
BRIEFING PAPER
EARTHING CONFIGURATIONS

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Briefing document explaining the earthing configurations for a non-specialised audience with technical background

In this document the various earthing schemes will be explained with the purpose of advocating the TN-S system and with the emphasis on the specific issue to regularly earth the PE conductor.

Note: A list of definitions can be found at the end of the document.

INTRODUCTION

The dangers of electricity are well known and in this paper we will focus mainly on the danger of electric shock, although the risk of fire originating from the electrical installation will also be briefly covered.

The fundamental rule of protection against electric shock is: hazardous-live-parts shall not be accessible and accessible conductive parts shall not be hazardous live, either under normal conditions, or under single-fault conditions.

Basically, there are two ways of getting a shock from an electrical installation: first by touching a live part of the installation (a phase or the neutral or a conductive part expected to be live, such as terminals and connexions), also called “direct contact”, and secondly by touching a conductive part that is not supposed to be live, but that has become live due to failure of the basic insulation in the electrical equipment, also called “indirect contact”.

Interesting to say that the term “protection against direct and indirect contact” is not used any longer in the international standardisation documents and we now speak of *protection under normal conditions* and *protection under fault conditions*.

PROTECTION AGAINST ELECTRIC SHOCK

It is obvious that the protection under normal conditions will be quite easy, as the live parts of the electrical installation will be basically protected by:

- insulation,
- barriers or enclosures,
- obstacles,
- putting out of reach.

Note: the last two protective measures are only allowed in installations that are controlled or supervised by skilled or instructed persons.

In most cases, and certainly for the general public, the chosen protective measures will include a protection against direct and against indirect contact or “protection under normal and under fault condition”. Indeed, although safe electrical equipment is used and adequate maintenance is carried out on the electrical installation, the possibility of insulation faults always remains, be it very small. But with increasing age this risk increases. Therefore, persons and animals have to be protected against direct and indirect contact.

PROTECTION UNDER FAULT CONDITION

In the protective measures under fault conditions, two possibilities exist: passive measures such as supplementary insulation, and active measures, which will break the current in the faulty circuit. The circuit has to be switched off before the voltage can do harm to a person touching the accessible conductive part under fault.

For the exposed-conductive-parts to be properly protected it is necessary to connect them with a conductor, the Protective Earth or PE-conductor. It will not always be necessary to really connect the conductive parts to earth, a so-called PU or Protective Unearthed conductor can be used, but in this paper we will only focus on the earthed variant.

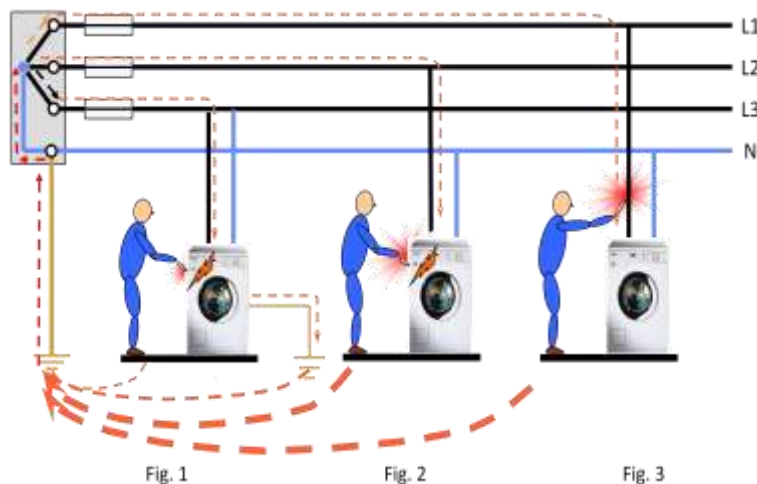
By connecting the exposed-conductive-parts with a PE-conductor, a path is created for the fault current, which can be detected and, if necessary, can be interrupted.

Apart from the function of helping to prevent electrocution caused by insulation faults, earthing systems can also be used to prevent fires caused by short-circuits, to prevent damage to electronic equipment caused by the effects of electromagnetic disturbances and it can be used to avoid human injuries and fatalities in case of a direct or nearby lightning strike.

Historically, those three protection functions were developed separately, under the names 'protective earthing', 'lightning protection', and 'functional earthing'. In the course of time it became clear that these three different earthing systems could influence each other up to the point of hampering each other's proper and efficient functioning. As a result, the only way to ensure that all protective functions are well covered, is to design a single integrated earthing system that deals with all three issues simultaneously. Designing such a network is a specialized task, to be executed by a properly trained engineer.

In this paper we will only consider the so-called protective earthing.

It must be realised that touching an exposed-conductive-part that is not connected to a PE, is equivalent to a direct contact:



In general, when an insulation becomes defective, there will be a rapid evolution to a full fault and therefore the person touching the exposed conductive part in fig. 2 will be subjected to the same fault current as the person touching the active part in fig.3.

But just connecting the exposed conductive parts to earth is not enough. The fault current in fig.1 creates a potential rise between the exposed-conductive-part and the earth and this voltage can be dangerous if it exceeds a certain value for a certain time.

Lots of studies have been carried out on the effects of current on human beings and livestock and the IEC has decided that the following should be applied:

For distribution circuits and for final circuits not exceeding 32A, and for a nominal voltage of U_0 of 230 V, the maximum disconnecting times are:

From table 41.1 of the IEC 60364-4-41

Earthing scheme	Final circuit < 32A	Distribution circuit
	s	s
TN	0,4	5
TT	0,2	1
IT (2 nd fault)	0,4	5

HOW ARE THESE REQUIREMENTS MET FOR THE DIFFERENT EARTHING ARRANGEMENTS?

The active protective measures, or protective measures with automatic disconnection of the supply, are based on compliance with the above table.

Their application requires the connection of the exposed conductive parts to a protective conductor and the use of disconnection devices, the operating characteristics of which make it possible to comply with the table, taking into account the impedances of the fault loops and of the earthing arrangements.

A brief overview of the different earthing schemes:

The IEC has adapted three earthing arrangements, each distinguished by a code formed by a minimum of two letters and, where applicable, by three or four letters

The first letter gives the location of one point of the supply with respect to earth:

- T: direct connection of a point with earth (T= Terre)
- I: either insulation of all the live parts with respect to earth, or connection of a point with earth through an impedance (I= Isolated)

The second letter gives the location of the exposed-conductive-parts of the electrical installation with respect to earth:

- T: exposed-conductive-parts connected direct to earth, independently of any earthing of a point of the supply,
- N: exposed-conductive-parts connected to the earthed point of the supply (the earthed point is usually the neutral point for AC).

Any third or fourth letters, separated from the first two by a dash, as well as any between them, give the arrangement of the neutral conductor and of the protective conductor:

- S: neutral and protective functions provided by **S**eparate conductors,
- C: neutral and protective functions **C**ombined in a single conductor (PEN conductor).

The three earthing arrangements so defined are:

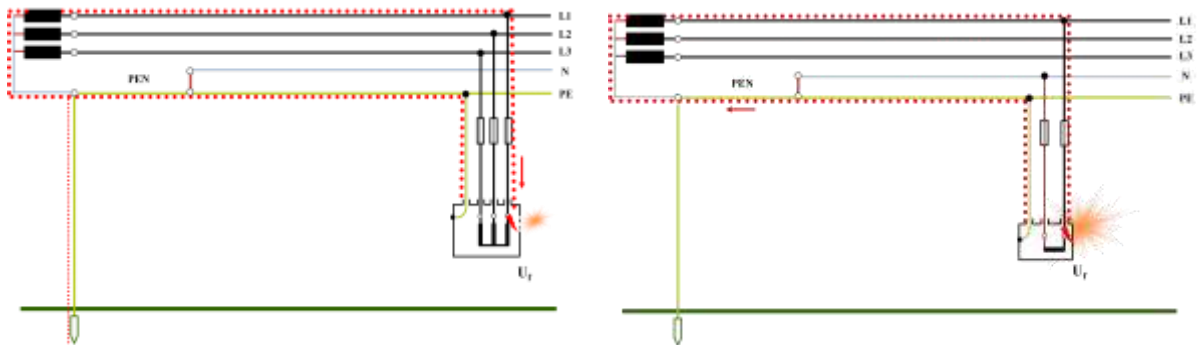
- The alternatives TN-S, TN-C-S and TN-C of the TN system,
- The TT system
- The IT system.

For a basic briefing on these various earthing configuration, view this minute lecture by Leonardo ENERGY:

<http://www.leonardo-energy.org/earthing-configurations>

PROTECTIVE MEASURES IN CASE OF AN INSULATION FAULT.

TN SYSTEM



It is clear that in all the alternatives of the TN system, an insulation fault will give rise to a high fault current, as the current is only limited by the impedance of the conductors of the fault loop.

The protective devices and the cross-sectional areas of the conductors are selected so that if, at any position a short circuit occurs between a phase conductor and the protective conductor or an exposed-conductive-part which is connected to it, the disconnection is achieved within the time of table 41.1

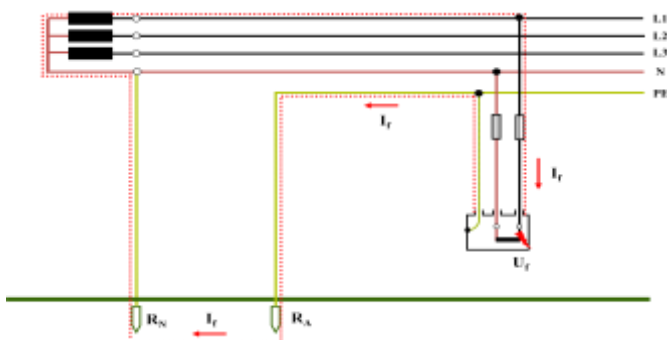
This condition is satisfied if U_0 being the voltage with respect to earth of the network, Z_s being the fault loop impedance, the current I_a determined by the equation

$$I_a \leq U_0 / Z_s$$

ensures the operation of the automatic disconnection device within the required time.

This means that in many cases the overcurrent protective devices can be used to protect against indirect contact.

THE TT SYSTEM:



The fault current will be mainly limited by the earth resistances of the electrode of the supply and the electrode of the exposed-conductive-parts.

The earth electrode resistance R_A to which the exposed-conductive-parts of the installation are connected shall be at least less than or equal to the quotient of the voltage U_L , by the rated operating current I_A of the protective device:

$$R_A \leq U_L / I_A$$

In most cases a RCD will be used.

THE IT SYSTEM

As there is no connection of the supply to earth (or via a large impedance) there will be no dangerous fault current when the first insulation fault occurs. However, upon arrival of a second fault on another phase conductor, the system will behave like a TN system or TT system, according to whether all the exposed-conductive-parts are interconnected or not by a protective conductor.

The protective measures specified for the installation supplied by a TN or TT must then be taken.

USAGE OF THE THREE SYSTEMS.

Concerning the safety of persons, the three systems are equivalent if, of course, all requirements are fully met. Concerning the protection against fire, there is quite a difference between the three systems. For example, the use of the TN-C system will be forbidden in cases where there is an elevated risk of fire or explosion. There are other advantages and drawbacks linked to the three systems, but this is outside the scope of this paper.

According to the IEC the TN-C systems should not be used in buildings containing, or likely to contain, significant amounts of information technology. In TN-C installations load current or fault current will be diverted via equipotential bonding into metallic infrastructures (e.g. piping, beams...) within the building.

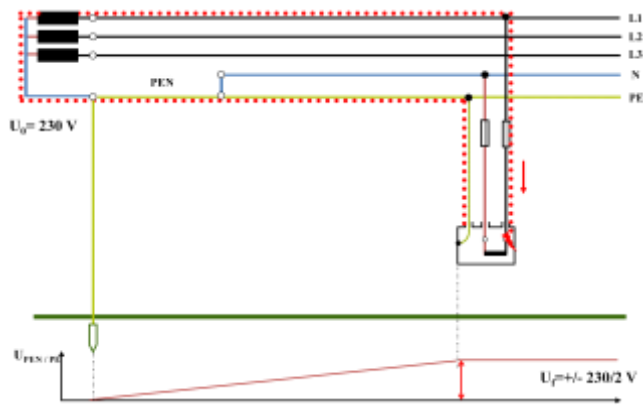
This can be avoided using the TN-S system (or TN-C-S with a limited part TN-C). It is a widely used system and we will therefore give some more attention to it.

MULTIPLE EARTHING.

LOW POTENTIAL RISE

It is necessary to connect the PE to earth at multiple points, distributed as evenly as possible. This will ensure that the potentials of the protective conductors remain, in case of a fault, as near as possible to that of earth.

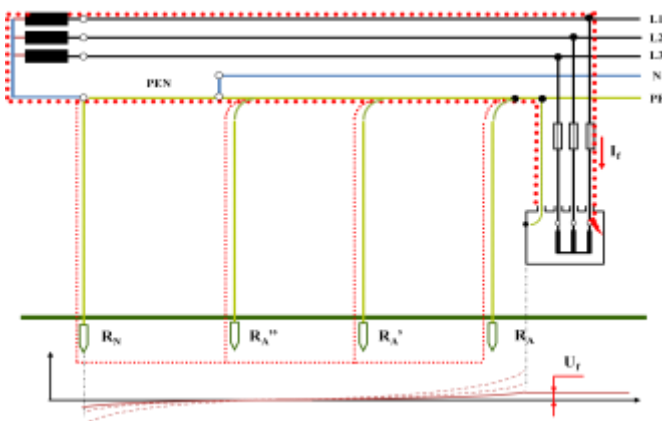
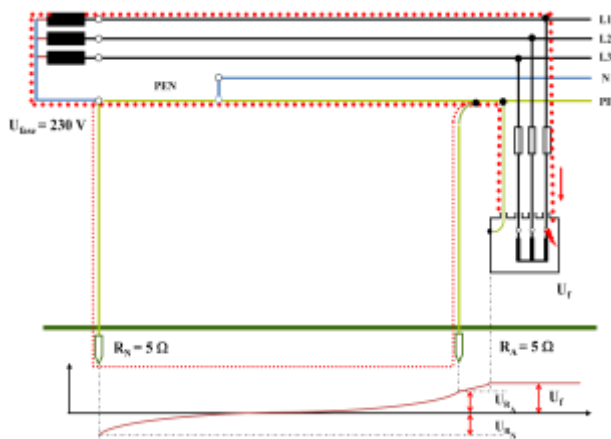
The figure below explains the advantages of multiple earthing:



If $R_{\text{phase}} = R_{\text{PE}}$ the fault voltage is about $U_0/2$ (taking into account the voltage drop). This dangerous voltage must be switched off in time.

If automatic disconnection cannot be achieved in the time required by the table 41.1, supplementary protective equipotential bonding shall be provided.

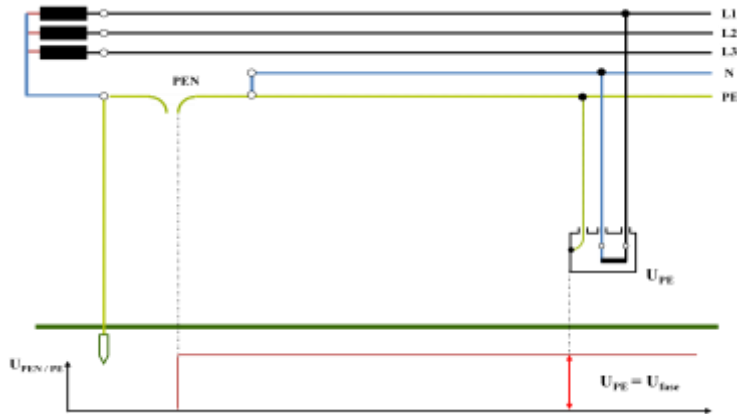
The potential rise on the PE/PEN will be kept low by connecting the PE to earth at regular intervals along its length.



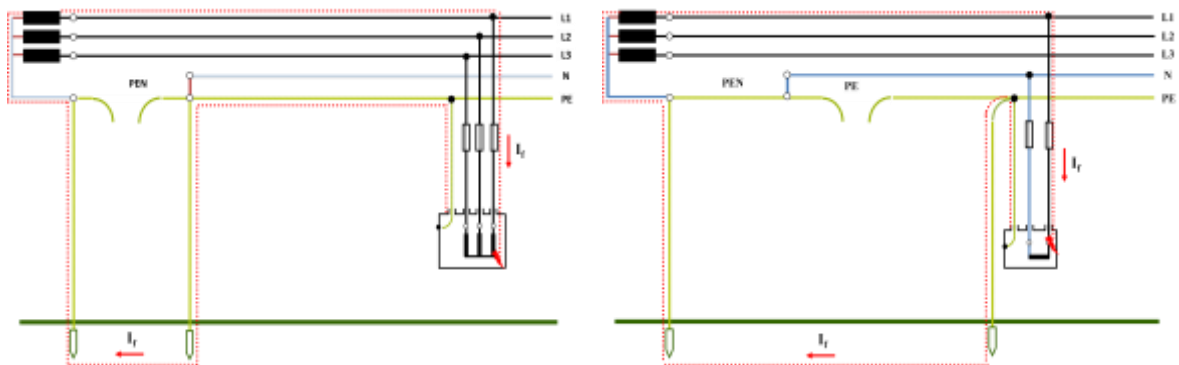
BREAK OF THE PEN CONDUCTOR

Another reason to connect the PEN/PE to earth at a number of points is to minimize the risks in case of a break in the PEN or PE conductor.

If only one point of connection to earth: dangerous situation when PEN breaks.



TN to TT when more than 1 connection to earth:



DEFINITIONS:

Earth: the conductive mass of the Earth; its electrical potential is by convention taken as being zero

NOTE: the concept “earth” means the planet and all its physical matter

Earthing arrangement (or earthing scheme): all the electric connections and devices involved in the earthing of a system, an installation and equipment

System earthing: a connection between an active point of the supply, mostly the neutral point of the secondary of the transformer, and the earth

Earth electrode or ground electrode: a conductor or group of conductors in intimate contact with, and providing an electrical connection, with the earth

Earth electrode resistance: the contact resistance of an earth electrode with the earth

Equipotential bonding: provision of electric connection between conductive parts, intended to achieve equipotentiality

Exposed-conductive-part: conductive part of equipment which can be touched and which is not normally live, but which can become live when basic insulation fails

Extraneous-conductive-part: conductive part not forming part of the electrical installation and liable to introduce an electric potential, generally the electric potential of a local earth

Touch voltage (or effective touch voltage): voltage between conductive parts when touched simultaneously by a person or an animal

Prospective touch voltage: voltage between simultaneously accessible conductive parts when those conductive parts are not being touched by a person or an animal

Conventional prospective touch voltage limit U_L : maximum value of the prospective touch voltage which is permitted to be maintained indefinitely in specified conditions of external influences

Basic protection: protection against electric shock (corresponds to protection against direct contact)

Fault protection: protection against electric shock under single-fault conditions (generally this corresponds to protection against indirect contact, mainly with regard to failure of basic insulation)

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