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Environmental Impacts on Underground Power Distribution

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Preface

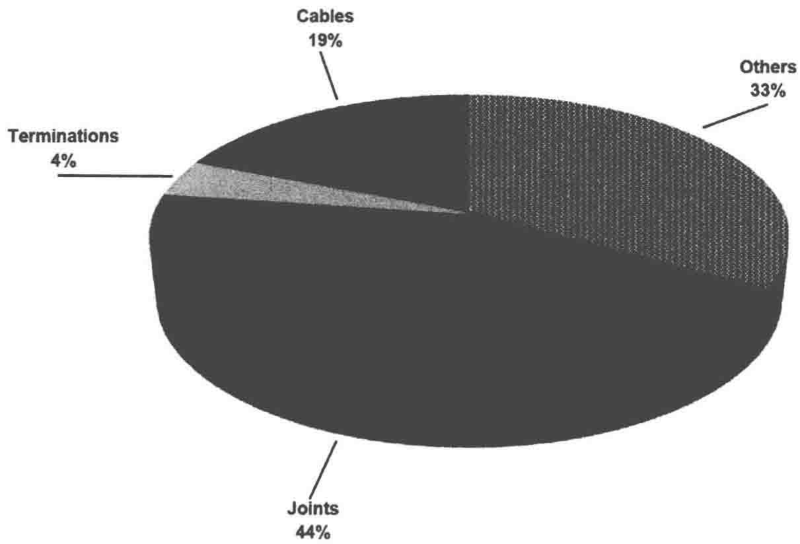
This book covers a study of underground power cables from some points of view. The field of underground power cables is very wide and the division into suitable chapters posed a number of problems one of them is that whatever in selected headings there is no sharp line of demarcation and considerable merging occurs in practices and there is sometimes overlapping may cause distraction in some chapters. This book gives a review as comprehensive as possible on the application of power cables. In order to handle this book easily, although many topics are covered, the tables and figures giving electrical constants and useful relations for various parameters affecting power cables capacity as well as explanations and information are collected from different sources. As it is known all underground electric distribution and power cables consist essentially of conductors having low resistance to carry the load current, good insulation to isolate the conductors from each other and from the their surroundings, metallic sheath or screen to make radial field, and non-metallic sheath to protect the metallic components from corrosion and to keep out moisture. Armoring is used in some cables for mechanical protection. Generally as the cable voltage increases the cable construction becomes more complex.

High, medium and low voltage cables usually have similar characteristics throughout the world. For wiring and different voltages level cables there are no differences in the design concept, but many individual countries have preferences for the materials used in the production. As example in the early stages of distribution cables development, the American systems used rubber as insulating materials while at the same time the impregnated paper was widely used as insulation for low and medium cables in Europe and other countries. Now thermoplastic and thermoset materials are used as insulation for cables around the world.

In 1950 full commercial PVC as thermoset insulation for wiring system was produced, by the end of the same year PVC power cables was in use. In 1959, 275 kV oil filled cables were in operation. The oil filled cables voltage is increased to 400 kV by the end of 1969. Since 1970 gradual extension of the use of thermoset insulation, mainly XLPE is carried out as an alternative to paper insulation. In 1980 until now rapid use of XLPE as insulation is noticed in medium cables 11kV-33 kV range with significant quantities installed for transmission voltages for voltage ranges 66 kV – 400 kV.

All distribution companies face some problems of power interruptions which cause major financial losses for utilities and the customers. One of the network components prone to breakdown is the cable. It is noticed that an increase was happened in the rate of the failure numbers in MV power cables during the years 2009 to 2013. By investigating the causes of these cumulative failures it is found that 4 8% of these faults are caused by breakdown of joints and terminations, 19% are happened by internal faults and 33% of the failures are carried out by others such as digging activities. Figure 1 shows the percentage rate of cumulative failures of medium voltage cables rate through years from 2009 to 2013.

Figure 1. Cumulative failure rate from 2009 to 2013



These defects may occur due to inaccurate assembling of joints and terminations. Installed cables are, moreover, subject to natural aging, or due to temporary extreme circumstances overload, overvoltage degradation and under design stresses (particularly electrical and thermal) or other factors of influence (digging, water …). Once the fault occurs in the cable, the utility isolates the faulted cable from grid and starts to pinpoint the location of fault.

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Chapter 1
Underground Power Cable Construction

ABSTRACT

This chapter deals with many special features of underground power cables. Important points are presented in this chapter. In this chapter the various components of the different underground cables used in transmission and distribution of electric energy are explained. The materials used in the manufacture of these cables are given in details. This chapter also contains the different types of cable joints and terminations.

1.1 CABLES ADVANTAGES AND DRAWBACKS

1.1.1 Cables Advantages

Underground power cables are widely used in transmission and distribution of electrical power, the following are the advantages of underground power cables compared with the overhead transmission lines feeders:

1. They need less space compared to overhead transmission lines (Underground cables need a narrower surrounding strip of about 1–10 meters to install (up to 30 meters for 400 kV cables during construction), whereas an overhead line requires a surrounding strip of about 20–200 meters wide to be kept permanently clear for safety, maintenance and repair).
2. No visual pollution compared with transmission lines in which its insulators exposed to different types of pollution.
3. Less subject to damage from atmospheric activity like wind and lightning as overhead transmission lines.
4. Higher surge impedance reduces severity of switching, lightning and resonance over voltages.
5. Ideal way to transmit power supply to an island.

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1.1.2 Cable-Drawbacks

In spite of the underground cables have many advantages, they have also some drawback. The following are the cables drawbacks:

1. Fault location of underground power cables is difficult and time taking.
2. Underground cables are expensive compared with overhead transmission line feeders (the cost of underground cables is two to four times the cost of an overhead power line at the same voltage level).
3. More monitoring, for certain types of cables, is required.
4. Jointing/termination require persons with high skill levels.
5. Joints/terminations are weak points because the joints and terminations need thicker insulation to reach to the same insulation level of the cable, also the joints are mechanically weak.
6. Testing of underground power cables is difficult and time-consuming.

1.2 CABLE CONSTRUCTION

1.2.1 Cable Conductors

The conductor is the part of a cable carries the load current. The most commonly used materials in conductors are aluminum and copper. The use of aluminum is based mainly on its favorable conductivity-to-weight ratio (the highest of the electrical conductor materials), its ready availability, and the stable low cost of the primary metal. Copper is used in high capacity power cables due to its better conductance. Stranded conductors are used to make the cable more flexible. (Figure 1) gives a sample of stranded conductors' cable. Because moisture has a negative effect on the cable the conductor is made longitudinally watertight with swelling powder or semi conductive filling (Al-Khalidi & Kalam, 2006). Table 1 gives the electrical properties of some metals used in underground power cables. Aluminum wire, which has 61% of the conductivity of copper, has been used in distribution and transmission wiring for its lower cost. By weight, aluminum has higher conductivity than steel, but it has properties that cause problems when used for building wiring. It forms a resistive oxide within connections, causing terminals of wiring devices to heat. Aluminum can "creep", slowly deforming under load, eventually causing device connections to loosen, and also has a different coefficient of thermal expansion compared to the materials used for connections. This accelerates the loosening of connections. These effects can be avoided by using wiring devices approved for use with aluminum. Aluminum wires used for low voltage distribution, such as buried cables and service drops, require use of compatible connectors and installation methods to prevent heating at joints. Aluminum is also the most common metal used in high-voltage transmission lines, in combination with steel as structural reinforcement. Anodized aluminum surfaces are not conductive. This affects the design of electrical enclosures that require the enclosure to be electrically connected

Figure 1. Sample of stranded conductors

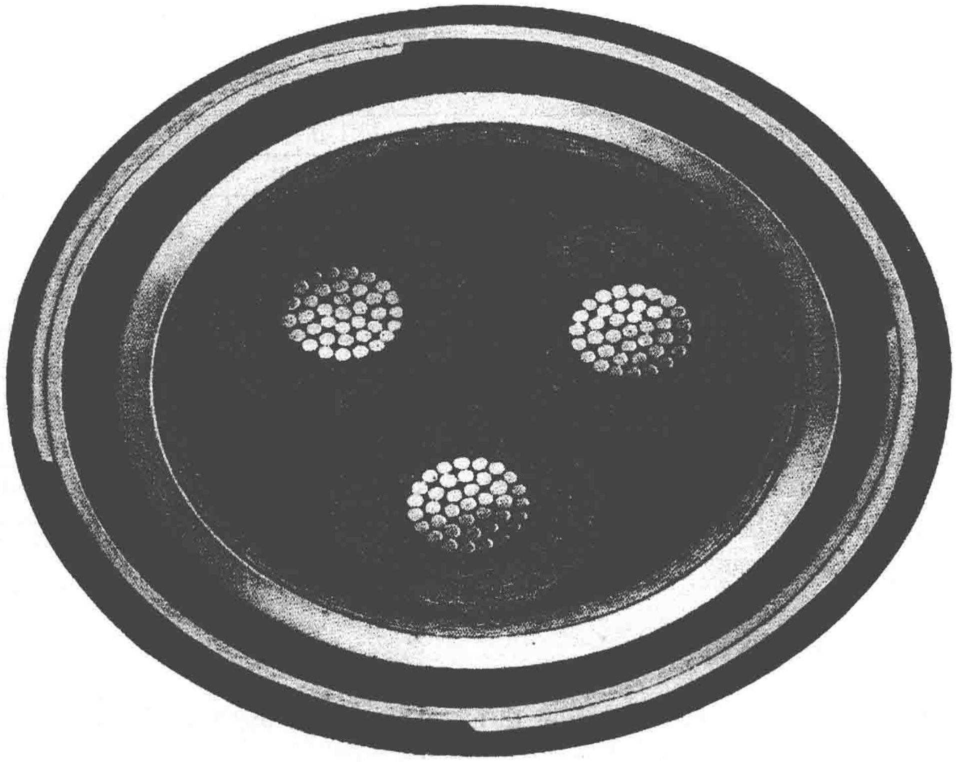

Table 1. Electrical properties of some metals used in underground power cables

Metal	Relative conductivity (copper = 100)	Electrical resistivity at 20 °C (Ω.m, 10^{-8})	Temperature coefficient of resistance (per °C)
Silver	106	1.626	0.0041
Copper (HC, annealed)	100	1.724	0.0039
Copper (HC, hard drawn)	97	1.777	0.0039
Tinned copper	95-99	1.741-1.814	0.0039
Aluminum (EC grade, soft)	61	2.803	0.0040
Aluminum (EC grade,1/2H-H)	61	2.826	0.0040
Sodium	35	4.926	0.0054
Mild steel	12	13.8	0.0045
Lead	8	21.4	0.0040

1.2.1.1 Classes of Conductors

Conductors are classified as solid or stranded. A solid conductor is a single conductor of solid section. A stranded conductor is composed of a group of small conductors in common contact. A stranded conductor is used where the solid conductor is too large and not flexible enough to be handled readily.

Comparison between copper and aluminum conductors are given in table 2.

Table 2. Comparison between copper and aluminum conductors

	Aluminum	Copper
Coefficient of Expansion per °C x 10^{-6} at 20°C	23	16.6
Thermal Conductivity BTU/ft/hr/fft^2/°F at 20°C	126	222
Electrical Conductivity %IAS at 20°C	61	101
Tensile Strength ib/in^2 (soft)	12,000	32,000

Large solid conductors are also easily damaged by bending. The need for mechanical flexibility usually determines whether a solid or a stranded conductor is used, and the degree of flexibility is a function of the total arranged in concentric number of strands. Beside that the skin effect is lesser in stranded conductor compared with solid conductor having the same cross sectional area. The strands in the stranded conductor are usually layers about a central core. The smallest number of wires in a stranded conductor is three. The next number of strands is 7, 19, 37, 61, 91, 127, etc. Both copper and aluminum conductors may be stranded. The skin effect is negligible in stranded conductors compared with the solid conductors having the same cross sectional areas.

1.2.1.2 Conductor Sizes

Conductor sizes are ordinarily expressed by four different numbering methods: the AWG formerly known as American Wire Gage, the circular mil, mm^2 and inch square.

A. The AWG or conductor sizes are numbered from 30 to 1, then continuing with 0, 00, 000, and 0000 or (1/0, 2/0, 3/0, and 4/0 respectively). Number 30 is the smallest size and 4/0 the largest in this system. As an example of the actual physical size of the conductors commonly used in transmission and distribution work, the diameter of a number 8 AWG is 0.1285 inches and for a 4/0 AWG it is 0.460 inches.

B. The circular mil is the unit customarily used in designating the cross sectional area of wires. A circular mil is defined as the area of a circle having a diameter of 1/1000 of an inch. The circular mils of cross section in a wire are obtained by squaring the diameter expressed as thousandths of an inch. For example, a wire with a diameter of 0.102 inches (102 thousandths of an inch) has a circular mils cross section of 102 X 102 = 10,404. Conductors larger than 4/0 AWG are designated in circular mils. These range from 250,000 to 2,000,000 circular mils. Each mm^2 equals approximately 1973 circular mils.

1.2.1.3 Metallic Sheaths

These materials are used when a high degree of mechanical, chemical or short-time thermal protection of the underlying cable components are required. Commonly used are galvanized steel or lead strips, aluminum, or bronze or steel armor wires. The use of any of these materials will reduce flexibility of the overall cable, but flexibility must be sacrificed to obtain the other benefits.

A. The unprotected interlocked armor provides a high degree of mechanical protection without significantly sacrificing flexibility. While not entirely impervious to moisture or corrosive agents, interlocked armor does provide protection from thermal shock by acting as a heat sink for short-time localized exposure. Where corrosion and moisture resistance are required, in addition to mechanical protection, an overall jacket of extruded material may be used. Commonly used interlocked armor materials are: galvanized steel, aluminum (for less weight and general corrosion resistance), and marine bronze and other alloys (for highly corrosive atmospheres).

B. Longitudinally corrugated metal sheaths (corrugations or bellows formed perpendicular to the cable axis) have been used for many years in direct-burial communications cables, but only recently has this method of cable core protection been applied to control and power cables. The sheath material may be of copper, aluminum, a corrosion resistant steel or copper alloy, or a bimetallic composition of materials selected to best meet the intended service.

C. Lead or lead alloys are used for industrial power cable sheaths for maximum cable protection in underground manhole and tunnel or underground duct distribution systems subject to flooding. While not as resistant to crushing loads as interlocked armor, it's very high degree of corrosion and moisture resistance makes lead attractive in the above applications. Protection from installation damage can be provided by an outer jacket of extruded material.

D. Extruded aluminum, copper, die-drawn aluminum, or copper sheaths are used in certain applications for weight reduction and moisture penetration protection. While more crush resistant than lead, aluminum sheaths are subject to electrolytic attack when installed underground. Under these conditions, aluminum sheathed cable should be protected with another extruded jacket.

E. A high degree of mechanical protection and longitudinal strength can be obtained by using spirally wrapped or braided round steel armor wire. This type of outer covering is frequently used in submarine cable and vertical riser cable for support.

1.2.1.4 Non- Metallic Sheaths

A. There are outer coverings (extruded jackets) either thermoplastic or vulcanized, which may be extruded directly over insulation or over electrical shielding systems of metal sheaths or tapes, copper braid, or semi conducting layers with copper drain wires or spiraled copper concentric wires, or over multi conductor constructions. Commonly used materials include: polyvinyl chloride, nitrile butadiene/polyvinyl chloride (NBR/PVC), polyethylene, cross-linked polyethylene, polychloroprene (neoprene), chloro-sulfonated polyethylene, and polyurethane. These materials provide a high degree of moisture, chemical, and weathering protection. They are reasonably flexible, provide some degree of electrical isolation, and are of sufficient mechanical strength to protect the insulating and shielding components from normal service and installation damage.

B. A commonly used material is braided asbestos fiber. Asbestos braid is used on cables to minimize flame propagation, smoking, and other hazardous or damaging products of combustion which may be evolved by some extruded jacketing materials. All fiber braids require saturate or coating and impregnating materials to provide some degree of moisture and solvent resistance as well as abrasive and weathering resistance.

1.2.1.5 Voltage Drop

The supply conductor, if not of sufficient size, will cause excessive voltage drop in the circuit, and the drop will be in direct proportion to the circuit length. Proper starting and running of motors, lighting equipment, and other loads having heavy inrush currents must be considered. It is recommended that the steady state voltage drop in distribution feeders be no more than 5%. The voltage drop can be calculated according the relation:

Voltage drop in case of three phase cable = Root of 3 (R Cos Y + X sin Y) I L ohms

In case of single phase the voltage drop = (R Cos Y + X sin Y) I L ohms

where I is the load current in ampere, R and X are the resistance and reactance per unit length of underground cable, L is the cable length and Y is the angle between the voltage and current.

1.2.2 Cable Insulating Materials

Insulation is the most crucial part of a cable as it isolates the live parts from the surroundings. The most commonly used insulation materials in extruded cables are cross linked polyethylene (XLPE), ethylene propylene rubber (EPR) and water tree retardant cross linked polyethylene (TR-XLPE). As the insulation ages its electric strength decreases until a final breakdown happens. Temperature, electric field and moisture are the main factors affecting insulation aging.

For fire risk analysis, cable insulation and jacket materials can be separated into two broad categories, as discussed in the following subsections:

1.2.2.1 Thermoplastic Materials

Thermoplastic materials are defined as high molecular weight polymers that are not cross-linked and are generally characterized by the distinct melting point of the insulation material. Thermoplastic materials can be repeatedly softened by heating and hardened by cooling within a temperature band that is a physical property of the material. This property is a function of the loose molecular bonding of the material. Some thermoplastic materials have a low melting point, which can be a disadvantage in that melting insulation can lead to conductor failures (e.g., conductor-to-conductor shorts and conductor-to-ground shorts) at relatively low temperatures. Some thermoplastic insulation is also problematic in that they produce dripping, flaming fires after ignition. Cables using thermoplastic insulation are not usually qualified to survive the full environment qualification exposure condition of IEEE Std. 383. Many thermoplastic cables will however, pass the limited flame spread test included in the IEEE Std. 383. Thermoplastic insulation is generally easy to manufacture and economical to use. Common thermoplastic insulations include cellular; low and high polyethylene (PE); polyvinyl chloride (PVC); polyurethane; polypropylene (PPE); nylon; chlorinated polyethylene (CPE); tetrafluoroethylene (TFE), Teflon, and fluorinated polymers. (Figure 2) shows typical thermoplastic (PVC) insulated cable construction. In general, cables that do not pass IEEE 383 rating (i.e., non-IEEE qualified) are thermoplastic.