Cable Construction

Introduction

This article gives a brief exposition on the construction of typical low voltage, medium / high voltage and instrumentation cables. The focus is on thermoplastic and thermosetting insulated cables, however the construction of other cables are similar. Although there is more than one way to construct a cable and no one standard to which all vendors will adhere, most cables tend to have common characteristics.

- **Low voltage power and control cables** pertain to electrical cables that typically have a voltage grade of 0.6/1 kV or below.
- **Low voltage instrumentation cables** pertain to cables for use in instrument applications and typically have a voltage grade of 450/750 V or below.
- **Medium / High voltage cables** pertain to cables used for electric power transmission at madium and high voltage (usually from 1 to 33 kV are medium voltage cables and those over 50 kV are high voltage cables).

Cable Parts

Here, we will take a short overview of the main and the most typical cable construction parts:

Conductor

Usually stranded copper (Cu) or aluminium (Al). Copper is densier and heavier, but more conductive than aluminium. Electrically equivalent aluminium conductors have a cross-sectional area approximately 1.6 times larger than copper, but are half the weight (which may save on material cost).

Annealing – is the process of gradually heating and cooling the conductor material to make it more malleable and less brittle.

Coating – surface coating (eg. tin, nickel, silver, lead alloy) of copper conductors is common to prevent the insulation from attacking or adhering to the copper conductor and prevents deterioration of copper at high temperatures. Tin coatings were used in the past to protect against corrosion from rubber insulation, which contained traces of the sulfur used in the vulcanising process.

Conductor Screen

A semi-conducting tape to maintain a uniform electric field and minimise electrostatic stresses (for MV/HV power cables).

Insulation

Commonly thermoplastic (eg. PVC) or thermosetting (eg. EPR, XLPE) type materials. Mineral insulation is sometimes used, but the construction of MI cables are entirely different to normal plastic / rubber insulated cables. Typically a thermosetting(eg. EPR, XLPE) or paper/lead insulation for cables under 22kV. Paper-based insulation in combination with oil or gas-filled cables are generally used for higher voltages.

Plastics are one of the more commonly used types of insulating materials for electrical conductors. It has good insulating, flexibility, and moisture-resistant qualities. Although there are many types of plastic insulating materials, thermoplastic is one of the most common. With the use of thermoplastic, the conductor temperature can be higher than with some other types of insulating materials without

damage to the insulating quality of the material. Plastic insulation is normally used for low- or medium-range voltage.

The designators used with thermoplastics are much like those used with rubber insulators. The following letters are used when dealing with NEC type designators for thermoplastics:

T - Thermoplastic

H - Heat-resistant

W - Moisture-resistant

A - Asbestos

N - Outer nylon jacket

M - Oil-resistant

Paper has little insulation value alone. However, when impregnated with a high grade of mineral oil, it serves as a satisfactory insulation for extremely high-voltage cables. The oil has a high dielectric strength, and tends to prevent breakdown of the paper insulation. The paper must be thoroughly saturated with the oil. The thin paper tape is wrapped in many layers around the conductors, and then soaked with oil.

Enamel: the wire used on the coils of meters, relays, small transformers, motor windings, and so forth, is called magnet wire. This wire is insulated with an enamel coating. The enamel is a synthetic compound of cellulose acetate (wood pulp and magnesium). In the manufacturing process, the bare wire is passed through a solution of hot enamel and then cooled. This process is repeated until the wire acquires from 6 to 10 coatings. Thickness for thickness, enamel has higher dielectric strength than rubber. It is not practical for large wires because of the expense and because the insulation is readily fractured when large wires are bent.

Mineral-insulated (MI) cable was developed to meet the needs of a noncombustible, high heat-resistant, and water-resistant cable. MI cable has from one to seven electrical conductors. These conductors are insulated in a highly compressed mineral, normally magnesium oxide, and sealed in a liquidtight, gastight metallic tube, normally made of seamless copper.

Silk and Cotton: in certain types of circuits (for example, communications circuits), a large number of conductors are needed, perhaps as many as several hundred. Because the insulation in this type of cable is not subjected to high voltage, the use of thin layers of silk and cotton is satisfactory.

Silk and cotton insulation keeps the size of the cable small enough to be handled easily. The silk and cotton threads are wrapped around the individual conductors in reverse directions. The covering is then impregnated with a special wax compound.

Insulation Screen

A semi-conducting material that has a similar function as the conductor screen (ie. control of the electric field for MV/HV power cables).

Conductor Sheath

A conductive sheath / shield, typically of copper tape or sometimes lead alloy, is used as a shield to keep electromagnetic radiation in, and also provide a path for fault and leakage currents (sheaths are earthed at one cable end). Lead sheaths are heavier and potentially more difficult to terminate than copper tape, but generally provide better earth fault capacity.

Filler

The interstices of the insulated conductor bundle is sometimes filled, usually with a soft polymer material.

Bedding / Inner Sheath

Typically a thermoplastic (eg. PVC) or thermosetting (eg. CSP) compound, the inner sheath is there to keep the bundle together and to provide a bedding for the cable armour.

Individual Screen (Instrument Cables)

An individual screen is occasionally applied over each insulated conductor bundle for shielding against noise / radiation and interference from other conductor bundles. Screens are usually a metallic (copper, aluminium) or semi-metallic (PETP/Al) tape or braid. Typically used in instrument cables, but not in power cables.

Drain Wire (Instrument Cables)

Each screen has an associated drain wire, which assists in the termination of the screen. Typically used in instrument cables, but not in power cables.

Overall Screen (Instrument Cables)

An overall screen is applied over all the insulated conductor bundles for shielding against noise / radiation, interference from other cables and surge / lightning protection. Screens are usually a metallic (copper, aluminium) or semi-metallic (PETP/Al) tape or braid. Typically used in instrument cables, but not in power cables.

Armour

For mechanical protection of the conductor bundle. Steel wire armour or braid is typically used. Tinning or galvanising is used for rust prevention. Phosphor bronze or tinned copper braid is also used when steel armour is not allowed.

- SWA - Steel wire armour, used in multi-core cables (magnetic),
- AWA - Aluminium wire armour, used in single-core cables (non-magnetic).

When an electric current passes through a cable it produces a magnetic field (the higher the voltage the bigger the field). The magnetic field will induce an electric current in steel armour (eddy currents), which can cause overheating in AC systems. The non-magnetic aluminium armour prevents this from happening.

Outer Sheath

Applied over the armour for overall mechanical, weather, chemical and electrical protection. Typically a thermoplastic (eg. PVC) or thermosetting(eg. CSP) compound, and often the same material as the bedding. Outer sheath is normally colour coded to differentiate between LV, HV and instrumentation cables. Manufacturer’s markings and length markings are also printed on the outer sheath.

Termite Protection

For underground cables, a nylon jacket can be applied for termite protection, although sometimes a phosphor bronze tape is used.

Conductor Protection (Appendix)

Wires and cables are generally subject to abuse. The type and amount of abuse depends on how and where they are installed and the manner in which they are used. Cables buried directly in the ground must resist moisture, chemical action, and abrasion. Wires installed in buildings must be protected against mechanical injury and overloading. Wires strung on crossarms on poles must be kept far enough apart so that the wires do not touch. Snow, ice, and strong winds make it necessary to use conductors having high tensile strength and substantial frame structures.

Generally, except for overhead transmission lines, wires or cables are protected by some form of covering. The covering may be some type of insulator like rubber or plastic. Over this, additional layers of fibrous braid or tape may be used and then covered with a finish or saturated with a protective coating. If the wire or cable is installed where it is likely to receive rough treatment, a metallic coat should be added.

The materials used to make up the conductor protection for a wire or cable are grouped into one of two categories: non-metallic or metallic.

Non-Metallic

The category of non-metallic protective coverings is divided into three areas. These areas are:

(1) according to the material used as the covering,

(2) according to the saturant in which the covering was impregnated, and

(3) according to the external finish on the wire or cable.

These three areas reflect three different methods of protecting the wire or cable. These methods allow some wire or cable to be classified under more than one category. Most of the time, however, the wire or cable will be classified based upon the material used as the covering regardless of whether or not a saturant or finish is applied.

Many types of non-metallic materials are used to protect wires and cables. Fibrous braid is by far the most common and will be discussed first.

Fibrous Braid

Fibrous braid is used extensively as a protective covering for cables. This braid is woven over the insulation to form a continuous covering without joints. The braid is generally saturated with asphalt, paint, or varnish to give added protection against moisture, flame, weathering, oil, or acid. Additionally, the outside braid is often given a finish of stearin pitch and mica flakes, paint, wax, lacquer, or varnish depending on the environment where the cable is to be used.

Woven Covers

Woven covers, commonly called loom, are used when exceptional abrasion-resistant qualities are required. These covers are composed of thick, heavy, long-fibered cotton yarns woven around the cable in a circular loom, much like that used on a fire hose. They are not braids, although braid covering are also woven; they are designated differently.

Rubber and Synthetic Coverings

Rubber and synthetic coverings are not standardized. Different manufactures have their own special compounds designated by individual trade names. These compounds are different from the rubber compounds used to insulate cable. These compounds have been perfected not for insulation qualities but for resistance to abrasion, moisture, oil, gasoline,

acids, earth solutions, and alkalies. None of these coverings will provide protection against all types of exposure. Each covering has its own particular limitations and qualifications.

Jute and Asphalt Coverings

Jute and asphalt coverings are commonly used as a cushion between cable insulation and metallic armour. Frequently, they are also used as a corrosive-resistant covering over a lead sheath or metallic armour. Jute and asphalt coverings consist of asphalt-impregnated jute yarn heli-wrapped around the cable or of alternate layers of asphalt-impregnated jute yarn. These coverings serve as a weatherproofing.

Unspun Felted Cotton

Unspun felted cotton is commonly used only in special classes of service. It is made as a solid felted covering for a cable.

Metallic

Metallic protection is of two types: sheath or armour. As with all wires and cables, the type of protection needed will depend on the environment where the wire or cable will be used.

Metallic Sheath

Cables or wires that are continually subjected to water must be protected by a watertight cover. This watertight cover is either a continuous metal jacket or a rubber sheath molded around the cable.

Lead-sheathed cable is one of three types currently being used: alloy lead, pure lead, and reinforced lead. An alloy-lead sheath is much like a pure lead sheath but is manufactured with 2-percent tin. This alloy is more resistant to gouging and abrasion during and after installation. Reinforced lead sheath is used mainly for oil-filled cables where high internal pressures can be expected. Reinforced lead sheath consists of a double lead sheath. A thin tape of hard-drawn copper, bronze, or other elastic metal (preferably nonmagnetic) is wrapped around the inner sheath. This tape gives considerable additional strength and elasticity to the sheath, but must be protected from corrosion. For this reason, a second lead sheath is applied over the tape.

Metallic Armour

Metallic armour provides a tough protective covering for wires and cables. The type, thickness, and kind of metal used to make the armour depend on three factors:

(1) the use of the conductors,

(2) the environment where the conductors are to be used, and

(3) the amount of rough treatment that is expected.

1. Wire-braid armour

Wire-braid armour, also known as basket-weave armour, is used when light and flexible protection is needed. Wire braid is constructed much like fibrous braid. The metal is woven directly over the cable as the outer covering. The metal used in this braid is galvanized steel, bronze, copper, or aluminum. Wire-braid armour is mainly for shipboard use.

2. Steel tape

A second type of metallic armour is steel tape. Steel tape covering is wrapped around the cable and then covered with a serving of jute. There are two types of steel tape armour. The first is called interlocking armour. Interlocking armour is applied by wrapping the tape around the cable so that each turn is overlapped by the next and is locked in place. The second type is flat- band armour. Flat-band armour consists of two layers of steel tape. The first layer is wrapped around the cable but is not overlapped. The second layer is then wrapped around the cable covering the area that was not covered by the first layer.

3. Wire armour

Wire armour is a layer of wound metal wire wrapped around the cable. Wire armour is usually made of galvanized steel and can be used over a lead sheath (see view C of the figure above). It can be used with the sheath as a buried cable where moisture is a concern, or without the sheath when used in buildings.

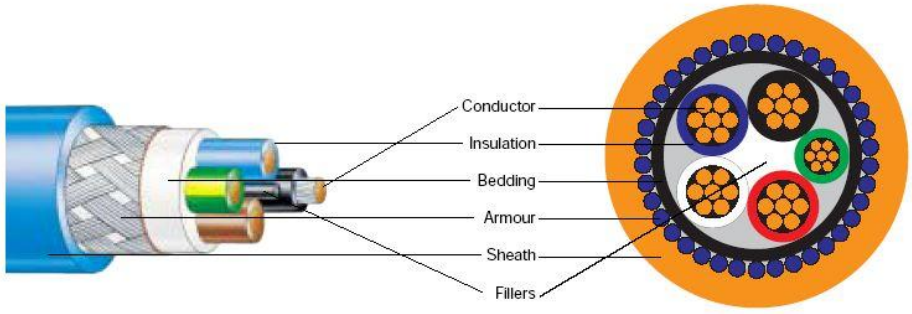
4. Coaxial cable

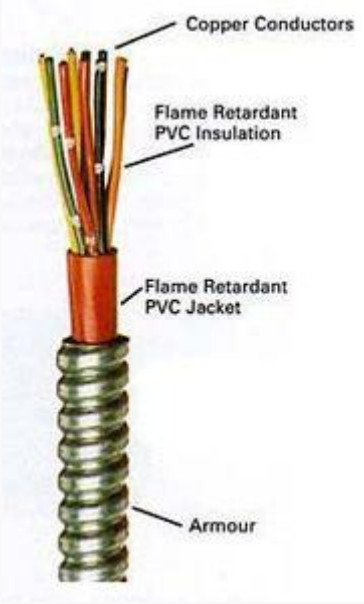
Coaxial cable is defined as two concentric wires, cylindrical in shape, separated by a dielectric of some type. One wire is the center conductor and the other is the outer conductor. These conductors are covered by a protective jacket. The protective jacket is then covered by an outer protective armour.

Coaxial cables are used as transmission lines and are constructed to provide protection against outside signal interference.

Low Voltage Power and Control Cables

Low voltage power and control cables pertain to electrical cables that typically have a voltage grade of 0.6/1 kV or below.





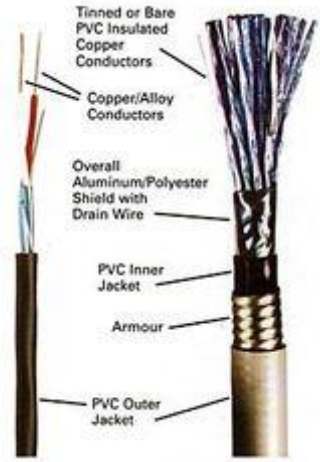
Armoured FAS Cable

An important item that is under the grouping known as 'Low Voltage Cables', is Type FAS (Fire Alarm & Signal Cable). This 300-volt cable, is specifically designed for the interconnection of security system elements, including fire protection signalling devices such as smoke and fire detectors, fire alarms, and two-way emergency communications systems.

Fire alarm installations in non-combustible buildings require mechanical protection, consisting of interlock armour, metallic conduit, non-metallic conduit embedded in concrete or installed under-ground. Armoured FAS Cable provided with an interlocking aluminum armour, may be expected to have an appreciable cost advantage, compared with cables installed in rigid conduit.

Other common cables are LVT (Low Voltage Thermoplastic) and ELC (Extra Low Voltage Control), which are frequently used in residential installations for such items as door bells and thermostats.

Low Voltage Instrumentation Cables



Instrumentation cables

Low voltage instrumentation cables pertain to cables for use in instrument applications and typically have a voltage grade of 450/750 V or below.

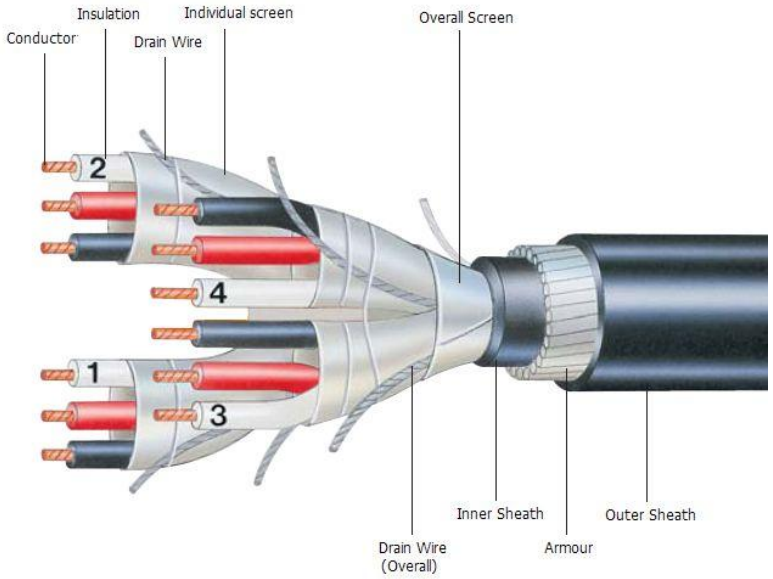
Instrumentation Cables rated at 300 volts have copper conductors 0.33 mm^2 (#22 AWG) to 2.08 mm^2 (#14 AWG), while those rated at 600 volts have 0.82 mm^2(#18 AWG) to 5.26 mm^2(#10 AWG), and unarmoured and armoured types are available. The cables may be an assembly of single conductors, pairs, triads or quads. The conductors are stranded seven-wire tinned or bare copper. The insulation is usually a PVC compound chosen dependant on the environment for which it is intended. Insulated conductors are paired with staggered lays to prevent electromagnetic coupling and crosstalk. When individual shielding is specified, each pair is aluminum/polyester shielded with drain wire to eliminate electrostatic interference.

Armoured cables have an interlocked aluminum or galvanized steel armour. The armouring is applied over an inner PVC jacket, followed by a PVC outer jacket. Armoured cables are suitable for installation on cable trays in dry, damp and wet locations, or direct earth burial.

Unarmoured Instrumentation Cables are intended for installation in raceways/conduit (except cable trays) in dry, damp or wet locations, or direct earth buried. Unarmoured Cable with Type TC (Tray Cable) designation, may be installed in cable trays.

Thermocouple Extension Cables

Thermocouple Extension Cables have a 300 volt rating, and are of similar construction to Instrumentation Cables, but the metals/alloys used for the conductors are different. Thermocouples measure temperature using the electric current created when heat is applied to two dissimilar metals/alloys. The cable assembles may consist of as many as 50 pairs, depending on the number of locations being temperature monitored.



Medium / High Voltage Power Cables

Medium or High Voltage power cables have voltage grade greater than 1 kV. Medium voltage usually goes up to 46 kV and High voltage is considering all voltage levels above 46 kV.

Medium Voltage distribution systems begin at substations and supply electricity to a wide spectrum of power consumers. When selecting a cable, the basic aim is to safely provide adequate electrical power, with continuous, trouble-free operation, in a system that is able to withstand unexpected demands and overload conditions. Each installation has particular requirements that must be considered. There are distinct benefits from specifying a copper-conductor cable that has been manufactured under rigid specification and quality control procedures. It will provide maximum performance with minimum maintenance. There are seven types different by construction for medium voltage copper power cables in the 1 kV to 46 kV range. Most are available in single- and multi-core configurations. There are ranges of sizes and design variations for each type.

The MV cable types are:

- Teck Cables,
- Shielded Cables,
- Concentric Neutral Cables,
- Paper-Insulated Lead-Covered Cables,
- Submarine Cables,
- Mining Cables,
- Aluminum-Sheathed Cables.

In the cable descriptions a number of insulation and sheath (jacket) materials have been abbreviated as follows:

- Cross-Linked Polyethylene - XLPE,
- Ethylene-Propylene Rubber - EPR,
- Polyvinyl Chloride - PVC,
- Polyethylene - PE,
- Tree-Retardant Cross-Linked Polyethylene - TR-XLPE.

Teck Cables

Teck Cables were originally developed for use in mines, but they are now widely used in primary and secondary industries, chemical plants, refineries and general factory environments. They are also used in multi-storey and commercial buildings. They are flexible, resistant to mechanical abuse, corrosion resistant, compact and reliable. A modified Teck Cable construction may be used for vertical installations, such as in mine shafts and multi-storey buildings, where the armour is locked-in-place to prevent slippage of the inner core. There are many different combinations of conductor size, voltage rating, armour type and so forth, available in Teck Cables to meet the requirements of particular installations. Annealed, bare, copper is used for the conductor (s), and they are usually compact stranded to reduce diameter. In multi-conductor cables, the insulated conductors are cabled together, including the bare copper bonding (grounding) conductor. In shielded multi-conductor cables, the bonding (grounding) conductor is positioned to contact the copper shields. A PVC outer jacket which may be colour-coded depending on the rating of the cable is applied.

Shielded Cables

Shielded Power Cable may be single-or three-conductor. The basic construction begins with a conductor of annealed, bare, solid or concentric-stranded copper, which may be compact or compressed. This is followed by a semi-conducting conductor shield, insulation, and then a semi-conducting insulation shield. Metallic shielding follows, which is usually either gapped or lapped copper tape. Other types of metallic shielding are available, including concentric wires and longitudinally corrugated copper tape. The outer jacket is either PVC or PE.

Concentric Neutral Cables

These power cables may be used in dry or wet locations, for a wide variety of types of installations, and may be single- or three-conductor. The two standard constructions are Unjacketed and Jacketed, the latter being most frequently used. The conductor is typically annealed, bare, stranded copper, but tin-coated wire and solid conductors are also available. The concentric neutral conductor, from which the cable derives its name, is bare or tin-coated copper wire, applied helically over the insulation shield. These wires act as the metallic component of the shield and the neutral, at the same time.

Paper-Insulated Lead-Covered Cables (PILC)

PILC cables are used in power distribution and industrial applications, and they may be installed exposed, in underground ducts or directly buried. Their design begins with annealed, bare copper conductor(s) which may be round, concentric, compressed or compact stranded, compact sector, and in larger sizes … Type M segmental stranded. An example of compact sector conductors is shown in the illustration. The insulated cable core is impregnated with a medium viscosity polybutene-based compound. The combination of the excellent electrical and mechanical characteristics of the liquid and the paper has resulted in a reliable and economic insulation, which now claims a

history of almost 100 years. It is little wonder why so many utilities and power-consuming industries, still continue to specify PILC. To prevent the ingress of moisture, a seamless lead-alloy sheath is applied. The outer jacket may be PVC or PE, and if required by the application, armour is available.

Submarine Cables

For submarine installations, usually Self-Contained Liquid-Filled Cables (SCLF), or Solid Dielectric Cables are selected, depending on voltage and power load. SCLF Cables are capable of handling very high voltages. However, for medium-voltage installations, a Solid Dielectric Cable can easily fulfil the electrical demands of the system. A submarine Solid Dielectric Cable is shown in the illustration. Its construction begins with a compact stranded, annealed, bare copper conductor, followed by a semi-conducting conductor shield. A copper tape shield is helically applied, followed by a lead-alloy sheath. Due to the severe environmental demands placed on submarine cables, a lead-alloy sheath is often specified because of its compressibility, flexibility and resistance to moisture and corrosion. The sheath is usually covered by a number of outer layers, comprising a PE or PVC jacket and metal wire armouring.

Mining Cables

A number of different types of cables are used in mines. There are fixed mining cables and portable mining cables, the latter being described here. The key requirements of portable cables are flexibility, and resistance to mechanical abrasion and damage. Due to the additional demands put on portable mining cables used for reeling and dereeling applications, special design may be required. There are many types of portable mining cables. They are available in ratings up to 25 kV, and may have as many as five conductors. An example of SHD-GC Cable, is shown in the illustration. It has three insulated, shielded conductors, two bare ground wires, a ground check wire, and an overall jacket. The conductors for this cable are annealed, bare or tinned copper wires. The braided shield may be tin-coated wires, or a tin-coated copper wire/textile composite. The grounding conductor(s) annealed, bare or tinned, stranded copper wires, and the ground check conductor is annealed, bare, stranded copper wires with EPR insulation and nylon braid, elastomeric jacket holds the conductor assembly firmly in place, to minimize snaking and cork-screwing during reeling and dereeling.

Aluminum-Sheathed Cables

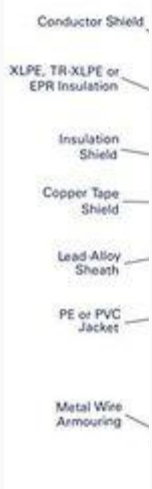
These power cables are used for exposed and concealed wiring, in wet and dry locations, and where exposed to the weather. They may be installed in ventilated, unventilated and ladder-type cable-troughs, and ventilated flexible cableways. Aluminum-Sheathed Power Cables may be single-,two-,three- or four-conductor, the conductor(s) being annealed, bare, compressed-round stranded copper. The insulated core is enclosed in a liquid- and vapour-tight solid corrugated aluminum sheath, covered by a PVC jacket.

Teck Cable overview

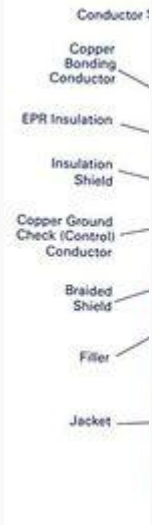
Shielded Cable overview

Concentric Neutral Cable overview

Paper-Insulated Lead-Covered Cable overview

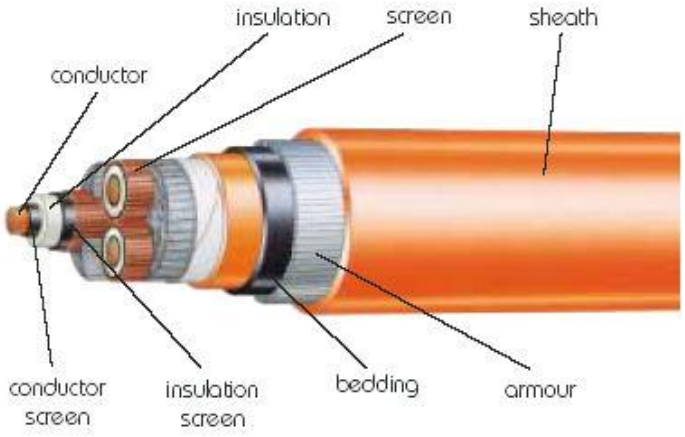


Submarine Cable overview



Mining Cable overview

Aluminum-Sheathed Cable overview



Trivia

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