E- BOOK

PROTECTION AND SWITCHGEAR

10133EE702 PROTECTION AND SWITCHGEAR

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UNIT I INTRODUCTION 9

Importance of protective schemes for electrical apparatus and power system. Qualitative review of faults and fault currents - relay terminology – definitions - and essential qualities of protection.
Protection against over voltages due to lightning and switching - arcing grounds – Peterson Coil - ground wires - surge absorber and diverters Power System earthing – neutral Earthing - basic ideas of insulation coordination.

UNIT II OPERATING PRINCIPLES AND RELAY CHARACTERISTICS 9

Electromagnetic relays – over current, directional and non-directional, distance, negative sequence, differential and under frequency relays – Introduction to static relays.

UNIT III APPARATUS PROTECTION 9

Main considerations in apparatus protection - transformer, generator and motor protection - protection of busbars. Transmission line protection - zones of protection. CTs and PTs and their applications in protection schemes.

UNIT IV THEORY OF CIRCUIT INTERRUPTION 9

Physics of arc phenomena and arc interruption. DC and AC circuit breaking – restriking voltage and recovery voltage - rate of rise of recovery voltage - resistance switching – current chopping - nterruption of capacitive current.

UNIT V CIRCUIT BREAKERS 9

Types of circuit breakers – air blast, air break, oil, SF6 and vacuum circuit breakers – C merits of different circuit breakers – testing of circuit breakers.

TOTAL : 45 PERIODS

TEXT BOOKS

1. Soni.M.L, Gupta.P.V, Bhatnagar.V.S, Chakrabarti.A, “A Text Book on Power System Engineering”, Dhanpat Rai & Co., 1998. (For All Chapters 1, 2, 3, 4 and 5).
2. Rajput.R.K, “A Text book of Power System Engineering”, Laxmi Publications, First Edition Reprint 2007.

REFERENCE BOOKS

1. Sunil S. Rao, “Switchgear and Protection”, Khanna publishers, New Delhi, 1986.
2. Wadhwa.C.L, “Electrical Power Systems”, Newage International (P) Ltd., 2000.
3. Ravindranath.B, and Chander.N, “Power System Protection & Switchgear”, Wiley Eastern Ltd., 1977.
4. Badri Ram, Vishwakarma, “Power System Protection and Switchgear”, Tata McGraw Hill, 2001.
5. Paithankar.Y.G and Bhide.S.R, “Fundamentals of Power System Protection”, Prentice Hall

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DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING
LESSON PLAN

FACULTY NAME : **S.LAKSHMI KANTHAN BHARATHI**
DESIGNATION : **ASSISTANT PROFESSOR**
DEPARTMENT : **EEE**
SUBJECT NAME : **PROTECTION & SWITCHGEAR**
SUBJECT CODE : **10133EE702**
YEAR : **IV**
SEMESTER : **VIII**
DEGREE & BRANCH : **B.E/EEE**

S.No	Hour	Unit	Topic	No of Periods required	Book(s) Referred
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2.		I	Importance of protective schemes for power system	1	T2
3.		I	Qualitative review of faults and fault currents	1	T2
4.		I	Qualitative review of faults currents	1	T2
5.		I	Relay terminology – definitions	1	T2
6.		I	Essential qualities of protection	1	T2
7.		I	Protection against over voltages due to lightning and switching	1	T2
8.		I	Arcing grounds – Peterson Coil - ground wires	1	T2
9.		I	Surge absorber	1	T2
10.		I	Surge diverters	1	T2
11.		I	Power System earthing – neutral Earthing	1	T2
12.		I	Basic ideas of insulation coordination	1	T2
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15.		II	Over current relay	1	T2
16.		II	Directional Relay	1	T2
17.		II	Non-directional Relay	1	T2
18.		II	Distance Relay	1	T2
19.		II	Negative sequence,	1	T2
20.		II	Differential	1	T2
21.		II	Under frequency relays	1	T2
22.		II	Introduction to static relays	1	T2
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24.		II	Over frequency relays	1	T2
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27.		**III**	Transformer apparatus protection	1	T2
28.		**III**	Generator	1	T2
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32.		**III**	Zones of protection	1	T2
33.		**III**	CTs and their applications	1	T2
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UNIT IV THEORY OF CIRCUIT INTERRUPTION					
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38.		**IV**	Physics of arc phenomena	1	T1
39.		**IV**	Arc interruption	1	T1
40.		**IV**	DC circuit breaking	1	T1
41.		**IV**	AC circuit breaking	1	T1
42.		**IV**	Restriking voltage	1	T1
43.		**IV**	Recovery voltage	1	T1
44.		**IV**	Rate of recovery voltage	1	T1
45.		**IV**	Rise of recovery voltage	1	T1
46.		**IV**	Resistance switching	1	T1
47.		**IV**	Current chopping	1	T1
48.		**IV**	Interruption of capacitive current	1	T1
UNITV CIRCUIT BREAKERS					
49.		**V**	Introduction about Circuit Breaker	1	T1
50.		**V**	Types of circuit breakers merits of different circuit breakers.	1	T1
51.		**V**	Air blast circuit breakers	1	T1
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53.		**V**	Oil circuit breakers	1	T1
54.		**V**	SF6 circuit breakers	1	T1
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58.		**V**	Application of Air Blast, Air Break circuit breakers	1	T1
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STAFF **CLASS INCHARGE** **HOD /EEE** **PRINCIPAL**

PROTECTION AND SWITCHGEAR

UNIT – I INTRODUCTION

10133EE702 - PROTECTION AND SWITCHGEAR

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INTRODUCTION :

Power system protection is a branch of electrical power engineering that deals with the protection of electrical power systems from faults through the isolation of faulted parts from the rest of the electrical network.

IMPORTANCE OF PROTECTIVE SCHEMES FOR ELECTRICAL APPARATUS AND POWER SYSTEM:

The objective of a protection scheme is to keep the power system stable by isolating only the components that are under fault, whilst leaving as much of the network as possible still in operation. Thus, protection schemes must apply a very pragmatic and pessimistic approach to clearing system faults. For this reason, the technology and philosophies utilized in protection schemes can often be old and well-established because they must be very reliable

Protection systems usually comprise five components:

- Current and voltage transformers to step down the high voltages and currents of the electrical power system to convenient levels for the relays to deal with;
- Protective relays to sense the fault and initiate a trip, or disconnection, order;
- Circuit breakers to open/close the system based on relay and autorecloser commands;
- Batteries to provide power in case of power disconnection in the system.
- Communication channels to allow analysis of current and voltage at remote terminals of a line and to allow remote tripping of equipment.

For parts of a distribution system, fuses are capable of both sensing and disconnecting faults.

Failures may occur in each part, such as insulation failure, fallen or broken transmission lines, incorrect operation of circuit breakers, short circuits and open circuits. Protection devices are installed with the aims of protection of assets, and ensure continued supply of energy. The three classes of protective devices are:

- Protective relays control the tripping of the circuit breakers surrounding the faulted part of the network
- Automatic operation, such as auto-reclosing or system restart
- Monitoring equipment which collects data on the system for post event analysis

While the operating quality of these devices, and especially of protective relays, is always critical, different strategies are considered for protecting the different parts of the system. Very important equipment may have completely redundant and independent protective systems, while a minor branch distribution line may have very simple low-cost protection.

TYPES OF PROTECTION :

- Generator sets – In a power plant, the protective relays are intended to prevent damage to alternators or to the transformers in case of abnormal conditions of operation, due to internal failures, as well as insulating failures or regulation malfunctions. Such failures are unusual, so the protective relays have to operate very rarely. If a protective relay fails to detect a fault, the resulting damage to the alternator or to the transformer might require costly equipment repairs or replacement, as well as income loss from the inability to produce and sell energy.

- High voltage transmission network – Protection on the transmission and distribution serves two functions: Protection of plant and protection of the public (including employees). At a basic level, protection looks to disconnect equipment which experience an overload or a short to earth. Some items in substations such as transformers might require additional protection based on temperature or gas pressure, among others.

- Overload & Back-up for Distance (Overcurrent) – Overload protection requires a current transformer which simply measures the current in a circuit. There are two types of overload protection: instantaneous overcurrent and time overcurrent (TOC). Instantaneous overcurrent requires that the current exceeds a pre-determined level for the circuit breaker to operate. TOC protection operates based on a current vs time curve. Based on this curve if the measured current exceeds a given level for the preset amount of time, the circuit breaker or fuse will operate.

- Earth fault (Ground fault in the United States) – Earth fault protection again requires current transformers and senses an imbalance in a three-phase circuit. Normally the three phase currents are in balance, i.e. roughly equal in magnitude. If one or two phases become connected to earth via a low impedance path, their magnitudes will increase dramatically, as will current imbalance. If this imbalance exceeds a pre-determined value, a circuit breaker should operate.

- Distance (Impedance Relay)– Distance protection detects both voltage and current. A fault on a circuit will generally create a sag in the voltage level. If the ratio of voltage to current measured at the relay terminals, which equates to an impedance, lands within a pre-determined level the circuit breaker will operate. This is useful for reasonable length lines, lines longer than 10 miles, because its operating characteristics are based on the line characteristics. This means that when a fault appears on the line the impedance setting in the relay is compared to the apparent impedance of the line from the relay terminals to the fault. If the relay setting is determined to be below the apparent impedance it is determined that the fault is within the zone of protection. When the transmission line length is too short, less than 10 miles, distance protection becomes more difficult to coordinate. In these instances the best choice of protection is current differential protection.

- Back-up – The objective of protection is to remove only the affected portion of plant and nothing else. A circuit breaker or protection relay may fail to operate. In important systems, a failure of primary protection will usually result in the operation of back-up protection. Remote back-up protection will generally remove both the affected and unaffected items of plant to clear the fault. Local back-up protection will remove the affected items of the plant to clear the fault.

- Low-voltage networks – The low voltage network generally relies upon fuses or low-voltage circuit breakers to remove both overload and earth faults.

FAULT AND FAULT CURRENT:

Fault (technology), an abnormal condition or defect at the component, equipment, or sub-system level which may lead to a failure

In an electric power system, a **fault** is any abnormal electric current. For example, a short circuit is a fault in which current bypasses the normal load. An open-circuit fault occurs if a circuit is interrupted by some failure. In three-phase systems, a fault may involve one or more phases and ground, or may occur only between phases. In a "ground fault" or "earth fault", charge flows into the earth. The prospective short circuit current of a fault can be calculated for power systems. In power systems, protective devices detect fault conditions and operate circuit breakers and other devices to limit the loss of service due to a failure.

In a polyphase system, a fault may affect all phases equally which is a "symmetrical fault". If only some phases are affected, the resulting "asymmetrical fault" becomes more complicated to analyze due to the simplifying assumption of equal current magnitude in all phases being no longer applicable. The analysis of this type of fault is often simplified by using methods such as symmetrical components.

Design of systems to detect and interrupt power system faults is the main objective of power system protection.

TRANSIENT FAULT

A **transient fault** is a fault that is no longer present if power is disconnected for a short time and then restored. Many faults in overhead powerlines are transient in nature. When a fault occurs, equipment used for power system protection operate to isolate area of the fault. A transient fault will then clear and the power-line can be returned to service. Typical examples of transient faults include:

- momentary tree contact
- bird or other animal contact
- lightning strike
- conductor clashing

In electricity transmission and distribution systems an automatic re-close function is commonly used on overhead lines to attempt to restore power in the event of a transient fault. This functionality is not as common on underground systems as faults there are typically of a persistent nature. Transient faults may still cause damage both at the site of the original fault or elsewhere in the network as fault current is generated.

PERSISTENT FAULT

A **persistent fault** does not disappear when power is disconnected. Faults in underground power cables are most often persistent due to mechanical damage to the cable, but are sometimes transient in nature due to lightning

SYMMENTRIC FAULT

A **symmetric** or **balanced fault** affects each of the three phases equally. In transmission line faults, roughly 5% are symmetricThis is in contrast to an asymmetric fault, where the three phases are not affected equally. In practice, most faults in power systems are unbalanced. With this in mind, symmetric faults can be viewed as somewhat of an abstraction; however, as asymmetric faults are difficult to analyze, analysis of asymmetric faults is built up from a thorough understanding of symmetric faults

ASYMMENTRIC FAULT:

An **asymmetric** or **unbalanced fault** does not affect each of the three phases equally. Common types of asymmetric faults, and their causes:

- *line-to-line* - a short circuit between lines, caused by ionization of air, or when lines come into physical contact, for example due to a broken insulator.
- *line-to-ground* - a short circuit between one line and ground, very often caused by physical contact, for example due to lightning or other storm damage
- *double line-to-ground* - two lines come into contact with the ground (and each other), also commonly due to storm damage

ARCING AND BOLTED FAULT:

Where the system voltage is high enough, an electric arc may form between power system conductors and ground. Such an arc can have a relatively high impedance (compared to the normal operating levels of the system) and can be difficult to detect by simple overcurrent protection. For example, an arc of several hundred amperes on a circuit normally carrying a thousand amperes may not trip overcurrent circuit breakers but can do enormous damage to bus bars or cables before it becoems a complete short circuit. Utility, industrial, and commercial power systems have additional protection devices to detect relatively small but undesired currents escaping to ground. In residential wiring, electrical regulations may now require Arc-fault circuit interrupters on building wiring circuits, so as to detect small arcs before they cause damage or a fire.

When calculating the prospective short-circuit current in a circuit, to maximize the value, the impedance of the arc is neglected. Notionally, all the conductors are considered connected to ground as if by a metallic conductor; this is called a "bolted fault". It would be unusual in a well-designed power system to have a metallic short circuit to ground but such faults can occur by mischance. In one type of transmission line protection, a "bolted fault" is deliberately introduced to speed up operation of protective devices.

ANALYSIS:

Symmetric faults can be analyzed via the same methods as any other phenomena in power systems, and in fact many software tools exist to accomplish this type of analysis automatically (see power flow study). However, there is another method which is as accurate and is usually more instructive.

First, some simplifying assumptions are made. It is assumed that all electrical generators in the system are in phase, and operating at the nominal voltage of the system. Electric motors can also be considered to be generators, because when a fault occurs, they usually supply rather than draw power. The voltages and currents are then calculated for this*base case*.

Next, the location of the fault is considered to be supplied with a negative voltage source, equal to the voltage at that location in the base case, while all other sources are set to zero. This method makes use of the principle of superposition.

To obtain a more accurate result, these calculations should be performed separately for three separate time ranges:

- *subtransient* is first, and is associated with the largest currents
- *transient* comes between subtransient and steady-state
- *steady-state* occurs after all the transients have had time to settle

An asymmetric fault breaks the underlying assumptions used in three-phase power, namely that the load is balanced on all three phases. Consequently, it is impossible to *directly*use tools such as the one-line diagram, where only one phase is considered. However, due to the linearity of power systems, it is usual to consider the resulting voltages andcurrents as a superposition of symmetrical components, to which three-phase analysis can be applied.

In the method of symmetric components, the power system is seen as a superposition of three components:

- a *positive-sequence* component, in which the phases are in the same order as the original system, i.e., *a-b-c*
- a *negative-sequence* component, in which the phases are in the opposite order as the original system, i.e., *a-c-b*
- a *zero-sequence* component, which is not truly a three-phase system, but instead all three phases are in phase with each other.

To determine the currents resulting from an asymmetrical fault, one must first know the per-unit zero-, positive-, and negative-sequence impedances of the transmission lines, generators, and transformers involved. Three separate circuits are then constructed using these impedances. The individual circuits are then connected together in a particular arrangement that depends upon the type of fault being studied (this can be found in most power systems textbooks). Once the sequence circuits are properly connected, the network can then be analyzed using classical circuit analysis techniques. The solution results in voltages and currents that exist as symmetrical components; these must be transformed back into phase values by using the **A** matrix.

Analysis of the prospective short-circuit current is required for selection of protective devices such as fuses and circuit breakers. If a circuit is to be properly protected, the fault current must be high enough to operate the protective device within as short a time as possible; also the protective device must be able to withstand the fault current and extinguish any resulting arcs without itself being destroyed or sustaining the arc for any significant length of time.

The magnitude of fault currents differ widely depending on the type of earthing system used, the installation's supply type and earthing system, and its proximity to the supply. For example, for a domestic UK 230 V, 60 A TN-S or USA 120 V/240 V supply, fault currents may be a few thousand amperes. Large low-voltage networks with multiple sources may have fault levels of 300,000 amperes. A high-resistance-grounded system may restrict line to ground fault current to only 5 amperes. Prior to selecting protective devices, prospective fault current must be measured reliably at the origin of the installation and at the furthest point of each circuit, and this information applied properly to the application of the circuits.

DETECTING AND LOCATING FAULT:

Locating faults in a cable system can be done either with the circuit de-energized, or in some cases, with the circuit under power. Fault location techniques can be broadly divided into terminal methods, which use voltages and currents measured at the ends of the cable, and tracer methods, which require inspection along the length of the cable. Terminal methods can be used to locate the general area of the fault, to expedite tracing on a long or buried cable.[2]

In very simple wiring systems, the fault location is often found through inspection of the wires. In complex wiring systems (for example, aircraft wiring) where the wires may be hidden, wiring faults are located with a Time-domain reflectometer.[3] The time domain reflectometer sends a pulse down the wire and then analyzes the returning reflected pulse to identify faults within the electrical wire.

In historic submarine telegraph cables, sensitive galvanometers were used to measure fault currents; by testing at both ends of a faulted cable, the fault location could be isolated to within a few miles, which allowed the cable to be grappled up and repaired. The *Murray loop* and the *Varley loop* were two types of connections for locating faults in cables

Sometimes an insulation fault in a power cable will not show up at lower voltages. A "thumper" test set applies a high-energy, high-voltage pulse to the cable. Fault location is done by listening for the sound of the discharge at the fault. While this test contributes to damage at the cable site, it is practical because the faulted location would have to be re-insulated when found in any case.[4]

In a high resistance grounded distribution system, a feeder may develop a fault to ground but the system continues in operation. The faulted, but energized, feeder can be found with a ring-type current transformer collecting all the phase wires of the circuit; only the circuit containing a fault to ground will show a net unbalanced current. To make the ground fault current easier to detect, the grounding resistor of the system may be switched between two values so that the fault current pulses.

RELAY:

A **relay** is an electrically operated switch. Many relays use an electromagnet to operate a switching mechanism mechanically, but other operating principles are also used. Relays are used where it is necessary to control a circuit by a low-power signal (with complete electrical isolation between control and controlled circuits), or where several circuits must be controlled by one signal. The first relays were used in long distance telegraph circuits, repeating the signal coming in from one circuit and re-transmitting it to another. Relays were used extensively in telephone exchanges and early computers to perform logical operations.

A type of relay that can handle the high power required to directly control an electric motor or other loads is called a contactor. Solid-state relays control power circuits with no moving parts, instead using a semiconductor device to perform switching. Relays with calibrated operating characteristics and sometimes multiple operating coils are used to protect electrical circuits from overload or faults; in modern electric power systems these functions are performed by digital instruments still called "protective relays"

BASIC DESIGN AND OPERATION

A simple electromagnetic relay consists of a coil of wire wrapped around a soft iron core, an iron yoke which provides a low reluctancepath for magnetic flux, a movable iron armature, and one or more sets of contacts (there are two in the relay pictured). The armature is hinged to the yoke and mechanically linked to one or more sets of moving contacts. It is held in place by a spring so that when the relay is de-energized there is an air gap in the magnetic circuit. In this condition, one of the two sets of contacts in the relay pictured is closed, and the other set is open. Other relays may have more or fewer sets of contacts depending on their function. The relay in the picture also has a wire connecting the armature to the yoke. This ensures continuity of the circuit between the moving contacts on the armature, and the circuit track on the printed circuit board (PCB) via the yoke, which is soldered to the PCB.

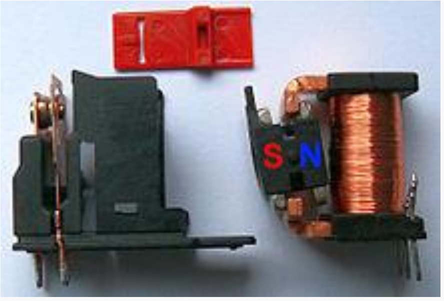
When an electric current is passed through the coil it generates a magnetic field that activates the armature, and the consequent movement of the movable contact(s) either makes or breaks (depending upon construction) a connection with a fixed contact. If the set of contacts was closed when the relay was de-energized, then the movement opens the contacts and breaks the connection, and vice versa if the contacts were open. When the current to the coil is switched off, the armature is returned by a force, approximately half as strong as the magnetic force, to its relaxed position. Usually this force is provided by a spring, but gravity is also used commonly in industrial motor starters. Most relays are manufactured to operate quickly. In a low-voltage application this reduces noise; in a high voltage or current application it reduces arcing.

When the coil is energized with direct current, a diode is often placed across the coil to dissipate the energy from the collapsing magnetic field at deactivation, which would otherwise generate a voltage spike dangerous to semiconductor circuit components. Some automotive relays include a diode inside the relay case. Alternatively, a contact protection network consisting of a capacitor and resistor in series (snubber circuit) may absorb the surge. If the coil is designed to be energized with alternating current (AC), a small copper "shading ring" can be crimped to the end of the solenoid, creating a small out-of-phase current which increases the minimum pull on the armature during the AC cycle.

A solid-state relay uses a thyristor or other solid-state switching device, activated by the control signal, to switch the controlled load, instead of a solenoid. An optocoupler (a light-emitting diode (LED) coupled with a photo transistor) can be used to isolate control and controlled circuits.

TYPES :

Latching relay



Latching relay with permanent magnet

A *latching relay* has two relaxed states (bistable). These are also called "impulse", "keep", or "stay" 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 remanent 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 one coil consumes power only for an instant, while it is being switched, and the relay contacts retain this setting across a power outage. A remanent core latching relay requires a current pulse of opposite polarity to make it change state.

A stepping relay is a specialized kind of multi-way latching relay designed for early automatic telephone exchanges.

An earth leakage circuit breaker includes a specialized latching relay.

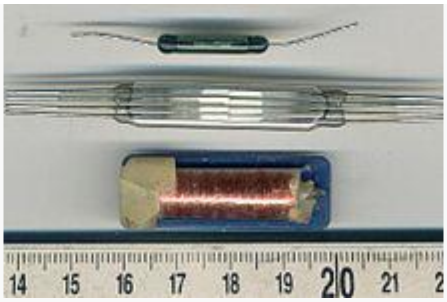
Very early computers often stored bits in a magnetically latching relay, such as ferreed or the later memreed in the 1ESS switch.

Some early computers used ordinary relays as a kind of latch -- they store bits in ordinary wire spring relays or reed relays by feeding an output wire back as an input, resulting in a feedback loop or sequential circuit. Such an electrically-latching relay requires continuous power to maintain state, unlike magnetically latching relays or mechanically racheting relays.

In computer memories, latching relays and other relays were replaced by delay line memory, which in turn was replaced by a series of ever-faster and ever-smaller memory technologies.

REED RELAY

A reed relay is a reed switch enclosed in a solenoid. The switch has a set of contacts inside an evacuated or inert gas-filled glass tube which protects the contacts against atmospheric corrosion; the contacts are made of magnetic material that makes them move under the influence of the field of the enclosing solenoid. Reed relays can switch faster than larger relays, require very little power from the control circuit. However they have relatively low switching current and voltage ratings. Though rare, the reeds can become magnetized over time, which makes them stick 'on' even when no current is present; changing the orientation of the reeds with respect to the solenoid's magnetic field can resolve this problem.



Top, middle: reed switches, bottom: reed relay

MERCURY-WETTED RELAY

A **mercury-wetted reed 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) where the mercury reduces the contact resistance and associated voltage drop, for low-current signals where surface contamination may make for a poor contact, or for high-speed applications where the mercury eliminates 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 now rarely used.

POLARIZED RELAY

A **polarized relay** placed the armature between the poles of a permanent magnet to increase sensitivity. Polarized relays were used in middle 20th Century telephone exchanges to detect faint pulses and correct telegraphic distortion. The poles were on screws, so a technician could first adjust them for maximum sensitivity and then apply a bias spring to set the critical current that would operate the relay.

- **External links**
  - Schematic diagram of a polarized relay used in a teletype machine.

MACHINE TOOL RELAY

A **machine tool relay** is a type standardized for industrial control of machine tools, transfer machines, and other sequential 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 (PLC) mostly displaced the machine tool relay from sequential control applications.

A relay allows circuits to be switched by electrical equipment: for example, a timer circuit with a relay could switch power at a preset time. For many years relays were the standard method of controlling industrial electronic systems. A number of relays could be used together to carry out complex functions (relay logic). The principle of relay logic is based on relays which energize and de-energize associated contacts. Relay logic is the predecessor of ladder logic, which is commonly used in programmable logic controllers.

RATCHET RELAY

This is again a clapper type relay which does not need continuous current through its coil to retain its operation. A ratchet holds the contacts closed after the coil is momentarily energized. A second impulse, in the same or a separate coil, releases the contacts.

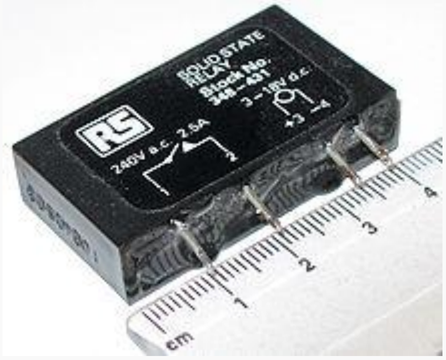
COAXIAL RELAY

Where radio transmitters and receivers share a common antenna, often a coaxial relay is used as a TR (transmit-receive) relay, which switches the antenna from the receiver to the transmitter. This protects the receiver from the high power of the transmitter. Such relays are often used in transceivers which combine transmitter and receiver in one unit. The relay contacts are designed not to reflect any radio frequency power back toward the source, and to provide very high isolation between receiver and transmitter terminals. Thecharacteristic impedance of the relay is matched to the transmission line impedance of the system, for example, 50 ohms.[2]

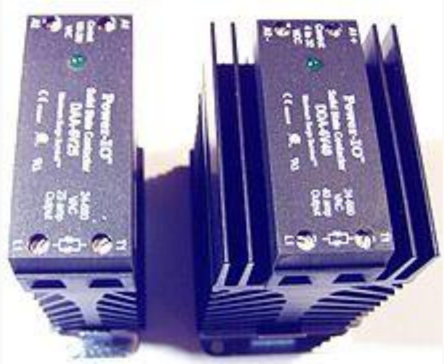
CONTACTOR RELAY

A **contactor** is a very heavy-duty relay used for switching electric motors and lighting loads, although contactors are not generally called relays. Continuous current ratings for common contactors range from 10 amps to several hundred amps. High-current contacts are made with alloys containing silver. The unavoidable arcing causes the contacts to oxidize; however, silver oxide is still a good conductor.[3] Such devices are often used for motor starters. A motor starter is a contactor with overload protection devices attached. Contactor relays can be extremely loud to operate, making them unfit for use where noise is a chief concern.

SOLID-STATE RELAY



Solid state relay with no moving parts



25 A or 40 A solid state contactors

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. Every solid-state device has a small voltage drop across it. This voltage drop limits the amount of current a given SSR can handle. The minimum voltage drop for such a relay is a function of the material used to make the device. Solid-state relays rated to handle as much as 1,200 amperes have become commercially available. Compared to electromagnetic relays, they may be falsely triggered by transients.

SOLID STATE CONTACTOR RELAY

A **solid state contactor** is a heavy-duty solid state relay, including the necessary heat sink, used where frequent on/off cycles are required, such as with electric heaters, small electric motors, and lighting loads. There are no moving parts to wear out and there is no contact bounce due to vibration. They are activated by AC control signals or DC control signals from Programmable logic controller(PLCs), PCs, Transistor-transistor logic (TTL) sources, or other microprocessor and microcontroller controls.

BUCHHOLZ RELAY

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.

FORCED-GUIDED CONTACTS RELAY

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".

OVERLOAD PROTECTION RELAYS

Electric motors need overcurrent protection to prevent damage from over-loading the motor, or to protect against short circuits in connecting cables or internal faults in the motor windings.[4] The overload sensing devices are a form of heat operated relay where a coil heats a bimetallic 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 excess current in the load, the coil is de-energized.

This thermal protection operates relatively slowly allowing the motor to draw higher starting currents before the protection relay will trip. Where the overload relay is exposed to the same environment as the motor, a useful though crude compensation for motor ambient temperature is provided.

The other common overload protection system uses an electromagnet coil in series with the motor circuit that directly operates contacts. This is similar to a control relay but requires a rather high fault current to operate the contacts. To prevent short over current spikes from causing nuisance triggering the armature movement is damped with a dashpot. The thermal and magnetic overload detections are typically used together in a motor protection relay.

Electronic overload protection relays measure motor current and can estimate motor winding temperature using a "thermal model" of the motor armature system that can be set to provide more accurate motor protection. Some motor protection relays include temperature detector inputs for direct measurement from a thermocouple or resistance thermometersensor embedded in the winding.

POLE AND THROW:

Since relays are switches, the terminology applied to switches is also applied to relays; a relay switches one or more *poles*, each of whose contacts can be *thrown* by energizing the coil in one of three ways:

- Normally-open (**NO**) contacts connect the circuit when the relay is activated; the circuit is disconnected when the relay is inactive. It is also called a **Form A** contact or "make" contact. **NO** contacts may also be distinguished as "early-make" or **NOEM**, which means that the contacts close before the button or switch is fully engaged.
- Normally-closed (**NC**) contacts disconnect the circuit when the relay is activated; the circuit is connected when the relay is inactive. It is also called a **Form B** contact or "break" contact. **NC** contacts may also be distinguished as "late-break" or **NCLB**, which means that the contacts stay closed until the button or switch is fully disengaged.
- Change-over (**CO**), or double-throw (**DT**), contacts control two circuits: one normally-open contact and one normally-closed contact with a common terminal. It is also called a **Form C** contact or "transfer" contact ("break before make"). If this type of contact utilizes a "make before break" functionality, then it is called a **Form D** contact.

The following designations are commonly encountered:

- **SPST** – Single Pole Single Throw. These have two terminals which can be connected or disconnected. Including two for the coil, such a relay has four terminals in total. It is ambiguous whether the pole is normally open or normally closed. The terminology "SPNO" and "SPNC" is sometimes used to resolve the ambiguity.
- **SPDT** – Single Pole Double Throw. A common terminal connects to either of two others. Including two for the coil, such a relay has five terminals in total.
- **DPST** – Double Pole Single Throw. These have two pairs of terminals. Equivalent to two SPST switches or relays actuated by a single coil. Including two for the coil, such a relay has six terminals in total. The poles may be Form A or Form B (or one of each).
- **DPDT** – Double Pole Double Throw. These have two rows of change-over terminals. Equivalent to two SPDT switches or relays actuated by a single coil. Such a relay has eight terminals, including the coil.

The "S" or "D" may be replaced with a number, indicating multiple switches connected to a single actuator. For example 4PDT indicates a four pole double throw relay (with 12 terminals).

EN 50005 are among applicable standards for relay terminal numbering; a typical EN 50005-compliant SPDT relay's terminals would be numbered 11, 12, 14, A1 and A2 for the C, NC, NO, and coil connections, respectively.

APPLICATION

Relays are used for:

- Amplifying a digital signal, switching a large amount of power with a small operating power. Some special cases are:
    - A telegraph relay, repeating a weak signal received at the end of a long wire

  - Controlling a high-voltage circuit with a low-voltage signal, as in some types of modems or audio amplifiers,
  - Controlling a high-current circuit with a low-current signal, as in the starter solenoid of an automobile,
- Detecting and isolating faults on transmission and distribution lines by opening and closing circuit breakers (protection relays),

A DPDT AC coil relay with "ice cube" packaging

- Isolating 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 to conserve energy,
- Logic functions. For example, the boolean AND function is realised by connecting normally open relay contacts in series, the OR function by connecting normally open 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 normally closed contacts. The Ladder programming language is often used for designing relay logicnetworks.
  - The application of Boolean Algebra to relay circuit design was formalized by Claude Shannon in A Symbolic Analysis of Relay and Switching Circuits
  - Early computing. Before vacuum tubes and transistors, relays were used as logical elements in digital computers. See electro-mechanical computers such as ARRA (computer), Harvard Mark II, Zuse Z2, and Zuse Z3.
  - Safety-critical logic. Because relays are much more resistant than semiconductors to nuclear radiation, they are widely used in safety-critical logic, such as the control panels of radioactive waste-handling machinery.
- 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.

- Vehicle battery isolation. A 12v relay is often used to isolate any second battery in cars, 4WDs, RVs and boats.
- Switching to a standby power supply.

LIGHTNING :

Lightning is a massive electrostatic discharge between electrically charged regions within clouds, or between a cloud and the Earth's surface. The charged regions within the atmosphere temporarily equalize themselves through a lightning **flash**, commonly referred to as a *strike* if it hits an object on the ground. There are three primary types; from a cloud to itself (intra-cloud or IC); from one cloud to another cloud (CC) and finally between a cloud and the ground (CG). Although lightning is always accompanied by the sound of thunder, distant lightning may be seen but be too far away for the thunder to be heard.

Lightning occurs approximately 40–50 times a second worldwide, resulting in nearly 1.4 billion flashes per year.[1]

Many factors affect the frequency, distribution, strength, and physical properties of a "typical" lightning flash to a particular region of the world. These factors include ground elevation, latitude, prevailing wind currents, relative humidity, proximity to warm and cold bodies of water, etc. To a certain degree, the ratio between IC, CC and CG lightning may also vary by season in middle latitudes.

Because human beings are terrestrial and most of their possessions are on the Earth, where lightning can damage or destroy them, CG lightning is the most studied and best understood of the three types, even though IC and CC are more common. Lightning's unpredictability limits a complete explanation of how or why it occurs, even after hundreds of years of scientific investigation. A typical cloud to ground lightning flash culminates in the formation of an electrically conducting plasma channel through the air in excess of 5 km (3 mi). The actual **discharge** is the final stage of a very complex process.[2] A typicalthunderstorm has three or more *strikes* to the Earth per minute at its peak.

Lightning primarily occurs when warm air is mixed with colder air masses resulting in atmospheric disturbances necessary for polarizing the atmosphere. However, it can also occur during dust storms, forest fires, tornadoes, volcanic eruptions, and even in the cold of winter, where the lightning is known as thundersnow.[4][5] Hurricanes typically generate some lightning, mainly in the rainbands as much as 160 km (100 mi) from the center.[6][7][8]

The science of lightning is called *fulminology*.[9] The fear of lightning is called astraphobia.

A *lightning protection system* is designed to protect a structure from damage due to lightning strikes by intercepting such strikes and safely passing their extremely high currents to ground. A lightning protection system includes a network of air terminals, bonding conductors, and ground electrodesdesigned to provide a low impedance path to ground for potential strikes.

Lightning protection systems are used to prevent or lessen damage to structures done by lightning strikes. Lightning protection systems mitigate the fire hazard which lightning strikes pose to structures. A lightning protection system provides a low-impedance path for the lightning current to lessen the heating effect of current flowing through flammable structural materials. If lightning travels through porous and water-saturated materials, these parts of a building may literally explode if their water content is flashed to steam by heat produced from lightning current.

Because of the high energy and current levels associated with lightning (currents can be in excess of 150,000 amps), and the very rapid rise time of a lightning strike, no lightning protection system can guarantee absolute safety from lightning. Lightning current will divide to follow every conductive path to ground, and even the divided current can cause damage. Secondary "side-flashes" can be enough to ignite a fire, blow apart brick, stone, or concrete, or injure occupants within a structure or building. However, the benefits of basic lightning protection systems have been evident for well over a century.[13]

Laboratory-scale measurements of the effects of [any lightning investigation research] do not scale to applications involving natural lightning.[14] Field applications have mainly been derived from trial and error based on the best intended laboratory research of a highly complex and variable phenomena.

The parts of a lightning protection system are air terminals (lightning rods or strike termination devices), bonding conductors, ground terminals (ground or "earthing" rods, plates, or mesh), and all of the connectors and supports to complete the system. The air terminals are typically arranged at or along the upper points of a roof structure, and are electrically bonded together by bonding conductors (called "down conductors" or "downleads"), which are connected by the most direct route to one or more grounding or earthing terminals.[15] Connections to the earth electrodes must not only have low resistance, but must have low self-inductance.

An example of a structure vulnerable to lightning is a wooden barn. When lightning strikes the barn, the wooden structure and its contents, may be ignited by the heat generated by lightning current conducted through parts of the structure. A basic lightning protection system would provide a conductive path between an air terminal and earth, so that most of the lightning's current will follow the path of the lightning protection system, with substantially less current traveling through flammable materials.

A controversy over the assortment of operation theories dates back to the 18th century, when Franklin himself stated that his lightning protectors protected buildings by dissipating electric charge. He later retracted the statement, stating that the device's exact mode of operation was something of a mystery at that point.

Originally, scientists believed that such a lightning protection system of air terminals and "downleads" directed the current of the lightning down into the earth to be "dissipated". However, high speed photography has clearly demonstrated that lightning is actually composed of both a cloud component and an oppositely charged ground component. During "cloud-to-ground" lightning, these oppositely charged components usually "meet" somewhere in the atmosphere well above the earth to equalize previously unbalanced charges. The heat generated as this electrical current flows through flammable materials is the hazard which lightning protection systems attempt to mitigate by providing a low-resistance path for the lightning circuit. No lightning protection system can be relied upon to "contain" or "control" lightning completely (nor thus far, to prevent lightning strikes), but they do seem to help immensely on most occasions of lightning strikes.

Steel framed structures can bond the structural members to earth to provide lighting protection. A metal flagpole with its foundation in the earth is its own extremely simple lightning protection system. However, the flag(s) flying from the pole during a lightning strike may be completely incinerated.

The majority of lightning protection systems in use today are of the traditional Franklin design. The fundamental principle used in Franklin-type lightning protections systems is to provide a sufficiently low impedance path for the lightning to travel through to reach ground without damaging the buildingThis is accomplished by surrounding the building in a kind of Faraday cage. A system of lightning protection conductors and lightning rods are installed on the roof of the building to intercept any lightning before it strikes the building.

TYPES:

There are three primary types of lightning, defined by what is at the "ends" of a flash channel. They are Intracloud (IC), which occurs within a single thundercloud unit; Cloud to Cloud (CC), which starts and ends between two different "functional" thundercloud units; and Cloud to Ground, that primarily originates in the thundercloud and terminates on an Earth surface, but may also occur in the reverse direction aka Ground to Cloud. There are variations of each type, such as "positive" versus "negative" CG flashes, that have different physical characteristics common to each which can be measured. Different common names used to describe a particular lightning event may be attributed to the same or different events.

CLOUD TO GROUND (CG)

Cloud-to-ground is the best known and third most common type of lightning. It is the best understood of all forms because it allows for scientific study given it terminates on a physical object, namely the Earth, and lends itself to being measured by instruments. Of the three primary types of lightning, it poses the greatest threat to life and property since it terminates or "strikes" the Earth. Cloud-to-ground (CG) lightning is a lightning discharge between a thundercloud and the ground. It is usually negative in polarity and is usually initiated by a stepped leader moving down from the cloud.

- **Ground-to-cloud** lightning is an artificially initiated, or *triggered*, category of CG flashes. Triggered lightning originates from tall, positively-charged structures on the ground, such as towers on mountains, that have been inductively charged by the negative cloud layer above

- **Positive lightning**

CG lightning can occur with both positive and negative polarity. The polarity refers to the polarity of the charge in the region that originated the lightning leaders. An average bolt of negative lightning carries an electric current of 30,000 amperes (30 kA), and transfers 15 coulombs of electric charge and 500megajoules of energy. Large bolts of lightning can carry up to 120 kA and 350 coulombs.

Anvil-to-ground *(Bolt from the blue)*lightning strike.

Unlike the far more common "negative" lightning, positive lightning originates from the positively charged top of the clouds (generallyanvil clouds) rather than the lower portion of the storm. Leaders form in the anvil of the cumulonimbus and may travel horizontally for several miles before veering towards the ground. A positive lightning bolt can strike anywhere within several miles of the anvil of the thunderstorm, often in areas experiencing clear or only slightly cloudy skies; they are also known as "bolts from the blue" for this reason. Positive lightning typically makes up less than 5% of all lightning strikes.

Because of the much greater distance to ground, the positively-charged region can develop considerably larger levels of charge levels and voltages than the negative charge regions in the lower part of the cloud. Positive lightning bolts are considerably hotter and longer than negative lightning. They can develop six to ten times the amount of charge and voltage of a negative bolt and the discharge current may last ten times longer. A bolt of positive lightning may carry an electric current of 300 kA and the potential at the top of the cloud may exceed a billion volts — about 10 times that of negative lightning. During a positive lightning strike, huge quantities of ELF and VLF radio waves are generated.

As a result of their greater power, as well as lack of warning, positive lightning strikes are considerably more dangerous. At the present time, aircraft are not designed to withstand such strikes, since their existence was unknown at the time standards were set, and the dangers unappreciated until the destruction of a glider in 1999. The standard in force at the time of the crash, Advisory Circular AC 20-53A, was replaced by Advisory Circular AC 20-53B in 2006, however it is unclear whether adequate protection against positive lightning was incorporated.

Positive lightning is also now believed to have been responsible for the 1963 in-flight explosion and subsequent crash of Pan Am Flight 214, a Boeing 707.[Due to the dangers of lightning, aircraft operating in U.S. airspace have been required to have static discharge wicks to reduce the possibility of attracting a lightning strike, as well as to mitigate radio interference due to static buildup through friction with the air, but these measures may be insufficient for positive lightning

Positive lightning has also been shown to trigger the occurrence of upper atmosphere lightning between the tops of clouds and the ionosphere. Positive lightning tends to occur more frequently in winter storms, as with thundersnow, and towards the end of a thunderstorm.

Cloud to cloud (CC) and Intra-Cloud (IC)

Multiple paths of cloud-to-cloud lightning,Swifts Creek, Australia.

Cloud-to-cloud lightning, Victoria, Australia.

Lightning discharges may occur between areas of cloud without contacting the ground. When it occurs between two separate clouds it is known as *inter-cloud lightning*, and when it occurs between areas of differing electric potential within a single cloud it is known as *intra-cloud lightning*. Intra-cloud lightning is the most frequently occurring type.[45]

Intra-cloud lightning most commonly occurs between the upper anvil portion and lower reaches of a given thunderstorm. This lightning can sometimes be observed at great distances at night as so-called "heat lightning". In such instances, the observer may see only a flash of light without hearing any thunder. The "heat" portion of the term is a folk association between locally experienced warmth and the distant lightning flashes.

Another terminology used for cloud–cloud or cloud–cloud–ground lightning is "Anvil Crawler", due to the habit of the charge typically originating from beneath or within the anvil and scrambling through the upper cloud layers of a thunderstorm, normally generating multiple branch strokes which are dramatic to witness. These are usually seen as a thunderstorm passes over the observer or begins to decay. The most vivid crawler behavior occurs in well developed thunderstorms that feature extensive rear anvil shearing.

Observational variations

Ball lightning may be an atmospheric electrical phenomenon, the physical nature of which is still controversial. The term refers to reports of luminous, usually spherical objects which vary from pea-sized to several meters in diameter.[46] It is sometimes associated with thunderstorms, but unlike lightning flashes, which last only a fraction of a second, ball lightning reportedly lasts many seconds. Ball lightning has been described by eyewitnesses but rarely recorded by meteorologists.[47] Scientific data on natural ball lightning is scarce owing to its infrequency and unpredictability. The presumption of its existence is based on reported public sightings, and has therefore produced somewhat inconsistent findings.

Bead lightning is a name given to the decaying stage of a lightning channel in which the luminosity of the channel breaks up intosegments. Nearly every lightning discharge will exhibit *beading* as the channel cools immediately after a return stroke, sometimes referred to as the lightning's 'bead-out' stage. 'Bead lightning' is more properly a stage of a normal lightning discharge rather than a type of lightning in itself.

Beading of a lightning channel is usually a small-scale feature, and therefore is often only apparent when the observer/camera is close to the lightning.

Dry lightning is a term in Australia, Canada and the United States for lightning that occurs with no precipitation at the surface. This type of lightning is the most common natural cause of wildfires.[49] Pyrocumulus clouds produce lightning for the same reason that it is produced by cumulonimbus clouds.

Main article: Dry lightning

Forked lightning is a name, not in formal usage, for cloud-to-ground lightning that exhibits branching of its path.

Heat lightning is a common name for a lightning flash that appears to produce no discernable thunder because it occurs too far away for the thunder to be heard. The sound waves dissipate before they reach the observer

Ribbon lightning occurs in thunderstorms with high cross winds and multiple return strokes. The wind will blow each successive return stroke slightly to one side of the previous return stroke, causing a ribbon effect

Rocket lightning is a form of cloud discharge, generally horizontal and at cloud base, with a luminous channel appearing to advance through the air with visually resolvable speed, often intermittently.

Sheet lightning is an informal name for cloud-to-cloud lightning that exhibits a diffuse brightening of the surface of a cloud, caused by the actual discharge path being hidden or too far away. The lightning itself cannot be seen by the spectator, so it appears as only a flash, or a sheet of light. The lightning may be too far away to discern individual flashes.

Staccato lightning is a cloud-to-ground lightning (CG) strike which is a short-duration stroke that (often but not always) appears as a single very bright flash and often has considerable branching.] These are often found in the visual vault area near the mesocyclone of rotating thunderstorms and coincides with intensification of thunderstormupdrafts. A similar cloud-to-cloud strike consisting of a brief flash over a small area, appearing like a blip, also occurs in a similar area of rotating updrafts

Lightning arrester

In telegraphy and telephony, a lightning arrester is placed where wires enter a structure, preventing damage to electronic instruments within and ensuring the safety of individuals near them. Lightning arresters, also called surge protectors, are devices that are connected between each electrical conductor in a power or communications system, and the Earth. They prevent the flow of the normal power or signal currents to ground, but provide a path over which high-voltage lightning current flows, bypassing the connected equipment. Their purpose is to limit the rise in voltage when a communications or power line is struck by lightning or is near to a lightning strike.

Protection of electric distribution systems

In overhead electric transmission (high-tension) systems, one or two lighter gauge conductors may be mounted to the top of the pylons, poles, or towers not specifically used to send electricity through the grid. These conductors, often referred to "static", "pilot" or "shield" wires are designed to be the point of lightning termination instead of the high-voltage lines themselves. These conductors are intended to protect the primary power conductors from lightning strikes.

These conductors are bonded to earth either through the metal structure of a pole or tower, or by additional ground electrodes installed at regular intervals along the line. As a general rule, overhead power lines with voltages below 50 kV do not have a "static" conductor, but most lines carrying more than 50 kV do. The ground conductor cable may also support fibre optic cables for data transmission.

In some instances, these conductors are insulated from direct bonding with earth and may be used as low voltage communication lines. If the voltage exceeds a certain threshold, such as during a lightning termination to the conductor, it "jumps" the insulators and passes to earth.

Protection of electrical substations is as varied as lightning rods themselves, and is often proprietary to the electric company.

Lightning protection of mast radiators

Radio mast radiators may be insulated from the ground by a gap at the base. When lightning hits the mast, it jumps this gap. A small inductivity in the feed line between the mast and the tuning unit (usually one winding) limits the voltage increase, protecting the transmitter from dangerously high voltages. The transmitter must be equipped with a device to monitor the antenna's electrical properties. This is very important, as a charge could remain after a lightning strike, damaging the gap or the insulators. The monitoring device switches off the transmitter when the antenna shows incorrect behavior, e.g. as a result of undesired electrical charge. When the transmitter is switched off, these charges dissipate. The monitoring device makes several attempts to switch back on. If after several attempts the antenna continues to show improper behavior, possibly as result of structural damage, the transmitter remains switched off.

Lightning conductors and grounding precautions

Ideally, the underground part of the assembly should reside in an area of high ground conductivity. If the underground cable is able to resist corrosion well, it can be covered in saltto improve its electrical connection with the ground. While the electrical resistance of the lightning conductor between the air terminal and the Earth is concerning, the inductive reactance of the conductor could be more important. For this reason, the down conductor route is kept short, and any curves have a large radius. If these measures are not taken, lightning current may arc over an obstruction, resistive or reactive, that it encounters in the conductor. At the very least, the arc current will damage the lightning conductor and can easily find another conductive path, such as building wiring or plumbing, and cause fires or other disasters. Grounding systems without low resistivity to the ground can still be effective in protecting a structure from lightning damage. When ground soil has poor conductivity, is very shallow, or non-existent, a grounding system can be augmented by adding ground rods, counterpoise (ground ring) conductor, cable radials projecting away from the building, or a concrete building's reinforcing bars can be used for a ground conductor (Ufer Ground). These additions, while still not reducing the resistance of the system in some instances, will allow the [dispersion] of the lightning into the earth without damage to the structure.[18]

Additional precautions must be taken to prevent side-flashes between conductive objects on or in the structure and the lightning protection system. The surge of lightning current through a lightning protection conductor will create a voltage difference between it and any conductive objects that are near it. This voltage difference can be large enough to cause a dangerous side-flash (spark) between the two that can cause significant damage, especially on structures housing flammable or explosive materials. The most effective way to prevent this potential damage is to ensure the electrical continuity between the lightning protection system and any objects susceptible to a side-flash. Effective bonding will allow the voltage potential of the two objects to rise and fall in tandem, thereby eliminating any risk of a side-flash

Lightning protection system design

Considerable material is used to make up lightning protection systems, so it is prudent to consider carefully where an air terminal will provide the greatest protection. Historical understanding of lightning, from statements made by Ben Franklin, assumed that each *lightning rod* protected a cone of 45 degrees.[20] This has been found to be unsatisfactory for protecting taller structures, as it is possible for lightning to strike the side of a building.

A modeling system based on a better understanding of the termination targeting of lightning, called the Rolling Sphere Method, was developed by Dr Tibor Horváth. It has become the standard by which traditional Franklin Rod systems are installed. To understand this requires knowledge of how lightning 'moves'. As the step leader of a lightning bolt jumps toward the ground, it steps toward the grounded objects nearest its path. The maximum distance that each step may travel is called the *critical distance* and is proportional to the electrical current. Objects are likely to be struck if they are nearer to the leader than this critical distance. It is standard practice to approximate the sphere's radius as 46 m near the ground.

An object outside the critical distance is unlikely to be struck by the leader if there is a solidly grounded object within the critical distance. Locations that are considered safe from lightning can be determined by imagining a leader's potential paths as a sphere that travels from the cloud to the ground. For lightning protection, it suffices to consider all possible spheres as they touch potential strike points. To determine strike points, consider a sphere rolling over the terrain. At each point, we are simulating a potential leader position. Lightning is most likely to strike where the sphere touches the ground. Points that the sphere cannot roll across and touch are safest from lightning. Lightning protectors should be placed where they will prevent the sphere from touching a structure. A weak point in most lightning diversion systems is in transporting the captured discharge from the lightning rod to the ground, though.[22] Lightning rods are typically installed around the perimeter of flat roofs, or along the peaks of sloped roofs at intervals of 6.1 m or 7.6 m, depending on the height of the rod.[23] When a flat roof has dimensions greater than 15 m by 15 m, additional air terminals will be installed in the middle of the roof at intervals of 15 m or less in a rectangular grid pattern.

Should a lightning rod have a point?

Pointed lightning rod on a building

This was a controversy as early as the 18th century. In the midst of political confrontation between Britain and its American colonies, British scientists maintained that a lightning rod should have a ball on its end. American scientists maintained that there should be a point. As of 2003, the controversy had not been completely resolved. It is difficult to resolve the controversy because proper controlled experiments are nearly impossible in such work; in spite of the work of Moore, et al. [described below] most lightning rods seen on buildings have sharp points. Work performed by Charles B. Moore, et al in 2000 has helped this issue, finding that moderately rounded or blunt-tipped lightning rods act as marginally better strike receptors. [described below] As a result, round-tipped rods are installed the majority of the time on new systems in the United States. To quote:

Calculations of the relative strengths of the electric fields above similarly exposed sharp and blunt rods show that while the fields are much stronger at the tip of a sharp rod prior to any emissions, they decrease more rapidly with distance. As a result, at a few centimeters above the tip of a 20-mm-diameter blunt rod, the strength of the field is greater than over an otherwise similar, sharper rod of the same height. Since the field strength at the tip of a sharpened rod tends to be limited by the easy formation of ions in the surrounding air, the field strengths over blunt rods can be much stronger than those at

distances greater than 1 cm over sharper ones.
The results of this study suggest that moderately blunt metal rods (with tip height to tip radius of curvature ratios of about 680:1) are better lightning strike receptors than sharper rods or very blunt ones.

In addition, the height of the lightning protector relative to the structure to be protected and the Earth itself will have an effect.

Charge Transfer theory

The Charge Transfer theory states that a lightning strike to a protected structure can be prevented by reducing the electrical potential between the protected structure and the thundercloud. This is done by transferring electric charge (such as from the nearby Earth to the sky or vice versa). Transferring electric charge from the Earth to the sky is done by installing engineered products composed of many points above the structure. It is noted that pointed objects will indeed transfer charge to the surrounding atmosphere and that a considerable electric current can be measured through the conductors as ionization occurs at the point when a magnetic field is present, such as happens when thunderclouds are overhead.

The National Fire Protection Association, NFPA, does not currently endorse a device that can prevent or reduce lightning strikes. The NFPA Standards Council, following a request for a project to address Dissipation Array[tm] Systems and Charge Transfer Systems, denied the request to begin forming standards on such technology (though the Council did not foreclose on future standards development after reliable sources demonstrating the validity of the basic technology and science were submitted).[33]

Early streamer emission (ESE) theory

ESE lightning rod mounted at the Monastery of St. Nicholas Anapausas (Μονή του Αγίου Νικολάου),Meteora, Greece

The controversial[34] theory of early streamer emission proposes that if a lightning rod has a mechanism producing ionization near its tip, then its lightning capture area is greatly increased. At first, small quantities of radioactive isotopes (Radium-226 or Americium-241) were used as sources of ionization[35] between 1930 and 1980, later replaced with various electrical and electronic devices. According to an early patent, since most lightning protectors' ground potentials are elevated, the path distance from the source to the elevated ground point will be shorter, creating a stronger field (measured in volts per unit distance) and that structure will be more prone to ionization and breakdown

AFNOR, the French national standardization body, issued a standard, NF C 17-102, covering this technology. The NFPA also investigated the subject and there was a proposal to issue a similar standard in the USA. Initially, an NFPA independent third party panel stated that "the [Early Streamer Emission] lightning protection technology appears to be technically sound" and that there was an "adequate theoretical basis for the [Early Streamer Emission] air terminal concept and design from a physical viewpoint". (Bryan, 1999[37]) The same panel also concluded that "the recommended [NFPA 781 standard] lightning protection system has never been scientifically or technically validated and the Franklin rod air terminals have not been validated in field tests under thunderstorm conditions."

In response, the American Geophysical Union concluded that "[t]he Bryan Panel reviewed essentially none of the studies and literature on the effectiveness and scientific basis of traditional lightning protection systems and was erroneous in its conclusion that there was no basis for the Standard." AGU did not attempt to assess the effectiveness of any proposed modifications to traditional systems in its report The NFPA withdrew its proposed draft edition of standard 781 due to a lack of evidence of increased effectiveness of Early Streamer Emission-based protection systems over conventional air terminals.

Members of the Scientific Committee of the International Conference on Lightning Protection (ICLP) have issued a joint statement stating their opposition to Early Streamer Emission technology. ICLP maintains a web page with information related to ESE and related technologies (ESE issue)

ANALYSIS OF STRIKES:

Lightning strikes to a metallic structure can vary from leaving no evidence excepting perhaps a small pit in the metal to the complete destruction of the structure (Rakov, Page 364). When there is no evidence, analyzing the strikes is difficult. This means that a strike on an uninstrumented structure must be visually confirmed, and the random behavior of lightning renders such observations difficult. There are also inventors working on this problem, such as through a lightning rocket. While controlled experiments may be off in the future, very good data is being obtained through techniques which use radio receivers that watch for the characteristic electrical 'signature' of lightning strikes using fixed directional antennas. Through accurate timing and triangulation techniques, lightning strikes can be located with great precision, so strikes on specific objects often can be confirmed with confidence.

The energy in a lightning strike is typically in the range of 1 to 10 billion joules. This energy is released usually in a small number of separate strokes, each with duration of a few tens of microseconds (typically 30 to 50 microseconds), over a period of about one fifth of a second. The great majority of the energy is dissipated as heat, light and sound in the atmosphere.

LIGHTNING ARRESTER:

A **lightning arrester** (in Europe: **surge arrester**) is a device used on electrical power systems and telecommunications systems to protect the insulation and conductors of the system from the damaging effects of lightning. The typical lightning arrester has a high-voltage terminal and a ground terminal. When a lightning surge (or switching surge, which is very similar) travels along the power line to the arrester, the current from the surge is diverted through the arrestor, in most cases to earth.

In telegraphy and telephony, a lightning arrestor is placed where wires enter a structure, preventing damage to electronic instruments within and ensuring the safety of individuals near them. Smaller versions of lightning arresters, also called surge protectors, are devices that are connected between each electrical conductor in power and communications systems and the Earth. These prevent the flow of the normal power or signal currents to ground, but provide a path over which high-voltage lightning current flows, bypassing the connected equipment. Their purpose is to limit the rise in voltage when a communications or power line is struck by lightning or is near to a lightning strike.

If protection fails or is absent, lightning that strikes the electrical system introduces thousands of kilovolts that may damage the transmission lines, and can also cause severe damage to transformers and other electrical or electronic devices. Lightning-produced extreme voltage spikes in incoming power lines can damage electrical home appliances.

COMPONENTS:

A potential target for a lightning strike, such as a television antenna, is attached to the terminal labeled A in the photograph. Terminal E is attached to a long rod buried in the ground. Ordinarily no current will flow between the antenna and the ground because there is extremely high resistance between B and C, and also between C and D. The voltage of a lightning strike, however, is many times higher than that needed to move electrons through the two air gaps. The result is that electrons go through the lightning arrester rather than traveling on to the television set and destroying it.

A lightning arrester may be a spark gap or may have a block of a semiconducting material such as silicon carbide or zinc oxide. Some spark gaps are open to the air, but most modern varieties are filled with a precision gas mixture, and have a small amount of radioactive material to encourage the gas to ionize when the voltage across the gap reaches a specified level. Other designs of lightning arresters use a glow-discharge tube (essentially like a neon glow lamp) connected between the protected conductor and ground, or voltage-activated solid-state switches called varistors or MOVs.

Lightning arresters built for power substation use are impressive devices, consisting of a porcelain tube several feet long and several inches in diameter, typically filled with disks of zinc oxide. A safety port on the side of the device vents the occasional internal explosion without shattering the porcelain cylinder.

Lightning arresters are rated by the peak current they can withstand, the amount of energy they can absorb, and the breakover voltage that they require to begin conduction. They are applied as part of a lightning protection system, in combination with air terminals and bonding.

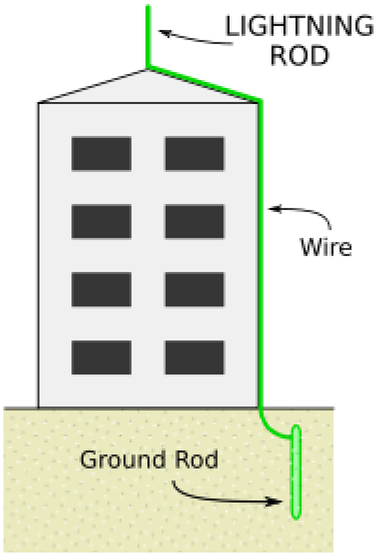
Simple spark gap device diverts lightning strike to ground (earth).

LIGHTNING ROD:

A **lightning rod** (US, AUS) or **lightning conductor** (UK) is a metal rod or metallic object mounted on top of a building, electrically bonded using a wire or electrical conductor to interface with ground or "earth" through an electrode, engineered to protect the building in the event of lightning strike. If lightning hits the building it will preferentially strike the rod and be conducted to ground through the wire, instead of passing through the building, where it could start a fire or cause electrocution.

A *lightning rod* is a single component in a *lightning protection system*. Lightning rods are also called *finials, air terminals* or *strike termination devices.* The lighting rod requires a connection to earth to perform its protective function. Lightning rods come in many different forms, including hollow, solid, pointed, rounded, flat strips or even *bristle brush-like*. The main attribute of all lightning rods is they are conductive.

Copper and its alloys are the most common materials used in lightning protection.[1]



SURGE ARRESTER:

A **surge arrester** is a product installed near the end of any conductor of sufficient length prior to the conductor landing on its intended electrical component. The purpose is to divert damaging lightning induced transients safely to ground through property changes to its varistor in parallel arrangement to the conductor inside the unit. Also called a surge protection device (SPD) or transient voltage surge suppressor (TVSS), they are only designed to protect against electrical transients resulting from the lightning flash, not a direct lightning termination to the conductors themselves.

Lightning termination to earth results in ground currents which pass over buried conductors and induce a transient that propagates outward towards the ends of the conductor. The same induction happens in overhead and above ground conductors which experience the passing energy of an atmospheric EMP caused by the flash. These devices only protect against induced transients characteristic of a lightning discharge's rapid rise-time and will not protect against the electrification due to a direct termination to the conductor. Transients similar to lightning induced, such as from high voltage system's switch faulting, may be safely diverted to ground, however continuous overcurrents are not protected by these devices. The energy in the transient is infinitesimally small in comparison to that of a lightning discharge, however it is still of sufficient quantity to cause arcing between different circuit pathways within today's microprocessors.

Without very thick insulation, which is generally cost prohibitive, most conductors running for any length whatsoever, say greater than ~50ft, will experience lightning induced transients at some point. Because the transient is usually initiated at some point between the two ends of the conductor, most applications install a surge arrestor just prior to the conductor's landing in each device to be protected. Each conductor must be protected, as each will have its own transient induced, and each SPD must provide a pathway to earth to safely divert the transient away from the protected component, be it instrument or computer, etc. The one notable exception where they are not installed at both ends is in high voltage distribution systems. In general, the induced voltage is not sufficient to do damage at the electric generation end of the lines, however installation at the service entrance to a building is key to protecting downstream products that are not as robust

Ground wires:

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

At some HVDC converter stations, the ground wire is used also as the electrode line to connect to a distant grounding electrode. This allows the HVDC system to use the earth as one conductor. The ground conductor is mounted on small insulators bridged by lightning arrestors above the conductors. The insulation prevents electrochemical corrosion of the pylon.

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

On some powerlines for very high voltages in the former Soviet Union, the ground wire is used for PLC-radio systems and mounted on insulators at the pylons

GROUNDING:

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

A typical earthing electrode *(left)*, consisting of a conductive rod driven into the ground, at a home in Australia. Electrical codes specify that earthing wires must be a certain color, to prevent wiring errors.

Electrical circuits may be connected to ground (earth) for several reasons. In mains powered equipment, exposed metal parts are connected to ground to prevent user contact with dangerous voltage if electrical insulation fails. Connections to ground limit the build-up of static electricity when handling flammable products or electrostatic-sensitive devices.

In some telegraph and power transmission circuits, the earth itself can be used as one conductor of the circuit, saving the cost of installing a separate return conductor. (See single-wire earth return)

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

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

NEUTRAL GROUNDING:

International standard IEC 60364 distinguishes three families of earthing arrangements, using the two-letter codes **TN**, **TT**, and **IT**.

The first letter indicates the connection between earth and the power-supply equipment (generator or transformer):

T

Direct connection of a point with earth (Latin: terra);

I

No point is connected with earth (isolation), except perhaps via a high impedance.

The second letter indicates the connection between earth and the electrical device being supplied:

T

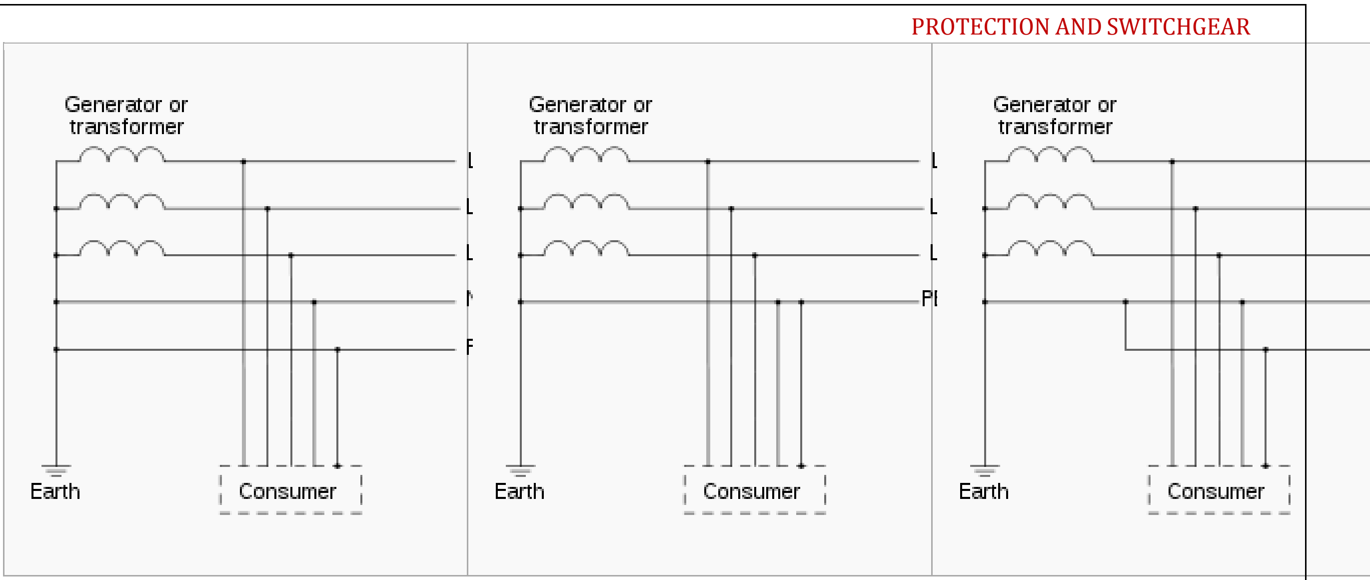
Direct connection of a point with earth

N

Direct connection to neutral at the origin of installation, which is connected to the earth

TN networks

In a **TN** earthing system, one of the points in the generator or transformer is connected with earth, usually the star point in a three-phase system. The body of the electrical device is connected with earth via this earth connection at the transformer.



The conductor that connects the exposed metallic parts of the consumer's electrical installation is called *protective earth* (*PE*; see also: Ground). The conductor that connects to the star point in a three-phase system, or that carries the return current in a single-phase system, is called *neutral* (*N*). Three variants of TN systems are distinguished:

TN−S

PE and N are separate conductors that are connected together only near the power source. This arrangement is the current standard for most residential and industrial electric systems partially in Europe.[*citation needed*]

TN−C

A combined PEN conductor fulfills the functions of both a PE and an N conductor. Rarely used.

TN−C−S

Part of the system uses a combined PEN conductor, which is at some point split up into separate PE and N lines. The combined PEN conductor typically occurs between the substation and the entry point into the building, and separated in the service head. In the UK, this system is also known as *protective multiple earthing (PME)*, because of the practice of connecting the combined neutral-and-earth conductor to real earth at many locations, to reduce the risk of broken neutrals - with a similar system in Australia and New Zealand being designated as *multiple earthed neutral (MEN)*.

TN-S: separate protective earth (PE) and neutral (N) conductors from transformer to consuming device, which are not connected together at any point after the building distribution point.	**TN-C**: combined PE and N conductor all the way from the transformer to the consuming device.	**TN-C-S earthing system**: combined PEN conductor fro transformer to buildin distribution point, but separate P and N conductors in fixed indoo wiring and flexible power cords.

It is possible to have both TN-S and TN-C-S supplies from the same transformer. For example, the sheaths on some underground cables corrode and stop providing good earth connections, and so homes where "bad earths" are found get converted to TN-C-S.

TT network

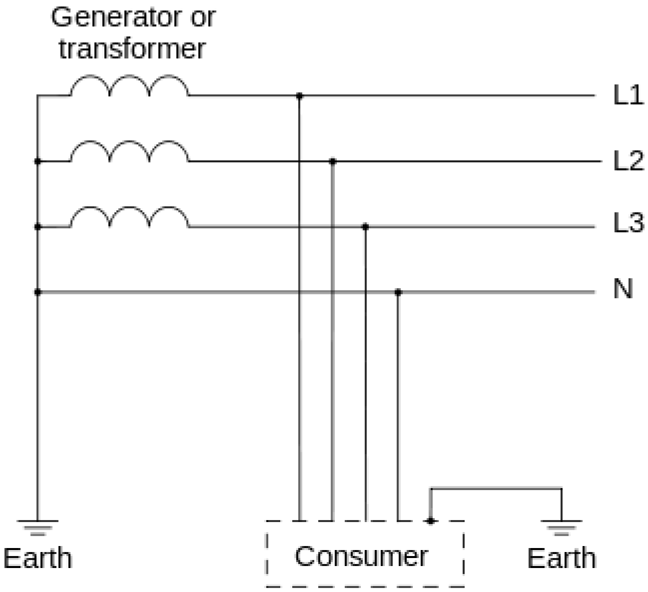
In a **TT** earthing system, the protective earth connection of the consumer is provided by a local connection to earth, independent of any earth connection at the generator.

The big advantage of the TT earthing system is that it is clear of high and low frequency noises that come through the neutral wire from connected equipment. TT has always been preferable for special applications like telecommunication sites that benefit from the interference-free earthing. Also, TT does not have the risk of a broken neutral.

In locations where power is distributed overhead and TT is used, installation earth conductors are not at risk should any overhead distribution conductor be fractured by, say, a fallen tree or branch.

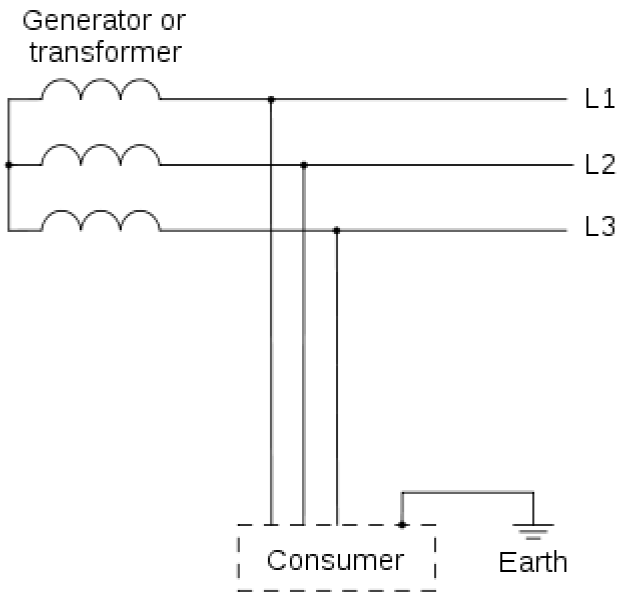
In pre-RCD era, the TT earthing system was unattractive for general use because of its worse capability of accepting high currents in case of a live-to-PE short circuit (in comparison with TN systems). But as residual current devices mitigate this disadvantage, the TT earthing system becomes attractive for premises where all AC power circuits are RCD-protected.

The TT earthing system is used throughout Japan, with RCD units in most industrial settings. This can impose added requirements on variable frequency drives and switched-mode power supplies which often have substantial filters passing high frequency noise to the ground conductor.



[edit]**IT network**

In an **IT** network, the electrical distribution system has no connection to earth at all, or it has only a high impedance connection. In such systems, an insulation monitoring device is used to monitor the impedance.



Insulation Coordination

Insulation Coordination is the process of determining the proper insulation levels of various components in a power system as well as their arrangements. It is the selection of an insulation structure that will withstand voltage stresses to which the system, or equipment will be subjected to, together with the proper surge arrester. The process is determined from the known characteristics of voltage surges and the characteristics of surge arresters.

Some common terms that must be known when performing an Insulation Coordination Study.

1. Basic Impulse Insulation Level (BIL)

This is the reference insulation level expressed as an impulse crest (or peak) voltage with a standard wave not longer than a **1.2 x 50 microsecond** wave.

A **1.2 x 50 microsecond** wave means that the impulse takes 1.2 microseconds to reach the peak and then decays to 50% of the peak in 50 microseconds. (Click here for a figure of the BIL waveform)

2. Withstand Voltage

This is the BIL level that can repeatedly be applied to an equipment without flashover, disruptive charge or other electrical failure under test conditions.

3. Chopped Wave Insulation Level

This is determined by using impulse waves that are of the same shape as that of the BIL waveform, with the exception that the wave is chopped after 3 microseconds. Generally, it is assumed that the Chopped Wave Level is 1.15 times the BIL level for oil filled equipment such as transformers. However, for dry type equipment, it is assumed that the the Chopped Wave Level is equal to the BIL level.

4. Critical Flashover Voltage

This is the peak voltage for a 50% probability of flashover or disruptive charge.

5. Impulses Ratio

This is normally used for Flashover or puncture of insulation. It is the ratio of the impulse peak voltage to the value of the 60 Hz voltage that causes flashover or puncture. Or, it is the ratio of breakdown voltage at surge frequency to breakdown voltage at normal system frequency (60 Hz).

Overvoltages that need to be considered when doing an Insulation Coordination Study.

There are three types of overvoltages that may occur on a plant:

- Internal Overvoltages
- Switching Surges
- External Overvoltages

1. Internal Overvoltages

These may usually be short power frequency overvoltages or weakly damped oscillatory voltages. The main causes of these overvoltages are:

- Phase to Earth Faults: Single line to Ground, Double line to Ground, 3 Phase to Ground.
- Load Rejection.
- Ferro Resonance.
- Ferranti Effect.

2. Switching Surges

These surges are of short duration, irregular (or impulse form) and highly damped. The effects of such overvoltages are of great concern when the transmission voltage is greater than 300kV. However, below 300kV, some causes of these overvoltages are:

- Resonance effects when switching transformer feeders, or cables and overhead lines.
- Ferro resonance encountered on transformer feeder double circuits, when one circuit is switched out but the other parallel feeder remains energised.

- Line energisation may cause switching surges especially at the remote end of the line that is being energised.

3. External Overvoltages

Power systems that operate below 145kV (example the T&TEC system) overvoltages due to lightning are of greater concern than the previous two types of overvoltages. Lightning discharges are usually very short, unidirectional and have a shape similar to the BIL waveform.

The point of insulation flashover depends on

(i) Geographical position of the lightning stroke
(ii) Magnitude of the stroke
(iii) Rise time of voltage wave
(iv) System insulation levels
(v) System Electrical characteristics
(vi) Local atmospheric or ambient conditions

Overvoltage Surge Protection

There are two methods of overvoltage protection:

1. Rod or Spark Gaps

These devices are easy and cheap to install and are usually installed in parallel with insulators between the live equipment terminal and earth. Some disadvantages of these devices include:

- When they operate, they cause a short circuit fault, which may cause protection to operate and isolate the equipment.
- The sudden reduction in the voltage during operation causes high stresses on the Transformer interturn insulation.
- The breakdown of plant insulation varies with the duration of the overvoltage.
- At lower voltages, where short distance gaps are used, maloperation may occur due to debris being deposited on the terminals of the gaps.

2. Surge Arresters

Modern Surge arresters are of the gapless Zinc Oxide type. Previously, Silicon Carbide arresters were used, but their use has been superceeded by the ZnO arresters, which have a non-linear resistance characteristic. Thus, it is possible to eliminate the series gaps between the individual ZnO block making up the arrester.

Selection Procedure for Surge arresters

1. Determine the continuous arrester voltage. This is usually the system rated voltage.
2. Select a rated voltage for the arrester.
3. Determine the normal lightning discharge current. Below 36kV, 5kA rated arresters are chosen. Otherwise, a 10kA rated arrester is used.
4. Determine the required long duration discharge capability.
   For rated voltage < 36kV, light duty surge arrester may be specified.
   For rated voltage between 36kV and 245kV, heavy duty arresters may be specified.
   For rated voltage >245kV, long duration discharge capabilities may be specified.
5. Determine the maximum prospective fault current and protection tripping times at the location of the surge arrester and match with the surge arrester duty.
6. Select the surge arrester having porcelain creepage distance in accordance with the environmental conditions.
7. Determine the surge arrester protection level and match with standard IEC 99 recommendations.

Some Common ratings associated with surge arresters

1. Rated Voltage

The power frequency voltage across the arrester must never exceed its rated voltage, otherwise the arrester may not reseal and may catastrophically fail after absorbing the energy of the surge.

For effectively earthed system:
Maximum phase to earth voltage = 80% maximum line voltage

2. Rated Current

Arresters are tested with 8/20 microsecond discharge current waves of varying magnitudes.

3. Normal Voltage

Nominal continuous voltage that the arrester can with stand before failing or flashover.

4. BIL

Basic Impulse Insulation Level which is the maximum impulse for a **1.2 x 50 microsecond** waveform.

5. Discharge voltage

When the overvoltage impulse reaches this value, the arrester begins to channel energy to earth

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