

# Electrical Power Cables

(Significant Component in  
Power Engineering)



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# Chapter 1

## Power Cable

A **power cable** is an assembly of two or more electrical conductors, usually held together with an overall sheath. The assembly is used for transmission of electrical power. Power cables may be installed as permanent wiring within buildings, buried in the ground, run overhead, or exposed.

Flexible power cables are used for portable devices, mobile tools and machinery.

### ***History***

Early telegraph systems used the first forms of electrical cabling, transmitting tiny amounts of power. Gutta-percha insulation used on the first submarine cables was, however, unsuitable for building wiring use since it deteriorated rapidly when exposed to air.

The first power distribution system developed by Thomas Edison in 1882 in New York City used copper rods, wrapped in jute and placed in rigid pipes filled with a bituminous compound. Although vulcanized rubber had been patented by Charles Goodyear in 1844, it was not applied to cable insulation until the 1880s, when it was used for lighting circuits. Rubber-insulated cable was used for 11,000 volt circuits in 1897 installed for the Niagara Falls power project.

Mass-impregnated paper-insulated medium voltage cables were commercially practical by 1895. During World War II several varieties of synthetic rubber and polyethylene insulation were applied to cables.

### ***Construction***

Modern power cables come in a variety of sizes, materials, and types, each particularly adapted to its uses. Large single insulated conductors are also sometimes called power cables in the industry.

Cables consist of three major components: conductors, insulation, protective jacket. The makeup of individual cables varies according to application. The construction and material are determined by three main factors:

- Working voltage, determining the thickness of the insulation;
- Current-carrying capacity, determining the cross-sectional size of the conductor(s);
- Environmental conditions such as temperature, water, chemical or sunlight exposure, and mechanical impact, determining the form and composition of the outer cable jacket.

Cables for direct burial or for exposed installations may also include metal armor in the form of wires spiralled around the cable, or a corrugated tape wrapped around it. The armor may be made of steel or aluminum, and although connected to earth ground is not intended to carry current during normal operation.

Power cables use stranded copper or aluminum conductors, although small power cables may use solid conductors. The cable may include uninsulated conductors used for the circuit neutral or for ground (earth) connection.

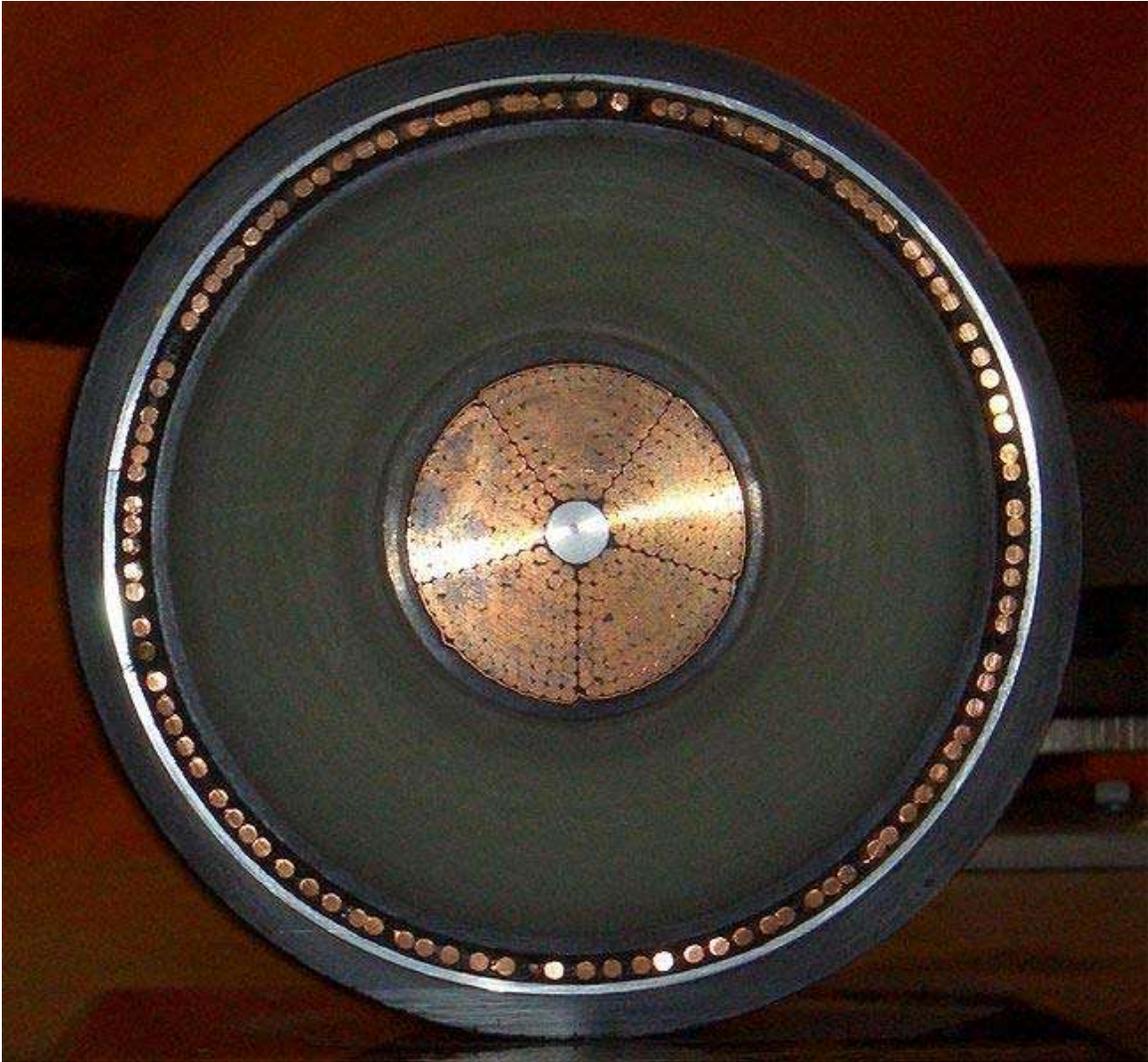
The overall assembly may be round or flat. Non-conducting filler strands may be added to the assembly to maintain its shape. Special purpose power cables for overhead or vertical use may have additional elements such as steel or Kevlar structural supports.

Some power cables for outdoor overhead use may have no overall sheath. Other cables may have a plastic or metal sheath enclosing all the conductors. The materials for the sheath will be selected for resistance to water, oil, sunlight, underground conditions, chemical vapors, impact, or high temperatures. In nuclear industry applications the cable may have special requirements for ionizing radiation resistance. Cable materials may be specified not to produce large amounts of smoke if burned. Cables intended for underground use or direct burial in earth will have heavy plastic or metal, most often lead sheaths, or may require special direct-buried construction. When cables must run where exposed to mechanical impact damage, they may be protected with flexible steel tape or wire armor, which may also be covered by a water resistant jacket.

## **Higher voltages**

For circuits operating at or above 2,000 volts between conductors, a conductive shield may surround each insulated conductor. This equalizes electrical stress on the cable insulation. This technique was patented by Martin Hochstadter in 1916; the shield is sometimes called a Hochstadter shield. The individual conductor shields of a cable are connected to earth ground at the ends of the cable, and at locations along the length if voltage rise during faults would be dangerous.

Cables for power distribution of 10kV or higher may be insulated with oil and paper, and are run in a rigid steel pipe, semi-rigid aluminum or lead sheath. For higher voltages the oil may be kept under pressure to prevent formation of voids that would allow partial discharges within the cable insulation.



A high voltage cable designed for 400 kv. Large center conductor carries the current, smaller conductors on the outside act as a shield to equalize the voltage stress in the thick polyethylene insulation layer.

Modern high voltage cables use polymers or polyethylene, including (XLPE) for insulation. They require special techniques for jointing and terminating.

Many multiconductor cables have a bare or insulated *grounding* or *bonding* wire which is for connection to earth ground. The grounding conductor connects equipment enclosures to ground for protection from electric shock.

Electrical power cables are often installed in raceways, including electrical conduit and cable trays, which may contain one or more conductors.

A hybrid cable can include conductors for control signals or may also include optical fibers for data.

## ***Flexible cables***

All electrical cables are somewhat flexible, allowing them to be shipped to installation sites wound on reels or drums. Where applications require a cable to be moved repeatedly, such as for portable equipment, more flexible cables called "cords" or "flex" are used. Flexible cords contain fine stranded conductors, not solid core conductors, and have insulation and sheaths to withstand the forces of repeated flexing and abrasion. Heavy duty flexible power cords such as those feeding a mine face cutting machine are carefully engineered — their life is measured in weeks. Very flexible power cables are used in automated machinery, robotics, and machine tools.

WWT

## Chapter 2

# Power Cord and Extension Cord

## Power cord

A **power cord**, **line cord**, or **mains cable** is a cord or cable that temporarily connects an electrical appliance to the distribution circuits of an electrical power source via a wall socket or extension cord.

The terms are generally used for cables using a power plug to connect to a single-phase alternating current power source at the local line voltage—(generally 100 to 240 volts, depending on the location). The terms **power cable**, **mains lead** or **flex** are also used. A **lamp cord** is a light weight ungrounded two wire cord used for small loads such as a table or floor lamp. The term **cord set** is also used to distinguish those cords that include connectors molded to the cord at each end.

Power cables may be either fixed or detachable from the appliance. In the case of detachable leads, the appliance end of the power cord has a socket rather than a plug to link it to the appliance, to avoid the dangers from having a live protruding pin. Cords may also have twist-locking features, or other attachments to prevent accidental disconnection at one or both ends. A cord set may include accessories such as fuses for overcurrent protection, a pilot lamp to indicate voltage is present, or a leakage current detector. Power cords for sensitive instruments, or audio/video equipment may also include a shield over the power conductors to minimize electromagnetic interference.

### **Connectors**

Common types of detachable power cables have appliance-side connectors such as the *IEC 60320 C13*, "kettle lead", "jug plug" or "IBM plug" (commonly used for higher current appliances where an earth or ground connection is required) and *IEC 60320 C7* commonly used for low-current applications such as a power supply inlet for use with a laptop computer. The *IEC C7* is also known as a "figure-of-eight lead", the connector has a figure-of-eight cross section). The polarised *IEC 60320 C5* connector is now commonly

used on the AC side of laptop computer power supplies. The IEC C5 is commonly known as "cloverleaf plug" or "Mickey Mouse plug" because of the shape of its cross section.

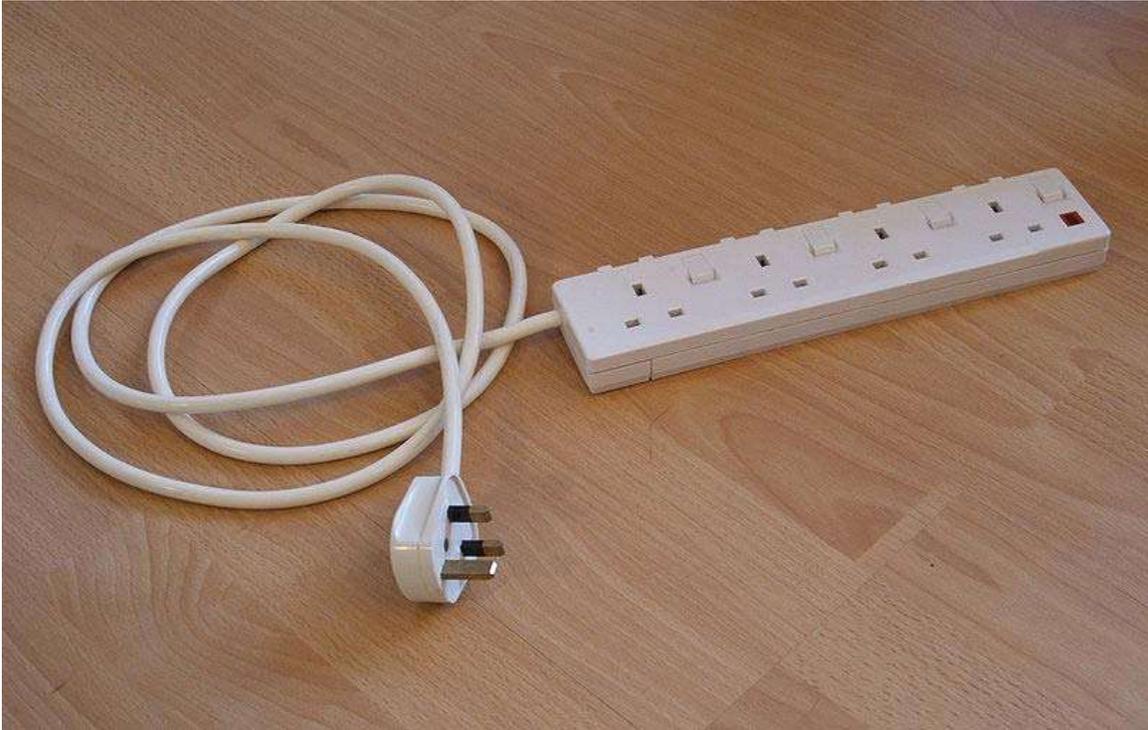
IEC power cables come in high-temperature and low-temperature variants, as well as various current capacities. The connectors have slightly different shapes to ensure that it is not possible to substitute a cable with a lower temperature or current rating, but that it *is* possible to use an over-rated cable. Cords also have different types of exterior jackets available to accommodate environmental variables such as moisture, temperature, oils, sunlight, flexibility, and heavy wear. For example, a heating appliance may come with a cord designed to withstand accidental contact with heated surfaces.

Worldwide, more than a dozen different types of connectors are used for fixed building wiring. Products sold in many different markets can use a standardized IEC connector and then use a detachable power cord to match the local electrical outlets. This simplifies safety approvals, factory testing, and production since the power cord is a low-cost item available as a commodity. Note that the same types of appliance-side connectors are used with both 110 V and 230 V power cables, so care must be used when moving appliances between countries with different voltage standards — substituting a power cord that matches local power outlets will result in an incorrect voltage being applied to the appliance or equipment. Some devices have a slide-switch to adapt to different voltages, or wide-ranging power supplies. Unless explicitly labelled as capable of handling local voltages, this is very likely to damage or destroy the appliance.

### ***Power supplies***

Cord sets must be distinguished from plug-in wall mounted power supplies, where the connector also contains a transformer, and possibly rectifiers, filters and regulators. Unwary substitution of a standard mains-voltage connector for the power supply would result in application of full line voltage to the connected device, resulting in its destruction and possible fire or personal injury.

# Extension cord



A British extension cord or power strip with a power indicator and switches for each individual socket.

An **extension cord**, **power extender**, or **extension lead** is a length of flexible electrical power cable (flex) with a plug on one end and one or more sockets on the other end (usually of the same type as the plug). The term usually refers to mains (household AC) extensions but is also used to refer to extensions for other types of cabling. If the plug and receptacle are of different types, the term "adapter cord" may be used. **Extension cable** is also used, but that has a distinct meaning from **extension cord** for many people.

## **Overview**

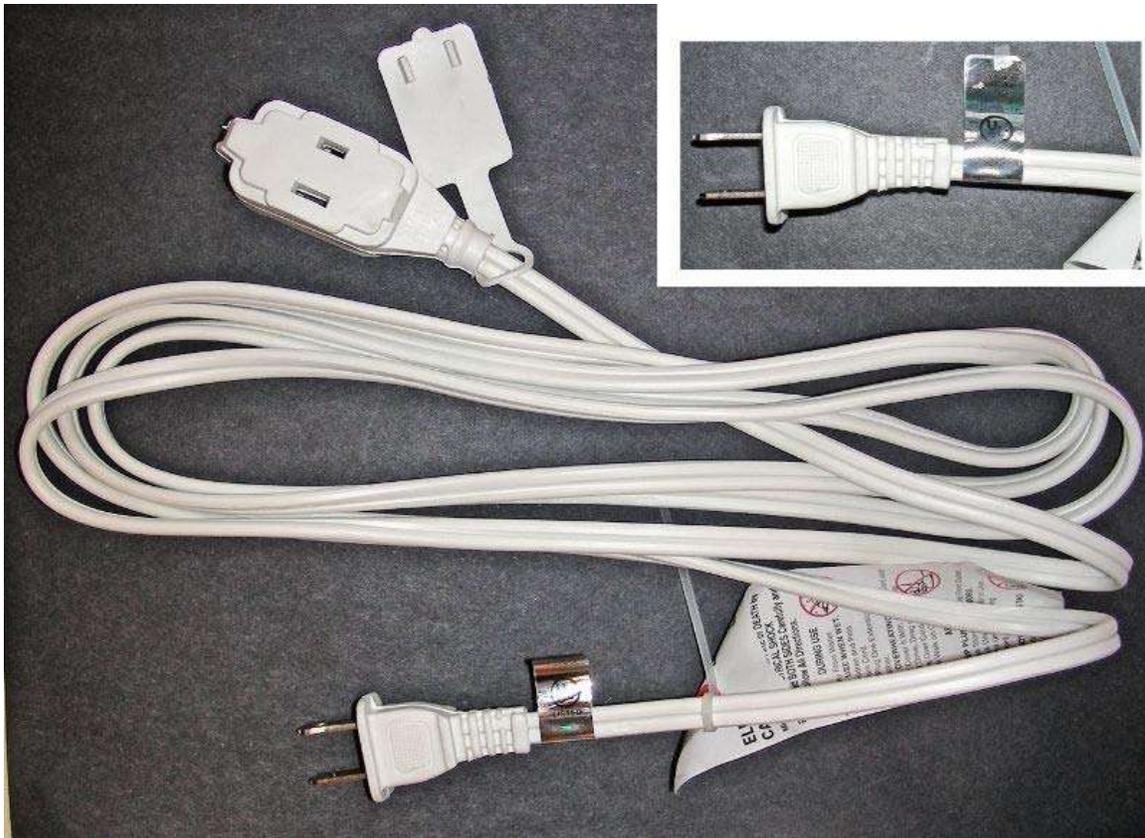
Some extension cords also incorporate safety features, such as a polarized plug and receptacle, grounded terminals, a 'power-on' indicator, a fusible link, or even a residual-current device (also known as a ground-fault circuit interrupter or GFCI).

Extension cords come in various lengths and thicknesses, and service duties. In general, the more power needed by the appliance, the thicker the cord should be (that is, larger wires inside). Cords to be used outdoors, in wet areas, around oils, or exposed to sunlight for long periods should be selected for such specific service.



Yellow NEMA 5-15 Extension Cord

In the USA where the domestic voltage is 120 V, the National Electrical Code (NEC) prohibits the use of extension cords in a 20 A circuit unless they are of 16 AWG or larger (for example, 14 AWG or 12 AWG). As with other flexible cords, the NEC also prohibits their use where attached to building surfaces, or concealed inside walls, floors, or ceilings, above suspended ceilings, or where run through holes or other openings (windows, doors) in structures (with limited exceptions). Cords run across the floor should be covered with a suitable device to protect them from physical damage.



Counterfeit extension cord (and labels) from China. Undersize wiring is a fire hazard.

Other countries also regulate the use of extension cables but the specific conditions and the nature of the regulation varies. In Europe and elsewhere where the normal domestic voltage is around 230 V, there is less risk of causing fire through overheating of cables for any given power due to the lower current. However most European extension reel cables now include an automatic current cut-out to avoid misuse of the cable. This requires manual re-setting if excess current is drawn through the cable. (American multiplug cords also include such a device but single- or triple-outlet cords do not.)

An extension reel is an extension lead that rolls up, usually into the socket end, which in some cases has more than one socket on it (often 2 or 4). Another type of extension reel hangs near the plug end and permits the user to draw the cord out by grasping the socket end. Such cables can only be used to carry full rated current when fully extended since the portion on the reel constitutes a concentration of the loss power (the result of its series resistance) which is not suitably dissipated unless most of the cable is unreel to expose it to ambient air.

A power cord is similar but the socket end is designed to mate with a panel plug (usually IEC or figure 8 style) and is usually much shorter. With IEC connectors cables are frequently seen with a line plug and socket. These may be considered either as powercords (if IEC outlets are in use) or as extensions (if used to extend a powercord.)

A power strip is a block on the end of a power cable with a number of sockets (usually 3 or more), often arranged in a line. This term is also used to refer to the whole unit of a short extension cord terminating in a power strip.

The term "extension cord" has been in use since at least 1946.

Below is the Coleman Cable Inc specifications as given to consider run footage for US cords:

<b>Gauge:</b>	<b>Max Current (Amps):</b>
16/2	13A 0'-50' 10A 50'-100'
16/3	13A 0'-50' 10A 50'-100'
14/3	15A 0'-50' 13A 50'-100'
12/3	15A 0'-100'
10/3	15A 0'-100'

Colors are assigned to cords, but they can be found across the gauges. 12 or 10 gauge used for heavy duty equipment.

### ***Length***

To avoid the need to roll-up any excess length, and to avoid the need for the user to cut the cord to size, extension cords are sometimes sold in prefabricated lengths 1 to 10 yards (Also measured by the foot). The longer the length of the cord the larger the wire should be to minimise voltage drop.

**Signal**



USB Extension Cord



Retractable Mouse Cord

**Extension cords** may sometimes refer to cables that transmit data, electricity, or both (for example, USB extension cable). This type of cable comes in handy when certain USB plugs cannot fit into the hubs, such as a USB flash drive. But they are more likely to be called "extenders" or "extender cables" or "cable extenders".

A retractable cord is capable of being retracted. It is used in optical mini-mouses and elsewhere.

### **Safety**

The majority of extension cords sold in the United States contain lead in the PVC housing. California Proposition 65 (1986) was passed to warn consumers when a product contains toxic chemicals such as lead which may cause cancer or reproductive harm. Many of these products carry warning labels, and advise to consumer to wash hands after handling the cable. There is currently no widespread movement in the USA to stop manufactured products containing lead in the first place. European countries developed RoHS to prevent products from containing harmful chemicals such as lead. However, some cables that fall under the Proposition 65 warning are RoHS compliant because of the amount of lead they contain, and for some applications RoHS doesn't apply.

## Chapter 3

# Ground (Electricity)

In electrical engineering, **ground** or **earth** may be the reference point in an electrical circuit from which other voltages are measured, or a common return path for electric current, or a direct physical connection to the Earth.



A typical earthing electrode (left) at a home in Australia. Fig. 1. Note the green and yellow marked earth wire.

Electrical circuits may be connected to ground (earth) for several reasons. In mains powered equipment, exposed metal parts are connected to ground to prevent contact with a dangerous voltage if electrical insulation fails. Connections to ground limit the build-up

of static electricity when handling flammable products or when repairing electronic devices. In some telegraph and power transmission circuits, the earth itself can be used as one conductor of the circuit, saving the cost of installing a separate return conductor.

For measurement purposes, the Earth serves as a (reasonably) constant potential reference against which other potentials can be measured. An electrical ground system should have an appropriate current-carrying capability in order to serve as an adequate zero-voltage reference level. In electronic circuit theory, a "ground" is usually idealized as an infinite source or sink for charge, which can absorb an unlimited amount of current without changing its potential. Where a real ground connection has a significant resistance, the approximation of zero potential is no longer valid. Stray voltages or earth potential rise effects will occur, which may create noise in signals or if large enough will produce an electric shock hazard.

The use of the term ground (or earth) is so common in electrical and electronics applications that circuits in portable electronic devices such as cell phones and media players as well as circuits in vehicles such as ships, aircraft, and spacecraft may be spoken of as having a "ground" connection without any actual connection to the Earth. This is usually a large conductor attached to one side of the power supply (such as the "ground plane" on a printed circuit board) which serves as the common return path for current from many different components in the circuit.

## **Synonyms**

The terms *ground* and *grounding* are used in US electrical practice. In the UK the equivalent terms are *earth* and *earthing*.

## **History**

Long-distance electromagnetic telegraph systems from 1820 onwards used two or more wires to carry the signal and return currents. It was then discovered, probably by the German scientist Carl August Steinheil in 1836-1837, that the ground could be used as the return path to complete the circuit, making the return wire unnecessary. However, there were problems with this system, exemplified by the transcontinental telegraph line constructed in 1861 by the Western Union Company between Saint Joseph, Missouri, and Sacramento, California. During dry weather, the ground connection often developed a high resistance, requiring water to be poured on the ground rod to enable the telegraph to work or phones to ring.

Later, when telephony began to replace telegraphy, it was found that the currents in the earth induced by power systems, electrical railways, other telephone and telegraph circuits, and natural sources including lightning caused unacceptable interference to the audio signals, and the two-wire system was reintroduced.

## ***Radio communications***

An electrical connection to earth can be used as a reference potential for radio frequency signals for certain kinds of antennas. The part directly in contact with the earth (the "earth electrode") can be as simple as a metal rod or stake driven into the earth (Fig. 1), or a connection to buried metal water piping (though this carries the risk of the water pipe being later replaced with plastic). Because high frequency signals can flow to earth through capacitance, capacitance to ground is an important factor in effectiveness of signal grounds. Because of this a complex system of buried rods and wires can be effective. An ideal signal ground maintains zero voltage regardless of how much electric current flows into ground or out of ground. The resistance at the signal frequency of the electrode-to-earth connection determines its quality, and that quality is improved by increasing the surface area of the electrode in contact with the earth, increasing the depth to which it is driven, using several connected ground rods, increasing the moisture of the soil, improving the conductive mineral content of the soil, and increasing the land area covered by the ground system.

Some types of transmitting antenna systems in the VLF, LF, MF and lower SW range depend on a good ground to operate efficiently. For example, a vertical monopole antenna requires a ground plane that often consists of an interconnected network of wires running radially away from the base of the antenna for a distance about equal to the height of the antenna. Sometimes such a ground plane is supported above ground to reduce losses.

## ***AC power wiring installations***

In a mains electricity (AC power) wiring installation, the term ground conductor typically refers to three different conductors or conductor systems as listed below.

**Equipment earthing conductor.** This provides an electrical connection between non-current-carrying metallic parts of equipment and the earth. The reason for doing this according to the U.S. National Electrical Code (NEC), is to limit the voltage imposed by lightning, line surges, and contact with higher voltage lines. Note that equipment earthing does not provide protection from equipment ground faults, unless it is a grounded system (see below) and the voltage is over one thousand volts (typically). This is because the earth is generally a very poor conductor—it takes a large voltage to push enough current through it back to the electrical system's source to operate a circuit breaker or fuse. The equipment earthing conductor is usually also used as the equipment bonding conductor (see below).

**Equipment bonding conductor.** The purpose of the equipment bonding conductor is to provide a low impedance path between non-current-carrying metallic parts of equipment and one of the conductors of that electrical system's source so that should these parts become energized for any reason, such as a frayed or damaged conductor, a short circuit will occur and thus cause an overcurrent protection device such as a circuit breaker or fuse to activate and disconnect the faulted circuit. Note that the earth itself has no role in

this fault-clearing process since current must return to its source, not the earth as is sometimes believed. By bonding (interconnecting) all exposed non-current carrying metal objects together, they should remain near the same potential thus reducing the chance of a shock. This is especially important in bathrooms where one may be in contact with several different metallic systems such as supply and drain pipes and appliance frames. The equipment bonding conductor is usually also used as the equipment earthing conductor (see above).

**Grounding electrode conductor.** is a conductor which connects one leg of an electrical system to one or more earth electrodes. This is called "system grounding" and most but not all systems are required to be grounded. The U.S. NEC and the UK's BS 7671 list systems that are required to be grounded. The grounding electrode conductor is usually but not always connected to the leg of the electrical system that is the "neutral wire". The grounding electrode conductor is also usually bonded to pipework and structural steel in larger structures. According to the NEC, the purpose of earthing an electrical system in this manner is to limit the voltage to earth imposed by lightning events and contact with higher voltage lines, and also to stabilize the voltage to earth during normal operation. In the past, water supply pipes were often used as ground electrodes, but this was banned in some countries when plastic pipe such as PVC became popular. This type of ground applies to radio antennas and to lightning protection systems.

Permanently installed electrical equipment usually also has permanently connected grounding conductors. Portable electrical devices with metal cases may have them connected to earth ground by a pin in the interconnecting plug. The size of power ground conductors is usually regulated by local or national wiring regulations.

### ***Power transmission***

Some HVDC power transmission systems use the ground as second conductor. This is especially common in schemes with submarine cables as sea water is a good conductor. Buried grounding electrodes are used to make the connection to the earth. The site of these electrodes must be chosen very carefully in order to prevent electrochemical corrosion on underground structures.

In Single Wire Earth Return (SWER) AC electrical distribution systems, costs are saved by using just a single high voltage conductor for the power grid, while routing the AC return current through the earth. This system is mostly used in rural areas where large earth currents will not otherwise cause hazards.

A particular concern in design of electrical substations is earth potential rise. When very large fault currents are injected into the earth, the area around the point of injection may rise to a high potential with respect to distant points. This is due to the limited finite conductivity of the layers of soil in the earth. The gradient of the voltage (changing voltage within a distance) may be so high that two points on the ground may be at significantly different potentials, creating a hazard to anyone standing on the ground in

the area. Pipes, rails, or communication wires entering a substation may see different ground potentials inside and outside the substation, creating a dangerous touch voltage.

## **Electronics**



Signal  
ground



Chassis  
ground



Earth  
ground

### Ground symbols

Signal grounds serve as return paths for signals and power (at extra low voltages, i.e., less than about 50 V) within equipment, and on the signal interconnections between equipment. Many electronic designs feature a single return that acts as a reference for all signals. Power and signal grounds often get connected together, usually through the metal case of the equipment.

### **Circuit ground versus earth**

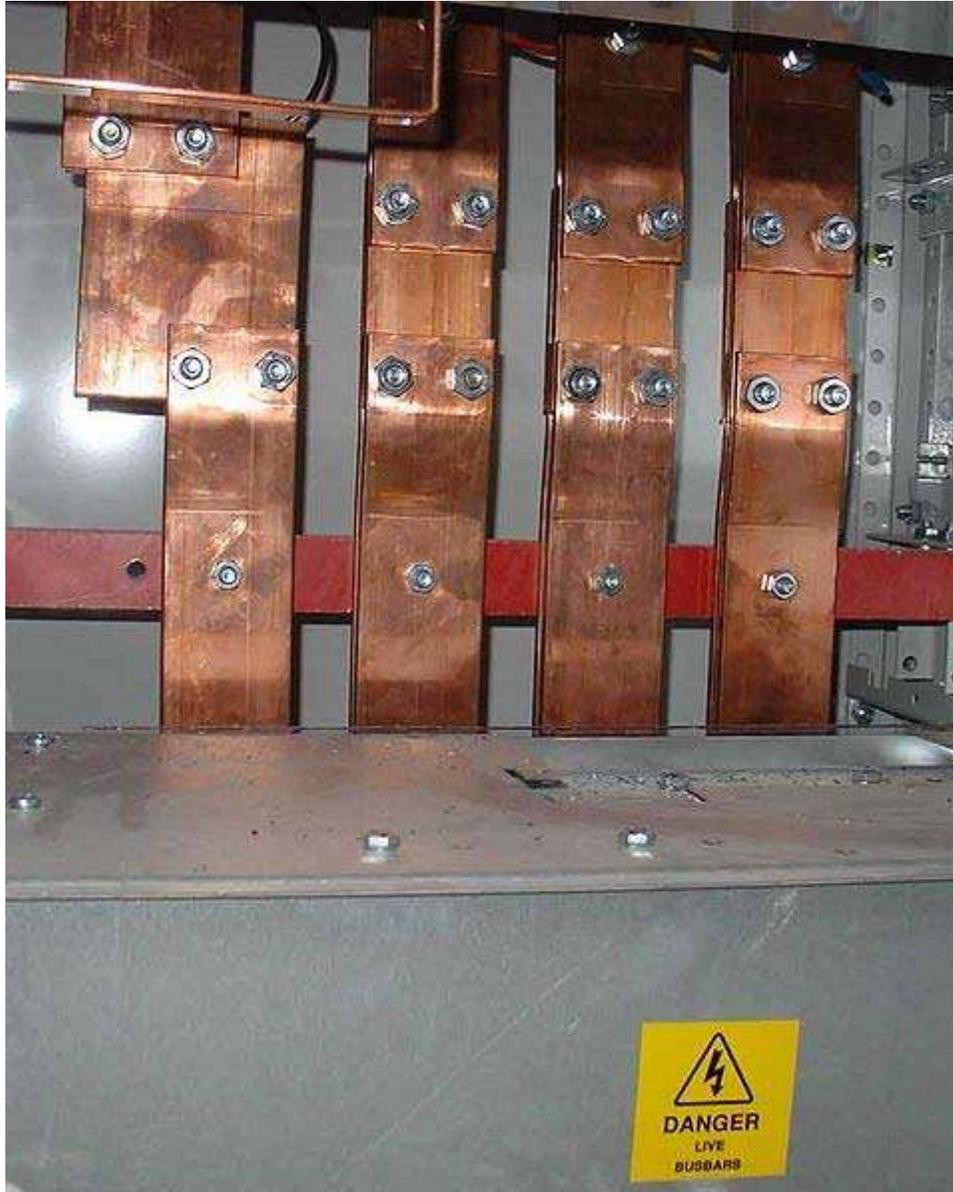
Voltage is a differential quantity. To measure the voltage of a single point, a reference point must be selected to measure against. This common reference point is called "ground" and considered to have zero voltage. This signal ground may not actually be connected to a power ground. A system where the system ground is not actually connected to another circuit or to earth (though there may still be AC coupling) is often referred to as a floating ground.

### **Separating low signal ground from a noisy ground**

In television stations, recording studios, and other installations where sound quality is critical, a special signal ground known as a "technical ground" (or "technical earth") is often installed, to prevent ground loops. This is basically the same thing as an AC power ground, but no appliance ground wires are allowed any connection to it, as they may carry electrical interference. In most cases, the studio's metal equipment racks are all joined together with heavy copper cables (or flattened copper tubing or busbars) and similar connections are made to the technical ground. Great care is taken that no AC-grounded appliances are placed on the racks, as a single AC ground connection to the technical ground will destroy its effectiveness. For particularly demanding applications, the main technical ground may consist of a heavy copper pipe, if necessary fitted by drilling through several concrete floors, such that all technical grounds may be connected by the shortest possible path to a grounding rod in the basement.

## ***Lightning protection systems***

Lightning protection systems are special grounding systems designed to safely conduct the extremely high voltage currents associated with lightning strikes.



Busbars are used for ground conductors in high-current circuits.

## ***Earthing system***

In electricity supply systems, an earthing (grounding) system defines the electrical potential of the conductors relative to that of the Earth's conductive surface. The choice of earthing system has implications for the safety and electromagnetic compatibility of

the power supply. Note that regulations for earthing systems vary considerably between different countries.

A functional earth connection serves a purpose other than providing protection against electrical shock. In contrast to a protective earth connection, a functional earth connection may carry a current during the normal operation of a device. Functional earth connections may be required by devices such as surge suppression and electromagnetic-compatibility filters, some types of antennas and various measurement instruments. Generally the protective earth is also used as a functional earth, though this requires care in some situations.

### ***Ground (Earth) mat***

A ground (earth) mat or grounding (earthing) mat is a flat, flexible pad used for working on electrostatic sensitive devices. It is generally made of a conductive plastic or metal mesh covered substrate which is electrically attached to ground (earth). This helps discharge any static charge which a worker has built up, as well as any static charge on tools or exposed components laid on the mat. It is used most commonly in computer repair. Ground (earth) mats are also found on fuel trucks and tankers, which are otherwise insulated from ground (earth) as they make physical contact only with their tires and the air; obviously static discharge is undesirable during fuel-transfer operations. Similarly, in aircraft refueling, a ground (earth) cable connects the tanker (truck or airplane) to the fuel-seeking craft to eliminate charge differences before fuel is transferred.

In an electrical substation a ground (earth) mat is a mesh of conductive material installed at places where a person would stand to operate a switch or other apparatus; it is bonded to the local supporting metal structure and to the handle of the switchgear, so that the operator will not be exposed to a high differential voltage due to a fault in the substation.

## Chapter 4

# Ground and Neutral

Since the neutral point of an electrical supply system is often connected to earth ground, **ground and neutral** are closely related. Under certain conditions, a conductor used to connect to a system neutral is also used for grounding (earthing) of equipment and structures. Current carried on a grounding conductor can result in objectionable or dangerous voltages appearing on equipment enclosures, so the installation of grounding conductors and neutral conductors is carefully defined in electrical regulations. Where a neutral conductor is used also to connect equipment enclosures to earth, care must be taken that the neutral conductor never rises to a high voltage with respect to local ground.

### ***Definitions***

**Ground** or **earth** in a mains (AC power) electrical wiring system is a conductor that provides a low impedance path to the earth to prevent hazardous voltages from appearing on equipment (the terms "ground" (North American practice) and "earth" (most other English-speaking countries) are used synonymously here). Normally a grounding conductor does not carry current.

**Neutral** is a circuit conductor (that carries current in normal operation), which is connected to earth (or ground) generally at the service panel with the main disconnecting switch or breaker.

In a polyphase or three-wire (single-phase) AC system, the neutral conductor is intended to have similar voltages to each of the other circuit conductors. By this definition, a circuit must have at least three wires for one to serve as a neutral.

In the electrical trade, the conductor of a 2-wire circuit that is connected to the supply neutral point and earth ground is also referred to as the "neutral". This is formally described in the US and Canadian electrical codes as the "identified" circuit conductor.

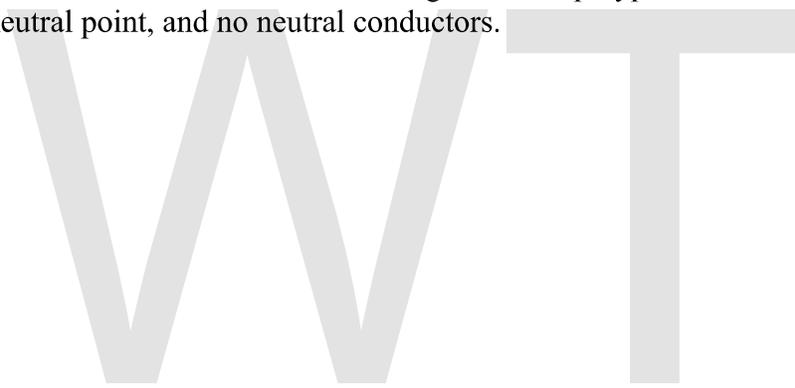
The NEC and Canadian electrical code only define neutral as the first of these. In North American use, the second definition is used in less formal language but not in official

specifications. In the UK the IET definition of a neutral conductor is one connected to the supply system neutral point, which includes both these uses.

All neutral wires of the same electrical system should have the same electrical potential, because they are all connected together through the system ground. Neutral conductors are usually insulated for the same voltage as the line conductors, with interesting exceptions.

### ***Circuitry***

Neutral wires are usually connected together at a neutral bus within panelboards or switchboards, and are "bonded" to earth ground at either the electrical service entrance, or at transformers within the system. For electrical installations with three-wire single phase service, the neutral point of the system is at the center-tap on the secondary side of the service transformer. For larger electrical installations, such as those with polyphase service, the neutral point is usually at the common connection on the secondary side of delta/wye connected transformers. Other arrangements of polyphase transformers may result in no neutral point, and no neutral conductors.



## Wiring colours

**CAUTION**

This installation has wiring colours to two versions of BS7671

Great care should be taken before undertaking extension, alteration or repair that all conductors are correctly identified.

**HARMONISED CORE COLOUR INTRODUCTION**

Old Colour	Transition Period	New Colour	Designation
Red	April 2004 - April 2006	Brown	(L1)
Yellow	April 2004 - April 2006	Black	(L2)
Blue	April 2004 - April 2006	Grey	(L3)
Black	April 2004 - April 2006	Blue	(N)

*To be read in conjunction with BS7671 2004 Amendment No. 2*

U.K. Electrical wiring colours notices.

The insulation of a neutral wire is coloured blue in the EU. This was the same in the UK until 2006, (although legacy cabling neutral wire is black in house wiring). In the USA white or grey is used. For large diameter wires or "mains" cables, the insulation of neutral conductors may be coloured black, as are also the phase or hot conductors, but they may be distinctively designated by applying the appropriate coloured tape—again blue in the EU (including the UK until recently), and white or grey in the USA and Canada. In the U.K. the phases of the incoming supply are designated L1, L2 and L3.

## **Earthing systems**

*The names for the following methods of earthing are those defined by IEC standards, which are used in Europe and many other regions. Different terminology is used in North America, but the basic principles should be the same everywhere.*

Different systems are used to minimize the voltage difference between neutral and local earth ground. In some systems, the neutral and earth join together at the service intake (TN-C-S); in others, they run completely separately back to the transformer neutral terminal (TN-S), and in others they are kept completely separate with the house earth having its own rod and the neutral connected to earth within the distribution network (TT). In a few cases, they are combined in house wiring (TN-C), but the dangers of broken neutrals (see below) and the cost of the special cables needed to mitigate this mean that it is rarely done nowadays.

### **Combining neutral with earth**

Stray voltages created in grounding (earthing) conductors by currents flowing in the supply utility neutral conductors can be troublesome. For example, special measures may be required in barns used for milking dairy cattle. Very small differential voltages, not usually perceptible to humans, may cause low milk yield, or even mastitis (inflammation of the udder). So-called "tingle voltage filters" may be required in the electrical distribution system for a milking parlour.

Connecting the neutral to the equipment case provides some protection against faults/shorts, but may produce a dangerous voltage on the case if the neutral connection is broken.

Combined neutral and ground conductors are commonly used in electricity supply companies' wiring and occasionally for fixed wiring in buildings and for some specialist applications where there is little choice like railways and trams. Since normal circuit currents in the neutral conductor can lead to objectionable or dangerous differences between local earth potential and the neutral, and to protect against neutral breakages, special precautions such as frequent rodding down to earth, use of cables where the combined neutral and earth completely surrounds the phase conductor(s), and thicker than normal equipotential bonding must be considered to ensure the system is safe.

### **Fixed appliances on three-wire circuits**

In North America, the cases of some ovens and clothes dryers were grounded through their neutral wires as a measure to conserve copper during the Second World War. This practice was removed from the NEC in the 1996 edition, but existing installations may still allow the case of such appliances to be connected to the neutral conductor for grounding. Note that the NEC may be amended by local regulations in each state and city. This practice arose from the three wire system used to supply both 120 volt and 240 volt loads. Because ovens and dryers have components that use both 120 and 240 volts

there is often some current on the neutral wire. This differs from the protective grounding wire, which only carries current under fault conditions. Using the neutral conductor for grounding the equipment enclosure was considered safe since the devices were permanently wired to the supply and so the neutral was unlikely to be broken without also breaking both supply conductors. Also, the unbalanced current due to lamps and small motors in the appliance was small compared to the rating of the conductors and therefore unlikely to cause a large voltage drop in the neutral conductor.

## **Portable appliances**

In North American practice small portable equipment connected by a cord set may have only two conductors in the attachment plug. A polarised plug is used to maintain the identity of the neutral conductor into the appliance but it is never used as a chassis/case ground. The small cords to lamps, etc., often have one or more ridges or embedded strings to identify the neutral conductor, or may be identified by color. Portable appliances never rely on using the neutral conductor for case grounding.

In places where the design of the plug and socket cannot ensure that a system neutral conductor is connected to particular terminals of the device, portable appliances must be designed on the assumption that either pole of each circuit may reach full voltage with respect to ground.

## Chapter 5

# High Voltage Cable

A **high voltage cable** - also called **HV cable** - is used for electric power transmission at high voltage. High voltage cables of differing types have a variety of applications in instruments, ignition systems, AC and DC power transmission. In all applications, the insulation of the cable must not deteriorate due to the high voltage stress, ozone produced by electric discharges in air, or tracking. The cable system must prevent contact of the high-voltage conductor with other objects or persons, and must contain and control leakage current. Cable joints and terminals must be designed to control the high-voltage stress to prevent breakdown of the insulation. Often a high-voltage cable will have a metallic shield layer over the insulation, connected to earth ground and designed to equalize the dielectric stress on the insulation layer, and to prevent shock.

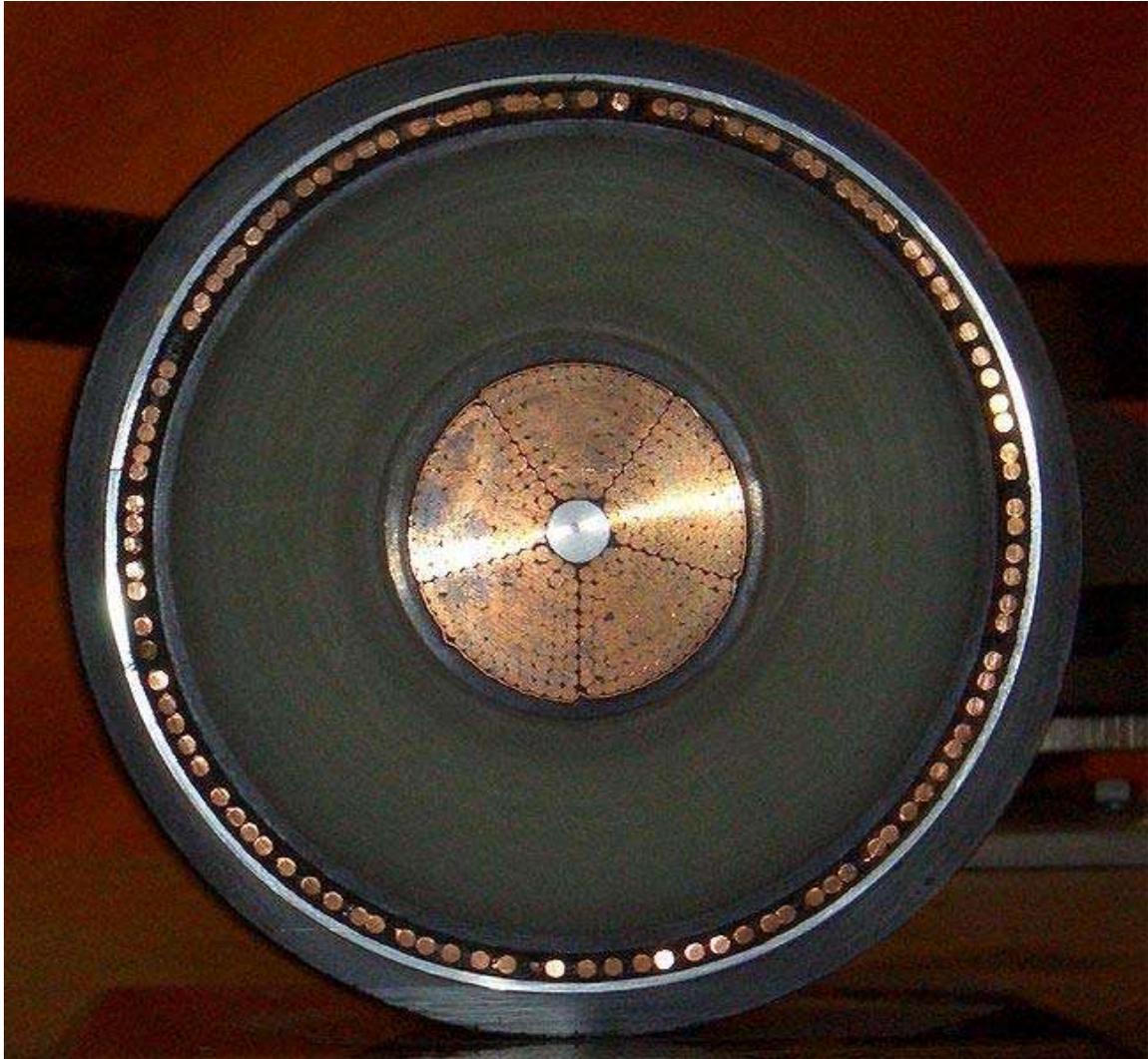


Segments of high-voltage cables

High voltage cables may be any length, with relatively short cables used in apparatus, longer cables run within buildings or as buried cables in an industrial plant or for power

distribution, and the longest cables are often run as submarine cables under the ocean for power transmission.

### ***Construction***



A cross-section through a 400 kV cable, showing the stranded segmented copper conductor in the center, semiconducting and insulating layers, copper shield conductors, aluminum sheath and plastic outer jacket.

Like other power cables, high voltage cables have the structural elements of one or more conductors, insulation, and a protective jacket. High voltage cables differ from lower-voltage cables in that they have additional internal layers in the insulation jacket to control the electric field around the conductor.

For circuits operating at or above 2,000 volts between conductors, a conductive shield may surround each insulated conductor. This equalizes electrical stress on the cable insulation. This technique was patented by Martin Hochstadter in 1916; the shield is

sometimes called a Hochstadter shield. The individual conductor shields of a cable are connected to earth ground at the ends of the shield, and at splices. Stress relief cones are applied at the shield ends.

Cables for power distribution of 10kV or higher may be insulated with oil and paper, and are run in a rigid steel pipe, semi-rigid aluminum or lead sheath. For higher voltages the oil may be kept under pressure to prevent formation of voids that would allow partial discharges within the cable insulation.

Sebastian Ziani de Ferranti was the first to demonstrate in 1887 that carefully dried and prepared paper could form satisfactory cable insulation at 11,000 volts. Previously paper-insulated cable had only been applied for low-voltage telegraph and telephone circuits. An extruded lead sheath over the paper cable was required to ensure that the paper remained absolutely dry.

Vulcanized rubber was patented by Charles Goodyear in 1844, but it was not applied to cable insulation until the 1880s, when it was used for lighting circuits. Rubber-insulated cable was used for 11,000 volt circuits in 1897 installed for the Niagara Falls power project.

Mass-impregnated paper-insulated medium voltage cables were commercially practical by 1895. During World War II several varieties of synthetic rubber and polyethylene insulation were applied to cables. Modern high voltage cables use polymers or polyethylene, including (XLPE) for insulation.

### **AC power cable**

High voltage is defined as any voltage over 1000 volts. Cables for 3000 and 6000 volts exist, but the majority of cables are used from 10 kV and upward. Those of 10 to 33 kV are usually called *medium voltage* cables, those over 50 kV *high voltage* cables.

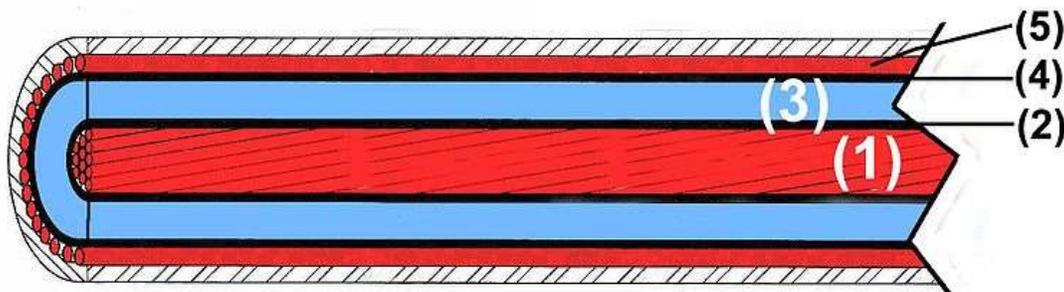


Figure 1, cross section of a high voltage cable, (1) conductor, (3) insulation.

Modern HV cables have a simple design consisting of few parts. A conductor of copper or aluminum wires transports the current, see (1) in figure 1. Conductor sections up to 2000 mm<sup>2</sup> may transport currents up to 2000 amperes. The individual strands are often preshaped to provide a smoother overall circumference. The insulation (3) may consist

of cross-linked polyethylene, also called XLPE. It is reasonably flexible and tolerates operating temperatures up to 120 °C. EPDM is also an insulation.

At the inner (2) and outer (4) sides of this insulation, semi-conducting layers are fused to the insulation. The function of these layers is to prevent air-filled cavities between the metal conductors and the dielectric so that little electric discharges can arise and endanger the insulation material.

The outer conductor or sheath (5) serves as an earthed layer and will conduct leakage currents if needed.

Most high voltage cables for power transmission that are currently sold on the market are insulated by a sheath of cross-linked polyethylene (XLPE). Some cables may have a lead or aluminium jacket in conjunction with XLPE insulation to allow for fiber optics. Before 1960, underground power cables were insulated with oil and paper and ran in a rigid steel pipe, or a semi-rigid aluminium or lead jacket or sheath. The oil was kept under pressure to prevent formation of voids that would allow partial discharges within the cable insulation. There are still many of these oil-and-paper insulated cables in use worldwide. Between 1960 and 1990, polymers became more widely used at distribution voltages, mostly EPDM (ethylene propylene diene M-class); however, their relative unreliability, particularly early XLPE, resulted in a slow uptake at transmission voltages. While cables of 330 kV are commonly constructed using XLPE, this has occurred only in recent decades.

## **Quality**

During the development of the HV insulation, which has taken about half a century, two characteristics proved to be paramount. First, the introduction of the semiconducting layers. These layers must be absolutely smooth, without even protrusions as small as some microns. Further the fusion between the insulation and these layers must be absolute; any fission, air-pocket or other defect - of the same micro-dimensions as above - is detrimental for the breakdown characteristics of the cable.

Secondly, the insulation must be free of inclusions, cavities or other defects of the same sort of size. Any defect of these types shortens the voltage life of the cable which is supposed to be in the order of 30 years or more.

Cooperation between cable-makers and manufacturers of materials has resulted in grades of XLPE with tight specifications about the number and size of foreign particles per pound or per kilogram. Packing the raw material and unloading it within a cleanroom environment in the cable-making machines is required. The development of extruders for plastics extrusion and cross-linking has resulted in cable-making installations for making defect-free and pure insulations.

## ***HVDC cable***

A high voltage cable for HVDC transmission has the same construction as the AC cable shown in figure 1. The physics and the test-requirements are different. In this case the smoothness of the semiconducting layers (2) and (4) is of utmost importance. Cleanliness of the insulation remains imperative.

Many HVDC cables are used for DC submarine connections, because at distances over 30 km AC can no longer be used. The longest submarine cable today is the NorNed cable between Norway and Holland that is almost 600 km long and transports 700 megawatts, a capacity equal to two large power stations.

Most of these long deep-sea cables are made in an older construction, using oil-impregnated paper as an insulator.



## Cable terminals

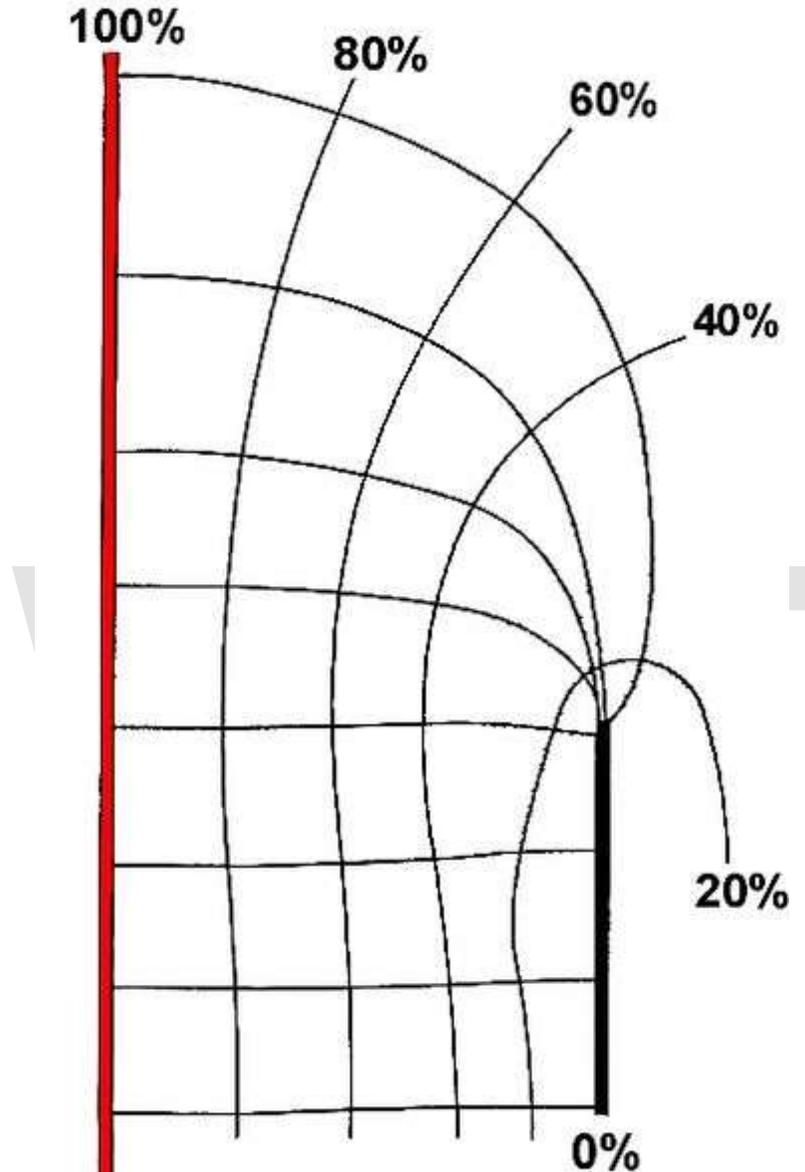


Figure 2, the earth shield of a cable (0%) is cut off, the equipotential lines (from 20% to 80%) concentrate at the edge of the earth electrode, causing danger of breakdown.

Terminals of high voltage cables must manage the electric fields at the ends. Without such a construction the electric field will concentrate at the end of the earth-conductor as shown in figure 2.

Equipotential lines are shown here which can be compared with the contour lines on a map of a mountainous region: the nearer these lines are to each other, the steeper the slope and the greater the danger, in this case the danger of an electric breakdown. The equipotential lines can also be compared with the isobars on a weather map: the denser the lines, the more wind and the greater the danger of damage.

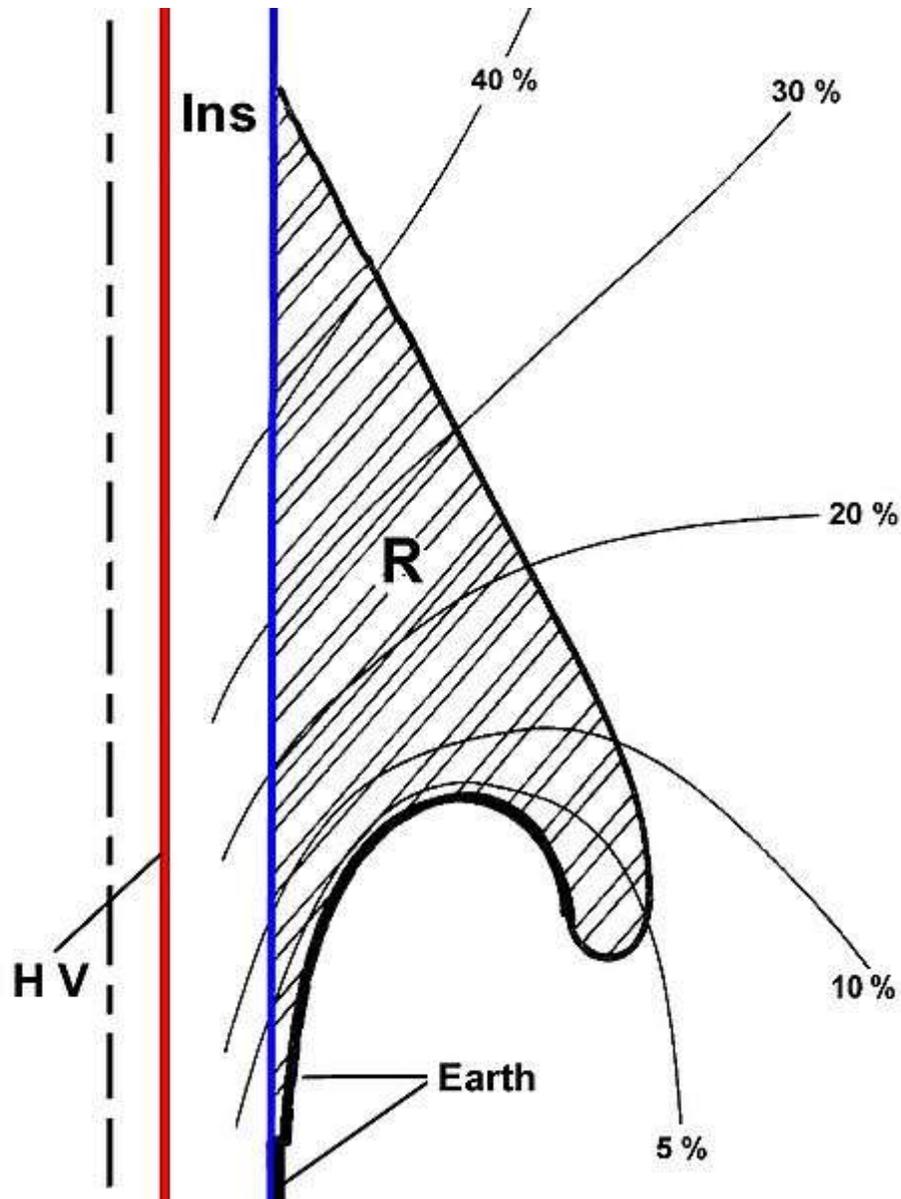


Figure 3, a rubber or elastomer body **R** is pushed over the insulation (blue) of the cable. The equipotential lines between **HV** (high voltage) and **earth** are evenly spread out by the shape of the earth electrode. Field concentrations are prevented in this way.

In order to control the equipotential lines (that is to control the electric field) a device is used that is called a **stress-cone**, see figure 3. The crux of stress relief is to flare the shield end along a logarithmic curve. Before 1960, the stress cones were hand made using tape—after the cable was installed. These were protected by potheads, so named because a potting compound/ dielectric was poured around the tape inside a metal/ porcelain body insulators. About 1960, preformed terminations were developed. Shuch consists of a rubber or elastomer body that is stretched over the cable end. On this rubber-like body **R** an **earth** electrode is applied that spreads the equipotential lines. These lines pass the

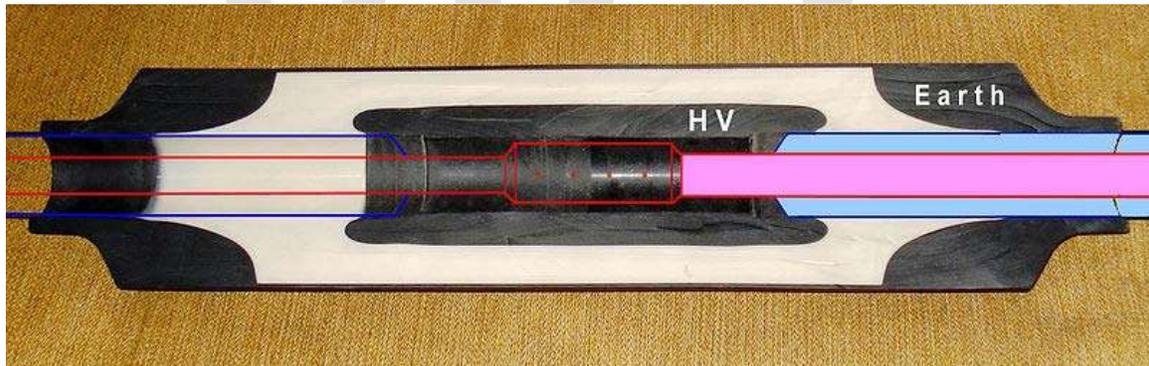
surface of the body after they have sufficiently been spread out to guarantee a low electric field.

The crux of this device, invented by NKF in Delft in 1964, is the fact that the bore of the elastic body R is narrower than the diameter of the cable. In this way the (blue) interface between cable and stress-cone is brought under mechanical pressure so that no cavities or air-pockets can be formed between cable and cone. Electric breakdown in this region is prevented in this way.

This construction can further be surrounded by a porcelain or silicone insulator for outdoor use, or by contraptions to enter the cable into a power transformer under oil, or switchgear under gas-pressure.

### **Cable joints**

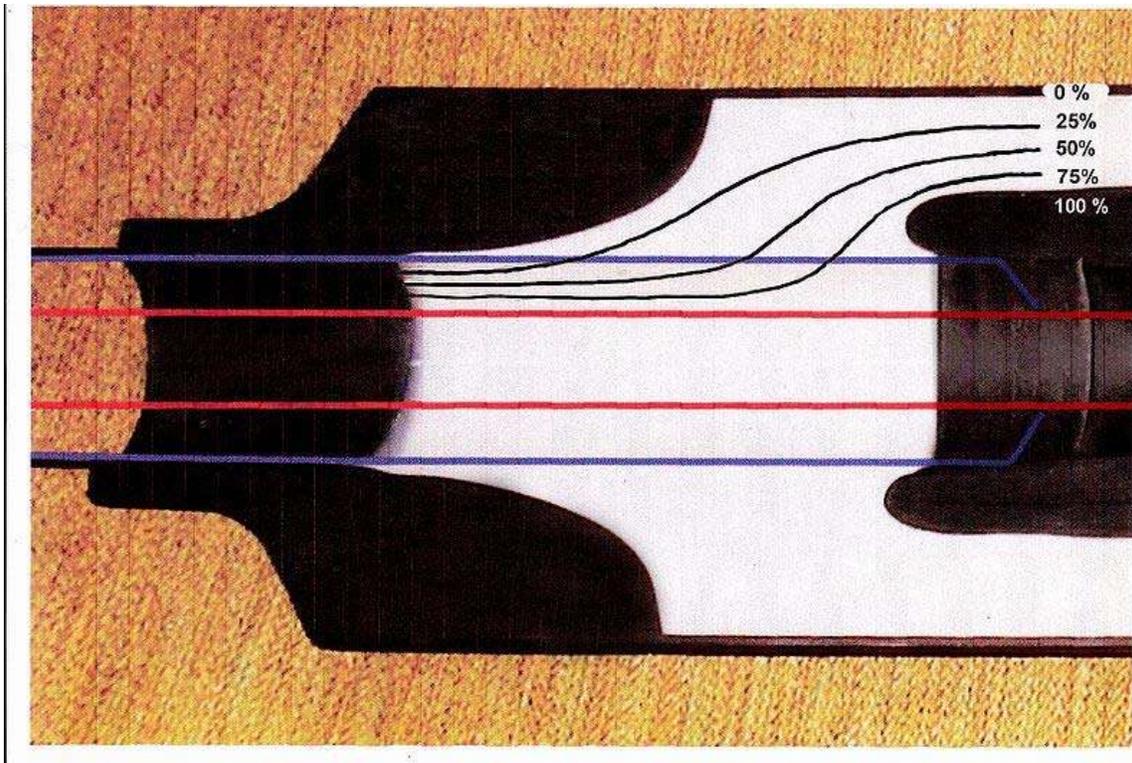
Connecting two high-voltage cables with one another poses two main problems. First, the outer conducting layers in both cables shall be terminated without causing a field concentration, similar as with the making of a cable terminal. Secondly, a field free space shall be created where the cut-down cable insulation and the connector of the two conductors safely can be accommodated. These problems have been solved by NKF in Delft in 1965 by introducing a device called **bi-manchet**.



Photograph of a section of a high-voltage joint, **bi-manchet**, with a high voltage cable mounted at the right hand side of the device.

Figure 4 shows a photograph of the cross-section of such a device. At one side of this photograph the contours of a high voltage cable are drawn. Here **red** represents the conductor of that cable and **blue** the insulation of the cable. The black parts in this picture are semi-conducting rubber parts. The outer one is at earth potential and spreads the electric field in a similar way as in a cable terminal. The inner one is at high-voltage and shields the connector of the conductors from the electric field.

The field itself is diverted as shown in figure 5, where the equipotential lines are smoothly directed from the inside of the cable to the outer part of the bi-manchet (and vice versa at the other side of the device).



Field distribution in a **bi-manchet** or HV joint.

The crux of the matter is here, like in the cable terminal, that the inner bore of this bi-manchet is chosen smaller than the diameter over the cable-insulation. In this way a permanent pressure is created between the bi-manchet and the cable surface and cavities or electrical weak points are avoided.

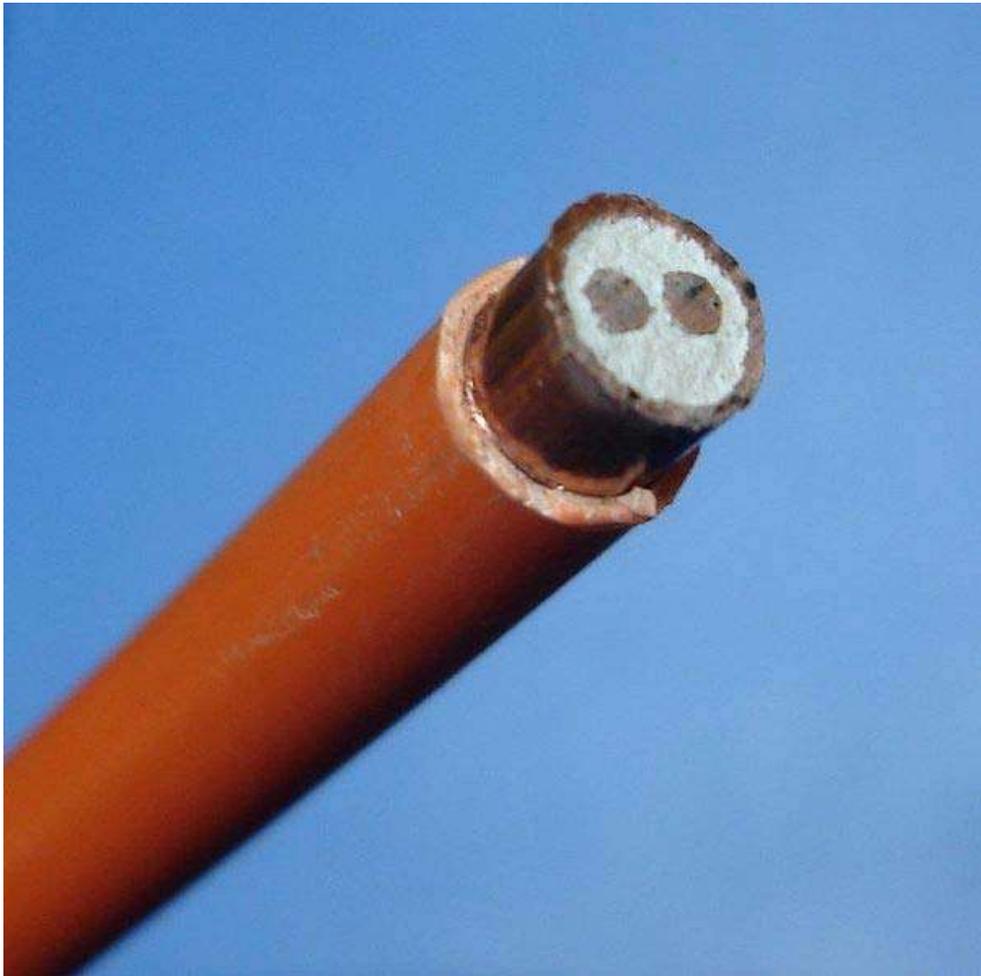
Installing a terminal or bi-manchet is skilled work. Removing the outer semiconducting layer at the end of the cables, placing the field-controlling bodies, connecting the conductors, etc., require skill, cleanness and precision.

### ***X-ray cable***

X-ray cables are used in lengths of some meters to connect the HV source with an X-ray tube or any other HV device in scientific equipment. They transmit small currents, in the order of milliamperes at DC voltages of 30 to 200 kV, or sometimes higher. The cables are flexible, with rubber or other elastomer insulation, stranded conductors, and an outer sheath of braided copper-wire. The construction has the same elements as other HV power cables.

## Chapter 6

# Mineral-Insulated Copper-Clad Cable



PVC-sheathed MICC cable. Conductor cross section area is  $1.5 \text{ mm}^2$ ; overall diameter is 7.2 mm



Mineral insulated cables at a panel board

**Mineral-insulated copper-clad cable** is a variety of electrical cable made from copper conductors inside a copper sheath, insulated by inorganic magnesium oxide powder. The name is often abbreviated to MICC or MI cable, and colloquially known as **pyro** (because the original manufacturer and vendor for this product in the UK is a company called Pyrotenax). A similar product sheathed with metals other than copper is called *mineral insulated metal sheathed* (MIMS) cable.

MI cable is made by placing copper rods inside a circular copper tube and filling the intervening spaces with dry magnesium oxide powder. The overall assembly is then pressed between rollers to reduce its diameter (and increase its length). Up to seven conductors are often found in an MI cable, with up to 19 available from some manufacturers.

Since MI cables use no organic material as insulation (except at the ends), they are more resistant to fires than plastic-insulated cables. MI cables are used in critical fire protection applications such as alarm circuits, fire pumps, and smoke control systems. In process industries handling flammable fluids MI cable is used where small fires would otherwise cause damage to control or power cables. MI cable is also highly resistant to ionising radiation and so finds applications in instrumentation for nuclear reactors and nuclear physics apparatus.

The metal tube surrounding the conductors effectively shields circuits in MI cable from electromagnetic interference. The metal sheath provides protection against accidental contact with energised circuit conductors.

MI cables may be covered with a plastic sheath, coloured for identification purposes. The plastic sheath also provides additional corrosion protection for the copper sheath.

## ***History***

The first patent for MI cable was issued to the Swiss inventor Arnold Francois Borel in 1896. Initially the insulating mineral was described in the patent application as pulverized glass, silicious stones, or asbestos, in powdered form. Much development ensued by the French company Societe Alsacienne de Construction Mechaniques. Commercial production began in 1932 and much mineral-insulated cable was used on ships such as the Normandie and oil tankers, and in such critical applications as the Louvre museum. In 1937 a British company *Pyrotenax*, having purchased patent rights to the product from the French company, began production. During the Second World War much of the company's product was used in military equipment.

About 1947 the British Cable Maker's Association investigated the option of manufacturing a mineral-insulated cable that would compete with the Pyrotenax product. The manufacturers of the products "Bicalmin" and "Glomin" eventually merged with the Pyrotenax company.

The Pyrotenax company introduced an aluminum sheathed version of its product in 1964. MI cable is now manufactured in several countries. Pyrotenax is now a wholly owned subsidiary of Tyco Corporation.

## ***Purpose and use***

MI cables are used for power and control circuits of critical equipment, such as the following examples:

- Nuclear reactors
- Air pressurisation systems for stairwells to enable building egress during a fire
- Hospital operating rooms
- Fire alarm systems
- Emergency power systems
- Emergency lighting systems
- Temperature measurement devices; RTD's and Thermocouples.
- Critical process valves in the petrochemical industry
- Public buildings such as theatres, cinemas, hotels
- Transport hubs (railway stations, airports etc)
- Tunnels and mines
- Electrical equipment in hazardous areas where flammable gases may be present e.g. oil refineries, petrol stations

- Areas where corrosive chemicals may be present e.g. factories
- Building plant rooms
- Hot areas e.g. power stations, foundries, and close to or even inside industrial furnaces, kilns and ovens

MI cable fulfills the passive fire protection called circuit integrity, which is intended to provide operability of critical electrical circuits during a fire. It is subject to strict listing and approval use and compliance

### ***Heating cable***

A similar appearing product is mineral-insulated trace heating cable, in which the conductors are made of a high-resistance alloy. A heating cable is used to protect pipes from freezing, or to maintain temperature of process piping and vessels. An MI resistance heating cable may not be repairable if damaged. Most electric stove and oven heating elements are constructed in a similar manner.

### ***Typical specifications***

maximum voltage	600 or 1000 volts
current rating	18 - 450 amperes
conductor area	1.0 - 240 mm <sup>2</sup>
copper sheath area	5 - 70 mm <sup>2</sup> effective
number of cores	1,2,3,4,7,12,19
overall diameter	5 - 26 mm
minimum bend radius	6 x diameter (3 x diameter if bent once only)
weight	100 - 3300 kg/km
twists per metre	0, 20; In many applications NO twist is preferred.
finish	bare copper, standard PVC sheath, low smoke and fume (LSF) polymer sheath, various Stainless Steels, Inconel, Titanium, and some super alloys.
colour	natural (Bare Stainless),(bare copper), white, black, red, orange

maximum operating temperature	continuous - exposed to touch	70 °C
	continuous - not exposed to touch; PVC- sheathed	90 °C
	continuous - not exposed to touch; not PVC- sheathed	250 °C
	intermittent	>1000 °C
(melting point of copper is 1083 °C)		

## ***Advantages***

The metal sheath and solid filling of MI cable makes it mechanically robust and resistant to impact; an MI cable may be struck repeatedly with a hammer and still provide adequate insulation resistance for a circuit . Copper sheathing is waterproof and resistant to ultraviolet light and many corrosive elements. MI cable is approved by electrical codes for use in areas with hazardous concentrations of flammable gas in air; an MI cable will not allow propagation of an explosion inside the copper tube, and the cable is unlikely to initiate an explosion even during circuit fault conditions. Metal sheathing will not contribute fuel or hazardous combustion products to a fire, and cannot propagate a fire along a cable tray or within a building. The cable is inherently fire-rated without additional coatings, and will survive designated fire tests representative of actual fire conditions longer than the enclosing structure.

When used within a tenanted area, carrying electricity supplied and billed to the landlord, for example for a communal extract system or antenna booster, it provides a supply cable that cannot easily be 'tapped' into to obtain free energy.

Although made from solid copper elements, the finished cable assembly is still pliable due to the malleability of copper. The cable can be bent to follow shapes of buildings or bent around obstacles, allowing for a neat appearance when exposed.

Since the inorganic insulation does not degrade with (moderate) heating, the finished cable assembly can be allowed to rise to higher temperatures than plastic-insulated cables; the limits to temperature rise may be only due to possible contact of the sheath with people or structures. This may also allow a smaller cross-section cable to be used in particular applications.

Due to oxidation, the copper cladding darkens with age and MICC is therefore often used in historic buildings such as castles where it blends in with stonework.

## **Disadvantages**

- *The termination points:* While the length of the MI cable is very tough, at some point, each run of cabling terminates at a splice or within electrical equipment. These terminations are vulnerable to fire, moisture, or mechanical impact.
- *Vibration:* MICC is not suitable for use where it will be subject to vibration or flexing, for example connection to heavy or movable machinery. Vibration will crack the cladding and cores, leading to failure.
- *Labour Cost:* During installation MI cable must not be bent repeatedly as this will cause work hardening and cracks in the cladding and cores. A minimum bend radius must be observed and the cable must be supported at regular intervals. The magnesium oxide insulation is hygroscopic so MICC cable must be protected from moisture until it has been terminated. Termination requires stripping back the copper cladding and attaching a compression gland fitting. Individual conductors are insulated with plastic sleeves. A sealing tape, insulating putty or an epoxy resin is then poured into the compression gland fitting to provide a watertight seal. If a termination is faulty due to workmanship or damage then the magnesium oxide will absorb moisture and lose its insulating properties. Depending on the size and number of conductors, a single termination can take between 1 to 2 hours of labour. Installation of a 3-conductor MI cable (size No. 10 AWG (about 5 square mm)) takes about 65% more time than installation of a PVC-sheathed armored cable of the same conductor size. Installation of MICC is therefore a costly task. Certain PTFE, silicone or other polymer-insulated cables have been substituted in applications which require similar properties in terms of flame spread, which use less labour to terminate. MICC is still used in applications which are particularly suited to its combination of properties.
- *Voltage rating:* MI cable is only manufactured with ratings up to 1000 volts.
- *Moisture absorption:* The magnesium oxide insulation has a high affinity for moisture. Moisture introduced into the cable can cause electrical leakage from the internal conductors to the metal sheath. Moisture absorbed at a cut end of the cable may be driven off by heating the cable.
- *Corrosion:* The copper sheath material is resistant to most chemicals but can be severely damaged by ammonia-bearing compounds and urine. A pinhole in the copper sheathing will allow moisture into the insulation, and eventual failure of the circuit. A PVC over jacket or sheaths of other metals may be required where such chemical damage is expected. When MI cable is embedded in concrete as snow melting cable it is subject to physical damage by concrete workers working the concrete into the pour. If the 3-5mil coating is damaged pin holes in the copper jacket develop causing premature failure of the snow melting system.

- *Repair:* If the MI cable jacket has been damaged the magnesium oxide will wick moisture into the cable and it will lose its insulating properties causing high resistance shorts to the grounding jacket (Copper Jacket). It is often necessary to remove 2' to 10' of the MI Cable and splice in a new section to accomplish the repair. Depending on the size and number of conductors, a single termination can take between 1 to 2 hours of labor.

## **Alternatives**

Circuit integrity for conventional plastic-insulated cables requires additional measures to obtain a fire-resistance rating or to lower the flammability and smoke contributions to a minimum degree acceptable for certain types of construction. Sprayed-on coatings or flexible wraps cover the plastic insulation to protect it from flame and reduce its flame spreading ability. However, since these coatings reduce the heat dissipation of the cables, often they must be rated for less current after application of fire-resistant coatings. This is called ampacity derating. It can be tested through the use of IEEE 848 Standard Procedure for the Determination of the Ampacity Derating of Fire-Protected Cables. The following materials have been used on their own and/or in combination with one another for fireproofing electrical circuits:

- Calcium silicate
- Vermiculite boards
- Ceramic fibre boards and blankets
- Rockwool boards and blankets
- Intumescent coatings and boards
- Endothermic coatings and boards

So far as building code and fire code compliance are concerned, what matters is Listing and approval use and compliance in order to be able to demonstrate empirically, that the field-installed configuration is capable of achieving a fire-resistance rating. Whether one uses MI Cable or ordinary cables that have been externally fireproofed is a matter of choice, which is largely dictated by economics.

## Chapter 7

# Overhead Power Line



Transmission lines in Lund, Sweden



Overhead lines in Japan



High and medium voltage power lines in Łomża, Poland

An **overhead power line** is an electric power transmission line suspended by towers or utility poles. Since most of the insulation is provided by air, overhead power lines are generally the lowest-cost method of transmission for large quantities of electric energy. Towers for support of the lines are made of wood (as-grown or laminated), steel (either lattice structures or tubular poles), concrete, aluminium, and occasionally reinforced plastics. The bare wire conductors on the line are generally made of aluminium (either plain or reinforced with steel or sometimes composite materials), though some copper wires are used in medium-voltage distribution and low-voltage connections to customer premises. A major goal of overhead power line design is to maintain adequate clearance between energized conductors and the ground so as to prevent dangerous contact with the line.

The invention of the strain insulator was a critical factor in allowing higher voltages to be used. At the end of the 19th century, the limited electrical strength of telegraph-style pin insulators limited the voltage to no more than 69,000 volts. Today overhead lines are routinely operated at voltages exceeding 765,000 volts between conductors, with even higher voltages possible in some cases.

Overhead power transmission lines are classified in the electrical power industry by the range of voltages:

- Low voltage – less than 1000 volts, used for connection between a residential or small commercial customer and the utility.
- Medium Voltage (Distribution) – between 1000 volts (1 kV) and to about 33 kV, used for distribution in urban and rural areas.
- High Voltage (subtransmission less than 100 kV; subtransmission or transmission at voltage such as 115 kV and 138 kV), used for sub-transmission and transmission of bulk quantities of electric power and connection to very large consumers.
- Extra High Voltage (transmission) – over 230 kV, up to about 800 kV, used for long distance, very high power transmission.
- Ultra High Voltage – higher than 800 kV.

## **Structures**

Structures for overhead lines take a variety of shapes depending on the type of line. Structures may be as simple as wood poles directly set in the earth, carrying one or more cross-arm beams to support conductors, or "armless" construction with conductors supported on insulators attached to the side of the pole. Tubular steel poles are typically used in urban areas. High-voltage lines are often carried on lattice-type steel towers or pylons. For remote areas, aluminium towers may be placed by helicopters. Concrete poles have also been used. Poles made of reinforced plastics are also available, but their high cost restricts application.

Each structure must be designed for the loads imposed on it by the conductors. A large transmission line project may have several types of towers, with "tangent" ("suspension" or "line" towers, UK) towers intended for most positions and more heavily constructed towers used for turning the line through an angle, dead-ending (terminating) a line, or for important river or road crossings. Depending on the design criteria for a particular line, semi-flexible type structures may rely on the weight of the conductors to be balanced on both sides of each tower. More rigid structures may be intended to remain standing even if one or more conductors is broken. Such structures may be installed at intervals in power lines to limit the scale of cascading tower failures.

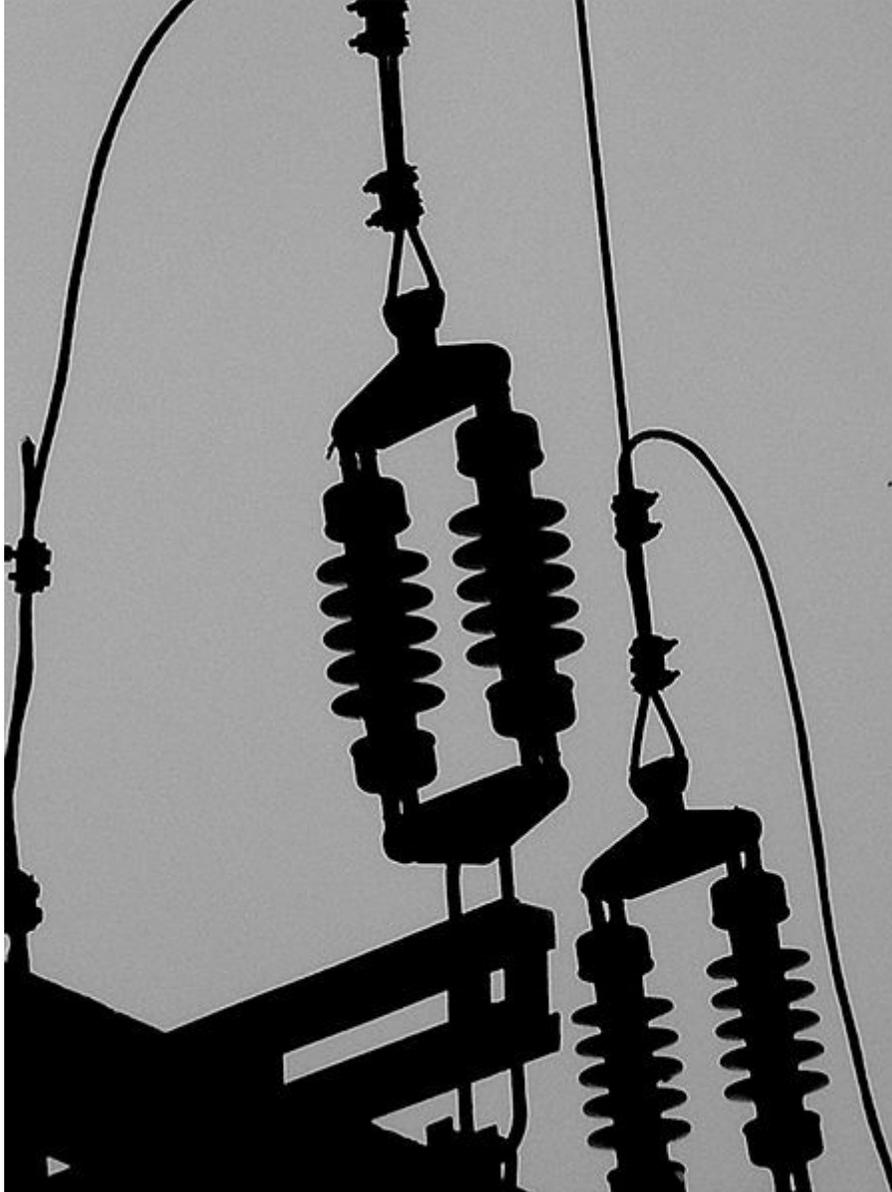
Foundations for tower structures may be large and costly, particularly if the ground conditions are poor, such as in wetlands. Each structure may be stabilized considerably by the use of guy wires to counteract some of the forces applied by the conductors.

Power lines and supporting structures can be a form of visual pollution. In some cases the lines are buried to avoid this, but this "undergrounding" is more expensive and therefore not common.

For a single wood utility pole structure, a pole is placed in the ground, then three crossarms extend from this, either staggered or all to one side. The insulators are attached to the crossarms. For an "H"-type wood pole structure, two poles are placed in the ground, then a crossbar is placed on top of these, extending to both sides. The insulators are attached at the ends and in the middle. Lattice tower structures have two common forms. One has a pyramidal base, then a vertical section, where three crossarms extend out, typically staggered. The strain insulators are attached to the crossarms. Another has a pyramidal base, which extends to four support points. On top of this a horizontal truss-like structure is placed. The insulators are attached to this.

## ***Insulators***

Insulators must support the conductors and withstand both the normal operating voltage and surges due to switching and lightning. Insulators are broadly classified as either pin-type, which support the conductor above the structure, or suspension type, where the conductor hangs below the structure. Up to about 33 kV (69 kV in North America) both types are commonly used. At higher voltages only suspension-type insulators are common for overhead conductors. Insulators are usually made of wet-process porcelain or toughened glass, with increasing use of glass-reinforced polymer insulators. However, with rising voltage levels and changing climatic conditions, polymer insulators (silicone rubber based) are seeing increasing usage. China has already developed polymer insulators having a highest system voltage of 1100kV and India is currently developing a 1200kV (highest system voltage) line which will initially be charged with 400kV to be upgraded to a 1200kV line.



Ceramic insulators

Suspension insulators are made of multiple units, with the number of unit insulator disks increasing at higher voltages. The number of disks is chosen based on line voltage, lightning withstand requirement, altitude, and environmental factors such as fog, pollution, or salt spray. Longer insulators, with longer creepage distance for leakage current, are required in these cases. Strain insulators must be strong enough mechanically to support the full weight of the span of conductor, as well as loads due to ice accumulation, and wind.

Porcelain insulators may have a semi-conductive glaze finish, so that a small current (a few milliamperes) passes through the insulator. This warms the surface slightly and

reduces the effect of fog and dirt accumulation. The semiconducting glaze also ensures a more even distribution of voltage along the length of the chain of insulator units.

Polymer insulators by nature have hydrophobic characteristics providing for improved wet performance. Also, studies have shown that the specific creepage distance required in polymer insulators is much lower than that required in porcelain or glass. Additionally, the mass of polymer insulators (especially in higher voltages) is approximately 50% to 30% less than that of a comparative porcelain or glass string. Better pollution and wet performance is leading to the increased use of such insulators.

Insulators for very high voltages, exceeding 200 kV, may have grading rings installed at their terminals. This improves the electric field distribution around the insulator and makes it more resistant to flash-over during voltage surges.

## **Conductors**

Aluminium conductors reinforced with steel (known as ACSR) are primarily used for medium and high voltage lines and may also be used for overhead services to individual customers. Aluminium conductors are used as it has the advantage of better resistivity/weight than copper, as well as being cheaper. Some copper cable is still used, especially at lower voltages and for grounding.

While larger conductors may lose less energy due to lower electrical resistance, they are more costly than smaller conductors. An optimization rule called *Kelvin's Law* states that the optimum size of conductor for a line is found when the cost of the energy wasted in the conductor is equal to the annual interest paid on that portion of the line construction cost due to the size of the conductors. The optimization problem is made more complex due to additional factors such as varying annual load, varying cost of installation, and by the fact that only definite discrete sizes of cable are commonly made.

Since a conductor is a flexible object with uniform weight per unit length, the geometric shape of a conductor strung on towers approximates that of a catenary. The sag of the conductor (vertical distance between the highest and lowest point of the curve) varies depending on the temperature. A minimum overhead clearance must be maintained for safety. Since the temperature of the conductor increases with increasing heat produced by the current through it, it is sometimes possible to increase the power handling capacity (uprate) by changing the conductors for a type with a lower coefficient of thermal expansion or a higher allowable operating temperature.

## **Bundle conductors**

Bundle conductors are used to reduce corona losses and audible noise. Bundle conductors consist of several conductor cables connected by non-conducting spacers. For 220 kV lines, two-conductor bundles are usually used, for 380 kV lines usually three or even four. American Electric Power is building 765 kV lines using six conductors per phase in

a bundle. Spacers must resist the forces due to wind, and magnetic forces during a short-circuit.

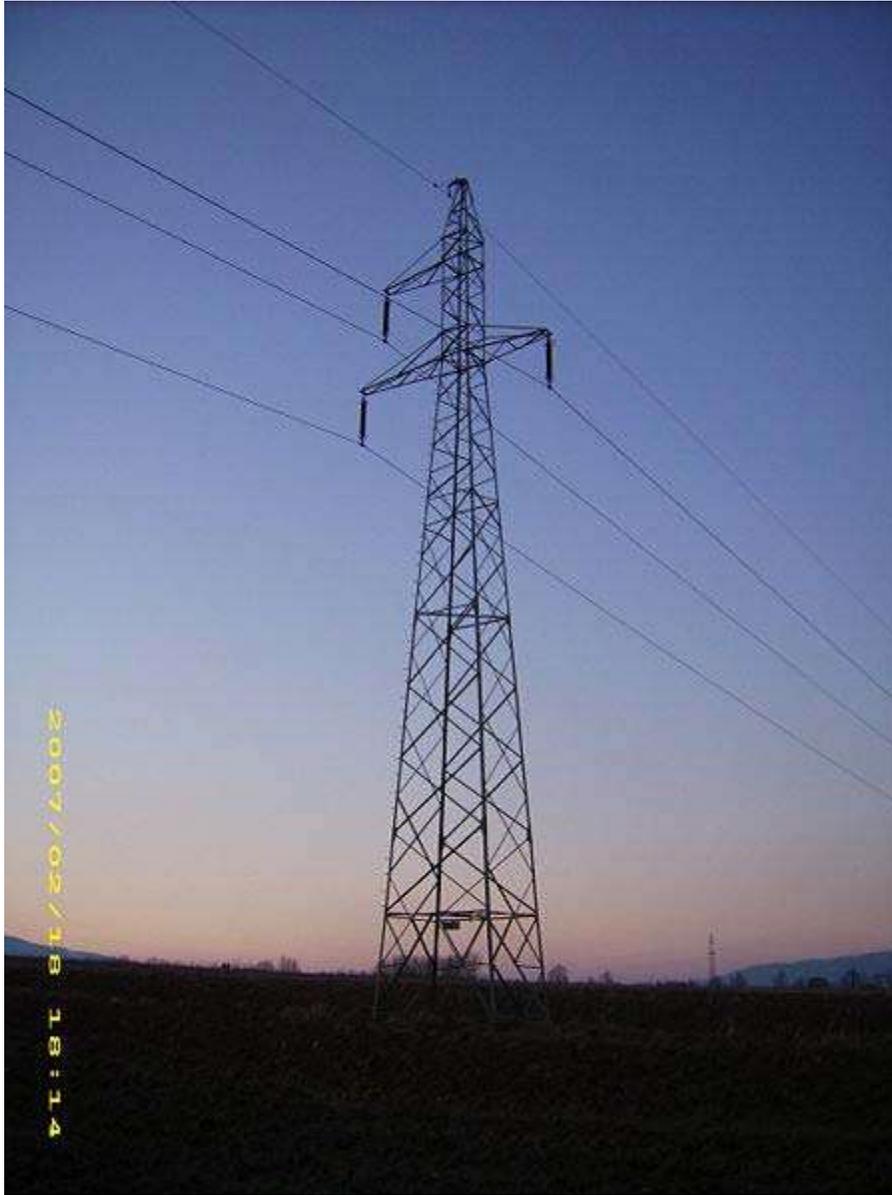
Bundle conductors are used to increase the amount of current that may be carried in a line. Due to the skin effect, ampacity of conductors is not proportional to cross section, for the larger sizes. Therefore, bundle conductors may carry more current for a given weight.

A bundle conductor results in lower reactance, compared to a single conductor. It reduces corona discharge loss at EHV (extra high voltage) and interference with communication systems. It also reduces voltage gradient in that range of voltage.

As a disadvantage, the bundle conductors have higher wind loading.

A large, light gray watermark logo consisting of the letters 'WWT' in a bold, sans-serif font. The 'W' is formed by two overlapping 'V' shapes, and the 'T' is a simple vertical bar with a horizontal top bar.

## Circuits



Single 3-phase circuit carried by electricity pylon, with ground wire

*A single-circuit transmission line* carries conductors for only one circuit. For a three-phase system, this implies that each tower supports three conductors.



Typical double-circuit line

A *double-circuit transmission line* has two circuits. For three-phase systems, each tower supports and insulates six conductors. Single phase AC-powerlines as used for traction current have four conductors for two circuits. Usually both circuits operate at the same voltage.

In HVDC systems typically two conductors are carried per line, but rarely only one pole of the system is carried on a set of towers.

In some countries like Germany most powerlines with voltages above 100 kV are implemented as double, quadruple or in rare cases even hexuple powerline as rights of way are rare. Sometimes all conductors are installed with the erection of the pylons; often

some circuits are installed later. A disadvantage of double circuit transmission lines is that maintenance works can be more difficult, as either work in close proximity of high voltage or switch-off of 2 circuits is required. In case of failure, both systems can be affected.

The largest double-circuit transmission line is the Kita-Iwaki Powerline.

## **Ground wires**

Overhead power lines are often equipped with a ground conductor (shield wire or overhead earth wire). A ground conductor is a conductor that is usually grounded (earthed) at the top of the supporting structure to minimise the likelihood of direct lightning strikes to the phase conductors. The ground wire is also a parallel path with the earth for fault currents in earthed neutral circuits. Very high-voltage transmission lines may have two ground conductors. These are either at the outermost ends of the highest cross beam, at two V-shaped mast points, or at a separate cross arm. Older lines may use surge arrestors every few spans in place of a shield wire; this configuration is typically found in the more rural areas of the United States. By protecting the line from lightning, the design of apparatus in substations is simplified due to lower stress on insulation. Shield wires on transmission lines may include optical fibers (OPGW), used for communication and control of the power system.

Medium-voltage distribution lines may have the grounded conductor strung below the phase conductors to provide some measure of protection against tall vehicles or equipment touching the energized line, as well as to provide a neutral line in Wye wired systems.

## **Insulated conductors**

While overhead lines are usually bare conductors, rarely overhead insulated cables are used, usually for short distances (less than a kilometer). Insulated cables can be directly fastened to structures without insulating supports. An overhead line with bare conductors insulated by air is typically less costly than a cable with insulated conductors.

A more common approach is "covered" line wire. It is treated as bare cable, but often is safer for wildlife, as the insulation on the cables increases the likelihood of a large wing-span raptor to survive a brush with the lines, and reduces the overall danger of the lines slightly. These types of lines are often seen in the eastern United States and in heavily wooded areas, where tree-line contact is likely. The only pitfall is cost, as insulated wire is often costlier than its bare counterpart. Many utility companies implement covered line wire as jumper material where the wires are often closer to each other on the pole, such as an underground riser/Pothead, and on reclosers, cutouts and the like.

## ***Low voltage***



Aerial bundled cable in Old Coulsdon, Surrey

Low voltage overhead lines may use either bare conductors carried on glass or ceramic insulators or an aerial bundled cable system. The number of conductors may be anywhere between four (three phase plus a combined earth/neutral conductor - a TN-C earthing system) up to as many as six (three phase conductors, separate neutral and earth plus street lighting supplied by a common switch).

## ***Train power***

Overhead lines or overhead wires are used to transmit electrical energy to trams, trolleybuses or trains. Overhead line is designed on the principle of one or more overhead wires situated over rail tracks. Feeder stations at regular intervals along the overhead line supply power from the high voltage grid. For some cases low-frequency AC is used, and distributed by a special traction current network.

## ***Further applications***

Overhead lines are also occasionally used to supply transmitting antennas, especially for efficient transmission of long, medium and short waves. For this purpose a staggered array line is often used. Along a staggered array line the conductor cables for the supply of the earth net of the transmitting antenna are attached on the exterior of a ring, while the conductor inside the ring, is fastened to insulators leading to the high voltage standing feeder of the antenna.

## ***Usage of area under overhead power lines***

Use of the area below an overhead line is restricted because objects must not come too close to the energized conductors. Overhead lines and structures may shed ice, creating a hazard. Radio reception can be impaired under a power line, due both to shielding of a receiver antenna by the overhead conductors, and by partial discharge at insulators and sharp points of the conductors which creates radio noise.

In the area surrounding overhead lines it is dangerous to risk interference; e.g. flying kites or balloons, using ladders or operating machinery.

Overhead distribution and transmission lines near airfields are often marked on maps, and the lines themselves marked with conspicuous plastic reflectors, to warn pilots of the presence of conductors.

Construction of overhead power lines, especially in wilderness areas, may have significant environmental effects. Environmental studies for such projects may consider the effect of brush clearing, changed migration routes for migratory animals, possible access by predators and humans along transmission corridors, disturbances of fish habitat at stream crossings, and other effects.

## ***History***

The first transmission of electrical impulses over an extended distance was demonstrated on July 14, 1729 by the physicist Stephen Gray, in order to show that one can transfer electricity by that method. The demonstration used damp hemp cords suspended by silk threads (the low resistance of metallic conductors not being appreciated at the time).

However the first practical use of overhead lines was in the context of telegraphy. By 1837 experimental commercial telegraph systems ran as far as 13 miles (20 km). Electric power transmission was accomplished in 1882 with the first high voltage transmission between Munich and Miesbach. 1891 saw the construction of the first three-phase alternating current overhead line on the occasion of the International Electricity Exhibition in Frankfurt, between Lauffen and Frankfurt.

In 1912 the first 110 kV-overhead power line entered service followed by the first 220 kV-overhead power line in 1923. In the 1920s RWE AG built the first overhead line for this voltage and in 1926 built a Rhine crossing with the pylons of Voerde, two masts 138 meters high.

In Germany in 1957 the first 380 kV overhead power line was commissioned (between the transformer station and Rommerskirchen). In the same year the overhead line traversing of the Strait of Messina went into service in Italy, whose pylons served the Elbe crossing 1. This was used as the model for the building of the Elbe crossing 2 in the second half of the 1970s which saw the construction of the highest overhead line pylons of the world. Starting from 1967 in Russia, and also in the USA and Canada, overhead lines for voltage of 765 kV were built. In 1982 overhead power lines were built in Russia between Elektrostal and the power station at Ekibastuz, this was a three-phase alternating current line at 1150 kV (Powerline Ekibastuz-Kokshetau). In 1999, in Japan the first powerline designed for 1000 kV with 2 circuits were built, the Kita-Iwaki Powerline. In 2003 the building of the highest overhead line commenced in China, the Yangtze River Crossing.

### ***Similar constructions***

- Aerial cable
- Antenna (Some antennas for lower frequencies are similar to overhead power lines)
- Electric fence
- Overhead cable
- Overhead line
- Radio masts and towers
- Third rail

## Chapter 8

# Electrical Wiring

**Electrical wiring** in general refers to insulated conductors used to carry electricity, and associated devices. Here we, describes general aspects of electrical wiring as used to provide power in buildings and structures, commonly referred to as **building wiring**.

### ***Wiring safety codes***

Wiring safety codes are intended to protect people and buildings from electrical shock and fire hazards. Regulations may be established by city, county, provincial/state or national legislation, sometimes by adopting in amended form a model code produced by a technical standards-setting organization, or by a national standard electrical code.

Electrical codes arose in the 1880s with the commercial introduction of electrical power. Many conflicting standards existed for the selection of wire sizes and other design rules for electrical installations.

The first electrical codes in the United States originated in New York in 1881 to regulate installations of electric lighting. Since 1897 the U.S. National Fire Protection Association, a private nonprofit association formed by insurance companies, has published the National Electrical Code (NEC). States, counties or cities often include the NEC in their local building codes by reference along with local differences. The NEC is modified every three years. It is a consensus code considering suggestions from interested parties. The proposals are studied by committees of engineers, tradesmen, manufacturer representatives, fire fighters, and other invitees.

Since 1927, the Canadian Standards Association (CSA) has produced the Canadian *Safety Standard for Electrical Installations*, which is the basis for provincial electrical codes. The CSA also produces the Canadian Electrical Code, the 2006 edition of which references IEC 60364 (*Electrical Installations for Buildings*) and states that the code addresses the fundamental principles of electrical protection in Section 131. The Canadian code reprints Chapter 13 of IEC 60364, and it is interesting to note that there are no numerical criteria listed in that chapter whereby the adequacy of any electrical installation can be assessed.

Although the U.S. and Canadian national standards deal with the same physical phenomena and broadly similar objectives, they differ occasionally in technical detail. As part of the North American Free Trade Agreement (NAFTA) program, U.S. and Canadian standards are slowly converging toward each other, in a process known as harmonization.

In European countries, an attempt has been made to harmonize national wiring standards in an IEC standard, IEC 60364 *Electrical Installations for Buildings*. Hence national standards follow an identical system of sections and chapters. However, this standard is not written in such language that it can readily be adapted as a national wiring code. Neither is it designed for field use by electrical tradesmen and inspectors for testing compliance with national wiring standards. National codes, such as the NEC or CSA C22.1, exemplify the common objectives of IEC 60364, and provide rules in a form that allows for guidance of those installing and inspecting electrical systems.

*DKE* - the German Commission for Electrical, Electronic and Information Technologies of DIN and VDE - is the German organisation responsible for the promulgation of electrical standards and safety specifications. DIN VDE 0100 is the German wiring regulations document harmonised with IEC 60364.

In the United Kingdom wiring installations are regulated by the Institution of Engineering and Technology *Requirements for Electrical Installations: IEE Wiring Regulations, BS 7671: 2008*, which are harmonised with IEC 60364. The previous edition (16th) was replaced by the current 17th Edition in January 2008. The 17th edition includes new sections for microgeneration and solar photovoltaic systems. The first edition was published in 1882.

AS/NZS 3000 is an Australian/New Zealand standard, commonly known as the "wiring rules," that specifies the requirements for the selection and installation of electrical equipment and the design and testing of such installations. The standard is a mandatory standard in both New Zealand and Australia; therefore, all electrical work covered by the standard must comply.

The international standard wire sizes are given in the IEC 60228 standard of the International Electrotechnical Commission. In North America, the American Wire Gauge is used.

### ***Colour code***

To enable wires to be easily and safely identified, all common wiring safety codes mandate a colour scheme for the insulation on power conductors. Many local rules and exceptions exist. Older installations vary in colour codes, and colours may shift with heat and age of insulation.

**Standard wire colours for FLEXIBLE cable  
(e.g. Extension cords, power (line) cords and lamp cords)**

Region or Country	Phases	Neutral	Protective earth/ground
European Union (EU), Australia, South Africa (IEC 60446)	brown	blue	green/yellow
Australia, New Zealand (AS/NZS 3000:2007 3.8.1)	brown	light blue	green/yellow
United States, Canada	black ( <i>brass</i> )	white ( <i>silver</i> )	green ( <i>green</i> )

**Standard wire colours for FIXED cable  
(e.g. In-, On-, or Behind-the-wall wiring cables)**

Region or Country	Phases	Neutral	Protective earth/ground
European Union (EU) (IEC 60446) including UK from 31 March 2004	brown, black, grey	blue	green/yellow
UK prior to 31 March 2004	red, yellow, blue	black	green/yellow green (formerly) bare conductor, sleeved at terminations (formerly)
Australia	red	black	green/yellow (since about 1980) green (since about 1980) bare conductor, sleeved at terminations (formerly)
South Africa	red	black	green/yellow bare conductor, sleeved at

terminations

United States	black, red, blue (120/208/240V) <i>(brass)</i> brown, orange, yellow (277/480V)	white (120/208/240V) <i>(silver)</i> grey(277/480V)	green <i>(green)</i> bare conductor green/yellow (isolated ground)
Canada	red, black (120/208/240V) red, black, blue (600/347V)	white (120/208/240V) white (600/347V)	green <i>(green)</i> bare conductor green (isolated ground)

Notes:

Parenthesized colours in *italics* are used on metallic terminals.

"Green/yellow" means green with yellow stripe.

The colours in this table represent the most common and preferred standard colours for wiring; however others may be in use, especially in older installations.

The Canadian and American wiring standards are very similar with small differences, and have different operating voltages in ICI applications.

## ***Wiring methods***



Installing electrical wiring by cutting into the bricks of the building

Materials for wiring interior electrical systems in buildings vary depending on:

- Intended use and amount of power demand on the circuit
- Type of occupancy and size of the building
- National and local regulations
- Environment in which the wiring must operate.

Wiring systems in a single family home or duplex, for example, are simple, with relatively low power requirements, infrequent changes to the building structure and

layout, usually with dry, moderate temperature, and noncorrosive environmental conditions. In a light commercial environment, more frequent wiring changes can be expected, large apparatus may be installed, and special conditions of heat or moisture may apply. Heavy industries have more demanding wiring requirements, such as very large currents and higher voltages, frequent changes of equipment layout, corrosive, or wet or explosive atmospheres. In facilities that handle flammable gases or liquids, special rules may govern the installation and wiring of electrical equipment in hazardous areas.

Wires and cables are rated by the circuit voltage, temperature rating, and environmental conditions (moisture, sunlight, oil, chemicals) in which they can be used. A wire or cable has a voltage (to neutral) rating, and a maximum conductor surface temperature rating. The amount of current a cable or wire can safely carry depends on the installation conditions.

### **Early wiring methods**

The very first interior power wiring systems used conductors that were bare or covered with cloth, which were secured by staples to the framing of the building or on running boards. Where conductors went through walls, they were protected with cloth tape. Splices were done similarly to telegraph connections, and soldered for security. Underground conductors were insulated with wrappings of cloth tape soaked in pitch, and laid in wooden troughs which were then buried. Such wiring systems were unsatisfactory because of the danger of electrocution and fire and the high labour cost for such installations.

## Knob and tube



Knob-and-Tube wiring

The earliest standardized method of wiring in buildings, in common use in North America from about 1880 to the 1930s, was *knob and tube* (K&T) wiring: single conductors were run through cavities between the structural members in walls and ceilings, with ceramic tubes forming protective channels through joists and ceramic knobs attached to the structural members to provide air between the wire and the lumber and to support the wires. Since air was free to circulate over the wires, smaller conductors could be used than required in cables. By arranging wires on opposite sides of building structural members, some protection was afforded against short-circuits that can be caused by driving a nail into both conductors simultaneously. By the 1940s, the labour cost of installing two conductors rather than one cable resulted in a decline in new knob-and-tube installations.

## Metal-sheathed wires

In the United Kingdom, an early form of insulated cable, introduced in 1896, consisted of two impregnated-paper-insulated conductors in an overall lead sheath. Joints were soldered, and special fittings were used for lamp holders and switches. These cables were similar to underground telegraph and telephone cables of the time. Paper-insulated cables

proved unsuitable for interior wiring installations because very careful workmanship was required on the lead sheaths to ensure moisture did not affect the insulation.

A system later invented in the UK in 1908 employed vulcanized-rubber insulated wire enclosed in a strip metal sheath. The metal sheath was bonded to each metal wiring device to ensure continuity.

A system developed in Germany called *Kuhlo wire* used one, two, or three rubber-insulated wires in a brass or lead-coated iron sheet tube, with a crimped seam. The enclosure could also be used as a return conductor. Kuhlo wire could be run exposed on surfaces and painted, or embedded in plaster. Special outlet and junction boxes were made for lamps and switches, made either of porcelain or sheet steel. The crimped seam was not considered as watertight as the *Stannos* wire used in England, which had a soldered sheath.

A somewhat similar system called "concentric wiring" was introduced in the United States around 1905. In this system, an insulated copper wire was wrapped with copper tape which was then soldered, forming the grounded (return) conductor of the wiring system. The bare metal sheath, at earth potential, was considered safe to touch. While companies such as General Electric manufactured fittings for the system, and a few buildings were wired with it, it was never adopted into the US National Electrical Code. Drawbacks of the system were that special fittings were required, and that any defect in the connection of the sheath would result in the sheath becoming energized.

## **Other historical wiring methods**

Other methods of securing wiring that are now obsolete include:

- Re-use of existing gas pipes for electric lighting. Insulated conductors were pulled into the pipes feeding gas lamps.
- Wood mouldings with grooves cut for single conductor wires, covered by a wooden cap strip. These were prohibited in North American electrical codes by 1928. Wooden moulding was also used to some degree in England, but was never permitted by German and Austrian rules.
- A system of flexible twin cords supported by glass or porcelain buttons was used near the turn of the 20th century in Europe, but was soon replaced by other methods.
- During the first years of the 20th century various patented forms of wiring system such as Bergman and Peschel tubing were used to protect wiring; these used very thin fibre tubes or metal tubes which were also used as return conductors.
- In Austria, wires were concealed by embedding a rubber tube in a groove in the wall, plastering over it and then removing the tube and pulling in wires in the cavity.

Metal moulding systems, with a flattened oval section consisting of a base strip and a snap-on cap channel, were more costly than open wiring or wooden moulding, but could be easily run on wall surfaces. Similar systems are still available today.

## **Cables**



Wiring in extremely-wet conditions

Armoured cables with two rubber-insulated conductors in a flexible metal sheath were used as early as 1906, and were considered at the time a better method than open knob-and-tube wiring, although much more expensive.

The first polymer-insulated cables for building wiring were introduced in 1922. These were two or more solid copper wires, with rubber insulation, woven cotton cloth over each conductor for protection of the insulation, with an overall woven jacket, usually impregnated with tar as a protection from moisture. Waxed paper was used as a filler and separator.

Rubber-insulated cables become brittle over time because of exposure to oxygen, so they must be handled with care, and should be replaced during renovations. When switches, outlets or light fixtures are replaced, the mere act of tightening connections may cause insulation to flake off the conductors. Rubber was hard to separate from bare copper, so copper was tinned, causing slightly more resistance.



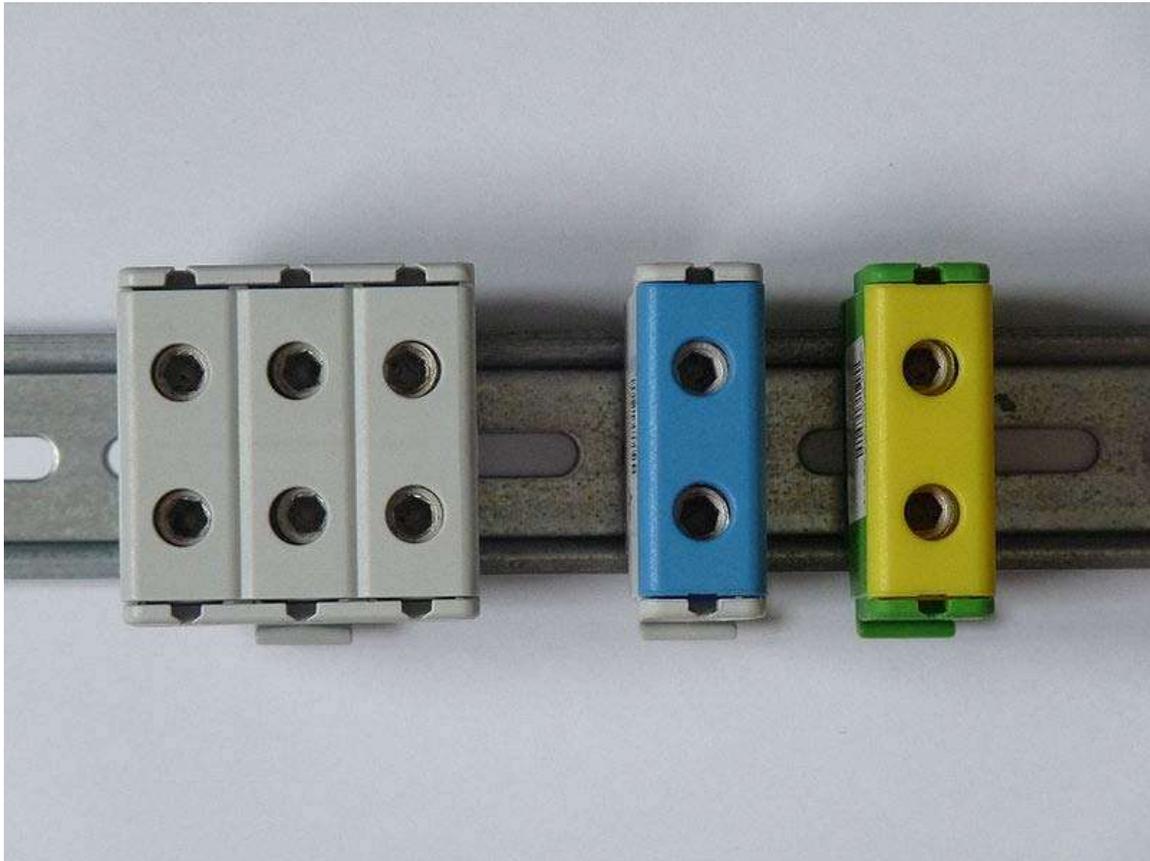
Three-phase copper cable TN-S 16mm<sup>2</sup> (5AWG) with PVC insulation

About 1950, PVC insulation and jackets were introduced, especially for residential wiring. About the same time, single conductors with a thinner PVC insulation and a thin nylon jacket became common.

The simplest form of cable has two insulated conductors twisted together to form a unit; such unjacketed cables with two or three conductors are used for low-voltage signal and control applications such as doorbell wiring. In North American practice, an overhead cable from a transformer on a power pole to a residential electrical service consists of three twisted (triplexed) wires, often with one being a bare copper wire (protective earth/ground) and the other two being insulated for the line voltage (hot/live wire and neutral wire).

## Aluminium conductors

Aluminium wire was common in North American residential wiring from the late 1960s to mid 1970s due to the rising cost of copper. Because of its greater resistivity, aluminium wiring requires larger conductors than copper. For instance, instead of 14 AWG (American wire gauge) for most lighting circuits, aluminium wiring would be 12 AWG on a typical 15 ampere circuit, though local building codes may vary.



Terminal blocks for joining aluminium and copper conductors. The terminal blocks may be mounted on a DIN rail.

Aluminium conductors were originally used with wiring devices intended for copper wires. This can cause defective connections unless the aluminium was one of a special alloy, or all devices — breakers, switches, receptacles, splice connectors, i.e., wire nuts, etc. — were designed to address problems with junctions between dissimilar metals, oxidation on metal surfaces and mechanical effects that occur as different metals expand at different rates with increases in temperature. Unlike copper, aluminium has a tendency to cold-flow under pressure, so screw clamped connections may get loose over time. This can be mitigated by using spring-loaded connectors that apply constant pressure, applying high pressure cold joints in splices and termination fittings, and torquing the bolted connection. Unlike copper, aluminium forms an insulating oxide layer on the surface. This is sometimes addressed by coating aluminium wires with an antioxidant paste at

joints, or applying a mechanical termination designed to break through the oxide layer during installation.

Because of improper design and installation, some junctions to wiring devices overheated under heavy current load and caused fires. Revised standards for wiring devices (such as the CO/ALR "copper-aluminium-revised" designation) were developed to reduce these problems. Nonetheless, aluminium wiring for residential use has acquired a poor reputation and has fallen out of favour.

Aluminium conductors are still used for power distribution and large feeder circuits, because they cost less than copper wiring, and weigh less, especially in the large sizes needed for heavy current loads. Aluminium conductors must be installed with compatible connectors.

WWT

## Modern wiring materials



An electrical "3G" power cable found commonly in modern European houses. The cable consists of 3 wires (2 wires + 1 grounding in case if cable has "3G" name) and is double-insulated.

Modern nonmetallic sheathed cables (NMC), like (U.S. and Canadian) Type NM, consist of two to four wires covered with thermoplastic insulation and a bare wire for grounding (bonding) surrounded by a flexible plastic jacket. Some versions wrap the individual conductors in paper before the plastic jacket is applied. It is often called **Romex™** cable, since the first of its type was manufactured by Rome Cable Division of Cyprus Mines, Rome, New York. The trade name has been owned by Southwire since it purchased the electrical building wire assets of General Cable in 2001.

Rubber-like synthetic polymer insulation is used in industrial cables and power cables installed underground because of its superior moisture resistance.

Insulated cables are rated by their allowable operating voltage and their maximum operating temperature at the conductor surface. A cable may carry multiple usage ratings for applications, for example, one rating for dry installations and another when exposed to moisture or oil.

Generally, single conductor building wire in small sizes is solid wire, since the wiring is not required to be very flexible. Building wire conductors larger than 10 AWG (or about 6 mm<sup>2</sup>) are stranded for flexibility during installation, but not stranded enough to be flexible enough to use as appliance cord.

Cables for industrial, commercial, and apartment buildings may contain many insulated conductors in an overall jacket, with helical tape steel or aluminium armour, or steel wire armour, and perhaps as well an overall PVC or lead jacket for protection from moisture and physical damage. Cables intended for very flexible service or in marine applications may be protected by woven bronze wires. Power or communications cables (e.g., computer networking) that are routed in or through air-handling spaces (plenums) of office buildings are required under the model code to be either encased in metal conduit or rated for low flame and smoke production.

For some industrial uses in steel mills and similar hot environments, no organic material gives satisfactory service. Cables insulated with compressed mica flakes are sometimes used. Another form of high-temperature cable is a mineral insulated cable, with individual conductors placed within a copper tube, and the space filled with magnesium oxide powder. The whole assembly is drawn down to smaller sizes, thereby compressing the powder. Such cables have a certified fire resistance rating, are more costly than non-fire rated cable, and have little flexibility and are effectively rigid to the user of the cable.



Mineral insulated cables at a panel board

Because multiple conductors bundled in a cable cannot dissipate heat as easily as single insulated conductors, those circuits are always rated at a lower "ampacity". Tables in electrical safety codes give the maximum allowable current for a particular size of conductor, for the voltage and temperature rating at the surface of the conductor for a given physical environment, including the insulation type and thickness. The allowable current will be different for wet or dry, for hot (attic) or cool (underground) locations. In a run of cable through several areas, the most severe area will determine the appropriate rating of the overall run.

Cables usually are secured by special fittings where they enter electrical apparatus; this may be a simple screw clamp for jacketed cables in a dry location, or a polymer-gasketed cable connector that mechanically engages the armour of an armoured cable and provides a water-resistant connection. Special cable fittings may be applied to prevent explosive gases from flowing in the interior of jacketed cables, where the cable passes through areas where inflammable gases are present. To prevent loosening of the connections of individual conductors of a cable, cables must be supported near their entrance to devices and at regular intervals through their length. In tall buildings special designs are required to support the conductors of vertical runs of cable. Usually, only one cable per fitting is allowed unless the fitting is otherwise rated.

Special cable constructions and termination techniques are required for cables installed in ocean-going vessels; in addition to electrical safety and fire safety, such cables may also be required to be pressure-resistant where they penetrate bulkheads of a ship.

## ***Raceways***



Electrical Conduit risers, seen inside fire-resistance rated shaft, as seen entering bottom of a firestop. The firestop is made of firestop mortar on top, rockwool on the bottom. Raceways are used to protect cables from damage.

Insulated wires may be run in one of several forms of a raceway between electrical devices. This may be a pipe, called a conduit, or in one of several varieties of metal (rigid steel or aluminum) or non-metallic (PVC or HDPE) tubing. Rectangular cross-section metal or PVC wire troughs (North America) or trunking (UK) may be used if many circuits are required. Wires run underground may be run in plastic tubing encased in concrete, but metal elbows may be used in severe pulls. Wiring in exposed areas, for example factory floors, may be run in cable trays or rectangular raceways having lids.

Where wiring, or raceways that hold the wiring, must traverse fire-resistance rated walls and floors, the openings are required by local building codes to be firestopped. In cases where the wiring has to be kept operational during an accidental fire, fireproofing must be applied to maintain circuit integrity in a manner to comply with a product's certification listing. The nature and thickness of any passive fire protection materials used in conjunction with wiring and raceways has a quantifiable impact upon the ampacity derating.



A cable tray can be used in stores and dwellings

Cable trays are used in industrial areas where many insulated cables are run together. Individual cables can exit the tray at any point, simplifying the wiring installation and reducing the labour cost for installing new cables. Power cables may have fittings in the tray to maintain clearance between the conductors, but small control wiring is often installed without any intentional spacing between cables.

Since wires run in conduits or underground cannot dissipate heat as easily as in open air, and adjacent circuits contribute induced currents, wiring regulations give rules to establish the current capacity (ampacity).

Special fittings are used for wiring in potentially explosive atmospheres.

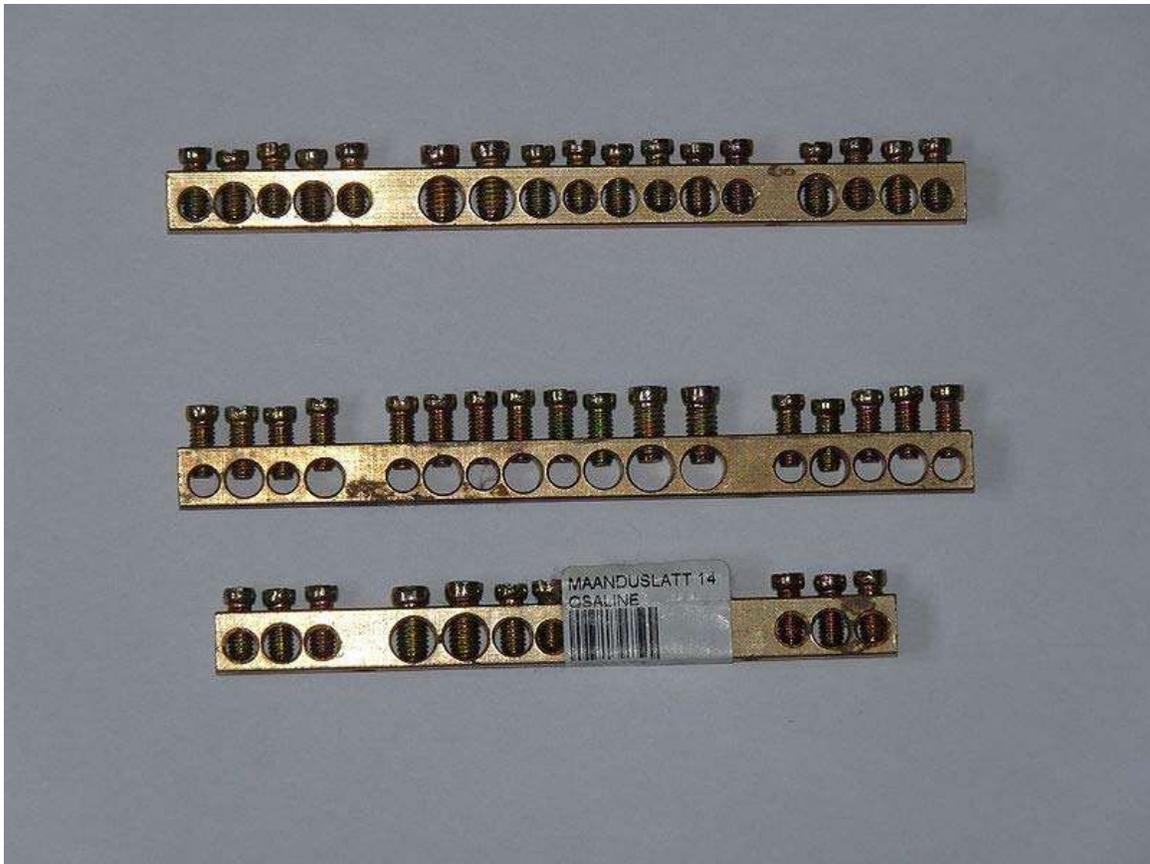
## ***Bus bars, bus duct, cable bus***



Topside of firestop with penetrants consisting of electrical conduit on the left and a bus duct on the right. The firestop consists of firestop mortar on top and rockwool on the bottom, for a 2 hour fire-resistance rating.

For very heavy currents in electrical apparatus, and for heavy currents distributed through a building, bus bars can be used. Each live conductor of such a system is a rigid piece of copper or aluminium, usually in flat bars (but sometimes as tubing or other shapes). Open bus bars are never used in publicly accessible areas, although they are used in manufacturing plants and power company switch yards to gain the benefit of air cooling. A variation is to use heavy cables, especially where it is desirable to transpose or "roll" phases.

In industrial applications, conductor bars are assembled with insulators in grounded enclosures. This assembly, known as bus duct or busway, can be used for connections to large switchgear or for bringing the main power feed into a building. A form of bus duct known as plug-in bus is used to distribute power down the length of a building; it is constructed to allow tap-off switches or motor controllers to be installed at definite places along the bus. The big advantage of this scheme is the ability to remove or add a branch circuit without removing voltage from the whole duct.



Busbars for distributing PE (ground)

Bus ducts may have all phase conductors in the same enclosure (non-isolated bus), or may have each conductor separated by a grounded barrier from the adjacent phases (segregated bus). For conducting large currents between devices, a cable bus is used. For very large currents in generating stations or substations, where it is difficult to provide circuit protection, an isolated-phase bus is used. Each phase of the circuit is run in a separate grounded metal enclosure. The only fault possible is a phase-to-ground fault, since the enclosures are separated. This type of bus can be rated up to 50,000 amperes and up to hundreds of kilovolts (during normal service, not just for faults), but is not used for building wiring in the conventional sense.

## ***Electrical panels***



Electrical panels in an electrical service room at St. Mary's Pulp and Paper, Sault Ste. Marie, Ontario, Canada, April 1996

Electrical panels, cables and firestops in an electrical service room at St. Mary's Pulp and Paper, a paper mill in Sault Ste. Marie, Ontario, Canada.

**Electrical panels** are easily accessible junction boxes used to reroute and switch electrical services.

## Chapter 9

# Submarine Power Cable

**Submarine power cables** are major transmission cables for carrying electric power below the surface of the water. These are called "submarine" because they usually carry electric power beneath salt water (arms of the ocean, seas, straits, etc.) but it is also possible to use submarine power cables beneath fresh water (large lakes and rivers). Examples of the latter exist that connect the mainland with large islands in the St. Lawrence River.

### *Design technologies*

The majority of submarine power cables use high-voltage direct current (HVDC) electric power transmission. This is a form of power transmission that was favored by Thomas Edison long ago, but mostly rejected in the late 19th century in favor of alternating-current (AC) transmission. This is the kind of electricity that is now used to power almost everything that is significant. However, high-voltage alternating-current (HVAC) power lines are sometimes difficult to use, because the electromagnetic interactions between the current and the metal casing of the cable can drive up voltages to unusable peaks - damaging insulation and causing many other problems.) However, there are several significant engineering advantages in using HVDC to transmit large amounts of electric power underwater. (what are the advantages?)

Direct-current transmission has also undergone a modest revival over dry land, over long distances, because in this case its power losses (due to waste heat) are smaller, and its current flows are easier to control.

A DC power-transmission system can use the earth (including seafloor)s and seawater as the return path for current. However, this method cannot always be used because of deleterious ecological effects of electrochemical reactions below ground and where the electrical conductors are connected to the ground.

The overall length of AC submarine cables is restricted by the capacitance between their active electric conductors and their surrounding metallic shields. If the cable were to be made long enough, the reactive power produced by an AC cable would take up the entire

current carrying capacity of the conductor, so no usable power would be transmitted. Therefore, for transmission of large amounts of electric power via long submarine cables, DC transmission is nearly-always preferable over AC transmission, because DC cables have no such effect as mentioned above.

## ***Operational submarine power cables***

### **Alternating current cables**

Alternating-current (AC) submarine cable systems for transmitting lower amounts of three phase electric power can be constructed with three-core cables in which all three insulated conductors are placed into a single underwater cable. Most offshore-to-shore wind-farm cables are constructed this way.

For larger amounts of transmitted power, the AC systems are composed of three separate single-core underwater cables, each containing just one insulated conductor and carrying one phase of the three-phase electric current. A fourth identical cable is often added in parallel with the other three, simply as a spare in case one of the three primary cables is damaged and needs to be replaced. This damage can happen, for example, from a ship's anchor carelessly dropped onto it. The fourth cable can substitute for any one of the other three, given the proper (and complicated) electrical switching system.

- Mainland British Columbia to Nelson Island to Texada Island to Vancouver Island, the destination of the power. This is a high-capacity 500 kilovolt (kV) three-phase system.
- Mainland Sweden to Bornholm Island, Denmark (110 kilovolts, but some sources state 72 kV).
- Under the Strait of Messina, connecting southern tip of the mainland of Italy with the large island of Sicily (380 kV). This submarine cable replaced an earlier, and very long overhead line crossing (the "Pylons of Messina")
- Negros Island to Panay Island, in the Philippines (138 kV)

### **Direct current cables**

- Baltic-Cable - between Germany and Sweden beneath the Baltic Sea
- Basslink - between the mainland State of Victoria and the island of Tasmania, Australia, 500 kilovolts (kV), with a length of 290 kilometers beneath the Bass Strait
- BritNed - between the Netherlands and Great Britain beneath the North Sea
- Cross Sound Cable - between Long Island, New York, and the State of Connecticut beneath Long Island Sound
- Estlink - between northern Estonia and southern Finland beneath the Gulf of Finland
- Fenno-Skan - between Sweden and Finland beneath the Baltic Sea
- HVDC Cross-Channel - very high power cable between the French mainland and the island of Great Britain beneath the English Channel

- HVDC Gotland - the first HVDC submarine power cable (non-experimental) - between the Swedish mainland and the Swedish island of Gotland beneath the Baltic Sea
- HVDC Inter-Island - between the power-rich South Island (much hydroelectric power) of New Zealand and the more-populous North Island beneath the Cook Strait
- HVDC Italy-Corsica-Sardinia (SACOI) - between the Italian mainland, the Italian island of Sardinia, and its neighboring French island of Corsica beneath the Mediterranean Sea
- HVDC Italy-Greece - between Italy and Greece beneath the Adriatic Sea
- HVDC Leyte - Luzon - between Leyte Island and Luzon in the Philippines, beneath the Pacific Ocean
- HVDC Moyle - connecting Scotland with Northern Ireland within the United Kingdom, and thence to the Republic of Ireland, beneath the Irish Sea
- HVDC Vancouver Island - between Vancouver Island and the mainland of the Province of British Columbia, beneath the Strait of Juan de Fuca
- Kii Channel HVDC system - now (2010) the world's highest-capacity long-distance submarine power cable (rated at 1400 megawatts). This power cable connects the large islands of Honshu and Shikoku beneath the Kii Channel in the Japanese Home Islands
- Kontek - between Germany and Denmark beneath the Baltic Sea
- Konti-Skan - between Sweden and Denmark beneath the Baltic Sea
- Neptune Cable - between the State of New Jersey and Long Island, New York - 64 miles beneath the Atlantic Ocean
- Swepol - between Poland and Sweden beneath the Baltic Sea

## **Longest**

- NorNed (between Eemshaven, Netherlands and Feda, Norway), HVDC, 700 MW, 580 km (360 mi)

## ***Proposed submarine power cables***

- Champlain Hudson Power Express, 335-mile line. The Transmission Developers Company of Toronto, Ontario, is proposing "to use the [ Hudson River ] for the most ambitious underwater transmission project yet. Beginning south of Montreal, a 335-mile line would run along the bottom of Lake Champlain, [and then] down the bed of the Hudson all the way to New York City."
- Power Bridge, Hawaii
- Power Bridge, State of Maine
- Puerto Rico to the Virgin Islands
- 400 kV HVDC India to Sri Lanka
- Atlantic Wind Connection between Delaware and New Jersey, potentially between Virginia and New York
- 100 megawatts 165 km Canadian province of Newfoundland and Labrador and province of Nova Scotia

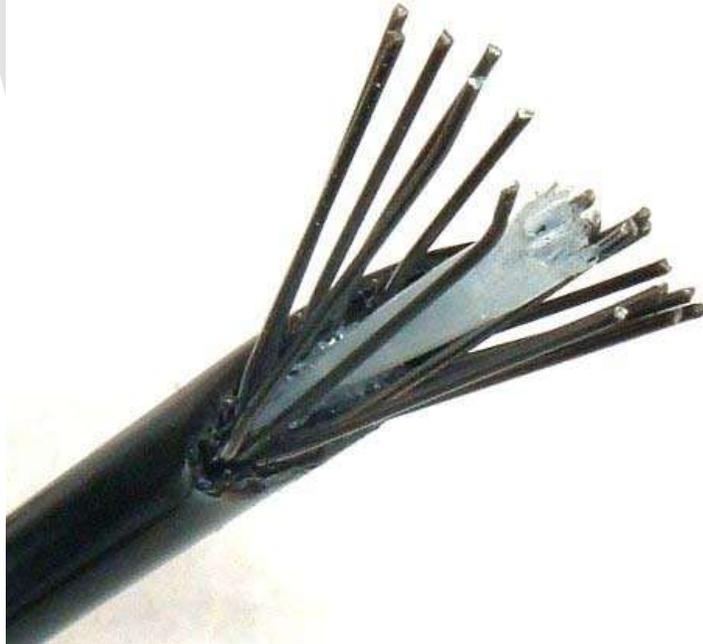
- 200 megawatts 95 km Magħtab (Malta) and Marina the Ragusa (Sicily)

WWT

## Chapter 10

# Steel Wire Armoured (SWA) Cable and Strain Insulator

## Steel Wire Armoured (SWA) Cable



**Steel Wire Armoured Cable**, commonly abbreviated as SWA, is a hard-wearing power cable designed for the supply of mains electricity. It is one of a number of armoured electrical cables - which include 11kV Cable and 33kV Cable - and is found in underground systems, power networks and cable ducting.

The typical construction of an SWA Cable can be broken down as follows:

- **Conductor:** consists of plain stranded copper (cables are classified to indicate the degree of flexibility. Class 2 refers to rigid stranded copper conductors as stipulated by British Standard BS EN 60228:2005)
- **Insulation:** Cross-linked polyethylene (XLPE) is used in a number of power cables because it has good water resistance and excellent electrical properties. Insulation in cables ensures that conductors and other metal substances do not come into contact with each other.
- **Bedding:** Polyvinyl chloride (PVC) bedding is used to provide a protective boundary between inner and outer layers of the cable.
- **Armour:** Steel wire armour provides mechanical protection, which means the cable can withstand higher stresses, be buried directly and used in external or underground projects. The armouring is normally connected to earth and can also be used as the circuit protective conductor ("earth wire") for the equipment supplied by cable.
- **Sheath:** a black PVC sheath holds all components of the cable together and provides additional protection from external stresses.

The PVC version of SWA Cable, described above, meets the requirements of both British Standard BS5467 and International Electrotechnical Commission standard IEC 60502. It is known as SWA BS5467 Cable and it has a voltage rating of 600/1000V.

SWA Cable can be referred to more generally as Mains Cable, Armoured Cable, Power Cable and Booklet Armoured Cable. The name Power Cable, however, applies to a wide range of cables including 6381Y, NYCY, NYY-J and 6491X Cable.

### ***Aluminium Wire Armoured Cable***

Steel Wire Armour is only used on multicore versions of the cable. A multicore cable, as the name suggests, is one where there are a number of different cores. When SWA Cable has only one core, aluminium wire armour (AWA) is used instead of steel wire. This is because the aluminium is non-magnetic. A magnetic field is produced by the current in a single core cable. This would induce an electric current in the steel wire, which could cause overheating.

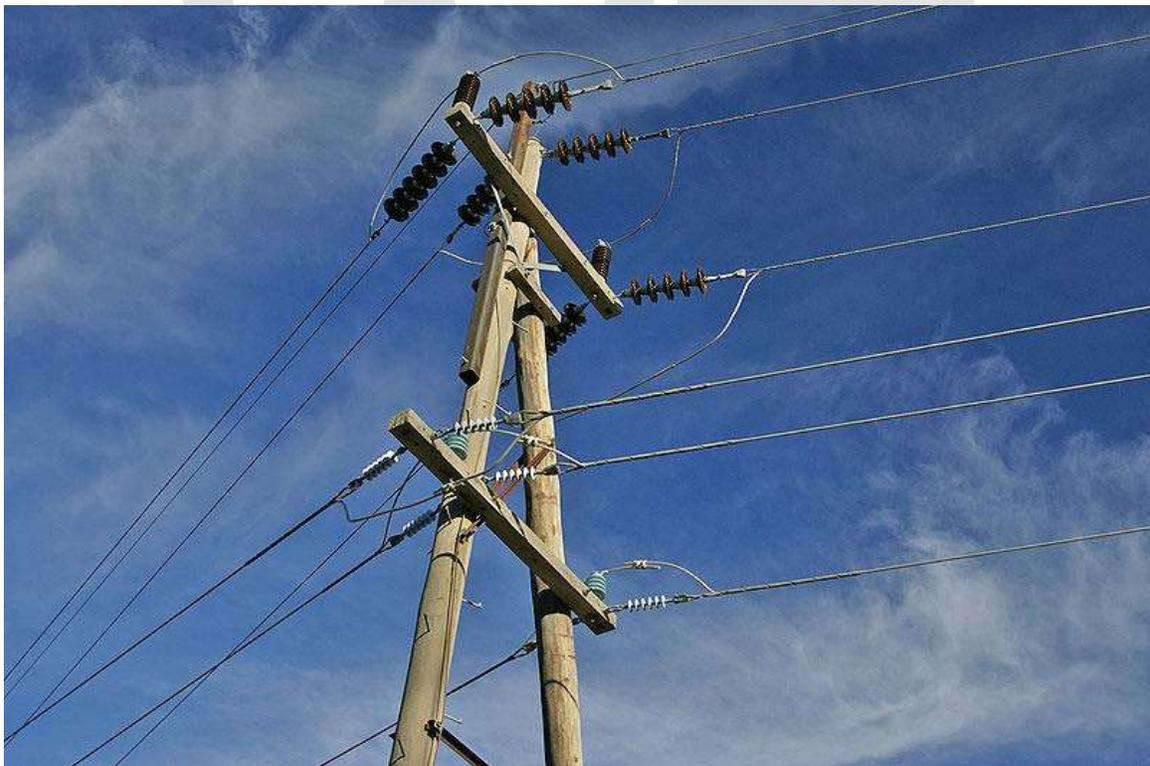
### ***Use of armour for earthing***

The use of the armour as the means of providing earthing to the equipment supplied by the cable (a function technically known as the circuit protective conductor or CPC) is a matter of debate within the electrical installation industry. It is sometimes the case that an additional core within the cable is specified as the CPC (for instance, instead of using a two core cable for line and neutral and the armouring as the CPC, a three core cable is used) or an external earth wire is run alongside the cable to serve as the CPC. Primary concerns are the relative conductivity of the armouring compared to the cores (which reduces as the cable size increases) and reliability issues. Recent articles by authoritative sources have analysed the practice in detail and concluded that, for the majority of situations, the armouring is adequate to serve as the CPC under UK wiring regulations.

## **SWA BS6724 Cable**

The construction of an SWA Cable, however, does depend on the intended use of the cable. When the power cable needs to be installed in a public area, for example, a Low Smoke Zero Halogen (LSZH) equivalent, called SWA BS6724 Cable must be used. After the King's Cross fire in London in 1987 it became mandatory to use LSZH sheathing on all London Underground cables - a number of the fatalities were due to toxic gas and smoke inhalation. As a result, LSZH cables are now recommended for use in highly populated enclosed public areas. This is because they emit non-toxic levels of Halogen and low levels of smoke when exposed to fire. SWA Cable BS6724 - which meets the requirements of British standard BS6724 - has LSZH bedding and a black LSZH sheath.

## **Strain insulator**



Strain insulators on high voltage powerlines

A **strain insulator** is an insulator that provides both large electrical insulation and a large load-bearing capacity. Strain insulators were first used in telegraph systems to isolate the signal wire from ground while still supporting the wire. Strain insulators are used to support radio antennas and overhead power lines.

## ***Description and use***

A typical strain insulator is a piece of glass or porcelain that is shaped to accommodate two cables or a cable shoe and the supporting hardware on the support structure (hook eye, or eyelet on a steel pole/tower). The shape of the insulator maximizes the distance between the cables while also maximizing the load-bearing transfer capacity of the insulator.



Pyrex glass strain insulator used for radio antennas

In practice, for radio antennas, guy-wires, overhead power lines and most other loads, the strain insulator is usually in physical tension.

When the line voltage requires more insulation than a single insulator can supply, strain insulators are used in series: A set of insulators are connected to each other using special hardware. The series can support the same strain as a single insulator, but the series provides a much higher effective insulation.

If one string is insufficient for the weight of a cable(s), a heavy steel plate is used to effectively bundle all the insulator strings together mechanically. One plate is on the "hot" end and another is located at the support structure. This setup is almost universally used on long spans, such as when a power line crosses a river, canyon, lake, or other terrain requiring a longer than nominal span.



High voltage strain insulators used on 66 kv, 230 kv and 115 kv AC lines. The number of insulator skirts varies with voltage and atmospheric conditions.

Strain insulators are typically used outdoors in overhead wiring. In this environment they are exposed to rain and in urban settings, pollution. As a practical matter, the shape of the insulator becomes critically important, since a wetted path from one cable to the other can create a low-resistance electrical path.

Strain insulators intended for horizontal mounting (often referred to as Dead-Ends) therefore incorporate flanges to shed water, and strain insulators intended for vertical mounting (referred to as Suspension Insulators) are often bell-shaped.

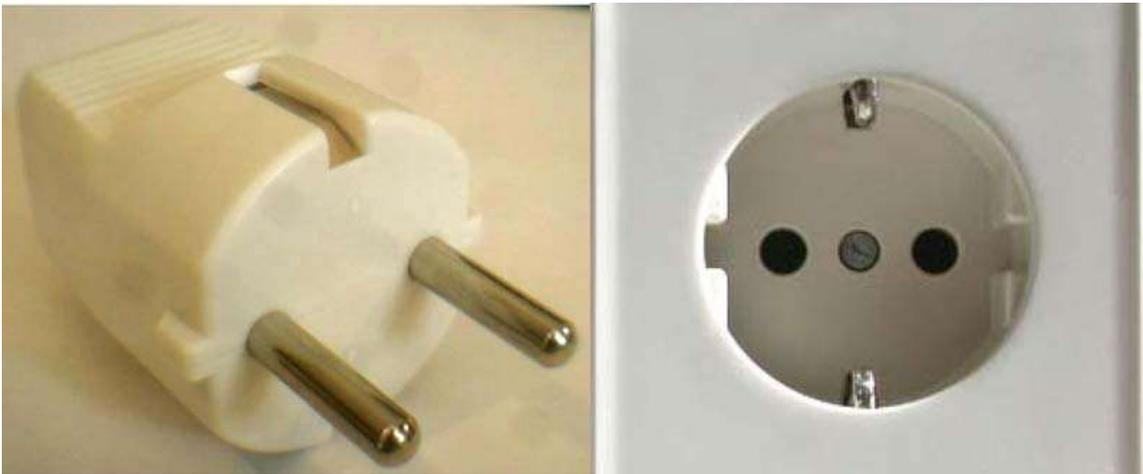
## ***Collectors***

Other than their industrial use for which they are produced some people collect insulators, especially antique ones.

WWT

## Chapter 11

# AC Power Plugs and Sockets



Plugs and sockets may sometimes combine male and female aspects, but the exposed pins or terminals in the socket are generally safe to touch. (clockwise from top left)



CEE 7/4 Type F plug and socket, CEE 7/5 Type E socket)

**AC power plugs and sockets** are devices for removably connecting electrically operated devices to the power supply.

An **electric plug** connects mechanically to a matching socket. Usually plugs are movable connectors, and sockets are fixed to equipment.

**Wall sockets** (also known as **power points, power sockets, electric receptacles, plug sockets, electrical outlets** or just **sockets**) are mostly or completely female electrical connectors that have slots or holes which accept and deliver current to the prongs of inserted plugs.

To reduce the risk of injury or death by electric shock, some plug and socket systems incorporate a variety of safety features. Sockets can be designed to accept only compatible plugs and reject all others. There is some variation in male/female mating, in that some plugs can have sockets or exposed contact plates, while some wall sockets have pins or exposed contact plates. The exposed contacts in the wall socket are commonly used for safety purposes such as grounding and electrostatic energy dissipation.

## Terminology

There are differences between British and American nomenclature related to power plugs and sockets. Other regional variations (e.g. Australian) also exist.

British English	American English	Other Terms	Meaning
<i>mains power</i>	<i>line power</i> <i>service entrance conductors</i>		Primary electrical power supply wires serving a building, connected to the main fuses or circuit breakers.
<i>domestic power</i> <i>230 volt power</i>	<i>residential power</i> <i>household power</i> <i>AC power</i>		Single-phase 120 or 230 V AC power as used in a single-family residence
<i>earth connection</i>	<i>ground wire</i> <i>grounding conductor</i> (NEC)		Safety connection to the earth or ground
<i>live connection</i> <i>active connection</i> <i>line connection</i> (rare)	<i>hot wire</i> <i>live wire</i> <i>supply wire</i> <i>ungrounded conductor</i> (NEC)	<i>phase conductor</i> (electrical engineers)	Phase or active connection
<i>neutral connection</i>	<i>cold wire</i> <i>neutral wire</i> <i>return wire</i> <i>grounded conductor</i> (old NEC) <i>identified conductor</i> (old NEC)		Return or neutral connection
<i>pin</i> <i>plug</i>	<i>plug</i> <i>pin</i> <i>prong</i>		Part of male electrical connector
<i>power port</i> <i>socket</i>	<i>receptacle</i> <i>socket</i> <i>outlet</i> <i>jack</i>	<i>power point</i>	Female electrical connector
<i>flex lead</i> <i>mains lead</i> <i>mains wire</i> <i>mains wiring</i>	<i>line cord</i> <i>power cord</i>	<i>power lead</i> <i>lead</i>	Flexible electric cable from plug to appliance

mains extension lead	extension cord drop cord		Device providing single outlet at a distance from a single outlet
4, 6, or 8 way mains extension lead	power bar	power board	Device providing multiple outlets from a single outlet
mains extension adaptor	power strip	board	

Previous to 2008, the old US National Electrical Code (NEC) distinguished the terms *grounding*, *grounded*, and *ungrounded* conductor. As of 2008, the NEC has officially defined **neutral conductor** and is phasing out the use of the term **grounded conductor**.

In United Kingdom electrical engineering, the *line* voltage is that between the live conductors of the three-phase distribution system, while the *phase* voltage is that between live and neutral.

### **The three contacts**

Each receptacle has two or three wired contacts. The contacts may be steel or brass, and may be plated with zinc, tin, or nickel. The **live** contact carries current from the source to the load. The **neutral** returns current to the source. Many receptacles and plugs also include a third contact for a connection to earth ground, intended to protect against insulation failure of the connected device. A common approach is for electrical sockets to have three holes, which can accommodate either 3-pin earthed or 2-pin non earthed plugs. The types below B, H, I, J, K and L use this approach (type B accepting type A plugs and types H, J, K and L accepting type C). The Europlug (type C) will fit type E and F sockets, and the earthed type E / F 2-pin plugs will fit type C (and certain hybrid) sockets though without making earthing contact. Types D, G and M plugs are exclusively 3-pin, used for both earthed and non-earthed appliances.

### **Polarization**

*Polarized* plugs and sockets are those designed to connect only in one orientation, so the live and neutral conductors of the outlet are connected (respectively) to the live and neutral poles of the appliance. Polarization is maintained by the shape, size, or position of plug pins and socket holes to ensure that a plug fits only one way into a socket. The switch of the appliance is then connected in series with the live wire. If the neutral wire were interrupted instead, the device would be deactivated but its internal wiring would still remain live. This is a shock hazard; if the energized parts are touched, current travels to earth through the body. Devices that especially present this hazard include toasters and other appliances with exposed heating elements, which with reversed polarity can remain live even when they are cool to the touch. Screw-in light bulbs with reversed polarity may have exposed portions of the socket still energized even though the lamp is switched off. Transposition of the live and neutral wires in the wiring to sockets defeats the safety

purpose of polarized sockets and plugs; a circuit tester can be used to detect swapped wires.

*Unpolarized* plugs and sockets are those which can connect either way around, so live and neutral wires are connected arbitrarily. Unpolarized plug/socket systems such as the Europlug rely on device construction requirements to avoid the shock hazards created by interchange of live and neutral connections.

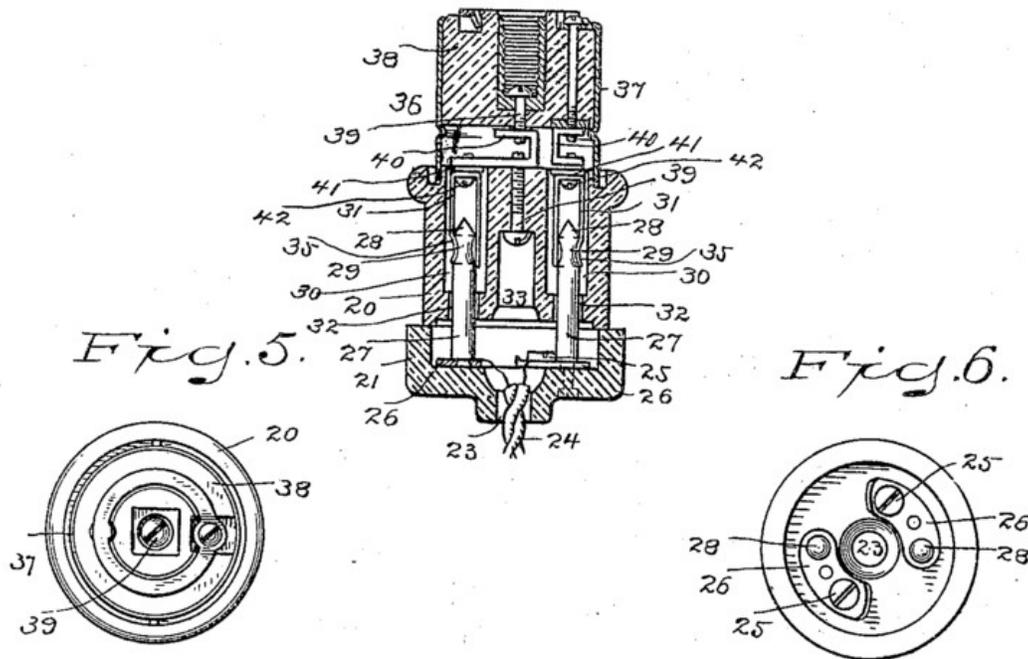
### ***Interchange hazards***

Plugs and sockets are designed as a system to meet standards for safety and reliability. Some types of receptacles may accept more than one type of plug; where this is an official, approved intention of the receptacle design, all the approved combinations will be tested to the applicable safety standards. Occasionally, plug and receptacle combinations may allow power to flow but may not meet product standards for mating force, grounding, current capacity, life expectancy, or safety. Improvised or user-modified connectors will not meet the product safety standards.

### ***History***

#### **Early history**

When electricity was first introduced into the household, it was primarily used for lighting. At that time, many electricity companies operated a split-tariff system where the cost of electricity for lighting was lower than that for other purposes. This led to portable appliances (such as vacuum cleaners, electric fans, and hair driers) being connected to light bulb sockets.



U.S. Patent 774,250. The first electric power plug and receptacle.

However, as electricity became a common method of lighting houses and operating labour-saving appliances, a safe means of connection to the electric system other than using a light socket was needed. The original two pin electrical plug and socket were invented by Harvey Hubbell and patented in 1904. The original socket into which the user inserted the appliance's plug (of Hubbell's design) itself screwed into the sort of socket used for light bulbs, rather than being directly connected to the building's fixed wiring. (U.S. Patent #774,250) Other manufacturers adopted the Hubbell pattern and by 1915 they were widespread, although in the 1920s and even later, household and light commercial equipment was still powered through cables connected with Edison screw-base adapters to lampholders.

The grounded consumer plug has several claimants to its invention. The earliest patent for a grounded plug appears to be one applied for on January 11, 1915 by George P. Knapp, on behalf of the Harvey Hubbell company and granted on April 18, 1916. This patent covers the use of a grounding pin which extends further than the other two contacts to ensure that it is engaged first. However, the suggested configuration of the pins was that found in the Type I plug used today primarily in Australasia and China, which was not interoperable with existing two-contact ungrounded plugs. Other grounded plugs that are widely used today were developed later by others so as to be interoperable with ungrounded plugs.

The Schuko-system plug was invented by Albert Büttner, who patented it in 1926. The current American version of the grounded plug, with two vertical blades and a round grounding pin was invented by Philip F. Labre, while he was attending the Milwaukee

School of Engineering (MSOE). It is said that his landlady had a cat which would knock over her fan when it came in the window. When she plugged the fan back in, she would get an electric shock. Labre figured out that if the plug were grounded, the electricity would go to earth through the plug rather than through his landlady. He applied a patent on May 12, 1927 and was issued a US patent for grounding receptacle and plug in June, 1928. As the need for safer installations became apparent, earthed three-contact systems were made mandatory in most industrial countries.

## **Proliferation of standards**

During the first fifty years of commercial use of electric power, standards developed rapidly based on growing experience. Technical, safety, and economic factors influenced the development of all wiring devices and numerous varieties were invented. Gradually the desire for trade eliminated some standards that had been used only in a few countries. Former colonies may retain the standards of the colonising country, occasionally—as with the UK and a number of its former colonies—after the colonising country has changed its standard. Sometimes offshore industrial plants or overseas military bases use the wiring practices of their controlling country instead of the surrounding region. Hotels and airports may maintain receptacles of foreign standards for the convenience of travellers. Some countries have multiple voltages, frequencies and plug designs in use, which can create inconvenience and safety hazards.

## **Design for safety**

Design features and aspects of plugs and sockets have gradually developed to reduce the risk of electric shock and appliance destruction. Depending on the plug and socket system, safety measures may include pin and slot composition to permit only the precise insertion of plug into socket, earth pins longer than power pins so the device becomes earthed before power is connected, electrical insulation of pin shanks to reduce or eradicate live-contact exposure when a plug is partially inserted in a socket, socket slot shutters that open only for the correct plug, as well as inbuilt fuses and switches.

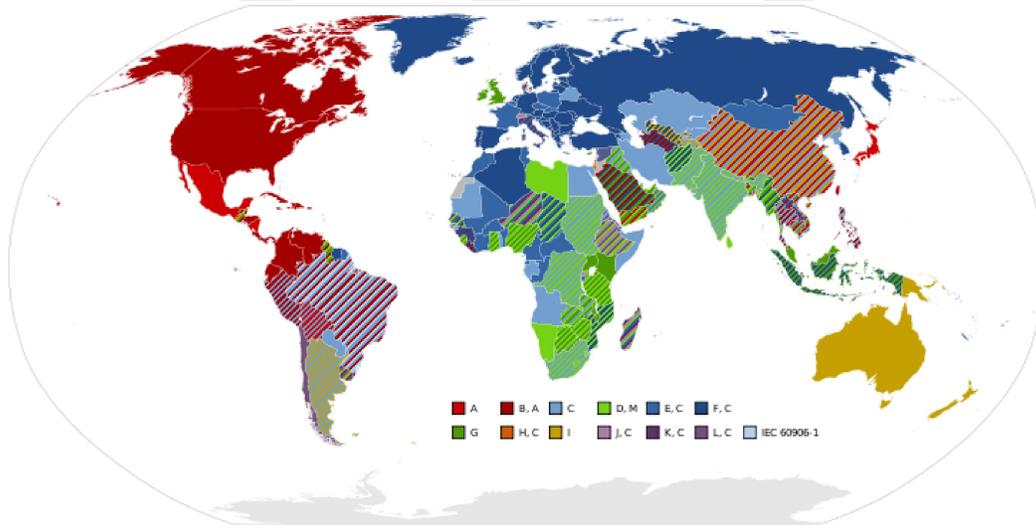
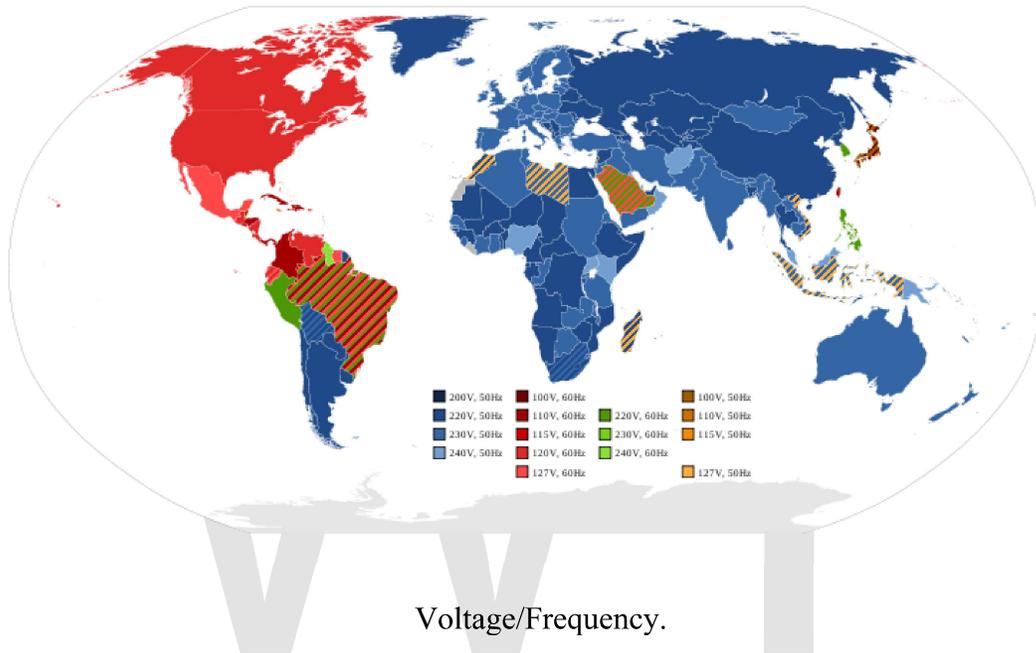
## **Consolidation of standards**

In recent years many countries have settled on one of a few *de facto* standards, which became formalised as official national standards, although there remain older installations of obsolete wiring in most countries. Some buildings have wiring that has been in use for almost a century and which pre-dates all modern standards.

There has been some movement towards consolidation of standards for international interoperability. For example, the CEE 7/7 plug has been adopted in several European countries and is compatible with both Type E and Type F sockets, while the ungrounded and unpolarised Europlug is compatible with an even greater proportion of European and other socket types. IEC 60906-1 has been proposed as a common standard for all 230 V plugs and sockets worldwide but has only been adopted in Brazil to date.

Many manufacturers of electrical devices like personal computers have adopted the practice of putting a single world-standard IEC connector on the device, and supplying for each country a power cord equipped with a standard IEC connector on one end and a national power plug at the other. The electrical device itself is designed to adapt to a wide range of voltage and frequency standards. This has the practical benefit of reducing the amount of testing required for approval, and reduces the number of different product variations that must be produced to serve world markets.

## World maps



There are two basic standards for voltage and frequency in the world. One is the North American standard of 120 volts at a frequency of 60 Hz, which uses plugs A and B, and the other is the European standard of 220–240 volts at 50 Hz, which uses plugs C to M.

Countries on other continents have adopted one of these two voltage standards, although some countries use variations or a mixture of standards. The outline maps show the different plug types, voltages and frequencies used around the world, color-coded for easy reference.

### ***Types in present use***

Electrical plugs and their sockets differ by country in shape, size and type of connectors. The type used in each country is set by national standards legislation. Here each type is designated by a letter designation from a U.S. government publication, plus a short comment in parentheses giving its country of origin and number of contacts. Subsections then detail the subtypes of each type as used in different parts of the world.

In many areas, different types of plugs are used depending on the IEC classes assigned to the electrical device. The assigned class depends on whether or not the device is earthed, and the degree of insulation it incorporates. Class I, for example, refers to earthed equipment, while class II refers to unearthed equipment protected by double insulation.

Special purpose sockets may be found in residential, industrial, commercial or institutional buildings. These may be merely labelled or coloured, or may have different arrangements of pins or keying provisions. Some special-purpose systems are incompatible with general-purpose lighting and appliances. Examples of systems using special purpose sockets include:

- "clean" ground for use with computer systems,
- emergency power supply,
- uninterruptible power supply, for critical or life-support equipment,
- isolated power for medical instruments,
- "balanced" or "technical" power used in audio and video production studios,
- theatrical lighting
- outlets for electric clothes dryers, electric ovens, and air conditioners with higher current rating.

Depending on the nature of the system, special-purpose sockets may just identify a reserved use of a system (for example, computer power) or may be physically incompatible with utility sockets to prevent use of unintended equipment which could create electrical noise or other problems for the intended equipment on the line.

## Type A



Unpolarized type A plug

NEMA 1–15 (North American 15 A/125 V ungrounded)

This plug and socket, with two flat parallel non-coplanar blades and slots, is used in most of North America and on the east coast of South America on devices not requiring a ground connection, such as lamps and "double insulated" small appliances. It has been adopted by 38 countries outside North America, and is standardized in the U.S. by the National Electrical Manufacturers Association. NEMA 1–15 sockets have been prohibited in new construction in the United States and Canada since 1962, but remain in many older homes and are still sold for replacement. Type A plugs are still very common because they are also compatible with newer type B (three-prong) sockets. In Pakistan Type A plug is used with hybrid socket, for home and small offices.

Initially, the plug's prongs and the socket's slots were the same width (or height, in a vertical orientation), so the plug could be inserted into the socket either way around. Most sockets and plugs manufactured from the 1950s onward are polarized by means of a neutral blade/slot wider than the live blade/slot, so the plug can be inserted only the right way. Polarized type A plugs will not fit into unpolarized type A sockets, which possess only narrow slots. But both unpolarized and polarized type A plugs will fit into polarized type A sockets and into type B (three-prong) sockets. Some devices that do not

distinguish between neutral and live, such as internally isolated electronic power supplies, are still produced with unpolarized type A pins (both narrow).

JIS C 8303, Class II (Japanese 15 A/100 V ungrounded)



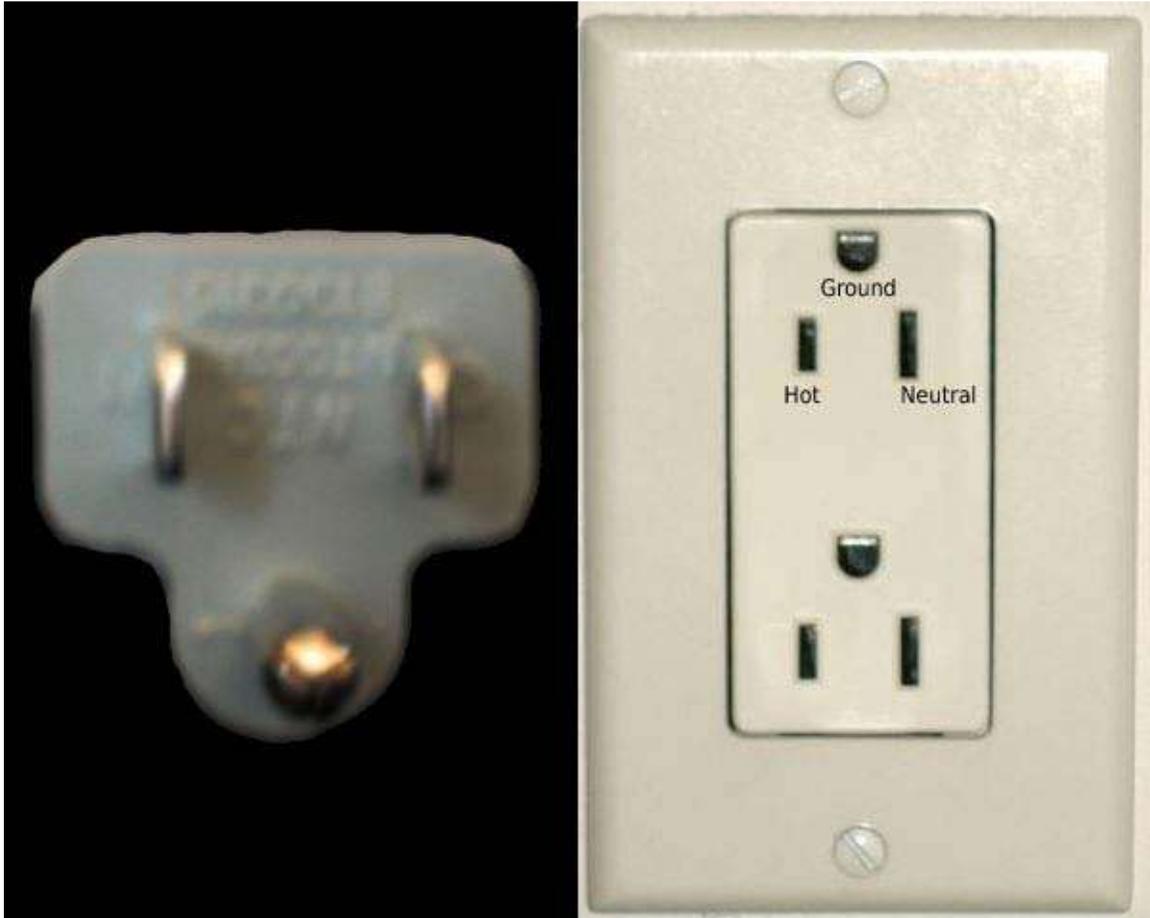
Japanese outlet with ground post, for a washing machine.

The Japanese plug and socket appear physically identical to NEMA 1–15. However, the Japanese system incorporates stricter dimensional requirements for the plug housing, different marking requirements, and mandatory testing and approval by MITI or JIS.

Many Japanese outlets and multi-plug adapters are unpolarized—the slots in the sockets are the same size—and will accept only unpolarized plugs. Japanese plugs generally fit into most North American outlets without modification, but polarized North American

plugs may require adapters or replacement non-polarized plugs to connect to older Japanese outlets. However, in Japan the voltage is supplied at only 100 volts, and the frequency in eastern Japan is 50 rather than 60 Hz. Therefore, many North American devices which can be physically plugged into Japanese sockets may not function properly, though some devices with rectified power supplies may work without problems.

### Type B



Decorative-style duplex outlet, center



Ordinary duplex outlet

The type B plug has two flat parallel blades like type A, but also adds a round or U-shaped grounding prong (American standard NEMA 5-15/CSA 22.2, No.42). It is rated for 15 amperes at 125 volts. The ground pin is longer than the live and neutral blades, so the device is grounded before the power is connected. Both current-carrying blades on type B plugs are narrow, since the ground pin enforces polarity. Type A plugs are also compatible with type B sockets, in which case the socket enforces polarity by means of a wide and a narrow slot.

Adapters that allow a Type B plug to be fitted to a Type A outlet are readily available. Proper grounding is dependent on the outlet being an ordinary duplex receptacle with a

grounded center screw, and the grounding tab of the adapter being connected to that screw.

The 5–15 socket is standard in all of North America (Canada, the United States, and Mexico). It is also used in Central America, the Caribbean, northern South America (Colombia, Ecuador, Venezuela and part of Brazil), Japan, Taiwan and Saudi Arabia. Looking directly at a type B outlet with the ground at the bottom, the neutral slot is on the left, and the live slot is on the right. Outlets may also be installed oriented with the ground at the top, or on either side. Typically connections are:

- Ground: bottom, round hole, green terminal, green or bare wire
- Neutral: top left, larger flat slot, silver terminal, white wire
- Live/Hot: top right, narrower flat slot, brass terminal, black wire (or red wire for 2nd live circuit, top and bottom socket are then separated)

In some parts of the United States and all of Canada, tamper-resistant outlets are now required in new construction. These prevent contact by objects like keys or paper clips inserted into the receptacle.



5–20RA (Canada) or 5-20R (USA) T-slot receptacle mounted with the ground hole up. The neutral connection is the wider T-shaped slot on the lower right.

In theater lighting, this connector is sometimes known as *PBG* for "Parallel Blade with Ground", *Edison* or *Hubbell*, the name of a common manufacturer.

NEMA 5–20 (North American 20 A/125 V grounded)

This is a 20 amperes receptacle; type 5-20 A has a T-slot for the neutral blade which allows either 15 amperes parallel-blade plugs or 20 amperes plugs to be used.

JIS C 8303, Class I (Japanese 15 A/100 V grounded)

Japan also uses a Type B plug similar to the North American one. However it is less common than its Type A equivalent.

### **Type C**

CEE 7/16 (Europlug 2.5 A/250 V ungrounded)



**CEE 7/16 plug and old type c socket**

This two-prong plug is popularly known as the Europlug. The plug is ungrounded and has two round 4 mm (0.157 in) pins, which usually converge slightly towards their free ends. It is described in CEE 7/16 and is also defined in Italian standard CEI 23-5 and Russian standard GOST 7396. This plug is intended for use with devices that require 2.5 amperes or less. Because it is unpolarised, it can be inserted in either direction into the socket, so live and neutral are connected arbitrarily. The separation and length of the pins allow its safe insertion in most Type E (French), type F (CEE 7/4 "Schuko"), Type H (Israeli), CEE 7/7, Type J (Swiss), Type K (Danish) and Type L (Italian) outlets, as well as BS 4573 UK shaver sockets. It can be forced into type D (5 amperes) and some G sockets, if the shutters are opened, though the connection may be neither reliable in either case, nor safe regarding overcurrent or short-circuit protection with type G sockets which may well be wired on a ring circuit with a 30 A rewirable (semi-enclosed) BS3036 fuse or 32 A circuit breaker.

The Europlug (plug only, not socket from the picture) is used in Class II applications throughout continental Europe (Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Czech Republic, Croatia, Denmark, Estonia, Finland, France, Germany, Greece, Greenland, Hungary, Iceland, Italy, Latvia, Lithuania, Luxembourg, Macedonia, the Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey). It is also used in the Middle East, most African nations, South America (Brazil, Chile, Argentina, Uruguay, Peru and Bolivia), Asia (Bangladesh, Sri Lanka, Indonesia, Pakistan and the Philippines) as well as Russia and the former Soviet republics, such as Ukraine, Armenia, Georgia, and many developing nations. It is also used alongside the BS 1363 in many nations, particularly former British colonies.

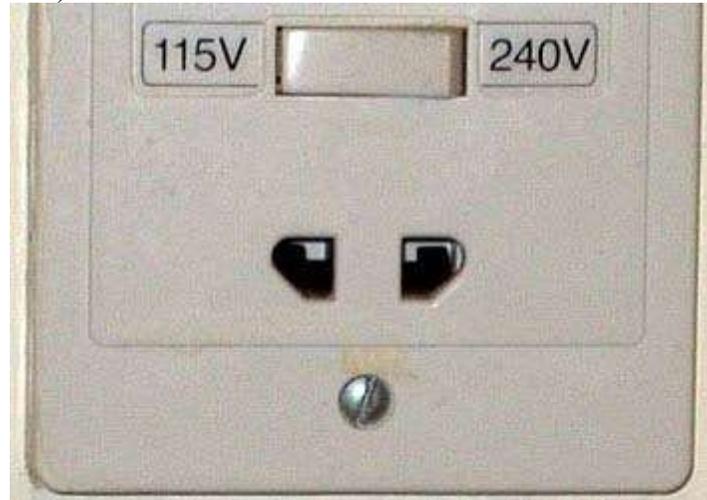
CEE 7/17 (German/French 16 A/250 V ungrounded)



**CEE 7/17 plug**

This plug also has two round pins but the pins are 4.8 mm (0.189 in) in diameter like types E and F and the plug has a round plastic or rubber base that stops it being inserted into small sockets intended for the Europlug. Instead, it fits only into large round sockets intended for types E and F. The base has holes in it to accommodate both side contacts and socket earth pins. It is used for large appliances, and in South Korea for all domestic non-earthed appliances. It is also defined in Italian standard CEI 23-5. Can also be safely inserted in to Israeli type H sockets, although with some difficulty.

BS 4573 (UK shaver)



**BS 4573** socket

In the United Kingdom and Ireland, what appears to be a larger version of the type C plug exists for use with shavers (electric razors) in bath or shower rooms. In fact it was not derived from the type C plug at all, but was a legacy from the obsolete 2 pin 5 amperes plug used in Britain in the 1920s and 1930s but still prevalent, especially in bathrooms, as late as the 1960s. It has 0.2 in (5.08 mm) diameter pins  $\frac{5}{8}$  in (15.88 mm) apart, and the sockets for this plug are often designed to accept unearthed CEE 7/16, US or Australian plugs as well. Sockets are often able to supply either 230 V or 115 V. In wet zones, they must contain an isolation transformer compliant with BS 3535.

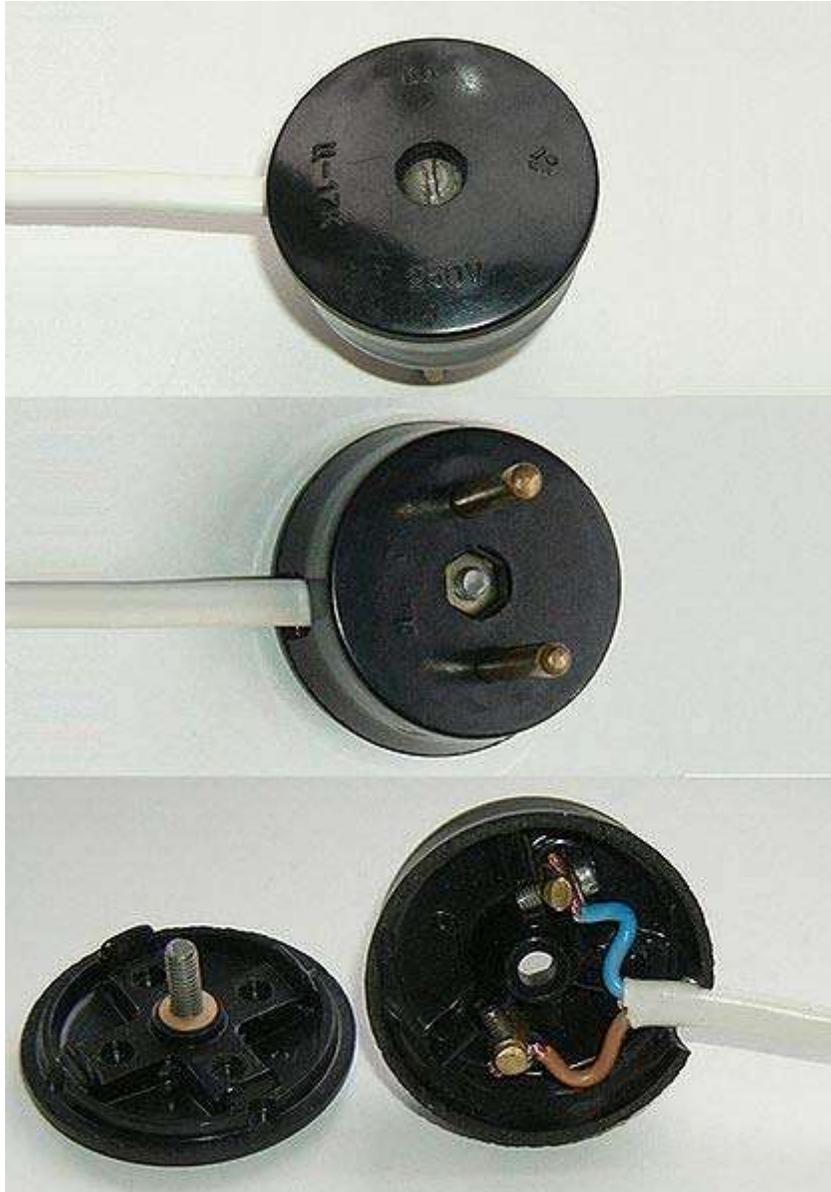
GOST 7396 C 1 (6 A or 16 A /250 V ungrounded)

This Soviet plug, still widely used in modern Russia, has pin dimensions and spacing equal to the Europlug, but lacks the insulation sleeves. Unlike the Europlug, it was rated for 6 A. It has a round body like the French type E or flat body with a round base like CEE 7/17. The round base has no notches. The pins are parallel and do not converge. The body is made of fire resistant thermoset plastic. The corresponding 6 A socket accept the Europlug, but not the type E or F plugs, nor the CEE 7/17 as the 4.5 holes are too small to accept the 4.8 mm pins of those plugs.

There were also moulded rubber plugs available for devices up to 16 A similar to CEE 7/17, but with a round base without any notches. They could be altered to fit a type E or F socket by cutting notches with a sharp knife.



Soviet grip plug, 6 A 250 V AC, thermoset plastic



Soviet round plug, 6 A 250 V AC, thermoset plastic, half height



Moulded rubber soviet plugs cut with knife in attempt to be similar to CEE 7/16 (left) and CEE 7/17 (right). Originally the plugs had a round base.



Soviet shaver power cord. The plug is similar to CEE7/16, but has different configuration. Thermoplastic plug is rated for 6 A 250 V.

#### Variations in sockets



Unearthed socket compatible with both Schuko and French plugs

Type C sockets have no ground provisions and consequently have been phased out in most countries. For example, in Germany, ungrounded outlets are rare, found only in very old installations, whereas in the Netherlands they are common in "dry areas" such as in bedrooms or living rooms. Standards also vary between countries as to whether child-resistant shutters are required. Depending on the country and the age of the socket these sockets may have 4.0 or 4.8 mm receptacles. The latter accept type E and F plugs in addition to type C, though without ground connection. Countries using the type E or F standards vary in whether ungrounded type C outlets are still permitted in environments where the need for grounding is less critical. Adaptors and trailing sockets and power strips designed to accept only Europlugs with 4 mm (0.157 in) pins may also have plastic barriers in place to prevent CEE 7/17, Schuko or French plugs from entering.

### **Type D**

BS 546 (United Kingdom, 5 A/250 V grounded), equivalent to IA6A3 (India), rated at 6 A / 250 V



D Plug

India and Pakistan have standardised on a plug which was originally defined in British standard BS 546. It has three large round pins in a triangular pattern. The BS 546 standard is also used in parts of the Middle East (Kuwait, Qatar) and parts of Asia and South East Asia that were electrified by the British. This type was also previously used in South Africa, but has been phased out in favour of the 15 A version there. Similarly, in Ghana, Kenya and Nigeria, the plug has been mostly replaced by the British 3-pin (Type G). This 5 A plug, along with its smaller 2 A cousin, is sometimes used in the UK for centrally switched domestic lighting circuits, in order to distinguish them from normal power circuits.

BS 546 (United Kingdom, 15 A/250 V grounded), equivalent to IA16A3 (India) & SABS 164 (South Africa), rated at 16 A / 250 V



M Plug

This plug is sometimes referred to as type M, but it is in fact merely the 15 A version of the plug above, though its pins are much larger at 7.05 by 21.1 mm (0.278 by 0.831 in). Live and neutral are spaced 1 in (25.4 mm) apart, and earth is  $1\frac{1}{8}$  in (28.58 mm) away from each of them. Although the 5 A version is standard in India, Pakistan, Sri Lanka, Nepal and Namibia, the 15 A version is also used in these countries for larger appliances. Some countries like South Africa use it as the main domestic plug and socket type, where sockets always have an on-off switch built into them. Type M is still commonly found in installations in Hong Kong and Botswana, alongside type G. The Type M was almost universally used in the UK and Ireland for indoor dimmable theatre and architectural lighting installations, but there is now a widespread move to using CEE 16 A industrial sockets in new installations. It was also often used for non-dimmed but centrally controlled sockets within such installations. The main reason for doing this is that fused plugs, while convenient for domestic wiring (as they allow 32 A socket circuits to be used safely), are not convenient if the plugs and sockets are in hard-to-access locations (like lighting bars) or if using chains of extension cords since it is hard to figure out which fuse has blown. Both of these situations are common in theatre wiring. This plug is also widely used in Israel, Singapore, Sri Lanka and Malaysia for air conditioners and clothes dryers.

A socket has been developed for the Indian subcontinent that accepts both type D and type M plugs, with adjacent holes of the appropriate gauge.

### **Type E**

CEE 7/5 (French type E)



French socket



French plug

France, Belgium, Poland, Czech Republic, Slovakia and some other countries have standardized on a round plug with two round pins measuring 4.8 by 19 mm (0.189 by 0.748 in), spaced 19 mm (0.748 in) apart and with a hole for the socket's ground pin. This standard will also accept Europlug (type C) and CEE 7/17 plugs. Sockets are installed with the earth pin upwards. Although the plug is polarised, there is no universally observed standard for connecting the live and neutral. In the former Czechoslovakia Standard ČSN 33 2180:1979, section 6.2.2. required live to be on the left side of socket. Child-resistant outlet shutters are required by French and Belgian standards, however they are not required in all countries where this type is used.

Although similar under many aspects, type E plug is not compatible with the CEE 7/4 socket (type F) standard in Germany and other continental European countries. The reason for incompatibility is that grounding in the E socket is done by a round male pin permanently mounted in the socket. As well as type F plug below, type E plug will fit some other types of socket either easily or with force. However, there will be no ground connection with such sockets, and in some cases forcing the plug may damage the socket.

This type has been authorised in Denmark since 1 July 2008, but sockets of this kind are not yet common.

## Type F

CEE 7/4 (German "Schuko" 16 A/250 V grounded)



Schuko plug and socket

The type F plug, defined in CEE 7/4 and commonly called a "Schuko plug", is like type E except that it has two grounding clips on the sides of the plug instead of a female ground contact. The Schuko connection system is symmetrical and unpolarised by design, allowing live and neutral to be reversed. The socket also accepts Europlugs and CEE 7/17 plugs. It supplies up to 16 amperes. It is used in Austria, Bulgaria, Chile, Croatia, Estonia, Finland, Germany, Greece, Hungary, Iceland, Indonesia, Italy, Latvia, Luxembourg, the Netherlands, Norway, Pakistan, Portugal, Romania, Russia, Serbia, Slovenia, South Korea, Spain, Sweden, Turkey and Uruguay.

"Schuko" is an abbreviation for the German word *Schutzkontakt*, which means "Protective (that is, grounded) contact".

Some countries – notably Finland, Norway and Sweden – require child-proof outlet shutters; the German Schuko standard does not have this requirement.

## Type E / F hybrid



CEE 7/7 plug

CEE 7/7 (French/German 16 A/250 V grounded)

In order to bridge the differences between sockets E and F, the CEE 7/7 plug was developed. It is polarised to prevent the live and neutral connections from being reversed when used with a type E outlet, but allows polarity reversal when inserted into a type F socket. The plug is rated at 16 A. It has grounding clips on both sides to connect with the CEE 7/4 socket and a female contact to accept the grounding pin of the type E socket. It is also used in Spain and Portugal. Currently, when appliances are sold with type E/F plugs attached, the plugs are CEE 7/7 and non-rewirable. This means that the plugs are now identical between countries like France and Germany, but the sockets are different.

## Type G

BS 1363 (British 13 A/230-240 V 50 Hz grounded and fused), equivalent to IS 401 & 411 (Ireland), MS 589 (Malaysia) and SS 145 (Singapore), SASO 2203 (Saudi Arabia)



BS 1363

The British Standards 1363 plug. This design is used not only in the United Kingdom, but also in Pakistan, Ireland, Sri Lanka, Maldives, Bahrain, UAE, Qatar, Yemen, Oman, Jordan, Cyprus, Malta, Gibraltar, Botswana, Ghana, Hong Kong, Macau, Brunei, Malaysia, Singapore, Indonesia, Bangladesh, Kenya, Uganda, Malawi, Nigeria, Mauritius, Iraq, Kuwait, Tanzania, Zambia and Zimbabwe. BS 1363 is also standard in several of the former British Caribbean colonies such as Belize, Dominica, St. Lucia, Saint Vincent and the Grenadines and Grenada. It is also used in Saudi Arabia in 220 V installations although 110 V installations using the NEMA connector are more common.

This plug, commonly known as a "13 amp plug", is a large plug that has three rectangular prongs forming a triangle. Live and neutral are 18 mm (0.709 in) long, and spaced 22 mm (0.866 in) apart. 9 mm (0.354 in) of insulation at the trailing ends of the prongs prevents accidental contact with a bare connector while the plug is partially inserted. The earth prong is approximately 4 by 8 mm (0.157 by 0.315 in) and 23 mm (0.906 in) long.

The plug has a fuse inside. The fuse is required to protect the cord, as British wiring standards allow very high current ring main circuits to the socket. Accepted practice is to choose the smallest standard fuse (3, 5 or 13 A) that will allow the appliance to function. Using a 13 A fuse on an appliance with thin cord is a fire hazard. The fuse is 1 in (25.40 mm) long, conforming to standard BS 1362. Sockets are required to be wired with neutral on the left and live on the right (viewed from the front of the socket) so that the fuse in the plug disconnects the live feed if it blows. The same convention is used for all British sockets connected directly to "mains" wiring.

UK wiring regulations (BS 7671) require sockets in homes to have shutters over the live and neutral connections to prevent the insertion of objects other than electric plugs. On most designs, these shutters are opened by the insertion of the longer earth prong. On some designs they are opened by the simultaneous insertion of the live and neutral prongs

of the right shape and spacing. The effect of the shutters is to help prevent the use of plugs made to other standards, and to prevent children and others poking things into the dangerous connections. On plugs for Class II appliances that do not require an earth, the earth pin is often plastic and serves only to open the shutters and to enforce the correct orientation of live and neutral. It may be possible to open the shutters by putting a screwdriver blade into the earth socket, so as to insert a Type C Plug (but not the BS 4573 UK shaver) or other plug types, but this can be dangerous for such plugs will not have a fuse and will often not fit properly.

BS 1363 plugs and sockets started appearing in 1946 and BS 1363 was first published in 1947. By the end of the 1950s, it had replaced the earlier type D BS 546 in new installations, and by the end of the 1960s, most earlier type D installations had been rewired to BS 1363 standards. Outlets usually include switches on the live side for convenience and safety.

### Type H



Two Israeli plugs and one socket. The left plug is the old standard, the one on the right is the 1989 revision. SI 32 (Israeli 16 A/250 V grounded)

This plug, defined in SI 32 (IS16A-R), is unique to Israel and is incompatible with all other sockets. It has three flat pins to form a Y-shape. Live and neutral are spaced 19 mm (0.75 in) apart. The Type H plug is rated at 16 A but in practice the thin flat pins can

cause the plug to overheat when connecting large appliances. In 1989, the standard was revised to use three round 4.5 mm (0.177 in) pins in the same locations. Sockets made since 1989 accept both flat and round pins for compatibility with both old and new plugs. This also allows the Type H socket to accommodate the type C plugs used in Israel for non-earthed appliances. Older sockets, from about the 1970s, have both flat and round holes for live and neutral in order to accept both Type C (CEE 7/16 Europlug) and Type H plugs. As of 2008, type H sockets which accept only old-style type H plugs are very rare in Israel.

This plug is also used in the areas controlled by the Palestinian National Authority in the West Bank and all of the Gaza Strip.

Thai 3 pin plug TIS 166-2549 (2006)

Thai multi-standard 3-pin sockets (like that shown in the section on multi-standard sockets below) safely accept type A, B, C and H plugs, and also the Thai 3 pin plug. This round-pin plug is similar to the Israeli plug but its pin dimensions are 4.8 mm instead of 4.0 mm and the pins are insulated.

### **Type I**

AUS/NZS 3112 (Australasian 10 A/240 V)



Australasian switched 3-pin dual power point (socket)

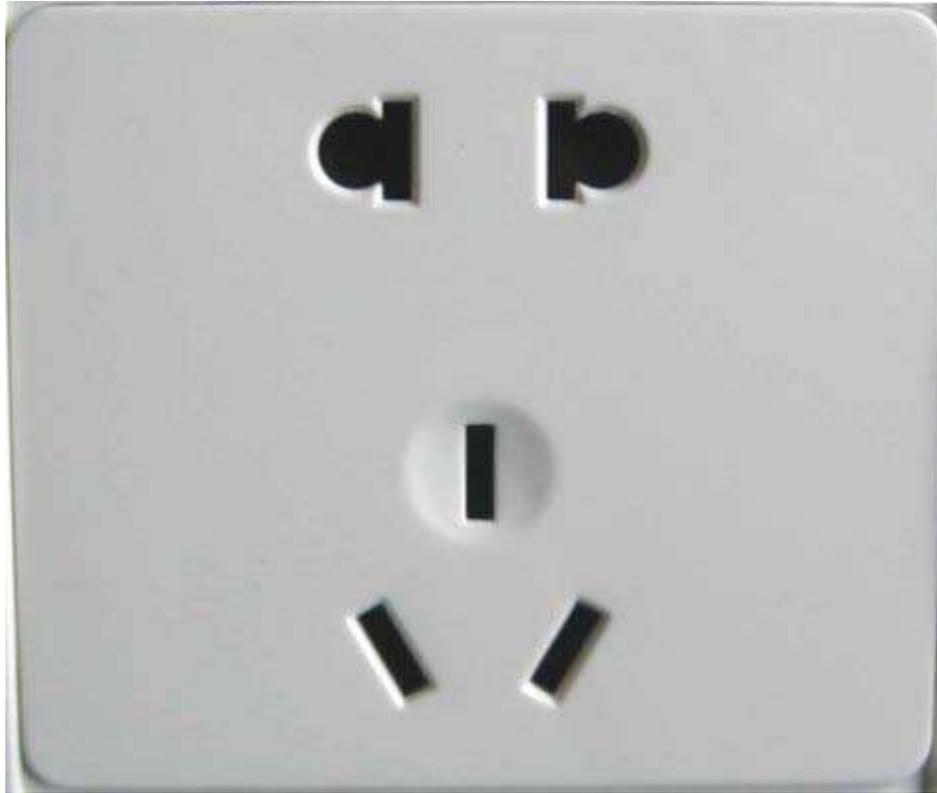
This plug, used in Australia, New Zealand, Fiji, Argentina, Solomon Islands and Papua New Guinea, has a grounding pin, and two flat current-carrying pins forming an upside down V-shape. The flat blades measure 6.5 by 1.6 mm (0.256 by 0.063 in) and are set at 30° to the vertical at a nominal pitch of 13.7 mm (0.539 in). Australian and New Zealand wall sockets almost always have switches on them for extra safety, as in the UK. An unearthed version of this plug with two angled power pins but no earthing pin is used with small double-insulated appliances, but the powerpoint (wall) outlets always have three pins, including a ground pin.

There are several AS/NZS 3112 plug variants, including ones with larger pins and/or differently shaped ground pins used for devices drawing 15, 20, 25 and 32 amps. These sockets accept plugs of equal or of a lower current capacity, but not of higher capacity. For example, a 10 A plug will fit all sockets but a 20 A plug will fit only 20, 25 and 32 A outlets.



Australian 2005 standard power plug

Australasia's standard plug/socket system was originally codified as standard C112 (floated provisionally in 1937, and adopted as a formal standard in 1938), which was superseded by AS 3112 in 1990. As of 2005, the latest major update is AS/NZS 3112:2004, which mandated insulated pins by 2005 at the point of sale in all Australian States and New Zealand. However, equipment and cords made before 2003 can still be used.



Chinese sockets accepting plug types A, C (upper) and I (lower, standard)  
CPCS-CCC (Chinese 10 A/250 V)

Although the pins on the Chinese plug are 1 mm (0.039 in) longer, the Australasian plug can be used with mainland Chinese socket. The standard for Chinese plugs and sockets is set out in GB 2099.1–2008 and GB 1002–2008. As part of China's commitment for entry into the WTO, the new CPCS (Compulsory Product Certification System) has been introduced, and compliant Chinese plugs have been awarded the CCC Mark by this system. The plug is three wire, earthed, rated at 10 A, 250 V and used for Class 1 applications.

In China, the sockets are installed upside-down relative to the Australasian ones.

China also uses American/Japanese "Type A" sockets and plugs for Class-II appliances. However, the voltage across the pins of a Chinese socket will always be 220, no matter what the plug type.

IRAM 2073 (Argentinian 10 A/250 V)

The Argentinian plug is a three-wire earthed plug rated at 10 A, 250 V defined by IRAM and used in Class 1 applications in Argentina and Uruguay.

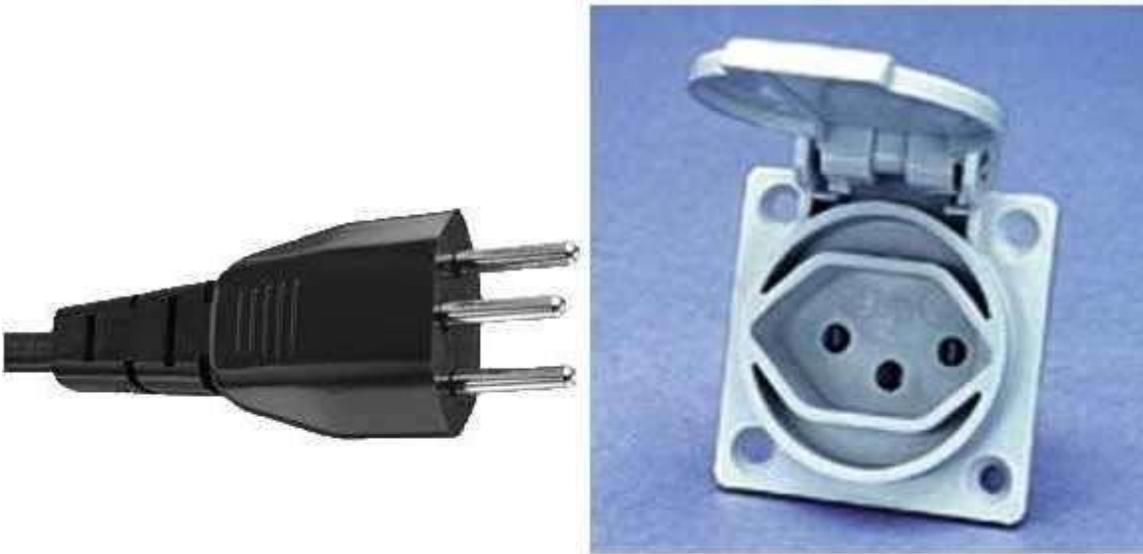
This plug is similar in appearance to the Australasian and Chinese plugs. The pin length is same as the Chinese version. The most important difference from the Australasian plug is that the Argentinian plug is wired with the live and neutral contacts reversed.

## Brazil

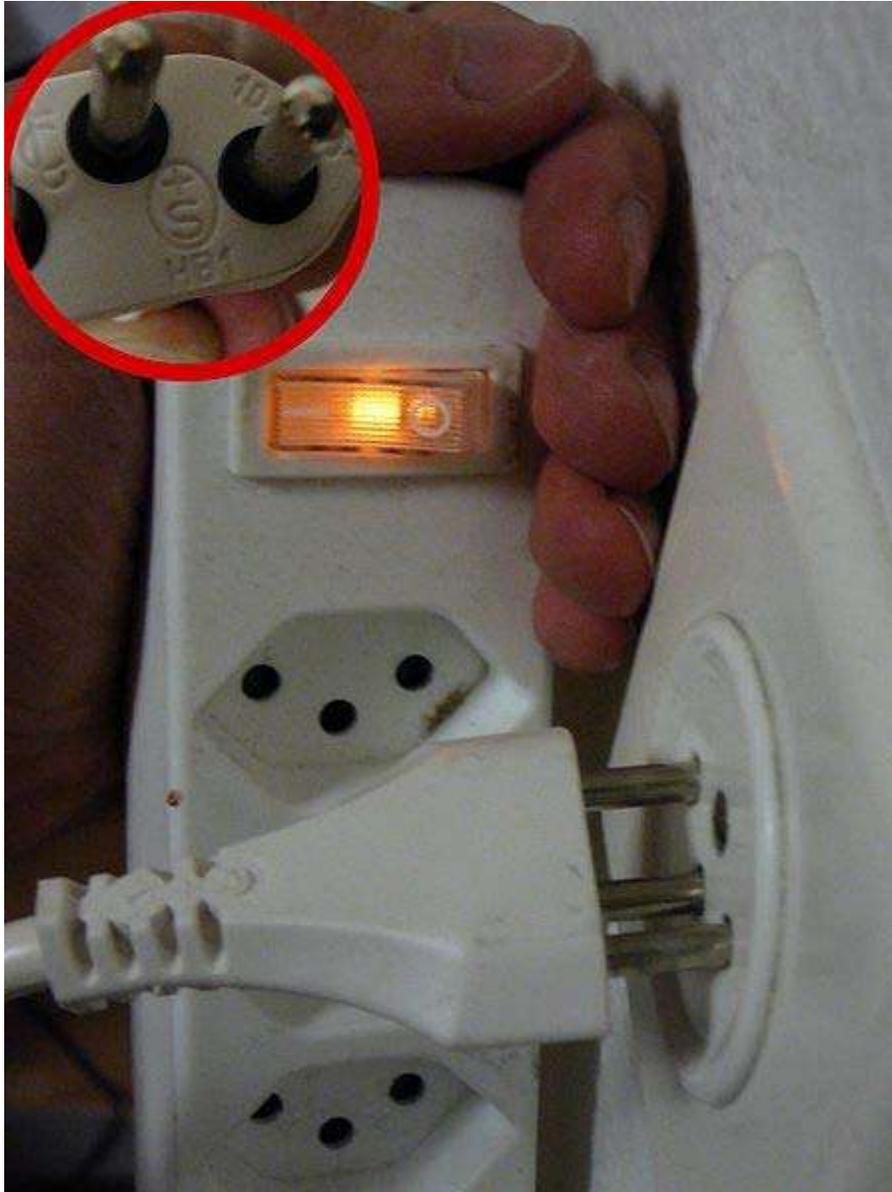
In Brazil, this kind of plug is still commonly found in high-power appliances like air conditioners, dishwashers, and household oven. Since the adopted IEC 60906-1 standard prescribes a high-current plug version, the original motivation to use the "Argentinian" plug ceased to exist, and the new standard should prevail in the long term.

## Type J

SEV 1011 (Swiss 10 A/250 V)



regular Type J plug and covered socket



Type J plugs and non-SEV 1011 socket showing a potential shock hazard: the appliance is energised although the plug is not fully inserted.

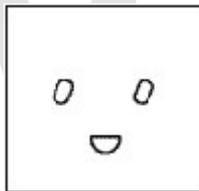
Switzerland has its own standard which is described in SEV 1011. (ASE1011/1959 SW10A-R) This plug is similar to the type C Europlug (CEE 7/16), except that it has an offset earth pin and the pin shanks are not insulated, so plugs partially inserted into non-recessed sockets present a shock hazard. Sockets used in kitchens, bathrooms and other wet areas are recessed, while those used elsewhere are not. Some plugs and adaptors have a tapered form and can be used in either environment, while others will fit only the non-recessed sockets. Swiss sockets accept Swiss plugs or Europlugs (CEE 7/16). There is also a non-earthed two-pin variant with the same pin shape, size, and spacing as the SEV 1011's live and neutral pins, but with a more flattened hexagonal form. It fits into round and hexagonal Swiss sockets and CEE 7/16 sockets, and is rated for up to 10 A.

A less-common variant has 3 square pins and is rated for 16 amperes. Above 16 amperes, equipment must either be hardwired to the electrical supply system with appropriate branch circuit protection, or connected to the mains with an appropriate high power industrial connector.

### Type K (Danish standard)



Danish 107-2-D1, standard DK 2-1a, with round power pins and half round ground pin



Outlet for Danish computer equipment plug's tilted flattened pins and half round ground pin (mainly used in professional environment), standard DK 2-5a  
Section 107-2-D1 (Danish 13 A/250 V earthed)

This Danish standard plug is described in the Danish Plug Equipment Section 107-2-D1 Standard sheet (SRAF1962/DB 16/87 DN10A-R). The plug is similar to the French type E except that it has an earthing pin instead of an earthing hole (and vice versa on the socket). This makes the Danish socket more unobtrusive than the French socket which is a cavity into the wall to protect the earthing pin from mechanical damage (and to protect from touching the live pins). The Danish standard provides for outlets to have child-resistant shutters.

The Danish socket will also accept the type C CEE 7/16 Europlug or type E/F CEE 7/17 Schuko-French hybrid plug. Type F CEE 7/4 (Schuko), type E/F CEE 7/7 (Schuko-French hybrid), and grounded type E French plugs will also fit into the socket but should not be used for appliances that need earth contact. The current rating on both plugs is 13 A.

A variation (standard DK 2-5a) of the Danish plug is for use only on surge protected computer outlets. It fits into the corresponding computer socket and the normal type K socket, but normal type K plugs deliberately don't fit into the special computer socket. The plug is often used in companies, but rarely in private homes.

There is a variation for hospital equipment with a rectangular left pin, it is used for life support equipment.

Traditionally all Danish sockets were equipped with a switch to prevent touching live pins when connecting/disconnecting the plug. Today, sockets without switch are allowed, but then it is a requirement that the sockets have a cavity to prevent touching the live pins. However, the shape of the plugs generally makes it difficult to touch the pins when connecting/disconnecting.

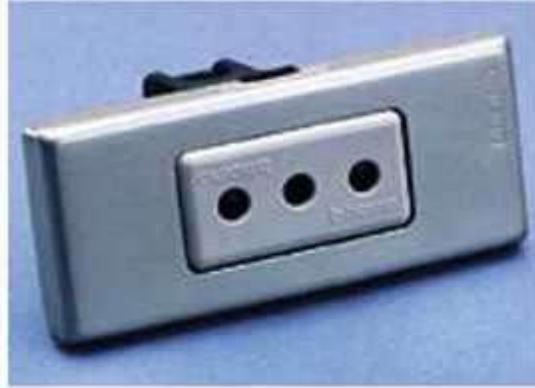
Since the early 1990s grounded outlets have been required in all new electric installations in Denmark. Older outlets need not be grounded, but all outlets, including old installations, must be protected by ground-fault interrupters (HFI or HPFI in Danish) by 1 July 2008.

As of 1 July 2008, wall outlets for type E (French 2-pin, female earth) are permitted for installations in Denmark. This was done because no electrical equipment sold to private users is equipped with a type K plug, and to break the monopoly of Lauritz Knudsen — the only company making type K sockets and plugs.

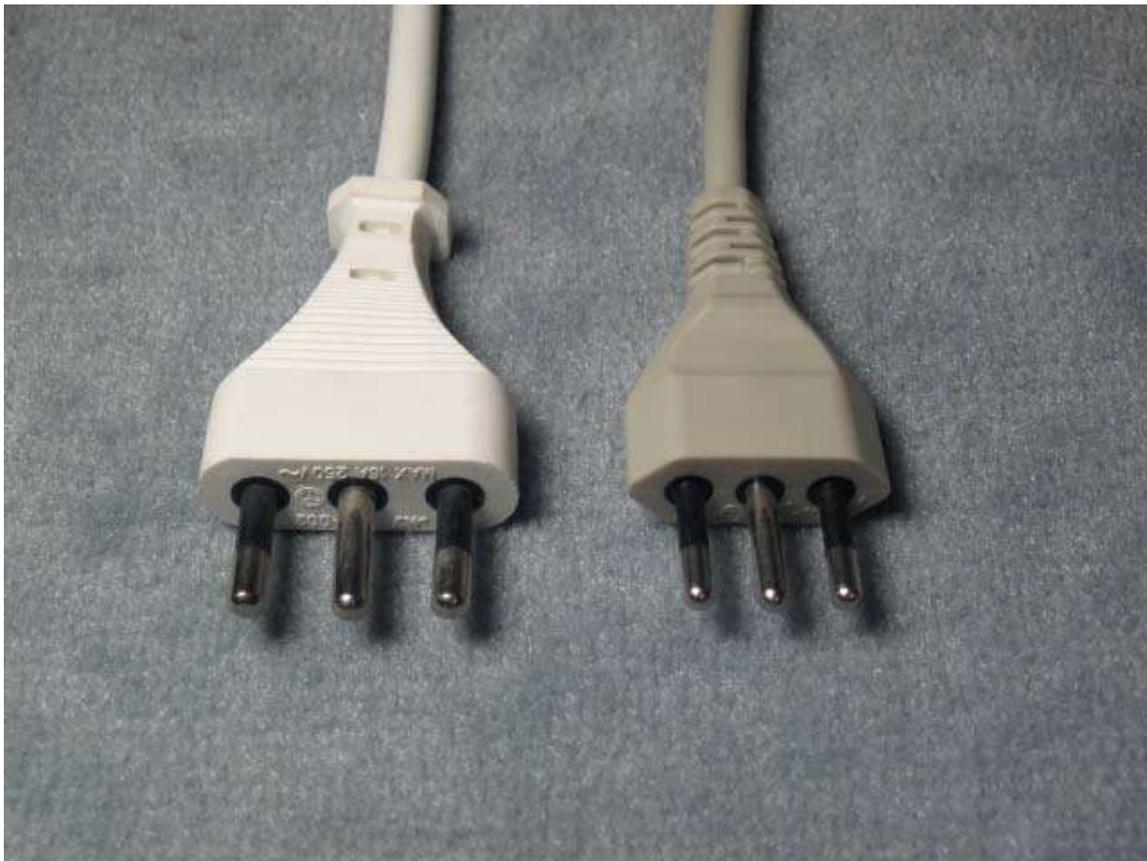
Sockets for the Schuko F type will not be permitted. The reason is that a large number of currently used Danish plugs (coincidentally made by the afore mentioned Lauritz Knudsen monopoly) will jam when inserted into a Schuko socket. This may cause damage to the socket. It may also result in a bad connection of the pins, with resultant risk of overheating and fire. Broken type F sockets are often seen in German hotels visited by Danes. Many international travel adapter sets sold outside Denmark match type C CEE 7/16 (Europlug) and type E/F CEE 7/7 (Schuko-French hybrid) plugs which can readily be used in Denmark.

### **Type L**

CEI 23-16/VII (Italian 10 A/250 V and 16 A/250 V)



23-16/VII plug with socket



Side by side comparison of Italian type L plugs rated 16 amperes (left) and 10 amperes (right).



An Italian installation carrying both Italian type L sockets (16 A on the left; 10 A on the right).

The Italian earthed plug/socket standard, CEI 23-16/VII, includes two models rated at 10 A and 16 A that differ in contact diameter and spacing. Both are symmetrical, allowing the live and neutral contacts to be inserted in either direction.

The double standard was initially adopted because in Italy, up to the second half of the twentieth century, the electric power used for lamps (*Luce* = lighting) and the one used for all other appliances (*Forza* = electromotive force; or *Usa Promiscuo* = general purpose) were sold at different fares, charged with different taxes, accounted with separated electricity meters, and sent on different wire lines that ended with different sockets. Even though the two electric lines (and respective fares) were definitively unified during the summer of 1974 many houses kept twin wires and twin electricity meters for years thereafter. The two gauges for plugs and sockets thus became a de facto standard which is still in use today and has been standardized with CEI 23-16/VII. Older installations often have sockets that are limited to either the 10 A or the 16 A style plug, requiring the use of an adapter if the other gauge needs to be connected.

CEE 7/16 (type C) ungrounded Europlugs are also in common use; they are standardized in Italy as CEI 23-5 and fit most of the appliances with low current requirement and double insulation.

Appliances with CEE 7/7 Schuko-French plugs are often sold in Italy too; however not every socket will accept them since the pins of the CEE 7/7 Schuko-French plugs are thicker than the Italian ones. Adapters are cheap and commonly used to connect CEE 7/7 plugs to CEI 23-16/VII sockets, though the power rating may be mismatched (16 A to 10 A) and may lead to potentially unsafe connection in some cases.

The current Italian standard provides for outlets to have child-resistant shutters.

CEI 23-16/VII (Italian 10 A/250 V)

The 10 (former 6) amperes style extends CEE 7/16 by adding a central earthing pin of the same gauge. Thus, CEI 23-16-VII 10 A sockets can accept CEE 7/16 Europlugs. This is the plug shown in the first picture.

CEI 23-16/VII (Italian 16 A/250 V)

The 16 amperes style looks like a magnified version of the 10 A style, identical in shape. However, the pins are 5 mm (0.197 in) thick (being 4 mm (0.157 in) thick in 10 A type), 8 mm (0.315 in) apart (while 5.5 mm (0.217 in) apart in 10 A type) and 7 mm (0.276 in) longer. The packaging of these plugs in Italy may claim they are a "North European" type. In the past they were also referred to as *per la forza motrice* (for electromotive force, see above) or sometimes *industriale* (industrial), although the latter has never been a correct definition as factories used predominantly three-phase current and specialized connectors.

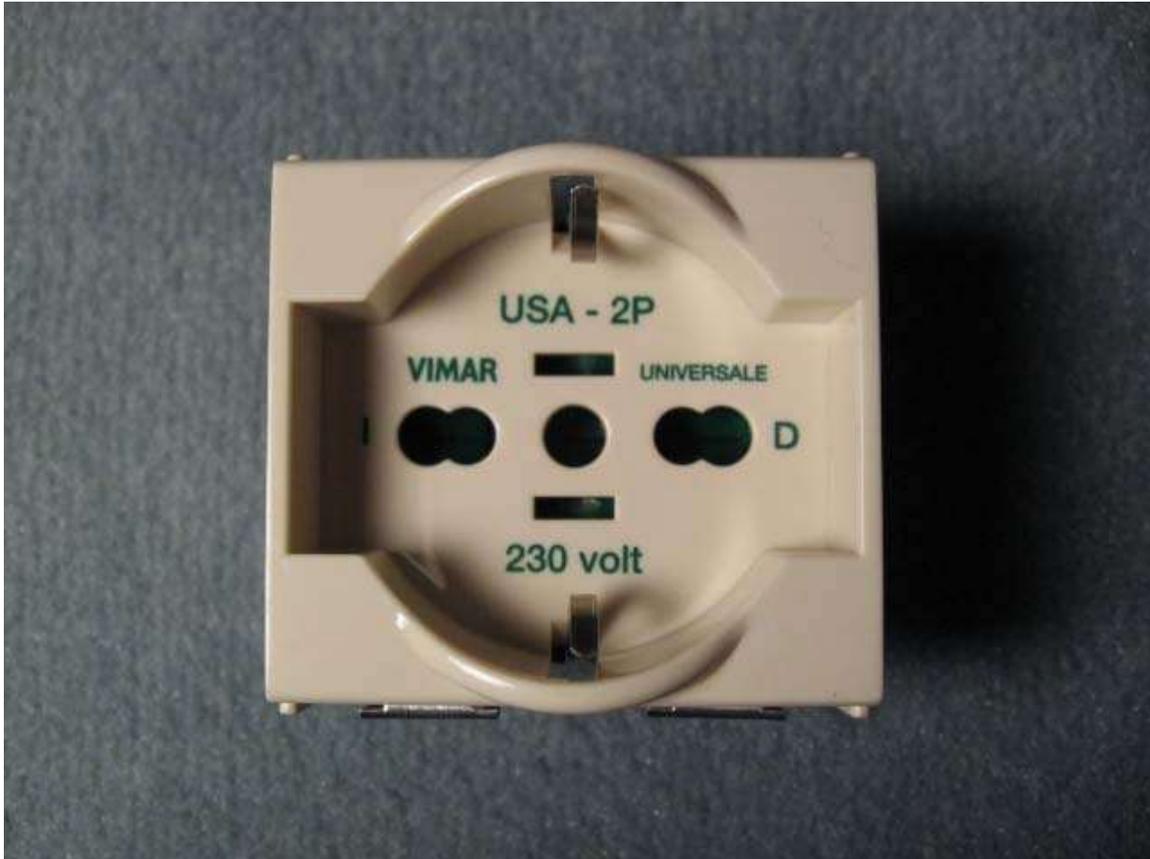
Twin-gauge or multi-type sockets



A *bipasso* socket (number 1) and an Italian adapted *schuko* (number 2 in the photo) in a modern installation.

Given that the plug with which appliances are fitted and sold varies, modern installations in Italy (and in other countries where type L plugs are used) are likely to use sockets that can accept more than one standard. The simpler type has a central round hole and two 8-shaped holes above and below. This design allows the connection of both styles of type L

plugs (CEI 23-16/VII 10 A and 16 A) and the type C CEE 7/16 Europlug. The advantage of this socket style is its small, compact face. VIMAR brand claims to have patented this socket first in 1975 with their *Bpresa* model; however soon other brands started selling similar products mostly naming them with the generic term *presa bipasso* (twin-gauge socket) that is now of common use.



An Italian VIMAR brand *universale* socket which can accept type C (most sorts of), F, and E/F hybrid plugs as well as both 10 A and 16 A type L plugs.

A second, quite common type looks like a type F socket, but adds a central grounding hole. This design can accept CEE 7/7 (type E/F) plugs, in addition to type C and type L 10 A plugs. Some of these sockets may also have 8-shaped holes to accept type L 16 A plugs as well. One drawback is that it is twice as large as a normal type L socket; also, 90° angled type L plugs often do not fit these sockets because they are too much recessed.

Other types may push compatibility even further. The VIMAR-brand *universale* (all purpose) socket, for example, accepts CEE 7/7 (type E/F) plugs, type C plugs, both 10 A and 16 A type L plugs, and American/Japanese type A plugs as well.

Other countries

Outside of Italy, type L CEI 23-16/VII (Italian 10 A/250 V) plug is found in Syria, Libya, Ethiopia, Chile, Uruguay, various countries in North Africa, and occasionally in older buildings in Spain.

### **Type M**

BS 546 (South African 15 A/250 V)

Type M is sometimes used to describe the 15 A version of the old British type D, used in South Africa and elsewhere.

### **North American oven and dryer outlets**

NEMA 14–30

A 30 amperes, 3 wire single-phase grounding receptacle is often used for electric clothes dryers. 240 volts from the split phase system is used for the heating elements, and the motor and controls run on 120 volts.

NEMA 14–50

A 50 amperes 3 wire single-phase grounding outlet is usually installed in kitchens and used for electric cooking ranges and ovens. As for dryers, lighting and motors run on 120 V and the main heating element is connected for 240 V.

## ***Proposed common standard***



A Brazilian socket for 20 A/250 V, meant for use with larger pins than 10 A version IEC 60906-1 (Brazilian 10 A and 20 A /250 V - NBR 14136:2002)

In 1986, the International Electrotechnical Commission published IEC 60906-1, the specification for a plug that looks similar but is not identical to the Swiss (Type J) plug. This plug was intended to one day become the common standard for all of Europe and other regions with 230 V mains, but the effort to adopt it as a European Union standard was put on hold in the mid 1990s.

Brazil, which had been using mostly Class II Europlugs (while households also commonly presenting socket fittings for the NEMA 1–15 and NEMA 5–15 standards), set out IEC 60906-1 as the national standard in 2001 under specification NBR 14136. However, this standard was never really enforced or encouraged in that country until 2007, when the adoption of IEC 60906-1 was made optional for manufacturers. Also, it helped domestic consumers that most of Class II plugs fitted in the new IEC 60906-1 socket.

Since January 1, 2010, new electrical appliances in Brazil must now comply with the new IEC 60906-1 requirement. End-user stores and resellers can sell equipments without adoption deadlines, but importers will no longer be allowed to bring in nonconforming devices, nor will manufacturers be able to sell them in Brazil.

There are two types of sockets and plugs in this system: one for 10 A, with a 4mm pin diameter, and another for 20 A, with a 4.8 mm pin diameter, the latter used for heavier appliances such as microwave ovens.

South Africa has also introduced the IEC 60906 standard as SANS 164-2 in parallel with the types C and M standard.

### **Comparison of plugs**

Type	Plug standard	Power rating	Grounded	Polarised	Fused	Insulated pins
A	NEMA 1–15 unpolarised	15 A/125 V	No	No	No	No
	NEMA 1–15 polarised	15 A/125 V	No	Yes	No	No
	JIS C 8303, Class II	15 A/100 V	No	No	No	No
B	NEMA 5–15	15 A/125 V	Yes	Yes	No	No
	NEMA 5–20	20 A/125 V	Yes	Yes	No	No
	JIS C 8303, Class I	15 A/100 V	Yes	Yes	No	No
C	CEE 7/16 (Europlug)	2.5 A/250 V	No	No	No	Yes
	CEE 7/17	16 A/250 V	No	No <sup>1</sup>	No	No
	GOST 7396 C 1	6 A/250 V 16 A/250 V	No	No	No	No
D	BS 546 (2 pin)	2 A/250 V 5 A/250 V = BS 4573	No	No	No	No
	BS 546 (3 pin)	2 A/250 V 5 A/250 V 15 A/250 V = SABS 164 30 A/250 V	Yes	Yes	No	No
E	CEE 7/5	16 A/250 V	Yes	Yes	No	No
F	CEE 7/4 (Schuko)	16 A/250 V	Yes	No	No	No
E+F	CEE 7/7	16 A/250 V	Yes	Yes <sup>2</sup>	No	No
G	BS 1363, IS 401 & 411, MS 589, SS 145	13 A/230-240 V	Yes	Yes	Yes	Yes

H	SI 32	16 A/250 V	Yes	Yes	No	No
	TIS 166–2549	16 A/250 V	Yes	Yes	No	Yes
I	AS/NZS 3112	10 A/240 V	Yes and No	Yes	No	Yes
		20 A/240 V				
		25 A/240 V				
32 A/240 V						
	CPCS-CCC	10 A/250 V	Yes	Yes	No	No
	IRAM 2073	10 A/250 V	Yes	Yes	No	No
J	SEV 1011	10 A/250 V 16 A/250 V	Yes	Yes	No	No
K	Section 107-2-D1	13 A/250 V	Yes	Yes	No	No
L	CEI 23-16/VII	10 A/250 V 16 A/250 V	Yes	No	No	Yes
-	IEC 60906-1 (2 pin)	10 A and 20 A/250 V	No	No	No	Yes
	IEC 60906-1 (3 pin)	10 A and 20 A/250 V	Yes	Yes	No	Yes

<sup>1</sup> There are some CEE 7/17 plugs with special shape which are polarised when used with french socket of type E (mechanically only)

<sup>2</sup> Plug can only be inserted one way with French socket of type E, but lack of wiring convention means that the type is not polarised in practice

### **Multi-standard sockets**

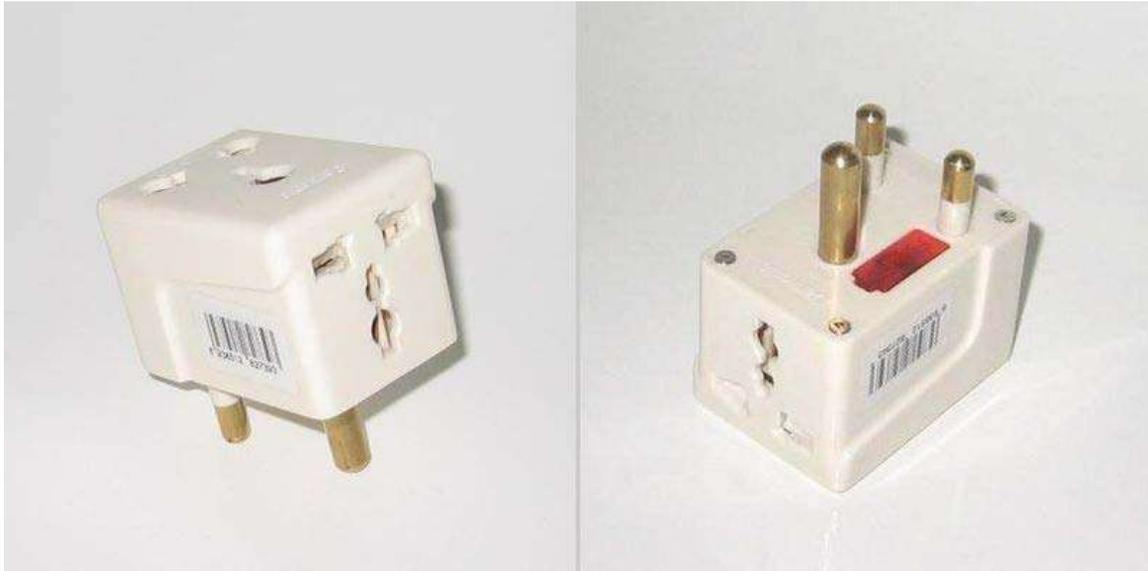


A standard grounded **Thai** outlet supporting European 2-pin plugs and earthed and unearthed American plugs and Thai 3 pin plugs. Though this receptacle accepts standard US Type A or B plugs, the standard Thai voltage is 220 volts.

Sockets that take a variety of plug types can be found in various countries where market size or local market conditions make a specific plug standard impractical to implement. These socket accept plugs fitting various European, Asian and North American standards. Since many plug standards are also associated with corresponding voltages, multi-standard sockets do not safeguard against devices being damaged by the wrong voltage. This forces users to be aware of the voltage requirements of their appliances as well as the prevailing local voltage. Devices designed to adapt automatically to whatever voltage and frequency is supplied, and which don't require grounding, are generally safe to use with these sockets.

These sockets have one or more ground holes to allow 3-pin plugs. On properly wired circuits, the ground contact may be actually grounded; however, as with most other forms of plugs, they are not immune to poor wiring. They may also not provide grounding to all types of plugs, as is the case of Schuko or French plugs where the grounding pin that mates with the plug is part of the socket rather than the plug.

### **Adapters**

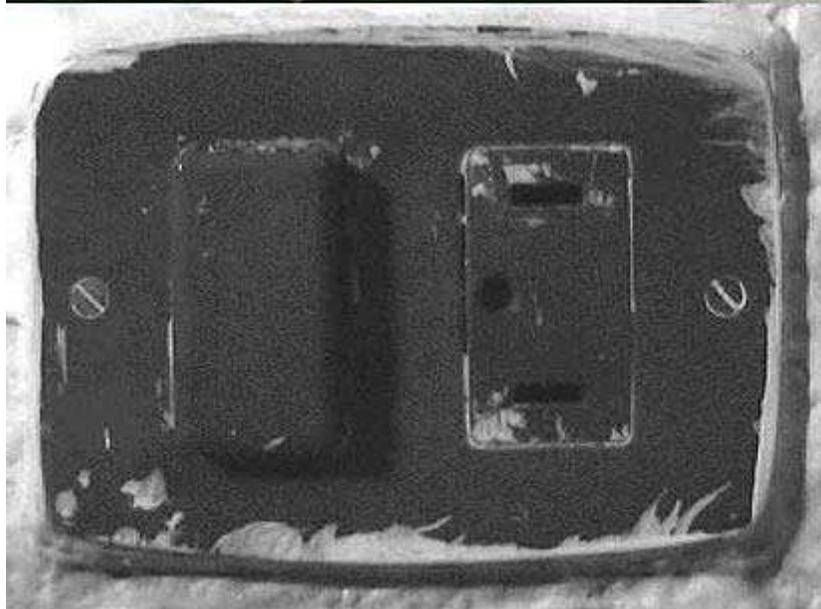


A type M (15 A version of type D) travel adapter

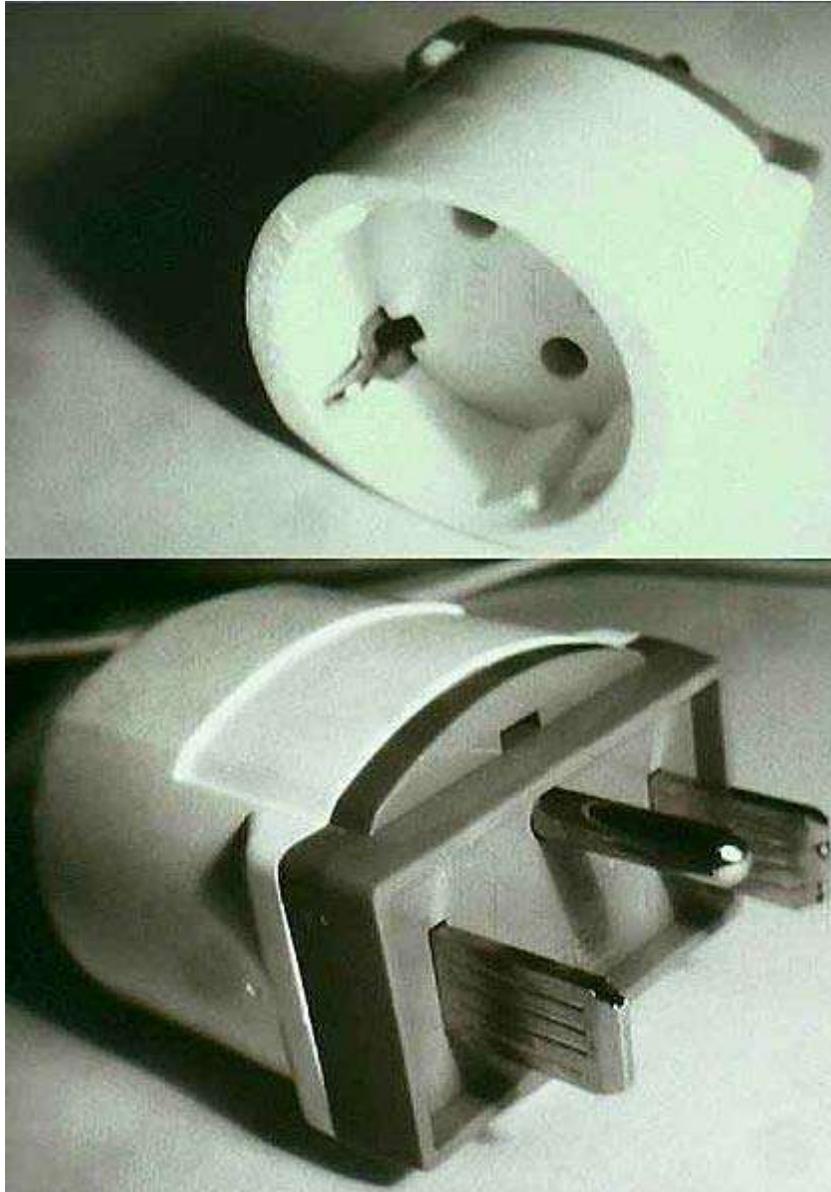
To facilitate travelers' use of personal electric devices, adapters are available to permit the interconnection of normally incompatible plugs and sockets. Such adapters overcome only the physical incompatibilities between plugs and sockets built to different standards; often a voltage converter is required for electrical compatibility.

***Obsolete types***

**Old Spanish sockets**



Spanish three-prong plug and socket, with easily removable fuse



An adapter to allow types C and F to be inserted

Some older industrial buildings in Spain used sockets that took a particular type of plug which was rated for higher current and had two flat contacts and a round ground pin, somewhat similar in design to the ones found on American plugs but larger in size.

The live and neutral measure 9 by 2 mm (0.354 by 0.079 in), and are 30 mm (1.181 in) apart. All three pins are 19 mm (0.748 in) long, and the earth pin is a cylinder of 4.8 mm (0.189 in) diameter.

While the plug resembles an American connector, the two flat contacts are much wider apart than on a standard American plug, which will therefore not fit in these sockets.

No domestic appliances were ever sold with these plugs.

### **UK electric clock connector**



British electric clock connector, 3-pin made by MK. Showing the rear of the plug with its 2 A fuse. Different manufacturers' clock connectors were generally not compatible.

Fused plugs and sockets of various proprietary and non-interchangeable types are found in older public buildings in the UK, where they are used to feed AC electric wall clocks. They are smaller than conventional socket outlets, commonly being made to fit BESA junction boxes, and are often of very low profile. Early types were available fused in both poles, later types fused in the live only and provided an earth pin. Most are equipped with a retaining screw or clip to prevent accidental disconnection. The prevalence of battery powered quartz controlled wall clocks has meant that this connector is rarely seen in new installations.

## NEMA 1-15 5-receptacle Type A outlet



Unusual American 5-receptacle Type A outlet, ca. 1928

This is a very rare 5-way outlet from circa 1928, and is able to accept modern ungrounded polarized NEMA 1-15 plugs because the outlet itself is polarized. However, the outlet itself is still obsolete as the NEMA standard only provides for having at most 3 outlets from a single wallplate.

## American "Type I"



American Type I duplex outlet



### Compatibility of American and Australian Type I plugs

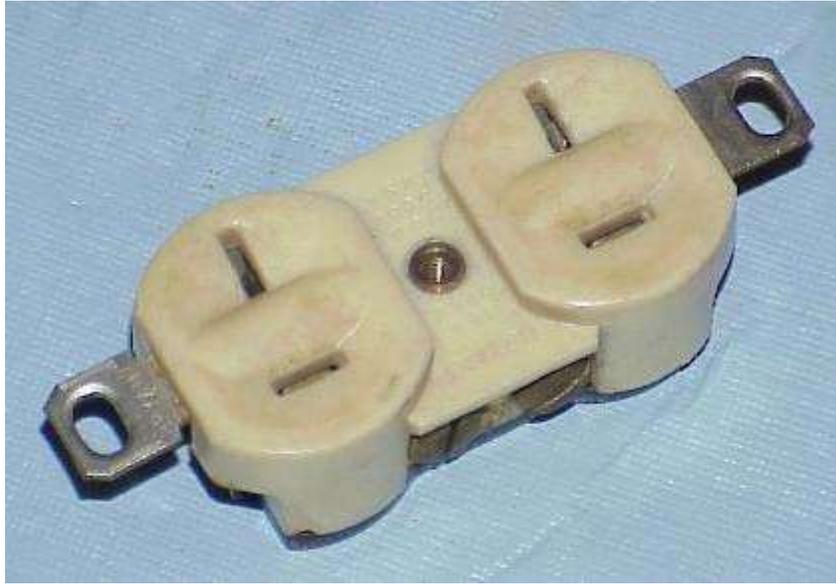
The American electrical supply manufacturers Hubbell, Eagle, and possibly others made outlets and plugs that would match Type I plugs and sockets exactly. Type I connectors are used in Australia for 240 V service. These American outlets date back to at least 1915 (as seen in US Patent 1,179,728 filed in 1915), antedating the American 3 prong Type B sockets and plugs. They were meant for appliances that needed grounding (120 V at 15 amperes), and to be used in laundry rooms for washing machines and gas dryers (to power the motor). These did not become popular because American type A 2-prong plugs would not fit.

### Split current/voltage ratings

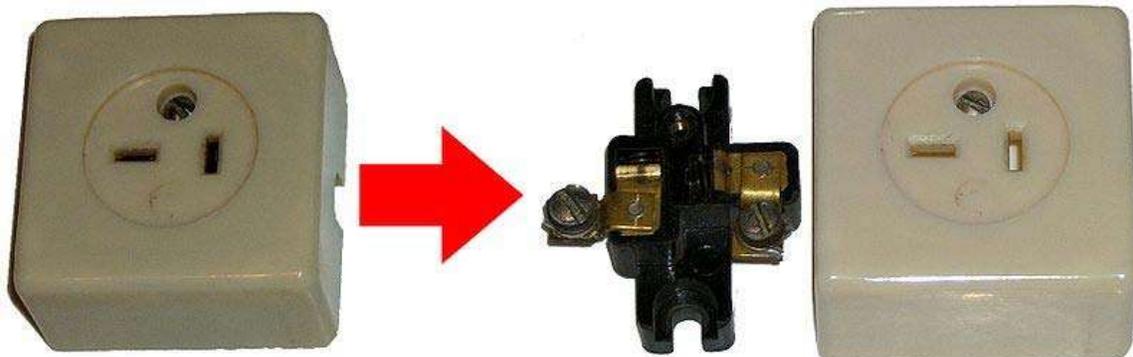
Many older North American receptacles have two different current and voltage ratings, most commonly 10 A 250 V/15 A 125 V. This has to do with a peculiarity of the National Electrical Code from 1923 to the 1950s. Originally, receptacles were rated at 10 A 250 V, because the NEC limited lighting circuits to 10 amperes. In 1923, the code changed to allow lighting circuits to be fused at 15 amperes; however, the old rule still applied to circuits over 125 volts. The higher voltages were rarely used for lighting and appliances. Most receptacles with this rating are of the "T-slot" type. This type of rating was phased out in the 1950s, and finally abolished in the 1960s with the adoption of the current NEMA standards.

Pre-NEMA *twist-lock* devices can sometimes be found with split 250/600 V ratings. These are also obsolete.

## U.S. perpendicular outlet



Perpendicular slot duplex outlet



**Розетка РП-2Б ~10А 42В**

Perpendicular slot RP-2B outlet 10 A 42 V AC

Another obsolete outlet, made by Bryant, 125 V 15 A and 250 V 10 A rating. A NEMA 5–20 125 V 20 A or 6–15 250 V 15 A plug with a missing ground pin would fit this outlet, but a NEMA 2–20 plug is slightly too big to fit.

The upper slots as seen in the illustration connect to silver-colored wiring screws on the upper side, and the lower slots connect to brass-colored wiring screws on the lower side.

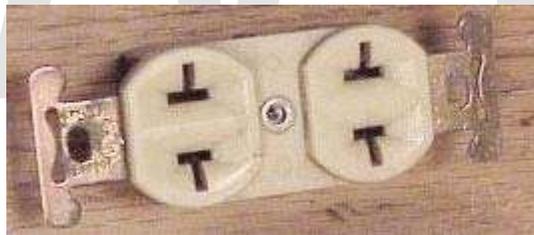
In Australia, the same or similar T-configuration sockets are used for DC power outlets, such as in stand-alone power systems (SAPS) or on boats.

In Soviet Union and now Russia this socket is commonly used for wiring in places where the voltage is lowered for safety purposes, like in schools, gas stations or in wet areas, rated 42 V 10 A AC. Such an unusual connection is intended specifically to make the connection of standard higher-voltage equipment impossible.

### **U.S. Combination duplex outlet**



An extremely old "Nurpolian"-brand black parallel and tandem duplex outlet rated at 250 V 10 A (although this type was normally supplied with 120 V).



T-slot duplex outlet.

The parallel and tandem outlet accepts normal parallel NEMA 1–15 plugs and also tandem NEMA 2–15 plugs. Both pair of receptacles are fed internally by the same supply.

A more recent and fairly common version of this type is the T-slot outlet, in which the locations of the tandem and the parallel slots were combined to create T-shaped slots. This version also accepts normal parallel NEMA 1–15 plugs and also tandem NEMA 2–15 plugs. Incidentally, a NEMA 5–20 (125 V, 20 A), a NEMA 6-15 (250 V, 15 A) or 6–20 (250 V, 20 A) plug with a missing ground pin would fit this outlet. This type is no longer available in retail shops since the 1960s.

## U.K. Dorman & Smith (D&S)



D&S Socket

The D&S plugs and sockets were rated at 13 amperes and were one of the early competing types for use on ring main circuits. They were never popular in private houses but were widely deployed in prefabricated houses and council housing. The BBC also used them. D&S supplied the sockets to local authorities at very low cost, with the intention of making money out of the sales of plugs typically priced at 4 times the price of a type G plug. It is not known exactly when D&S ceased manufacturing the plugs and sockets but some local authorities continued to use them in new installations until the late 1950s. Many D&S sockets were still in use until the early 1980s, although the difficulty in obtaining plugs for them after around 1970 often forced their users to replace them with type G sockets. This generally violated local authority regulations on alterations to council housing. The D&S plug suffered from a serious design fault: the live pin was a fuse which screwed into the plug body and tended to come unscrewed on its own in use. A fuse that worked loose could end up protruding from the socket, electrically live and posing a shock hazard, when the plug was removed.

## U.K. Wylex Plug



Wylex 13A Plug

The Wylex plugs and sockets were produced by Wylex Electrical Supplies Ltd. as a competitor to the type G and D&S sockets for use on ring main circuits. The plugs were available in both 5 A and 13 A versions, differing only by the widths of the live and neutral pins, and contained an internal fuse of the same rating as the plug. A plug had a central round earth pin and two flat pins, one on each side of the earth pin, for live and neutral. The two flat pins were slightly offset above and below the line cutting through the horizontal diameter of the earth pin. Wall sockets were rated at 13 amperes and took both 5 A and 13 A plugs. Many 13 A plugs had a socket on the back which took a 5 A plug, but would not take another 13 A plug because the slots for the live and neutral pins were narrower than those of the wall sockets, resulting in a stacked arrangement. Wylex sockets were used in council housing and public sector buildings, and for a short while in private housing. They were particularly popular in the Manchester area although they were installed throughout England, mainly in schools, university accommodation, and government laboratories. Wylex plugs and sockets continued to be manufactured for several years after type G sockets became standard and were commonly used by banks and in computer rooms during the 1960s and 70s for uninterruptible power supplies or "clean" filtered mains supplies. It is not known exactly when Wylex ceased manufacturing its plugs and sockets; however plugs were available in electrical shops of the Manchester area until the mid 1980s.

### Lampholder plug



Two Italian bypass lampholder plugs with Edison screw mount. Left: early type (porcelain and brass, circa 1930); right: late type (black plastic, circa 1970).

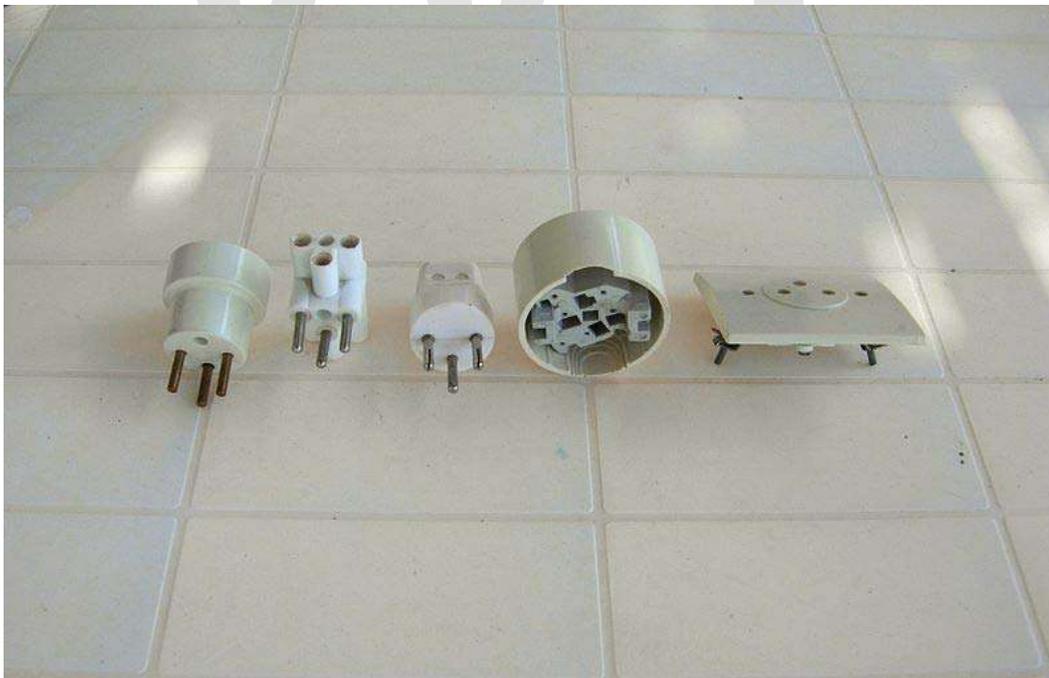
A lampholder plug fits into the Bayonet cap or Edison screw socket of a lampholder in place of a light bulb and enables an electrical appliance to be powered from a wall or ceiling light fitting. They were commonly used during the 1920s to 1960s when wall sockets were scarce or nonexistent in many houses. Lampholder plugs were rarely fused.

Conventional practice in the U.K. is to protect lighting circuits with a 5 A or 6 A fuse or circuit breaker, which will rapidly blow or trip when one attempts to utilise a lampholder plug to power an appliance requiring significantly more than 5 A or 6 A. If the current-draw is only slightly higher (e.g. 45%) than the circuit breaker rating, the circuit breaker may take more than 1 minute to trip and can take 1 hour to trip with a current that is 10% above the rating of the circuit breaker. Wiring regulations in the U.K. and some other countries no longer approve lampholder plugs because of the risks of overheating and fire.

In Italy, bypass lampholder plugs with Edison screw mount were in broad use until light wire cables were separated from general purpose wire cables and some areas of the house (cellars, etc.) were commonly not provided with sockets.

Edison screw lampholder adaptors (for Type A plugs) are still easily found and commonly used in the Americas.

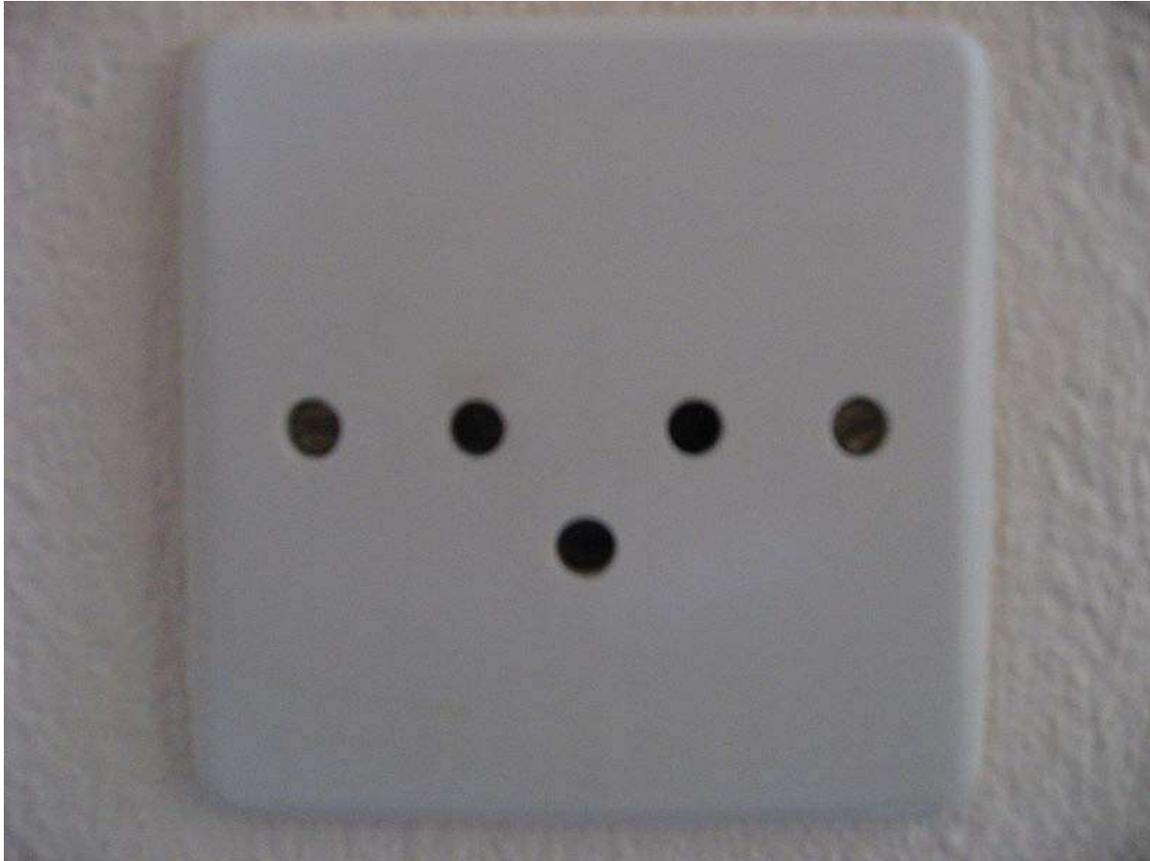
### **Old Greek sockets**



old earthed standard adaptor



plugs



socket

Called "Tripoliki" the 3 Pin round standard similar to type J and post-1989 type H, virtually abandoned by 1995.

Previous to the large-scale adoption of schuko plugs, this was the only way to use an earthed appliance.

### ***Unusual types***

#### **NEMA 2–15 and 2–20**

These ungrounded plugs with two flat parallel prongs are variants of the 1–15 but are intended to deliver 240 volts instead of 120. The 2–15 has coplanar current prongs (rotated 90° from ordinary American plugs), and is used for 240 V service at 15 amperes, while the 2–20 has the two current prongs rotated 90° relative to each other (one vertical, one horizontal) and is used for 240 V service at 20 amperes. NEMA 2 plugs and sockets are rare because they have been prohibited for household use in the United States and Canada for several decades. They are potentially hazardous since they have no ground or neutral, and in some cases plugs can be inserted into incorrect-voltage sockets. Prior to the adoption of the NEMA standard, a plug nearly identical to the 2–20 was used for 120

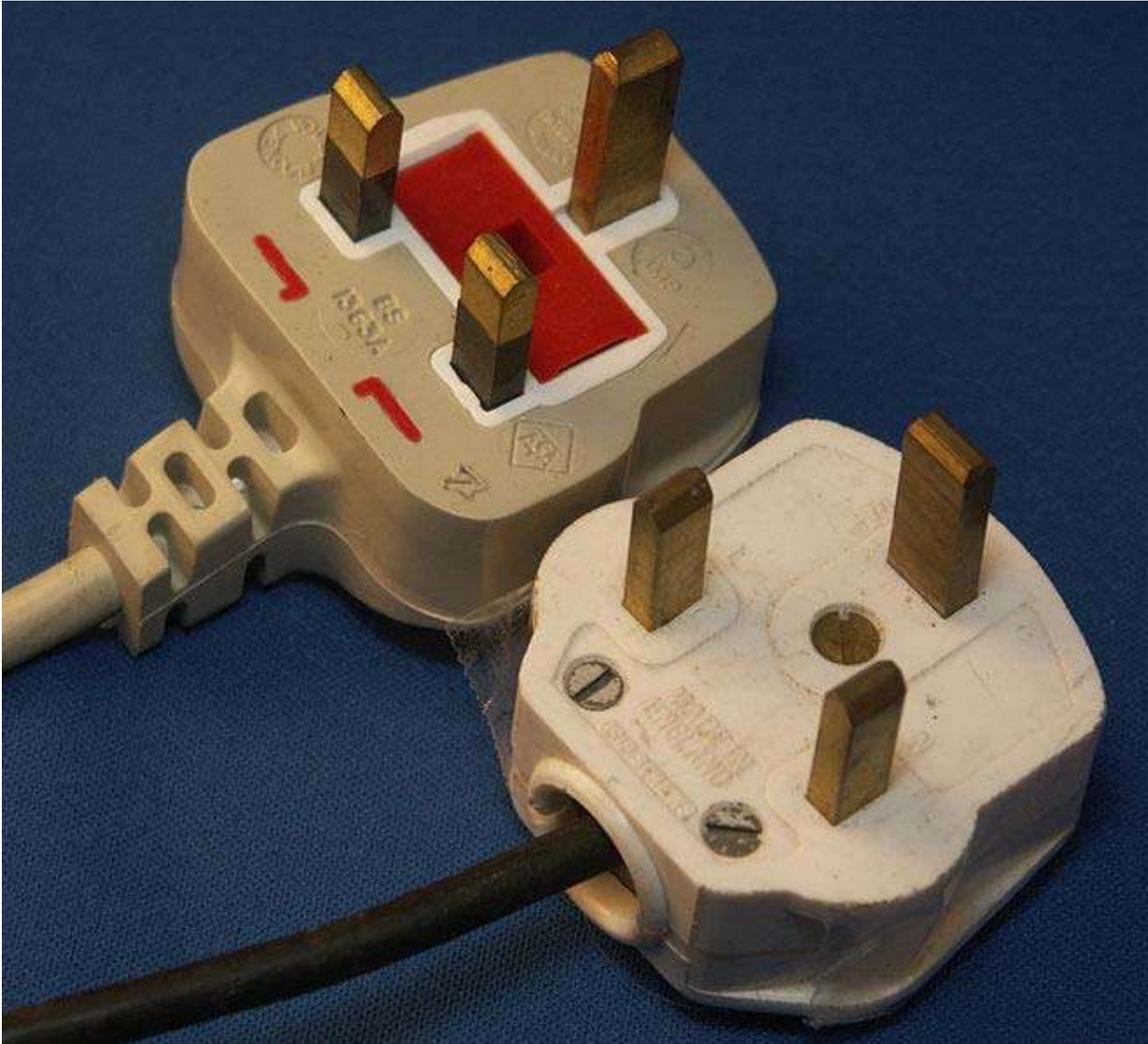
V at 20 A. That obsolete plug would fit into 5–20 and 6–20 sockets, which supply different voltages, but the NEMA 2-20 plug is dimensionally incompatible.

### **Soviet adaptor plugs**



Some appliances sold in the Soviet Union had a flat unearthed plug with an additional pass-through socket on the top, allowing stacked arrangement of plugs. This design was very helpful (for the usual Soviet apartment of the 1960s had very few wall sockets), but completely unsafe, as the brass cylinders of the secondary socket were uncovered at the ends (to unscrew them easily), recessed only for 3 mm and provided bad contact because they relied on the secondary plug's bisected expanding pins. The pins of the secondary plug (without insulation sleeves) could not be inserted into the cylinders completely, and were accessible through a 5mm gap between the primary and secondary plugs.

## U.K. Walsall Gauge plug



Walsall Gauge 13 A plug (bottom) compared to regular BS 1363 plug

Unlike the standard BS 1363 plugs found in the U.K., the earth pin is on a horizontal axis and the live and neutral pins on a vertical axis. This style of plug/socket was used by University laboratories (from batteries) and the BBC, and is still in use on parts of the London Underground for 220V DC voltage supply.

**Italian Bticino brand Magic security connector**



Bticino Magic Security receptacle, detail.



assortment of Magic Security receptacles (in orange, the industrial three-phase type).



assortment of Magic Security plugs.

This style of connector, produced by Italian brand Bticino, appeared in the 1960s and was intended as an alternative to the Europlug or type L connectors then in use. The socket is an almost rectangular receptacle, with one or more lateral key pins and indents to prevent inverting the plug (it is polarised), or connecting plugs and sockets with different ampere ratings. At least four models were produced: three single-phase general purpose connectors rated respectively 10 A, 16 A and 20 A; plus a three-phase industrial connector rated 10 A; all of them have different key-pin positioning so plugs and sockets cannot be mismatched. The socket is closed by a safety lid (bearing the word "Magic" on it) which can be opened only with an even pressure on its surface, thus preventing the insertion of objects (except the plug itself) inside the socket. The contacts are blades positioned on both sides of the plug; the plug is energized only when it is inserted fully into the socket.

The obvious drawback of the system is that it is not compatible with europlugs. As household appliances were never sold fitted with these security plugs and the use of adapters would defeat all of the newly introduced safety features, once this system is adopted all standard plugs must be cut off and replaced with the appropriate security connector. However, the *Magic* security system had some success at first because its enhanced safety features appealed to customers; standard connectors of the day were considered not safe enough. The decline of the system occurred when safety lids similar

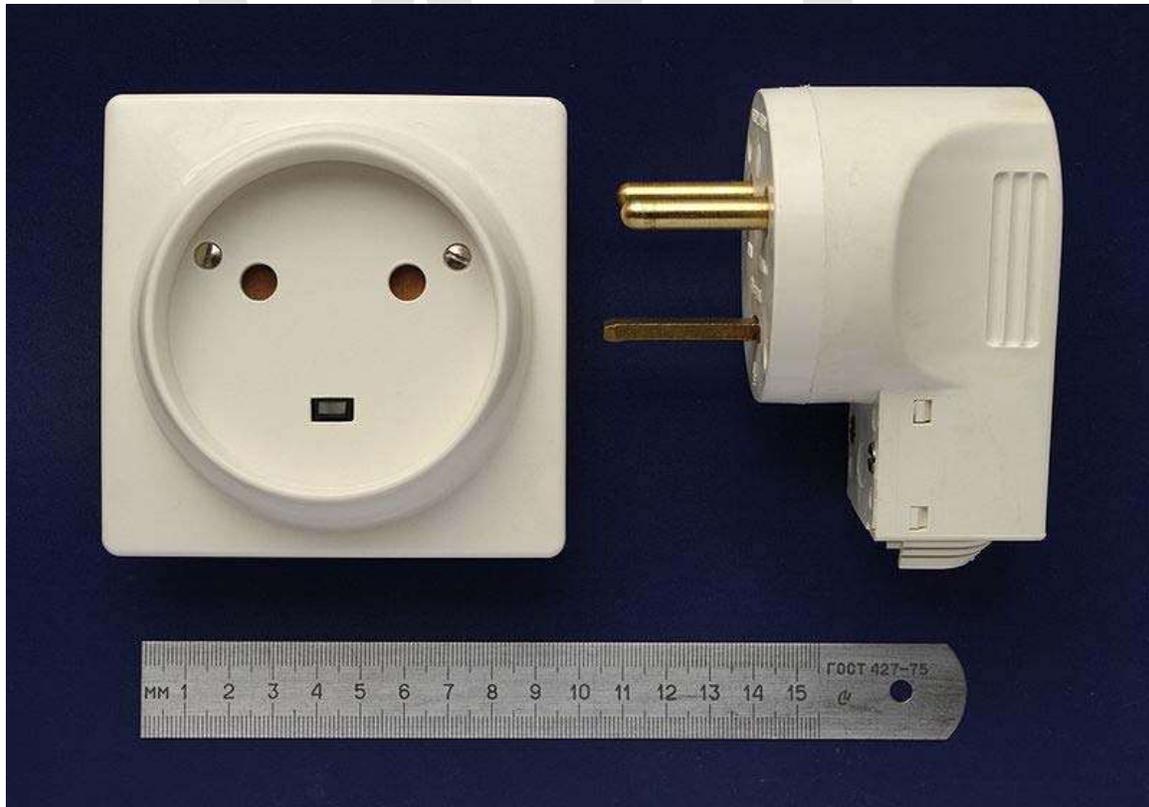
to the Magic type were developed (VIMAR Sicury) and then applied to standard type L sockets by third brands and by Bticino itself.

In Italy, the system was never definitively abandoned and, though rarely seen today, is still marked as available in Bticino's products catalogue.

In Chile, 10 [A] Magic connectors are commonly used for computer/laboratory power networks, as well as for communications or data equipment. This allows delicate electronics equipment to be connected to an independent circuit breaker, usually including a surge protector or an uninterruptible power supply backup. The different style of plug makes it more difficult for office workers to connect computer equipment to a standard unprotected power line, or to overload the UPS by connecting other office appliances.

In Iceland, Magic connectors were widely used in homes and businesses alongside Europlug and Schuko installations. Their installation in new homes was still quite common even in the late 1980s.

### ***Single phase electric stove plugs and sockets***



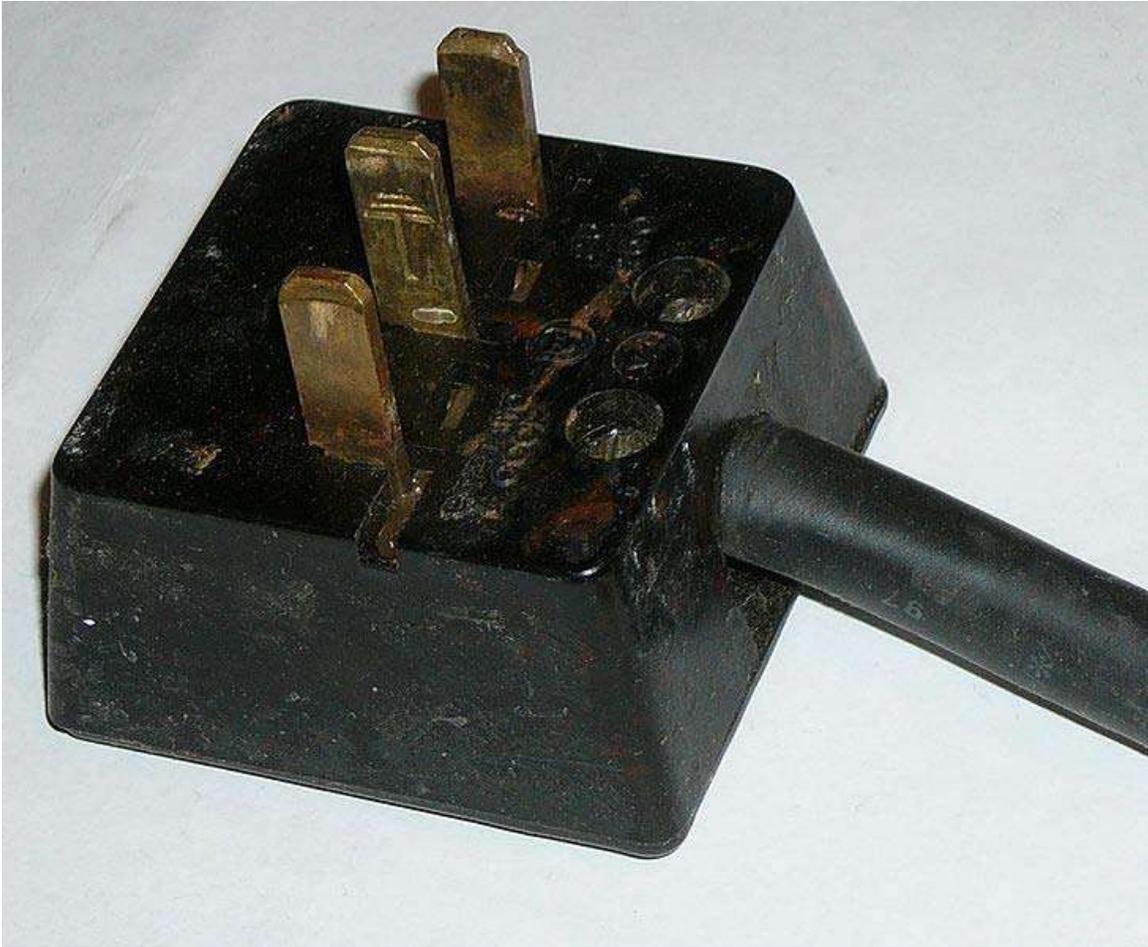
Power connector Legrand (400 V, 32 A)



Russian stove connectors rated for 250 V 25 A AC



plug and socket. Center: Socket.



Right: Plug.

The plugs and sockets used to power electric stoves from a single-phase line have to be rated for greater current values than ones for three-phase system because all the power has to be transferred through a single line. Electric stoves are often hardwired to the electrical supply system, connected to the mains with an appropriate high power industrial connector or with non-standard high power proprietary domestic connector (as some countries do not have wiring regulations for single-phase electric stoves). In Russia an electric stove can be often seen connected with an 25–32 amperes connector.