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صدق الله العظيم

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ELECTRICAL POWER SYSTEMS (1)

Part II

2nd Grade EE Students

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Chapter 5

UNDERGROUND CABLES

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**Introduction**

- Electric power can be transmitted or distributed either by overhead system or by underground cables

**Advantages of underground cables:**

- less liable to damage through storms or lightning,
- low maintenance cost,
- less chance of faults,
- smaller voltage drop as the Inductive reactance of O.H.T. Lines is more
- better general appearance.
Disadvantages of underground cables:

- they have greater installation cost
- they introduce insulation problems at high voltages compared with the equivalent overhead system.
- Capacitance and charging current is high in case of underground cables, so that for long distance power transmission, the charging current is very high results in over voltages problems.
The use of underground cables

Underground cables are employed where it is impracticable to use overhead lines, such as:

- **populated areas (cities)** where municipal authorities prohibit overhead lines for reasons of safety,
- around plants and substations where maintenance conditions do not permit the use of overhead construction.
- **Submarine crossing.**
- **Airports.**
What are the advantages and disadvantages of using Cables in transmitting electrical power?
Requirements of underground cables

• Generally electric Cables consists of

  **Conductors**: Stranded aluminum conductors

  **Insulation**: to insulate the conductors from direct contact or contact with earth

  **Protecting cover**

The type of cable to be used will depend upon the **working voltage** and **service requirements**.
Requirements of underground cables

• The conductor used in cables should be tinned stranded copper or aluminium of high conductivity.

• The conductor size should be such that the cable carries the desired load current without overheating and voltage drop within permissible limits.

• The cable must have proper thickness of insulation in order to give high degree of safety and reliability at the voltage for which it is designed.

• The cable must be provided with suitable mechanical protection to withstand the rough use in laying it.

• The materials used in manufacture of cables should be such that there is complete chemical and physical stability throughout.
5.2. Construction of Cables

- Cores or Conductors.
- Insulation.
- Metallic sheath.
- Bedding.
- Armouring.
- Serving.
Conductor Shield
Impregnated Paper Insulation
Insulation Shield
Paper and Copper Tape Core Binder
Lead-Alloy Sheath
PVC or PE Outer Jacket
Copper Conductor
22kv Medium Voltage Underground XLPE Power Cable
11kv Copper Core and Shield Power Cable 25mm
500KV extra high voltage power cable
500 Kv High Voltage XLPE Cable (YJLW02/ YJLW03)
5.2. Construction of Cables

- **Cores or Conductors.**
- **Insulation.**
- **Metallic sheath.**
- **Bedding.**
- **Armouring.**
- **Serving.**
5.2. Construction of Cables

- **Cores or Conductors.** A cable may have one or more than one core (conductor) depending upon the type of service for which it is intended. The conductors are made of tinned copper or aluminium and are usually stranded in order to provide flexibility to the cable.

- **Insulation.** Each core or conductor is provided with a suitable thickness of insulation, the thickness of layer depending upon the voltage to be withstood by the cable. The commonly used materials for insulation are impregnated paper, varnished cambric or rubber mineral compound.
5.2. Construction of Cables

- **Metallic sheath.** In order to protect the cable from moisture, gases or other damaging liquids (acids or alkalis) in the soil and atmosphere, a metallic sheath of lead or aluminium is provided over the insulation as shown in Fig. 5.1

- **Bedding.** غطاء Over the metallic sheath is applied a layer of bedding which consists of a fibrous material like jute or hessian tape. The purpose of bedding is to protect the metallic sheath against corrosion and from mechanical injury due to armouring.
• **Armouring.** في الدرع Over the bedding, armouring is provided which consists of one or two layers of galvanized steel wire or steel tape to protect the cable from mechanical injury. Armouring may not be done in the case of some cables.

• **Serving.** In order to protect armouring from atmospheric conditions, a layer of fibrous material (like jute) similar to bedding is provided over the armouring. This is known as serving.
5.2. Construction of Cables

• **Armouring.** الدَّرَع Over the bedding, armouring is provided which consists of one or two layers of galvanized steel wire or steel tape to protect the cable from mechanical injury. Armouring may not be done in the case of some cables.

• **Serving.** (Outer cover) In order to protect armouring from atmospheric conditions, a layer of fibrous material (like jute) similar to bedding is provided over the armouring. This is known as serving.
5.3. Insulating Materials for Cables

• the proper choice of insulating material for cables is of considerable importance

• The insulating materials used in cables should have the following properties:
  ✓ High insulation resistance to avoid leakage current.
  ✓ High dielectric strength to avoid electrical breakdown
  ✓ High mechanical strength to withstand mechanical handling.
  ✓ Unaffected by acids and alkalies to avoid chemical actions.
Insulating materials properties (continue):

✓ Non-hygroscopic i.e., لا يمتص الرطوبة it should not absorb moisture from air or soil. The moisture tends to decrease the insulation resistance and hastens يعجل the breakdown of the cable.

In case the insulating material is hygroscopic, it must be enclosed in a waterproof covering like lead sheath.

✓ Non-inflammable. غير قابل للاشتعال

✓ Low cost
1. **Rubber**: Rubber may be obtained from milky sap of tropical trees or it may be produced from oil products. It has relative permittivity varying between 2 and 3, dielectric strength is about 30 kV/mm and resistivity of insulation is $10^{17} \ \Omega\text{-cm}$. Major drawbacks viz., readily absorbs moisture, maximum safe temperature is low (about 38ºC), soft and liable to damage due to rough handling and ages when exposed to light.
Types of Insulation Materials

2. **Vulcanized Rubber (V.R.).** It is prepared by mixing pure rubber with mineral matter such as zine oxide, red lead etc., and 3 to 5% of sulphur. The V R insulation is generally used for low and moderate voltage cables.

3. **Impregnated paper.** It consists of chemically pulped paper and impregnated with some compound such as paraffinic. It has the advantages of low cost, low capacitance, high dielectric strength and high insulation resistance. The only disadvantage is that paper is hygroscopic.
Types of Insulation Materials

4. **Varnished cambric.** It is a cotton cloth impregnated and coated with varnish. As the varnished cambric is hygroscopic, therefore, such cables are always provided with metallic sheath. Its dielectric strength is about 4 kV/mm and permittivity is 2.5 to 3.8.

5. **Polyvinyl chloride (PVC).** This insulating material is a synthetic compound. It has high insulation resistance, good dielectric strength and mechanical toughness over a wide range of temperatures. As the mechanical properties (i.e., elasticity etc.) of PVC are not as good as those of rubber, those from PVC insulated cables are not as good.
5. Polyvinyl chloride (PVC). This insulating material is a synthetic compound. It has high insulation resistance, good dielectric strength and mechanical toughness over a wide range of temperatures. As the mechanical properties (i.e., elasticity etc.) of PVC are not as good as those of rubber, therefore, PVC insulated cables are generally used for low and medium domestic lights and power installations.
5.4. Classification of Cables

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

(i) the **type of insulating material** used in their manufacture

(ii) the **voltage** for which they are manufactured

(iii) the **number of Cores**
Classification according to the **voltage**

- Low-tension (L.T.) cables - up to 1000 V
- High-tension (H.T.) cables - up to 11,000 V
- Super-tension (S.T.) cables - from 22 kV to 33 kV
- Extra high-tension (E.H.T) cables - from 33 kV to 66 kV
- Extra super voltage cables - beyond 132 kV
5.4. Classification of Cables

Classification according to the voltage

(i) single-core
(ii) two-core
(iii) three-core
(iv) four-core etc.

For a 3-phase service, either 3-single-core cables or three-core cable can be used depending upon the operating voltage and load demand.
This shows that insulation resistance of a cable is inversely proportional to its length.

In other words, if the cable length increases, its insulation resistance decreases and vice-versa.
the leakage resistance is inversely proportional to the length of cable.

the resistance of the core of the cable is directly proportional to the length of the cable
5.6. Capacitance of a Single-Core Cable

\[ C = \frac{\varepsilon_r \cdot l}{41 \cdot 4 \cdot \log_{10} \frac{D}{d}} \times 10^{-9} \text{ F} \]
The insulation of a cable is subjected to electrostatic forces, known as dielectric stress. The dielectric stress is in fact the potential gradient (or electric field intensity) at that point.

\[
g_{\text{max}} = \frac{2V}{d \log_e \frac{D}{d}} \text{ volts/m}
\]

\[
g_{\text{min}} = \frac{2V}{D \log_e \frac{D}{d}} \text{ volts/m}
\]

\[
\frac{g_{\text{max}}}{g_{\text{min}}} = \frac{2V}{d \log_e \frac{D}{d}} \frac{\frac{D}{d}}{2V} = \frac{D}{d}
\]
5.9. Grading of Cables

The process of achieving uniform electrostatic stress in the dielectric of cables is known as grading of cables. \( g_{\text{max}} \) at the conductor surface and decreasing as we move towards the sheath.

To overcome these disadvantages, it is necessary to have a uniform stress distribution in cables.

The following are the two main methods of grading of cables:

- (i) Capacitance grading
- (ii) Intersheath grading
5.9.1. Capacitance Grading

- The process of achieving uniformity in the dielectric stress by using layers of different dielectrics is known as **capacitance grading**.

\[
\frac{1}{\varepsilon_1 d} = \frac{1}{\varepsilon_2 d_1} = \frac{1}{\varepsilon_3 d_2}
\]

- The main **disadvantage** of this method is that there are a few high grade dielectrics of **reasonable cost** whose permittivities vary over the required range.
5.9.2. Intersheath Grading

In this method of cable grading, a homogeneous dielectric is used, but it is divided into various layers by placing metallic intersheaths between the core and lead sheath.

\[
\frac{V_1}{\frac{d}{2} \log_e \frac{d_1}{d}} = \frac{V_2}{\frac{d_1}{2} \log_e \frac{d_2}{d_1}} = \frac{V_3}{\frac{d_2}{2} \log_e \frac{D}{d_2}}
\]

Disadvantages: pp. 175
Intersheath Grading is a method of creating uniform voltage gradient across the insulation by means of separating the insulation into two or more layers by thin conductive strips. These strips are kept at different voltage levels through the secondary of a transformer.
5.10. Capacitance of 3-Core Cables

The capacitance of a cable system is much more important than that of overhead line because in cables (i) conductors are nearer to each other and to the earthed sheath (ii) they are separated by a dielectric of permittivity much greater than that of air.
(i) $C_C \parallel C_C \parallel C_C$

(ii) $C_{eq} = 3C_C$

(iii) $C_{eq} = 3C_C$

(iv) $C_{eq} = 3C_C$

(v) $C_N = C_e + 3C_c$

(vi) $C_N = C_e + 3C_c$
Capacitance of a 3-core Cable
SEE YOU ON THIRD GRADE
Measurement of Capacitance of 3-core Cables p.436

**Case 1**: The core 2 and 3 are connected to sheath.

Thus the $C_C$ between cores 2 and 3 and $C_s$ between cores 2, 3 and sheath get eliminated as shown:

$$C_y = C_s + 2C_c$$
Case 2: All the three cores are bundled together. This eliminates all the core-core capacitances.

\[ C_x = 3 \, C_s \]
The capacitance per phase is given by:

\[ C_0 = C_s + 3C_c = \left( \frac{C_x}{3} \right) + 3\left( \left( \frac{C_y}{2} \right) - \left( \frac{C_x}{2} \right) \right) \]

\[ C_0 = 3 \left( \frac{C_y}{2} \right) - \left( \frac{C_x}{6} \right) \]

In case the test are not available the following empirical formulas can be used (p. 347)
Measurement of Capacitance of 3-core Cables

Capacitance measurement

Capacitance measurement