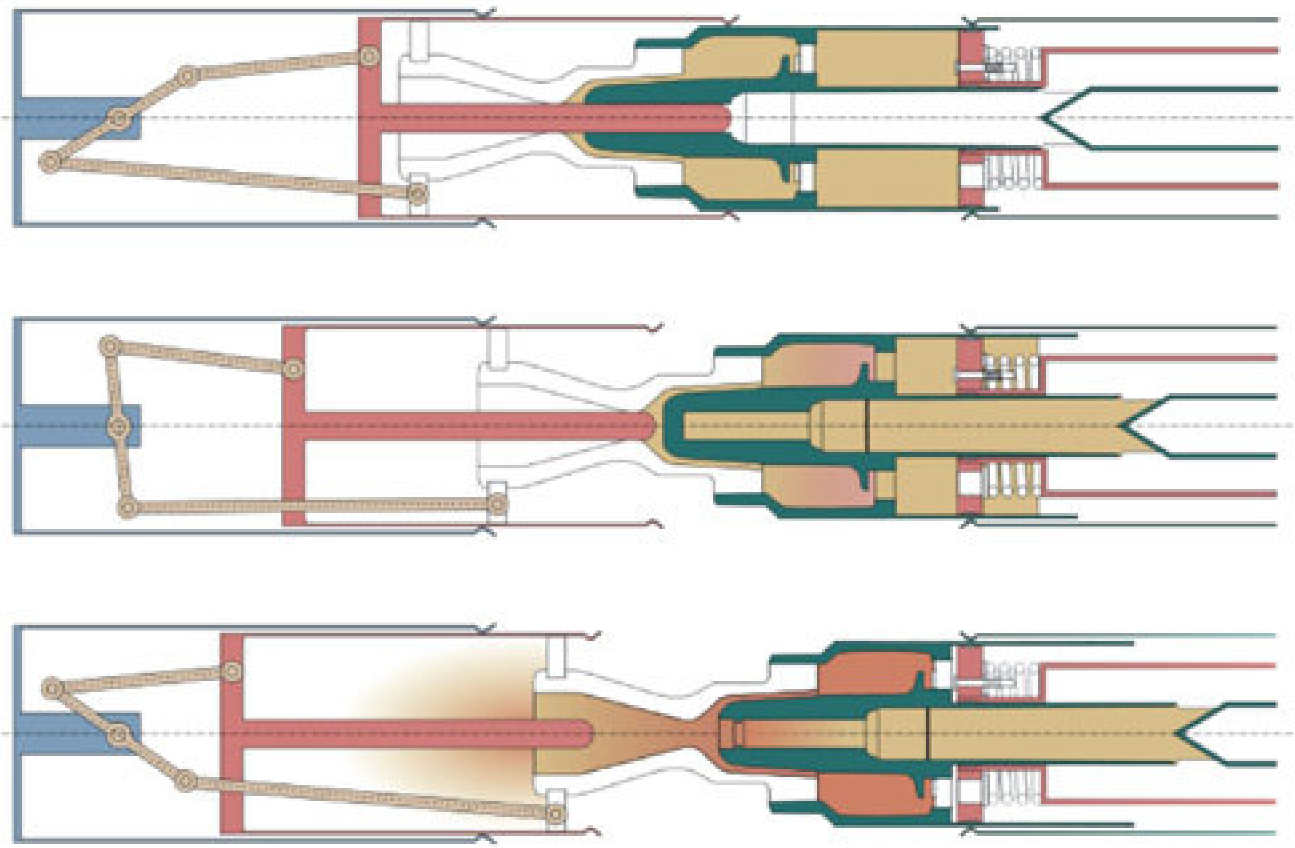
Electrician - A Complete Course

Gary Price



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Electrician

An **electrician** is a tradesman specializing in electrical wiring of buildings and related equipment. Electricians may be employed in the construction of new buildings or maintenance of existing electrical infrastructure.[1]

Terminology

In the USA electricians are sometimes referred to as Inside Wireman as opposed to Outside Linemen who work on electric utility company distribution systems at higher voltages. "Electrician" is also used as the name of a role in stagecraft, where electricians are tasked primarily with hanging, focusing, and operating stage lighting. In this context, the Master Electrician is the show's chief electrician. Although theater electricians routinely perform electrical work on stage lighting instruments and equipment, they are not part of the electrical trade and have a different set of skills and qualifications from the electricians that work on building wiring.

In English slang an electrician is sometimes referred to as a "Sparky", "Sparks" or "Lecky."

Training and regulation of trade

In most countries, the job of an electrician is a regulated trade for safety reasons, requiring testing, registration, or licensing. They are usually required to serve an apprenticeship lasting from 3 to 5 years under the general supervision of a Master Electrician and usually the direct supervision of a Journeyman Electrician. Schooling in electrical theory and electrical building codes is usually required to complete the apprenticeship program. A Journeyman electrician is a well rounded craftsman trained in all phases of electrical construction installation in various building styles and maintenance of equipment after installation. A Master Electrician must first be a Journeyman and usually has a minimum of two years more experience and has to pass further testing. A Master Electrician is further trained in layout, estimation, and design of electrical installations.

Licensing

In some jurisdictions a licensed electrician is required for permanent installation of any current carrying conductors, including low voltage alarm and data signal wiring, whereas in other places an electrician is only necessary for dealing with permanent connection at mains voltages, and yet others permit unlicensed homeowners to do all of their own electrical work (not "in the trade"), although it may still be subject to inspection for compliance with the relevant code or regulations, such as the US National Electrical Code or the UK IEE Wiring Regulations.

JIB (UK)

For electricians in the construction industry the JIB Electrotechnical Certification scheme provides certification and qualification for the Electrical Contracting Industry (ECA).

JIB is in place to regulate and control Employment of electricians in the construction industry. It is responsible for skill levels, proficiency, wage levels and welfare benefits of its members.

Building code

A **building code** is a set of rules that specify the minimum acceptable level of safety for constructed objects such as buildings and nonbuilding structures. The main purpose of the building codes is to protect public health, safety and general welfare as they relate to the construction and occupancy of buildings and structures. The building code becomes law of a particular jurisdiction when formally enacted by the appropriate authority.

Building codes are generally intended to be applied by architects and engineers, but are also used for various purposes by safety inspectors, real estate developers, contractors and subcontractors, manufacturers of building products and materials, insurance companies, facility managers, tenants, and other categories of users.

There are often additional codes or sections of the same building code that have more specific requirements that apply to dwellings and special construction objects such as canopies, signs, pedestrian walkways, parking lots, radio and television antennas.

Types of building codes

The practice of developing, approving, and enforcing building codes may vary widely from country to country.

In some countries building codes are developed by the government agencies or quasi-governmental standards organizations and then enforced across the country by the central government. Such codes are known as the **national building codes** (in a sense they enjoy a mandatory nation-wide application).

In other countries, where the power of regulating construction and fire safety is vested in local authorities, a system of **model building codes** is used. Model building codes have no legal status unless adopted or adapted by an authority having jurisdiction. The developers of model codes urge public authorities to reference model codes in their laws, ordinances, regulations, and administrative orders. When referenced in any of these legal instruments, a particular model code becomes law. This practice is known as *adoption by reference*. When an adopting authority decides to delete, add, or revise any portions of the model code being adopted, it is usually required by the model code developer to follow a formal adoption procedure in which those modifications can be documented for legal purposes.

There are instances when some local jurisdictions choose to develop their own building codes. For example, at some point in time all major cities in the United States had their own building codes as part of their municipal codes. Since having its own building code can be very expensive for a municipality, many have decided to adopt model codes instead. Only the cities of New York and Chicago continue to use the building codes they developed on their own; yet these codes also include multiple references to model codes, such as the National Electrical Code. Additionally, New York City is currently working to modify and apply the International Building Code for the city in a massive Model Code Program.

Because of copyright law, one must obtain a copy of the local code and separately any model code it references.

Scope

Building codes generally include:

- Structural safety: buildings should be strong enough to resist internally and externally applied forces without collapsing;
- Fire safety: includes requirements to prevent the fire spread to/from neighbours, provide warning of occupants, and safe exiting of building, limitation on fire spread, and provisions for fire suppression/fire fighting;
- Health requirements: adequate washrooms, adequate air circulation, and plumbing materials.

Some building codes sometimes include requirements for:

- Noise mitigation to protect building occupants from noise pollution (see Noise regulation)
- Accessibility: requirements to ensure that a building is accessible for persons in wheelchairs or having other disabilities.

Building codes generally do not include:

- Aesthetics: Any regulation of the aesthetics of buildings are usually included in zoning by-laws;
- Traffic convenience: Limitations on traffic flow are usually either in zoning or other municipal by-laws;
- Building Use: the safe use of a building is generally in the Fire code; or
- Required upgrades for existing building: unless the building is being renovated the building code usually does not apply.

Building codes include:

- specifications on components;
- allowable installation methodologies;
- minimum and maximum room and exit sizes and location;
- qualification of individuals or corporations doing the work.

Any high structure can be an obstacle for aircraft, and must therefore often be marked.

These requirements are usually a combination of prescriptive requirements that spell out exactly how something is to be done, and performance requirements which just outline what the required level of performance is and leave it up to the designer how this is achieved. Historically they are very reactive in that when a problem occurs the building codes change to ensure that the problem never happens again. In recent years there has been a move amongst most of the building codes to move to more performance requirements and less prescriptive requirements.

Traditionally building codes were generally long complex interrelated sets of rules. They generally included reference to hundreds of other codes, standards and guidelines that specify the details of the component or system design, specify testing requirements for components, or outline good engineering practice. These detailed codes required a great deal of specialization to interpret, and also greatly constrained change and innovation in building design. In recent years several countries, beginning with Australia, have moved to much shorter objective based buildings codes. Rather than prescribing specific details, objective codes lists a series of objectives all buildings must meet while leaving open how these objectives will be met. When applying for a building permit the designers must demonstrate how they meet each objective.

History

Building codes have a long history. What is generally accepted as the first building code was in the Code of Hammurabi which specified:

- 229. If a builder build a house for some one, and does not construct it properly, and the house which he built fall in and kill its owner, then that builder shall be put to death.
- 230. If it kill the son of the owner the son of that builder shall be put to death.
- 231. If it kill a slave of the owner, then he shall pay slave for slave to the owner of the house.
- 232. If it ruin goods, he shall make compensation for all that has been ruined, and inasmuch as he did not construct properly this house which he built and it fell, he shall re-erect the house from his own means.
- 233. If a builder build a house for some one, even though he has not yet completed it; if then the walls seem toppling, the builder must make the walls solid from his own means.

Circuit breaker

A 2 pole MCB

A **circuit breaker** is an automatically-operated electrical switch which is designed to protect an electrical circuit from damage caused by overload or short circuit. Unlike a fuse, which operates once and then has to be replaced, a circuit breaker can be reset (either manually or automatically) to resume normal operation. Circuit breakers are made in varying sizes, from small devices which protect an individual household appliance up to large switchgear designed to protect high voltage circuits feeding an entire city.

Operation

Magnetic circuit breakers are implemented using a solenoid (electromagnet) whose pulling force increases exponentially as the current increases. The circuit breaker's contacts are held closed by a latch and, as the current in the solenoid increases beyond the rating of the circuit breaker, the solenoid's pull releases the latch which then allows the contacts to open by spring action. Some types of magnetic breakers incorporate a hydraulic time delay feature wherein the solenoid core is located in a tube containing a viscous fluid. The core is restrained by a spring until the current exceeds the breaker rating. During an overload, the solenoid pulls the core through the fluid to close the magnetic circuit, which then provides sufficient force to release the latch. The delay permits brief current surges beyond normal running current for motor starting, energizing equipment, etc. Short circuit currents provide sufficient solenoid force to release the latch regardless of core position thus bypassing the delay feature. Ambient temperature affects the time delay but does not affect the current rating of a magnetic breaker.

Thermal breakers use a bimetallic strip, which heats and bends with increased current, and is similarly arranged to release the latch. This type is commonly used with motor control circuits. Thermal breakers often have a compensation element to reduce the effect of ambient temperature on the device rating.

Thermomagnetic circuit breakers, which are the type found in most distribution boards, incorporate both techniques with the electromagnet responding instantaneously to large surges in current (short circuits) and the bimetallic strip responding to less extreme but longer-term overcurrent conditions.

Circuit breakers for larger currents are usually arranged with pilot devices to sense a fault current and to operate the trip opening mechanism.

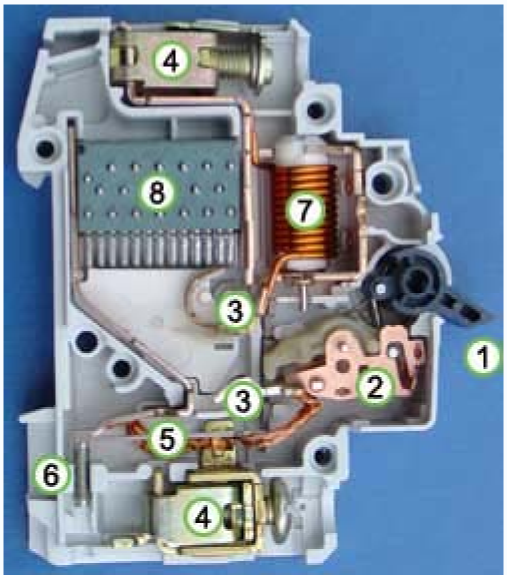
Under short-circuit conditions, a current many times greater than normal can flow (see maximum prospective short circuit current). When electrical contacts open to interrupt a large current, there is a tendency for an arc to form between the opened contacts, which would allow the flow of current to continue. Therefore, circuit breakers must incorporate various features to divide and extinguish the arc. In air-insulated and miniature breakers an arc chute structure consisting (often) of metal plates or ceramic ridges cools the arc, and blowout coils deflect the arc into the arc chute. Larger circuit breakers such as those used in electrical power distribution may use vacuum, an inert gas such as sulfur hexafluoride or have contacts immersed in oil to suppress the arc.

The maximum short-circuit current that a breaker can interrupt is determined by testing. Application of a breaker in a circuit with a prospective short-circuit current higher than the breaker's interrupting capacity rating may result in failure of the breaker to safely interrupt a fault. In a worst-case scenario the breaker may successfully interrupt the fault, only to explode when reset, injuring the technician.

Small circuit breakers are either installed directly in equipment, or are arranged in a breaker panel. Power circuit breakers are built into switchgear cabinets. High-voltage breakers may be free-standing outdoor equipment or a component of a gas-insulated switchgear line-up.

Low voltage European circuit breaker

Below is a photograph of the internal details of a 10 ampere European DIN rail mounted thermal-magnetic miniature circuit breaker. Circuit breakers such as this are the most common style in modern domestic consumer units and commercial electrical distribution boards throughout Europe. Unfortunately, while the size and shape of the opening in the front and its elevation from the rail are standardised, the arrangements for busbar connections are **not**, so installers need to take care that the chosen breaker fits the bus bar in a particular board.



1. Actuator lever - used to manually trip and reset the circuit breaker. Also indicates the status of the circuit breaker (On or Off/tripped). Most breakers are designed so they can still trip even if the lever is held or locked in the on position. This is sometimes referred to as "free trip" or "positive trip" operation.
2. Actuator mechanism - forces the contacts together or apart.
3. Contacts - Allow current to flow when touching and break the flow of current when moved apart.
4. Terminals
5. Bimetallic strip
6. Calibration screw - allows the manufacturer to precisely adjust the trip current of the device after assembly.
7. Solenoid
8. Arc divider / extinguisher

Rated current

International Standard IEC 60898-1 and European Standard EN 60898-1 define the *rated current* I_n of a circuit breaker for household applications as the current that the breaker is designed to carry continuously (at an ambient air temperature of 30 °C). The commonly-available preferred values for the rated current are 6 A, 10 A, 13 A, 16 A, 20 A, 25 A, 32 A, 40 A, 50 A, 63 A, 80 A and 100 A (Renard series, slightly modified to include current limit of British BS 1363 sockets). The circuit breaker is labeled with the rated current in ampere, but without the unit symbol "A". Instead, the ampere figure is preceded by a letter "B", "C" or "D" that indicates the *instantaneous tripping current*, that is the minimum value of current that causes the circuit-breaker to trip without intentional time delay (i.e., in less than 100 ms):

Type	Instantaneous tripping current
B	above $3I_n$ up to and including $5I_n$
C	above $5I_n$ up to and including $10I_n$
D	above $10I_n$ up to and including $20I_n$

Common trip breakers

Three pole common trip breaker for supplying a three-phase device. This breaker has a 2 A rating

When supplying a branch circuit with more than one live conductor, each live conductor must be protected by a breaker pole. To ensure that all live conductors are interrupted when any pole trips, a "common trip" breaker must be used. These may either contain two or three tripping mechanisms within one case, or for small breakers, may externally tie the poles together via their operating handles. Two pole common trip breakers are common on 120/240 volt systems where 240 volt loads (including major appliances or further distribution boards) span the two out-of-phase live wires. Three pole common trip breakers are typically used to supply three phase power to large motors or further distribution boards.

Types of circuit breaker

Front panel of a 1250 A air circuit breaker. The breaker can be withdrawn from its housing for servicing. Trip characteristics are configurable via DIP switches on the front panel.

There are many different technologies used in circuit breakers and they do not always fall into distinct categories. Types that are common in domestic, commercial and light industrial applications at low voltage (less than 1000 V) include:

- MCB (Miniature Circuit Breaker)—rated current not more than 100 A. Trip characteristics normally not adjustable. Thermal or thermal-magnetic operation. Breakers illustrated above are in this category.

- MCCB (Moulded Case Circuit Breaker)—rated current up to 1000 A. Thermal or thermal-magnetic operation. Trip current may be adjustable.

Electric power systems require the breaking of higher currents at higher voltages. Examples of high-voltage AC circuit breakers are:

- Vacuum circuit breaker—With rated current up to 3000 A, these breakers interrupt the current by creating and extinguishing the arc in a vacuum container. These can only be practically applied for voltages up to about 35,000 V, which corresponds roughly to the medium-voltage range of power systems. Vacuum circuit breakers tend to have longer life expectancies between overhaul than do air circuit breakers.
- Air circuit breaker—Rated current up to 10,000 A. Trip characteristics often fully adjustable including configurable trip thresholds and delays. Usually electronically controlled, though some models are microprocessor controlled. Often used for main power distribution in large industrial plant, where the breakers are arranged in draw-out enclosures for ease of maintenance.

High-voltage circuit breakers

A 1200 A 3-pole 115,000 V breaker at a generating station in Manitoba, Canada.

Electrical power transmission networks are protected and controlled by high-voltage breakers. The definition of "high voltage" varies but in power transmission work is usually thought to be 72,500 V or higher, according to a recent definition by the International Electrotechnical Commission (IEC). High-voltage breakers are nearly always solenoid-operated, with current sensing protective relays operated through current transformers. In substations the protection relay scheme can be complex, protecting equipment and busses from various types of overload or ground/earth fault.

High-voltage breakers are broadly classified by the medium used to extinguish the arc.

- Oil-filled (dead tank and live tank)
- Oil-filled, minimum oil volume
- Air blast
- Sulfur hexafluoride

High voltage breakers are routinely available up to 765 kV AC.

Live tank circuit breakers are where the enclosure that contains the breaking mechanism is at line potential, that is, "Live". *Dead tank* circuit breaker enclosures are at earth potential.

Interrupting principles for high-voltage circuit-breakers

High-voltage circuit-breakers have greatly changed since they were first introduced about 40 years ago, and several interrupting principles have been developed that have contributed successively to a large reduction of the operating energy.

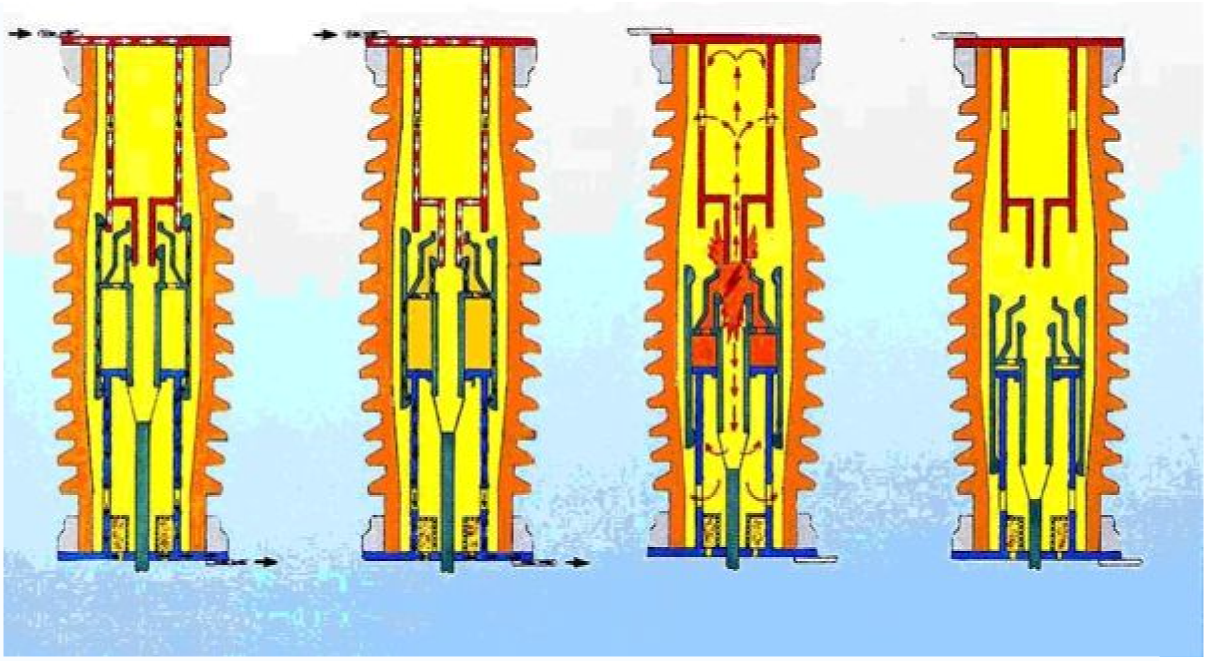
Current interruption in a high-voltage circuit-breaker is obtained by separating two contacts in a medium, such as sulfur hexafluoride (SF_6), having excellent dielectrical and arc quenching properties. After contacts separation, current is carried through an arc and is interrupted when this arc is cooled by a gas blast of sufficient intensity.

Gas blast applied on the arc must be able to cool it rapidly so that gas temperature between the contacts is reduced from 20,000 K to less than 2000 K in a few hundred microseconds, so that it is able to withstand the Transient Recovery Voltage that is applied across the contacts after current interruption. Sulfur hexafluoride is generally used in present high-voltage circuit-breakers (of rated voltage higher than 52 kV).

In the 1980s and 1990s, the pressure necessary to blast the arc was generated mostly by gas heating using arc energy. It is now possible to use low energy spring-loaded mechanisms to drive high-voltage circuit-breakers up to 800 kV.

Brief history

The first patents on the use of SF_6 as an interrupting medium was filed in Germany in 1938 by Vitaly Grosse (AEG) and independently later in the USA in July 1951 by H.J. Lingal, T.E. Browne and A.P. Storm (Westinghouse). The first industrial application of SF_6 for current interruption dates back to 1953. High-voltage 15 kV to 161 kV load switches were developed with a breaking capacity of 600 A. The first high-voltage SF_6 circuit-breaker built in 1956 by Westinghouse, could interrupt 5 kA under 115 kV, but it had 6 interrupting chambers in series per pole. In 1957, the puffer-type technique was introduced for SF_6 circuit-breakers where the relative movement of a piston and a cylinder linked to the moving part is used to generate the pressure rise necessary to blast the arc via a nozzle made of insulating material (figure 1). In this technique, the pressure rise is obtained mainly by gas compression. The first high-voltage SF_6 circuit-breaker with a high short-circuit current capability was produced by Westinghouse in 1959. This Dead tank circuit-breaker could interrupt 41.8 kA under 138 kV (10,000 MV·A) and 37.6 kA under 230 kV (15,000 MV·A). These performances were already significant, but 3 chambers were necessary per pole and the high pressure source needed for the blast (1.35 MPa) was a constraint that had to be avoided in subsequent developments. The excellent properties of SF_6 lead to the fast extension of this technique in the 1970s and to its use for the development of circuit-breakers with high interrupting capability, up to 800 kV.



The achievement around 1983 of the first single-break 245 kV and the corresponding 420kV to 550 kV and 800kV, with respectively 2, 3, and 4 chambers per pole, lead to the dominance of SF_6 circuit breakers in the complete range of high voltages.

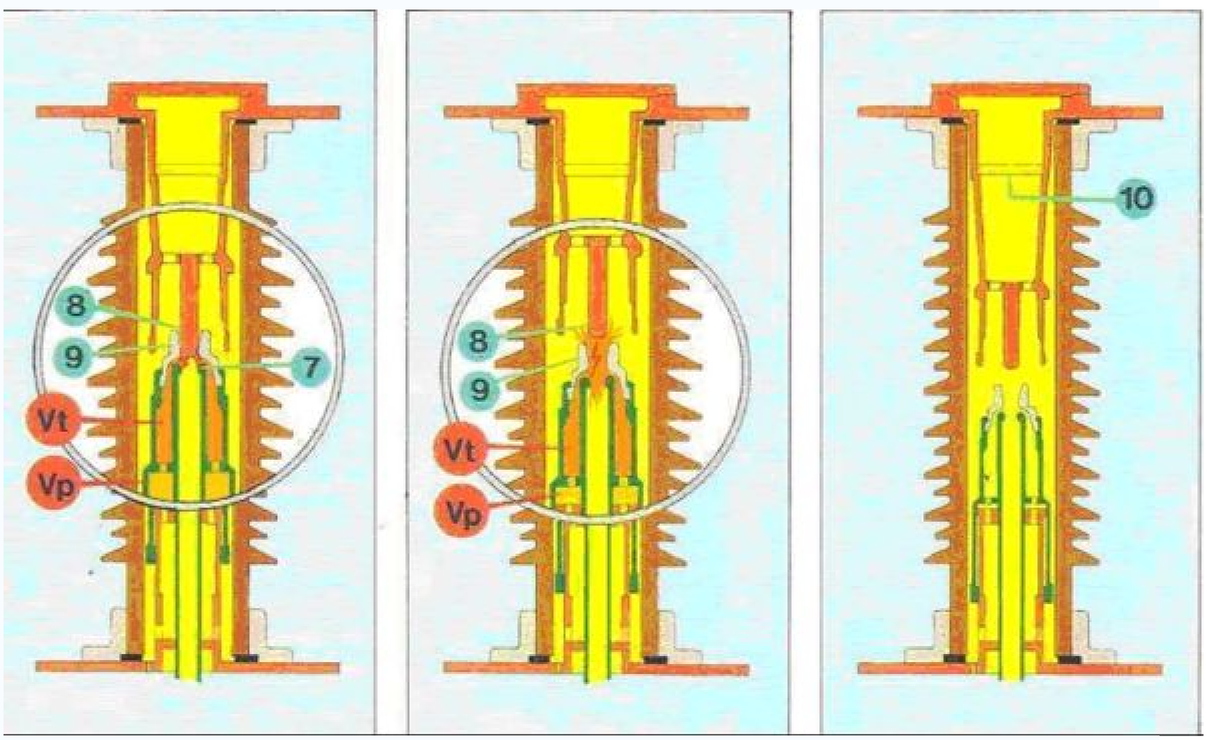
Several characteristics of SF_6 circuit-breakers can explain their success:

- Simplicity of the interrupting chamber which does not need an auxiliary chamber for breaking;
- Autonomy provided by the puffer technique;
- The possibility to obtain the highest performances, up to 63 kA, with a reduced number of interrupting chambers;
- Short break time of 2 to 2.5 cycles;
- High electrical endurance, allowing at least 25 years of operation without reconditioning;
- Possible compact solutions when used for GIS or hybrid switchgear;
- Integrated closing resistors or synchronised operations to reduce switching overvoltages;
- Reliability and availability;
- Low noise level.

The reduction in the number of interrupting chambers per pole has led to a considerable simplification of circuit-breakers as the number of parts was decreased as well as the number of seals. As a direct consequence, the reliability of circuit-breakers was improved, as verified later on by CIGRE surveys.

Thermal blast chambers

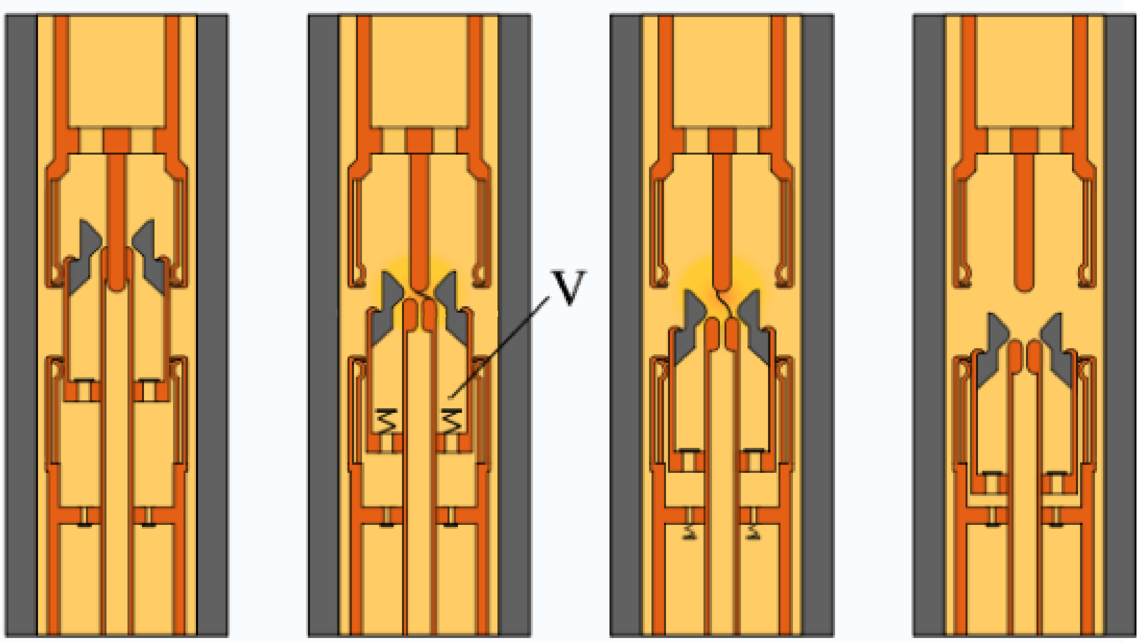
The last ten years have seen the development of the self-blast technique of interruption for SF_6 interrupting chambers. This technique has proved to be very efficient and has been widely applied for high voltage circuit breakers up to 550 kV. It has allowed the development of new ranges of circuit breakers operated by low energy spring-operated mechanisms. These developments have been facilitated by the progress made in digital simulations that were widely used to optimize the geometry of the interrupting chamber and the linkage between the poles and the mechanism. New types of SF_6 breaking chambers, which implement innovative interrupting principles, have been developed over the course of the past 15 years, with the objective of reducing the operating energy of the circuit-breaker. One aim of this evolution was to further increase the reliability by reducing the dynamic forces in the pole and its mechanism.



The reduction of operating energy was mainly achieved by the lowering energy used for gas compression and by making increased use of arc energy to produce the pressure necessary to quench the arc and obtain current interruption. Low current interruption, up to about 30% of rated short-circuit current, is obtained by a puffer blast.

Self blast chambers

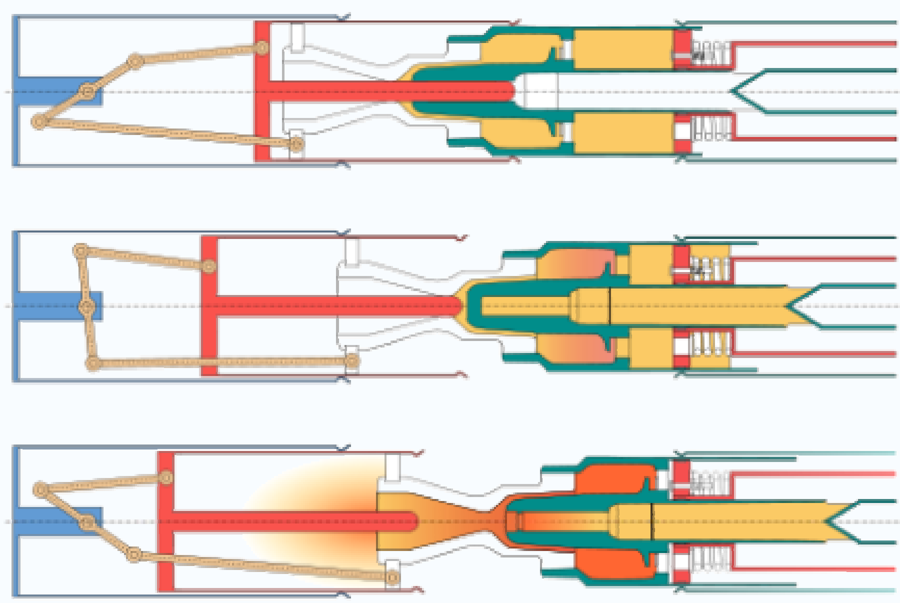
Further development in the thermal blast technique was made by introducing a valve between the expansion volume and the compression volume. When interrupting low currents the valve opens under the effect of the overpressure generated in the compression volume. The blow-out of the arc is made as in a puffer circuit breaker thanks to the compression of the gas obtained by the piston action. In the case of high currents interruption, the arc energy produces a high overpressure in the expansion volume, which leads to the closure of the valve and thus isolating the expansion volume from the compression volume. The overpressure necessary for breaking is obtained by the optimal use of the thermal effect and of the nozzle clogging effect produced whenever the cross-section of the arc significantly reduces the exhaust of gas in the nozzle. In order to avoid excessive energy consumption by gas compression, a valve is fitted on the piston in order to limit the overpressure in the compression to a value necessary for the interruption of low short circuit currents.



This technique, known as “self blast” has now been used extensively for more than 10 years for the development of many types of interrupting chambers. The better knowledge of arc interruption obtained by digital simulations and validation of performances by breaking tests, contribute to a higher reliability of these self blast circuit-breakers. In addition the reduction in operating energy, allowed by the self blast technique, leads to a higher mechanical endurance.

Double motion of contacts

An important decrease in operating energy can also be obtained by reducing the kinetic energy consumed during the tripping operation. One way is to displace the two arcing contacts in opposite directions so that the arc speed is half that of a conventional layout with a single mobile contact.



The thermal and self blast principles have enabled the use of low energy spring mechanisms for the operation of high voltage circuit breakers. They progressively replaced the puffer technique in the 1980s; first in 72.5 kV breakers, and then from 145 kV to 800 kV.

Comparison of single motion and double motion techniques

The double motion technique halves the tripping speed of the moving part. In principle, the kinetic energy could be quartered if the total moving mass was not increased. However, as the total moving mass *is* increased, the practical reduction in kinetic energy is closer to 60%. The total tripping energy also includes the compression energy, which is almost the same for both techniques. Thus, the reduction of the total tripping energy is lower, about 30%, although the exact value depends on the application and the operating mechanism. Depending on the specific case, either the double motion or the single motion technique can be cheaper. Other considerations, such as rationalization of the circuit-breaker range, can also influence the cost.

Thermal blast chamber with arc-assisted opening

In this interruption principle arc energy is used, on the one hand to generate the blast by thermal expansion and, on the other hand, to accelerate the moving part of the circuit breaker when interrupting high currents. The overpressure produced by the arc energy downstream of the interruption zone is applied on an auxiliary piston linked with the moving part. The resulting force accelerates the moving part, thus increasing the energy available for tripping.

With this interrupting principle it is possible, during high-current interruptions, to increase by about 30% the tripping energy delivered by the operating mechanism and to maintain the opening speed independently of the current. It is obviously better suited to circuit-breakers with high breaking currents such as Generator circuit-breakers.

Generator circuit-breakers

Generator circuit-breakers are connected between a generator and the step-up voltage transformer. They are generally used at the outlet of high power generators (100 MVA to 1800 MVA) in order to protect them in a reliable, fast and economic manner. Such circuit breakers must be able to allow the passage of high permanent currents under continuous service (6.3 kA to 40 kA), and have a high breaking capacity (63 kA to 275 kA). They belong to the medium voltage range, but the TRV withstand capability required by ANSI/IEEE Standard C37.013 is such that the interrupting principles developed for the high-voltage range must be used. A particular embodiment of the thermal blast technique has been developed and applied to generator circuit-breakers. The self-blast technique described above is also widely used in SF_6 generator circuit breakers, in which the contact system is driven by a low-energy, spring-operated mechanism. An example of such a device is shown in the figure below; this circuit breaker is rated for 17.5 kV and 63 kA.

Generator circuit breaker rated for 17.5 kV and 63 kA

tae ka

Evolution of tripping energy

The operating energy has been reduced by 5 to 7 times during this period of 27 years. This illustrates well the great progress made in this field of interrupting techniques for high-voltage circuit-breakers.

Future perspectives

In the near future, present interrupting technologies can be applied to circuit-breakers with the higher rated breaking currents (63 kA to 80 kA) required in some networks with increasing power generation.

Self blast or thermal blast circuit breakers are nowadays accepted world wide[*citation needed*] and they are in service for high voltage applications since about 15 years[*citation needed*], starting with the voltage level of 72.5 kV. Today this technique is also available for the voltage levels 420/550/800 kV.

Other breakers

The following types are described in separate articles.

- Breakers for protections against earth faults too small to trip an overcurrent device:
    - RCD—Residual Current Device (formerly known as a *Residual Current Circuit Breaker*) - detects current imbalance. Does NOT provide overcurrent protection.
    - RCBO—Residual Current Breaker with Overcurrent protection - combines the functions of an RCD and an MCB in one package. In the United States and Canada, panel-mounted devices that combine ground(earth) fault detection and overcurrent protection are called Ground Fault Circuit Interrupter (GFCI) breakers; a wall mounted outlet device providing ground fault detection only is called a GFI.
    - ELCB—Earth leakage circuit breaker. This detected earth current directly rather than detecting imbalance. They are no longer seen in new installations for various reasons.

- Autorecloser A type of circuit breaker which closes again after a delay. These are used on overhead power distribution systems, to prevent short duration faults from causing sustained outages.

- Polyswitch (polyfuse) A small device commonly described as an automatically-resetting fuse rather than a circuit breaker.

Switch

Electrical switches. Top, left to right: circuit breaker, mercury switch, wafer switch, DIP switch, surface mount switch, reed switch. Bottom, left to right: wall switch (U.S. style), miniature toggle switch, in-line switch, push-button switch, rocker switch, microswitch.

A **switch** is a device for changing the course (or flow) of a circuit. The prototypical model is a mechanical device (for example a railroad switch) which can be disconnected from one course and connected to another. The term "switch" typically refers to electrical power or electronic telecommunication circuits. In applications where multiple switching options are required (e.g., a telephone service), mechanical switches have long been replaced by electronic variants which can be intelligently controlled and automated.

The switch is referred to as a "gate" when abstracted to mathematical form. In the philosophy of logic, operational arguments are represented as logic gates. The use of electronic *gates* to function as a system of logical gates is the fundamental basis for the computer—i.e. a computer is a system of electronic switches which function as logical gates.

A simple electrical switch

In the simplest case, a switch has two pieces of metal called *contacts* that touch to make a circuit, and separate to break the circuit. The contact material is chosen for its resistance to corrosion, because most metals form insulating oxides that would prevent the switch from working. Sometimes the contacts are plated with noble metals. They may be designed to wipe against each other to clean off any contamination. Nonmetallic conductors, such as conductive plastic, are sometimes used. The moving part that applies the operating force to the contacts is called the *actuator*, and may be a **toggle** or *dolly*, a **rocker**, a **push-button** or any type of mechanical linkage *(see photo).*

A simple semiconductor switch is a a transistor.

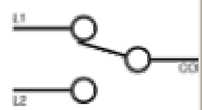
Contact arrangements

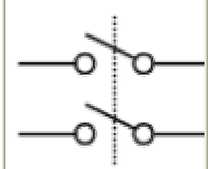
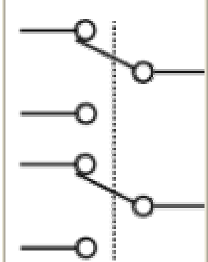
Triple Pole Single Throw (TPST or 3PST) switch used to short the windings of a 3 phase wind turbine for braking purposes. Here the switch is shown in the open position.

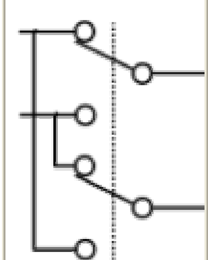
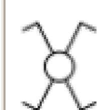
A pair of contacts is said to be 'closed' when there is no space between them, allowing electricity to flow from one to the other. When the contacts are separated by a space, they are said to be 'open', and no electricity can flow.

Switches can be classified according to the arrangement of their contacts. Some contacts are normally open until closed by operation of the switch, while others are normally closed and opened by the switch action. A switch with both types of contact is called a changeover switch.

The terms *pole* and *throw* are used to describe switch contacts. A *pole* is a set of contacts that belong to a single circuit. A *throw* is one of two or more positions that the switch can adopt. These terms give rise to abbreviations for the types of switch which are used in the electronics industry. In mains wiring names generally involving the word *way* are used; however, these terms differ between British and American English and the terms *two way* and *three way* are used in both with different meanings.

Electronics abbreviation	Expansion of abbreviation	British mains wiring name	American mains wiring name	Description	Symbol	IEC 60617
SPST	Single pole, single throw	One way	Two way	A simple on-off switch: The two terminals are either connected together or not connected to anything. An example is a light switch.		
SPDT	Single pole, double throw	Two way	Three way	A simple changeover switch: C (Common) is connected to L1 or to L2.		

SPCO	Single pole changeover *or* Single pole, centre off			Equivalent to *SPDT*. Some suppliers use *SPCO* for switches with a stable off position in the centre and *SPDT* for those without.		
DPST	Double pole, single throw	Double pole	Double pole	Equivalent to two *SPST* switches controlled by a single mechanism		
DPDT	Double pole, double throw			Equivalent to two *SPDT* switches controlled by a single mechanism : A is connected to B and D to E, or B is connected to C and E to F.		

DPCO	Double pole changeover *or* Double pole, centre off			Equivalent to *DPDT*. Some suppliers use *DPCO* for switches with a stable off position in the centre and *DPDT* for those without.		
		Intermediate switch	4-way switch	*DPDT* switch internally wired for polarity-reversal applications: only four rather than six wires are brought outside the switch housing; with the above, B is connected to F and C to E; hence A is connected to B and D to C, or A is connected to C and D to B.		

Switches with larger numbers of poles or throws can be described by replacing the "S" or "D" with a number or in some cases the letter T (for triple). In the rest of this article the terms *SPST SPDT* and *intermediate* will be used to avoid the ambiguity in the use of the word "way".

Make-before-break, break-before-make

In a multi-throw switch, there are two possible transient behaviors as you move from one position to another. In some switch designs, the new contact is made before the old contact is broken. This is known as make-before-break, and ensures that the moving contact never sees an open circuit. The alternative is break-before-make, where the old contact is broken before the new one is made. This ensures that the two fixed contacts are never shorted to each other. Both types of design are in common use, for different applications.

Biased switches

A biased switch is one containing a spring that returns the actuator to a certain position. The "on-off" notation can be modified by placing parentheses around all positions other than the resting position. For example, an (on)-off-(on) switch can be switched on by moving the actuator in either direction away from the centre, but returns to the central off position when the actuator is released.

The momentary push-button switch is a type of biased switch. The most common type is a **push-to-make switch**, which makes contact when the button is pressed and breaks when the button is released. A **push-to-break switch**, on the other hand, breaks contact when the button is pressed and makes contact when it is released. An example of a push-to-break switch is a button used to release a door held open by an electromagnet. Changeover push button switches do exist but are even less common.

Special types

Switches can be designed to respond to any type of mechanical stimulus: for example, vibration (the *trembler switch*), tilt, air pressure, fluid level (the *float switch*), the turning of a key (*key switch*), linear or rotary movement (the *limit switch* or **microswitch**), or presence of a magnetic field (the *reed switch*).

The mercury switch consists of a blob of mercury inside a glass bulb. The two contacts pass through the glass, and are shorted together when the bulb is tilted to make the mercury roll on to them. The advantage of this type of switch is that the liquid metal flows around particles of dirt and debris that might otherwise prevent the contacts of a conventional switch from closing.

Other types of switch include:

- Centrifugal switch
- DIP switch
- Hall-effect switch
- Inertial switch
- Toggle switch
- Transfer switch

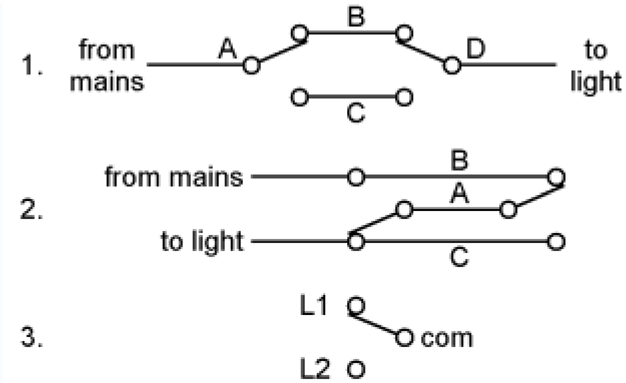
Intermediate switch

A DPDT switch has six connections, but since polarity reversal is a very common usage of DPDT switches, some variations of the DPDT switch are internally wired specifically for polarity reversal. They only have four terminals rather than six. Two of the terminals are inputs and two are outputs. When connected to a battery or other DC source, the 4-way switch selects from either normal or reversed polarity. Intermediate switches are also an important part of multiway switching systems with more than two switches (see next section).

Multiway switching

Multiway switching is a method of connecting switches in groups so that any switch can be used to connect or disconnect the load. This is most commonly done with lighting.

Two locations



1. First method
2. Second method
3. Labelling of switch terminals

Switching a load on or off from two locations (for instance, turning a light on or off from either end of a flight of stairs) requires two SPDT switches. There are two basic methods of wiring to achieve this.

In the first method, mains is fed into the common terminal of one of the switches; the switches are then connected through the L1 and L2 terminals (swapping the L1 and L2 terminals will just make the switches work the other way round), and finally a feed to the light is taken from the common of the second switch. A connects to B or C, D connects to B or C; the light is on if A connects to D, i.e. if A and D both connect to B or both connect to C.

The second method is to join the three terminals of one switch to the corresponding terminals on the other switch and take the incoming supply and the wire out to the light to the L1 and L2 terminals. Through one switch A connects to B or C, through the other also to B or C; the light is on if B connects to C, i.e. if A connects to B with one switch and to C with the other.

Wiring needed in addition to the mains network (not including protective earths):

First method:

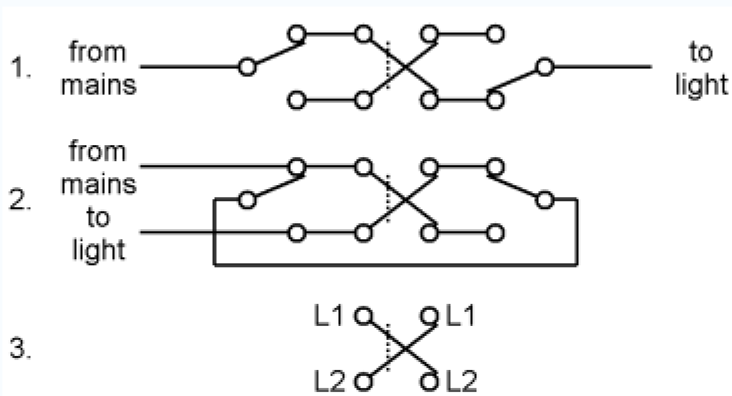
- double wire between both switches
- single wire from one switch to the mains
- single wire from the other switch to the load
- single wire from the load to the mains

Second method:

- triple wire between both switches
- single wire from any position between the two switches, to the mains
- single wire from any position between the two switches, to the load
- single wire from the load to the mains

If the mains and the load are connected to the system of switches at one of them, then in both methods we need three wires between the two switches. In the first method one of the three wires just has to pass through the switch, which tends to be less convenient than being connected. When multiple wires come to a terminal they can often all be put directly in the terminal. When wires need to be joined without going to a terminal a crimped joint, piece of terminal block, wirenut or similar device must be used and the bulk of this may require use of a deeper backbox.

More than two locations



Three-way switching.
1. First method
2. Second method
3. Labelling of switch terminals

For more than two locations, the two cores connecting the L1 and L2 of the switches must be passed through an intermediate switch (as explained above) wired to swap them over. Any number of intermediate switches can be inserted, allowing for any number of locations.

Wiring needed in addition to the mains network (not including protective earths):

First method:

- double wire along the sequence of switches
- single wire from the first switch to mains
- single wire from the last switch to the load
- single wire (neutral) from load to mains

Second method:

- double wire along the sequence of switches
- single wire from first switch to last switch
- single wire from anywhere between two of the switches to the mains
- single wire from anywhere between the same two switches to the load
- single wire (neutral) from load to mains

Power switching

When a switch is designed to switch significant power the transitional state of the switch as well as the ability to stand continuous operating currents must be considered. When a switch is on its resistance is near zero and very little power is dropped in the contacts, when a switch is in the off state its resistance is extremely high and even less power is dropped in the contacts. However when the switch is flicked the resistance muzt pass through a state where briefly a quarter (or worse if the load is not purely resistive) of the loads rated power is dropped in the switch.

For this reason most power switches (most lightswitches and almost all larger switches) have spring mechanisms in them to make sure the transition between on and off is as short as possible regardless of the speed at which the user moves the rocker.

Contact bounce

Contact bounce (also called *chatter*) is a common problem with mechanical switches and relays. Switch and relay contacts are usually made of springy metals that are forced into contact by an actuator. When the contacts strike together, their momentum and elasticity act together to cause bounce. The result is a rapidly pulsed electrical current instead of a clean transition from zero to full current. The waveform is then further modified by the parasitic inductances and capacitances in the switch and wiring, resulting in a series of damped sinusoidal oscillations. This effect is usually unnoticeable in AC mains circuits, where the bounce happens too quickly to affect most equipment, but causes problems in some analogue and logic circuits that are not designed to cope with oscillating voltages.

Sequential digital logic circuits are particularly vulnerable to contact bounce. The voltage waveform produced by switch bounce usually violates the amplitude and timing specifications of the logic circuit. The result is that the circuit may fail, due to problems such as metastability, race conditions, runt pulses and glitches. There are a number of techniques for debouncing (dealing with switch bounce) They can be split into timing based techniques and Hysteresis based techniques.

Timing based

Timing based techniques rely on adding sufficient delays to prevent bounce being detected. Their big advantage is they do not require any special design on the switch side and so are generally cheaper. However for good performance they must be designed to suit the switch (too much delay and the response will be needlessly sluggish, too little and bounce will not be eliminated).

Resistor/Capacitor

If an on/off switch is used with a pull up (or pull down) resistor and a single capacitor is placed over the switch (you can also place it across the resistor but this can cause nasty spikes of current on the power supply lines) then when the switch is closed (generally pressed) the capacitor will almost instantly discharge through the switch. But when the switch is opened (generally released) the capacitor takes some time to recharge. Therefore contact bounce will have negligible effect on the output. The slow edges can be cleaned up with a schmitt trigger if necessary. This method has the advantage of fast response to the initial press but the current surges through the switch may be undesirable. Other RC based systems are also possible with various responses and such systems are probably the easiest method when constructing with simple logic gates and discrete components.

State machines and software

A finite state machine or software running on a CPU can be designed to wait a fixed number of clock cycles after any transition before registering another one. This provides a cheap option for debouncing when a microprocessor, microcontroller or gate array is already in use but is unlikely to be worthwhile if constructing with single logic gates.

Hysteresis

Alternatively, it is possible to build in hysteresis by making the position where a press is detected separate from that where a release is detected. As long as the bounces are small enough not to take the switch between these positions, bounce problems will be eliminated.

Changeover switch

A changeover switch provides two distinct events, the making of one contact and the breaking of the other. These can be used to feed the inputs of a flip flop. This way the press will only be detected when the pressed contact is made and the release will only be detected when the released contact is made. When the switch is bouncing around in the middle no change is detected. To get a single logic signal from such a setup a simple RS flip flop can be used.

Variable resistance

Normal switches are designed to give a hard on-off but it is also possible to design one that varies more gradually between the hard-on and hard-off states. This keeps the output changes caused by bouncing small. Then by feeding the output to a schmitt trigger the effect of those bounce based changes can be eliminated.

Electrical network

An **electrical network** is an interconnection of electrical elements such as resistors, inductors, capacitors, and switches.

An **electrical circuit** is a network that has a closed loop, giving a return path for the current. A network is a connection of two or more components, and may not necessarily be a circuit.

Design methods

To design any electrical circuits, electrical engineers need to be able to predict the voltages and currents in the circuit. Linear circuits can be analysed to a certain extent by hand because complex number theory gives engineers the ability to treat all linear elements using a single mathematical representation.

Many engineers utilize special software to design and simulate circuits before building them. This method increases both time and cost efficiency since it does not require the engineer to build every circuit prototype in order to test it. The development of technologies such as VHDL has also eased the burden from engineers by simulating and automatically generating circuit designs.

Electrical laws

A number of electrical laws apply to all electrical networks. These include

- Kirchhoff's current law: the sum of all currents entering a node is equal to the sum of all currents leaving the node.
- Kirchhoff's voltage law: the directed sum of the electrical potential differences around a circuit must be zero.
- Ohm's law: the voltage across a resistor is the product of its resistance and the current flowing through it.
- the Y-delta transform
- Norton's theorem: any two-terminal collection of voltage sources and resistors is electrically equivalent to an ideal current source in parallel with a single resistor.

- Thevenin's theorem: any two-terminal combination of voltage sources and resistors is electrically equivalent to a single voltage source in series with a single resistor.
- Millman's method: the voltage on the ends of branches in parallel is equal to the sum of the currents flowing in every branch divided by the total equivalent conductance.

- See also Analysis of resistive circuits.

Other more complex laws may be needed if the network contains nonlinear or reactive components. Non-linear self-regenerative heterodyning systems can be approximated. Applying these laws results in a set of simultaneous equations that can be solved either by hand or by a computer.

Network simulation software

In more complex circuits, engineers need to turn to circuit simulation software. SPICE and EMTP are the most famous of these.

Linearization around operating point

When faced with a new circuit, the software first tries to find a steady state solution. This is a solution where all nodes conform to Kirchhoff's Current Law *and* the voltages across and through each element of the circuit conform to the voltage/current equations governing that element.

Once the steady state solution is found, the operating points of each element in the circuit are known. For a small signal analysis, every non-linear element can be linearized around its operation point to obtain the small-signal estimate of the voltages and currents. This is an application of Ohm's Law. The resulting linear circuit matrix can be solved with Gaussian elimination.

Piece-wise linear approximation

This type of simulator uses piece-wise linear approximations of the equations governing the elements of a circuit. This approximation comes down to splitting the circuit into two parts: a completely linear network with a number of terminals that connect to ideal diodes. Every time a diode switches from on to off or vice versa, the linear network is configured differently. Increasing the accuracy of the simulation can be achieved by adding more detail to the approximation of equations, this will increase the running time of the simulation. This flexibility allows an engineer to make a trade-off between simulation time and the precision of the results, something that is not easily done with the previous simulation technique.

An example for a software using this technique is the Simulink toolbox PLECS.

Electrical overload

An **electrical overload** is a situation where an electrical machine or system is subjected to a greater load than it was designed for. This can be caused by short circuit, by incorrect installation, or by misuse such as running a high-powered appliance off a low-power extension cable. Systems should incorporate suitable overload protection devices to prevent damage should such a situation occur. Fuses and circuit breakers are commonly employed for this purpose.

Short circuit

Tree limbs cause a short circuit during a storm

A **short circuit** (sometimes abbreviated to **short** or **s/c**) is an accidental low-resistance connection between two nodes of an electrical circuit that are meant to be at different voltages. This results in an excessive electric current limited only by the Thevenin equivalent resistance of the rest of the network and potentially causes circuit damage, overheating, fire or explosion. Although usually the result of a fault, there are cases where short circuits are caused intentionally, for example, for the purpose of voltage-sensing crowbar circuit protectors.

The electrical opposite of a *short circuit* is an *open circuit*, which is infinite resistance between two nodes. It is common to misuse "short circuit" to describe any electrical malfunction, regardless of the actual problem.

Explanation

In circuit analysis, the term **short circuit** is used by analogy to designate a zero-impedence connection between two nodes. This forces the two nodes to be at the same voltage. In an ideal short circuit, this means there is no resistance and no voltage drop across the short. In simple circuit analysis, wires are considered to be shorts. In real circuits, the result is a connection of nearly zero impedance, and almost no resistance. In such a case, the current drawn is limited by the rest of the circuit.

Example

A *short circuit* is to connect the positive and negative terminals of a battery together with a low-resistance conductor, like a wire. With low resistance in the connection, a high current flows, causing the cell to deliver a large amount of energy in a short time. (See also: Ohm's law, power).

In electrical devices, unintentional *short circuits* are usually caused when a wire's insulation breaks down, or when another conducting material (such as water) is introduced, allowing charge to flow along a different path than the one intended.

A large current through a battery (also called a cell) can cause the rapid buildup of heat, potentially resulting in an explosion or the release of hydrogen gas and electrolyte, which can burn tissue and may be either an acid or a base. Overloaded wires can also overheat, sometimes causing damage to the wire's insulation, or a fire. High current conditions may also occur with electric motor loads under stalled conditions, such as when the impeller of an electrically driven pump is jammed by debris.

Damage from *short circuits* can be reduced or prevented by employing fuses, circuit breakers, or other overload protection, which disconnect the power in reaction to excessive current. Overload protection must be chosen according to the maximum prospective short circuit current in a circuit. For example, large home appliances (such as clothes dryers) typically draw 10 to 20 amperes, so it is common for them to be protected by 20 - 30 ampere circuit breakers, whereas lighting circuits typically draw less than 10 amperes and are protected by 10 - 15 ampere breakers. Wire sizes are specified in building and electrical codes, and must be carefully chosen for their specific application to ensure safe operation in conjunction with the overload protection.

In mains circuits, short circuits are most likely to occur between two phases, between a phase and neutral or between a phase and earth (ground). Such short circuits are likely to result in a very high current flowing and therefore quickly trigger an overcurrent protection device. However, it is possible for short circuits to arise between neutral and earth conductors, and between two conductors of the same phase. Such short circuits can be dangerous, particularly as they may not immediately result in a large current flowing and are therefore less likely to be detected. Possible effects include unexpected energisation of a circuit presumed to be isolated. To help reduce the negative effects of short circuits, power distribution transformers are deliberately designed to have a certain amount of leakage reactance. The leakage reactance (usually about 5 to 10% of the full load impedance) helps limit both the magnitude and rate of rise of the fault current.

Virtual short

In circuit design, a common cause of a short circuit is a virtual short.

This is when a node is e through a resistance (typically an output impedance) that is larger than usually seen in a direct short, but still small enough to draw larger than normal current. For example, outputting a voltage on a pin that is connected to ground will cause a virtual short. In such an example, a common output impedance of 50 ohms with 5 volts across it will draw 100 mA, much more than a typical draw of a few milliamperes. Another cause is when a highly capacitive load is connected to a supply rail, usually via a FET switch. When switched, the supply rail is directly connected to a load that is at ground, and the amount of current necessary to charge the capacitive load is more than can be supplied by the power source. Voltage droop is experienced in cases where the power supply reaches its maximum current output before the load is charged.

Electric current

Electric current is by definition the flow of electric charge. The SI unit of electric current is the ampere (A), which is equal to a flow of one coulomb of charge per second.

Definition

The magnitude of an electric current is defined as the time derivative of electric charge:

$$I = \frac{dQ}{dt}$$

Formally this is written as:

$$i(t) = \frac{dq(t)}{dt}$$ or inversely as $$q(t_0) = \int_{-\infty}^{t_0} i(t)\, dt$$

The amount of charge ***Q*** flowing per unit of time ***t*** is ***I***, standing for the *intensity* of the current.

Current in a metal wire

In solid conductive metal, with no external forces applied, there exists random motion of free electrons created by the thermal energy that the electrons gain from the surrounding medium. When an atom loses a free electron, it acquires a net positive charge. The free electron can move amongst these positive ions, while the positive ions can only oscillate about their mean fixed positions. The free electron is therefore the charge carrier in a typical solid conductor. Given an imaginary plane through which the wire passes, the number of electrons moving from one side to the other in any period of time is exactly equal to the number passing in the opposite direction.

When a wire is connected across the two terminals of a DC voltage source such as a battery, the source places an electric field across the conductor. The moment contact is made, the free electrons of the conductor will drift toward the positive terminal under the influence of this field. For every ampere of current, 1 coulomb of electric charge (which consists of about 6.242×10^{18} electrons) drifts every second at the same velocity through the imaginary plane through which the conductor passes.

The current *I* in amperes can be calculated with the following equation:

$$I = \frac{Q}{t}$$

where

Q is the electric charge in coulombs (ampere seconds)
t is the time in seconds

It follows that:

$Q = It$ and $t = \frac{Q}{I}$

Current density

Current density is a measure of the density of electrical current. It is defined as a vector whose magnitude is the electric current per cross-sectional area. In SI unit, the current density is measured in amperes per square meter.

The drift speed of electric charges

The mobile charged particles within a conductor move constantly in random directions. In order for a net flow of charge to exist, the particles must also move together with an average drift rate. Electrons are the charge carriers in metals and they follow an erratic path, bouncing from atom to atom, but generally drifting in the direction of the electric field. The speed at which they drift can be calculated from the equation:

$$I = nAvQ$$

where

I is the electric current
n is number of charged particles **per unit volume**
A is the cross-sectional area of the conductor
v is the drift velocity, and
Q is the charge on each particle.

Electric currents in solid matter are typically very slow flows. For example, in a copper wire of cross-section 0.5 mm², carrying a current of 5 A, the *drift velocity* of the electrons is of the order of a millimetre per second. To take a different example, in the near-vacuum inside a cathode ray tube, the electrons travel in near-straight lines ("ballistically") at about a tenth of the speed of light.

However, we know that electrical signals are electromagnetic waves which propagate at very high speed (at the speed of light, as can be deduced from Maxwell's Equations). For example, in AC power lines, the waves of electromagnetic energy propagate rapidly through the space between the wires from a source to a distant load, even though the electrons in the wires only move back and forth over a tiny distance. Although the velocity of the flowing charges is quite low, the associated electromagnetic energy travels at the speed of light. The ratio of the signal velocity through a medium versus the speed of light in a vacuum is called the velocity factor.

Ohm's law

Ohm's law predicts the current in an (ideal) resistor (or other ohmic device) to be applied voltage divided by resistance:

$$I = \frac{V}{R}$$

where

I is the current, measured in amperes
V is the potential difference measured in volts
R is the resistance measured in ohms

Conventional current

Conventional current was defined early in the history of electrical science as a flow of positive charge. In solid metals, like wires, the positive charges are immobile, and only the negatively charged electrons flow in the direction opposite conventional current, but this is not the case in most non-metallic conductors. In other materials, charged particles flow in both directions at the same time. Electric currents in electrolytes are flows of electrically charged atoms (ions), which exist in both positive and negative varieties. For example, an electrochemical cell may be constructed with salt water (a solution of sodium chloride) on one side of a membrane and pure water on the other. The membrane lets the positive sodium ions pass, but not the negative chlorine ions, so a net current results. Electric currents in plasma are flows of electrons as well as positive and negative ions. In ice and in certain solid electrolytes, flowing protons constitute the electric current. To simplify this situation, the original definition of conventional current still stands.

There are also instances where the electrons are the charge that is moving, but where it makes more sense to think of the current as the movement of positive "holes" (the spots that should have an electron to make the conductor neutral). This is the case in a p-type semiconductor.

Examples

Natural examples include lightning and the solar wind, the source of the polar auroras (the aurora borealis and aurora australis). The most familiar artificial form of electric current is the flow of conduction electrons in metal wires, such as the overhead power lines that deliver electrical energy across long distances and the smaller wires within electrical and electronic equipment. In electronics, other forms of electric current include the flow of electrons through resistors or through the vacuum in a vacuum tube, the flow of ions inside a battery, and the flow of holes within a semiconductor.

Electromagnetism

Every electric current produces a magnetic field. The magnetic field can be visualized as a pattern of circular field lines surrounding the wire.

Electric current can be directly measured with a galvanometer, but this method involves breaking the circuit, which is sometimes inconvenient. Current can also be measured without breaking the circuit by detecting the magnetic field it creates. Devices used for this include Hall effect sensors, current clamps, current transformers, and Rogowski coils.

Reference direction

When studying electrical circuits, it is possible that the actual direction of current flow in a specific circuit element is not known at the start. Consequently, we arbitrarily assign each current variable a *reference direction*. After current values are solved for, some of them might display negative values. Hence, for the negative current variables, the actual current flows in the direction opposite to the reference direction which was originally selected.

Electrical safety

The most obvious hazard is electrical shock, where a current passing through part of the body can cause a slight tingle, to cardiac arrest, or severe burns. It is the amount of current passing through the body that determines the effect, and this depends on the nature of the contact, the condition of the body part, the current path through the body and the voltage of the source. The effect also varies considerably from individual to individual. (For approximate figures see **Shock Effects** under electric shock.)

Due to this and the fact that passing current cannot be easily predicted in most practical circumstances, any supply of over 50 volts should be considered a possible source of dangerous electric shock. In particular, note that 110 volts (a minimum voltage at which AC mains power is distributed in many countries) can certainly be lethal.

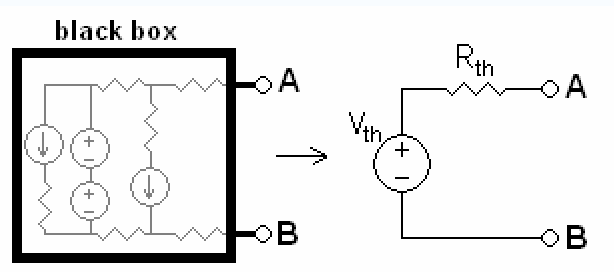
Electric arcs, which can occur with supplies of any voltage (for example, a typical arc welding machine has a voltage between the electrodes of just a few tens of volts), are very hot and emit ultra-violet (UV) and infra-red radiation (IR). Proximity to an electric arc can therefore cause severe thermal burns, and UV is damaging to unprotected eyes and skin.

Accidental electric heating can also be dangerous. An overloaded power cable is a frequent cause of fire. A battery as small as an AA cell placed in a pocket with metal coins can lead to a short circuit heating the battery and the coins which may inflict burns. NiCad, NiMh cells, and Lithium batteries are particularly risky because they can deliver a very high current due to their low internal resistance.

Thévenin's theorem

In electrical circuit theory, **Thévenin's theorem** for electrical networks states that any combination of voltage sources and resistors with two terminals is electrically equivalent to a single voltage source *V* and a single series resistor *R*. For single frequency AC systems the theorem can also be applied to general impedances, not just resistors. The theorem was first discovered by German scientist Hermann von Helmholtz in 1853, but was then rediscovered in 1883 by French telegraph engineer Léon Charles Thévenin (1857-1926).

This theorem states that a circuit of voltage sources and resistors can be converted into a **Thévenin Equivalent**, which is a simplification technique used in circuit analysis. The Thévenin Equivalent can be used as a good model for a power supply or battery (with the resistor representing the internal impedance and the source representing the EMF). The circuit consists of an ideal voltage source in series with an ideal resistor.



Any black box containing only voltage sources, current sources, and resistors can be converted to a Thévenin equivalent circuit.

Calculating the Thévenin equivalent

To calculate the equivalent circuit, one needs a resistance and a voltage - two unknowns. And so, one needs two equations. These two equations are usually obtained by using the following steps, but any conditions one places on the terminals of the circuit should also work:

1. Calculate the output voltage, V_{AB}, when in open circuit condition (no load resistor - meaning infinite resistance). This is V_{Th}.

2. Calculate the output current, I_{AB}, when those leads are short circuited (load resistance is 0). R_{Th} equals V_{Th} divided by this I_{AB}.

- The equivalent circuit is a voltage source with voltage V_{Th} in series with a resistance R_{Th}.

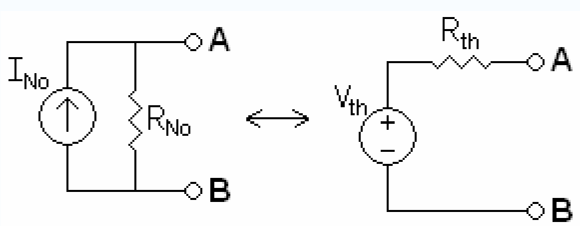
Case 2 could also be thought of like this:

2a. Now replace voltage sources with short circuits and current sources with open circuits.
2b. Replace the load circuit with an imaginary ohm meter and measure the total resistance, R, "looking back" into the circuit. This is R_{Th}.

The Thévenin-equivalent voltage is the voltage at the output terminals of the original circuit. When calculating a Thevenin-equivalent voltage, the voltage divider principle is often useful, by declaring one terminal to be V_{out} and the other terminal to be at the ground point.

The Thévenin-equivalent resistance is the resistance measured across points A and B "looking back" into the circuit. It is important to first replace all voltage- and current-sources with their internal resistances. For an ideal voltage source, this means replace the voltage source with a short circuit. For an ideal current source, this means replace the current source with an open circuit. Resistance can then be calculated across the terminals using the formulae for series and parallel circuits.

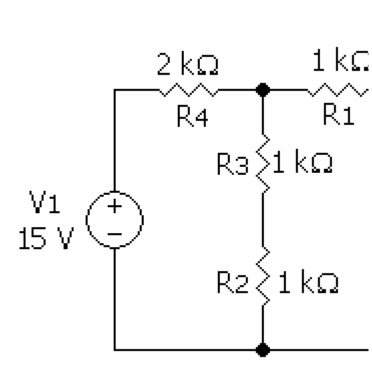
Conversion to a Norton equivalent



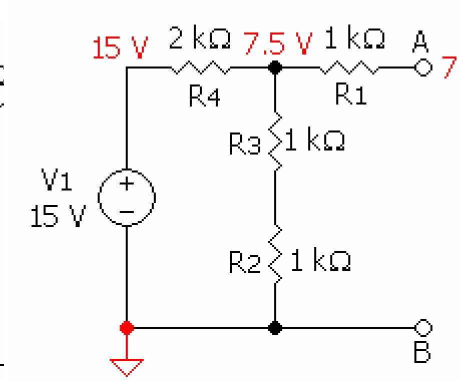
To convert to a Norton equivalent circuit, one can follow the following equations:

$$R_{Th} = R_{No}$$
$$V_{Th} = I_{No} R_{No}$$

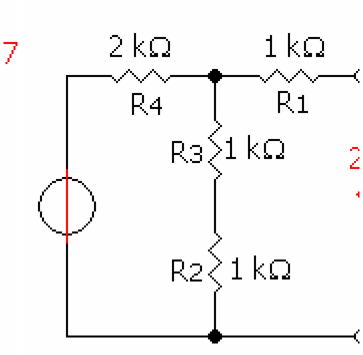
Example of a Thévenin equivalent circuit



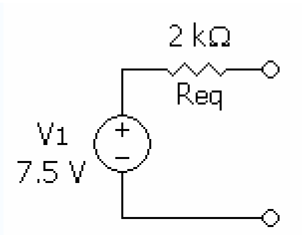
Step 0: The original circuit



Step 1: Calculating the equivalent output voltage



Step 2: Calculating the equivalent resistance



Step 3: The equivalent circuit

In the example, calculating equivalent voltage:

$$V_{AB} = \frac{R_2 + R_3}{(R_2 + R_3) + R_4} \cdot V_1$$
$$= \frac{1\,\mathrm{k}\Omega + 1\,\mathrm{k}\Omega}{(1\,\mathrm{k}\Omega + 1\,\mathrm{k}\Omega) + 2\,\mathrm{k}\Omega} \cdot 15\mathrm{V}$$
$$= \frac{1}{2} \cdot 15\mathrm{V} = 7.5\mathrm{V}$$

Calculating equivalent resistance:

$$R_{AB} = R_1 + ((R_2 + R_3) \| R_4)$$
$$= 1\,\mathrm{k}\Omega + ((1\,\mathrm{k}\Omega + 1\,\mathrm{k}\Omega) \| 2\,\mathrm{k}\Omega)$$
$$= 1\,\mathrm{k}\Omega + \left(\frac{1}{(1\,\mathrm{k}\Omega + 1\,\mathrm{k}\Omega)} + \frac{1}{(2\,\mathrm{k}\Omega)}\right)^{-1} = 2\,\mathrm{k}\Omega$$

In popular culture

While one might doubt that there is any popular culture around electrical theorems, both Thévenin's theorem and Norton's theorem feature in the 4th and 10th of May 2006 Doonesbury comic strip panels .

Crowbar (circuit)

A **crowbar** or **crowbar circuit** is an electrical circuit used to prevent an overvoltage condition of a power supply unit from damaging the circuits attached to the power supply. It operates by putting a short circuit across the voltage source, much as if one dropped a tool of the same name across the output terminals of the power supply. Crowbar circuits are frequently implemented using a thyristor (also called an *SCR*) or a trisil or thyratron as the shorting device. Once triggered, they depend on the current-limiting circuitry of the power supply or, if that fails, the blowing of the line fuse or circuit breaker.

A **crowbar circuit** is distinct from a clamp in that, once triggered, it pulls the voltage below the trigger level, usually close to ground. A clamp prevents the voltage from exceeding a preset level. Thus, a crowbar will not automatically return to normal operation when the overvoltage condition is removed; power must be removed entirely to stop its conduction.

The advantage of a crowbar over a clamp is that the low holding voltage of the crowbar lets it carry higher fault current without dissipating much power which could cause overheating. Also, a crowbar is more likely than a clamp to deactivate a device (by blowing a fuse, or throwing breakers), bringing attention to the faulty equipment.

The term is also used as a verb to describe the act of short-circuiting the output of a power supply.

Fuse (electrical)

200 A Industrial fuse. 80 kA breaking capacity.

In electronics and electrical engineering a **fuse**, short for 'fusible link', is a type of overcurrent protection device. It has as its critical component a metal wire or strip that will melt when heated by a prescribed electric current, opening the circuit of which it is a part, and so protecting the circuit from an overcurrent condition.

A practical fuse was one of the essential features of Edison's electrical power distribution system. An early fuse was said to have successfully protected an Edison installation from tampering by a rival from a gas-lighting concern.

Properly-selected fuses (or other overcurrent devices) are an essential part of a power distribution system to prevent fire or damage due to overload or short-circuits. Usually the maximum size of the overcurrent device for a circuit is regulated by law. For example, the Canadian Electrical Code, the United States National Electrical Code (NFPA 70), and the UK Wiring Regulations provide limits for overcurrent device ampere rating for a given conductor, insulation material and installation conditions. Local authorities will incorporate these national codes as part of law. An overcurrent device should normally be selected with a rating just over the normal operating current of the downstream wiring or equipment which it is to protect.

Fuse characteristics

Each type of fuse (and all other overcurrent devices) has a time-current characteristic which shows the time required to melt the fuse and the time required to clear the circuit for any given level of overload current. Where the fuses in a system are of similar types, simple ratios between ratings of the fuse closest to the load and the next fuse towards the source can be used, so that only the affected circuit is interrupted after a fault. In power system design, main and branch circuit overcurrent devices can be co-ordinated for best protection by plotting the time-current characteristics on a consistent scale, making sure that the source curve never crosses that of any of the branch circuits. To prevent damage to utilization devices, both "maximum clearing" and "minimum melting" fuse curves are plotted.

Fuses are often characterized as "fast-blow" or "slow-blow" | "time-delay", according to the time they take to respond to an overcurrent condition. Fast-blow fuses (sometimes marked 'F') open quickly when the rated current is reached. Ultrafast fuses (marked 'FF') are used to protect semiconductor devices that can tolerate only very short-lived overcurrents. Slow-blow fuses (household plug type are often marked 'T') can tolerate a transient overcurrent condition (such as the high starting current of an electric motor), but will open if the overcurrent condition is sustained.

A fuse also has a rated interrupting capacity, also called breaking capacity, which is the maximum current the fuse can safely interrupt. Generally this should be higher than the maximum prospective short circuit current though it may be lower if another fuse or breaker upstream can be relied upon to take out extremely high current shorts. Miniature fuses may have an interrupting rating only 10 times their rated current. Fuses for low-voltage power systems are commonly rated to interrupt 10,000 amperes, which is a minimum capacity regulated by the electrical code in some jurisdictions. Fuses for larger power systems must have higher interrupting ratings, with some low-voltage current-limiting "high rupturing capacity" (HRC) fuses rated for 300,000 amperes. Fuses for high-voltage equipment, up to 115,000 volts, are rated by the total apparent power (megavoltamperes, MVA) of the fault level on the circuit.

Overcurrent devices installed inside of enclosures are "derated" at least per the US NEC. This is a hold-over from the first mounting of electrical devices on the surface of slate slabs. The slate was the insulating material between devices mounted in air. So, rather than change the fuse rating, it became common to allow only 80% of the current value of the overcurrent device when the circuit is in operation for 3 hours or more (continuous loading).

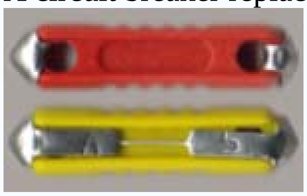
As well as a current rating, fuses also carry a voltage rating indicating the maximum circuit voltage in which the fuse can be used. For example, glass tube fuses rated 32 volts should never be used in line-operated (mains-operated) equipment even if the fuse physically can fit the fuseholder. Fuses with ceramic cases have higher voltage ratings. Fuses carrying a 250 V rating can be safely used in a 125 V circuit, but the reverse is not true as the fuse may not be capable of safely interrupting the arc in a circuit of a higher voltage.

Fuse packages

Car fuses with plastic body (plug-in type)

Plug-in type fuses come in three physical sizes: mini, ATO and maxi

A circuit breaker replacement for midi-sized plug-in fuses



Bosch type fuse (used in old cars)

Fuses are often sold in standardised packages to make them easily interchangeable. Cartridge fuses are cylindrical and are made in standard lengths such as 20 mm, 1 in (25 mm) and 1.25 in (32 mm). Smaller fuses often have a glass body with nothing but air inside so that the fuse wire can be inspected. Under extremely high current or voltage, such fuses can arc over and therefore continue to supply a current. Fuses used in higher energy circuits (for example building wiring installations) have a strong ceramic body which prevents arc over, and are filled with sand to quench any arcs. Small fuses may be held by metal clips on their end ferrules, but larger fuses (100 amperes and larger) are usually bolted into the fuse holder.

High-voltage fuses used outdoors may be of the expulsion type, allowing arc by-products to be discharged to the air with considerable noise when they operate.

Plug-in type

Plug-in fuses (also called blade or spade fuses), with a plastic body and two prongs that fit into sockets, are used in automobiles. These types of fuses come in three different physical dimensions: mini (or minifuse), ATO® (or ATC) and maxi (or maxifuse).
The physical dimensions, including the connector, of the fuses are as follows (LxWxH) (ampere ratings in the parenthesis):

- mini: 10.9x3.6x16.3 mm (1A, 2A, 3A, 4A, 5A, 7.5A, 10A, 15A, 20A, 25A, 30A)
- ATO: 19.1x5.1x18.5 mm (2A, 3A, 4A, 5A, 7.5A, 10A, 15A, 20A, 25A, 30A, 40A)
- maxi: 29.2x8.5x34.3 mm (20A, 30A, 40A, 50A, 60A, 70A, 80A)

Replacement circuit breaker

It is possible to replace an ATO-type plug-in fuse with a circuit breaker that has been designed to fit in the socket of a ATO-sized fuse holder. These circuit protectors are more expensive than a regular fuse.

Bosch type

Bosch type fuses are used in older (often European) automobiles, and can also be used instead of glass type fuses in inline fuse holders (but not in ganged fuse holders). The physical dimension of this type of fuse is 6x25 mm.

Color coding of Bosch type fuses

Most fuses of the Bosch type usually use the same color coding for the rated current.

Color	Ampere
yellow	5A
white	8A
red	16A
blue	25A

Sub-miniature

Sub-miniature fuses for instruments may be rated as little as 50 milliamperes. These may have wire leads or may be fitted into small two-pin sockets. Sub-miniature and pico fuses used in electronic devices may be directly soldered to a printed circuit board. Often these fuses are installed only to protect the external utilization device, not the electronics.

Power circuit fuses

The Swiss electric fuses (6 and 10 A) that are still in use in some older European buildings. In the three room flat, the 6 A fuse guards two rooms, and the 10 A fuse guards the remaining room and kitchen. The lower end (as in the picture) of the 10 A fuse is wider. So it is not possible to insert it into the socket for the 6 A fuse. When the wire melts, the colored point disappears

Fuses for power circuits are available in a wide range of ratings. Critical values in the specification of fuses are the normal rated current, the circuit voltage, and the maximum level of current available on a short-circuit. For example, in North America, a so-called "code" fuse may only be safely used in circuits with no more than 10,000 amperes available on a short circuit.

Fuses are used on power systems up to 115,000 volts AC. High-voltage fuses are used to protect instrument transformers used for electricity metering, or for small power transformers where the expense of a circuit breaker is not warranted. For example, in distribution systems, a power fuse may be used to protect a transformer serving 1-3 houses. A circuit breaker at 115 kV may cost up to five times as much as a set of power fuses, so the resulting saving can be tens of thousands of dollars.

Large power fuses use fusible elements made of silver or copper to provide stable and predictable performance. High voltage *expulsion fuses* surround the fusible link with gas-evolving substances, such as boric acid. When the fuse blows, heat from the arc causes the boric acid to evolve large volumes of gases. The associated high pressure (often greater than 100 atmospheres) and cooling gases rapidly extinguish (quench) the resulting arc. The hot gases are then explosively expelled out of the end(s) of the fuse. Other special High Rupturing Capacity (HRC) fuses surround one of more parallel connected fusible links with an energy absorbing material, typically silicon dioxide sand. When the fusible link blows, the sand absorbs energy from the arc, rapidly quenching it, creating an artificial fulgurite in the process.

Fuses compared with circuit breakers

Fuses have the advantages of often being less costly and simpler than a circuit breaker for similar ratings. The blown fuse must be replaced with a new device which is less convenient than simply resetting a breaker and therefore likely to discourage people from ignoring faults. On the other hand replacing a fuse without isolating the circuit first (most building wiring designs do not provide individual isolation switches for each fuse) can be dangerous in itself, particularly if the fault is a short circuit.

High rupturing capacity fuses can be rated to safely interrupt up to 300,000 amperes at 600 V AC. Special current-limiting fuses are applied ahead of some molded-case breakers to protect the breakers in low-voltage power circuits with high short-circuit levels.

"Current-limiting" fuses operate so quickly that they limit the total "let-through" energy that passes into the circuit, helping to protect downstream equipment from damage. These fuses clear the fault in less than one cycle of the AC power frequency. Circuit breakers cannot offer similar rapid protection.

Circuit breakers which have interrupted a severe fault should be removed from service and inspected and replaced if damaged.

In a multi-phase power circuit, if only one of the fuses opens, the remaining phases will have higher than normal currents, and unbalanced voltages, with possible damage to the coils of motors or solenoids. Fuses only sense overcurrent, or to a degree, over-temperature, and cannot usually be used with protective relaying to provide more advanced protective functions, for example, ground fault detection.

Some manufacturers of medium-voltage distribution fuses combine the overcurrent protection characteristics of the fusible element with the flexibility of relay protection by adding a pyrotechnic device to the fuse operated by external protection relays

Fuse boxes

Fuse box

Old electrical consumer units (also called fuse boxes) were fitted with fuse wire that could be replaced from a supply of spare wire that was wound on a piece of cardboard. Modern consumer units contain magnetic circuit breakers instead of fuses. Cartridge fuses were also used in consumer units and sometimes still are as miniature circuit breakers (MCBs) are rather prone to nuisance tripping. (In North America, fuse wire was never used in this way, although so-called "renewable" fuses were made that allowed replacement of the fuse link. It was impossible to prevent putting a higher-rated or double links into the holder ("overfusing") and so this type must be replaced.)

The box pictured is a "Wylex standard". This type was very popular in the British Isles up until recently when the wiring regulations started demanding Residual-Current Devices (RCDs) for sockets that could feasibly supply equipment outside the equipotential zone. The design does not allow for fitting of RCDs (there were a few wylex standard models made with an RCD instead of the main switch but that isn't generally considered acceptable nowadays either because it means you lose lighting in the event of almost any fault) or residual-current circuit breakers with overload (RCBOs) (an RCBO is the combination of an RCD and an MCB in a single unit). The one pictured is fitted with rewirable fuses but they can also be fitted with cartridge fuses and MCBs. There are two styles of fuse base that can be screwed into these units—one designed for the rewirable fusewire carriers and one designed for cartridge fuse carriers. Over the years MCBs have been made for both styles of base. With both styles of base higher rated carriers had wider pins so a carrier couldn't be changed for a higher rated one without also changing the base. Of course with rewirable carriers a user could just fit fatter fusewire or even a totally different type of wire object (hairpins, paper clips, nails etc.) to the existing carrier.

In North America, fuse boxes were also often used, especially in homes wired before about 1950. Fuses for these panels were screw-in "plug" type (not to be confused with what the British refer to as plug fuses), in holders with the same threads as Edison-base incandescent lamps, with ratings of 5, 10, 15, 20, 25, and 30 amperes. To prevent installation of fuses with too high a current rating for the circuit, later fuse boxes included rejection features in the fuseholder socket. Some installations have resettable miniature thermal circuit breakers which screw into the fuse socket. One form of abuse of the fuse box was to put a penny in the socket, which defeated the overcurrent protection function and resulted in a dangerous condition. Plug fuses are no longer used for branch circuit protection in new residential or industrial construction.

British plug fuse

20 mm 200 mA glass cartridge fuse used inside equipment and 1 inch 13 A ceramic British plug fuse.

The BS 1363 13 A plug has a BS 1362 cartridge fuse inside. This allows the use of 30 A/32 A (30 A was the original size; 32 A is the closest European harmonised size) socket circuits safely. In order to keep cable sizes manageable these are usually wired in ring mains. It also provides better protection for small appliances with thin flex as a variety of fuse ratings (1 A, 2 A, 3 A, 5 A, 7 A, 10 A 13 A with 3, 5 and 13 being the most common) are available and a suitable fuse should be fitted to allow the normal operating current while protecting the appliance and its cord as well as possible. With some loads it is normal to use a slightly higher rated fuse than the normal operating current. For example on 500 W halogen floodlights it is normal to use a 5 A fuse even though a 3 A would carry the normal operating current. This is because halogen lights draw a significant surge of current at switch on as their cold resistance is far lower than their resistance at operating temperature.

In most other wiring practices the wires in a flexible cord are considered to be protected by the branch circuit overcurrent device, usually rated at around 15 amperes, so a plug-mounted fuse is not used. Small electronic apparatus often includes a fuseholder on or in the equipment, to protect internal components only.

Other types of fuse

So-called "self-resetting" fuses use a thermoplastic conductive element that opens the circuit on overload, then restores the circuit when they cool. These are useful in aerospace applications where replacement is difficult. Common kind is the Polyswitch self-repairing fuses.

A "thermal fuse" is often found in consumer heating equipment such as coffee makers or hair dryers; it contains a fusible alloy which opens when the temperature is too high due to reduced air flow or other fault.

Switchgear

The term **switchgear**, commonly used in association with the electric power system, or grid, refers to the combination of electrical disconnects and/or circuit breakers used to isolate electrical equipment. Switchgear is used both to de-energize equipment to allow work to be done and to clear faults downstream.

Locations

Switchgear is located anywhere that isolation and protection may be required. These locations include generators, motors, transformers, substations, and high or medium voltage distribution networks. Switchgear of all types may be used by the power utility as protection against line to ground, phase to phase, or line to neutral faults. Switchgear is also used for heavy industry purposes. High or medium voltage equipment may be required for industrial processes and switchgear is used in these locations to isolate and protect this equipment.

Substations

Typically switchgear in substations is located on both the high voltage and the low voltage side of large power transformers. The switchgear located on the low voltage side of the transformers in distribution type substations, now are typically located in what is called a Power Distribution Center (PDC). Inside this building are typically smaller, medium-voltage (~15kV) circuit breakers feeding the distribution system. Also contained inside these Power Control Centers are various relays, meters, and other communication equipment allowing for intelligent control of the substation.

Housing

Switchgear for low voltages may be entirely enclosed within a building. For transmission levels of voltage (high voltages over 66 kV), often switchgear will be mounted outdoors and insulated by air, though this requires a large amount of space.

At small substations, switches may be manually operated, but at important switching stations on the transmission network all devices have motor operators to allow for remote control.

Types

A piece of switchgear may be a simple open air circuit breaker or it may be insulated by some other substance. An effective although more costly form of switchgear is "gas insulated switchgear" (GIS), where the conductors and circuit breakers are insulated by pressurized sulfur hexafluoride gas. Another common type is oil insulated switchgear. Vacuum circuit breakers are frequently used as medium voltage switchgear (up to 35 kV).

Functions

One of the main basic functions of switchgear is protection: discrimination between circuit breakers enhances availability, that is to say continuity of service. The overall approach is termed coordination: the standards provide a framework for discrimination and cascading that protects the integrity of the power system and minimizes the scope of downstream outages.

Distribution board

A fairly standard American circuit breaker panel manufactured by General Electric and using *interchangeable* circuit breakers

A **distribution board** (known in the United States as a (**circuit**) **breaker panel**, **panelboard**, or **load center** or for old ones, **fuse box**) is a mounting enclosure for multiple electrical circuit breakers. These are generally placed in two columns. Small single-phase boxes, with the breakers in just one row, are known as consumer units in Britain. Distribution boards are typically found in central locations inside buildings and often serve as the point at which electricity is distributed within a building. Circuit breakers can be used to manually de-energize electrical circuits when the downstream wiring is being serviced.

Circuit breaker panels are always *dead front*, that is, the operator of the circuit breakers cannot contact live electrical parts. During servicing of the distribution board itself, though, when the cover has been removed and the cables are visible, North American breaker panels commonly have some live parts exposed. British distribution boards generally have the live parts enclosed to IP20, even when the cover has been removed for servicing.

Breaker arrangement

Breakers are usually arranged in two columns. In a US-style board, breaker positions are numbered left-to-right, along each row from top to bottom. For 120/240 volts, hot wires (that which are live) are black and red (blue is used as the third leg of three-phase power [120/208 volts]) and white for neutral. For 277/480 volts (always three-phase) the hot wires are brown, orange and yellow and grey is the neutral. Green or bare wires are used as grounds in both configurations.

Illustration of breaker numbering in a North American type panelboard. Some labels are missing, and some lines have additional descriptive labels. The numbers on the toggles indicate the ampereage they will pass before tripping off and stopping all current. The top right breaker (Rated at 100 A) leads to a sub panel.

Phase	**Breakers**	
X	1	2
Y	3	4
Z	5	6
X	7	8
Y	9	10
Z	11	12

These breakers cycle through two or three phases, labelled as *X*, *Y*, and *Z* in the above diagram. This numbering system is universal across various competing manufacturers of breaker panels.

In a UK-style board, breaker positions are numbered top to bottom in the left hand column, then top to bottom in the right column. Each number is used to label one position on each phase, as below. It remains to be seen how the new wiring colours recently introduced in the UK will affect this labelling.

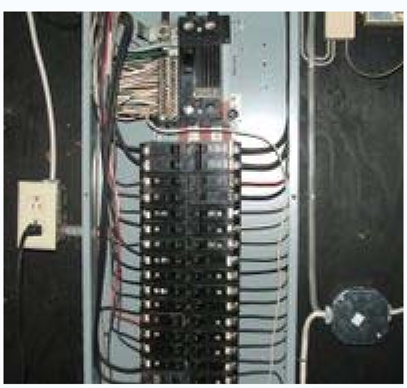
Phase	**Breakers**

Red	R1	R4
Yellow	Y1	Y4
Blue	B1	B4
Red	R2	R5
Yellow	Y2	Y5
Blue	B2	B5
Red	R3	R6
Yellow	Y3	Y6
Blue	B3	B6

In both labelling styles the reason for the alternating pattern of phases is to allow for common trip breakers to have one pole on each phase.

In North America it is common to wire large heating equipment line-to-line. This takes two slots in the panel (two-pole) and gives a voltage of 240V if the supply system is split phase and 208 V if the supply system is three phase. This practice is much less common in countries that use a higher line-neutral voltage. Large motors, air conditioners, subpanels, etc., are typically three-phase (where available). Therefore a three-pole breaker is needed which takes three slots in the breaker panel.

Inside a North American panel



The picture to the right (Click to enlarge it) shows the interior of a standard residential service, North-American General Electric style breaker panel. The three power lines can be seen coming in at the top (One going to the neutral busbar to the left with all the white wires, the other two attached to the main breaker). Below it are the two rows of circut breakers with the circuit's hot wire leading off. A line can be seen directly exiting the box and running to an electrical receptacle with something plugged into it.

Inside a UK distribution board

This picture shows the interior of a typical 12-position UK distribution panel. The three incoming phase wires connect to the busbars via an isolator switch in the centre of the panel. The incoming neutral connects to the neutral busbar at the centre right of the board, which is in turn connected to the neutral busbar at the top left side of the board. The incoming earth wire connects to the earth busbar at the centre left side of the panel, which is in turn connected to the earth busbar at the top right of the board. The cover has been removed from the neutral bar at the right of the board; the neutral bar on the left side has its cover in place.

Down the left side of the phase busbars are two two-pole RCBOs and two single-pole breakers, one unused. Down the right side of the busbars are a single-pole breaker, a two-pole RCBO and a three-pole breaker.

The two-pole RCDOs in the picture are not connected across two phases, but have supply-side neutral connections exiting behind the phase busbars.

It is likely that the manufacturer produces 18- and 24-position versions of this panel using the same chassis which explains why there appears to be so much unused space.

Manufacturer differences

Most of the time, the panel and the breakers inserted into it must both be from the same company. Each company has one or more "systems", or kinds of breaker panels, that only accept breakers of that type. In Europe this is still the case despite the adoption of a standard DIN rail for mounting and a standard cut-out shape as the positions of the busbar connections are not standardised.

It is commonly known in North America that Siemens and General Electric panels and breakers of the type shown in the above and below picture illustrations are interchangeable one-inch wide breakers. Therefore, these two types of breaker panels have gained widespread acceptance as a "standard". The two panels shown seem to fit GOULD Type QP, ITE type QT, Cutler Hammer Type BR, Square D "Homeline", Siemens, and General Electric breakers. The other two standards commonly found in North America are the Cutler Hammer "CH" standard and the Square D "QO" standard (both 3/4 inch breakers). These systems allow the use of breakers which accommodate two individual circuit breaker functions within the width of a standard (1" or 3/4") case, but not all positions in all distribution boards may allow the use of such dual breakers.

Numerous older systems are still in use in older buildings and are still manufactured for these legacy applications, such as Zinsco and others.

Location and designation

For reasons of aesthetics and security, circuit breaker panels are often placed in out-of-the-way closets, attics, garages, or basements, but sometimes they are also featured as part of the aesthetic elements of a building (as an art installation, for example) or where they can be easily accessed. However, current US building codes prohibit installing a panel in a bathroom (or similar room), or where there is insufficient space for a worker to access it.

In large buildings or facilities with higher electric power demand may have multiple circuit breaker panels. In this case, the panels are often indicated by letters of the alphabet. One case is The Decon Gallery, a modern building in downtown Toronto, which has 11 breaker panels designated "A", "B", "C", "D", and so on. A backstage outlet is therefore labeled "C27". In many such buildings, each outlet is on its own circuit breaker, and the outlets are labelled in the above specified manner to facilitate easy location of which breaker to shut off for servicing, rewiring, or the like.

In even larger buildings, such as schools, hospitals and sports/entertainment venues it is not uncommon to have scores of panels, specially designated for each building depending on how the architects and electrical engineers sub divide the building. They are commonly designated as either three-phase or single-phase and normal power or emergency power. In these set-ups they may also be designated for their use, such as distribution panels for supplying other panels, lighting panels for lights, power panels for equipment and receptacles and special uses for whatever type of building they are used in. It is also not uncommon for these panels to be located throughout the building in electric closets serving a section of the building.

Distribution boards may be surface-mounted on a wall or may be sunk in to the wall. The former arrangement allows for easier alteration or addition to wiring at a later date, but the latter arrangement may look neater, particularly in a residential situation. The other problem with recessing a distribution board into a wall is that if the wall is solid a lot of brick or block may need to be removed - for this reason recessed boards are generally only fitted on new-build projects when the required space can be built in to the wall.

Mobile operation

Sometimes it is desired to have a portable breaker panel, for example, for special events. In this case, a breaker panel is mounted to a board, together with various sockets. These are common in the movie industry. The American one pictured at the right has a cord with an L21-30 plug to supply power. Power leaves the board through four three-phase circuits: three 15 ampere circuits; and one 20 A circuit. The 15 A circuits each go to a triplex-box. The 20 A circuit goes to an L21-20 receptacle, and one leg of it goes to a 20 A duplex receptacle shown at the upper left. The neon nightlights on the upper right triplex box are to show the phase sequence.

Bi-metallic strip

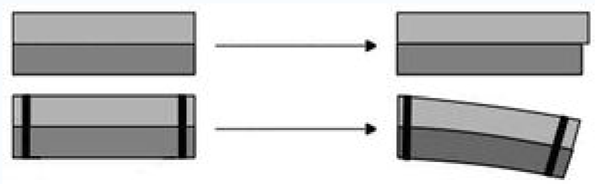
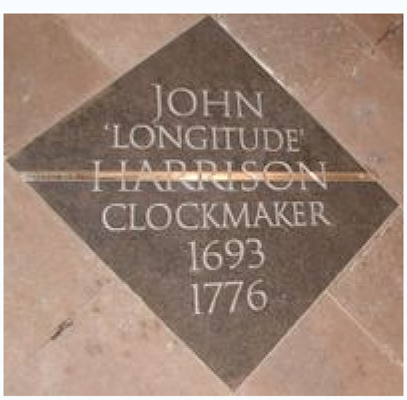


Diagram of a bi-metallic strip showing how the difference in thermal expansion in the two metals leads to a much larger sideways displacement of the strip

A **bi-metallic strip** is used to convert a temperature change into mechanical displacement. The strip consists of two strips of different metals which expand at different rates as they are heated, usually steel and copper. The strips are joined together throughout their length by rivets, by brazing or by welding. The different expansions force the flat strip to bend one way if heated, and in the opposite direction if cooled below its normal temperature. The metal with the higher expansion is on the outer side of the curve when the strip is heated and on the inner side when cooled.

The sideways displacement of the strip is much larger than the small lengthways expansion in either of the two metals. This effect is used in a range of mechanical and electrical devices. In some applications the bi-metal strip is used in the flat form. In others, it is wrapped into a coil for compactness. The greater length of the coiled version gives improved sensitivity.

History



Memorial

The bimetallic strip was probably invented by the eighteenth century clockmaker John Harrison for his third marine timekeeper (H3) to compensate for temperature-induced changes in the balance spring.[1] It should not be confused with his bimetallic mechanism for correcting for thermal expansion in the gridiron pendulum. His earliest examples had two individual metal strips joined by rivets but he also invented the later technique of directly fusing molten brass onto a steel substrate. A strip of this type was fitted to his last timekeeper, H5. His invention is recognised in the memorial to him in Westminster Abbey, England.

Applications

Clocks

Mechanical clock mechanisms are sensitive to temperature changes which lead to errors in time keeping. A bimetallic strip is used to compensate for this in some mechanisms. The most common method is to use a bimetallic construction for the circular rim of the balance wheel. As the spring controlling the balance becomes weaker with increasing temperature, so the balance becomes smaller in diameter to keep the period of oscillation (and hence timekeeping) constant.

Thermostats

In regulating mk,thermostats that operate over a wide range of temperatures the bi-metal strip is mechanically fixed and attached to an electrical power source while the other (moving) end carries an electrical contact. In adjustable thermostats another contact is positioned with a regulating knob or lever. The position so set controls the regulated temperature, called the **set point**.

Some thermostats use a mercury switch connected to both electrical leads. The angle of the entire mechanism is adjustable to control the set point of the thermostat.

Depending upon the application, a higher temperature may open a contact (as in a heater control) or it may close a contact (as in a refrigerator or air conditioner).

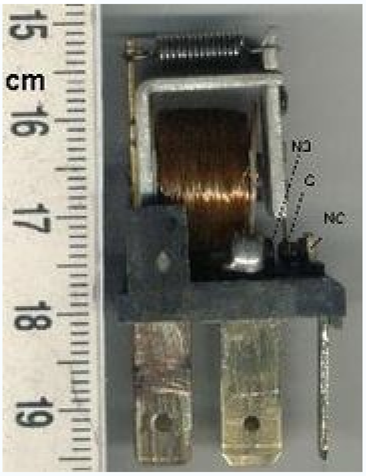
The electrical contacts may control the power directly (as in a household iron) or indirectly, switching electrical power through a relay or the supply of natural gas or fuel oil through an electrically operated valve. In some natural gas heaters the power may be provided with a thermocouple that is heated by a pilot light (a small, continuously burning flame). In devices without pilot lights for ignition (as in most modern gas clothes dryers and some natural gas heaters and decorative fireplaces) the power for the contacts is provided by reduced household electrical power that operates a relay controlling an electronic ignitor, either a resistance heater or an electrically powered spark generating device.

For an illustration of a bi-metal element in a simple thermostat, see the thermostat entry.

Thermometers

A direct indicating dial thermometer (such as a patio thermometer or a meat thermometer) uses a bi-metallic strip wrapped into a coil, as does a common household thermostat. One end of the coil is fixed to the housing of the device and the other drives an indicating needle through a train of gears much like that in a watch.

Relay



Automotive style miniature relay

A **relay** is an electrical switch that opens and closes under control of another electrical circuit. In the original form, the switch is operated by an electromagnet to open or close one or many sets of contacts. It was invented by Joseph Henry in 1835. Because a relay is able to control an output circuit of higher power than the input circuit, it can be considered, in a broad sense, to be a form of electrical amplifier.

These contacts can be either **Normally Open (NO)**, **Normally Closed (NC)**, or **change-over** contacts.

- Normally-open contacts connect the circuit when the relay is activated; the circuit is disconnected when the relay is inactive. It is also called **Form A** contact or "make" contact. Form A contact is ideal for applications that require to switch a high-current power source from a remote device.
- Normally-closed contacts disconnect the circuit when the relay is activated; the circuit is connected when the relay is inactive. It is also called **Form B** contact or "break" contact. Form B contact is ideal for applications that require the circuit to remain closed until the relay is activated.

Change-over contacts control two circuits: one normally-open contact and one normally-closed contact

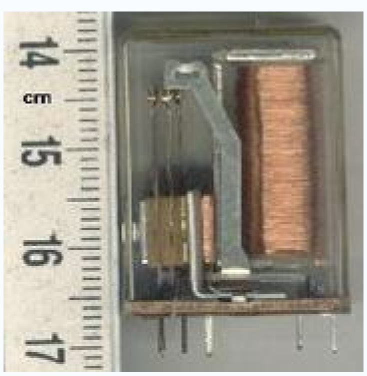
with a common terminal. It is also called Form C **contact.**

When a current flows through the coil, the resulting magnetic field attracts an armature that is mechanically linked to a moving contact. The movement either makes or breaks a connection with a fixed contact. When the current to the coil is switched off, the armature is returned by a force that is half as strong as the magnetic force to its relaxed position. Usually this is a spring, but gravity is also used commonly in industrial motor starters. Relays are manufactured to operate quickly. In a low voltage application, this is to reduce noise. In a high voltage or high current application, this is to reduce arcing.

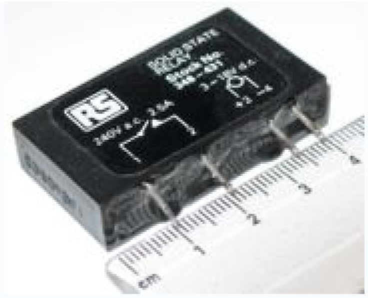
If the coil is energized with DC, a diode is frequently installed across the coil, to dissipate the energy from the collapsing magnetic field at deactivation, which would otherwise generate a spike of voltage and might cause damage to circuit components. If the coil is designed to be energized with AC, a small copper ring can be crimped to the end of the solenoid. This "shading ring" creates a small out-of-phase current, which increases the minimum pull on the armature during the AC cycle. [1]

By analogy with the functions of the original electromagnetic device, a solid-state relay is made with a thyristor or other solid-state switching device. To achieve electrical isolation, a light emitting diode (LED) is used with a photo transistor.

Types of relay



Small relay as used in electronics

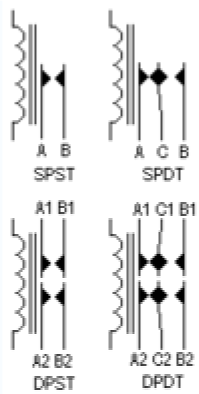


A solid state relay, which has no moving parts

- **latching relays** are available that have two relaxed states (bistable). These are also called 'keep' relays. When the current is switched off, the relay remains in its last state. This is achieved with a solenoid operating a ratchet and cam mechanism, or by having two opposing coils with an over-center spring or permanent magnet to hold the armature and contacts in position while the coil is relaxed, or with a remnant core. In the ratchet and cam example, the first pulse to the coil turns the relay on and the second pulse turns it off. In the two coil example, a pulse to one coil turns the relay on and a pulse to the opposite coil turns the relay off. This type of relay has the advantage that it consumes power only for an instant, while it is being switched, and it retains its last setting across a power outage.
- A **reed relay** has a set of, usually normally open, contacts inside a vacuum or inert gas filled glass tube. This protects the contacts against atmospheric corrosion. The two contacts are closed by magnetism from a coil around the glass tube. See also reed switch.
- A **mercury wetted relay** is a form of reed relay in which the contacts are wetted with mercury. Such relays are used to switch low-voltage signals (one volt or less) because of its low contact resistance, or for high-speed counting and timing applications where the mercury eliminated contact bounce. Mercury wetted relays are position-sensitive and must be mounted vertically to work properly. Because of the toxicity and expense of liquid mercury, these relays are rarely specified for new equipment. See also mercury switch.
- A **machine tool relay** is a type standardized for industrial control of machine tools, transfer machines, and other seqential control. They are characterized by a large number of contacts (sometimes extendable in the field) which are easily converted from normally-open to normally-closed status, easily replaceable coils, and a form factor that allows compactly installing many relays in a control panel. Although such relays once were the backbone of automation in such industries as

automobile assembly, the programmable logic controller mostly displaced the machine tool relay from sequential control applications.

- A **contactor** is a very heavy-duty relay used for switching electric motors and lighting loads. With high current, the contacts are made with pure silver. The unavoidable arcing causes the contacts to oxidize and silver oxide is still a good conductor. Such devices are often used for motor starters. A motor starter is a contactor with an overload protection devices attached. The overload sensing devices are a form of heat operated relay where a coil heats a bi-metal strip, or where a solder pot melts, releasing a spring to operate auxiliary contacts. These auxiliary contacts are in series with the coil. If the overload senses exess current in the load, the coil is de-energized.
- A **Buchholz relay** is a safety device sensing the accumulation of gas in large oil-filled transformers, which will alarm on slow accumulation of gas or shut down the transformer if gas is produced rapidly in the transformer oil.
- A **forced-guided contacts relay** has relay contacts that are mechanically linked together, so that when the relay coil is energized or de-energized, all of the linked contacts move together. If one set of contacts in the relay becomes immobilized, no other contact of the same relay will be able to move. The function of forced-guided contacts is to enable the safety circuit to check the status of the relay. Forced-guided contacts are also known as "positive-guided contacts", "captive contacts", "locked contacts", or "safety relays".
- A **solid-state relay (SSR)** is a solid state electronic component that provides a similar function to an electromechanical relay but does not have any moving components, increasing long-term reliability. With early SSR's, the tradeoff came from the fact that every transistor has a small voltage drop across it. This collective voltage drop limited the amount of current a given SSR could handle. As transistors improved, higher current SSR's, able to handle 100 to 1,200 amps, have become commercially available.
- One type of motor overload protection relay is operated by a heating element in series with the motor. The heat generated by the motor current operates a bi-metal strip or melts solder, releasing a spring to operate contacts. Where the overload relay is exposed to the same environment as the motor, a useful though crude compensation for motor ambient temperature is provided.



Circuit symbols of relays. *"C" denotes the common terminal in SPDT and DPDT types.*


The diagram on the package of a DPDT AC coil relay

Since relays are switches, the terminology applied to switches is also applied to relays. According to this classification, relays can be of the following types:

- **SPST** - **S**ingle **P**ole **S**ingle **T**hrow. These have two terminals which can be switched on/off. In total, four terminals when the coil is also included.
- **SPDT** - **S**ingle **P**ole **D**ouble **T**hrow. These have one row of three terminals. One terminal (common) switches between the other two poles. It is the same as a single change-over switch. In total, five terminals when the coil is also included.
- **DPST** - **D**ouble **P**ole **S**ingle **T**hrow. These have two pairs of terminals. Equivalent to two SPST switches or relays actuated by a single coil. In total, six terminals when the coil is also included. This configuration may also be referred to as DPNO.
- **DPDT** - **D**ouble **P**ole **D**ouble **T**hrow. These have two rows of change-over terminals. Equivalent to two SPDT switches or relays actuated by a single coil. In total, eight terminals when the coil is also included.
- **QPDT** - **Q**uadruple **P**ole **D**ouble **T**hrow. Often referred to as Quad Pole Double Throw, or 4PDT. These have four rows of change-over terminals. Equivalent to four SPDT switches or relays actuated by a single coil or two DPDT relays. In total, fourteen terminals when the coil is also included.

Applications

A DPDT AC coil relay with "ice cube" packaging

Relays are used:

- to control a high-voltage circuit with a low-voltage signal, as in some types of modems,
- to control a high-current circuit with a low-current signal, as in the starter solenoid of an automobile,
- to detect and isolate faults on transmission and distribution lines by opening and closing circuit breakers (protection relays),
- to isolate the controlling circuit from the controlled circuit when the two are at different potentials, for example when controlling a mains-powered device from a low-voltage switch. The latter is often applied to control office lighting as the low voltage wires are easily installed in partitions, which may be often moved as needs change. They may also be controlled by room occupancy detectors in an effort to conserve energy,
- to perform logic functions. For example, the boolean AND function is realised by connecting NO relay contacts in series, the OR function by connecting NO contacts in parallel. The change-over or Form C contacts perform the XOR (exclusive or) function. Similar functions for NAND and NOR are accomplished using NC contacts. Due to the failure modes of a relay compared with a semiconductor, they are widely used in safety critical logic, such as the control panels of radioactive waste handling machinery.
- to perform time delay functions. Relays can be modified to delay opening or delay closing a set of contacts. A very short (a fraction of a second) delay would use a copper disk between the armature and moving blade assembly. Current flowing in

the disk maintains magnetic field for a short time, lengthening release time. For a slightly longer (up to a minute) delay, a dashpot is used. A dashpot is a piston filled with fluid that is allowed to escape slowly. The time period can be varied by increasing or decreasing the flow rate. For longer time periods, a mechanical clockwork timer is installed.

Relay application considerations

A large relay with two coils and many sets of contacts, used in an old telephone switching system.

Selection of an appropriate relay for a particular application requires evaluation of many different factors:

- Number and type of contacts - normally open, normally closed, changeover (double-throw)
- In the case of changeover, there are two types. This style of relay can be manufactured two different ways. "Make before Break" and "Break before Make". The old style telephone switch required Make-before-break so that the connection didn't get dropped while dialing the number. The railroad still uses them to control railroad crossings.
- Rating of contacts - small relays switch a few amperes, large contactors are rated for up to 3000 amperes, alternating or direct current
- Voltage rating of contacts - typical control relays rated 300 VAC or 600 VAC, automotive types to 50 VDC, special high-voltage relays to about 15,000 V
- Coil voltage - machine-tool relays usually 24 VAC or 120 VAC, relays for switchgear may have 125 V or 250 VDC coils, "sensitive" relays operate on a few milliamperes
- Package/enclosure - open, touch-safe, double-voltage for isolation between circuits, explosion proof, outdoor, oil-splashresistant

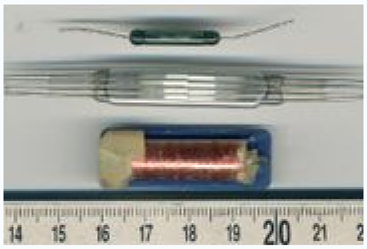
- Mounting - sockets, rail mount, panel mount, through-panel mount, enclosure for mounting on walls or equipment
- Switching time - where high speed is required
- "Dry" contacts - when switching very low level signals, special contact materials may be needed such as gold-plated contacts
- Contact protection - suppress arcing in very inductive circuits
- Coil protection - suppress the surge voltage produced when switching the coil current
- Isolation between coil circuit and contacts
- Aerospace or radiation-resistant testing, special quality assurance
- Accessories such as timers, auxiliary contacts, pilot lamps, test buttons
- Regulatory approvals
- Stray magnetic linkage between coils of adjacent relays on a printed circuit board.

- Relays are often plugged into a plug board, so that the relay can be changed without disturbing the wiring to it.

Protection relay

A **protection relay** is a complex electromechanical apparatus, often with more than one coil, designed to calculate operating conditions on an electrical circuit and trip circuit breakers when a fault was found. Unlike switching type relays with fixed and usually ill-defined operating voltage thresholds and operating times, protection relays had well-established, selectable, time/current (or other operating parameter) curves. Such relays were very elaborate, using arrays of induction disks, shaded-pole magnets, operating and restraint coils, solenoid-type operators, telephone-relay style contacts, and phase-shifting networks to allow the relay to respond to such conditions as over-current, over-voltage, reverse power flow, over- and under- frequency, and even distance relays that would trip for faults up to a certain distance away from a substation but not beyond that point. An important transmission line or generator unit would have had cubicles dedicated to protection, with a score of individual electromechanical devices. Each of the protective functions available on a given relay are denoted by standard ANSI Device Numbers. For example, a relay including function 51 would be a timed overcurrent protection relay.

Design and theory of these protective devices is an important part of the education of an electrical engineer who specializes in power systems. Today these devices are nearly entirely replaced (in new designs) with microprocessor-based instruments (numerical relays) that emulate their electromechanical ancestors with great precision and convenience in application. By combining several functions in one case, numerical relays also save capital cost and maintenance cost over electromechanical relays. However, due to their very long life span, tens of thousands of these "silent sentinels" are still protecting transmission lines and electrical apparatus all over the world.



Top, middle: reed switches, bottom: reed relay

Overcurrent relay

An "Overcurrent Relay" is a type of protective relay. The ANSI Device Designation Number is 50 for an Instantaneous OverCurrent (IOC), 51 for a Time OverCurrent (TOC). In a typical application the overcurrent relay is used for overcurrent protection, connected to a current transformer and calibrated to operate at or above a specific current level. When the relay operates, one or more contacts will operate and energize a trip coil in a Circuit Breaker and trip (open) the Circuit Breaker.

Transatlantic cable

The Transatlantic cable from London to New York was so long and the current was so weak, that a spectial kind of amplifier was devised. Basically, a light shining on an armature operated by the coil move across a screen to indicate the marks and spaces.

Maximum prospective short circuit current

The **maximum prospective short circuit current** is the maximum electrical current which can flow in a particular electrical system under short circuit conditions. It is determined by the voltage and impedance of the supply system. It is of the order of a few thousand amperes for a standard domestic mains electrical installation in the UK, but may be as low as a few milliamperes in a SELV (Safety Extra Low Voltage or, occasionally, Separated Extra Low Voltage) system or as high as hundreds of thousands of amps in large industrial power systems.

Importance

It is of particular interest when designing an electrical installation because fuses and circuit breakers must be capable of safely breaking the flow of current in the event of a short circuit. When a large electrical current is interrupted an arc may form and if the breaking capacity of a fuse or circuit breaker is exceeded then it may not be able to extinguish this arc meaning that the flow of current will continue, possibly resulting in a fire or explosion.

The examples and perspective in this article or section may not represent a **worldwide view**.
Please improve the article or discuss the issue on the talk page.

In domestic power installations in European countries (230V 50Hz AC single phase power) the short circuit current available on the electrical outlets needs to be taken into account when designing electrical power wiring. The short circuit current should not be too high or too low. The effect of too high short circuit current is discussed in the previous paragraph. The short circuit current should be of the order of around 200A or higher for normal 10A or 16A outlet to guarantee that the normal wire protecting fuse or breaker will quickly disconnect the supply in case of short circuit. Quick disconnecting is needed, because in live-ground short circuit the grounding pin potential on the power outlet can rise compared to the local earth (Concrete floor, water pipe etc.) during short circuit to a dangerous voltage, which needs to be shut down quickly for safety. If the short circuit current is lower than this figure, special precautions needs to be taken to make sure that the system is safe; those usually include using a residual current device for extra protection. The short circuit current available on the electrical outlets is often measured with a suitable instrument when examining electrical installations to make sure that the short circuit current is within reasonable limits. Having a high enough short circuit current on the outlet will also tell that the resistance from the electrical panel to the outlet is reasonably low, so there will not be too high voltage losses on the wires when outlets are loaded normally.

Domestic AC power plugs and sockets

CEE 7/7 plug and socket

Domestic AC power plugs and sockets are devices that connect the home appliances and portable light fixtures commonly used in homes to the commercial power supply so that AC electric power can flow to them.

Power plugs are male electrical connectors that fit into female electrical sockets. They have contacts that are pins or blades which connect mechanically and electrically to holes or slots in the socket. Plugs usually have a *live* or *hot* contact, a *neutral* contact, and an optional *earth* or *ground* contact. Many plugs make no distinction between the live and neutral contacts, and in some cases they have two live contacts. The contacts may be brass, tin or nickel plated.

Power sockets are female electrical connectors that have slots or holes which accept the pins or blades of power plugs inserted into them and deliver electricity to the plugs. Sockets are usually designed to reject any plug which is not built to the same electrical standard. Some sockets have one or more pins that connect to holes in the plug.

Standard wire colours for flexible cable

Region	Live	Neutral	Protective earth
EU, Australia & South Africa (IEC 60446)	brown	blue	green & yellow
UK, Ireland &	red	black	green

Australia before 1969			
United States and Canada (*screw colour*)	black (*brass*)	white (*silver*)	green (*green*)

Standard wire colours for fixed cable

Region	Live	Neutral	Protective earth
EU (IEC 60446) including UK from 31 March 2004	brown or black	blue	green & yellow
UK before 1 April 2006 & Australia	red	black	green & yellow (core is usually bare and should be sleeved at terminations)
United States and Canada (*screw colour*)	black or red (*brass*)	white (*silver*)	green or bare (*green*)

Note: the colours in this table represent the most common and preferred standard colours however others may be in use, especially in older installations.

The three contacts

In most countries, household power is single-phase electric power, in which a single live conductor brings alternating current into a house, and a neutral returns it to the power supply. Many plugs and sockets include a third contact used for a protective earth ground, which only carries current in case of a fault in the connected equipment.

Live or Phase

The **live** contact (also known as **phase**, **hot** or **active**) carries alternating current from the power source to the equipment. The voltage varies by country, as set by national standards. In some installations, there may be two live conductors, either being two phases from a three-phase system or being both phases from a split phase system. Some plug/socket combinations are designed in a way that a plug can be inserted only one possible way — this is referred to as a *polarized* plug (not to be confused with positive and negative polarity). Others allow the plug to be inserted with live and neutral either way round — this is referred to as an *unpolarized* plug. Furthermore even if live and neutral can only connect one way, in some countries it is common to wire them without regard for which is which. This can be hazardous with some equipment in which the neutral is connected directly to the chassis.

Neutral

The **neutral** contact returns current from the equipment back to the power source or distribution panel. It is in most (but not all) cases referenced to the earth. Except under fault conditions it does not pose a danger because the voltage between the neutral contact and the earth is close to zero, but is nevertheless treated as live in most installation practices because it can develop a high voltage under fault conditions.

The main danger posed by the neutral is the voltage can rise as high as the voltage on the live conductor if a broken neutral cable in the wiring disconnects the neutral but leaves the live conductor connected. Another possibility is that the live and neutral may be reversed or crossed by improper installation.

Neutral and earth (ground) are closely related and are usually connected at some point. However extra connections between the neutral and the earth should be avoided unless the relevant jurisdiction's regulations allow it. Connecting neutral and earth at more than one point can sometimes create a dangerous ground loop in the system.

Earth/Ground

The **earth** contact (known as **ground** in American English) is only intended to carry electric current when connected to equipment that has developed an insulation fault (except for EMI/RFI filters which do cause a small current down the earth). The earth connection was added to modern plugs because, if a live wire or other component in a device touches the metal casing, anybody touching the device may receive a dangerous electric shock. In many countries devices with metal cases must have the case connected to the earth contact. This reduces but does not eliminate the possibility of the case developing a high voltage relative to the earth and grounded metalwork.

It is a common misconception that the purpose of the earth connection is to take fault currents safely to earth. The primary purpose of the earthing system is to cause a fuse to blow or a breaker or RCD to trip to automatically disconnect the power supply to any device or cable which develops a wiring fault. The secondary purpose is to hold all touchable metal in a house to the same voltage to prevent electrical shocks when touching two metal objects at the same time.

There are two main approaches to the problem of how to disconnect power when a live wire comes into contact with metalwork attatched to the earthing system. One way is to get the resistance through the fault path and back to the supply very low by having a metalic connection from the earth back to the supply transformer (a TN system). Then when a fault happens a very high current will flow rapidly blowing a fuse (or tripping a MCB).

Where such a direct connection is not used (a TT system) the resistance of the fault path back to the supply is almost invariablly far higher and as a result the fault current is generally too low to reliably blow fuses (or trip MCBs). Therefore a residual-current device (**RCD**) must normally be used to disconnect the fault.

The neutral core could in theory be used as a ground, but this would be dangerous if the core broke, so this is not normally used in building wiring or portable appliances. It is, however, used in some other situations with special precautions. For instance, in Switzerland, sockets in houses with the old two wire installation have the ground and neutral contacts connected together, probably supposing, that the professionally maintained house installation is much more reliable than plugged-in device. Also using the neutral as a ground prevents the use of **RCD**s.

Differences in terminology

There are significant differences between American English and British English in talking about power plugs and sockets.

British	American	Meaning

mains power	*line* power	House electrical AC current
earth connection	*ground* connection	Safety connection to the earth or ground
flex	cord	Flexible electric cable from plug to appliance
socket, power point	outlet, receptacle	Female part of an electrical connection
pin	prong	Male part of an electrical connector

In the United States, the live contact may be called *live* or *hot*. The neutral contact may be called *cold*, *neutral*, *the grounded conductor*, or (in the National Electrical Code), the *identified conductor*. The earth contact is called *ground* or *the grounding conductor*.

In the United Kingdom the word "line" is occasionally used to denote the live terminal or wire. This terminology derives from its being at the line voltage relative to neutral and ground, as distinct from the "phase" voltage, between lines on different phases of the supply.

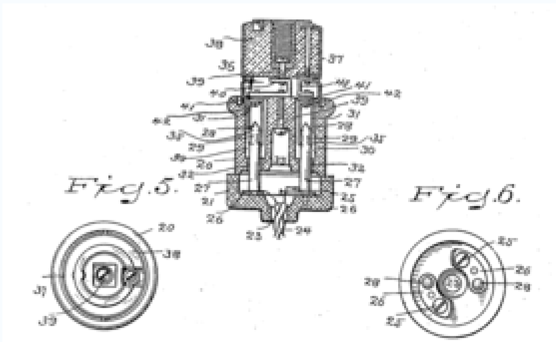
Live conductors are called *phases* when there is more than a single phase in use. Pins are also known as *prongs*, *contacts* or *terminals*.

In Australia, the live contact is called *active*.

History of plugs and sockets

Light fitting plug with toaster

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 low-power appliances (such as vacuum cleaners and hair driers) being connected to the light fitting. The picture to the right shows a 1909 electric toaster with a light bulb socket plug.



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

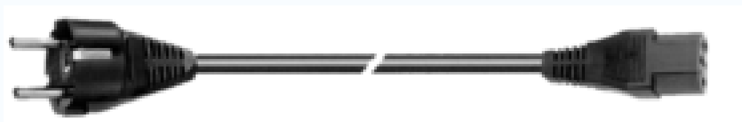
However, as electricity became a common method of heating houses and operating labour-saving appliances, a means of connection to the electric system other than using a light socket was needed. The original two prong electrical plug and socket were invented by Harvey Hubbell and patented in 1904. [1]

The three prong plug was invented in 1928 by Philip F. Labre, while he was going to school at 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. Philip figured out that if the plug was grounded, the electricity would go to earth through the plug rather than his landlady. He applied for and was issued a patent for grounding receptacle and plug on June 5, 1928.[2] As the need for safer installations became apparent, earthed three-contact systems were made mandatory in most industrial countries.

Proliferation of standards

The reason that there are now over a dozen different styles of plugs and wall outlets is that when European countries adopted 220-240V electricity, for nationalistic reasons they developed their own unique national plug designs instead of agreeing on a European standard plug. In contrast, the 38 different countries which adopted the American 110-120V standard electricity also adopted the U.S. type A and B plugs. Most countries elsewhere in the world were once colonies of European nations and usually adopted the standards of their colonial governments at the time electricity was introduced. In many other countries there is no single national standard and multiple voltages, frequencies and plug designs are in use, creating extra complexity and potential safety problems for users.

However, in recent years most countries have settled on one of a few *de facto* standards, although there are legacy installations of obsolete wiring in most countries of the world. Some buildings have wiring that has been in use for almost a century and which pre-dates all modern standards.



IEC power cord with CEE 7/7 plug at left end.

To minimize the difficulty of designing for different national standards, 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 device itself is designed to adapt to a wide range of voltage and frequency standards.

World maps by plug/socket and voltage/frequency

There are two basic standards for voltage and frequency in the world. One is the North American standard of 110-120 volts at 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 through M. The differences arose for historical reasons.

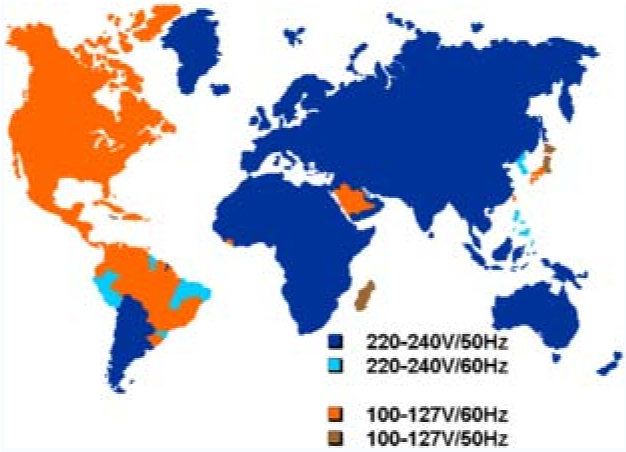
In the United States, Thomas Edison, the inventor of the first practical electric light bulb, insisted on using 110 volts direct current (DC) rather than alternating current (AC) for his electric system in New York City. However, George Westinghouse, who built the first large hydro-electric plants at Niagara Falls, decided to use AC instead of DC because it could be stepped up or stepped down in voltage using transformers. The electrical genius Nicola Tesla advised him that 240 V at 60 Hz was optimum, but authorities would not let him use more than 110 V for distribution. Eventually Edison switched his 110 V DC system over to AC as well, and so 110 V at 60 Hz became the American electrical standard, despite the fact it required conductors twice as large to carry the same amount of power as 240 V.

In Europe, the German company AEG built the first generating facilities, and chose 50 Hz because it fit better into the metric system of powers of ten (1, 10, 100). Unfortunately, 50 Hz is less efficient than 60 Hz because generators are 20% less efficient and transformers must be 30% bigger to step the voltage up and down. However, AEG had a virtual monopoly in Europe so their standard spread to the rest of the continent and eventually to Britain. Originally Europe was electrified at 110-120 V like North America, but after World War II, regulators decided to increase it to 220-240 V to reduce the amount of copper used for wiring.

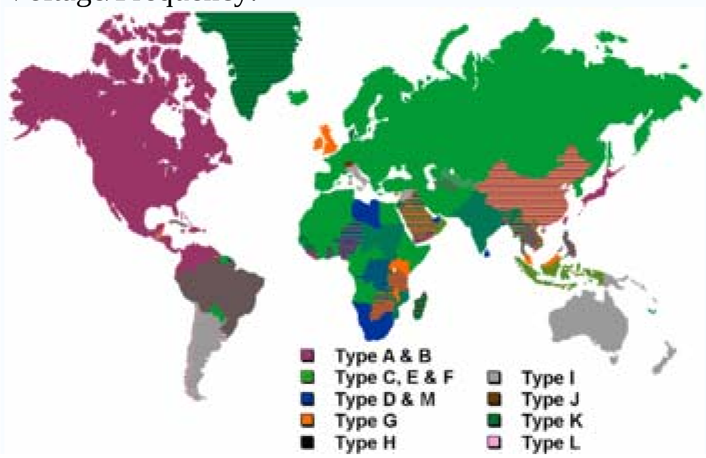
American regulators would have liked to double the voltage as well, but there were far more household electrical appliances than in Europe. They compromised by adopting a split phase 240 V system, supplying 120 V on two live conductors going into each household with a single neutral. Small appliances ran on 120 V, big ones on 240 V. It was more complicated but saved copper and was backward-compatible with existing appliances. The original plugs could be used with the system, as well.

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 below show the different plug types, voltages and frequencies used around the world,[3] colour-coded for easy reference.

See also List of countries with mains power plugs, voltages and frequencies for specific places.



Voltage/Frequency.

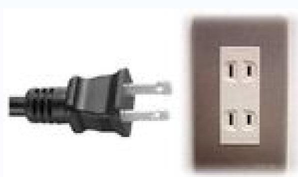


Types of plug and sockets

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. [4] In this article each type is designated by a letter, 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.

Note that IEC Class I refers to earthed equipment. IEC Class II refers to unearthed equipment protected by double insulation. See Appliance classes.

Type A (North American/Japanese 2-pin)



An **American ungrounded** polarized plug and a Japanese ungrounded socket. This plug can only be inserted into the socket in one manner, with the wider pin — the neutral contact — being inserted on the left.

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

Standardized by the U.S. National Electrical Manufacturers Association and adopted by 38 other countries, this simple plug with two flat parallel pins, or blades, is used in most of North America and on the west coast of South America on devices not requiring a ground connection, such as lamps and "double-insulated" small appliances. NEMA 1-15 sockets have been prohibited in new construction in the United States and Canada since 1965, but remain in many older homes and are still sold "for replacement use only". Type A plugs are still very common because they are compatible with type B sockets.

Early designs could be inserted either way, but modern ones prevent the neutral pin from being inserted into the live socket by making it wider than the live one, referred to as a *polarized plug*. (Note that this is not the same as positive/negative polarization in a direct current system.) New polarized plugs will not fit in old type A sockets, but both old and new type A plugs will fit in new type A and type B sockets. Some devices that do not distinguish between neutral and live, such as sealed electronic power supplies, are still sold with both pins narrow. When attaching a new polarized plug to a cord, it is useful to remember that the most common type of two-conductor cord for low-power use in North America has smooth insulation on the "hot" side and ribbed insulation on the "neutral" side.

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

The Japanese plug and socket are 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.

Some Japanese outlets are non-polarized — the slots in the sockets are the same size - and will only accept non-polarized plugs. Japanese plugs should be able to fit into North American outlets without trouble, but North American appliances with polarized plugs may require adapters or replacement non-polarized plugs to connect to Japanese outlets.

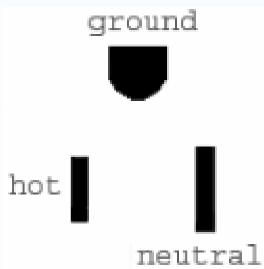
Japanese standard wire sizes and the resulting current ratings are somewhat different from those used elsewhere in the world. Japanese voltage is only 100 volts - lower than American voltage - and the frequency in eastern Japan is only 50 Hertz instead of 60, so even if a North American plug can be inserted into a Japanese socket, it does not always mean the device will work properly.

Type B (American 3-pin)

An **American grounded (earthed)** plug. Note that the receptacle will also accept an ungrounded (two prong) plug whether polarized or unpolarized.
NEMA 5-15 (North American 15 A/125 V grounded)

The type B plug has two flat parallel blades like type A, but has a round ground or earthing pin (American standard NEMA 5-15/Canadian standard CSA 22.2, Nº42).[5] It is rated for 15 amps at 125 volts. The ground pin is longer than the live and neutral blades, so the device is grounded before the power is connected. The neutral blade in the type B socket is wider than the live one to prevent type A plugs being inserted upside-down, but type B plugs often have both pins narrow since the ground pin enforces polarity.

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, the west coast of South America, Japan, parts of Korea, and Taiwan.



Pin orientation on the type B (NEMA 5-15) socket

With type B plugs, if you look directly at a socket with the ground socket at a bottom, the neutral slot is on the left, and the live slot is on the right. They may also be installed with the ground at the top or on either side, but the sockets going clockwise are always ground, neutral, live. The plug has the same connections going counterclockwise. If the plug is polarized, the widest pin is the neutral connector.

Due to the low power (1.8KW) available from a 120V 15A socket a number of other NEMA connectors for higher currents and 240 V supplies are also commonly encountered in North American homes.

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

Japan also uses a Type B plug similar to the North American one.[6] However it is less common than its Type A equivalent.

Type C (European 2-pin)

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

CEE 7/16 plug and socket

This two-pin plug is probably the single most widely used international plug, popularly known as the Europlug. The plug is unearthed and has two round, 4 mm pins, which usually converge slightly. It can be inserted into any socket that accepts 4 mm round contacts spaced 19 mm apart. It is described in CEE 7/16 and is also defined in Italian standard CEI 23-5 and Russian standard GOST 7396

The Europlug is used in Class II applications throughout continental Europe (Germany, Austria, Switzerland, Italy, Greece, the Netherlands, Belgium, France, Spain, Portugal, Denmark, Norway, Sweden, Finland, Poland, The Czech Republic, Slovakia, Hungary, Romania, Bulgaria). It is also used in Turkey, the Middle East, most of Africa and South America, as well as the former Soviet republics, and many developing nations.

This plug is intended for use with devices that require 2.5 A or less. Because it can be inserted in either direction into the socket, live and neutral are connected at random.

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

This plug also has two round pins but the pins are 4.8 mm 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 Class II appliances. Often used in South Korea, it is also defined in Italian standard CEI 23-5.

BS 4573 socket
BS 4573 (UK shaver)

In the United Kingdom and Ireland, there is a special version of the type C plug for use with shavers (electric razors) in bath or shower rooms. It has 5 mm diameter pins 16.6 mm apart, and the sockets for this plug can often take CEE 7/16, US and/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.

Unearthed socket compatible with both Schuko and French plugs
Variations in sockets

Some Type C sockets can only take 4 mm pins or have plastic barriers in place to prevent Schuko or French plugs from entering. However, many can take 4.8 mm pins and have enough room for a 4.8 mm pin round Schuko or French plug to be inserted.

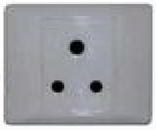
Type D (Old British 3-pin)

BS 546 (Indian 5 A/250 V earthed)

India has 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 Africa (Ghana, Kenya, Nigeria), the Middle East (Kuwait, Qatar), and parts of Asia and the Far East 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. This

5 A plug, along with its 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 (South African 15 A/250 V earthed)

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 mm × 21.1 mm. Live and neutral are spaced 25.4 mm apart, and earth is 28.6 mm away from each of them. Although the 5 A version is standard in India, 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 almost always have an on–off switch built into them. The Type M is almost universally used in the UK for indoor dimmable theatre and architectural lighting installations. It is 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 leads (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 for air conditioners.

Type E (French 2-pin, female earth)

French type E

France, Belgium, Poland, Czech Republic, Slovakia and some other countries have standardised on a socket which is not compatible with the CEE 7/4 socket (type F) that is standard in Germany and other continental European countries. The reason for incompatibility is that earthing in the E socket is accomplished with a round male pin permanently mounted in the socket. Sockets are installed with the earth pin upwards and wired with left as live and right as neutral. The plug itself is round with two round pins measuring 4.8 × 19 mm, spaced 19 mm apart and a hole for the socket's earth pin. It will accept Europlug and CEE 7/17 plugs.

As with the German plug below this plug will fit some other types of socket either easily or with force. However there is no earth connection with such sockets! Also in some cases if the plug is forced in, the socket may be damaged when the plug is removed.

Type F (German 2-pin, side clip earth)

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

The type F plug, defined in CEE 7/4 and commonly called a "Schuko plug", is like type E except that it has two earthing clips on the sides of the plug instead of a female earth contact. The Schuko connection system is symmetrical and allows live and neutral to be reversed. The socket also accepts Europlugs and CEE 7/17 plugs. It supplies up to 16 amperes. Above that, equipment must either be wired permanently to the mains or connected via another higher power connector such as the IEC 309 system.

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

Gost 7396 (Russian 16 A/250 V earthed)

The countries of the CIS use a standard plug and socket similar to the Schuko standard, defined in Russian Standard Gost 7396. The contacts are also 19 mm apart, but the diameter of the pins is 4.0 mm instead of 4.8 mm. It is possible to insert Russian plugs into Schuko outlets, but Russian sockets will not accept type E or F plugs because the holes are too small. This socket also accepts Europlugs, but does not accept CEE 7/17 plugs because they use the larger pin size.

Many official standards in Eastern Europe are virtually identical to the Schuko standard. One of the protocols governing the reunification of Germany required that the DIN and VDE standards would prevail without exception, so the former East Germany had to conform to the Schuko standard. Most other Eastern European countries use the Schuko standard internally but, prior to its collapse, they exported large volumes of appliances to the Soviet Union with the Soviet standard plug installed. Because of that, many of the Russian plugs found their way into other Eastern European countries.

Type E and F hybrid

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

CEE 7/7 plug

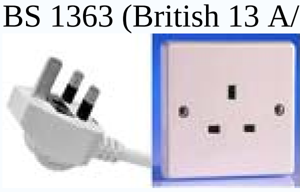
In order to bridge the differences between sockets E and F, the CEE 7/7 plug was developed. It has earthing clips on both sides to connect with the CEE 7/4 socket and a female contact to accept the earthing pin of the type E socket. Nowadays, when appliances are sold with type E/F plugs attached, the plugs are CEE 7/7 and non-rewirable. This means that the *plugs* are now identical between countries like France and Germany; only the *sockets* are different.

Type E and F plugs that are not compatible with both types of socket are only found if a cheap replacement plug has been attached to a cord that originally had another plug. Better-quality replacements are standard CEE 7/7 and are compatible with both Schuko and French standard sockets.

Note that the CEE 7/7 plug is polarized 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. Above that, equipment must either be wired permanently to the mains or connected via another higher power connector such as the IEC 309 system.

Type G (British 3-pin)

BS 1363 (British 13 A/250 V earthed and fused)



BS 1363

The BS 1363 plug, commonly known as a "13-amp plug", is a large plug that has three rectangular prongs forming a triangle. Live and neutral are 4 × 6 × 18 mm spaced 22 mm apart. 9 mm of insulation over the base of the pins prevents people from touching a bare connector while the plug is partly inserted. Earth is 4 × 8 × 23 mm.

The plug is unusual in that it has a fuse inside rather than relying on a circuit breaker in the distribution panel for protection. The fuse is required to protect the flex, as British wiring standards allow very high-current circuits to the socket. Accepted practice is to choose the smallest standard fuse (3 A, 5 A, or 13 A) that will allow the appliance to function. Using a 13 A fuse on an appliance with thin flex is considered bad practice.

The earth pin is required to open shutters over the live and neutral pins on most sockets to prevent children from inserting metal objects into them, and also prevents the use of plugs made to other standards. On plugs for Class II appliances that do not require an earth, the pin is often plastic. It is possible to open the shutters with a screwdriver to insert other plug types but this should be avoided as such plugs will not have a fuse.

BS 1363 was published in 1962 and since that time it has gradually replaced the earlier standard (type D) (BS 546). Despite being capable of carrying a maximum load of 13 A, it is considered a very safe system.

Type H (Israeli 3-pin)

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

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 apart. The type H plug is rated at 16 A but in practice the inadequate flat pins cause it to overheat when connecting large appliances. In 1989 the SI 32 was revised to use three round 4 mm pins in the same locations as the older standard. Sockets are manufactured to accept both flat and round pins in order to be compatible with both old and new plugs. This also allows the type H socket to accommodate type C plugs which are used in Israel for non grounded appliances. Older sockets, from about the 1970s have both flat and round holes for "Live" and "Neutral" in order to accept type C plugs. As of 2006, "pure" type H sockets (for 3 flat pins) that do not accept type C 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.

Type I (Australian/Chinese 2/3-pin)

AS 3112 (Australian 10 A/250 V)

This plug, used in Australia, New Zealand, and Papua New Guinea, has an earthing pin and two flat pins forming an upside down V-shape. There is an unearthed version of this plug as well, with no earthing pin. The flat blades measure 6.5 × 1.6 mm and are set 30° to the vertical on a nominal pitch of 13.7 mm. Australian wall sockets almost always have switches on them for extra safety, as in the UK.

There are several AS/NZS 3112 plug variants, including one with a wider earth pin is used for devices drawing up to 15 A; sockets supporting this pin will also accept 10 A plugs. Additionally, there exists a 20 A variant, in which all three pins are oversized and 25 and 32 A variants with the 20 A larger pins and the earthing pin forming an inverted "L" for the 25 A and a horizontal "U" for the 32 A (note that the 5 variants {10; 15; 20; 25 & 32 ampere sockets} will accommodate all the plugs that are equal or of a lesser current carring capacity but not a higher value; i.e. a 10 A plug will be accommodated by all sockets but a 20 A plug will only be accommodated by a 20: 25 and 32 A outlet).

Australia'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. However, equipment and cords made before 2003 can still be used.

CPCS-CCC (Chinese 10 A/250 V)

CCC Mark

Although the Chinese plug is slightly different (the pins are 1 mm longer) the Australian plug can be inserted into the socket used in the mainland China. The standard for Chinese plugs and sockets was set out in GB 2099.1–1996 and GB 1002–1996. 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 (China Compulsory Certification) Mark by this system. The plug is three wire, grounded, rated at 10 A, 250 V and used for Class 1 applications.

In China, the sockets are installed upside down, relative to the Australian one shown in the picture. However, the positions of the live and neutral contacts are *reversed* from those of the Australian plug. With devices conforming to current standards this is not too serious, as neutral is generally treated the same as live in appliance design. However with older or non-complying equipment this difference can be dangerous.

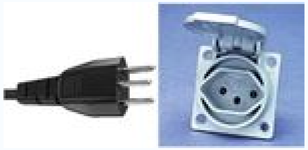
China also uses American/Japanese "Type A" sockets and plugs for Class-II appliances. However, the voltage across the pins of a Chinese socket will always be 220, no matter what the plug type.

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 Australian and Chinese plugs. The pin lengths and wiring are the same as those for the Chinese version. The most important difference from the Australian plug is that the Argentinian plug is wired with the live and neutral contacts **reversed** from those of the Australian plug.

Type J (Swiss 3-pin)



SEV 1011 (Swiss 10 A/250 V)

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 earth pin off to one side. Swiss sockets can take Swiss plugs or europlugs (CEE 7/16). This connector system is rated for up to 10 amperes. There is also a less common variant with 3 square pins rated for 16 A. Above 16 A, equipment must either be wired permanently to the electrical supply system with appropriate branch circuit protection, or connected to the mains with an appropriate high power industrial connector.

Switzerland also has a two-pin plug, 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 both Swiss sockets (round and hexagonal) and CEE 7/16 sockets, and is rated for up to 10 A.

IEC 60906-1 (Brazilian 16 A/250 V)

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 plug. This plug was intended to become one day 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 uses a mix of Europlug, Argentine and NEMA plugs — later adopted it as national standard NBR 14136 in 2001 and it will be the only plug permitted to be sold with domestic appliances in Brazil from 2009.

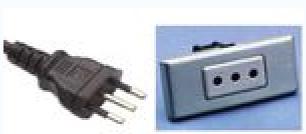
Type K (Danish 3-pin)

107-2-D1
DS Afsnit 107-2-D1 (Danish 10 A/250 V)

The Danish standard plug is described in DS section 107-2-D1 (SRAF1962/DB 16/87 DN10A-R). The plug is similar to the type F Schuko plug except that it has an earthing pin instead of earthing clips. 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 earthed type E French plugs will also fit in the socket but should not be used because the earth contact will not connect. A variation of this plug intended for use only on surge protected computer circuits has been introduced. The current rating on both plugs is 10 A.

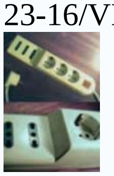
Adapter plugs exist to allow connection of CEE 7/7 prongs to non-computer outlets. These usually are not sold at the local supermarket so visitors wishing to be safe should contact an electrician.

Since the early 1990s grounded outlets have been required in all new electric installations in Denmark.



23-16/VII with socket

23-16/VII rewirable



Italian power strip showing both types of hybrid socket

Type L (Italian 3-pin)

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. CEE 7/16 (type C) unearthed Europlugs are also in common use, and standardized in Italy as CEI 23-5.

Appliances with CEE 7/7 Schuko-French plugs are often sold in Italy, but not every socket will accept them. Adapters are commonly used to connect CEE 7/7 plugs to CEI 23-16/VII sockets.

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

The 10 ampere style extends CEE 7/16 by adding a central earthing pin. Thus, CEI 23-16-VII 10 A sockets can accept CEE 7/16 Europlugs. This is the plug shown in the illustrations. Outside of Italy, this plug is found in Libya, Ethiopia, Chile, various countries in North Africa, and occasionally in old buildings in Spain.

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

The 16 ampere style looks like a bigger version of the 10 A style. The pins are a couple of millimetres further apart, and all three are slightly thicker. The packaging on these plugs in Italy may claim they are a "North European" type. They were also referred to as *industriale* ("industrial") although this is not a correct definition.

Variations in sockets

Two types of sockets are in common use in modern installations in Italy. One 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 type is its small footprint.

The other type looks like a type F socket, but adds a central grounding hole. This design accepts CEE 7/7 (type E/F) plugs, in addition to type C and type L 10 A plugs; its disadvantage is that it is twice as large as a normal type L socket. Some of these sockets also have extra holes to accept type L 16 A plugs.

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 style needs to be connected.

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. See type D for details.

A standard grounded **Thai** outlet supporting all common 2 pin plugs and also earthed american plugs

Multi standard sockets

Sockets that take a variety of incompatible plug types are often seen in developing countries which do not adequately enforce electrical standards. These sockets may accept both 120 V and 240 V plugs, although the voltages are incompatible, and devices may be damaged by the wrong voltage. Sometimes they have one or more earth holes to allow 3 pin plugs, despite the fact the ground contact may not actually be connected to earth. Great care should be taken to avoid incompatible voltage and grounding connections when using such outlets. Multi-standard devices designed to auto-adapt to different voltage and frequency standards, and which do not require a ground contact are best used with these sockets.

Safety notes

Despite the fact that it seems easy to connect a plug or socket, some mistakes may result in a working but highly dangerous installation, not only in the appliance but also throughout the whole house. The main issues are:

- Connecting live wire to the ground contact. This is very dangerous because the conductive case is made live and the appliance may cause death at any time. It is insidious because the appliance may still work.
- Not earthing an appliance that should be earthed. This is dangerous because the appliance case will remain live if there is a fault between the live wire and the conductive case. Many outlets are left unearthed, either by design or by improper installation. Thus, it is common to manage to fail to earth appliances that should be. In some countries using a RCD is considered an acceptable substitute for proper earthing when upgrading existing installs.

- Swapping live and neutral wires. In many countries this is not regarded as an error and it is perfectly feasible to design appliances such that they will be safe (e.g. by using double pole switches and protection devices) under this condition. However if appliances are intended for use only in countries that take care to avoid live/neutral swaps then they may have only a single pole switch which on live-neutral reversal will end up in the neutral wire, leaving portions of the device live at all times. This does not pose immediate danger but increases the risk of shock if there is another fault or if someone tries to work on the appliance without disconnecting it. For example if live and neutral have been swapped in lamps, the shell of the lamp base will be connected to the line, greatly increasing the risk of shock when changing light bulbs.
- Swapping ground and neutral wires for an appliance. This can cause a number of issues. In a TT earthing system it will mean that significant current will go down the earth rod and may lead to significant voltages between the case of the faulty appliance and other correctly wired appliances. In a TN-S or TN-C-S system immediate danger is unlikely, but there is still the potential for danger if a neutral or earth wire also breaks. If this fault were combined with a live-neutral swap further back in the circuit, live current could be supplied to the earth pin.
- Not providing adequate overcurrent/short circuit protection which would result in a far greater possibility of fire in the event of a fault.


Electricity

Lightning strikes during a night-time thunderstorm. Energy is radiated as light when powerful electric currents flow through the Earth's atmosphere.

Electricity (from Greek ήλεκτρον (electron) *"amber"*) is a general term for the variety of phenomena resulting from the presence and flow of electric charge. Together with magnetism, it constitutes the fundamental interaction known as electromagnetism. It includes many well-known physical phenomena such as lightning, electric fields and electric currents, and is put to use in industrial applications such as electronics and electric power.

Concepts in electricity

In casual usage, the term **electricity** is applied to several related concepts that are better identified by more precise terms:

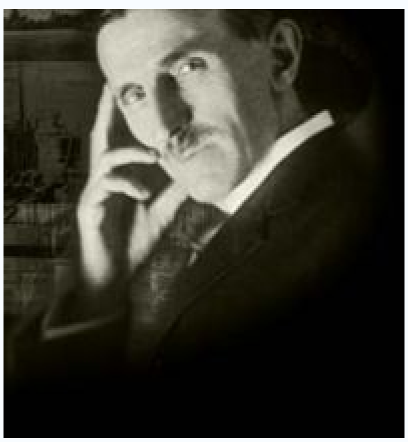
- **Electric potential** (often referred to as **voltage)** - the potential energy per unit charge associated with a static electric field.
- **Electric current** - a movement or flow of electrically charged particles.
- **Electric field** - an effect produced by an electric charge that exerts a force on charged objects in its vicinity.
- **Electrical energy** - the energy made available by the flow of electric charge through an electrical conductor.
- **Electric power** - the rate at which electric energy is converted to or from another energy form, such as light, heat, or mechanical energy.
- **Electric charge** - a fundamental conserved property of some subatomic particles, which determines their electromagnetic interactions. Electrically charged matter is influenced by, and produces, electromagnetic fields.

History of discovery

Franklin Kite Plaque

The ancient Greeks and Parthians knew of static electricity from rubbing objects against fur.

Though Benjamin Franklin's famous "invention" of electricity by flying a kite in a thunderstorm turned out to be more fiction than fact, his theories on the relationship between lightning and static electricity sparked the interest of later scientists whose work provided the basis for modern electrical technology. Most notably these include Luigi Galvani (1737–1798), Alessandro Volta (1745-1827), Michael Faraday (1791–1867), André-Marie Ampère (1775–1836), and Georg Simon Ohm (1789-1854). The late 19th and early 20th century produced such giants of electrical engineering as Nikola Tesla, Samuel Morse, Antonio Meucci, Thomas Edison, George Westinghouse, Werner von Siemens, Charles Steinmetz, and Alexander Graham Bell.



Nikola Tesla

Concepts in detail

Electric charge

Electric charge is a property of certain subatomic particles (e.g., electrons and protons) which interacts with electromagnetic fields and causes attractive and repulsive forces between them. Electric charge gives rise to one of the four fundamental forces of nature, and is a conserved property of matter that can be quantified. In this sense, the phrase "quantity of electricity" is used interchangeably with the phrases "charge of electricity" and "quantity of charge." There are two types of charge: we call one kind of charge positive and the other negative. Through experimentation, we find that like-charged objects repel and opposite-charged objects attract one another. The magnitude of the force of attraction or repulsion is given by Coulomb's law.

Electric field

Michael Faraday

The concept of electric field was introduced by Michael Faraday. The electrical field force acts between two charges, in the same way that the gravitational field force acts between two masses. However, the electric field is a little bit different. Gravitational force depends on the masses of two bodies, whereas electric force depends on the electric charges of two bodies. While gravity can only pull two masses together, the electric force can be an attractive *or* repulsive force. If both charges are of same sign (e.g. both positive), there will be a repulsive force between the two. If the charges are opposite, there will be an attractive force between the two bodies. The magnitude of the force varies inversely with the square of the distance between the two bodies, and is also proportional to the product of the unsigned magnitudes of the two charges.

Electric potential

The electric potential difference between two points is defined as the work done per unit charge (against electrical forces) in moving a positive point charge slowly between two points. If one of the points is taken to be a reference point with zero potential, then the electric potential at any point can be defined in terms of the work done per unit charge in moving a positive point charge from that reference point to the point at which the potential is to be determined. For isolated charges, the reference point is usually taken to be infinity. The potential is measured in volts. (1 volt = 1 joule/coulomb) The electric potential is analogous to temperature: there is a different temperature at every point in space, and the temperature gradient indicates the direction and magnitude of the driving force behind heat flow. Similarly, there is an electric potential at every point in space, and its gradient indicates the direction and magnitude of the driving force behind charge movement

Electric current

An electric current is a flow of electric charge, and its intensity is measured in amperes. Examples of electric currents include metallic conduction, where electrons flow through a conductor or conductors such as a metal wire, and electrolysis, where ions (charged atoms) flow through liquids. The particles themselves often move quite slowly, while the electric field that drives them propagates at close to the speed of light. See *electrical conduction* for more information.

Devices that use charge flow principles in materials are called electronic devices.

A direct current (DC) is a unidirectional flow, while an alternating current (AC) reverses direction repeatedly. The time average of an alternating current is zero, but its energy capability (RMS value) is not zero.

Ohm's Law is an important relationship describing the behaviour of electric currents, relating them to voltage.

For historical reasons, electric current is said to flow from the most positive part of a circuit to the most negative part. The electric current thus defined is called *conventional current*. It is now known that, depending on the conditions, an electric current can consist of a flow of charged particles in either direction, or even in both directions at once. The positive-to-negative convention is widely used to simplify this situation. If another definition is used - for example, "electron current" - it should be explicitly stated.

Electrical energy

Electrical energy is energy stored in an electric field or transported by an electric current. Energy is defined as the ability to do work, and electrical energy is simply one of the many types of energy. Examples of electrical energy include:

- the energy that is constantly stored in the Earth's atmosphere, and is partly released during a thunderstorm in the form of lightning
- the energy that is stored in the coils of an electrical generator in a power station, and is then transmitted by wires to the consumer; the consumer then pays for each unit of energy received
- the energy that is stored in a capacitor, and can be released to drive a current through an electrical circuit

Electric power

Electric power is the rate at which electrical energy is produced or consumed, and is measured in watts (symbol is: W).

A nuclear power station.

A fossil-fuel or nuclear power station converts heat to electrical energy, and the faster the station burns fuel, assuming constant efficiency of conversion, the higher its power output. The output of a power station is usually specified in megawatts (millions of watts). The electrical energy is then sent over transmission lines to reach the consumers.

Every consumer uses appliances that convert the electrical energy to other forms of energy, such as heat (in electric arc furnaces and electric heaters), light (in light bulbs and fluorescent lamps), or motion, i.e. kinetic energy (in electric motors). Like the power station, each appliance is also rated in watts, depending on the rate at which it converts electrical energy into another form. The power station must produce electrical energy at the same rate as all the connected appliances consume it.

In electrical engineering, the concepts of apparent power and reactive power are also used. Apparent power is the product of RMS voltage and RMS current, and is measured in volt-amperes (VA). Reactive power is measured in volt-amperes-reactive (VAr).

Non-nuclear electric power is categorized as either green or brown electricity.

Green power is a cleaner alternative energy source in comparison to traditional sources, and is derived from renewable energy resources that do not produce any nuclear waste; examples include energy produced from wind, water, solar, thermal, hydro, combustible renewables and waste.

Electricity from coal, oil, and natural gas is known as traditional power or "brown" electricity.

SI electricity units

SI electromagnetism units

Symbol	Name of Quantity	Derived Units	Unit	Base Units
I	Magnitude of current	ampere (SI base unit)	A	A = W/V = C/s
q	Electric charge, Quantity of electricity	coulomb	C	A·s
V	Potential difference or Electromotive force	volt	V	$J/C = kg{\cdot}m^2{\cdot}s^{-3}{\cdot}A^{-1}$
R, Z, X	Resistance, Impedance, Reactance	ohm	Ω	$V/A = kg{\cdot}m^2{\cdot}s^{-3}{\cdot}A^{-2}$

ρ	Resistivity	ohm metre	Ω·m	$kg·m^3·s^{-3}·A^{-2}$
P	Power, Electrical	watt	W	$V·A = kg·m^2·s^{-3}$
C	Capacitance	farad	F	$C/V = kg^{-1}·m^{-2}·A^2·s^4$
	Elastance	reciprocal farad	F^{-1}	$V/C = kg·m^2·A^{-2}·s^{-4}$
ε	Permittivity	farad per metre	F/m	$kg^{-1}·m^{-3}·A^2·s^4$
χ_e	Electric susceptibility	(dimensionless)	-	-
G, Y, B	Conductance, Admittance, Susceptance	siemens	S	$\Omega^{-1} = kg^{-1}·m^{-2}·s^3·A^2$
σ	Conductivity	siemens per metre	S/m	$kg^{-1}·m^{-3}·s^3·A^2$
H	Magnetic field, magnetic field intensity	ampere per metre	A/m	$A·m^{-1}$
Φ_m	Magnetic flux	weber	Wb	$V·s = kg·m^2·s^{-2}·A^{-1}$
B	Magnetic flux density, magnetic induction, magnetic field strength	tesla	T	$Wb/m^2 = kg·s^{-2}·A^{-1}$
	Reluctance	ampere-turn per weber	A/Wb	$kg^{-1}·m^{-2}·s^2·A^2$
L	Inductance	henry	H	$Wb/A = V·s/A = kg·m^2·s^{-2}·A^{-2}$
μ	Permeability	henry per metre	H/m	$kg·m·s^{-2}·A^{-2}$

χ_m	Magnetic susceptibility	(dimensionless)	-	-

Devices

- Battery
- Conductor
- Insulator
- Light fixture

Engineering

- Green electricity
- Electrical wiring
- MicroCHP

Safety

- Electric shock and injuries
- High-voltage hazards

Electrical phenomena in nature

- Matter: — since atoms and molecules are held together by electric forces.
- Lightning: electrical discharges in the atmosphere.
- The Earth's magnetic field — created by electric currents circulating in the planet's core.
- Sometimes due to solar flares, a phenomenon known as a power surge can be created.
- Piezoelectricity: the ability of certain crystals to generate a voltage in response to applied mechanical stress.
- Triboelectricity: electric charge taken on by contact or friction between two different materials.
- Bioelectromagnetism: electrical phenomena within living organisms.
    - Bioelectricity — Many animals are sensitive to electric fields, some (e.g., sharks) more than others (e.g., people). Most also generate their own electric fields.

- Gymnotiformes, such as the electric eel, deliberately generate strong fields to detect or stun their prey.
- Neurons in the nervous system transmit information by electrical impulses known as action potentials.

Electric light

Most of the industrialized world is lit by **electric lights**, which are used both at night and to provide additional light during the daytime. These lights are normally powered by the electric grid, but some run on local generators, and emergency generators serve as backups in hospitals and other locations where a loss of power could be catastrophic. Battery-powered lights, usually called "flashlights" or "torches", are used for portability and as backups when the main lights fail.

Types

Types of electric lighting include:

- incandescent light bulbs
- arc lamps
- gas discharge lamps, e.g., fluorescent lights, neon lamps, modern photographic flashes
- lasers
- light-emitting diodes, including OLEDs
- sulfur lamps

Different types of lights have vastly differing efficiencies. [1]

Name	**optical spectrum**	**nominal efficiency** (lm/W)	**Lifetime** (MTBF) (hours)	**Colour temperature** (kelvins)	**Colour**	**Color rendering index**
Incandescent light bulb	Continuous	12-17	1000-2500	2700	Warm white (yellowish)	100
Halogen lamp	Continuous	16-23	3000-6000	3200	Warm white (yellowish)	100
Fluorescent lamp	Mercury line + Phosphor	52-100	8000-20000	2700-5000*	White (with a tinge of green)	15-85
Metal halide lamp	quasi-Continuous	50-115	6000-20000	3000-4500	Cold White	65-93
Sulfur lamp	Continuous	80-110	15000-20000	6000	Pale green	79
High pressure sodium	broadband	55-140	10000-40000	1800-2200*	Pinkish orange	0-70

Low pressure sodium	narrow line	100-200	18000-20000	1800*	Yellow, virtually no color rendering	0

*Color temperature is defined as the temperature of a black body emitting a similar spectrum; these spectra are quite different from those of black bodies.

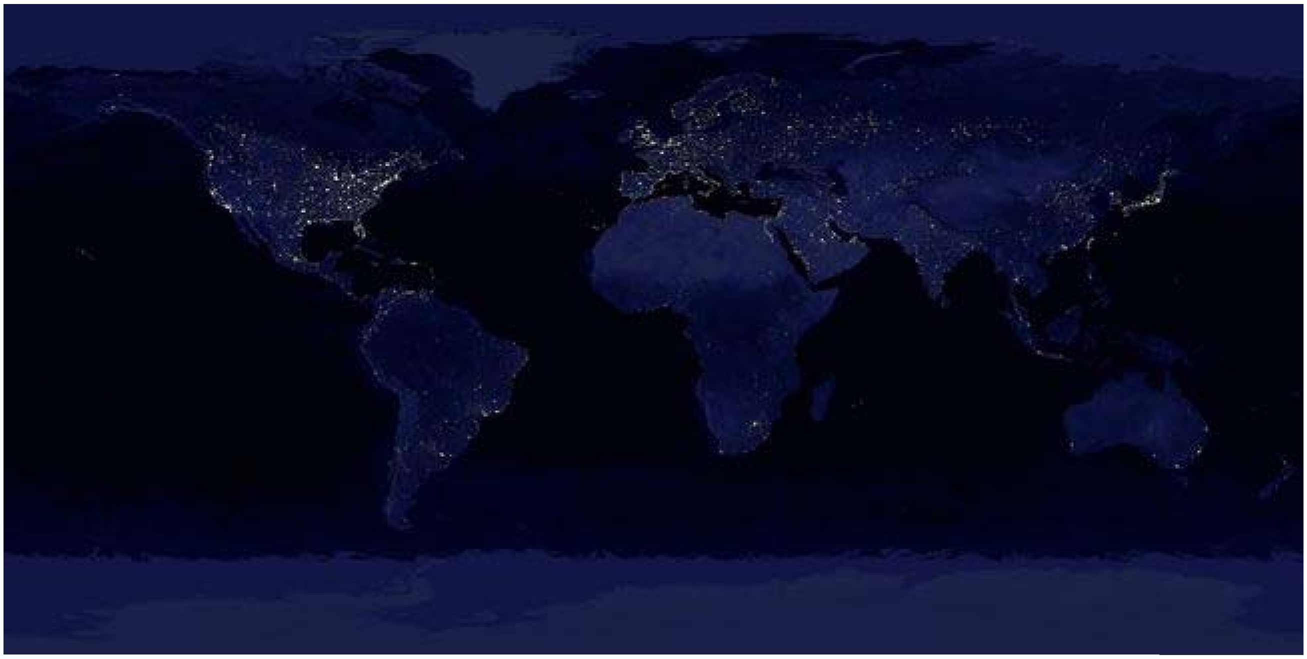
The most efficient source of electric light is the low-pressure sodium lamp. It produces an almost monochromatic orange light, which severely distorts color perception. For this reason, it is generally reserved for outdoor public lighting usages. Low-pressure sodium lights are favoured for public lighting by astronomers, since the light pollution that they generate can be easily filtered, contrary to broadband or continuous spectra.

Vendors

- GE Lighting
- Osram
- Philips

Public lighting

The total amount of artificial light is sufficient for cities to be easily visible at night from the air, and from space. This wasted light should not be confused with the light pollution that burdens astronomers and others, although it is the source of it.



Human-made lights highlight particularly developed or populated areas of the Earth's surface, including the seaboards of Europe, the eastern United States, and Japan

Fire safety

Inadequate fire safety can be destructive and deadly.

Fire safety is a component of Building Safety. It concerns safety measures to prevent the effects of fires and is the result of proper use of fire protection measures.

Some elements include:

- Having built a facility in accordance with the version of the local building code that was in effect at the time a building permit was applied for.
- Maintaining a facility and conducting oneself in accordance with the provisions of the fire code, from the moment that the building was occupied. This is based on

thorough knowledge of the code by the owner and ensuring that the occupants and operators of the building are fully aware of the currently applicable regulations, including supplementary documents that may be applicable, which are referenced in the fire code, such as, as an example, NFPA13 or NFPA96. Examples of such lawful conduct include, but are not limited to, the following:

- Not exceeding the maximum occupancy listing for any part of the building (Making sure that an area isn't so full of people that they can't all get out quickly in an emergency).
- Maintaining proper fire exits and proper signage of them (e.g., exit signs pointing to them that can function in a power failure)
- Placing and maintaining fire extinguishers and fire alarms in easily accessible places.
- Properly storing/using, and/or banning of flammable materials that may be needed inside the building for storage or operational requirements (such as solvents in spray booths).
- Routinely inspecting public buildings for violations, issuing Orders To Comply and, potentially, prosecuting or closing buildings that are not in compliance, until the violations are corrected or condemning it in extreme cases.
- Installing and maintaining fire alarm control panels for quick detection and warning of fire.
- Obtaining and maintaining a complete inventory of firestops.
- Ensuring that all spray fireproofing remains undamaged.
- Maintaining a high level of training and awareness of occupants and users of the building to avoid obvious mistakes, such as the propping open of fire doors.
- Conduct Fire drills at regular intervals throughout the year

The **Fire code** (also **Fire prevention code** or **Fire safety code**) is a model code adopted on a regional basis and enforced by fire prevention officers within municipal fire departments. It is a lawful set of rules prescribing minimum requirements to prevent fire and explosion hazards arising from storage, handling, or use of dangerous materials, or from other specific hazardous conditions. The fire code complements the building code. In the event of changes to fire safety provisions within a building, or a change of occupancy, the fire code typically references the building code, which can result in a requirement upon the owner to apply for a building permit to ensure proper review and lawful execution of contemplated changes that can have an effect upon fire safety and/or structural integrity. The building code includes construction requirements to minimise fire spread, enable suppression and detection and to provide for safe and rapid evacuation in the event of a fire. Although both codes address similar issues, the fire code is aimed primarily at preventing fires in the first place, including outside of buildings, and that necessary training and equipment will be on hand and the design basis of the building, which includes a basic plan set out by the architect is not compromised. The fire code also addresses inspection and maintenance requirements of various fire protection equipment in order to maintain optimal active fire protection and passive fire protection measures, with the aim of preserving stringent bounding.

A typical fire safety code includes administrative sections about the rule-making and enforcement process, and other substantive sections dealing with fire suppression equipment, particular hazards such as containers and transportation for combustible materials, and specific rules for hazardous occupancies, industrial processes, and exhibitions.

Each section may lay out the requirements for obtaining permits, and specific precautions required to remain in compliance with a permit. For example, a fireworks exhibition may require an application to be filed by a regionally licensed pyrotechnician, providing the information necessary for the issuing authority to determine whether the safety requirements can be met. Furthermore, once a permit is issued, the same authority (or another delegated authority) may inspect the site and monitor the safety during the exhibition, with the power to halt unapproved operations, or where unforeseen hazards arise.

Here is a list of some typical fire and explosion issues to be dealt with in a fire safety code:

- fireworks, explosives, mortars and cannons, model rockets (licenses for manufacture, storage, transportation, sale, use)
- certification for servicing, placement, and inspecing fire extinguishing equipment
- general storage and handling of flammable liquids, solids, gases (tanks, personnel training, markings, equipment)
- limitations on locations and quantities of flammables (e.g., 10 litres of gasoline inside a residential dwelling)

- specific uses and specific flammables (e.g., dry cleaning, gasoline distribution, explosive dusts, pesticides, space heaters, plastics manufacturing)
- permits and limitations in various building occupancies (assembly hall, hospital, school, theatre, elderly care, prisons, warehouses, etc)
- locations that require a smoke detector, sprinkler system, fire extinguisher, or other specific equipment or procedures
- removal of interior and exterior obstructions to emergency exits or firefighters and removal of hazardous materials
- permits and limitations in special outdoor applications (tents, asphalt kettles, bonfires, etc)
- other hazards (flammable decorations, welding, smoking, bulk matches, tire yards)
- Electrical safety code
- Fuel gas fitting code.

Industrial and multiphase power plugs and sockets

Pin and sleeve connectors

Industrial and multiphase plugs and sockets provide a connection to the electrical mains in situations where normal plugs and sockets are in some way inadequate. They are generally used because more than two current carrying conductors, high currents and/or protection from environmental hazards (particularly water) are required.

In many countries sockets are available that completely enclose a normal plug and have seals around the cable to keep water out. These reduce the need for special plugs and sockets but are often only suitable for fixed sockets due to their bulk, shape, and cable entry arrangements. Sockets on domestic extension leads are usually either not covered at all or covered with small covers that don't enclose an inserted plug.

Some connectors exist that are neither industrial nor multiphase but have higher voltage or current ratings than the normal plugs and sockets (e.g., the 16 A Italian socket and the 20 A American sockets). These are listed here in the domestic AC power plugs and sockets article grouped with the normal plugs and sockets of which they are variants.

Almost all three-phase power plugs have an earth (ground) connection, but may not have a neutral, because large appliances such as circular saws, air conditioners, etc. tend to be delta connected. Such plugs have only four prongs (earth, and the three phases). An example of a socket with neutral is the L21-30 (30 A) and the L21-20 (20 A) both of which have five pins (earth, neutral, and X, Y, Z phases).

While some forms of power plugs and sockets are set by international standards, countries may have their own different standards and regulations. For example, the colour-coding of wires may not be the same as for small mains plugs.

Europe

16 A 3P+E 400 V plug

16 A 2P+E 230 V plug

Mated 16 A plug and wall-mounted socket

Europe-wide IEC 60309 system

In Europe the most common range of heavy commercial and industrial plugs are made to IEC 60309 (formerly IEC 309) and various standards based on it (including BS 4343 and BS EN 60309-2). These are often referred to in the UK as CEE industrial or simply CEE plugs, or as "commando connectors" (presumably after the MK Commando range that contains these connectors).

Plugs are available in 2P+E (single phase), 3P+E (3 phase no neutral), and 3P+N+E (three phase with neutral). Current ratings available are 16 A, 32 A, 63 A, 125 A and 200 A.

Voltage is represented by a color code (in three-phase plugs the stated voltage is the phase-phase voltage, not the phase-neutral voltage). The different voltages have the key (or keys in the case of ELV plugs) in different places relative to the earth pin, therefore it is impossible to mate, for instance, a blue plug with a yellow socket. It is also not possible to mate different pin configurations or current ratings, therefore, for example, a 16 A 3P+E 400 V plug will not mate with a 16 A 3P+N+E 400 V socket and a 16 A 2P+E 230 V plug will not mate with a 32 A 2P+E 230 V socket.

The voltage ranges are:

- 25 V: purple
- 50 V: white
- 100–130 V: yellow
- 200–250 V: blue
- 346–460 V: red
- 500–750 V: black

Green is used for high frequency systems of any voltage over 50V

Yellow 2P+E, blue 2P+E, yellow 3P+E, red 3P+E, and red 3P+N+E are by far the most common arrangements. Blue 2P+E sockets (generally 16 A although 32 A is becoming more common) are used near-universally by UK campsites and yacht marinas to provide domestic mains power to caravans or boats; they are also used elsewhere in Europe for the same purpose, though in some countries the local domestic plug is also widely used.

A small number of marinas provide 240 volt single-phase power through a red three-phase connector (breaking the relevant standards in the process). This ensures that only boats that have paid the required fee (and thus obtained an appropriately made-up adaptor cable) are able to use the electricity.

A chart showing all available ratings and their key positions can be found at here (PDF).

UK

Lewden plugs

Lewden plugs and sockets are metal bodied waterproof plugs and sockets made by lewden. The pin arrangements of the smaller single phase varieties are the same as BS 1363 and BS 546 plugs and sockets. These plugs and sockets will mate with normal plugs and sockets of the same pin arrangement but they are only waterproof when a lewden plug is used in a lewden socket and the screw ring is properly tightened (sockets have a metal cover that screws on to waterproof them when not in use).

North America

Pin and Sleeve

Pin and Sleeve Plug

Pin and Sleeve circular connectors are not compatible with the newer IEC 309 type. Current ratings are 30, 60, 100, 200, and 400 amperes. All are rated for voltages up to 250 volts DC or 600 V AC. Contact arrangements are from 2 to 4 pins. There are two “styles” depending on the treatment of the ground. Style 1 grounds only on the shell.

Style 2 uses one of the contacts as well as the shell, internally connected together. They are not strongly typed for specific circuits and voltages as the IEC 309 are. One insert rotation option is available to prevent mating of similar connectors with different voltages.

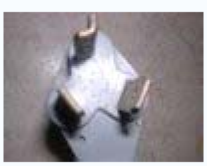
The contacts in the plug are simple cylinders (sleeves), while the pin contacts in the receptacle have the spring arrangement to hold contact pressure, the reverse of the IEC 309 type connectors. All contacts are the same diameter. Originally metal construction was used, but now they are also made with plastic shells.

NEMA connectors

NEMA devices are not exclusively industrial devices, but some types are found in nearly all buildings in the United States. Many of these standards are identical to their counterparts in Canada, although there are some exceptions. NEMA wiring devices are made in current ratings from 15 to 60 amperes, and voltage ratings from 125V to 600V.

There are two basic classifications of NEMA device: straight-blade and locking. The locking type is preferred in many industrial environments, while the residential and commercial environment is home to straight-blade devices. (Of course, the straight-blade 5-15 and 5-20 are found nearly everywhere.) Numbers prefixed by **L** are twistlock, others are straight blade.

NEMA 10-20, 10-30 and 10-50



nema 10-30

NEMA 10 devices are a curious throwback to an earlier time. They are classified as 125/250V non-grounding, yet they are usually used in a manner that effectively grounds the appliance, albeit not in a manner consistent with most modern practice.

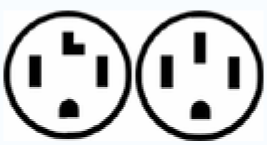
As commonly used, 10-30 and 10-50 plugs have the frame of the appliance grounded through the neutral pin. This was a legal grounding method under the National Electrical Code for electric ranges and electric clothes dryers from the 1947 to the 1996 edition.

Since North American dryers and ranges have certain parts (timers, lights, fans, etc.) that run on 120V, this means that the wire used for grounding is also carrying current. Although this is contrary to modern grounding practice, such installations remain extremely common in the United States and are relatively safe, because the larger conductors used are less likely to be broken than the smaller conductors used in ordinary appliance cords.

Persons moving their older appliances to newer NEMA 14-equipped buildings (or vice-versa) should have the cords replaced by a qualified electrician, as the grounding details may be quite confusing to the uninitiated.

NEMA 10-20 devices are very rare nowadays. There is also a similar obsolete design, lacking a NEMA configuration number, rated 125V 15A/ 250V 10A which is nearly identical to the AS/NZS 3112 standard used in Australia/New Zealand. These are also extremely rare.

NEMA 14



nema 14-30 and 14-50 receptacles

The NEMA 14 devices are 4-wire grounding devices available in ratings from 15 A to 60 A. Of the straight-blade NEMA 14 devices, only the 14-30 and 14-50 are common. The voltage rating is a design maximum of 125/250 V. They are essentially the replacements for the connectors above with the addition of a separate grounding connection.

All NEMA 14 devices offer two hots, a neutral and a ground, allowing for both 120 V and 240 V (or 120 V and 208 V if the supply system is three phase wye rather than split phase or three phase center tapped delta) appliances. They differ in rating and shape of the neutral pin. The 14-30 has a rating of 30 A and an L-shaped neutral pin. The 14-50 has a rating of 50 A and a straight neutral pin sized so that it will not fit in the slot of a 14-30.

NEMA 14-30 devices are most commonly found serving electrically-heated clothes dryers, while 14-50 devices most commonly serve kitchen ranges. In the United States, these are generally found in buildings constructed after the 1996 National Electrical Code, although they are also found in considerably earlier mobile homes. In Canada, the use of NEMA 10 devices was discontinued much earlier (if it was ever permitted at all), so NEMA 14 devices are more common there.

Twist-locking connectors


L21-30 Plug and receptacle

Twist-locking connectors were first invented by Harvey Hubbell III in 1938 and "Twist-Lock" remains a registered trademark of Hubbell Incorporated to this day[1], although the term tends to be used generically to refer to NEMA twist-locking connectors manufactured by any company. Unlike non-locking connectors, twist-locking connectors all use curved blades that have shapes that conform to portions of the circumference of a circle. Once pushed into the receptacle, the plug is twisted and its now-rotated prongs latch into the receptacle. To unlatch the plug, the rotation is reversed. The locking coupling makes for a very reliable connection in commercial and industrial settings.

Like non-locking connectors, these come in a variety of standardized configurations and follow the same general naming scheme except that they all begin with an "L" for "locking". Once again, the connector families are designed so that 120V connectors , 208/240V connectors, and various other, higher-voltage connectors can not be accidentally intermated.

Duplexing and triplexing


Triplex outlet. The top three are used to run a phase sequence indicator comprising three neon night lights. The bottom three run the desired triplex load.

Most receptacles in the USA and Canada are duplex receptacles. The top and bottom sockets can also be separated, if desired, and, for example, supplied by separate breakers with a **common neutral**. This is typically done in kitchens where a high load will likely be placed on both sockets. In this case, a common trip two-pole breaker is often used.

The concept of duplexing can be generalized to **triplexing**, so that three duplex receptacles can be supplied by a common neutral, from a three-phase supply. Typically, a three-pole common trip 15 A breaker is used to supply such a socket. This enables three single phase loads to be supplied in a phase-sequenced manner. An example of such a load is a light fixture having three bulbs. For flicker-free operation, three bulbs are each fitted with a separate plug, and driven 120° out of phase with one another, from a triplex receptacle. The top receptacles shown in the figure are fitted with neon night lights to indicate phase sequence, for triplex loads where proper phase sequence is desired.

Issues with dimmers

If done after passing through a bank of light dimmers that use a phase cutting technique, duplexing and triplexing can create problems. Harmonic "noise" created by dimming equipment can effectively overload a combined neutral and result in unreliable operation. Combined neutrals can also cause inconsistent response from individual circuits in this situation. Although not the case in older facilities, in all new installations of large-scale theatrical dimming equipment, manufacturers require individual neutrals after passing through the dimmers to maintain warranty status of the equipment.

Note that lots of theatrical dimming equipment actually uses shared neutrals prior to the dimming. For example, the Rosco Entertainment dimmers have a shared neutral on their plugs, where there are four conductors (not including ground) for neutral and the three hots, that feed the dimmer racks. While with a simple dimmer circuit the issue would be just as bad with a shared neutral either before or after the dimmer, filtering of the mains input makes this less of an issue.

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 History

Early telegraph systems were the first forms of electrical cabling but transmitted only small amounts of power. Gutta-percha insulation used for the first transatlantic cables was unsuitable for building wiring use since gutta-percha deteriorated rapidly when exposed to air. The first power distribution system developed by Thomas Edison 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. Oil-impregenated paper-insulated high voltage cables were commercially practical by 1895. During World War II several varieties of synthetic rubber, and polyethylene insulation was 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 called power cables in the trade.

Conductors are usually made of copper or aluminum wires, or may be composite conductors with steel strands at their core. Conductors are usually stranded for flexibility, but small cables may use solid conductors.

Conductors in a cable may be different sizes. Each conductor has its own electrical insulation. The cable may include uninsulated conductors used for the circuit neutral or for ground (earth) connection.

The overall assembly may be round or flat. 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.

For circuits operating at 2400 volts between conductors or more, a conductive shield surrounds each conductor. This equalizes electrical stress on the cable insulation. This technique was patented by Martin Hochstadter in 1916, and so the shield is sometimes called a Hochstadter shield. The individual conductor shields of a cable are connected to earth ground at one or both ends of each length of cable.

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 the intended application, and may be specially resistant to water, oil, sunlight, underground conditions, chemical vapors, impact resistance, or high temperatures. Cables intended for underground use or direct burial in earth will have heavy plastic sheaths, or may be protected by a lead sheath. Where cables must run where exposed to impact damage, they are protected with flexible steel tape or wire armor, which may also be covered by a water resistant jacket.

Cables for high-voltage (more than 65,000 volts) power distribution may be insulated with oil and paper, and are run in a rigid steel pipe, semi-rigid aluminium or lead jacket/sheath. The oil is kept under pressure to prevent formation of voids that would allow partial discharges within the cable insulation.

A hybrid cable will include conductors for control signals or may also include optical fibers for data. Besides data transmission, these optical fibres are used for distributed temperature monitoring in order to optimize the load/ampacity of the cable.

Named cable types

Common types of general-purpose cables used by electricians are defined by national or international regulations or codes. Commonly-used types of power cables are often known by a "shorthand" name. For example, NEC type *NM-B* (*Non-Metallic, variant B*), often referred to as Romex, a trade name, is a cable with a nonmetallic jacket. *UF* (*underground feeder*) is also nonmetallic but uses a moisture- and sunlight-resistant construction suitable for direct burial in the earth or in interiors in wet, dry, or corrosive locations. Type AC is a fabricated assembly of insulated conductors in a flexible metallic armor, made by twisting an interlocking metal strip around the conductors. *BX*, an early genericized trademark of the General Electric company was used before and during WWII, designating a particular design of armored cable.

In Canada, type TECK cable, with a flexible aluminum or steel armour and overall flame-retardent PVC jacket, is used in industry for wet or dry locations, run in trays or attached to building structure, above grade or buried in earth. A similar type of cable is designated type MC in the United States.

Electrical power cables are often installed in raceways including electrical conduit, and cable trays, which may contain one or more conductors. Conduit may also be rigid or flexible, metallic or nonmetallic, and differentiation from cable may require some investigation of the contents at their termination.

Mineral Insulated Copper Clad cable (type *MI*) is a fire-resistant cable using magnesium oxide as an insulator. It is used in demanding applications such as fire alarms and oil refineries.

Ampacity and ampacity derating

The ampacity (current-carrying capacity) of any given cable is the maximum amount of current a cable can constantly carry without jeopardizing the integrity of the insulating/sheathing materials due to excess heat dissipation. The heat-dissipating ability of the conductor is reduced by the electrical insulation around the conductor. If the current in a conductor is too high, its insulation will be damaged long before the conductor melts. Depending on the type of insulating material, common maximum allowable temperatures are 60, 90, or 105 degrees Celsius.

The ampacity for a cable is thus based on conductor composition, insulator composition, conductor size, ambient temperature, and environmental conditions adjacent to the cable. In a long run of cable different conditions govern, and installation regulations specify that the most severe condition along the run governs the cable's rating. Cables run in wet or oily locations may carry a lower temperature rating than in a dry installation. Special calculations are necessary for multiple circuits in proximity in adjacent raceways. When multiple cables are bundled together, each contributes heat to the bundle and diminishes the amount of cooling air that can flow past the individual cables. The overall ampacity of the insulated conductors in a bundle of more than 3 must be derated, whether in a raceway or cable. Usually the de-rating factor is tabulated in the wiring regulations.

The allowed current in cables can be decreased (derated) when the cable is covered in fireproofing material.

Flexible cables

All cables are flexible, which allows them to be shipped to installation sites on reels or drums. Where applications require a cable to be moved repeatedly, more flexible cables are used. Small cables are called "cords" or "flex". Flexible cords contain finer stranded conductors, rather than solid, and have insulation and sheaths that are engineered to withstand the forces of repeated flexing. Heavy duty flexible power cords such as feeding a mine face cutting machine are carefully engineered -- since their life is measurable in (6) weeks! See "Power cord" and "Extension cable" for further description of flexible power cables. Other types of flexible cable include twisted pair, extensible, coaxial, shielded, and communication cable.

Power cord

A **power cord** or **mains cable** is a cable that temporarily connects an electrical appliance to an electrical power source. The term is generally used for cables using a power plug to connect to a single-phase alternating current power source at "mains voltage" (100 to 240 volts, depending on the location). The terms **power cable**, **mains lead** or **flex** are also used. The term **cord set** is also used to distinguish those cords that include connectors molded to the cord at each end.

Power cords from those countries that use 110 V mains supply (chiefly the United States, Canada, parts of South America and Japan) tend to be bulkier than the mains cables used in the rest of the world, because of the higher currents required to deliver the same power (watts) at 110 V compared with 230 V.

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 (female connector) rather than a plug (male connector) 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.

Common types of detachable power cable have appliance-side connectors such as the *IEC 60320 C13* sometimes colloquially known as an "IEC connector" 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 an power supply inlet for use with a laptop computer. The IEC C7 is also known as a "figure-of-eight lead" (connecting by two small round pins, with round insulating bushings; 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.

Note that the same types of 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. Unless explicitly labelled as capable of handling local voltages, this is very likely to damage or destroy the appliance.

Residual-current device

A residual current device (RCD)

A **residual current device** (**RCD**), or **residual current circuit breaker** (**RCCB**), is an electrical wiring device that disconnects a circuit whenever it detects that the flow of current is not balanced between the phase ("hot") conductor and the neutral conductor. The presumption is that such an imbalance may represent current leakage through the body of a person who is grounded and accidentally touching the energized part of the circuit. A shock, possibly lethal, is likely to result from these conditions; RCDs are designed to disconnect quickly enough to prevent such shocks.

In the United States and Canada, a residual current device is also known as a **Ground Fault Circuit Interrupter** (**GFCI**) or an **Appliance Leakage Current Interrupter** (**ALCI**). In Germany, one is known as a **FI-Schalter**.

RCDs operate by measuring the current balance between two conductors using a differential current transformer, and opening the device's contacts if there is a balance fault (i.e. a difference in current between the phase conductor and the neutral conductor). More generally (single phase, three phase, etc.) RCDs operate by detecting a nonzero sum of currents, i.e. the current in the "hot" or "hots" plus that in the "neutral" must equal zero (within some small tolerance), otherwise there is a leakage of current to somewhere else (to ground, or to another circuit, etc.). The National Electrical Code, which is the enforcable code in most of the United States, requires GFCI devices for personnel to interrupt the circuit if the leakage current exceeds a range of 4 to 6 milliamps of current (the exact trip setting can be chosen by the manufacturer of the device and is typically 5 milliamps) within 25 milliseconds. GFCI devices which protect equipment (not personnel) are allowed to trip as high as 30 milliamps of current.

RCDs are designed to prevent electrocution by detecting the leakage current, which can be far smaller (typically 5- 6 milliamperes) than the trigger currents needed to operate conventional circuit breakers, which are typically measured in amperes. RCDs are intended to operate within 25 milliseconds, before electric shock can drive the heart into ventricular fibrillation, the most common cause of death through electric shock.

These values were set by tests at Underwriters Laboratories during which volunteers holding cups of rice were subjected to shocks of known amperage and voltage. Initially, the GFCI was developed using pigs and hogs in swimming pools, because their skin is like that of humans.

Residual current detection is complementary to, rather than a replacement for, conventional over-current detection, as residual current detection cannot provide protection for faults which do not involve an external leakage current, for example faults that pass the current directly from one side of the circuit through the victim to the other. Notably, RCDs do not provide protection against overloads or short circuits between phase (live, hot, line) and neutral or phase to phase.

Two wire (ungrounded) outlets may be replaced with three wire GFCIs to protect against electrocution, and a grounding wire does not need to be supplied to that GFCI, BUT, it shall be so tagged (the GFCI manufacturers are providing several tags for the approprate installation description).

Use and placement

In most houses, only some (if any) circuits are protected by RCDs. German law, for example, requires the installation of RCDs only for circuits leading to bathrooms (due to the highly increased danger of leakage currents when operating electrical devices in a wet environment; a hair dryer falling into a bathtub might otherwise be fatal). U.S. law (the National Electrical Code) requires GFCIs in bathrooms, kitchens, garages, exterior areas, crawl spaces, unfinished basements, near wet bars, swimming pools, and spas. Additionally, it might be a good idea to protect circuits leading to outlets in reach of children, or outlets that are indoors but near a door (where people are likely to plug something in while working outside) by RCDs.

Most manufacturers of utilization devices to be used in wet environments (for example, hair dryers and hydrotherapy devices for use in bathtubs) now build in RCDs. In many countries such is now required.

Sometimes a single RCD is installed covering the entire electrical installation in a property. However this is considered bad practice by some because any fault will cause all power to be cut to the premises including to devices such as freezers, fire alarms etc. and injury may be caused by occupants being suddenly plunged into darkness. Normal practice in domestic installations in the UK is to use a single RCD for all RCD protected cuircuits but to have some circuits that are not protected at all (sockets usually are on the RCD, lights usually aren't other circuits vary by who installed the system). This practice is widely regarded as far from ideal but cost considerations make it by far the most common. GFI outlets in the USA have connections to allow further outlets to be protected by the RCD; a very common practice is to connect the other outlets in a room "downstream" of a single GFI outlet so that they are also protected. For example, this is very common if a house has multiple bathrooms. RCD protection is also available in combination with an overcurrent breaker for fitting in a consumer unit/distribution board/breaker panel (known as a GFCI breaker in the US and as a RCBO in europe). In the US, this has become less common because RCBOs are much more expensive than RCD outlets.

More than one RCD feeding another is unnecessary, provided they have been wired properly. One exception is the case of a TT earthing system where the earth loop impedance may be high, meaning that a ground fault might not cause sufficient current to flow to trip an ordinary circuit breaker or fuse. In this case a special 100mA (or greater) trip current time-delayed RCD is installed covering the whole installation and then more sensitive RCDs should be installed downstream of it for sockets and other circuits which are considered high risk.

Testing

RCDs can be tested to see if they are operational and/or they have been wired correctly.

It is a good idea to check RCDs monthly. One way to test an RCD is to press the button labelled "Test" or "T" on the RCD unit (which will simulate a ground fault by bypassing some current) and see if the RCD reacts by correctly opening the circuit. If it does **not** trip, the RCD should be replaced. Unfortunately, the test button is a fairly crude test and it is quite possible (though rare) for an RCD to trip on the pressing of the test button even when it would not pass a proper test involving passing known leakage currents and measuring the resulting trip time (and comparing those values to the requirements given in a standards document such as BS 7671). For example, an incorrectly wired RCD may still trip when the test button is pressed even though a real ground fault may not cause it to trip. Use of a solenoid voltmeter from live to earth may provide a more effective test of the RCD; such a test should be performed at least once upon installation of the device. The test should be repeated at every outlet "downstream" of the RCD to ensure that the downstream outlets are also wired correctly.

Limitations

A residual current circuit breaker can improve the safety of an electrical system but cannot remove all risk of electric shock or fire. In particular, an RCD will not detect overload conditions, phase to neutral short circuits or phase-to-phase short circuits. Some sort of over-current protection (fuse or circuit breaker) must be employed to guard against these occurrences. Combined RCD/circuit breaker units are available, and these combine the functions of an RCD with those of a conventional circuit breaker, responding appropriately to fault currents and overload conditions. These are known as RCBOs, and are available in 1, 2, 3 and 4 pole configurations. RCBOs will typically have separate circuits for detecting current imbalance (RCD function) and for detecting overload current (circuit breaker function); however the device for interrupting the flow of current will be common to both functions.

An RCD will help to protect against electric shock where current flows through a person from a phase (live / line / hot) to earth. It cannot protect against electric shock where current flows through a person from phase to neutral or phase to phase, for example where a finger touches both live and neutral contacts in a light fitting. It is virtually impossible to provide electrical protection against such shocks as there is no way for a device to differentiate between current flow causing an electrical shock to a person and normal current flow through an appliance. Protection against electrical shock of this nature must be through mechanical means (guards or covers to protect against accidental contact) and procedure (e.g. switching off power before undertaking maintenance).

History and nomenclature

In the early 1970s most GFCI devices were of the circuit breaker type. However the most commonly used GFCIs since the early 1980s are built into outlet receptacles. The problem with those of the circuit breaker type was that of many false trips due to the poor alternating current characteristics of 120 volt insulations, especially in circuits having longer cable lengths. So much current leaked along the length of the conductors' insulation that the breaker might trip with the slightest increase of current unbalance.

One might more properly call the device a **Balance Fault Interrupter** (**BFI**), rather than GFI, because it will trip if current, for example, leaks to or from another circuit such as either the "hot" or "cold" side of a nearby 12 volt DC renewable energy system, or a nearby ethernet jack, etc. The device will trip on any balance fault, not just a balance fault to ground. However, the term "Balance Fault Interrupter" is rarely used in practice.

The term **earth leakage circuit breaker** (ELCB) is also (incorrectly) used, though strictly speaking this refers to a different type of device.

Types

A **Residual Current Breaker with Overload** (RCBO) is a combination of an RCD and a miniature circuit breaker (MCB).

In Europe RCDs can fit on the same DIN rail as the MCBs, however the busbar arrangements in consumer units and distribution boards can make it awkward to use them in this way. If it is desired to protect an individual circuit an RCBO (Residual-current Circuit Breaker with Overcurrent protection) can be used. This incorporates an RCD and a miniature circuit breaker in one device.

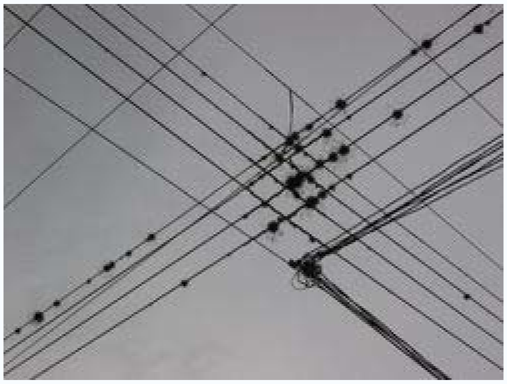
It is common to install an RCD in a consumer unit in what is known as a split load configuration where one group of circuits is just on the main switch (or time delay RCD in the case of a TT) and another group is on the RCD.

Electrical plugs which incorporate an RCD are sometimes installed on appliances which might be considered to pose a particular safety hazard, for example long extension leads which might be used outdoors or garden equipment or hair dryers which may be used near a tub or sink. Occasionally an in-line RCD may be used to serve a similar function to one in a plug. By putting the RCD in the extension lead you provide protection whatever outlet is used even if the building has old wiring.

Electrical sockets with included RCDs are becoming common. In the U.S. these are required by law in wet areas (See National Electrical Code (US) for details.)

In North America, RCD ("GFCI") sockets are usually of the **decora** size (a size that harmonizes outlets and switches, so that there is no difference in size between an outlet cover and a switch cover). For example, using the decora size outlets, RCD outlets can be mixed with regular outlets or with switches in a multigang box with a standard cover plate.

Wire



A **wire** is a single, usually cylindrical, elongated strand of drawn metal. Wires are used to bear mechanical loads and to carry electricity and telecommunications signals. Standard sizes are determined by various wire gauges. The term *wire* is also used more loosely to refer to a bundle of such strands, as in 'multistranded wire', which is more correctly termed a cable.

Wire has many uses. It forms the raw material of many important manufacturers, such as the wire-net industry, wire-cloth making and wire-rope spinning, in which it occupies a place analogous to a textile fibre. Wire-cloth of all degrees of strength and fineness of mesh is used for sifting and screening machinery, for draining paper pulp, for window screens, and for many other purposes. Vast quantities of aluminium, copper, nickel and steel wire are employed for telephone and data wires and cables, and as conductors in electric power transmission, and heating. It is in no less demand for fencing, and much is consumed in the construction of suspension bridges, and cages, etc. In the manufacture of stringed musical instruments and scientific instruments wire is again largely used. Among its other sources of consumption it is sufficient to mention pin and hair-pin making, the needle and fish-hook industries, nail, peg and rivet making, and carding machinery; indeed there are few industries into which it does not enter.

Not all metals and metallic alloys possess the physical properties necessary to make useful wire. The metals must in the first place be ductile and strong in tension, the quality on which the utility of wire principally depends. The metals suitable for wire, possessing almost equal ductility, are platinum, silver, iron, copper, aluminium and gold; and it is only from these and certain of their alloys with other metals, principally brass and bronze, that wire is prepared. By careful treatment extremely thin wire can be produced. Special purpose wire is however made from other metals (e.g. tungsten wire for light bulb and vacuum tube filaments, because of its high melting temperature).

History

In antiquity, jewellery often contains, in the form of chains and applied decoration, large amounts of wire that is accurately made and which must have been produced by some efficient, if not technically advanced, means. In some cases, strips cut from metal sheet were made by pulling them through perforations in stone beads. This causes the strips to fold round on themselves to form thin tubes. This strip drawing technique was in use in Egypt by the 2nd Dynasty. From the middle of the 2nd millennium BC most of the gold wires in jewellery are characterised by seam lines that follow a spiral path along the wire. Such twisted strips can be converted into solid round wires by rolling them between flat surfaces or the strip wire drawing method. Strip and block twist wire manufacturing methods were still in use in Europe in the 7th century AD, but by this time there seems to be some evidence of wires produced by true drawing. Square and hexagonal wires were possibly made using a swaging technique. In this method a metal rod was struck between grooved metal blocks, or between a grooved punch and a grooved metal anvil. Swaging is of great antiquity, possibly dating to the beginning of the 2nd millennium BC in Egypt and in the Bronze and Iron Ages in Europe for torcs and fibulae. Twisted square section wires are a very common filigree decoration in early Etruscan jewellery. In about the middle of the 2nd millennium BC a new category of decorative wires was introduced which imitated a line of granules. Perhaps the earliest such wire is the notched wire which first occurs from the late 3rd, early 2nd millennium BC in Anatolia and occasionally later.

Wire was drawn in England from the medieval period. The wire was used to make wool cards and pins, manufactured goods whose import was prohibited by Edward IV in 1463.[1] The first wire mill in Great Britain was established at Tintern in about 1568 by the founders of the Company of Mineral and Battery Works, who had a monopoly on this.[2] Apart from their second wire mill at nearby Whitebrook,[3] there were no other wire mills before the second half of the 17th century. Despite the existence of mills, the drawing of wire down to fine sizes continued to be done manually.

Wire is usually drawn of cylindrical form; but it may be made of any desired section by varying the outline of the holes in the draw-plate through which it is passed in the process of manufacture. The draw-plate or die is a piece of hard cast-iron or hard steel, or for fine work it may be a diamond or ruby. The object of utilizing precious stones is to enable the dies to be used for a considerable period without losing their size, and so producing wire of incorrect diameter. Diamond dies must be rebored when they have lost their original diameter of hole, but the metal dies are brought down to size again by hammering up the hole and then drifting it out to correct diameter with a punch.

Production

Wire is often reduced to the desired diameter and properties by repeated drawing through progressively smaller dies, or traditionally holes in draw plates. The wire may be heated to red heat in an inert atmosphere to soften it, and then cooled, in a process called annealing. An inert atmosphere is used to prevent oxidation, although some scaling always occurs and must be removed by 'pickling' before the wire is redrawn.

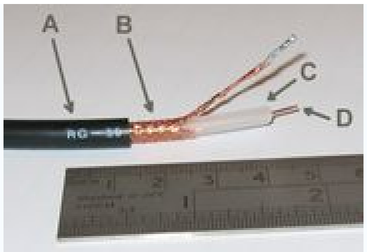
An important point in wire-drawing is that of lubrication to facilitate the operation and to lessen the wear on the dies. Various lubricants, such as oil, are employed. Another method is to immerse the wire in a copper (II) sulfate solution, so that a film of copper is deposited which forms a kind of lubricant, easing the drawing considerably; in some classes of wire the copper is left after the final drawing to serve as a preventive of rust.

The wire-drawing machines include means for holding the dies accurately in position and for drawing the wire steadily through the holes. The usual design consists of a cast-iron bench or table having a bracket standing up to hold the die, and a vertical drum which rotates and by coiling the wire around its surface pulls it through the die, the coil of wire being stored upon another drum or "swift" which lies behind the die and reels off the wire as fast as required. The wire drum or "block" is provided with means for rapidly coupling or uncoupling it to its vertical shaft, so that the motion of the wire may be stopped or started instantly. The block is also tapered, so that the coil of wire may be easily slipped off upwards when finished. Before the wire can be attached to the block, a sufficient length of it must be pulled through the die; this is effected by a pair of gripping pincers on the end of a chain which is wound around a revolving drum, so drawing the pincers along, and with them the wire, until enough is through the die to be coiled two or three times on the block, where the end is secured by a small screw clamp or vice ready for the drawing operation. Wire has to be pointed or made smaller in diameter at the end before it can be passed through the die; the pointing is done by hammering, filing, rolling or swaging in dies, which effect a reduction in diameter. When the wire is on the block the latter is set in motion and the wire is drawn steadily through the die; it is very important that the block shall rotate evenly and that it shall run true and pull the wire in an even manner, otherwise the "snatching" which occurs will break the wire, or at least weaken it in spots.

Continuous wire-drawing machines differ from the single-block machines in having a series of dies through which the wire passes in a continuous manner. The difficulty of feeding between each die is solved by introducing a block between each, so that as the wire issues it coils around the block and is so helped on to the next die. The speeds of the blocks are increased successively, so that the elongation due to drawing is taken up and slip compensated for. The operation of threading the wire first through all the dies and around the blocks is termed "stringing-up." The arrangements for lubrication include a pump which floods the dies, and in many cases also the bottom portions of the blocks run in lubricant. The speeds at which the wire travels vary greatly, according to the material and the amount of reduction effected.

Finishing, covering, and insulating

Wires and cables for electrical purposes are covered with various insulating materials, such as cotton, rubber, or plastic, wrapped in concentric fashion and further protected with, substances such as paraffin, some kind of preservative compound, bitumen or lead sheathing or steel taping. The stranding or covering machines employed in this work are designed to carry supplies of material and wind it on to the wire which is passing through at a rapid rate. Some of the smallest machines for cotton covering have a large drum, which grips the wire and moves it through toothed gears at a definite speed; the wire passes through the centre of disks mounted above a long bed, and the disks carry each a number of bobbins varying from six to twelve or more in different machines. A supply of covering material is wound on each bobbin, and the end is led on to the wire, which occupies a central position relatively to the bobbins; the latter being revolved at a suitable speed bodily with their disks, the cotton is consequently served on to the wire, winding in spiral fashion so as to overlap. If a large number of strands are required the disks are duplicated, so that as many as sixty spools may be carried, the second set of strands being laid over the first.



Coaxial Cable, one example of a covered **wire**

For the heavier cables, used for electric light and power, and submarine cables, the machines are somewhat different in construction. The wire is still carried through a hollow shaft, but the bobbins or spools of covering material are set with their spindles at right angles to the axis of the wire, and they lie in a circular cage which rotates on rollers below. The various strands coming from the spools at various parts of the circumference of the cage all lead to a disk at the end of the hollow shaft. This disk has perforations through which each of the strands pass, thence being immediately wrapped on the cable, which slides through a bearing at this point. Toothed gears having certain definite ratios are used to cause the winding drum for the cable and the cage for the spools to rotate at suitable relative speeds which do not vary. The cages are multiplied for stranding with a large number of tapes or strands, so that a machine may have six bobbins on one cage and twelve on the other.

Rubber covering of wires and cables is done by passing them through grooved rollers simultaneously with rubber strips above and below, so that the rubber is crushed on to the wires, the latter emerging as a wide band. The separate wires are parted forcibly, each retaining its rubber sheathing. Vulcanizing is afterwards done in steam-heated drums. However, the conductor needed to be tinned to provide some relief to stripping away the natural rubber. Since the mid 1960s, the insulation has been plastic or polymers exhibiting properties similar to rubber.

Many auxiliary machines are necessary in connection with wire and cable-covering, as plant for preparing the rubber and paper, etc., cutting it into strips, winding it, measuring lengths, etc.

Barbed wire

A selection of forms of barbed wire.

Barbed wire is a type of fencing wire constructed with sharp edges or points arranged at intervals along the strand(s). It is used to construct inexpensive fences and also on walls surrounding secured property. A person or animal trying to pass through or over barbed wire will suffer discomfort and possibly injury. Barbed wire fencing requires only fenceposts, wire and fixing devices such as staples. It is simple to construct and quick to erect by even an unskilled fencer.

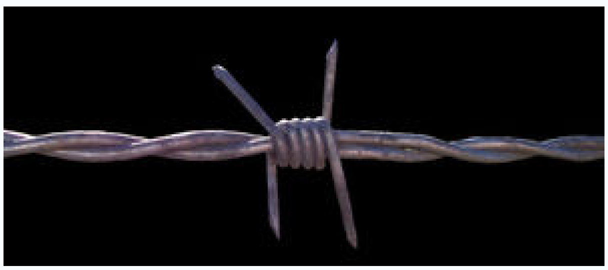
The most successful barbed wire was patented by Joseph F. Glidden of DeKalb, Illinois in 1874. It was an improvement on earlier less successful pointed wire products such as that invented in 1865 by Louis Jannin of France.

Barbed wire was the first wire technology capable of restraining cattle. Wire fences were cheaper to erect than their alternatives and when they became widely available in the late 19th century in the United States they made it affordable to fence much bigger areas than before. They made intensive animal husbandry practical on a much larger scale.

History

In late 1872 Waterman, Illinois farmer Henry Rose developed a wire fence with an attached wooden strip containing projecting wire points to dissuade encroaching livestock. He patented his fence in May, 1873 and exhibited it at the DeKalb County Fair that summer. This prompted DeKalb area residents Isaac Ellwood, Joseph Glidden and Jacob Haish to work on improving the concept. Ellwood patented a type of barbed wire in February 1874, but concluded that Glidden's design was superior to his. Glidden's barbs were made with a coffee grinder. Once they were made he placed the barbs on the wire and twisted them in. To keep them in place Glidden wrapped another wire around the barbs. Ellwood purchased one-half interest in Glidden's invention in July, 1874. Glidden's patent issued in November, and together they formed the I.L. Ellwood Manufacturing Company. In the beginning they produced two-strand, twisted barbed wire in the back of Ellwood's hardware store. The business was quickly successful. Jacob Haish also founded a successful business based on his own patents. In 1876 Glidden sold his half of his patent to the Washburn and Moen Manufacturing Company of Worcester, Massachusetts, which then joined with Ellwood to expand the business.

In the American Southwest



Modern barbed wire

John Warne Gates demonstrated barbed wire for Washburn and Moen in Military Plaza, San Antonio, Texas in 1876. The demonstration showing cattle restrained by the new kind of fencing was followed immediately by invitations to the Menger Hotel to place orders. Gates subsequently had a falling out with Washburn Moen. He went to St. Louis and founded the Southern Wire Company, which became the largest manufacturer of unlicensed barbed wire. An 1881 court decision invalidated competitors to the Glidden patent, effectively establishing a monopoly. This was affirmed by a US Supreme Court decision in 1892. In 1898 Gates took control of Washburn and Moen, and created the American Steel and Wire monopoly, which was a predecessor of United States Steel. In 1875, 270 tons of barbed wire had been manufactured, and by 1900 production had increased to over 150,000 tons.

In the American Southwest barbed wire fencing led to disputes known as the range wars between free-range ranchers and farmers in the late 19th century. These were similar to the disputes which resulted from enclosure laws in England in the early 18th century. These disputes were decisively settled in favor of the farmers, and heavy penalties were instituted for cutting the wire in a barbed wire fence. Within 25 years, nearly all of the open range had been fenced in under private ownership. For this reason, some historians have dated the end of the Old West era of American history to the invention and subsequent proliferation of barbed wire.

Agricultural fencing

Barbed wire fence in west Texas

Barbed wire fences remain the standard fencing technology for enclosing cattle in most regions of the US, but not all countries. The wire is aligned under tension between heavy, braced, fence posts (strainer posts) and then held at the correct height by being attached to wooden posts and battens, or steel star posts. The gaps between star posts vary depending on terrain—on short fences in hilly country they may be placed as closely as every 3 yards, whereas in flat terrain with long spans and relatively few stock they may be spaced out up to 30 to 50 yards. Wooden posts are normally spaced at 2 rods (10 metres) in any case with 4 or 5 battens in between.

Barbed wire for agricultural fencing is typically available in two varieties—"soft" or mild-steel wire and "high tensile". Both types are galvanised for long life. High-tensile wire is made with thinner but higher-strength steel. Its greater strength make fences longer-lasting because cattle cannot stretch and loosen it. It copes with the expansions and contractions caused by heat and animal pressure by stretching and relaxing within wider elastic limits. It also supports longer spans, but because of its "springy" nature it is hard to handle and somewhat dangerous for inexperienced fencers. Soft wire is much easier to work but is less durable and only suitable for short spans.

In high soil-fertility areas where dairy cattle are used in great numbers 5- or 7-wire fences are common as the main boundary and internal dividing fences. On sheep farms 7-wire fences are common with the second (from bottom) to fifth wire being plain wire. In New Zealand wire fences have to be easy to get through by dogs because they are the main means of controlling and driving animals on farms.

Human proof fencing

Fence with barbed wire on top

Most barbed wire fences, while sufficient to discourage cattle, are passable by humans who can simply climb over the fence—or through the fence by stretching the gaps between the wires using non-barbed sections of the wire as handholds. To prevent humans crossing, many prisons and other high-security installations construct fences with razor wire, a variant which instead of occasional barbs features near-continuous cutting surfaces sufficient to injure unprotected persons who climb on or over it. A commonly seen alternative is the placement of a few strands of barbed wire at the top of a chain link fence. The limited mobility of someone already climbing a fence makes passing conventional barbed wire all the more difficult. On some chainlink fences these strands are attached to a bracket tilted 45 degrees towards the intruder, making climbing over the fence even more difficult.

Barbed wire is used as a tool of war. During World War I the wire was placed either to halt the passage of soldiers or just to impede them long enough to be killed with machine guns. Much of the artillery bombardment on the Western Front in World War I was aimed at cutting the barbed wire that was a major component of trench warfare. As the war progressed the wire was used in shorter lengths that were easier to transport and more difficult to cut with artillery. During the Soviet-Afghan War, the accommodation of Afghan refugees into Pakistan was controlled in Pakistan's largest province, Balochistan, under General Rahimuddin Khan, by making the refugees stay for controlled durations in barbed wire camps (see Controlling Soviet-Afghan War Refugees).

Injuries caused by barbed wire

Barbed wire and razor wire

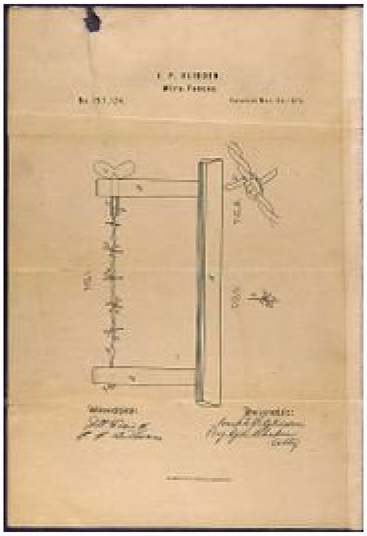
Unrestrained violence against barbed wire will always result in moderate to severe injuries to the skin and, depending on body area and barbed wire configuration, possibly to the underlying tissue. Humans can manage not to injure themselves too much when dealing with barbed wire as long as they exert a high degree of caution. Restriction of movement, appropriate clothing, and slowing down when close to barbed wire seem to be the key in reducing the extent of injury.

Injuries caused by barbed wire are typically seen in horses, bats or birds. Horses panic easily, and once they get caught in barbed wire, large patches of skin may be torn off, sometimes exposing the underlying bone. At best, such injuries may heal, but they may cause disability or death (particularly due to secondary infection). Birds or bats may not be able to perceive thin strands of barbed wire and suffer impalement or lacerating injuries.

Grazing animals with slow movements which will back off at the first notion of pain — sheep, cows — will not generally suffer the severe injuries often seen in other animals.

Barbed wire has been reported as a tool for human torture. When used as a whip it causes deep lacerations and severe bleeding.

Installation of barbed wire



Patent Drawing for Joseph F. Glidden's Improvement to Barbed Wire, 24 November 1874.

The most important and most time-consuming part of a barbed wire fence is constructing the *corner post* and the bracing assembly. A barbed wire fence is under tremendous tension, often up to half a ton, and so the corner post's sole function is to resist the tension for all fence spans connected to it. The bracing, in turn, keeps the corner post perfectly vertical and prevents slack from developing in the fence.

Brace posts are placed in-line about 8 feet from the corner post. A horizontal *compression brace* connects the top of the two posts, and a diagonal wire connects the top of the brace post to the bottom of the corner post. This diagonal wire prevents the brace post from leaning, which in turn allows the horizontal brace to prevent the corner post from leaning into the brace post. A second set of brace posts (forming a *double brace*) is used whenever the barbed wire span exceeds 200 feet (60 m).

When the barbed wire span exceeds 650 ft (200 m), a *braced line assembly* is added in-line. This has the function of a corner post and brace assembly but handles tension from opposite sides. It uses diagonal brace wire that connects the tops to the bottoms of all adjacent posts.

Line posts are installed along the span of the fence at intervals of 8 to 50 ft (2.5 m to 15 m). An interval of 16 ft (5 m) is most common. Heavy livestock and crowded pasture demands the smaller spacing. The sole function of a line post is not to take up slack but to keep the barbed wire strands spaced equally and up off the ground.

Once these posts and bracing have been erected, the wire is wrapped around one corner post, held with simple fence staples, and then reeled out along the span of the fence. It is then wrapped around the opposite corner post, pulled tightly by hand or metal wire stretchers, and nailed with more fence staples. Then it is attached to all of the line posts with fencing staples driven in partially to allow stretching of the barbed wire line.

It is installed from the top down.

There are several ways to anchor the wire to a corner post:

- **Hand-knotting**. The wire is wrapped around the corner post and knotted by hand.
- **Crimp sleeves**. The wire is wrapped around the corner post and bound to the incoming wire using metal sleeves.
- **Wire vise**. The wire is passed through a hole drilled into the corner post and is anchored on the far side.
- **Wire wrap**. The wire is wrapped around the corner post and wrapped onto a special, gritted helical wire which also wraps around the incoming wire; friction holds it in place.

Barbed wire for agriculture use is typically double-strand 12½-gauge, zinc-coated (galvanized) steel and comes in rolls of 1320 ft (402 m) length. Barbed wire is usually placed on the inner (pasture) side of the posts.

Galvanized wire is classified into three categories; Classes I, II, and III. Class I has the thinnest coating and the shortest life expectancy. A wire with Class I coating will start showing general rusting in 8 to 10 years, while the same wire with Class III coating will show rust in 15 to 20 years. Aluminum-coated wire is occasionally used which yields a longer life expectancy.

Corner posts are 6 to 8 inches (15 to 20 cm) in diameter, may consist of treated wood or from durable on-site trees such as osage orange, black locust, red cedar, or red mulberry and are anchored in a concrete base 20 inches (50 cm) square and 42 inches (105 cm) deep. Brace posts are a minimum 4 inches (10 cm) in diameter and are anchored in a concrete base 20 inches (50 cm) square and 24 inches (60 cm) deep. Iron posts, if used, are a minimum 2½ inch (64 mm) in diameter. Bracing wire is typically smooth 9-gauge. Line posts are set to a depth of about 30 inches (75 cm).

During the First World War, screw pickets were used for the installation of wire obstacles; these were metal rods with eyelets for holding strands of wire, and a corkscrew-like end that could literally be screwed into the ground rather than hammered, so that wiring parties could work at night within the vicinity of enemy soldiers and not give away their position by the sound of their hammers.

Sports and entertainment use

Barbed wire is used in the professional wrestling "barbed wire match". In some promotions the barbed wire is fake while in others it is very real. It was evident that the barbed wire was real during the Hardcore Homecoming professional wrestling tour with one particular instance in which wrestler Terry Funk got his arm caught in the wire and had to be very carefully cut out of the barbed wire in order not to cut his veins in his arm. It has also been used in hardcore wrestling promotions such as Extreme Championship Wrestling and Combat Zone Wrestling. Companies such as ECW and WWE have been reported to have been using "clipped" barbed wire throughout their existences, whereas companies like CZW, XPW, FMW, IWA-MS and IWA-DS use the real deal.

In other cases the barbed wire may be real, but rarely if ever used, such as the "Barbed Wire Cage Match" between wrestlers John "Bradshaw" Layfield and The Big Show. The barbed wire was placed at the top of the cage, thus making it impossible or very painful to escape the cage by climbing out. The wire was never used fully but once when John "Bradshaw" Layfield made a single attempt to escape and 'caught' his forearm on it to test it was real.

Razor wire

Razor wire

Barbed tape or **razor wire** is a mesh of metal strips with sharp edges whose purpose is to prevent passage by human beings. Although it is sharper than the barbs of barbed wire, it is not actually razor sharp; the name "razor wire" is a slang term derived from a manufacturer's brand name. The sharp edges of the wire can cause serious cuts in any person attempting to pass through quickly. In high security applications, barbed tape supplanted barbed wire which could be circumvented relatively quickly by humans without tools. Getting past razor wire without tools is considerably slower, giving security forces much more time in which to respond. There is little difference in the breaching time for a well equipped opponent.

Use

Razor wire at the Tuol Sleng Genocide Museum, Cambodia.

Starting in the late 1960s, barbed tape was typically found in prisons and long term mental hospitals, where the increased breaching time for a poorly equipped potential escapee was a definite advantage. Until the development of reinforced barbed tape in the early 1980s, it was rarely used for military purposes or genuine high security facilities because it was actually easier to breach with the correct tools. Since then, however, some military forces have also replaced barbed wire with barbed tape for many applications, mainly because it is slightly lighter for the same effective coverage.

More recently, barbed tape has been seen in more commercial and residential security applications. This is often primarily a visual deterrent since a well-prepared burglar can breach barbed wire and barbed tape barriers in similar amounts of time. A very simple defeat technique is to cut the wire or throw a piece of old carpet over the strands. Residential usage of barbed tape has been criticised by some as the aggressive appearance of the barbs is thought to detract from the appearance of a neighbourhood.

Construction

Barbed tape has a central strand of high tensile strength wire, and a steel tape punched into a shape with barbs. The steel tape is then cold-crimped tightly to the wire everywhere except for the barbs.

Types

Like barbed wire, barbed tape is available as either straight wire or concertina wire. Unlike barbed wire, which usually is available only as plain steel or galvanised, barbed tape is also manufactured in stainless steel, to prevent the points from rusting to bluntness. Typically the core wire is galvanised and the tape is stainless, although fully stainless barbed tape is used for expensive permanent installations or underwater usage.

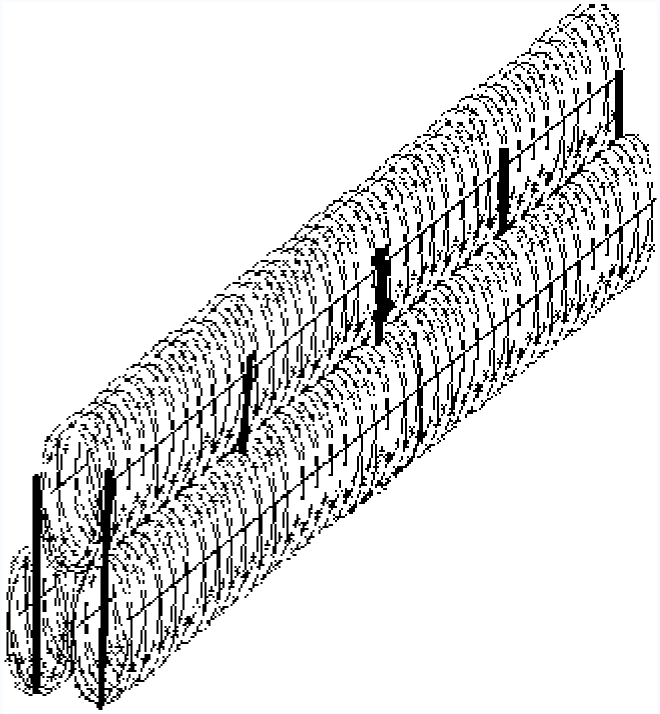
Barbed tape is also characterised by the shape of the barbs. Although there are no formal definitions, typically **short barb** barbed tape has barbs from 10 mm to 15 mm long, **medium barb** tape has barbs 20 mm to 25 mm long, and **long barb** tape has barbs from 60 to 66 mm long. There does not seem to be much available research to indicate whether longer barbs are actually more effective in resisting penetration, but they certainly provide a stronger psychological deterrent.

History

Barbed tape was first manufactured by Germany during World War I, as an expedient measure during a shortage of wire. Since it was simply punched out of a rolled ribbon of steel tape, it could also be manufactured much faster. This early barbed tape had triangular barbs, and no reinforcing wire. Consequently, although it was harder to cut with ordinary wire cutters, it was easier to cut with shears, and generally weaker.

Commencing in the early 1970s, unreinforced barbed tape started to be commonly used in perimeter barriers in US prisons. Several manufacturers of barbed wire and barbed tape began to offer barbed tape with a reinforcing wire in the early 1980s. The first to be manufactured was probably around 1981, although this has been subject to a patent dispute. Early brand names of reinforced barbed tape included "Man Barrier" and "Razor Ribbon"; the latter probably lent its name to the modern slang term.

Concertina wire



A sketch of a typical concertina wire obstacle

Concertina wire is a type of barbed wire or razor wire that is formed in large coils which can be expanded like a concertina. Each coil actually consists of two oppositely wound helices which support each other against crushing while allowing easy longitudinal movement. In conjunction with plain barbed wire and steel pickets, it is used to form military wire obstacles. During World War I soldiers manufactured concertina wire themselves, using ordinary barbed wire. Today it is factory made.

Concertina wire packs flat for ease of transport, but can then be deployed as an obstacle much more quickly than ordinary barbed wire.

US soldiers laying concertina wire on an exercise

A platoon of soldiers can deploy a single concertina fence at a rate of about a kilometre per hour. Such an obstacle is not very effective by itself, and concertinas are normally built up into more elaborate patterns as time permits.

Stranded wire

Stranded copper wire

Stranded wire (opposite to Solid wire) is composed of a bundle of small-gauge wires wrapped in a particular pattern inside insulation to make a larger conductor. Stranded wire is more flexible than a solid strand of the same overall gauge. Stranded conductors are commonly used for electrical applications carrying signals, a computer "mouse" and for power cables between an utilization device and its power source; eg: sweepers, table lamps, powered hand sanders, welding electrode cables, mining machine trailing machine cables. Most house wiring is done with solid, single strand, wire because it is cheaper to manufacture than stranded wire -- to the wall switches and receptacles.

However, the use of stranded conductors adds lots of surface area. The wire from the electrical service to earth is solid and large against physical problems.

If wires/cables are subject to frequent movement, they should be inspected regularly to see if any of the strands have broken. If so, the wire/cable should be replaced as soon as possible. [A quick splice in a mine cable is to use a square knot until the end of a shift.]

High frequency and heavy current electricity travels near the outside of the wire. This is commonly known as the skin effect and is resposible for some power loss within the circuit. Stranded wire ("Litz wire") reduces this effect and is therefore ideal for use in coils used as inductors in high-frequency tuned circuits. This is why coax cable is used in TV and cell phone tower cables.

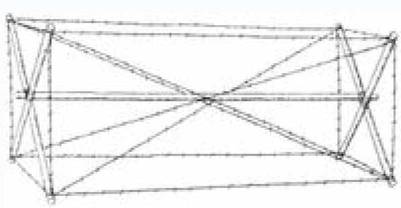
Wire obstacle

In the military science of fortification, **wire obstacles** are defensive obstacles made from barbed wire, barbed tape or concertina wire. They are designed to disrupt or delay an attacking enemy. Depending on the requirements and available resources, wire obstacles may range from a simple barbed wire fence in front of a defensive position, to elaborate patterns of fences, concertinas, "dragon's teeth" and minefields hundreds of metres thick.

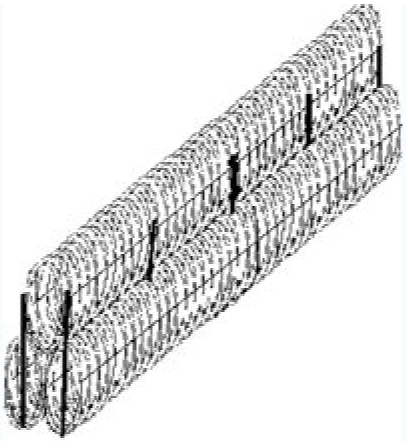
One example is the "low wire entanglement", which consists of irregularly placed stakes that have been driven into the ground with only some 15 cm (six inches) showing; the barbed wire is then wrapped and tightened on to these. An enemy combatant running through the barrier, which is hard to see, is apt to trip and get caught.

Wire obstacles first saw significant military use during the Second Boer War, and reached their pinnacle during World War I. Relatively elaborate obstacles were also used in some phases of the Korean War, and continue to be used on the Korean Demilitarized Zone, and a few other borders. However the more fluid nature of modern war means that most obstacles used today are relatively simple, temporary barriers.

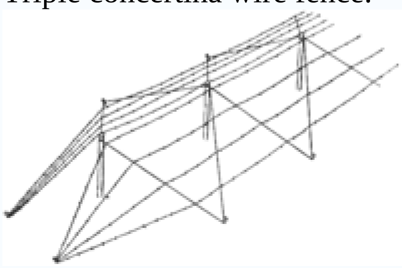
Tanks can generally flatten unmined wire obstacles, although some are designed to stop vehicles, and the heavier obstacles can sometimes stop light armoured vehicles. Wire obstacles can also be breached by intense artillery shelling or Bangalore torpedoes.



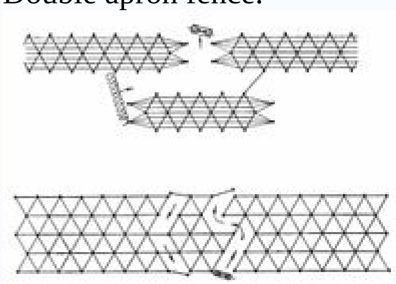
The "knife rest" or "Spanish rider" is a modern wire obstacle functionally similar to the cheval de frise, and sometimes called that.



Triple concertina wire fence.



Double apron fence.



A complex obstacle belt of low wire entanglement backed by a double apron fence. Both obstacles have movable openings that can be blocked with knife rests.

Electrical tape

Electrical tape, standard black

Electrical tape, color coded (grounding)

Electrical tape is a type of tape used to insulate electrical wires and other material that conduct electricity. It can be made of many plastics, but vinyl is most popular; it stretches better, giving a more effective and longer lasting insulation.

When used by an electrician, the tape is sometimes color coded to indicate the purpose of a wire, like power or ground.

The tape is usually available in hardware stores. The fact that it is often more UV-resistant than other tapes and its ability to stretch has led to a wide range of uses beyond insulation.

Not all black vinyl tape is safe for electrical usage, some are not even labeled as electrical tape. UL listed tape is certified to not catch fire and burn when overheated, meanwhile non-UL listed tape may contribute or start a fire and burn like a petroleum product.

Alternative Usage

Electrical tape is often also used to secure lighting cables to the truss in stagecraft, and is also commonly known as LX tape for this reason.

Electrical tape is often used by front rowers in rugby to tape back their ears. This is to prevent abrasion from causing cuts or problems like cauliflower ear.

Electrical tape is also used by youths in cricket playing nations to wrap around tennis balls to make them look and/or act or like cricket balls.

Before the introduction of mass produced roller hockey pucks, certain brands of electrical tape were used as a puck substitute as traditonal Ice Hockey pucks are poorly suited for use on concrete and asphalt. Scotch 88 tape, in particular, was commonly used even in organized leagues during the 1990's.

In the case where electrical tape is readily available, it can be used as temporary bandaging for minor cuts until proper treatment can be administered (often referred to as a Mandaid).

The fact that electrical tape is slightly stretchy, easily torn by hand, can be written on, is available in a number of colours and generally removes from smooth surfaces cleanly makes it useful for a number of other applications, including colour coding, labelling and temporarily taping things together.

Friction tape

Friction tape is a type of adhesive tape made from cloth impregnated with a rubber based adhesive. Because the adhesive is impregnated in the cloth, friction tape is sticky on both sides. The rubber based adhesive makes it an ideal electrical insulator and provides protection from liquids and corrosion. Friction tape is therefore commonly carried by electricians. The use of friction tape as an electrical insulator has declined over the years in favor of vinyl electrical tape. The frictional properties of the tape come from the cloth material which is often made from cotton. The versatility of friction tape is almost unlimited. One common use is to wrap it around the handle of a hockey stick to improve the grip.

Lineman's pliers

Lineman's pliers

Lineman's pliers (US English), also called **combination pliers** are a type of pliers used by Electricians and other tradesmen for gripping small objects, to cut and bend wire and cable, and to hammer other small tools, such as a chisel or screwdriver, and to hammer various types of hardware, especially staples and small nails. Lineman's pliers have a gripping joint at their snub nose, and cutting edge in their craw, and insulating handle grips that reduce (but do not eliminate) the risk of electric shock from contact with live wires (versions with properly tested and guaranteed insulation in two colors to make faults visible are also available). Some versions include either an additional gripping or crimping device at the crux of the handle side of the pliers' joint. Lineman's pliers typically are machined from forged steel and the two handles precisely joined with a heavy-duty rivet that maintains the pliers' accuracy even after repeated use under extreme force on heavy-gauge wire -- and even use as a hammer.

Durability

Lineman's pliers owe their effectiveness to the rigid accuracy of their closing (cutting/gripping) action, and to the durable, forged steel from which they are machined. Although the cutting edge may effectively dull with prolonged use or misuse (for example, cutting large steel screws or wire, cutting live wires that electrically short and melt the tool's cutting edges), this tool is otherwise virtually indestructible because it does not depend on a knife-sharp edge, only a 'breaking' edge.

Typical uses

Cutting

Lineman's pliers are an essential item in the electrician's tool complement. They cut, bend, and may be used to strip wire insulation or cable jackets. As with most pliers and scissors or shears, lineman's pliers apply most force closest to the pivot-point of the two handles, so for larger materials, the closer one can get the wire or cable to the joint or 'craw' of the pliers, the easier and cleaner will be the cut.

Cutting metal-clad (MC) cable

A rotosplit is the ideal tool for this job, but lineman's pliers can be used to first 'crack' the spiral casing of the cable by bending it sharply, partially exposing the insulated wires, inside. This creates a place for the pliers to gain purchase, and, with the application of strong force with two hands, they will cut the cable. To strip the cable, saw through one wrap of the spiral metal casing using a metal-cutting saw blade (for example, on a hack saw or powered reciprocating saw) and then use two pliers to twist the casing sharply and break apart the sections on either side of the saw cut; if no saw or rotosplit is available, use the lineman's pliers to grasp the end of the cable and laboriously unwind 12 inches of stiffly-spiralled aluminum to expose the wire inside.

Gripping

The most common application of the lineman's pliers in gripping is to twist bare (stripped) wires together, to form a common electrical connection between the wires (wire nuts can be used to enhance this electrical connection and guard against corrosion of the contact-points between wires, as well as to insulate the bared wire ends and provide additional mechanical 'locking' of the junction). The gripping action of lineman's pliers is also be used to pull fish-tape ends in a long (high-friction) wire run through conduit, to crimp soft metals, or to pull nails and other fasteners.

Hammering

The massive pliers make a good hammer, either to re-position or form materials, or to drive fasteners, such as small nails or staples. Another common hammering action for the lineman's pliers is to tighten (or loosen) the lock-nuts or 'lock-rings' of cable connectors (a.k.a. 'Romex connector', 'BX connector', 'MC connector').

Multimeter

howard piA digital multimeter

A low cost digital multimeter

An analog multimeter

A **multimeter** or a **multitester** is an electronic measuring instrument that combines several functions in one unit. The most basic instruments include an ammeter, voltmeter, and ohmmeter. Analog multimeters are sometimes referred to as "volt-ohm-meters", abbreviated **VOM**. Digital multimeters are usually referred to as "digital-multi-meters", abbreviated **DMM**.

A multimeter can be a handheld device useful for basic fault finding and field service work or a bench instrument which can measure to seven or eight and a half digits of accuracy. Such an instrument will commonly be found in a calibration lab and can be used to characterise resistance and voltage standards or adjust and verify the performance of multi-function calibrators.

Current, voltage, and resistance measurements are considered standard features for multimeter. AVO multimeters, a manufacturer of early multimeters, derived their name from amperes, volts, and ohms, the units used for the measurement of current, voltage, and resistance.

Newer equipment can measure many other quantities. Some common additional measured quantities and the units in which they are measured:

- Inductance in henrys.
- Capacitance in farads.
- Conductance in siemens.
- Temperature in degrees Celsius or degrees Fahrenheit.
- Frequency in hertz.
- Duty cycle as a percentage.

A multimeter may be implemented with an analog meter deflected by an electromagnet, as a classic galvanometer; or with a digital display such as an LCD or Vacuum fluorescent display.

Analog multimeters are not hard to find in the used market, but are not very accurate because of errors introduced in zeroing and reading the analog meter face.

Analog meters may be implemented with vacuum tubes to precondition and amplify the input signal. Such meters are known as vacuum tube volt meters (VTVM) or vacuum tube multimeters (VTMM).

The resolution of a multimeter is often specified in "digits" of resolution. The term "digits" dates back to the 1970's when multimeter vendors were very proud of how many digits their products could display (this was important, because readout displays were costly). The vendors started to specify the maximum resolution of the multimeter based on the digital display. For example, the term 5½ digits refers to the number of digits displayed on the readout of a multimeter. A 5½ digit multimeter would have five full digits that display values from 0 to 9 and one half digit that could only display 0 or 1. This digital multimeter could show positive or negative values from 0 to 199,999. For a modern DMM, such as a PC-based multimeter, the term "digits" actual maps to the noise performance of the device.

Modern multimeters are exclusively digital, and identified by the term **DMM** or **digital multimeter**. In such an instrument, the signal under test is converted to a digital voltage and an amplifier with an electronically controlled gain preconditions the signal. Since the digital display directly indicates a quantity as a number, there is no risk of parallax causing an error when viewing a reading.

Similarly, better circuitry and electronics have improved meter accuracy. Older analog meters might have basic accuracies of five to ten percent. Modern portable DMMs may have accuracies as good as ±0.025%, and bench-top instruments have accuracies in the single-digit parts per million figures.

The inclusion of solid state electronics, from a control circuit to small embedded computers, has provided a wealth of convenience features in modern digital meters. Commonly available measurement enhancements include:

- Current-limited tests for voltage drop across semiconductor junctions. While not a replacement for a transistor tester, this facilitates testing diodes and a variety of transistor types.
- A graphic representation of the quantity under test, as a bar graph. This makes go/no-go testing easy.
- A continuity tester that beeps when a circuit conducts.
- A low-bandwidth oscilloscope.
- A telephone test set.
- Automotive circuit testers, including tests for automotive timing and dwell signals.
- Simple data acquisition features to record maximum and minimum readings over a given period, or to take a number of samples at fixed intervals.
- Sample and hold, which will latch the most recent reading for examination after the instrument is removed from the circuit under test.
- Autoranging, which selects the correct range for the quantity under test without any risk of damaging the instrument.

Digital meters often feature circuitry or software to accurately measure AC voltages at any frequency. These meters integrate the input signal using the root mean square method, and will correctly read the true voltage of an input signal even if it isn't a perfect sine wave.

Modern meters may be interfaced with a personal computer by IrDA links, RS-232 connections, or an instrument bus such as IEEE-488. The interface allows the computer to record measurements as they are made or for the instrument to upload a series of results to the computer.

As modern appliances and systems become more complicated, the multimeter is becoming less common in the technician's toolkit. More complicated and specialized equipment replaces it. Where a service man might have used an ohmmeter to measure resistance while testing an antenna, a modern technician may use a hand-held analyzer to test several parameters in order to determine the integrity of a network cable.

Needle-nose pliers

Needle-nose pliers

Needle-nose pliers are both cutting and gripping pliers used by electricians and other tradespersons to bend, re-position and cut wire. Their namesake long gripping nose provides excellent control and reach for fine work in small or crowded electrical enclosures, while cutting edges nearer the pliers' joint provide "one-tool" convenience.

Rotosplit

Roto-Splitis a highly-specialized tool invented by Lucien C Ducret, the founder of Seatek Co. Inc. It is used in stripping the casing from metallic-clad electrical power cable (MC Cable). The tool does not actually strip the casing, but facilitates the process considerably.

The tool includes a guide or channel to hold the cable secure and uses a plier-type action to apply consistent force on a hand-cranked grinding wheel, which cuts across the spiralled aluminum, steel or lead casing of a multi-wire cable. Once this cut is made, the sections of spiral jacket on either side of the cut may be separated by a sharp twisting action in opposite directions.

Alternatives to the use of this tool include a metal saw, mounted in a hack-saw or other saw handle, or in a reciprocating saw.

Solenoid voltmeter

A **solenoid voltmeter** is a specific type of voltmeter used by electricians in the testing of electrical power circuits.

Wiggy is the registered trademark for a common solenoid voltmeter used in North America and manufactured by Square D.

Operation

Rather than using a D'Arsonval movement or digital electronics, the solenoid voltmeter simply uses a spring-loaded solenoid carrying a pointer (it might also be described as a form of moving iron meter). Greater voltage creates more magnetism pulling the solenoid's core in further against the spring loading, moving the pointer. A short scale converts the pointer's movement into the voltage reading. Solenoid voltmeters usually have a scale on each side of the pointer; one is calibrated for alternating current and one is calibrated for direct current. Only one "range" is provided and it usually extends from zero to about 600 volts.

A small permanent magnet rotor is usually mounted at the top of the meter. For DC, this magnet flips one way or the other, indicating by the revealed color (red or black) which lead of the voltmeter (the red or the black lead) is positive. For AC, the rotor simply vibrates, indicating that the meter is connected to an AC circuit.

Models made by some manufacturers include continuity test lights, which are energized by a battery within the tester. This is particularly advantageous when testing , for example, fuses in live circuits, since no switching is required to change from continuity mode to voltage detecting mode.

Advantages

Solenoid voltmeters are extremely rugged and not very susceptible to damage through either rough handling or electrical overload.

The probes (test prods) are very sturdy and the can be stored within the meter's body. A probe may also be extended from the meter's body, allowing one hand to both probe and hold the meter in a useful position. Probes are usually securely or permanentlly attached to the unit, so leads are unlikely to slip out if the tester is dropped.

The solenoid voltmeter has no switches that can be set incorrectly, simplifying operation.

For "go/no go" testing, there is no need to read the scale as application of power creates a perceivable vibration and sound within the meter.

Solenoid voltmeters draw appreciable current when operating. This makes them useful for testing residual-current devices (GFCIs) because the current drawn will trip most RCDs when the solenoid voltmeter is connected between the live and earth conductors. Also, when testing power supply circuits, a high-impedance connection (that is, a nearly open-circuit fault such as a burned switch contact or wire joint) in the power path might still allow enough voltage/current through to register on a high-impedance digital voltmeter, but it probably will not actuate the solenoid voltmeter.

Disadvantages

In conrast to modern multimeters, solenoid voltmeters have no other built-in functions (such as the ability to act as an ammeter, ohmmeter, or capacitance meter); they are just simple, easy-to-use power voltmeters. Solenoid voltmeters are practically useless on low-voltage circuits (for example, 12 volt circuits).

Solenoid voltmeters are by no means precise. For example, there would be no reliably perceptible difference in the reading between 220 VAC and 240 VAC circuits. They draw a large amount of power from the circuit under test and are meant for intermittent operation and will overheat if used continuously. Whilst this is an advantage when testing RCDs and power paths, it becomes a disadvantage if the circuit under test cannot supply much power. The basic rangeof this starts at around 90V (AC or DC)

Wire stripper

A simple manual wire stripper

An automatic wire stripper

Stripped copper wire

A **wire stripper** is a small, hand-held device used to strip the insulation from electric wires.

Types of wire strippers

Manual

- A simple manual wire stripper is a pair of opposing blades much like scissors or wire cutters. The addition of a center notch makes it easier to cut the insulation without cutting the wire. This type of wire stripper is used by rotating it around the insulation while applying pressure in order to make a cut around the insulation. Since the insulation is not bonded to the wire, it then pulls easily off the end. This is the most versatile type of wire stripper.

- Another type of manual wire stripper is very similar to the simple design previously mentioned, except this type has several notches of varying size. This allows the user to match the notch size to the wire size, thereby eliminating the need for twisting. Once the device is clamped on, the remainder of the wire can simply be pulled out, leaving the insulation behind.

Automatic

- When engaged, an automatic wire stripper simultaneously grips the wire from one side and cuts and removes the insulation from the other. To use it, one simply has to place the wire in the jaws and squeeze the handle. While this device allows even a novice to strip most wires very quickly, it does have some drawbacks. An automatic wire stripper only works on wires in a certain size range. If a wire is too small it may be broken by the pulling force, and if a wire is too large it will not fit in the jaws.