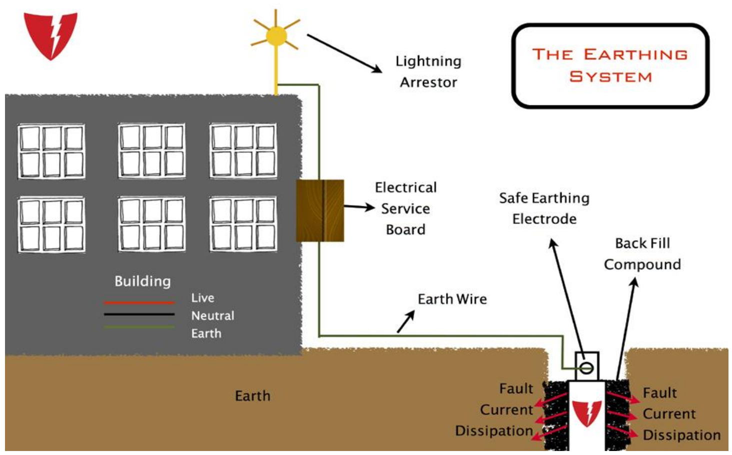
Earthing System

(PART-2)



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COGS GLOBAL

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Earthing System

INTRODUCTION

In an electrical installation, an earthing system (UK) or grounding system (US) connects specific parts of that installation with the Earth's conductive surface for safety and functional purposes. The point of reference is the Earth's conductive surface. The choice of earthing system can affect the safety and electromagnetic compatibility of the installation. Regulations for earthing systems vary considerably among countries, though most follow the recommendations of the IEC. Regulations may identify special cases for earthing in mines, in patient care areas, or in hazardous areas of industrial plants.

In addition to electric power systems, other systems may require grounding for safety or function. Tall structures may have lightning rods as part of a system to protect them from lightning strikes. Telegraph lines may use the Earth as one conductor of a circuit, saving the cost of installation of a return wire over a long circuit. Radio antennas may require particular grounding for operation, as well as to control static electricity and provide lightning protection.

International Electrotechnical Commission

Formation: 26 June 1906

Headquarter: Geneva, Switzerland

Membership: 86 countries

President: Yinbiao Shu

Purpose: Standardization for electrical technology, electronic and related

The **International Electro technical Commission** (**IEC**; in French: *Commission électrotechnique internationale*) is an international standards organization that prepares and publishes international standards for all electrical, electronic and related technologies – collectively known as ‘electro technology". IEC standards cover a vast range of technologies from power generation, transmission and distribution to home appliances and office equipment, semiconductors, fiber optics, batteries, solar technology, nanotechnology and marine energy as well as many others.
IEC standards have numbers in the range 60000–79999 and their titles take a form such as *IEC 60417: Graphical symbols for use on equipment*. Following the Dresden Agreement with CENELEC the numbers of older IEC standards were converted in 1997 by adding 60000, for example IEC 27 became IEC 60027. Standards of the 60000 series are also found preceded by EN to indicate that the IEC standard is also adopted by CENELEC as a European standard; for example, IEC 60034 is also available as EN 60034.

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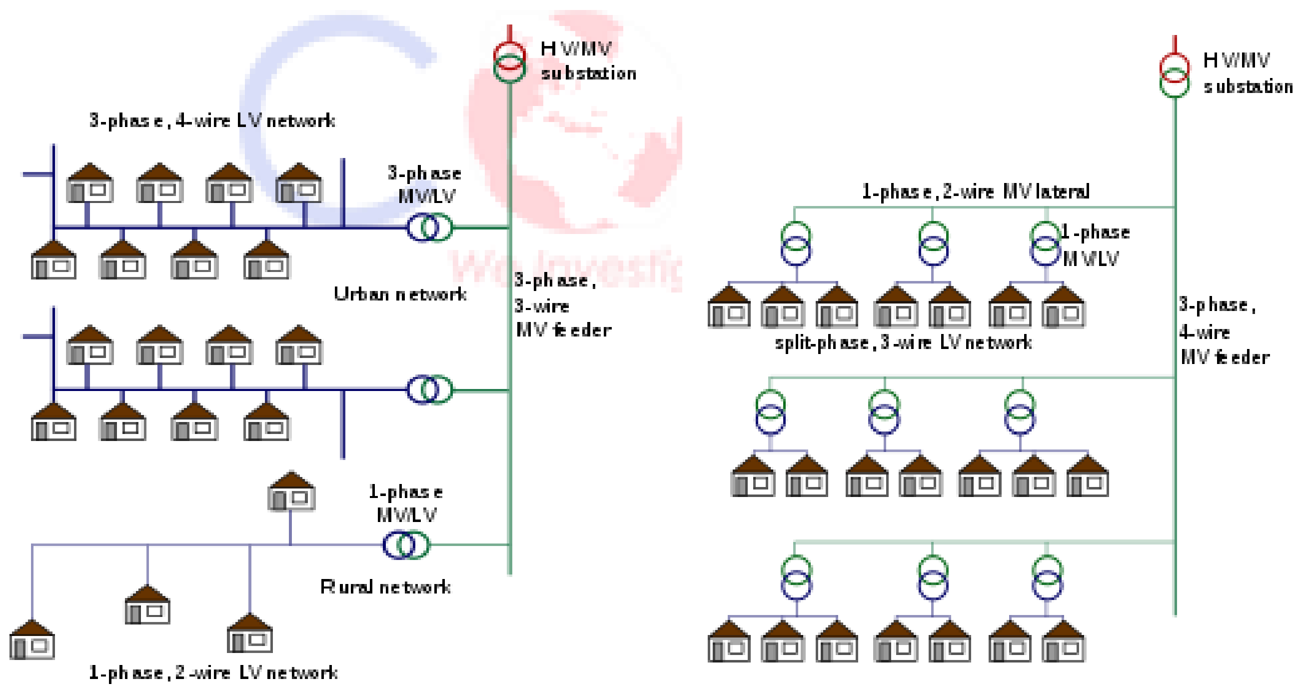
Low-voltage systems

In low-voltage networks, which distribute the electric power to the widest class of end users, the main concern for design of earthing systems is safety of consumers who use the electric appliances and their protection against electric shocks. The earthing system, in combination with protective devices such as fuses and residual current devices, must ultimately ensure that a person does not come into contact with a metallic object whose potential relative to the person's potential exceeds a *safe* threshold, typically set at about 50 V.

On electricity networks with a system voltage of 240 V to 1.1 kV, which are mostly used in industrial / mining equipment / machines rather than publicly accessible networks, the earthing system design is as equally important from safety point of view as for domestic users.

In most developed countries, 220 V, 230 V, or 240 V sockets with earthed contacts were introduced either just before or soon after World War II, though with considerable national variation in popularity. In the United States and Canada, 120 V power outlets installed before the mid-1960s generally did not include a ground (earth) pin. In the developing world, local wiring practice may not provide a connection to an earthing pin of an outlet.



For a time, US National Electrical Code allowed certain major appliances permanently connected to the supply to use the supply neutral wire as the equipment enclosure connection to ground. This was not permitted for plug-in equipment as the neutral and energized conductor could easily be accidentally exchanged, creating a severe hazard. If the neutral was interrupted, the equipment enclosure would no longer be connected to ground. Normal imbalances in a split phase distribution system could create objectionable neutral to ground voltages. Recent editions of the NEC no longer permit this practice. For these reasons, most countries have now mandated dedicated protective earth connections that are now almost universal.

If the fault path between accidentally energized objects and the supply connection has low impedance, the fault current will be so large that the circuit overcurrent protection device (fuse or circuit breaker) will open to clear the ground fault. Where the earthing system does not provide a low-impedance metallic conductor between equipment enclosures and supply return (such as in a TT separately earthed system), fault currents are smaller, and will not necessarily operate the overcurrent protection device. In such case a residual current detector is installed to detect the current leaking to ground and interrupt the circuit.

Terminology-

Low Voltage Network-A low-voltage network or secondary network is a part of electric power distribution which carries electric energy from distribution transformers to electricity meters of end customers. Secondary networks are operated at a low voltage level, which is typically equal to the mains voltage of electric appliances.

Most modern secondary networks are operated at AC rated voltage of 100–127 or 220–240 volts, at the frequency of 50 or 60 hertz. Operating voltage, required number of phases (three-phase or single-phase) and required reliability dictate topology and configuration of the network. The simplest form are radial service drop lines from the transformer to the customer premises. Low-voltage radial feeders supply multiple customers.

A **split-phase** or **single-phase three-wire** system is a type of single-phase electric power distribution. It is the alternating current (AC) equivalent of the original Edison three-wire direct-current system. Its primary advantage is that it saves conductor material over a single-ended single-phase system, while only requiring a single phase on the supply side of the distribution transformer.

The two 120 V AC lines are supplied to the premises from a transformer with a 240 V AC secondary winding which has a center tap connected to ground. This results in two 120 V AC line voltages which are out of phase by 180 degrees with each other. The system neutral conductor is connected to ground at the transformer center tap. 240 V AC can be obtained by connecting the load between the two 120 V AC lines.

A **residual-current device** (**RCD**), or **residual-current circuit breaker** (**RCCB**), is a device that quickly breaks an electrical circuit to prevent serious harm from an ongoing electric shock. Injury may still occur in some cases, for example if a human falls after receiving a shock, or if the person touches both conductors at the same time.

RCD is the name used in the United Kingdom. In the United States and Canada, the terms **ground fault circuit interrupter** (**GFCI**), **ground fault interrupter** (**GFI**) or **appliance leakage current interrupter** (**ALCI**) (also known as a **Leakage Current Detection Interrupter** (**LCDI**)) are used. If the RCD device has additionally overcurrent protection integrated in the same device, it is referred to as RCBO.

IEC terminology

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 (French: terre)**

"I" **— No point is connected with earth (French: isolé), except perhaps via a high impedance.**

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

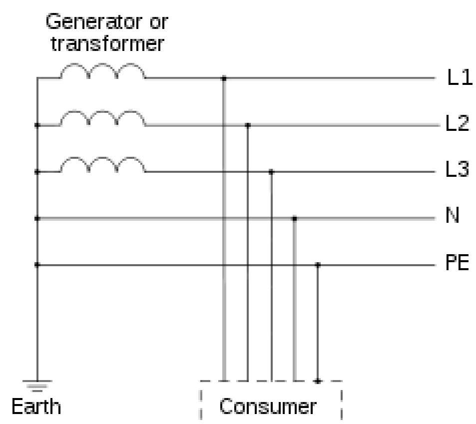
"T" **— Earth connection is by a local direct connection to earth (French: terre), usually via a ground rod.**

"N" **— the earth connection is supplied by the electricity supply network, either separately to the neutral conductor (TN-S), combined with the neutral conductor (TN-C), or both (TN-C-S). These are discussed below.**

Types of 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. This arrangement is a current standard for residential and industrial electric systems particularly in Europe.

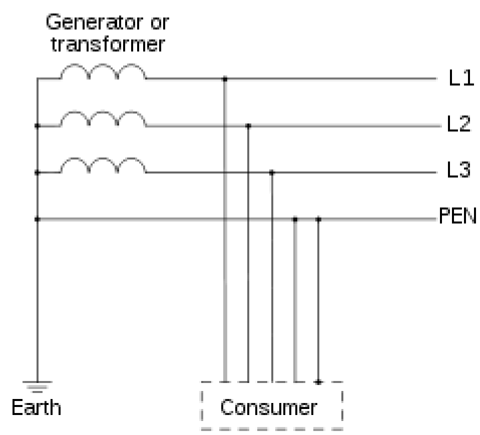
The conductor that connects the exposed metallic parts of the consumer's electrical installation is called *protective earth* (Ground). The conductor that connects to the star point in a three-phase system, or that carries the return current in a single-phase system, is called *neutral* (*N*). Three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



TN−S

PE and N are separate conductors that are connected together only near the power source.

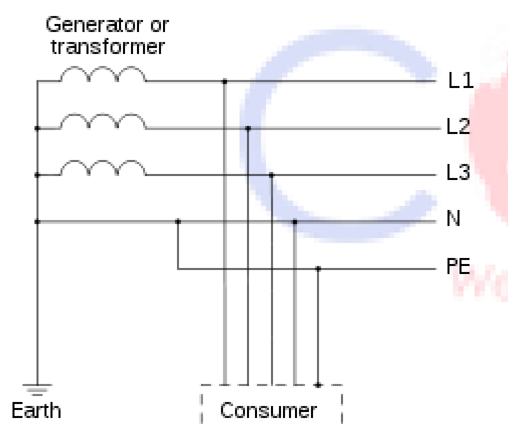
TN-S: separate protective earth (PE) and neutral (N) conductors from transformer to consuming devices, which are not connected together at any point after building distribution point.



TN–C

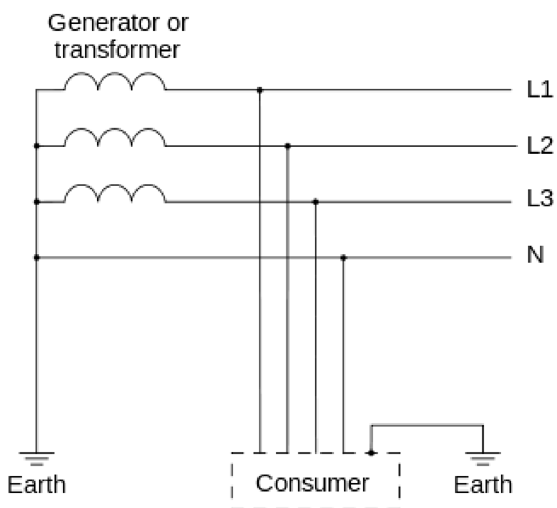
A combined PEN conductor fulfils the functions of both a PE and an N conductor. (On 230/400 V systems normally only used for distribution networks)

TN-C: combined PE and N conductor all the way from the transformer to the consuming device.



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 earth and neutral are 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 via the shortest practicable route to a local Earth-Rod at the source and at each premises, to provide both System Earthing and Equipment Earthing at each of these locations. Similar systems in Australia and New Zealand are designated as *multiple earthed neutral (MEN)* and, in North America, as *multi-grounded neutral (MGN)*. It is possible to have both TN-S and TN-C-S supplies taken from the same transformer. For example, the sheaths on some underground cables corrode and stop providing good earth connections, and so homes where high resistance "bad earths" are found may be converted to TN-C-S. This is only possible on a network when the neutral is suitably robust against failure, and conversion is not always possible. The PEN must be suitably reinforced against failure, as an open circuit PEN can impress full phase voltage on any exposed metal connected to the system earth downstream of the break. The alternative is to provide a local earth and convert to TT. The main attraction of a TN network is the low impedance earth path allows easy automatic disconnection (ADS) on a high current circuit in the case of a line-to-PE short circuit as the same breaker or fuse will operate for either L-N or L-PE faults, and an RCD is not needed to detect earth faults.



TT network

In a **TT** (terre-terre) earthing system, the protective earth connection for the consumer is provided by a local earth electrode, (sometimes referred to as the Terra-Firma connection) and there is another independently installed at the generator. There is no 'earth wire' between the two. The fault loop impedance is higher, and unless the electrode impedance is very low indeed, a TT installation should always have an RCD (GFCI) as its first isolator.

The big advantage of the TT earthing system is the reduced conducted interference from other users' connected equipment. TT has always been preferable for special applications like telecommunication sites that benefit from the interference-free earthing. Also, TT networks do not pose any serious risks in the case of a broken neutral. In addition, in locations where power is distributed overhead, earth conductors are not at risk of becoming live 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 the difficulty of arranging reliable automatic disconnection (ADS) in the case of a line-to-PE short circuit (in comparison with TN systems, where the same breaker or fuse will operate for either L-N or L-PE faults). But as residual current devices mitigate this disadvantage, the TT earthing system has become much more attractive providing that all AC power circuits are RCD-protected. In some countries (such as the UK) TT is recommended for situations where a low impedance equipotential zone is impractical to maintain by bonding, where there is significant outdoor wiring, such as supplies to mobile homes and some agricultural settings, or where a high fault current could pose other dangers, such as at fuel depots or marinas.

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.

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.

Electrical impedance: In electrical engineering, **electrical impedance** is the measure of the opposition that a circuit presents to a current when a voltage is applied.

Quantitatively, the impedance of a two-terminal circuit element is the ratio of the complex representation of the sinusoidal voltage between its terminals, to the complex representation of the current flowing through it. In general, it depends upon the frequency of the sinusoidal voltage.

Impedance extends the concept of resistance to alternating current (AC) circuits, and possesses both magnitude and phase, unlike resistance, which has only magnitude. When a circuit is driven with direct current (DC), there is no distinction between impedance and resistance; the latter can be thought of as impedance with zero phase angle.

Other terminologies

While the national wiring regulations for buildings of many countries follow the IEC 60364 terminology, in North America (United States and Canada), the term "equipment grounding conductor" refers to equipment grounds and ground wires on branch circuits, and "grounding electrode conductor" is used for conductors bonding an earth ground rod (or similar) to a service panel. "Grounded conductor" is the system "neutral". Australian and New Zealand standards use a modified PME earthing system called Multiple Earthed Neutral (MEN). The neutral is grounded (earthed) at each consumer service point thereby effectively bringing the neutral potential difference to zero along the whole length of LV lines. In the UK and some Commonwealth countries, the term "PNE", meaning Phase-Neutral-Earth is used to indicate that three (or more for non-single-phase connections) conductors are used, i.e., PN-S.

Electric generator: In electricity generation, a **generator** is a device that converts motive power (mechanical energy) into electrical power for use in an external circuit. Sources of mechanical energy include steam turbines, gas turbines, water turbines, internal combustion engines, wind turbines and even hand cranks.

The reverse conversion of electrical energy into mechanical energy is done by an **electric motor**, and motors and generators have many similarities. Many motors can be mechanically driven to generate electricity and frequently make acceptable manual generators.

Transformer: A **transformer** is a passive electrical device that transfers electrical energy from one electrical circuit to another, or multiple circuits. A varying current in any one coil of the transformer produces a varying magnetic flux in the transformer's core, which induces a varying electromotive force across any other coils wound around the same core. Electrical energy can be transferred between separate coils without a metallic (conductive) connection between the two circuits. Faraday's law of induction, discovered in 1831, describes the induced voltage effect in any coil due to a changing magnetic flux encircled by the coil.

Transformers are most commonly used for increasing low AC voltages at high current (a step-up transformer) or decreasing high AC voltages at low current (a step-down transformer) in electric power applications, and for coupling the stages of signal processing circuits. Transformers can also be used for isolation, where the voltage in equals the voltage out, with separate coils not electrically bonded to one another.

Resistance-earthed neutral (India)

A resistance earth system is used for mining in India as per Central Electricity Authority Regulations. Instead of a solid connection of neutral to earth, a neutral grounding resistor (NGR) is used to limit the current to ground to less than 750 mA. Due to the fault current restriction it is safer for gassy mines. Since the earth leakage is restricted, leakage protection devices can be set to less than 750 mA. By comparison, in a solidly earthed system, earth fault current can be as much as the available short-circuit current.

The neutral earthing resistor is monitored to detect an interrupted ground connection and to shut off power if a fault is detected.

Earth leakage protection

To avoid accidental shock, current sensing circuits are used at the source to isolate the power when leakage current exceed a certain limit. Residual-current devices (RCDs, RCCBs or GFCIs) are used for this purpose. Previously, a earth leakage circuit breaker is used. In industrial applications, earth leakage relays are used with separate core balanced current transformers. This protection works in the range of milli-Amps and can be set from 30 mA to 3000 mA.

Earth connectivity check

A separate pilot wire is run from distribution/ equipment supply system in addition to earth wire, to supervise the continuity of the wire. This is used in the trailing cables of mining machinery. If the earth wire is broken, the pilot wire allows a sensing device at the source end to interrupt power to the machine. This type of circuit is a must for portable heavy electric equipment (like LHD (Load, Haul, Dump machine)) being used in underground mines.

Properties

Cost

- TN networks save the cost of a low-impedance earth connection at the site of each consumer. Such a connection (a buried metal structure) is required to provide *protective earth* in IT and TT systems.
- TN-C networks save the cost of an additional conductor needed for separate N and PE connections. However, to mitigate the risk of broken neutrals, special cable types and lots of connections to earth are needed.
- TT networks require proper RCD (Ground fault interrupter) protection.

Safety

- In TN, an insulation fault is very likely to lead to a high short-circuit current that will trigger an overcurrent circuit-breaker or fuse and disconnect the L conductors. With TT systems, the earth fault loop impedance can be too high to do this, or too high to do it within the required time, so an RCD (formerly ELCB) is usually employed. Earlier TT installations may lack this important safety feature, allowing the CPC (Circuit Protective Conductor or PE) and perhaps associated metallic parts within reach of persons (exposed-conductive-parts and extraneous-conductive-parts) to become energized for extended periods under fault conditions, which is a real danger.

- In TN-S and TT systems (and in TN-C-S beyond the point of the split), a residual-current device can be used for additional protection. In the absence of any insulation fault in the consumer device, the equation $I_{L1}+I_{L2}+I_{L3}+I_N = 0$ holds, and an RCD can disconnect the supply as soon as this sum reaches a threshold (typically 10 mA – 500 mA). An insulation fault between either L or N and PE will trigger an RCD with high probability.
- In IT and TN-C networks, residual current devices are far less likely to detect an insulation fault. In a TN-C system, they would also be very vulnerable to unwanted triggering from contact between earth conductors of circuits on different RCDs or with real ground, thus making their use impracticable. Also, RCDs usually isolate the neutral core. Since it is unsafe to do this in a TN-C system, RCDs on TN-C should be wired to only interrupt the line conductor.
- In single-ended single-phase systems where the Earth and neutral are combined (TN-C, and the part of TN-C-S systems which uses a combined neutral and earth core), if there is a contact problem in the PEN conductor, then all parts of the earthing system beyond the break will rise to the potential of the L conductor. In an unbalanced multi-phase system, the potential of the earthing system will move towards that of the most loaded line conductor. Such a rise in the potential of the neutral beyond the break is known as a *neutral inversion* Therefore, TN-C connections must not go across plug/socket connections or flexible cables, where there is a higher probability of contact problems than with fixed wiring. There is also a risk if a cable is damaged, which can be mitigated by the use of concentric cable construction and multiple earth electrodes. Due to the (small) risks of the lost neutral raising 'earthed' metal work to a dangerous potential, coupled with the increased shock risk from proximity to good contact with true earth, the use of TN-C-S supplies is banned in the UK for caravan sites and shore supply to boats, and strongly discouraged for use on farms and outdoor building sites, and in such cases it is recommended to make all outdoor wiring TT with RCD and a separate earth electrode.
- In IT systems, a single insulation fault is unlikely to cause dangerous currents to flow through a human body in contact with earth, because no low-impedance circuit exists for such a current to flow. However, a first insulation fault can effectively turn an IT system into a TN system, and then a second insulation fault can lead to dangerous body currents. Worse, in a multi-phase system, if one of the line conductors made contact with earth, it would cause the other phase cores to rise to the phase-phase voltage relative to earth rather than the phase-neutral voltage. IT systems also experience larger transient over voltages than other systems.
- In TN-C and TN-C-S systems, any connection between the combined neutral-and-earth core and the body of the earth could end up carrying significant current under normal conditions, and could carry even more under a broken neutral situation. Therefore, main equipotential bonding conductors must be sized with

this in mind; use of TN-C-S is inadvisable in situations such as petrol stations, where there is a combination of lots of buried metalwork and explosive gases.

Electromagnetic compatibility

- In TN-S and TT systems, the consumer has a low-noise connection to earth, which does not suffer from the voltage that appears on the N conductor as a result of the return currents and the impedance of that conductor. This is of particular importance with some types of telecommunication and measurement equipment.
- In TT systems, each consumer has its own connection to earth, and will not notice any currents that may be caused by other consumers on a shared PE line.

Regulations

- In the United States, National Electrical Code and Canadian Electrical Code the feed from the distribution transformer uses a combined neutral and grounding conductor, but within the structure separate neutral and protective earth conductors are used (TN-C-S). The neutral must be connected to earth only on the supply side of the customer's disconnecting switch.
- In Argentina, France (TT) and Australia (TN-C-S), the customers must provide their own ground connections.
- Appliances in Japan must comply with PSE law, and building wiring uses TT earthing in most installations.
- In Australia, the Multiple Earthed Neutral (MEN) earthing system is used and is described in Section 5 of AS/NZS 3000. For an LV customer, it is a TN-C system from the transformer in the street to the premises, (the neutral is earthed multiple times along this segment), and a TN-S system inside the installation, from the Main Switchboard downwards. Looked at as a whole, it is a TN-C-S system.
- In Denmark the high voltage regulation and Malaysia the Electricity Ordinance 1994 states that all consumers must use TT earthing, though in rare cases TN-C-S may be allowed (used in the same manner as in the United States). Rules are different when it comes to larger companies.
- In India as per Central Electricity Authority Regulations, CEAR, 2010, rule 41, there is provision of earthing, neutral wire of a 3-phase, 4-wire system and the additional third wire of a 2- phase, 3-wire system. Earthing is to be done with two separate connections. The grounding system must also have a minimum of two or more earth pits (electrodes) to better ensure proper grounding. According to rule 42, installation with connected load above 5 kW exceeding 250 V shall have a suitable Earth leakage protective device to isolate the load in case of earth fault or leakage.

Application examples

- In the areas of UK where underground power cabling is prevalent, the TN-S system is common.
- In India LT supply is generally through TN-S system. Neutral is double grounded at each distribution transformer. Neutral and earth conductors run separately on overhead distribution lines. Separate conductors for overhead lines and armoring of cables are used for earth connection. Additional earth electrodes/pits are installed at each user end to provide redundant path to earth.
- Most modern homes in Europe have a TN-C-S earthing system. The combined neutral and earth occurs between the nearest transformer substation and the service cut out (the fuse before the meter). After this, separate earth and neutral cores are used in all the internal wiring.
- Older urban and suburban homes in the UK tend to have TN-S supplies, with the earth connection delivered through the lead sheath of an underground lead-and-paper cable.
- Older homes in Norway uses the IT system while newer homes use TN-C-S.
- Some older homes, especially those built before the invention of residual-current circuit breakers and wired home area networks, use an in-house TN-C arrangement. This is no longer recommended practice.
- Laboratory rooms, medical facilities, construction sites, repair workshops, mobile electrical installations, and other environments that are supplied via engine-generators where there is an increased risk of insulation faults, often use an IT earthing arrangement supplied from isolation transformers. To mitigate the two-fault issues with IT systems, the isolation transformers should supply only a small number of loads each and should be protected with an insulation monitoring device (generally used only by medical, railway or military IT systems, because of cost).
- In remote areas, where the cost of an additional PE conductor outweighs the cost of a local earth connection, TT networks are commonly used in some countries, especially in older properties or in rural areas, where safety might otherwise be threatened by the fracture of an overhead PE conductor by, say, a fallen tree branch. TT supplies to individual properties are also seen in mostly TN-C-S systems where an individual property is considered unsuitable for TN-C-S supply.