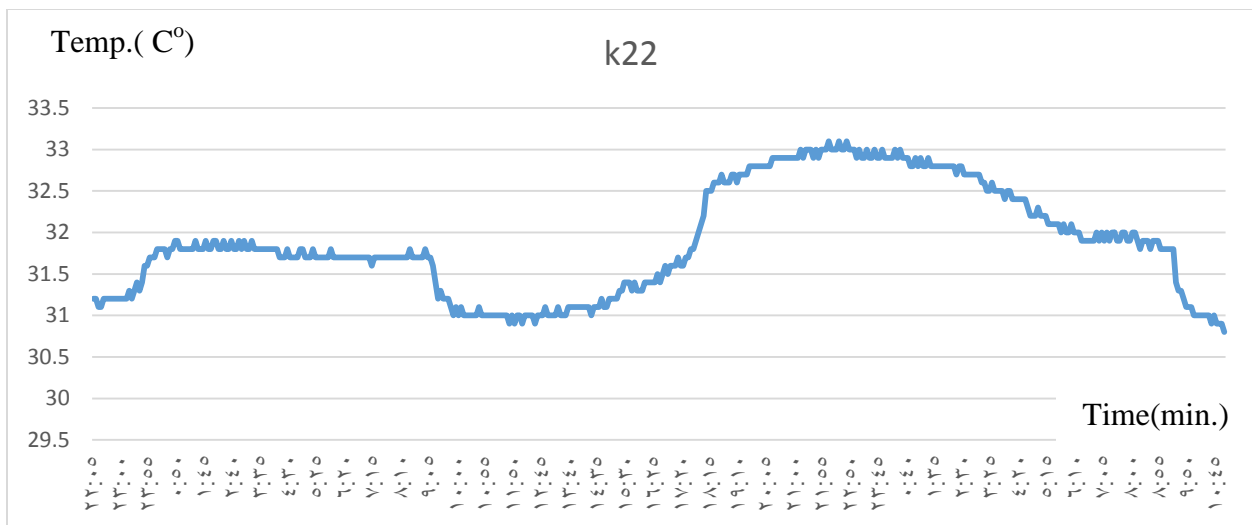


Fig (4.33) Relationship between time and temperature for K22 sensor

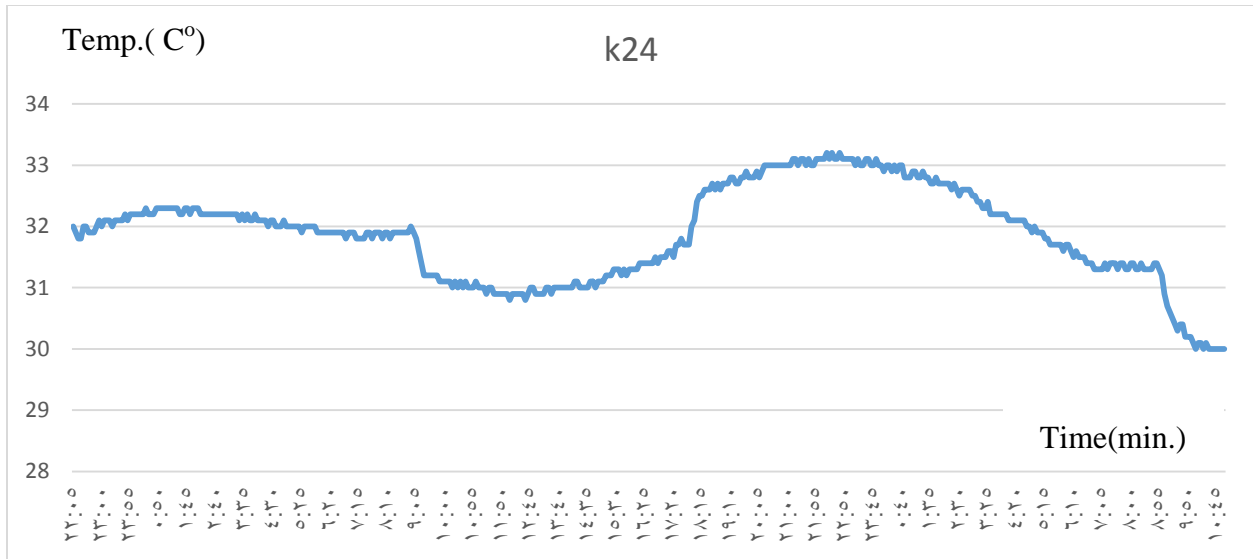


Fig (4.35) Relationship between time and temperature for K24 sensor

Fig (4.36) shows the temperature at the right corner of the cable for the case of using 450A and limestone soil as buried material. It can be seen that the temperature is starts with almost 34 C° and decreased gradually until it reached 25 oC at night and then increased again at midday until reach 42oC then decreased again, this is because the weather temperature increased significantly during this period then decreased at night.

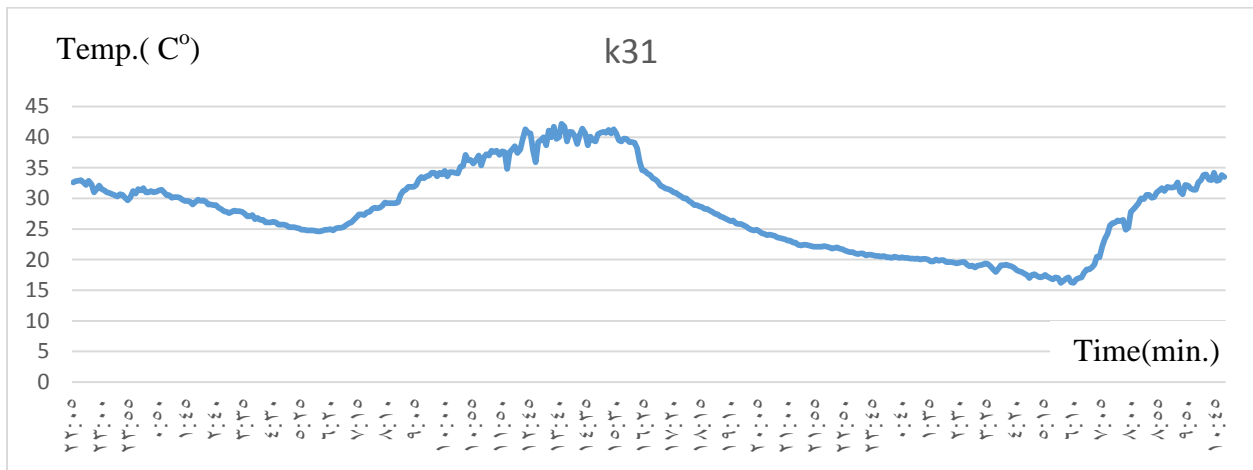


Fig (4.36) Relationship between time and temperature for K31 sensor

Fig (4.37) shows the temperature at 50cm left of the cable for the case of using 450A and limestone soil as buried material. It can be seen that the temperature is starts with almost 31.5 C° and decreased gradually until it reached 30.8 C° at night and then increased again at midday

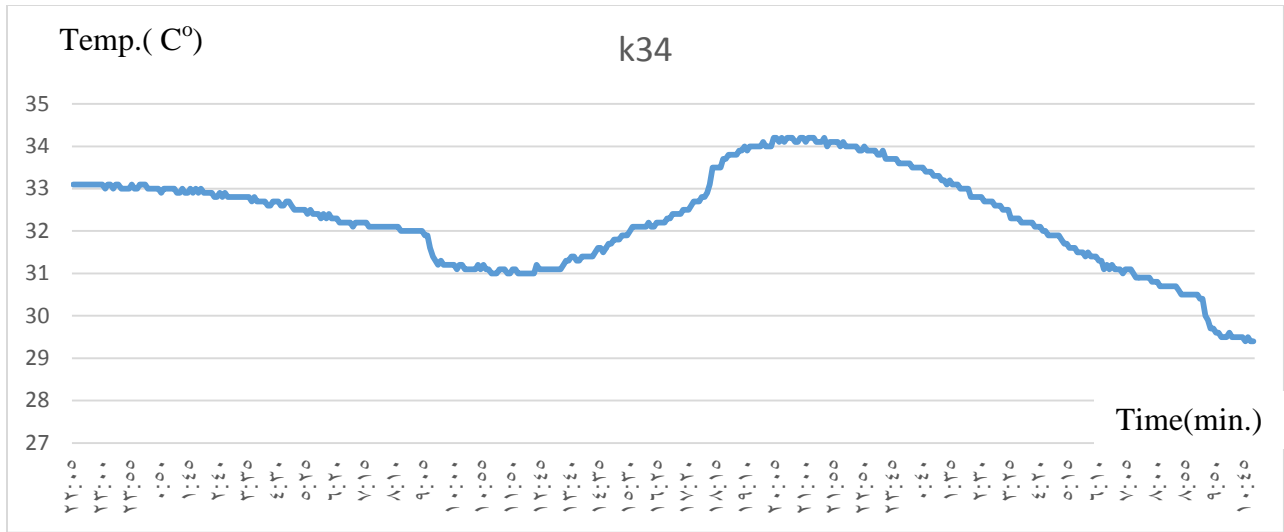


Fig (4.39) Relationship between time and temperature for K34 sensor

Table (4.2) the average value of temperature for wet sand soil, limestone and the percentage dissipation with load 450A.

Soil probes	Wet Sand 450 A	Limestone 450 A	Percentage dissipation of each probe in sand soil relative to K11 %	Percentage dissipation of each probe in limestone soil relative to K11 %	Percentage Difference %
<i>K₁₁</i>	56.126	55.299	—	—	—
<i>K₁₂</i>	36.159	35.521	35.5	35.7	0,2
<i>K₁₃</i>	34.891	32.516	37.8	41.2	3,4
<i>K₁₄</i>	35.083	35.028	37.5	36.6	-0,9
<i>K₂₁</i>	34.766	32.883	38	40.5	2,0
<i>K₂₂</i>	33.879	31.8937	39.6	42.32	2,72
<i>K₂₃</i>	33.571	31.653	40.1	42.7	2,6
<i>K₂₄</i>	33.633	31.882	40	42.2	2,2
<i>K₃₁</i>	30.440	28.080	45.7	49.2	3,0
<i>K₃₂</i>	33.569	31.597	40.1	42.86	2,7
<i>K₃₃</i>	33.517	31.574	40.2	42.9	2,7
<i>K₃₄</i>	34.140	32.289	39.1	41.6	2,0

As see in the table (4.2) average temperature for two type of soil that used in the project, and it explain that the average temperature for limestone soil less than sand soil for every sensor probe, and the heat dissipation for limestone better than sand soil; that means the limestone soil is better than sand for dissipate the heat.

- **Wet limestone 450A:**

Fig (4.40) shows the temperature at the surface of the cable for the case of using 450A and wet limestone soil as buried material. It can be seen that the temperature is starts with almost $49\text{ }^{\circ}\text{C}$ and increased gradually until it reached the steady state point at $64\text{ }^{\circ}\text{C}$. This is because, the effect of heat out from cable during this period.

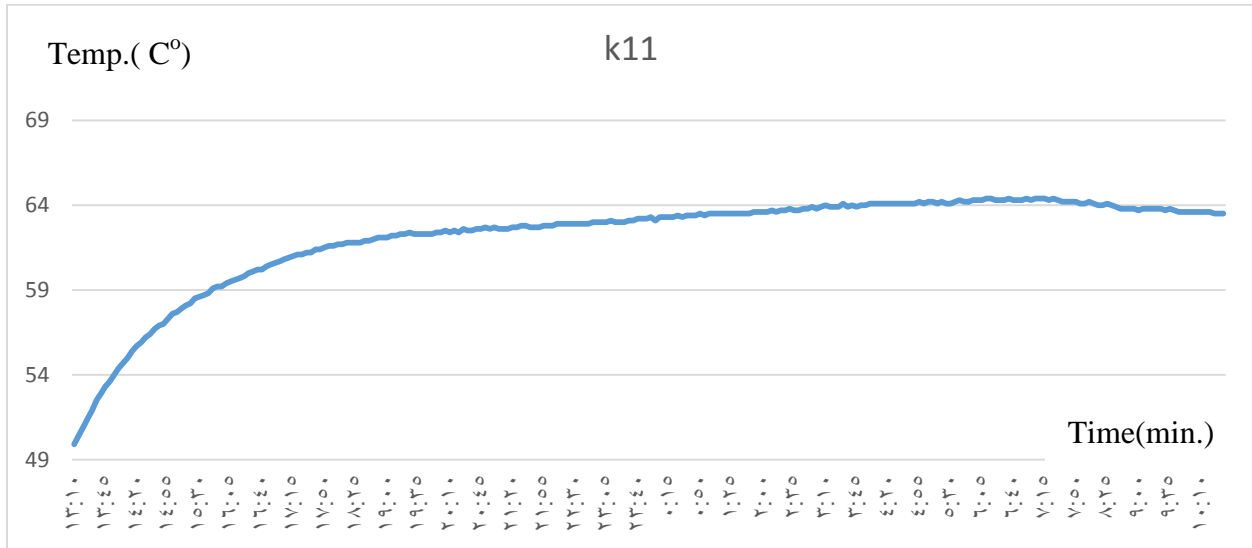


Fig (4.40) Relationship between time and temperature for K11 sensor

Fig (4.41) shows the temperature at 20cm to the right of the cable for the case of using 450A and wet limestone soil as buried material. It can be seen that the temperature is starts with almost $37\text{ }^{\circ}\text{C}$ and decreased gradually until it reached $36.4\text{ }^{\circ}\text{C}$ then increased again until reach steady state at $38.2\text{ }^{\circ}\text{C}$. This is because, the soil dissipate heat that out from cable

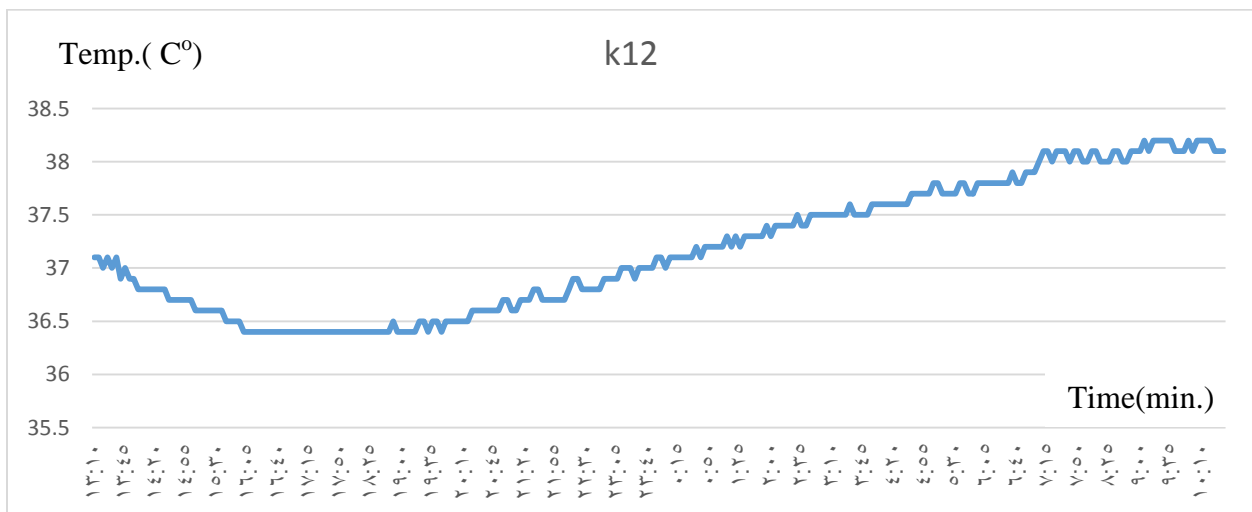


Fig (4.41) Relationship between time and temperature for K12 sensor

Fig (4.42) shows the temperature at 30cm in the top of the cable for the case of using 450A and wet limestone soil as buried material. It can be seen that the temperature is starts with almost 30 C° and increased gradually until it reached 38 C° in the midday. And then, decreased gradually until 27 C°. This is because, the weather temperature increased and decreased significantly during this period.

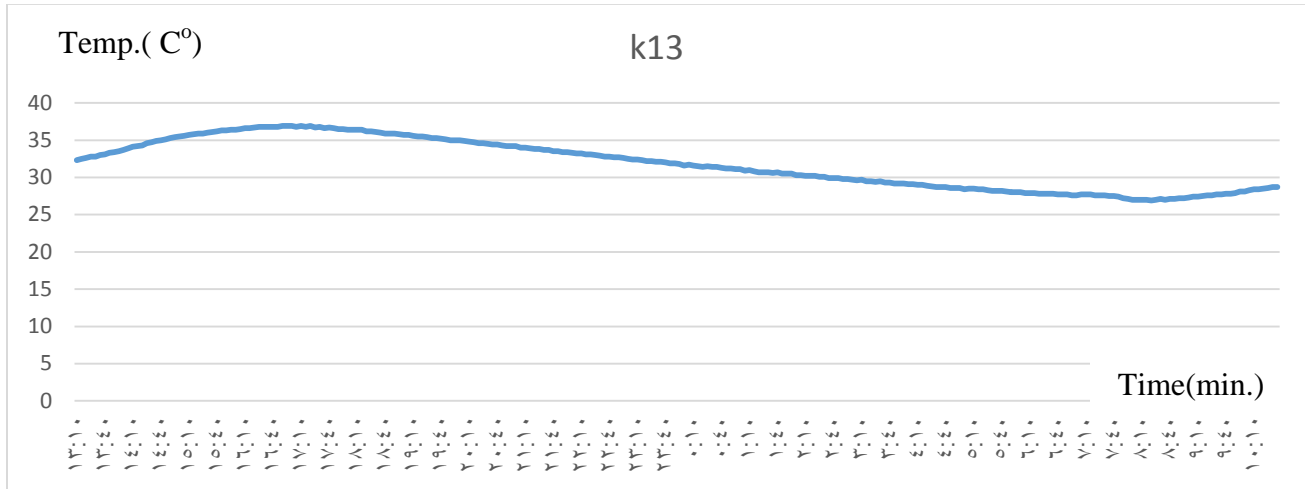


Fig (4.42) Relationship between time and temperature for K13 sensor

Fig (4.43) shows the temperature at 20cm left of the cable for the case of using 450A and wet limestone soil as buried material. It can be seen that the temperature is starts with almost 35.9 C° and decreased gradually until it reached 35.5 C° during the day. And then, increased gradually during the midday until 37 C°. This is because, the weather temperature increased significantly during this period.

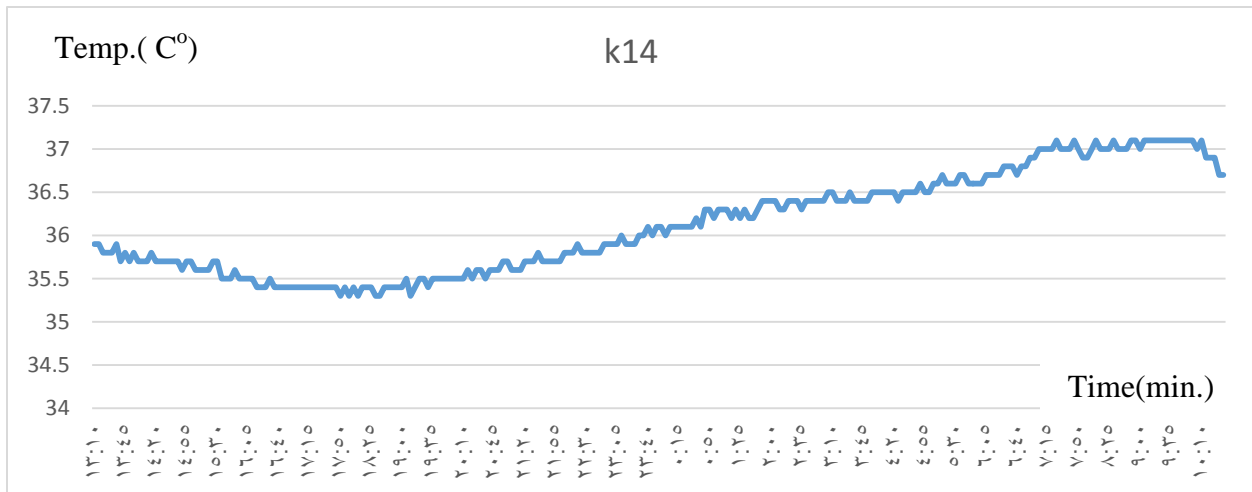


Fig (4.43) Relationship between time and temperature for K14 sensor

Fig (4.46) shows the temperature at the corner of the cable for the case of using 450A and wet limestone soil as buried material. It can be seen that the temperature is starts with almost 26 C° and increased gradually until it reached 33 C° during the day. And then, decreased gradually during the night until 26 C°. This is because, the weather temperature increased significantly during this period.

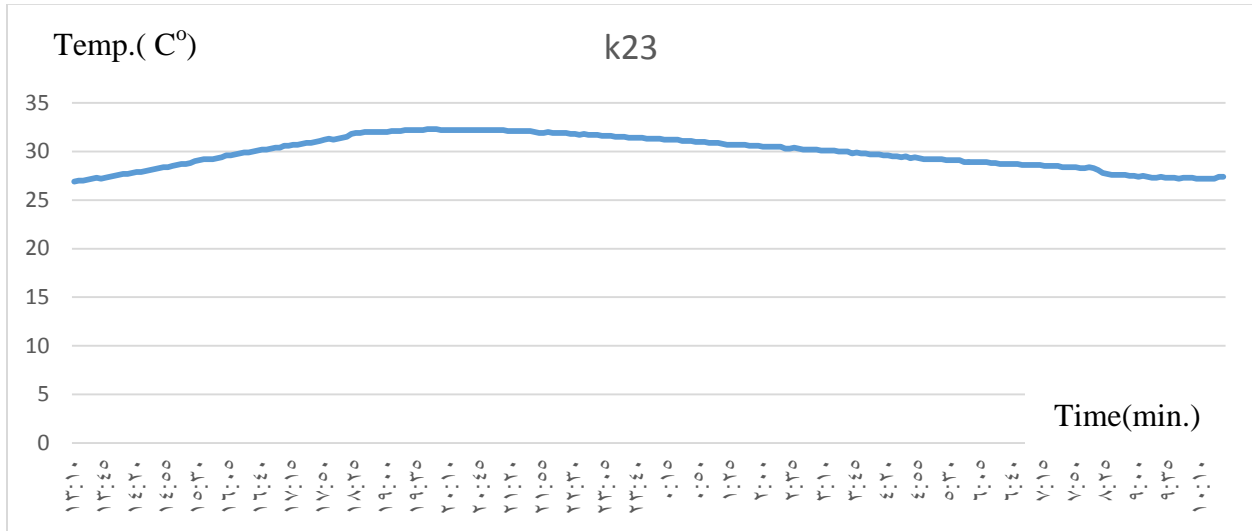


Fig (4.46) Relationship between time and temperature for K23 sensor

Fig (4.47) shows the temperature at the corner of the cable for the case of using 450A and wet limestone soil as buried material. It can be seen that the temperature is starts with almost 27.9 C° and increased gradually until it reached 31.1 C° during the day. And then, decreased gradually until 28 C°. This is because, the weather temperature increased significantly during the day.

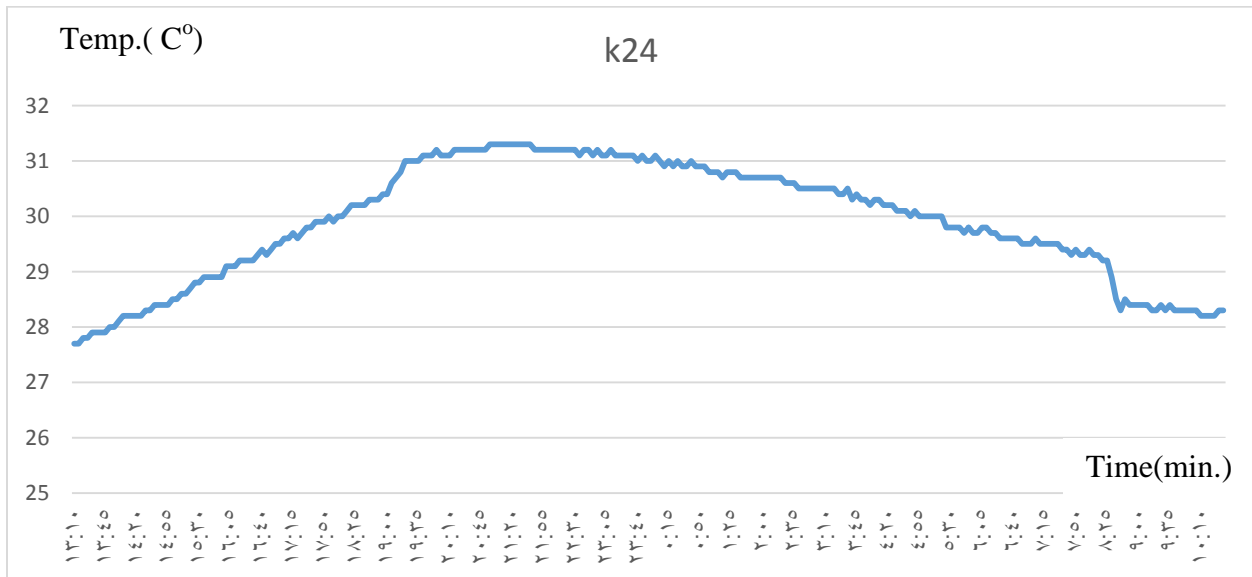


Fig (4.47) Relationship between time and temperature for K24 sensor

Fig (4.48) shows the temperature at the corner of the cable for the case of using 450A and wet limestone soil as buried material. It can be seen that the temperature is starts with almost 35 C° and decreased gradually until it reached 19 C° during the night. And then, increased gradually during the midday until 35 C°. This is because, the weather temperature increased significantly during this period.

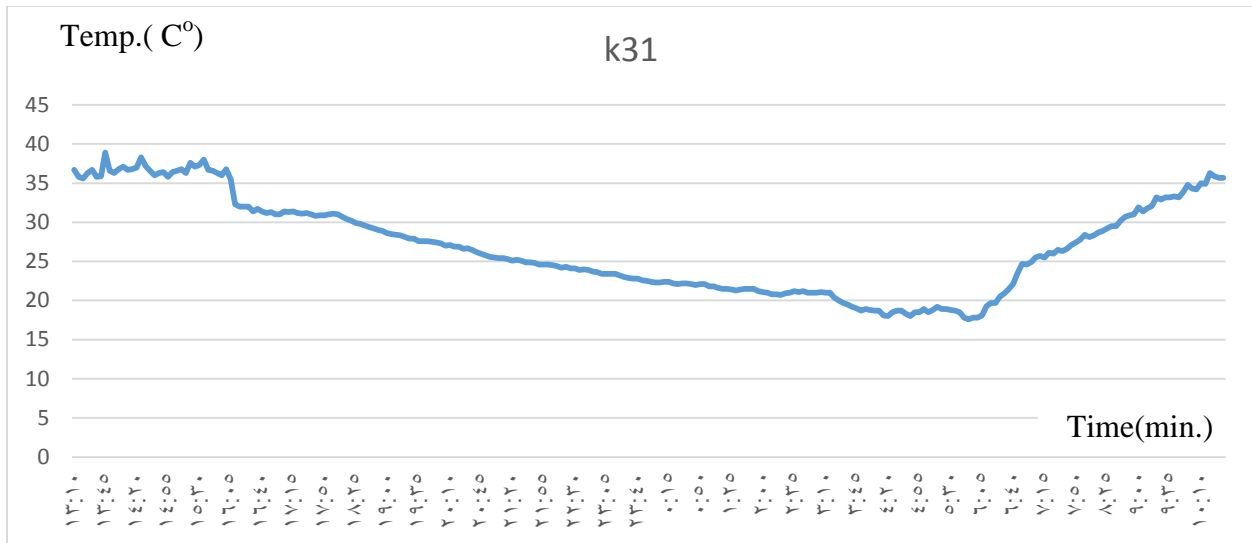


Fig (4.48) Relationship between time and temperature for K31 sensor

Fig (4.49) shows the temperature at 50cm to the left of the cable for the case of using 450A and wet limestone soil as buried material. It can be seen that the temperature is starts with almost 27 C° and increased gradually until it reached 31 C° during the day. And then, decreased gradually during the night until 27 C°. This is because, the weather temperature increased significantly during this period.

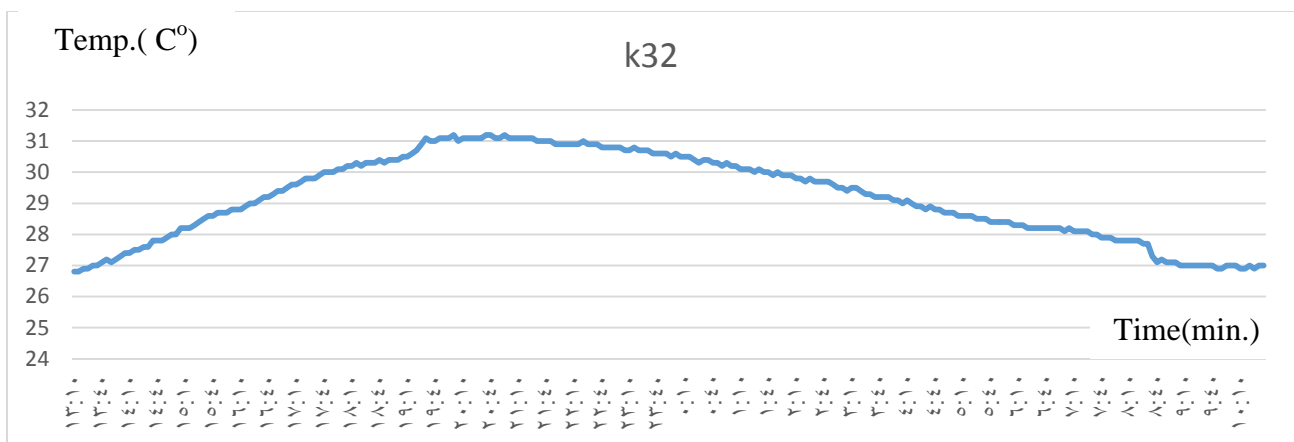


Fig (4.50) shows the temperature at left corner of the cable for the case of using 450A and wet limestone soil as buried material. It can be seen that the temperature is starts with almost 27 C° and increased gradually until it reached 31 C° and then decreased again at midday until reach 28 C°, this is because the weather temperature effect during the day.

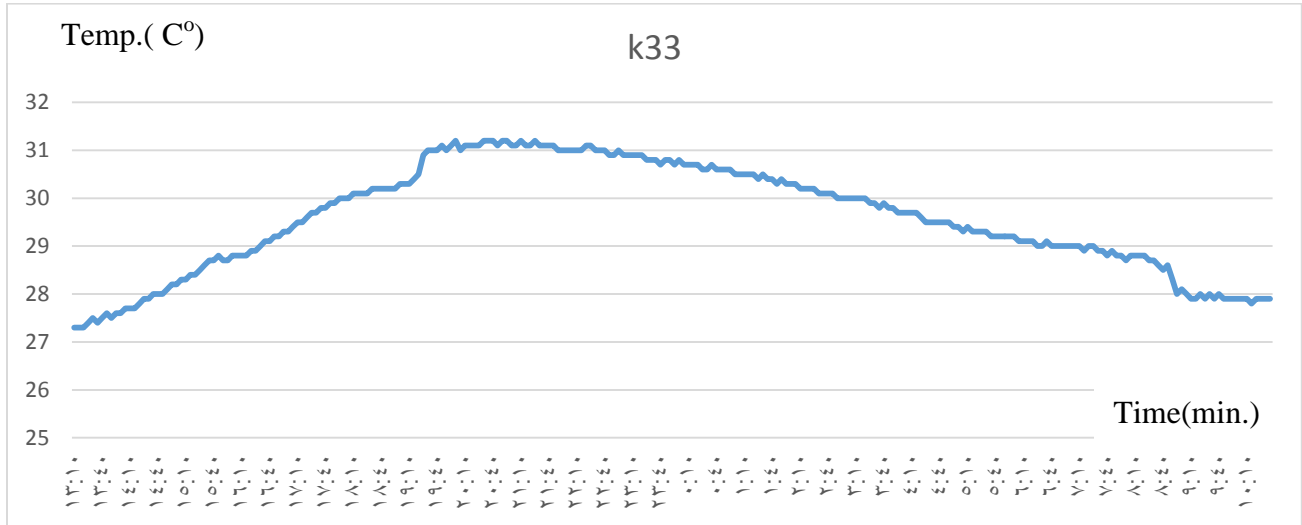


Fig (4.50) Relationship between time and temperature for K33 sensor

Fig (4.51) shows the temperature at the surface of the box for the case of using 450A and wet limestone soil as buried material. This curve describes the weather temperature at time period.

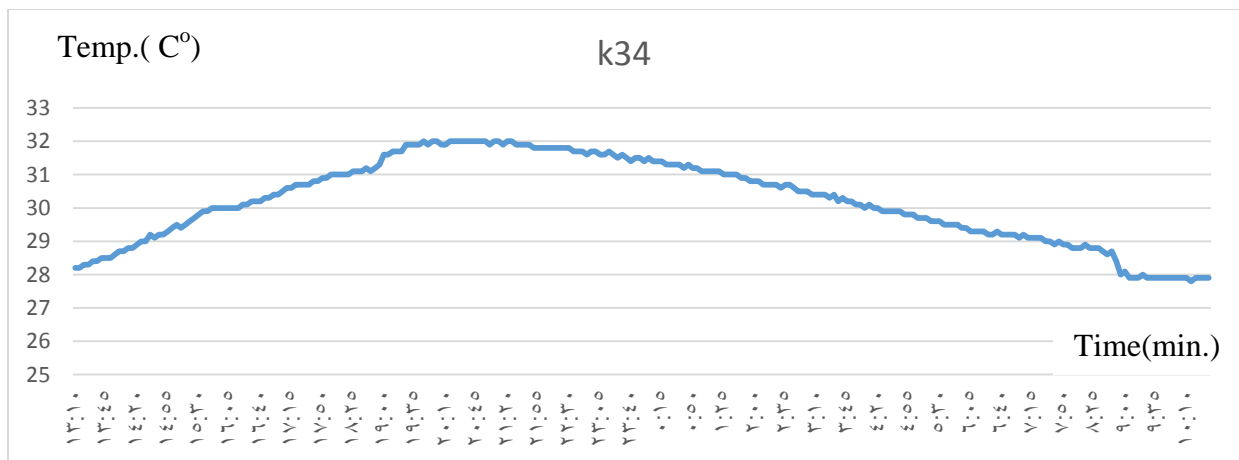


Fig (4.51) Relationship between time and temperature for K34 sensor

Table (4.3) the average value of temperature for wet sand and wet limestone soil with load 450A and the percentage dissipation for every one of them.

Soil probes	Wet Sand 450 A	Wet Limestone 450 A	Percentage dissipation of each probe in sand soil respective to K11 %	Percentage dissipation of each probe in wet limestone soil respective to K11 %	Percentage Difference %
K_{11}	56.126	62.132	—	—	—
K_{12}	36.159	37.169	35.5	40.1	4.6
K_{13}	34.891	31.815	37.8	48.8	11
K_{14}	35.083	36.123	37.5	41.8	4.3
K_{21}	34.766	31.810	38	48.8	10.8
K_{22}	33.879	30.221	39.6	51.3	11.7
K_{23}	33.571	29.923	40.1	51.8	11.7
K_{24}	33.633	29.905	40	51.8	11.8
K_{31}	30.440	26.922	45.7	56.6	10.9
K_{32}	33.569	29.205	40.1	53	12.9
K_{33}	33.517	29.581	40.2	52.4	12.2
K_{34}	34.140	30.216	39.1	51.3	12.2

As see in the table (4.3) average temperature for two type of soil that used in the project, and it explain that heat dissipation for wet limestone soil better than wet sand soil for every sensor probe, and; that means the wet limestone soil is better than wet sand for dissipate the heat.

- **Sand 100A:**

Fig (4.52) shows the temperature at the surface of the cable for the case of using 100A and sand soil as buried material. It can be seen that the temperature is starts with almost $27\text{ }^{\circ}\text{C}$ and increased gradually until it reached $30.1\text{ }^{\circ}\text{C}$ during the day. And then, decreased gradually during the night. This is because, the weather temperature increased significantly during the day.

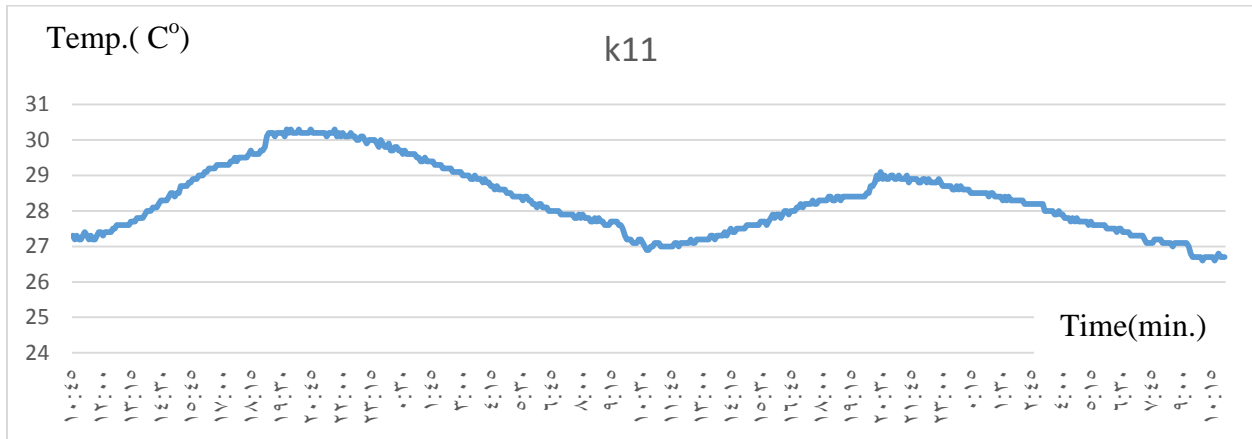


Fig (4.52) Relationship between time and temperature for K11 sensor

Fig (4.53) shows the temperature at 20cm to the right of the cable for the case of using 100A and sand soil as buried material. It can be seen that the temperature is starts with almost $27\text{ }^{\circ}\text{C}$ and increased gradually until it reached $29.8\text{ }^{\circ}\text{C}$ during the day. And then, decreased gradually during the midday until reach $26.8\text{ }^{\circ}\text{C}$. This is because, the weather temperature increased significantly during this period.

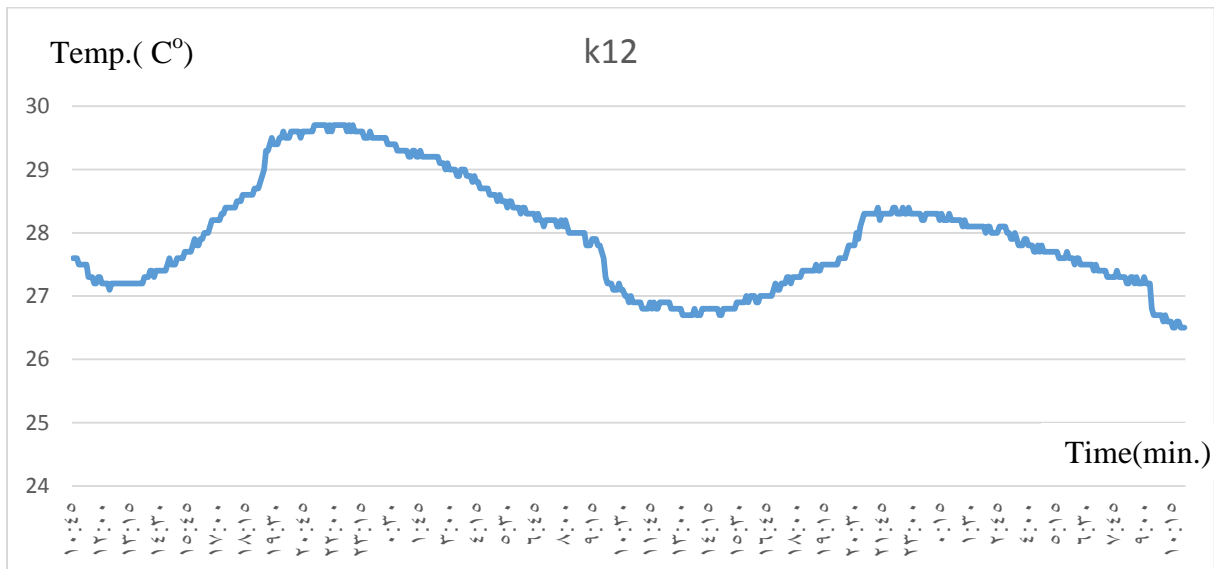


Fig (4.53) Relationship between time and temperature for K12 sensor

Fig (4.54) shows the temperature at 30cm in the top of the cable for the case of using 100A and sand soil as buried material. It can be seen that the temperature is starts with almost $25\text{ }^{\circ}\text{C}$ and increased gradually until it reached $35\text{ }^{\circ}\text{C}$ during the day. And then, decreased gradually during the night until $23\text{ }^{\circ}\text{C}$. This is because, the weather temperature increased significantly during day.

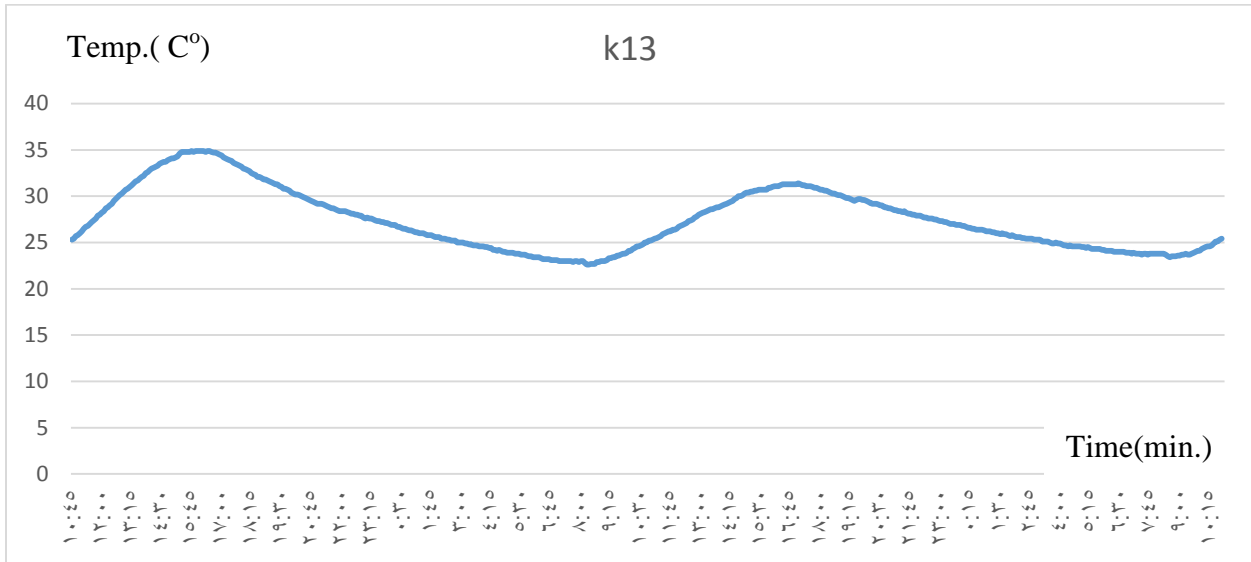


Fig (4.54) Relationship between time and temperature for K13 sensor

Fig (4.55) shows the temperature at 20cm left of the cable for the case of using 100A and sand soil as buried material. It can be seen that the temperature is starts with almost $27\text{ }^{\circ}\text{C}$ and increased gradually until it reached $29.8\text{ }^{\circ}\text{C}$ during the day. And then, decreased gradually during the night until $26.5\text{ }^{\circ}\text{C}$. This is because, the weather temperature decreased significantly during this period.

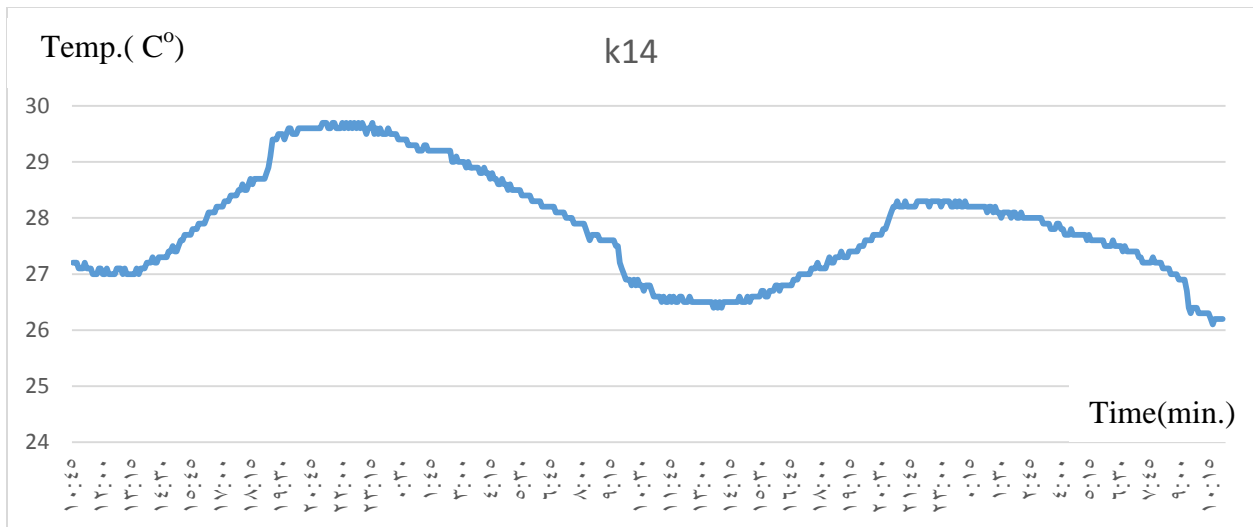
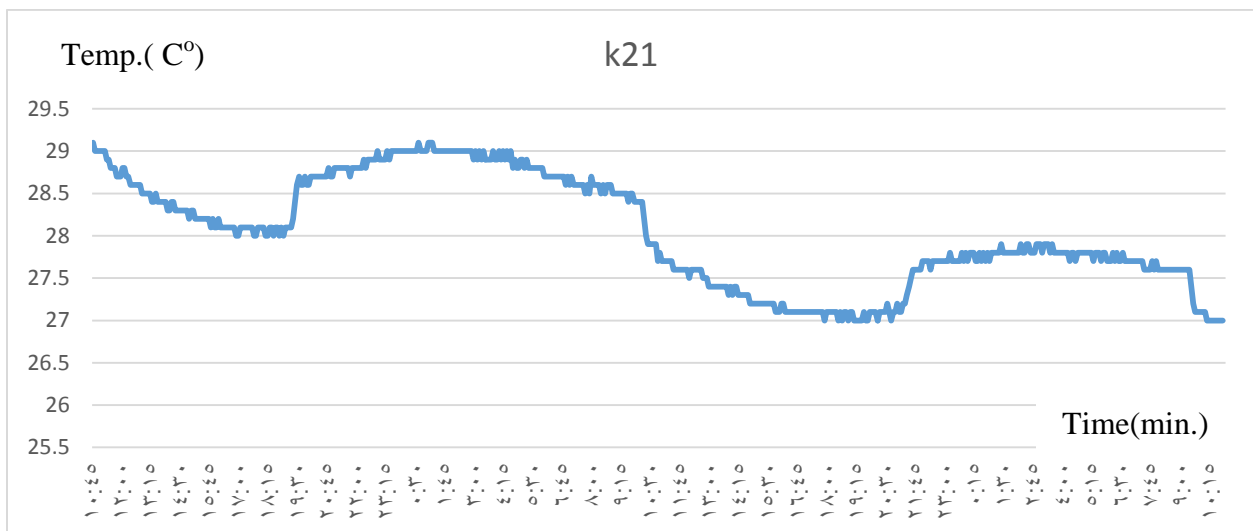
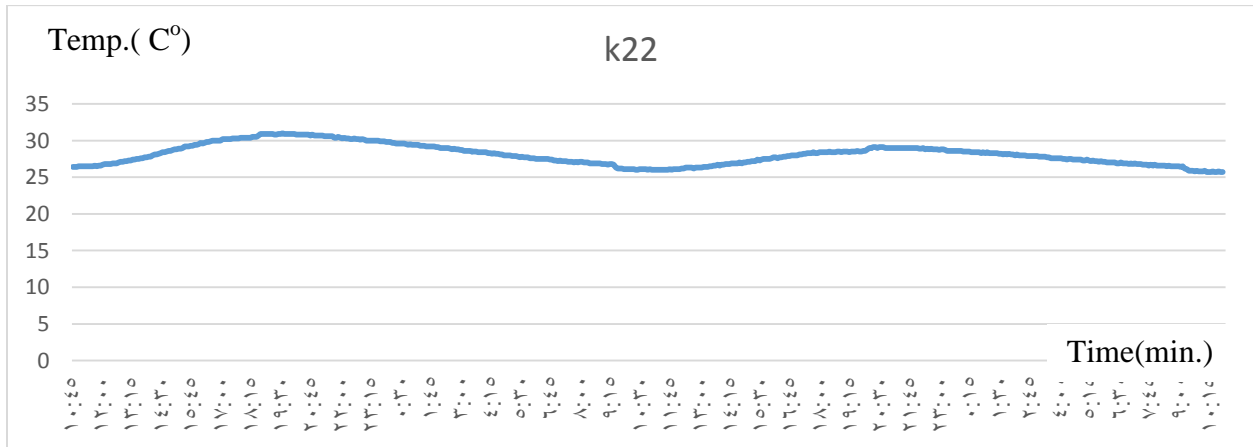


Fig (4.55) Relationship between time and temperature for K14 sensor

Fig (4.56) shows the temperature at 20cm in the bottom of the cable for the case of using 100A and sand soil as buried material. It can be seen that the temperature is starts with almost 29 C° and decreased gradually until it reached 28 C° then reach then increased directly until reach 28.6 C°. then increased gradually to 29, And then, decreased gradually during the midday 27 C° then increased. This curve doesn't effect of the weather because it's under the cable.



until $25.2\text{ }^{\circ}\text{C}$. This is because, the weather temperature decreased significantly during this period.



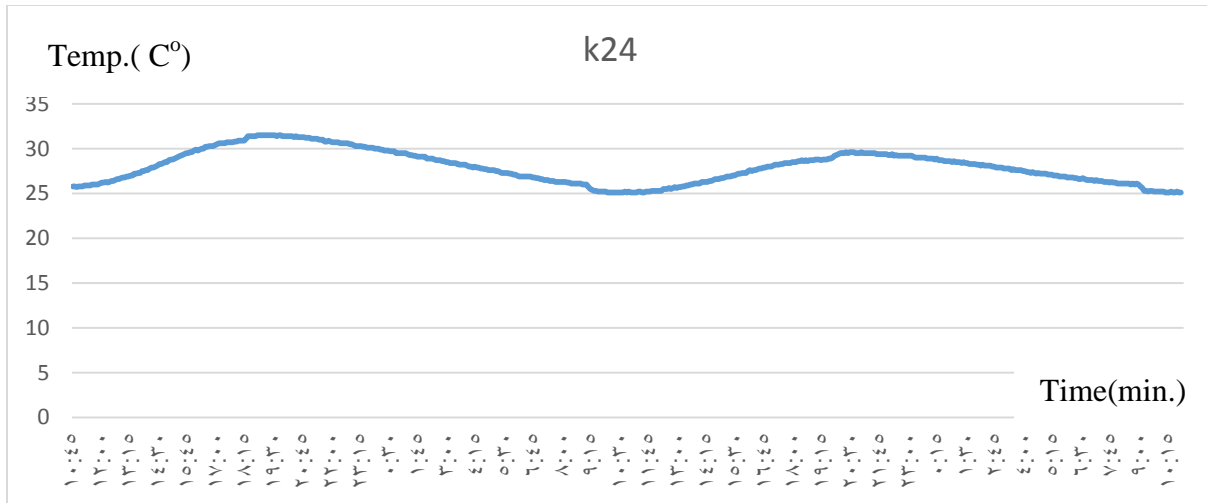


Fig (4.59) Relationship between time and temperature for K24 sensor

Fig (4.60) shows the temperature at the corner of the cable for the case of using 100A and sand soil as buried material. It can be seen that the temperature is starts with almost 25.2 C° and increased gradually until it reached 30.1 C° during the night. And then, decreased gradually during the midday until 25.2 C°. This is because, the weather temperature decreased significantly during this period.

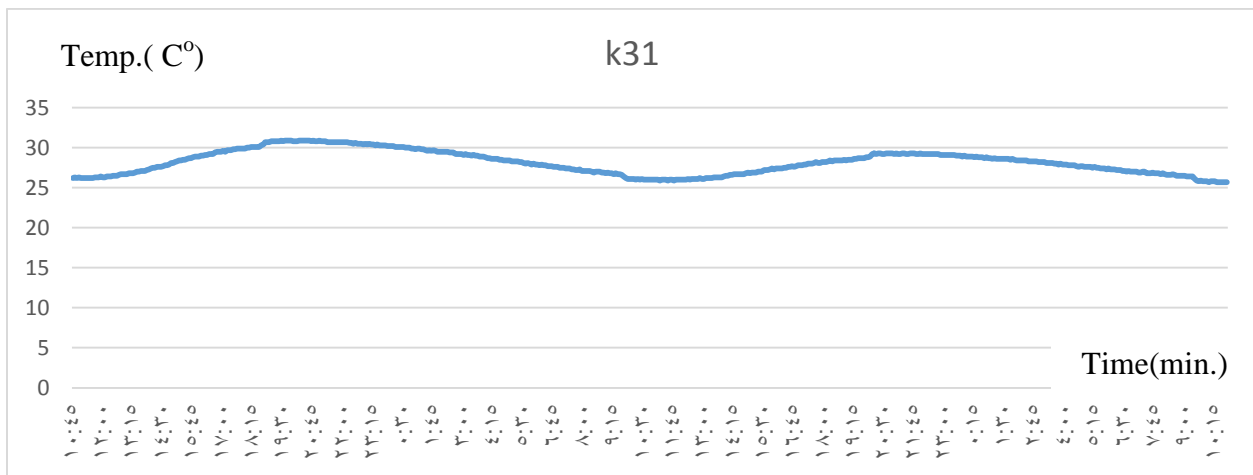


Fig (4.60) Relationship between time and temperature for K31 sensor

Fig (4.61) shows the temperature at 50cm to the left of the cable for the case of using 100A and sand soil as buried material. It can be seen that the temperature is starts with almost 26.5C° and increased gradually until it reached 30.2 C° during the day. And then, decreased gradually during the night until 26 C°. This is because, the weather temperature decreased significantly during this period.

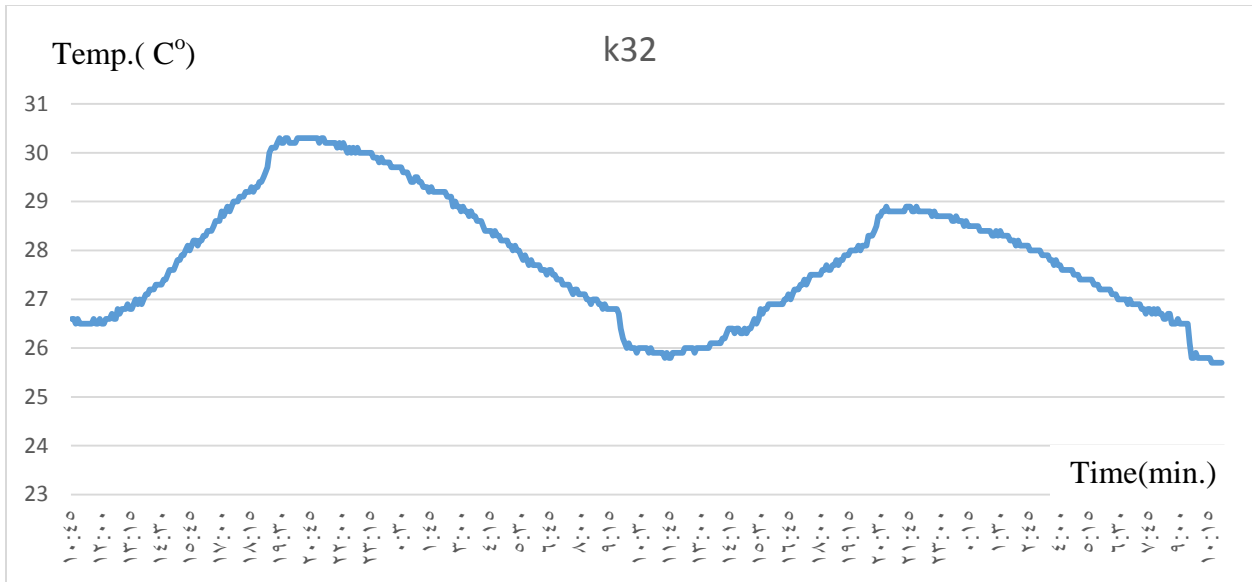


Fig (4.61) Relationship between time and temperature for K32 sensor

Fig (4.62) shows the temperature at the corner of the cable for the case of using 100A and sand soil as buried material. It can be seen that the temperature is starts with almost 26C° and increased gradually until it reached 30.2 C° during the day. And then, increased gradually during the night until 25.9 C°. This is because, the weather temperature decreased significantly during this period.

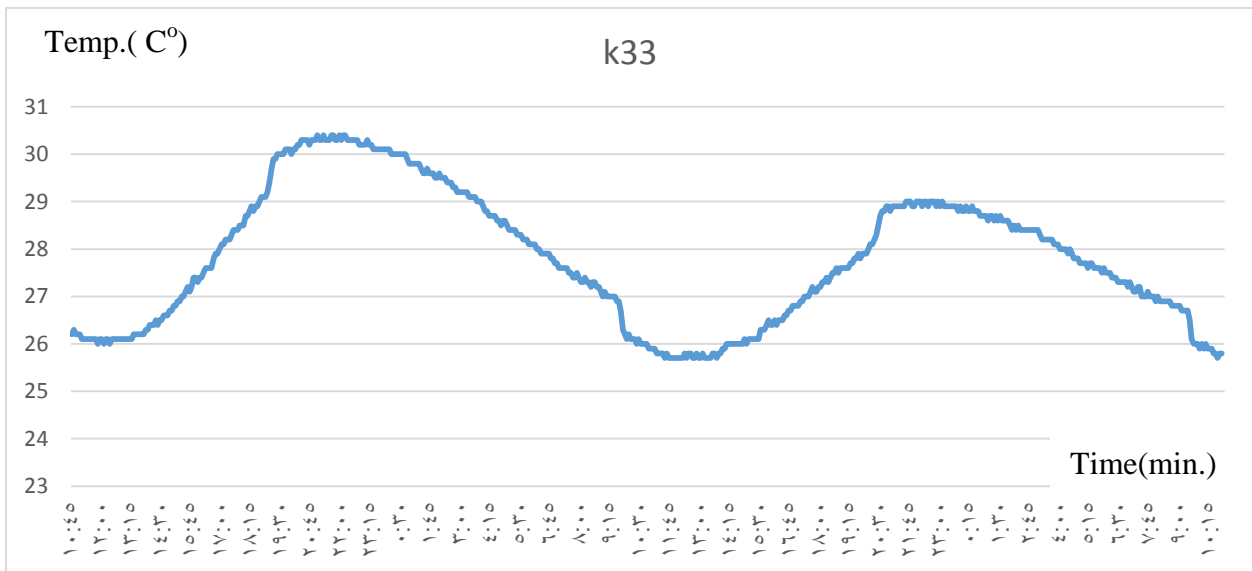


Fig (4.62) Relationship between time and temperature for K33 sensor

Fig (4.63) shows the temperature at the surface of the box for the case of using 450A and limestone soil as buried material. This curve describes the weather temperature at time period.

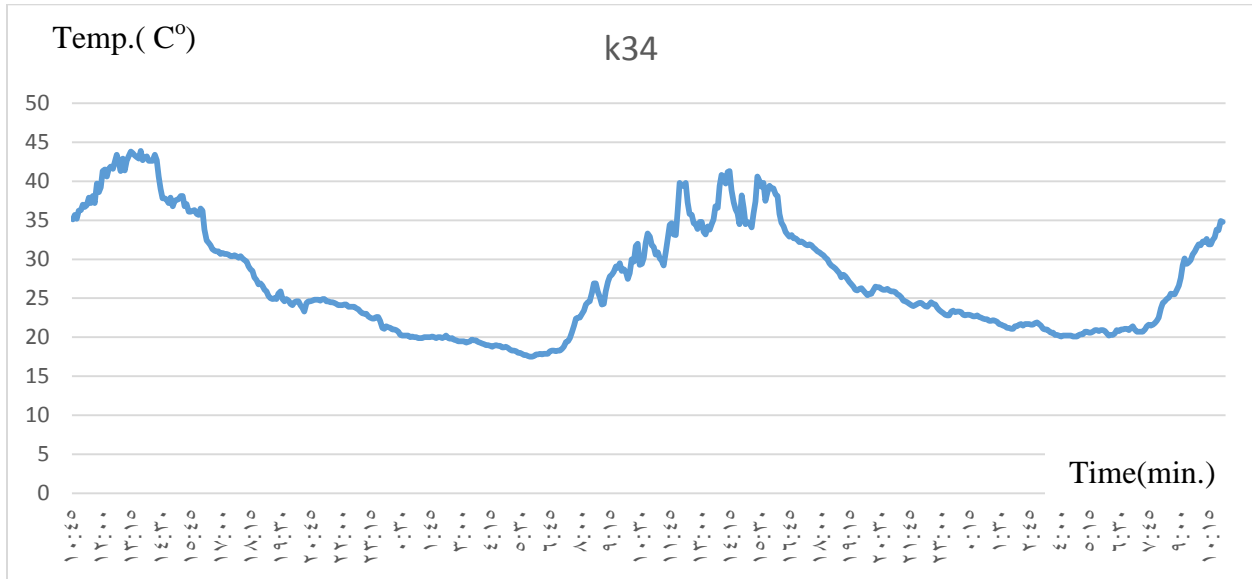


Fig (4.63) Relationship between time and temperature for K34 sensor

- **Limestone 100A:**

Fig (4.64) shows the temperature at the surface of the cable for the case of using 100A and limestone soil as buried material. It can be seen that the temperature is starts with almost 33.6 C° and decreased gradually until it reached the steady state point at 31 C°, this is because the heat from cable is affect more than weather temperature.

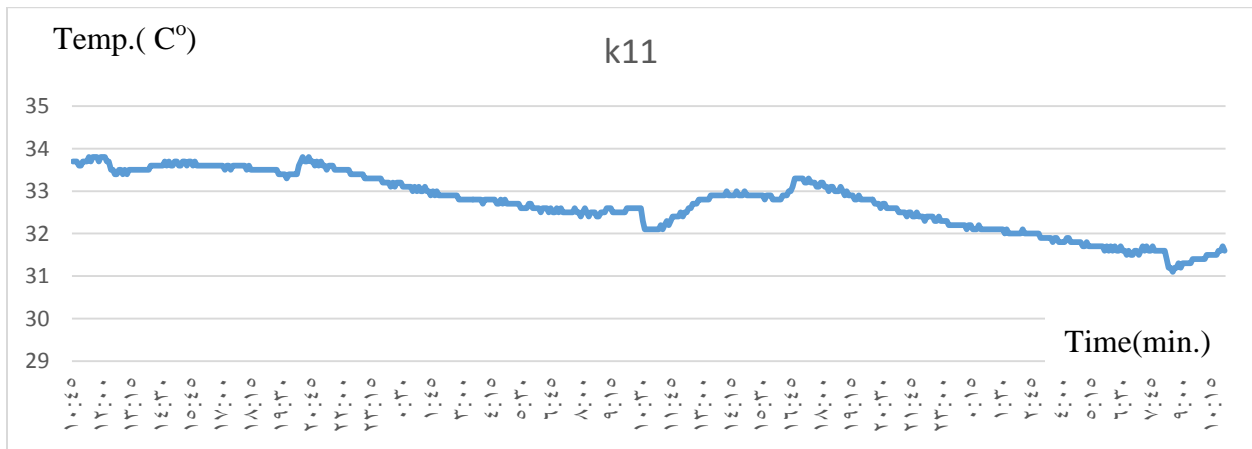


Fig (4.64) Relationship between time and temperature for K11 sensor

Fig (4.65) shows the temperature at 20cm to the right of the cable for the case of using 100A and limestone soil as buried material. It can be seen that the temperature is starts with almost 32.5

C° and decreased gradually until it reached $30.5 C^{\circ}$ and, this is because the soil dissipate heat that out from cable.

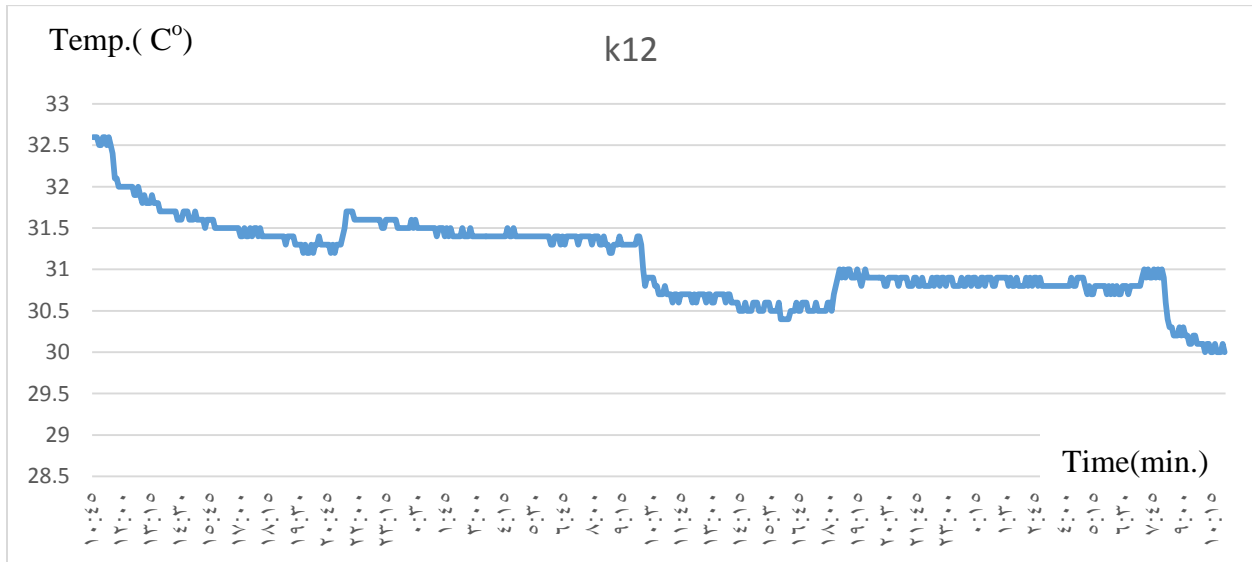


Fig (4.65) Relationship between time and temperature for K12 sensor

Fig (4.66) shows the temperature at 30cm at the top of the cable for the case of using 100A and limestone soil as buried material. It can be seen that the temperature is starts with almost $28 C^{\circ}$ and increased gradually until it reached $30.3 C^{\circ}$ at the day and then decreased again at night until reach $28 C^{\circ}$, this is because, the weather temperature increased significantly during this period.

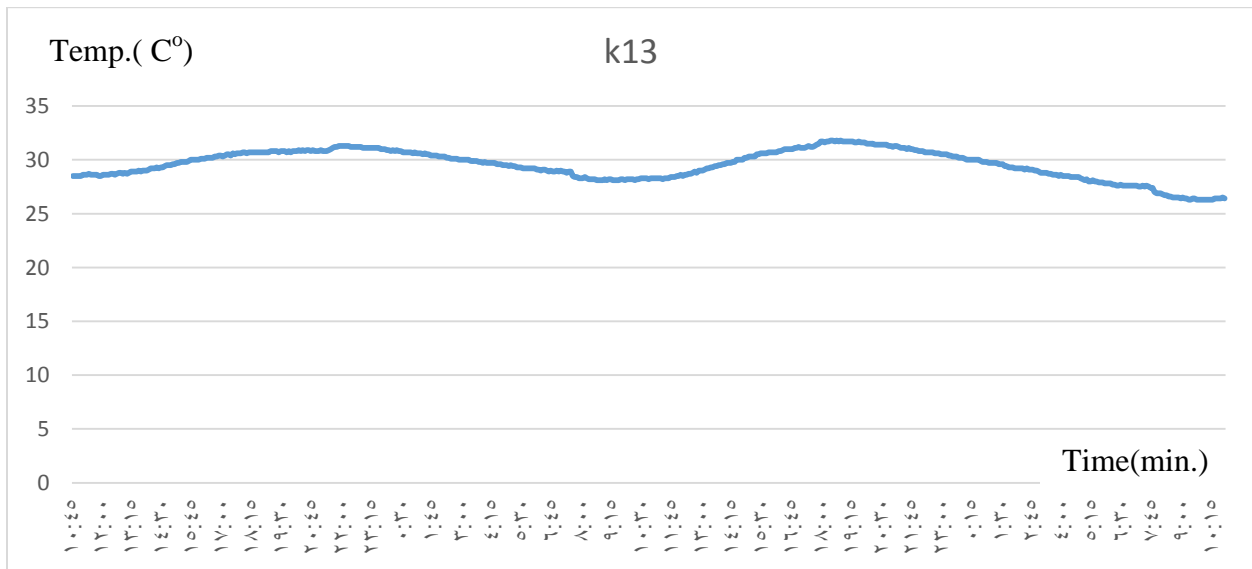


Fig (4.66) Relationship between time and temperature for K13 sensor

Fig (4.67) shows the temperature at 20cm at the left of the cable for the case of using 100A and limestone soil as buried material. It can be seen that the temperature is starts with almost 32.4 C° and decreased gradually until it reached 31 C° then increased directly then decrease again gradually and so on, this is because, the effect of the soil to the heat dissipation.

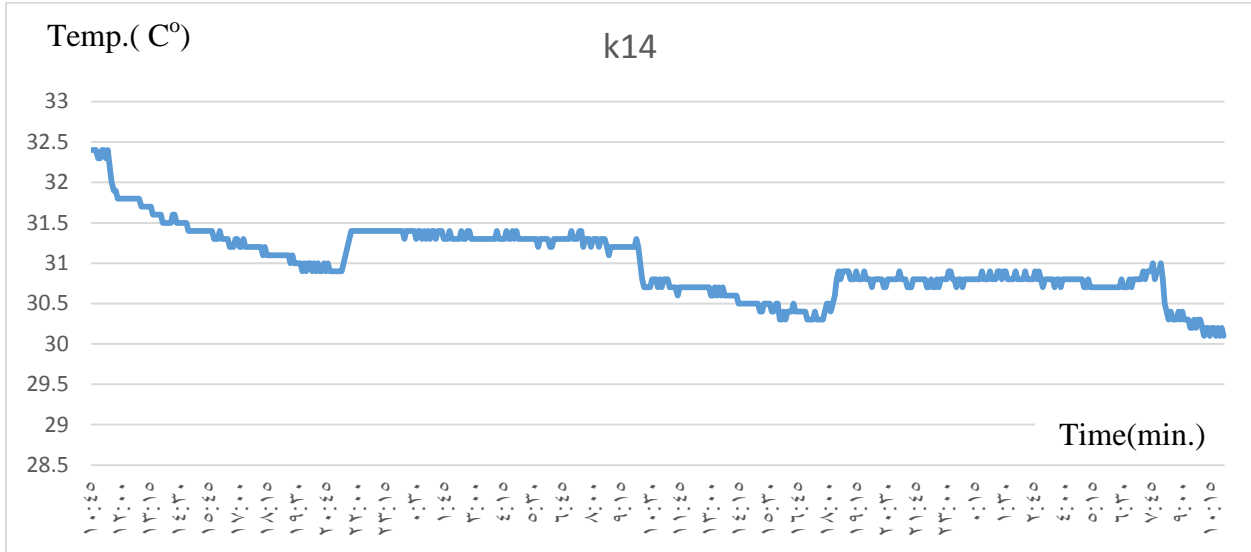


Fig (4.67) Relationship between time and temperature for K14 sensor

Fig (4.68) shows the temperature at 20cm at the bottom of the cable for the case of using 100A and limestone soil as buried material. It can be seen that the temperature is starts with almost 31.4 C° and decreased gradually until it reached 30.5 C° and then increased directly until reach 31 C° and then decreased again, this is because, the weather temperature is ignored.

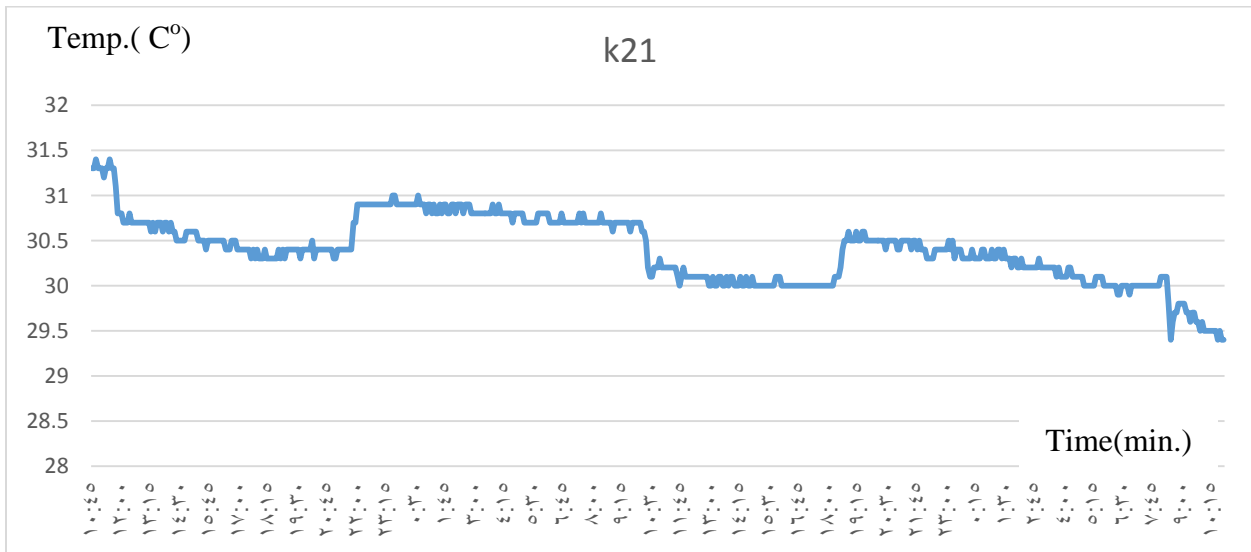


Fig (4.71) shows the temperature at the right corner of the cable for the case of using 100A and limestone soil as buried material. It can be seen that the temperature is starts with almost 30.5 C° and decreased gradually until it reached 29.4 C° and then increased again until reach 31 C°, this is because the weather temperature increased significantly during this period.

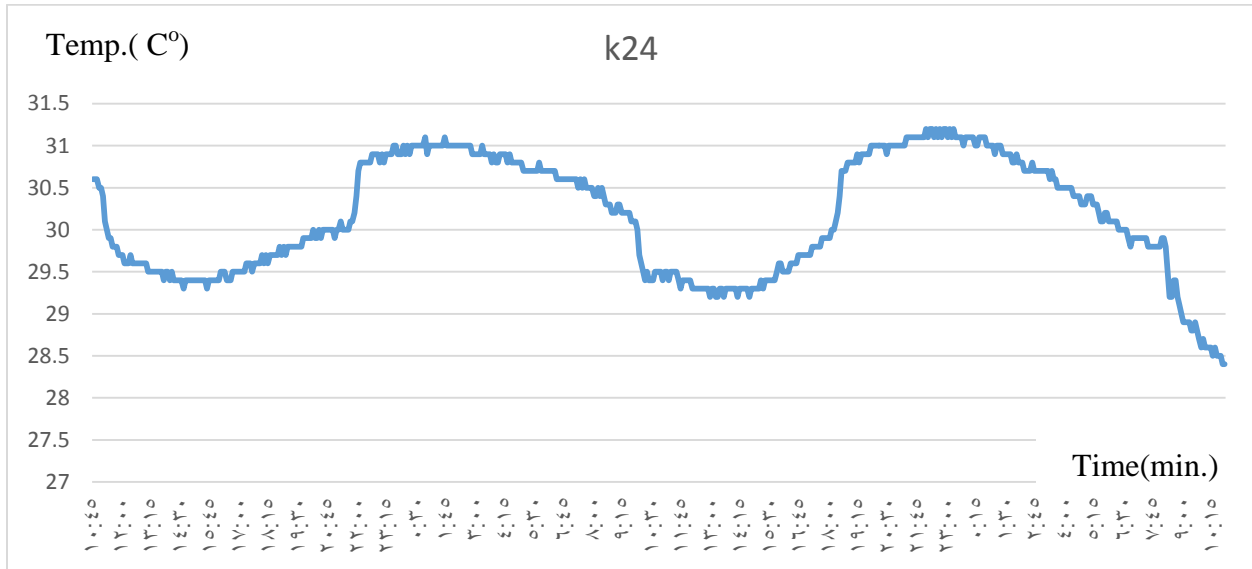


Fig (4.71) Relationship between time and temperature for K24 sensor

Fig (4.72) shows the temperature at the right corner of the cable for the case of using 100A and limestone soil as buried material. It can be seen that the temperature is starts with almost 39 C° and decreased gradually until it reached 25 C° and then increased again at midday until reach 40 C° then decreased again, this is because the weather temperature increased significantly during this period then decreased at night.

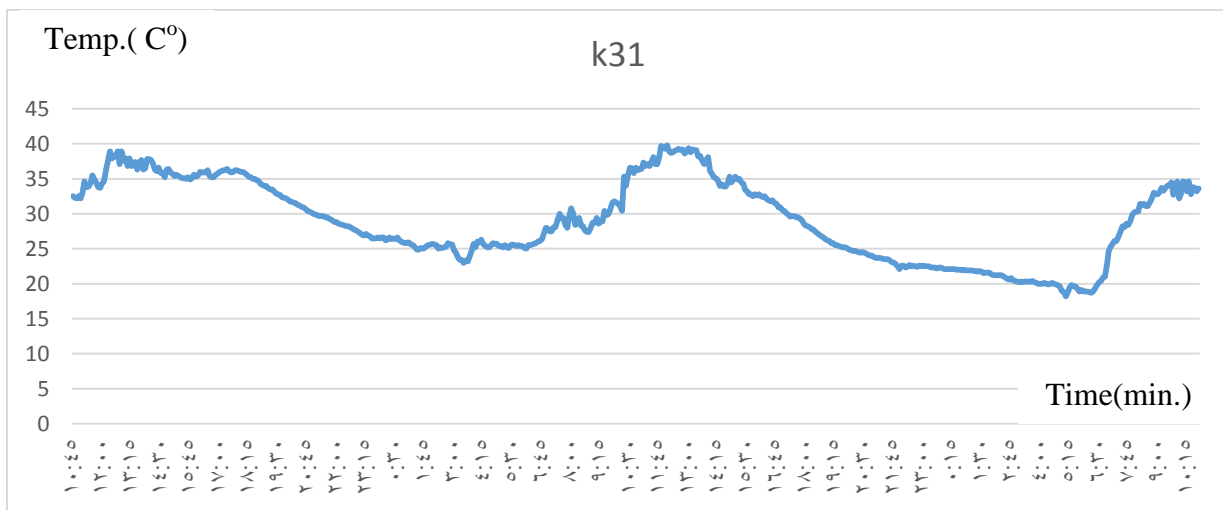


Fig (4.72) Relationship between time and temperature for K31 sensor

Fig (4.73) shows the temperature at 50cm left of the cable for the case of using 100A and limestone soil as buried material. It can be seen that the temperature is starts with almost 30 C° and decreased gradually until it reached 29.3 C° and then increased again until reach 31 oC then decreased again, this is because the weather temperature effect during this period.

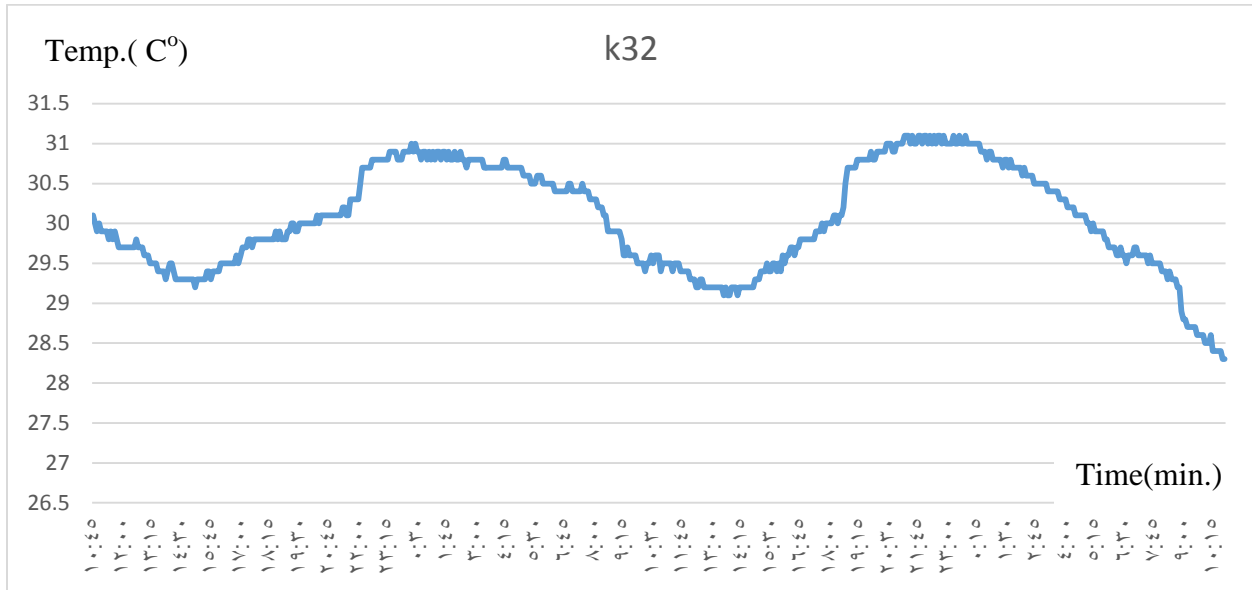


Fig (4.73) Relationship between time and temperature for K32 sensor

Fig (4.74) shows the temperature at left corner of the cable for the case of using 100A and limestone soil as buried material. It can be seen that the temperature is starts with almost 30.5 C° and decreased gradually until it reached 29.7 C° and then increased again at midday until reach 30.9 C° then increased, this is because the weather temperature effect during this period.

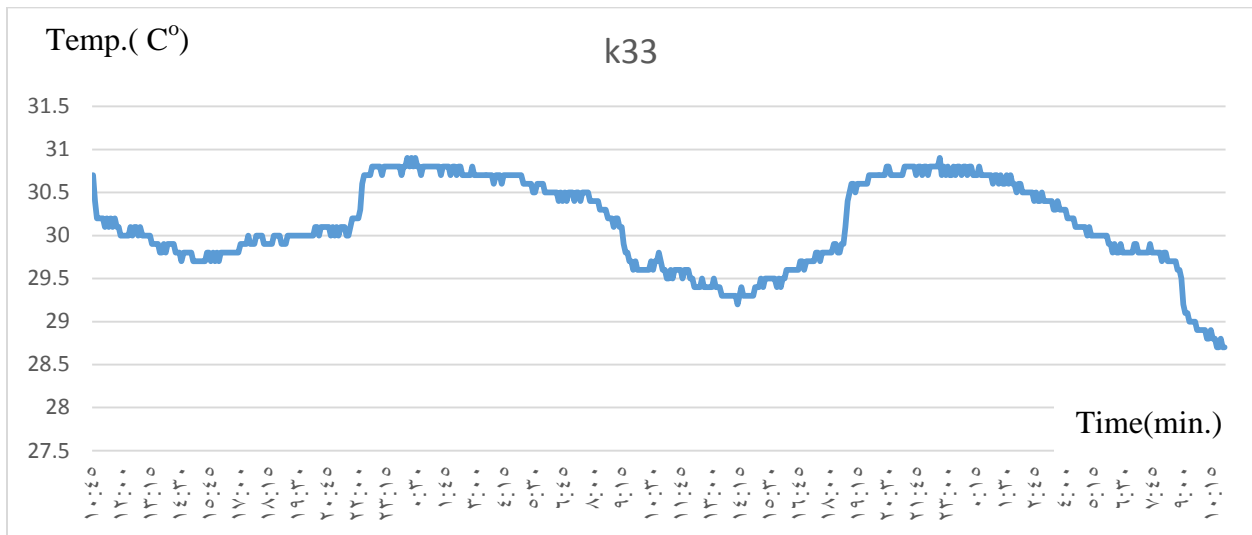


Fig (4.74) Relationship between time and temperature for K33 sensor

Fig (4.75) shows the temperature at the surface of the box for the case of using 100A and limestone soil as buried material. This curve describes the weather temperature at time period.

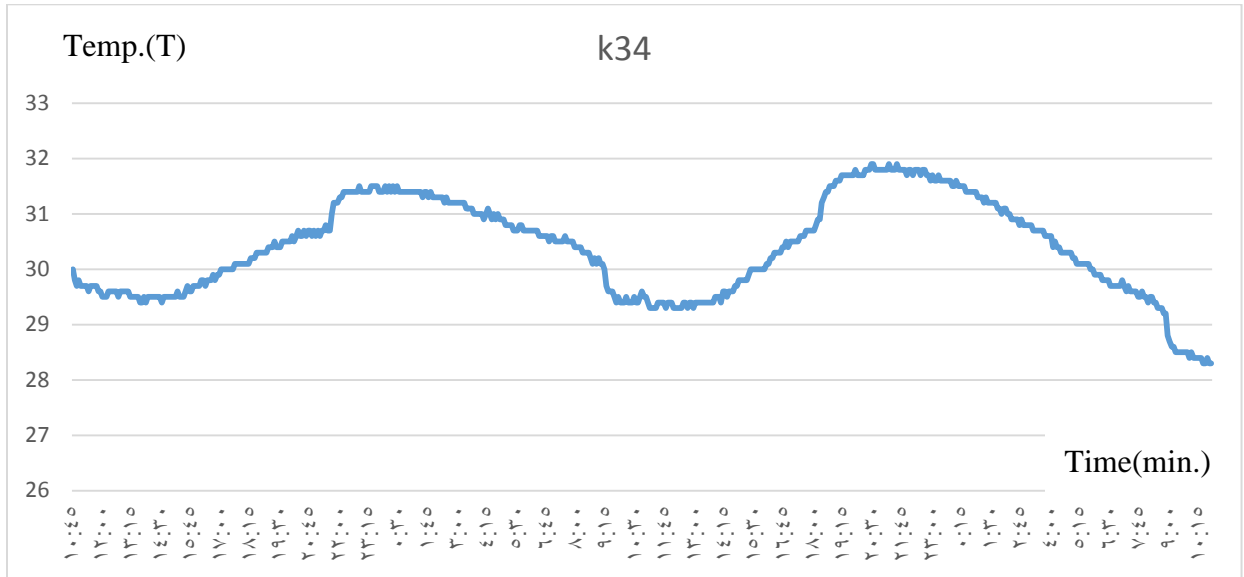


Table (4.4) the average value of temperature for sand and limestone soil and the percentage dissipation for every one of them.

Soil probes	Wet Sand 100A	Limestone 100 A	Percentage dissipation of each probe in sand soil respective to K11 %	Percentage dissipation of each probe in limestone soil respective to K11 %	Percentage Difference %
K₁₁	28.324 ^١	32.7209	—	—	—
K₁₂	27.9627	31.1027	١,٢٧	٤,٩٤	٣,٦٧
K₁₃	27.468 ^٤	29.5502	٣,٠٢	٩,٦٩	٦,٦٧
K₁₄	27.8547	30.996 ^٢	١,٦٥	٥,٢٧	٣,٦٢
K₂₁	28.0466	30.4026	٠,٩٨	٧,٠٨	٦,١
K₂₂	28.0899	30.317 ^٧	٠,٨٢	٧,٣٤	٦,٥٢
K₂₃	27.7660	29.9932	١,٩٧	٨,٣٣	٦,٣٦
K₂₄	27.9601	30.156 ^١	١,٢٨	٧,٨٣	٦,٥٥
K₃₁	28.1450	29.0724	٠,٦٣	١١,١٥	١٠,٥٢
K₃₂	27.8339	30.0601	١,٧١	٨,١٣	٦,٤٢
K₃₃	27.8105	30.120 ^٣	١,٨١	٧,٩٤	٦,١٣
K₃₄	27.2429	30.3939	٣,٨	٧,١١	٣,٣١

As seen in table 4.4 the heat dissipation for limestone soil is better than sand soil, so that the buried in the limestone become better than sand soil.

5

Chapter Five

Conclusion

5.1 Conclusion.

5.2 Recommendations.

5.1 Conclusion

This study investigates the thermal effect of underground cables. This investigation was carried out at the JDECo “Jerusalem District Electricity Co.ltd” because of availability of suitable current source, and its company that supporting the project.

There are many factors affect underground cables performance and aging. Thermal effect is one of these factors that plays an important role in designing and operation of such cables. Thermal effects are produced from the cable due to copper losses and its insulation resistance (IR) and also from the heat coming from the sun, the type of soil and its thermal resistivity.

In this experimental, time of all the cases was fixed to five minutes' interval, two days for every case, the temperature sensor location of twelve probe were arranged to sense the temperature variation due to the varied current loading and soil cycles, assuming the nearby location will demonstrate higher temperature and therefore the probe where it close fitting to the cable shows higher reading more than probes in the side, top and bottom location of the model.

Comparing between the wet sand soil and limestone soil cases at different loading it was observed that the effect of limestone soil for dispersal heat that out from the cable is better than sand soil, and limestone soil is cheaper than sand nearly half, so for buried cable in long distance the limestone is saving the money.

The cases have been studied and implemented in this experiment are four, first one is measuring temperature around the cable that loading 100 ampere buried in sand soil, second case was measuring the thermal effect of passing 450 amperes in the cable buried sand soil, other cases as first and second cases but when the cable is buried in limestone soil. 450 Ampere load is produce heat higher than 100 amperes, so that the effect of the heat from sun at 100 amperes is greater than its effect at 450 amperes, and the limestone absorbing the heat more than sand oil.

5.2 Recommendations

If anyone want to complete this project, should Observance some of thing

- ✓ Investigate the effect of wet soil on the temperature distribution.
- ✓ Carry out the experiment during the same time period for the comparison purpose.
- ✓ Investigate the effect of mixing materials such as sand with limestone soil.
- ✓ There is some of problem that exposed during the project should be careful about it such as:
 - 1- The delay from company to prepare the equipment's.
 - 2- Cutting the electricity on current source, that affect to stay at the steady state at long time.
 - 3- The winter that make the soil wet, and this help the soil to dissipate the heat quickly

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