January 6th, 2016

Presenter: Dr. Massimo Mitolo, ESI Inc.

# Title: Understanding NEC and IEC in the matter of bonding and grounding of low-voltage power systems

**Event to start shortly**

**Scheduled time: 11:00 USA Eastern Standard Time**

# Webinar Presenter: Dr. Massimo Mitolo

**Massimo Mitolo, Ph.D., P.E., P. Eng.**

- Ph.D. in Electrical Engineering from the University of Napoli "Federico II," Napoli, Italy
- *Prominent Lecturer* of IAS
- Authored over 75 journal papers
- Two books:
  1. *Electrical Safety of Low-Voltage Systems* (McGraw-Hill, 2009)
  2. *Laboratory Manual for Introduction to Electronics: A Basic Approach* (Pearson Prentice-Hall, 2013)
- Registered Professional Engineer in California and Italy
- Currently working as a senior consultant with Engineering Systems Inc. (**ESI**) in Foothill Ranch, CA, USA
- Area of expertise includes electrical safety engineering, and the analysis and grounding of power systems
- Active within the Industrial and Commercial Power Systems Department of IAS, as Department Secretary, Chair of the Power Systems Analysis Subcommittee, and Chair of the Grounding Subcommittee

# Outline

- Identify key concepts in the NEC for bonding and grounding
- Clarify the terminology used by IEC standards, with regards to the protection against indirect contact in ac (50/60 Hz) systems by *automatic disconnection of supply*.
- Examine types of grounding systems
- Examine “Bonding”
- Compare the EGCs/PE Conductor sizing procedures in IEC and NEC
- Discuss key technical concepts present in the IEC world regarding “bonding”

# NEC Art. 90.1 (1)

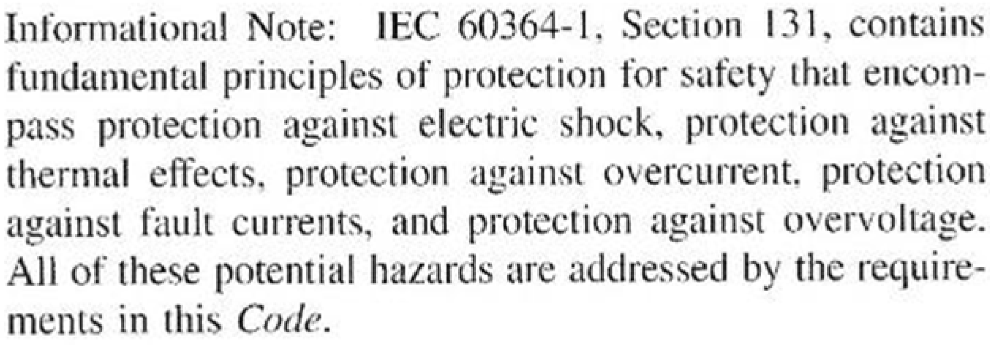
**Purpose.**

*(A)**<u>Practical Safeguarding</u>**. The purpose of this Code is the practical safeguarding <u>of persons and property from hazards arising from the use of electricity</u>.*

*(B)Adequacy. This Code contains provisions that are considered necessary for safety. Compliance therewith and proper maintenance results in an installation that is **<u>essentially</u>** free from hazard but **<u>not necessarily efficient, convenient, or adequate for good service or future expansion of electrical use.</u>***

# NEC Art. 90.1(2)

The requirements in this *Code* address the fundamental principles of protection for safety contained in Section 131 of **IEC 60364-1**, ***Electrical Installation of Buildings:***



Informational Note: IEC 60364-1, Section 131, contains fundamental principles of protection for safety that encompass protection against electric shock, protection against thermal effects, protection against overcurrent, protection against fault currents, and protection against overvoltage. All of these potential hazards are addressed by the requirements in this *Code*.

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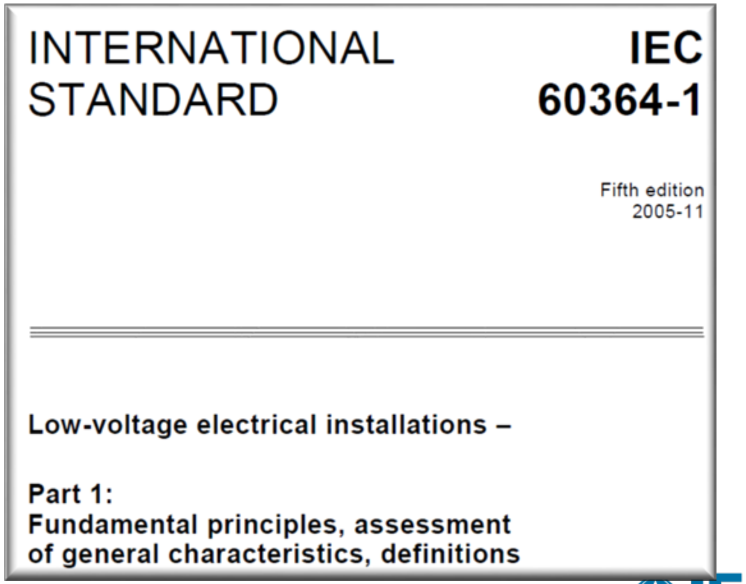


INTERNATIONAL STANDARD

**IEC 60364-1**

Fifth edition
2005-11

**Low-voltage electrical installations –**

**Part 1:**
**Fundamental principles, assessment of general characteristics, definitions**

# NEC Art. 250.4(3)

*Bonding of Electrical Equipment.*

Normally noncurrent-carrying conductive materials enclosing electrical conductors or equipment, or forming part of such equipment, shall be connected together and to the electrical supply source in a manner that establishes an effective ground fault current path.

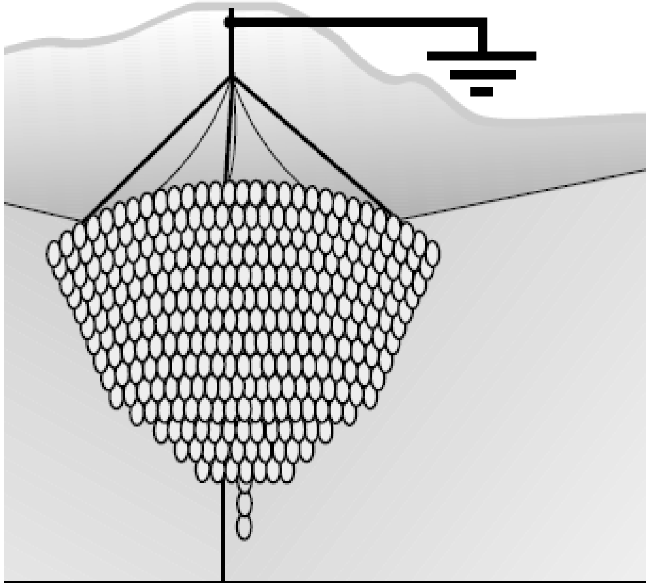
# NEC Art. 250.4(4)

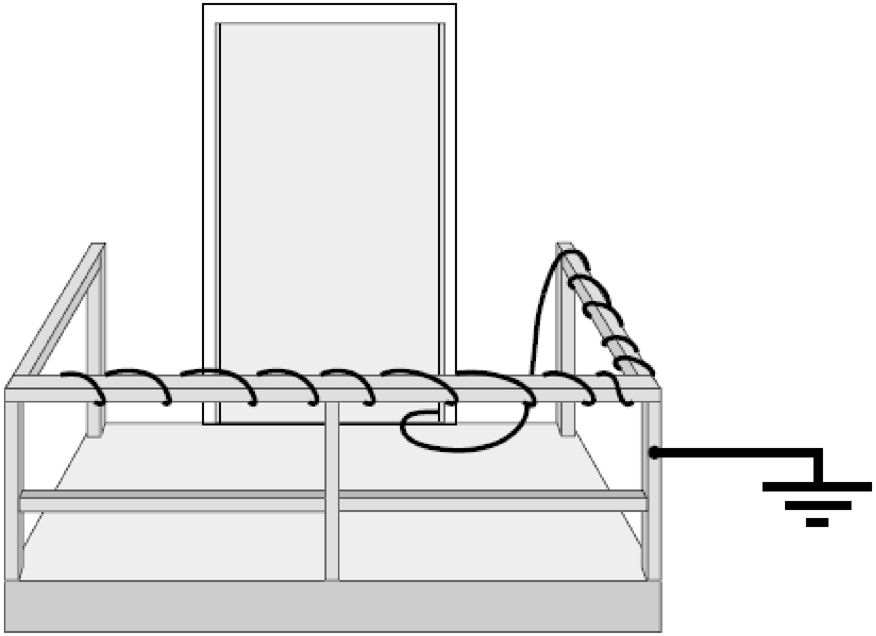
## *Bonding of Electrically Conductive Materials and Other Equipment*

Normally non-current-carrying electrically conductive materials that are likely to become energized shall be connected together and to the electrical supply source in a manner that establishes an effective ground fault current path.

# IEC 60364-1 Definitions (1)

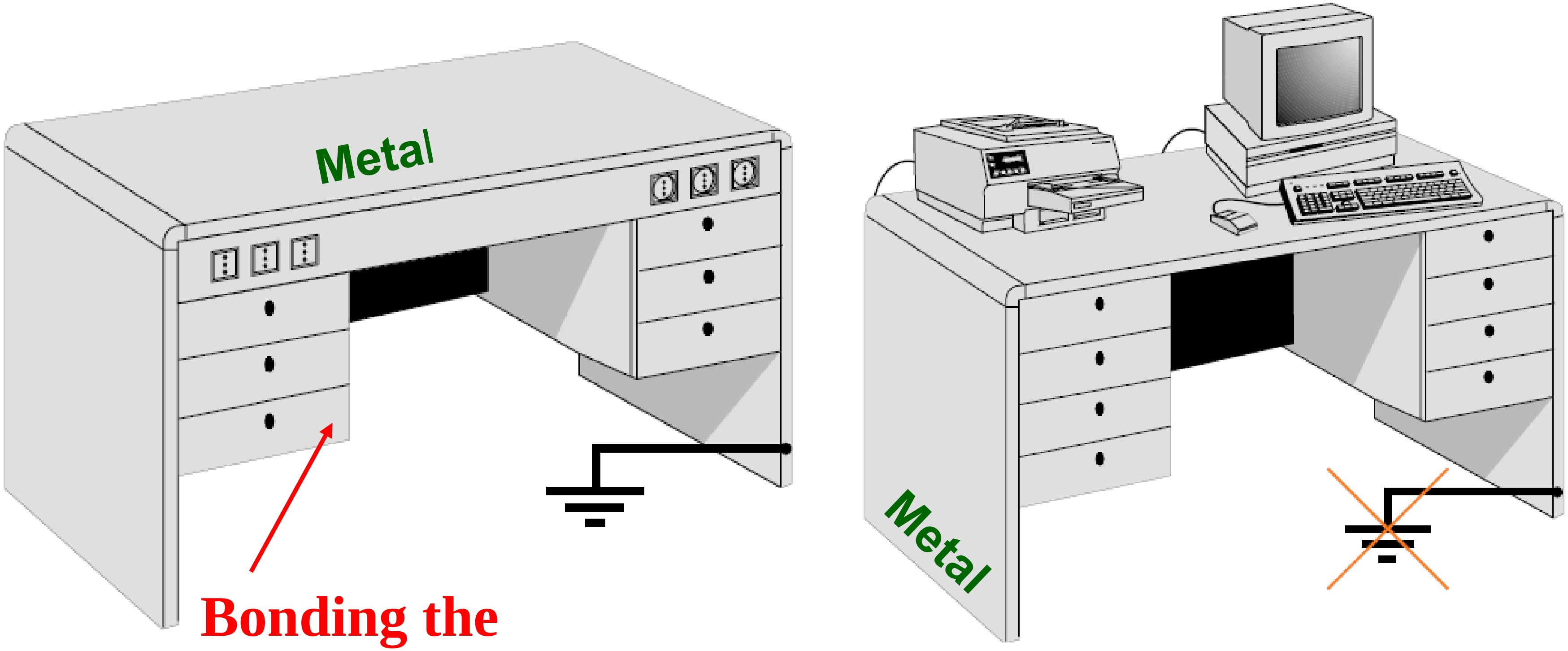
Exposed-Conductive-Parts (*ECP*): conductive elements, forming part of the electrical system, which can be touched (even if out of reach) and is not live, but likely to become live **when basic insulation fails**.





# IEC 60364-1 Definitions (2)

A conductive part of electrical equipment, which can only become live through contact with an *ECP*, which has become live, **is not considered an ECP by IEC**.



**Bonding the drawers?**

# IEC 60364-1 Definitions (3)

- **direct contact**: contacts with parts normally live (e.g. a damaged wire)
- **indirect contact**: contacts with metal parts normally not energized, but likely to become live upon faults (e.g. faulty equipment).
- Protections against direct and indirect contact are also respectively referred to as ***basic*** and ***fault*** protections.

# IEC 60364-1 Definitions (4)

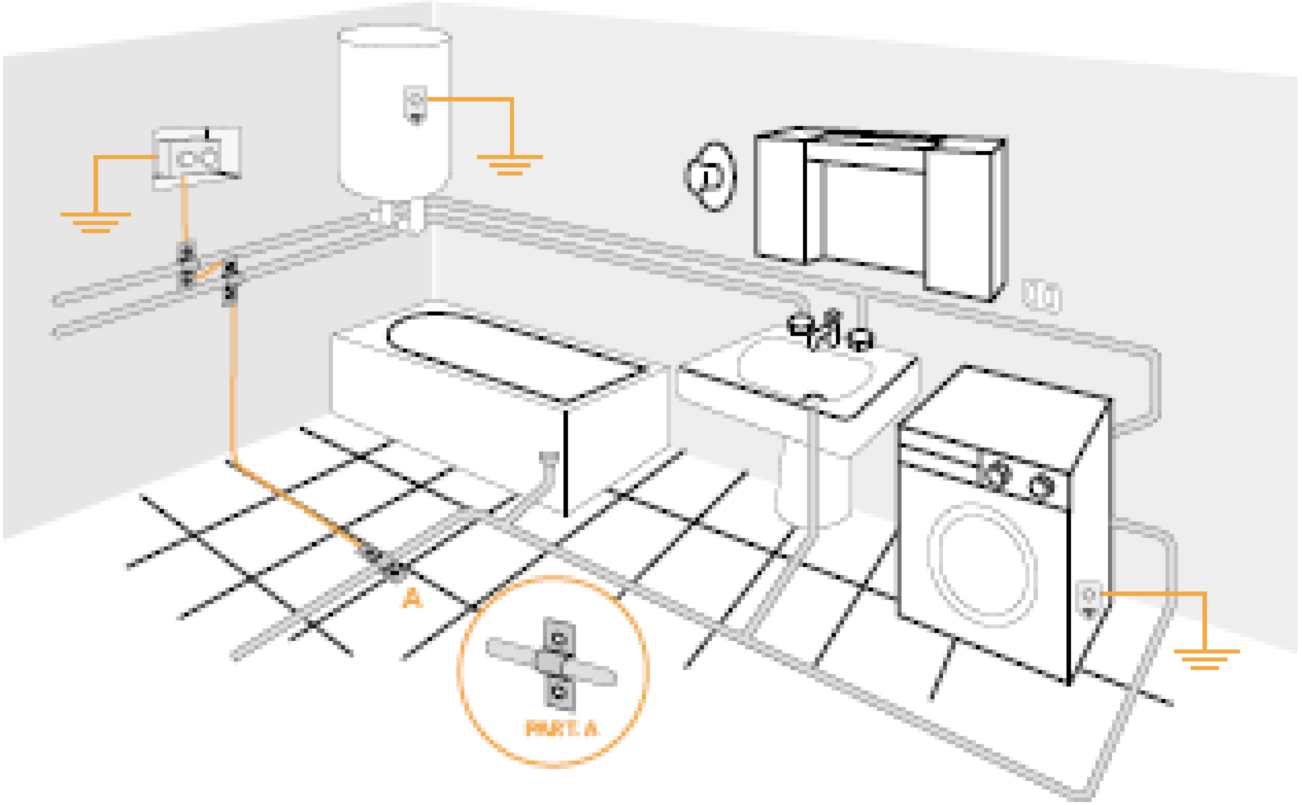
Both **IEC** and **NEC** prescribe that ECPs shall:

- be connected to the same earthing system individually, in groups or collectively, via a ***protective conductor*** (PE).
- be connected to earth, together and to the electrical supply source via an ***equipment grounding conductor***.

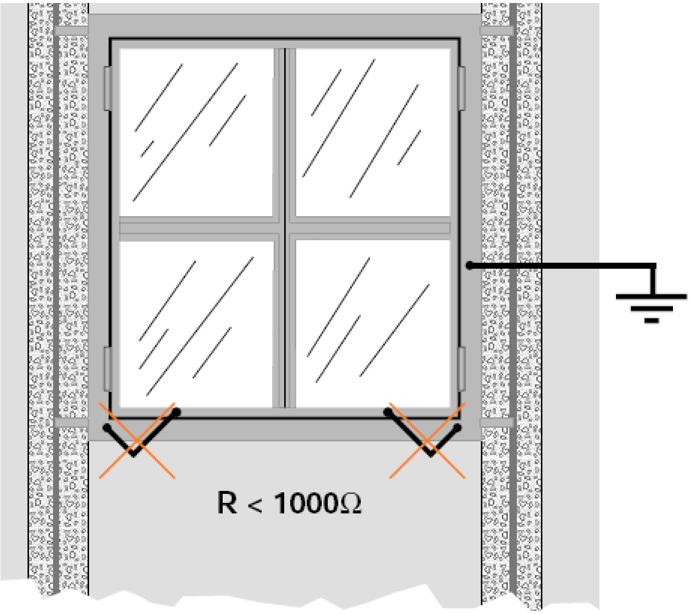
IEEE Standard P3003.2 "*Recommended Practice for Equipment Grounding and Bonding in Industrial and Commercial Power Systems*"; August 2014.

# IEC 60364-1 Definitions (5)

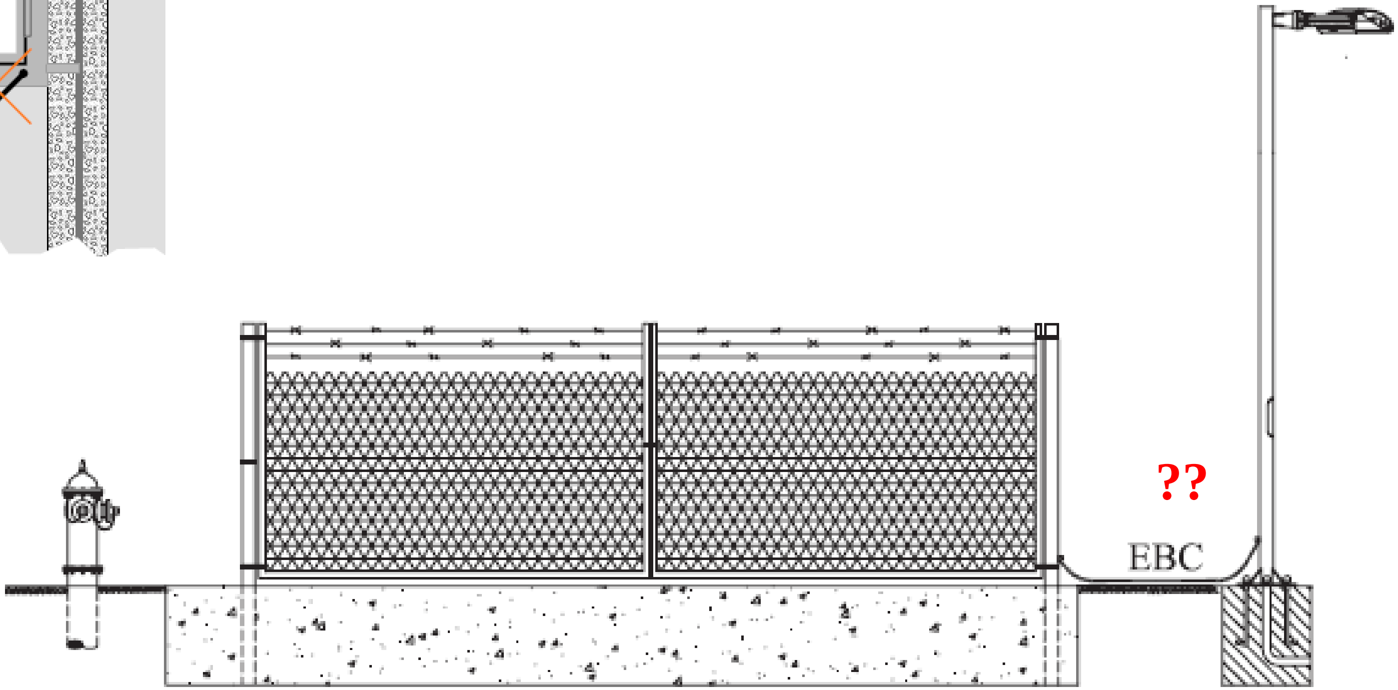
**Extraneous-Conductive-Parts (EXCP)**: conductive elements, not forming part of the electrical system, liable to introduce a <u>“zero” potential</u> or an arbitrary potential.



# continued EXCP



Jamb non-intentionally grounded if in contact with re-bars.



# continued EXCP

Totem: one that serves as an emblem or revered symbol

# NEC Grounding Electrode (1)

NEC defines the IEC EXCPs as non-intentional **ground electrodes** within the facility, such as:

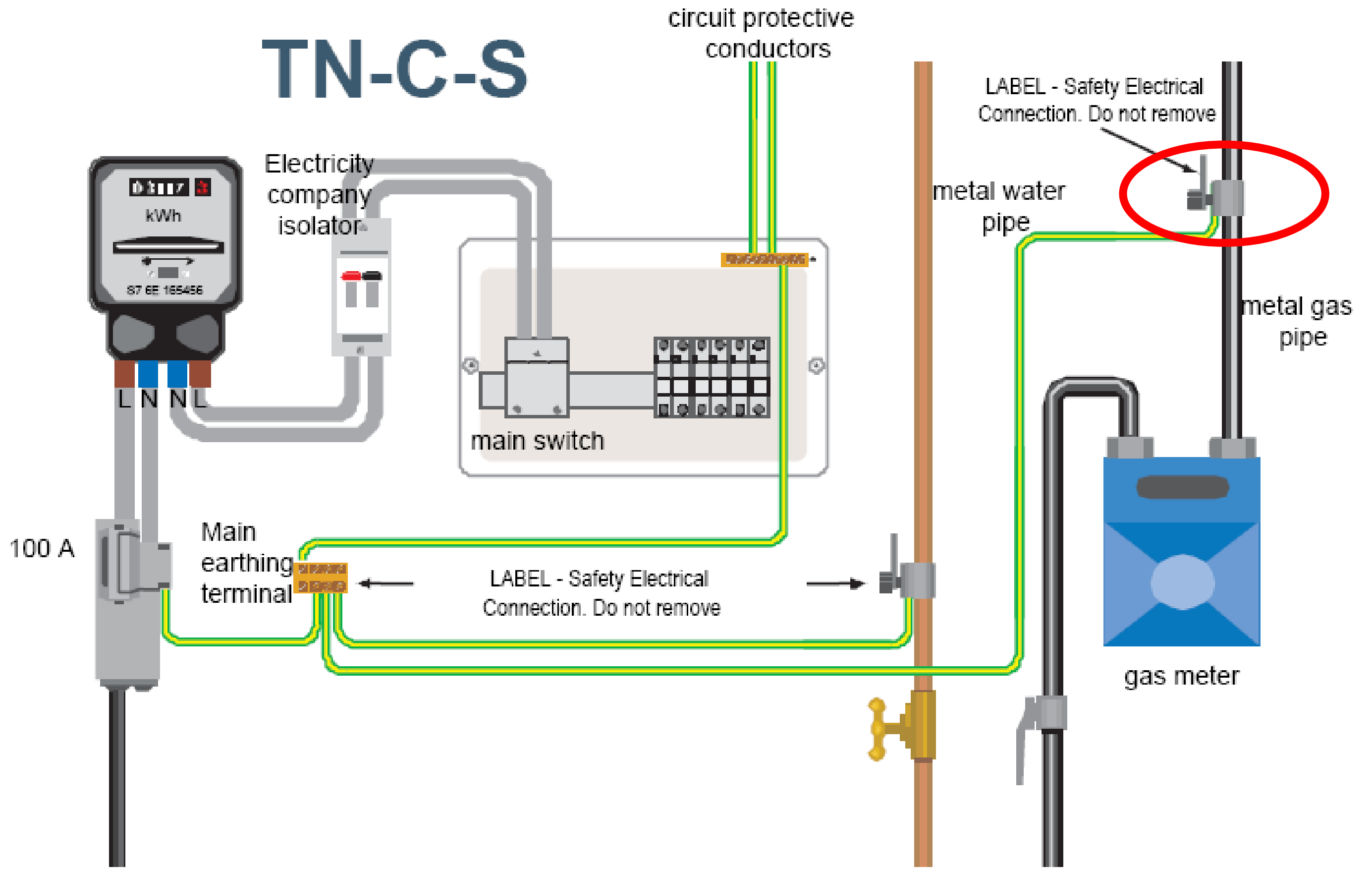
- metal underground water pipe
- metal frame of the building (if effectively grounded)
- reinforcing bars in concrete foundations.

"[…] *All the grounding electrodes present in a building must be bonded together to form a grounding electrode system.*"

# Grounding Electrode (2)

NEC Article 250.68 (B): [...] Where necessary to ensure the grounding path for a metal piping system used as a grounding electrode, ***bonding*** *shall be provided around insulated joints and around any equipment likely to be disconnected for repairs or replacement* […].

# Grounding Electrode (3)



**Both IEC and NEC do not permit the metal gas pipe to be an earth electrode.**

<u>However</u>:

- IEC does require always the <u>bonding</u> of gas pipes (load side of meter).
- NEC does require the <u>bonding</u> of gas pipes installed in buildings **only if** they are <u>likely to become energized</u> (250.104(B)).

# Ground electrode (3)

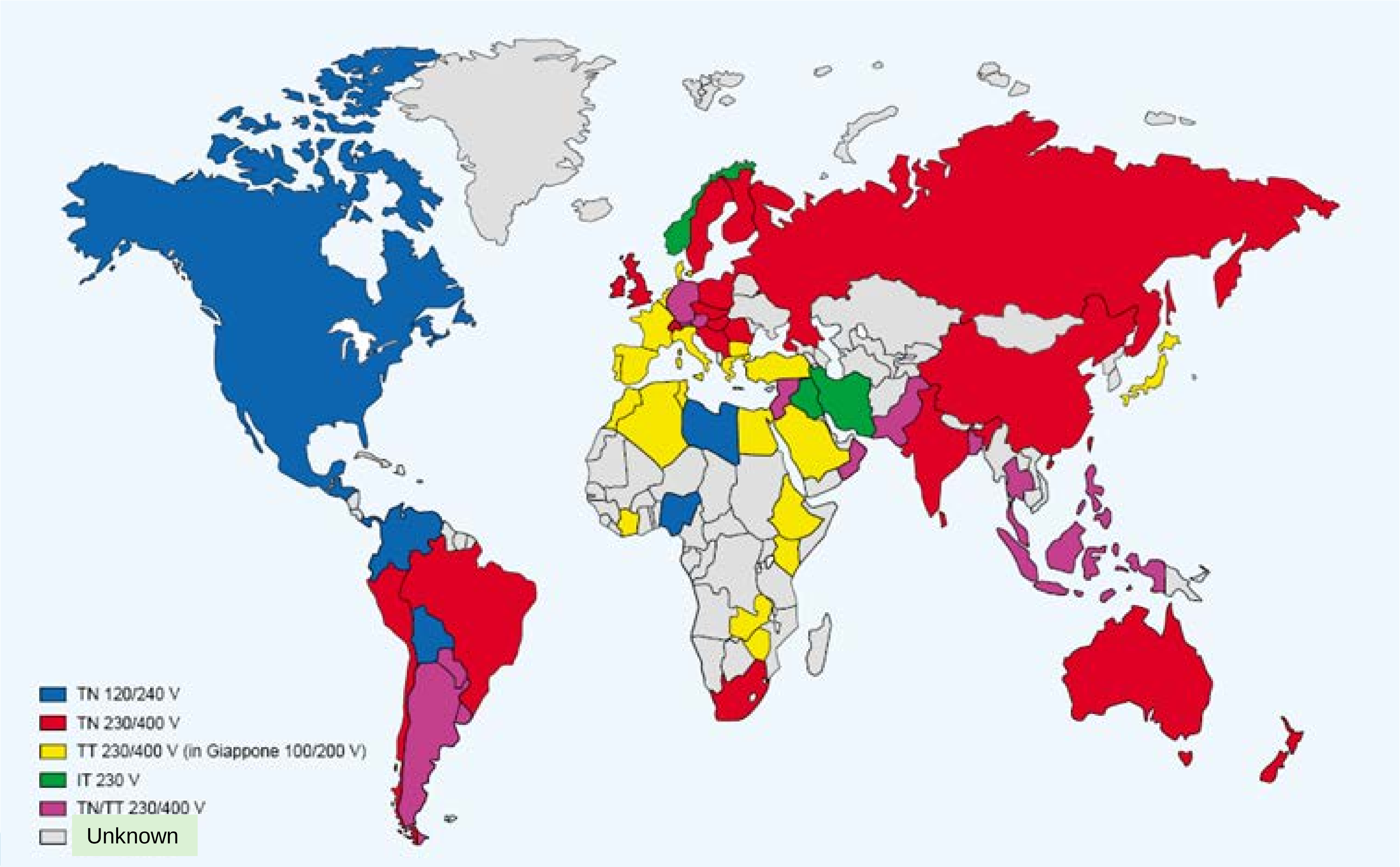
- IEC 60364-5-54 does not permit water pipes to be relied upon as earth electrodes, even with the consent of the water distributor, being questionable their metallic continuity in time;

- both NEC and IEC 60364-5-54 concur that metallic pipes employed for flammable liquids or gases must not be used as an earth electrode.

- However, as per IEC 60364-5-54 this requirement does not preclude the **protective bonding** connection of such pipes on the load side of the meter.

IEC 60364-5-54 "*Electrical installations of buildings –Part 5-54: "Selection and erection of electrical equipment – Earthing arrangements, protective conductors and protective bonding conductors*":

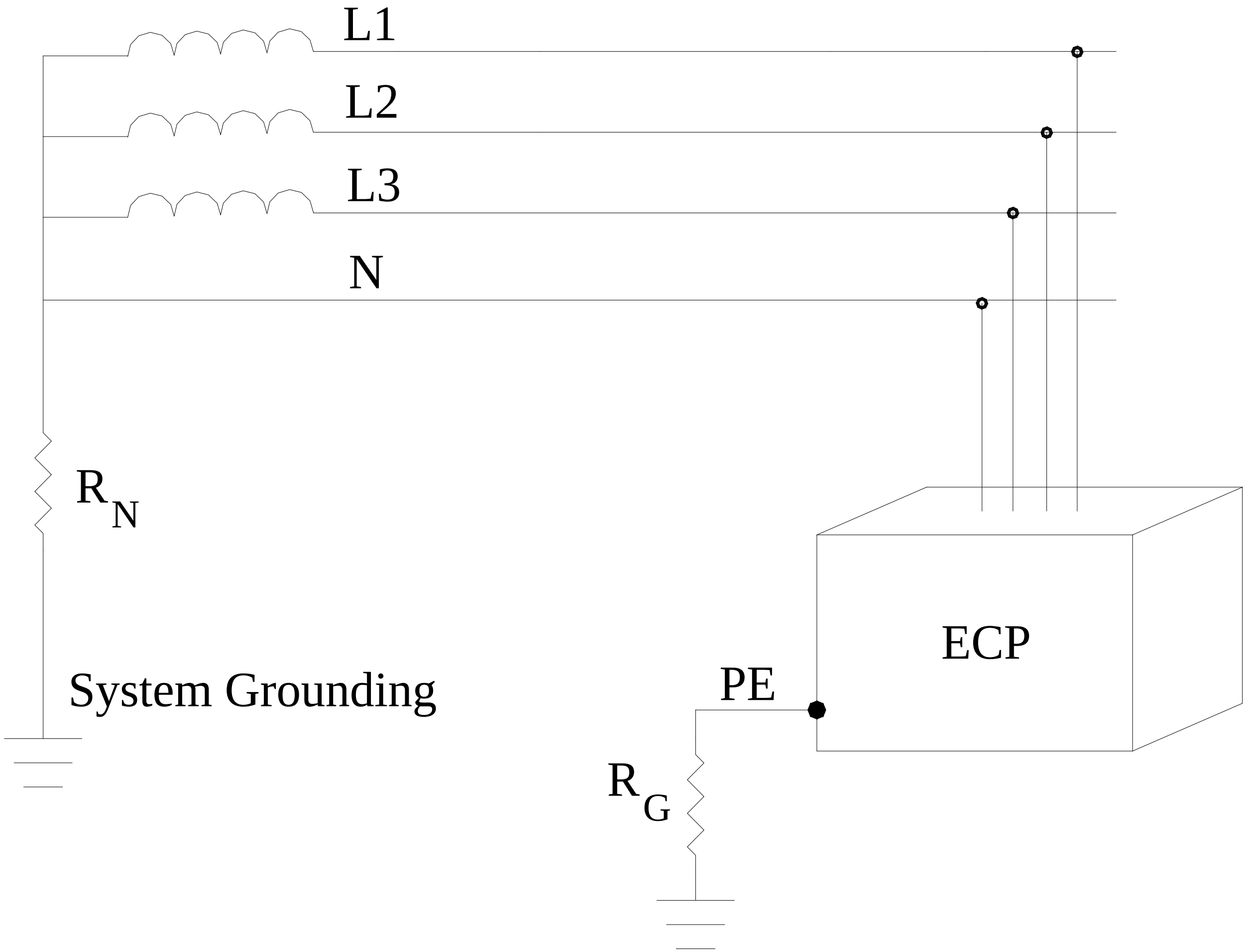
# World Grounding Map



# TT (Terre – Terre) Systems

Algeria, Belgium, Denmark, Egypt, France, Greece, Italy, Japan, Kenya, Luxemburg, Morocco, Tunisia, Spain, Portugal, Turkey, United Arab Emirates, etc.

# TT System (1)

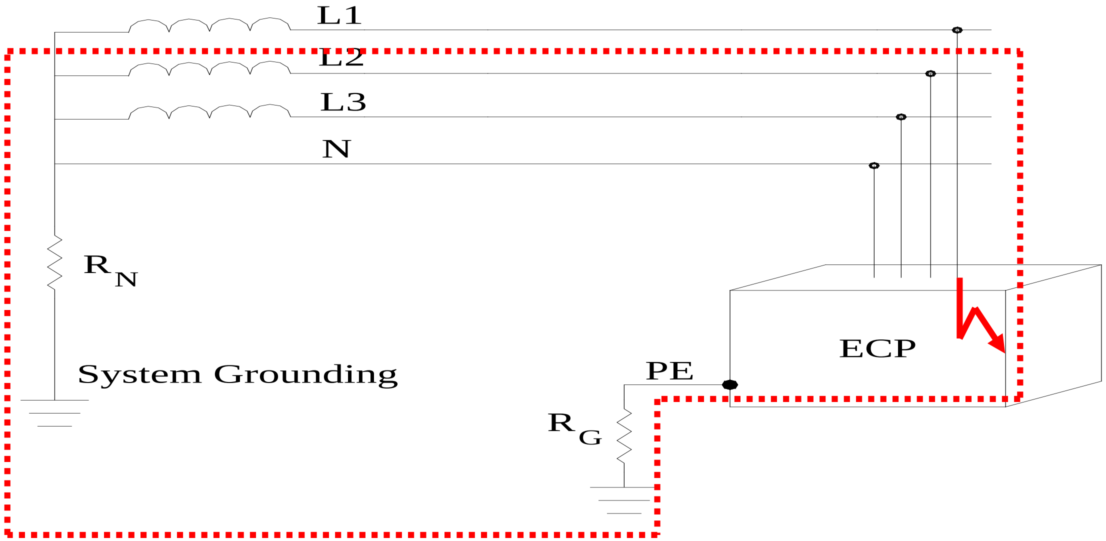


ECPs are connected to earth independently of the ground electrodes of the source.

The ground-fault current $I_G$ returns to the source through the actual earth.

# TT System (2)

Overcurrent devices can protect against indirect contact only if the following condition is fulfilled:



$$I_G = \frac{V_{ph}}{Z_{Loop}} \geq I_a$$

- **$Z_{Loop}$**= summation of fault-loop impedances of the source + the line conductor up to the point of the fault + the user's ground $R_G$ + the utility ground $R_N$.
- **$I_a$** is the current that causes the tripping of the over-current protective device within the safe time specified in the following **Table** (applicable to final/branch circuits not exceeding 32 A)

# TT System (3)

| Voltage (V) | Maximum disconnection times $t_a$ (s) |
|---|---|
| $50 < V_{ph} \leq 120$ | 0.3 |
| $120 < V_{ph} \leq 230$ | 0.2 |
| $230 < V_{ph} \leq 400$ | 0.07 |
| $V_{ph} > 400$ | 0.04 |

# TT System (4)

In practice, the previous condition is very difficult to fulfill, as generally, $Z_{Loop}$ is not a sufficiently low value.

*Residual Current Devices* (RCDs) (also referred to as *Ground Fault Circuit Interrupters* (GFCIs) in the NEC) must be employed.

$$\mathbf{R_G \cdot I_{dn} \leq 50\ V}$$

$I_{dn}$ is the rated residual operating current of the *RCD* in amperes, providing supply disconnection in the time specified in the previous Table.

# TT System (5)

## NEC Art. 250.4(5)

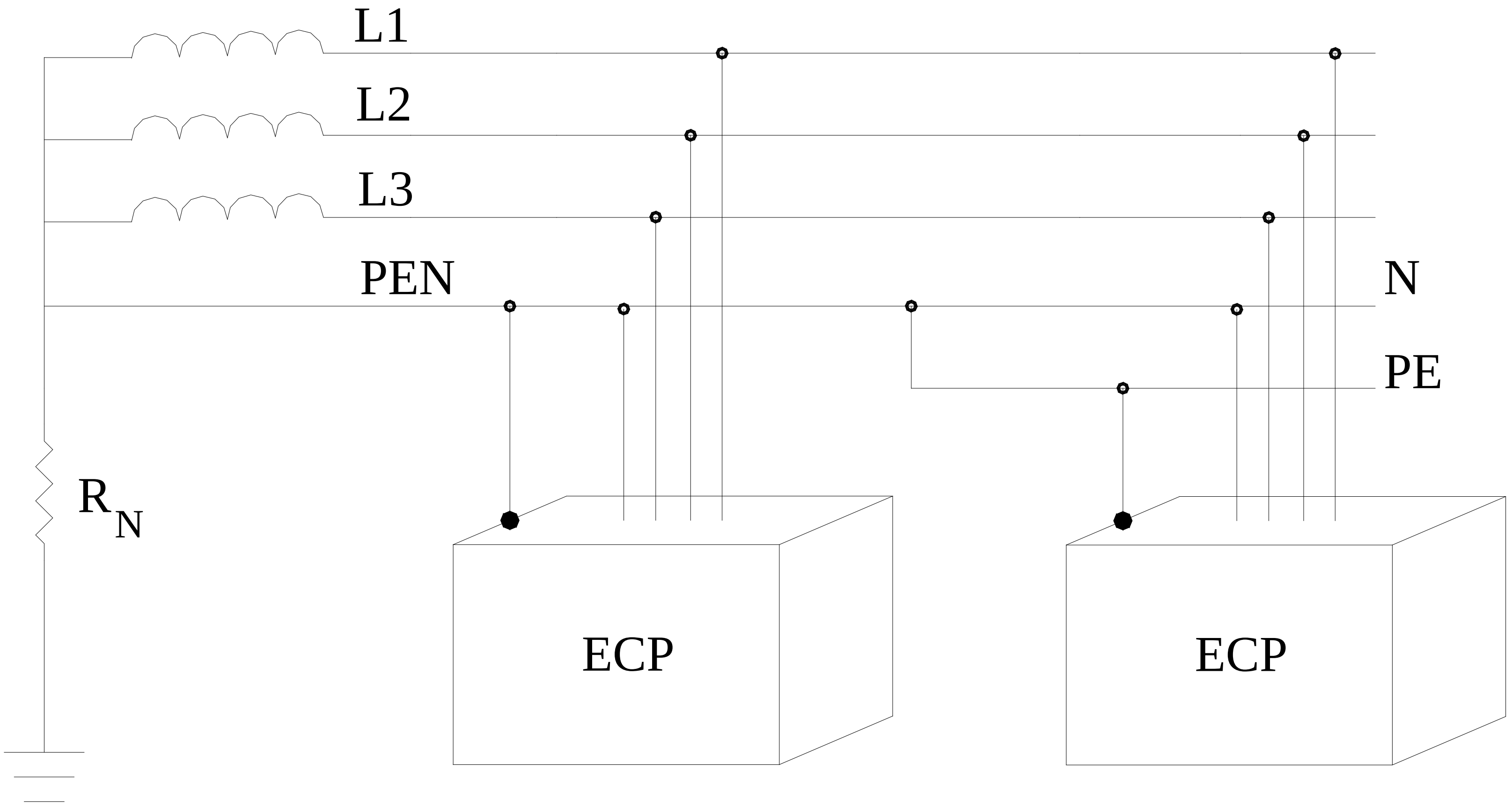
### Effective Ground-Fault Current Path

(5). Electrical equipment and wiring and other electrically conductive material likely to become energized shall be installed in a manner that creates a low-impedance circuit facilitating the operation of the overcurrent device or ground detector for high-impedance grounded systems. It shall be capable of safely carrying the maximum ground-fault current likely to be imposed on it from any point on the wiring system where a ground fault may occur to the electrical supply source. **The earth shall not be considered as an effective ground-fault current path**

# TN (Terre – Neutral) Systems

Australia, Canada, Germany, South Africa, Sweden, Switzerland, the UK, USA, etc.

# TN System (1)

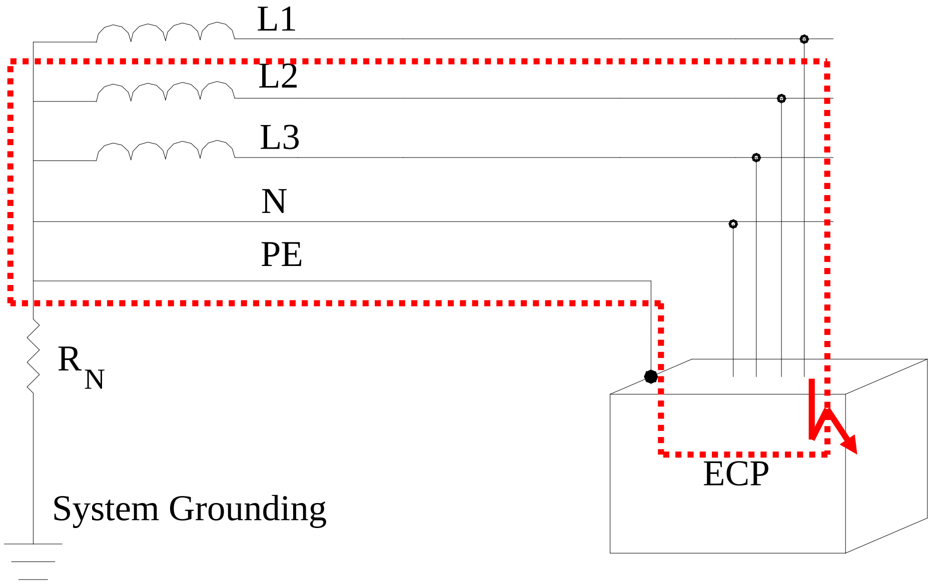


ECPs are directly connected to the solidly grounded point of the source.

# TN System (2)

Protective devices (i.e. overcurrent/RCD) can protect against indirect contact only if the following condition is fulfilled:

$$Z_{Loop} \cdot I_a \leq V_{ph}$$



- $\mathbf{Z_{Loop}}$= summation of fault-loop impedances of the source + the line conductor up to the point of the fault + the protective conductor between the point of the fault and the source.

- $\mathbf{I_a}$ is the current that causes the tripping of the over-current protective device within the safe time specified in the following **Table:**

# TN System (3)

| **Voltage (V)** | **Maximum disconnection times $t_a$ (s)** |
|---|---|
| $50 < V_{ph} \leq 120$ | 0.8 |
| $120 < V_{ph} \leq 230$ | 0.4 |
| $230 < V_{ph} \leq 400$ | 0.2 |
| $V_{ph} > 400$ | 0.1 |

# IT (Isolation -Terre) Systems

Norway; Albania; Iran; Iraq; Peru; critical facilities

# IT System (1)

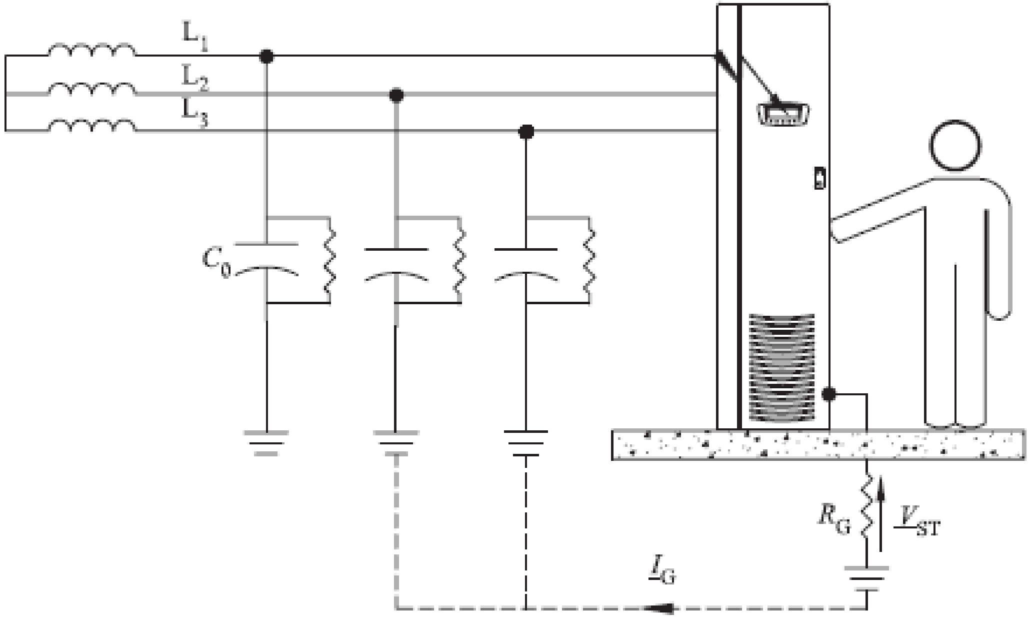
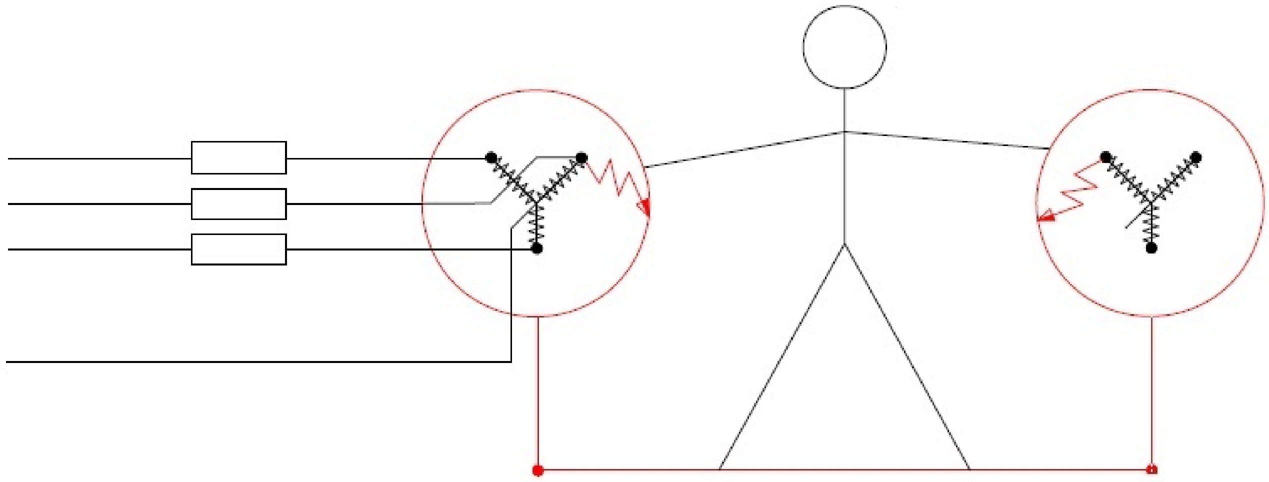


**FIGURE 9.2** Earth current flowing through the ECPs ground and the capacitive system impedance to ground.

Excerpted from: M. Mitolo *"Electrical Safety of Low-Voltage Systems", McGraw-Hill, 2009*

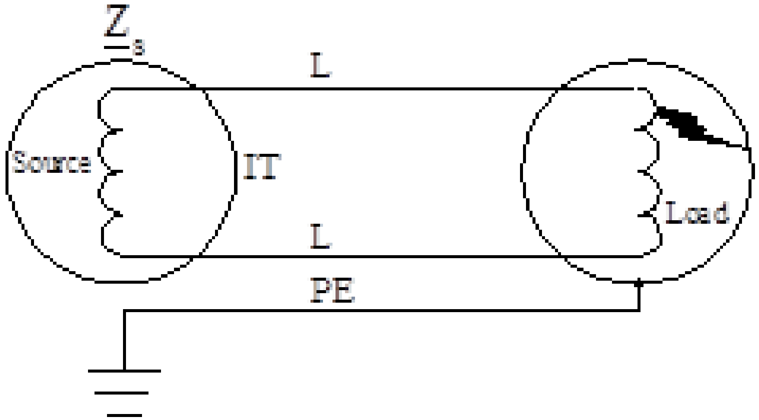
The capacitive current, although relatively small (i.e., tens of amperes), is large enough to be lethal to persons. To avoid this hazard, the ECPs shall be grounded.

# IT System (2)
# Equipotential bonding



- Connections between enclosures of equipment and EXCPs, when simultaneously accessible.
- The equipotential bonding should also connect, if practicable, the metal frame of the building or the reinforced bars embedded in the structure's concrete.

# Public IT System (3)

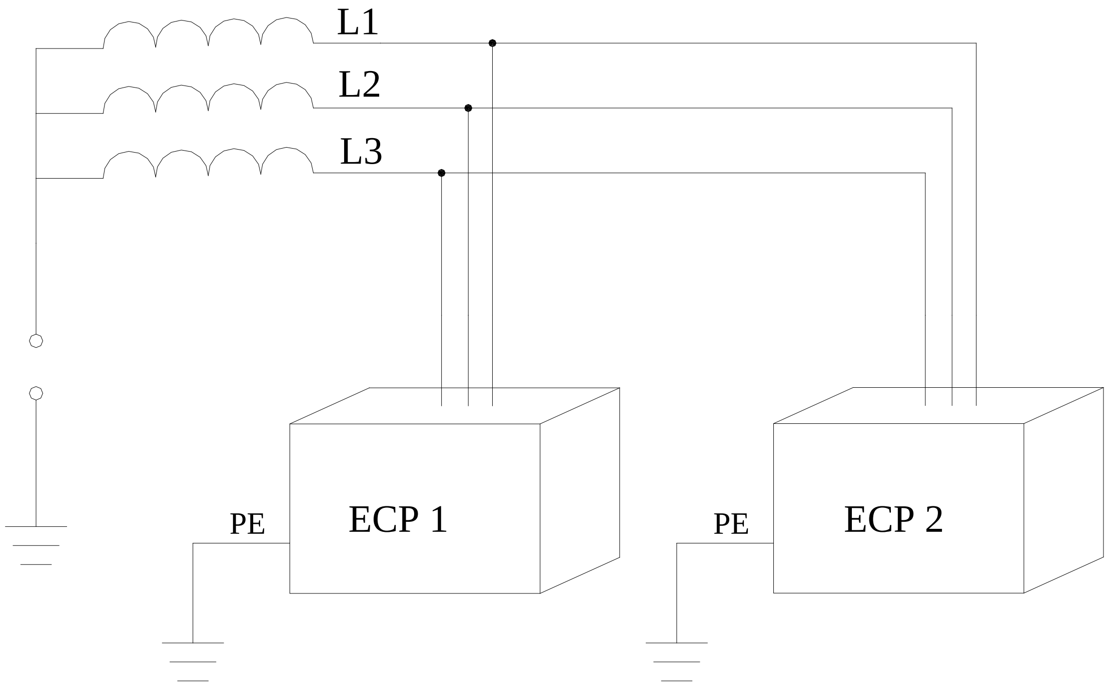


- The neutral point of the source of energy may be connected to earth through a *spark gap*, (also referred to as a *disneuter*) for protection against overvoltages

- the utility generally delivers the PE to low-voltage dwelling units in urban areas, where it is connected to a local earthing electrode;

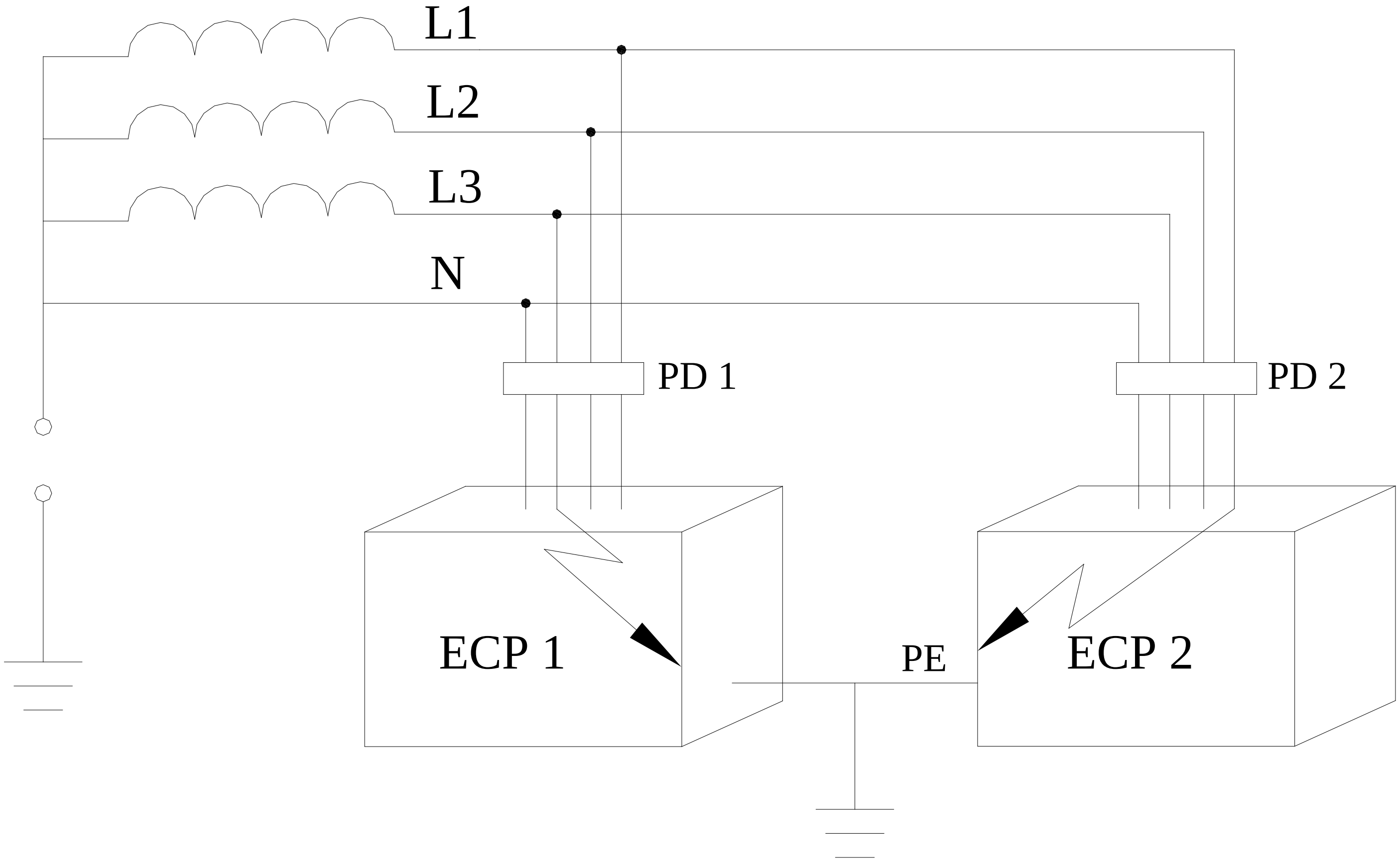
- Outside the city centers and in rural areas, the PE is generally not shipped, and user’s equipment is solely grounded through their local earthing electrode

# IT System (4)



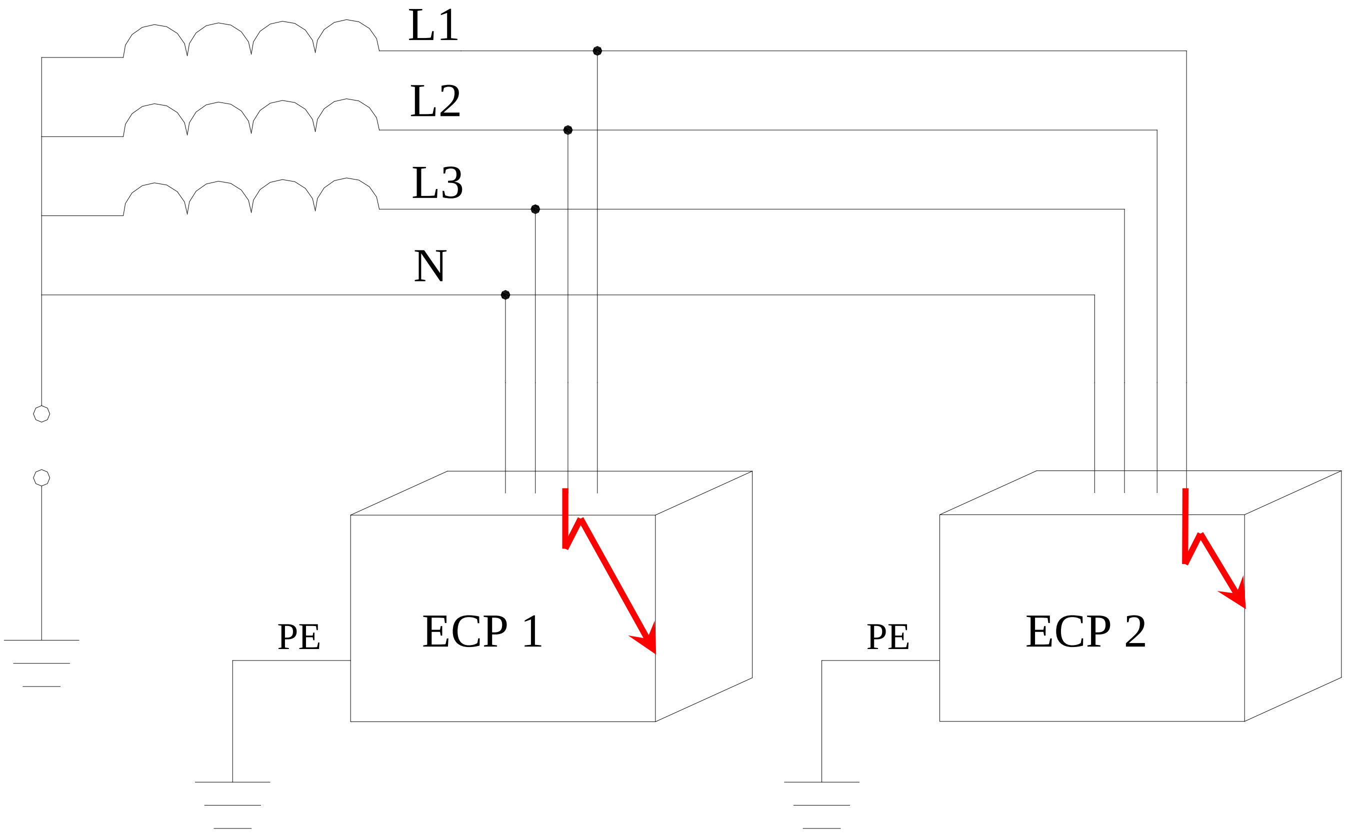
- Source is isolated from ground, or connected to it through sufficiently high impedance (e.g. 5 A rated neutral grounding resistor).
- <u>Although not forbidden</u>, it is advisable not to ship the neutral wire to loads, in order to safeguard its isolation from ground.
- ECPs are required to be grounded individually, or

# IT System (5)



- In groups, or collectively.
- if touch voltages are less than 50 V, the disconnection of supply as a protection against indirect contact is neither required, nor necessary for safety

# IT System (6) (individually grounded )



Upon the second ground-fault, **the IT system becomes TT**, and the following safety condition must be fulfilled for each and every ECP:

$$R_G \cdot I_a \leq 50\ V$$

# IT System (7) (collectively grounded)

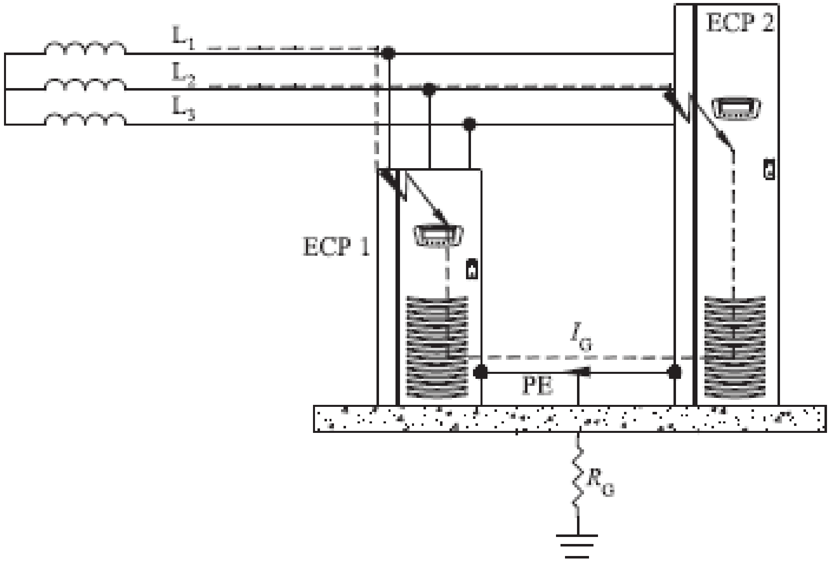


**FIGURE 9.9** ECPs earthed collectively to a single grounding system (neutral not distributed).

Excerpted from: M. Mitolo "*Electrical Safety of Low-Voltage Systems*", *McGraw-Hill, 2009*

Upon the second L-G ground-fault, **the IT system becomes TN,** and the following safety condition must be fulfilled:

$$\frac{\sqrt{3}V_{ph}}{2Z_S} \geq I_a$$

# IT System (8) (with neutral wire)

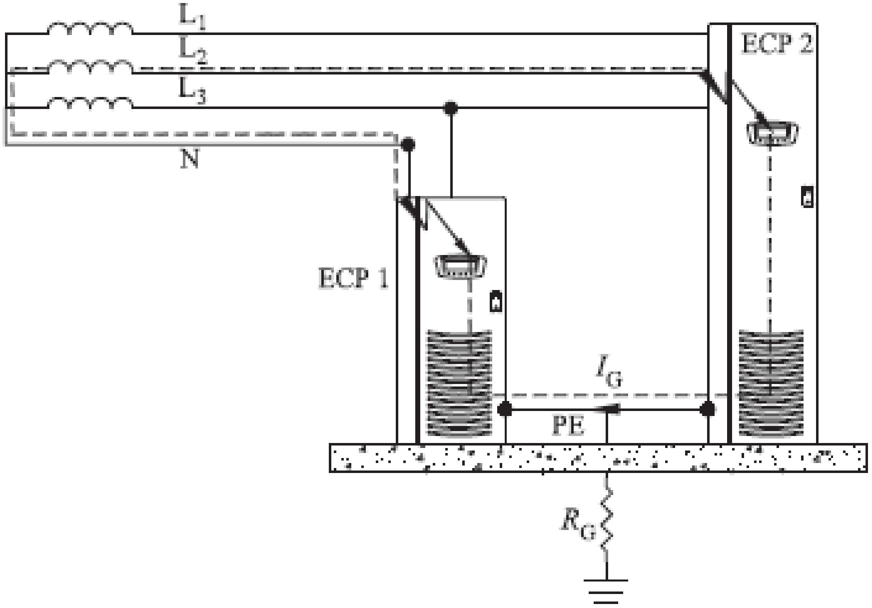


**FIGURE 9.11** First or second fault involving the neutral conductor in IT systems.

Excerpted from: M. Mitolo *"Electrical Safety of Low-Voltage Systems", McGraw-Hill, 2009*

Upon the 2nd N-G ground-fault, the following safety condition must be fulfilled :

$$\frac{V_{ph}}{2Z_S'} \geq I_a$$

# Sizing EGCs (NEC)

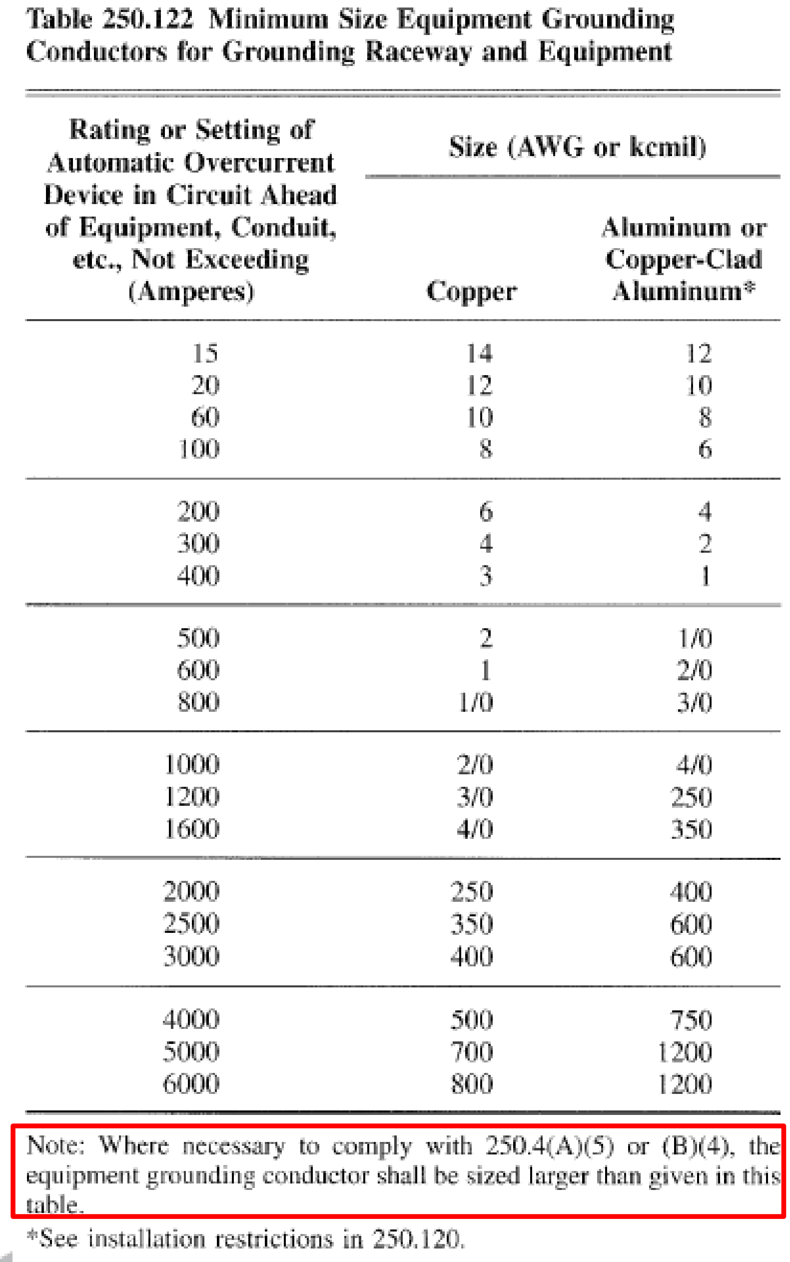


Table 250.122 Minimum Size Equipment Grounding Conductors for Grounding Raceway and Equipment

| Rating or Setting of Automatic Overcurrent Device in Circuit Ahead of Equipment, Conduit, etc., Not Exceeding (Amperes) | Size (AWG or kcmil) | |
|---|---|---|
| | Copper | Aluminum or Copper-Clad Aluminum* |
| 15 | 14 | 12 |
| 20 | 12 | 10 |
| 60 | 10 | 8 |
| 100 | 8 | 6 |
| 200 | 6 | 4 |
| 300 | 4 | 2 |
| 400 | 3 | 1 |
| 500 | 2 | 1/0 |
| 600 | 1 | 2/0 |
| 800 | 1/0 | 3/0 |
| 1000 | 2/0 | 4/0 |
| 1200 | 3/0 | 250 |
| 1600 | 4/0 | 350 |
| 2000 | 250 | 400 |
| 2500 | 350 | 600 |
| 3000 | 400 | 600 |
| 4000 | 500 | 750 |
| 5000 | 700 | 1200 |
| 6000 | 800 | 1200 |

Note: Where necessary to comply with 250.4(A)(5) or (B)(4), the equipment grounding conductor shall be sized larger than given in this table.

*See installation restrictions in 250.120.

| $S_{EGC}$ (AWG) | $S_{EGC}$ ($mm^2$) |
|---|---|
| #14 | 2.08 |
| #12 | 3.31 |
| #10 | 5.26 |
| #10 | 5.26 |
| #10 | 5.26 |
| #8 | 8.36 |
| #6 | 13.30 |

# Sizing Protective Conductors

## (IEC 60364-5-54)

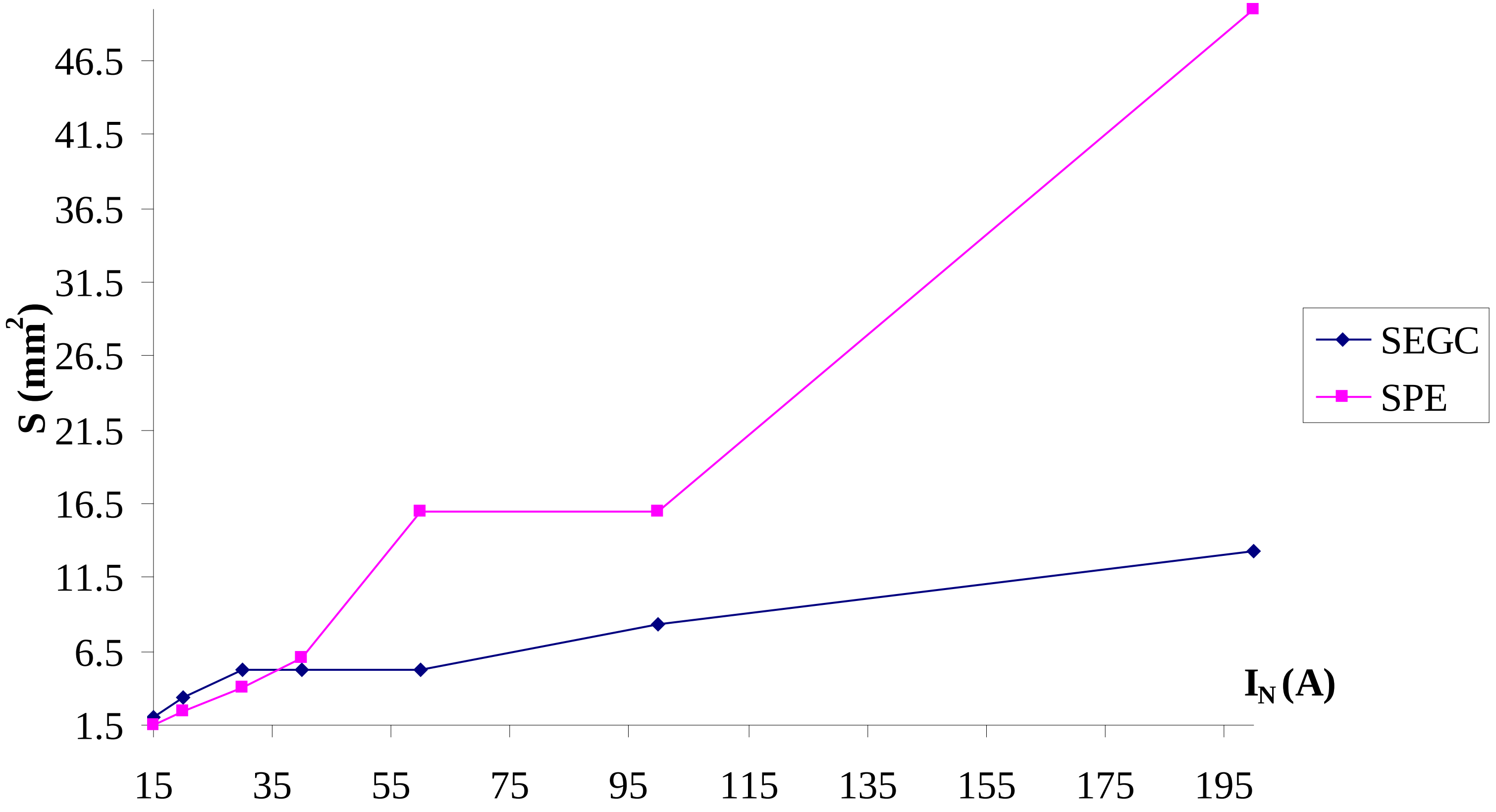
Minimum sizes as a function of the cross-sectional area S of the phase conductor

| **Phase conductor S ($mm^2$)** | **PE ($mm^2$)** |
|---|---|
| $S \leq 16$ | S |
| $16 < S \leq 35$ | 16 |
| $S > 35$ | S/2 |

# A comparison between EGC and PE (1)

| NEC | | | IEC | | |
|---|---|---|---|---|---|
| $I_N$ (A) | $S_{EGC}$ (AWG) | $S_{EGC}$ (mm$^2$) | $I_Z$ (A) | S (mm$^2$) (trade size) | $S_{PE}$ (mm$^2$) (trade sizes) |
| 15 | #14 | 2.08 | 17.5 | 1.5 | 1.5 |
| 20 | #12 | 3.31 | 24 | 2.5 | 2.5 |
| 30 | #10 | 5.26 | 32 | 4 | 4 |
| 40 | #10 | 5.26 | 41 | 6 | 6 |
| 60 | #10 | 5.26 | 76 | 16 | 16 |
| 100 | #8 | 8.36 | 101 | 25 | 16 |
| 200 | #6 | 13.30 | 232 | 95 | 50 |

# A comparison between EGC and PE (2)



# Ground Electrode conductor (1)

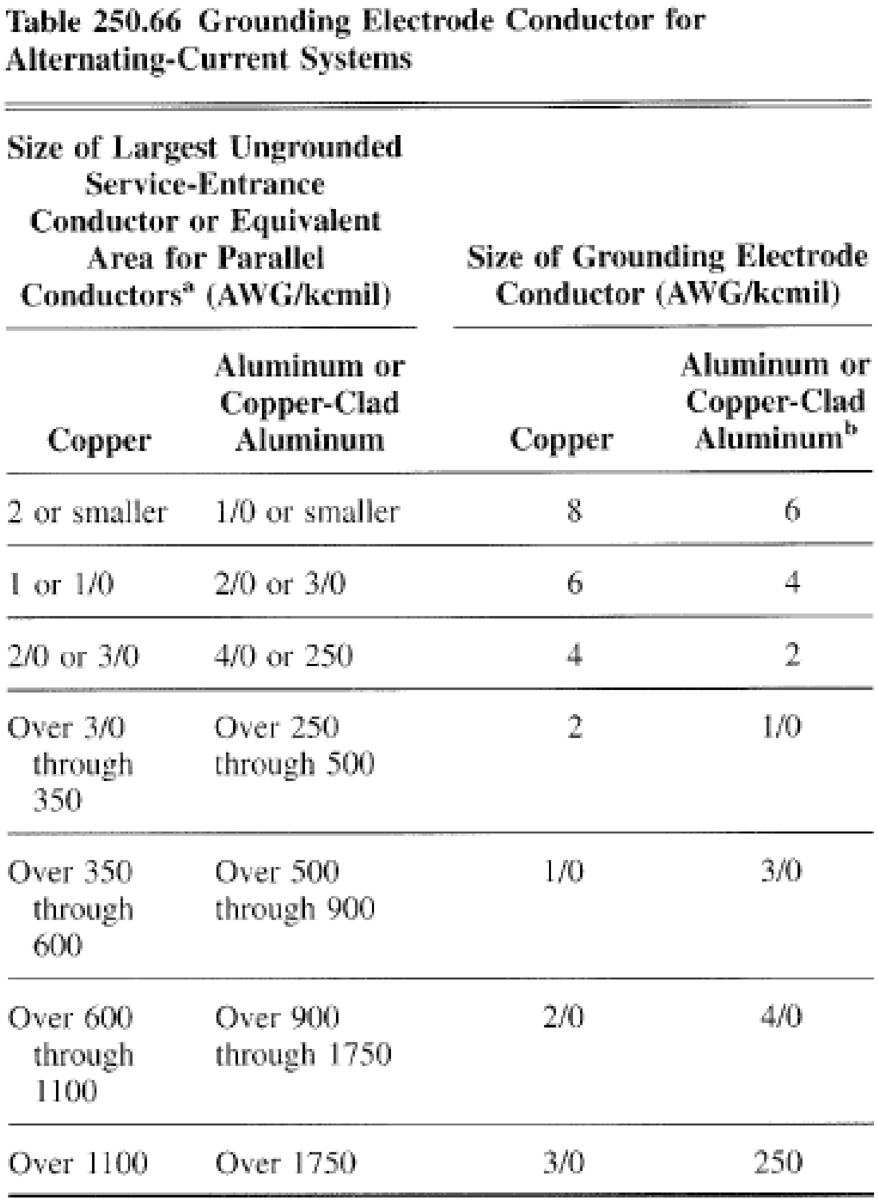


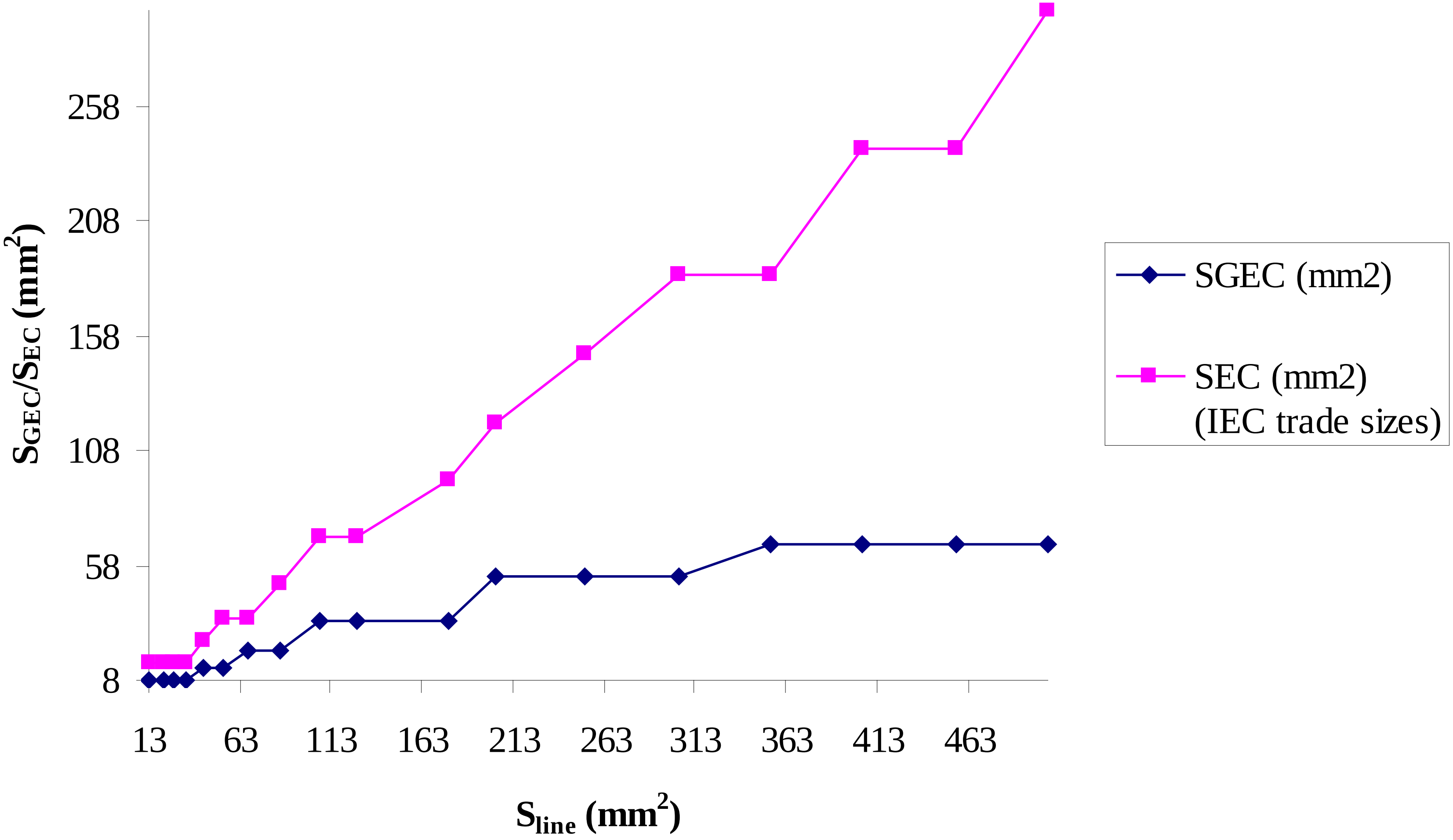
**Table 250.66 Grounding Electrode Conductor for Alternating-Current Systems**

| Size of Largest Ungrounded Service-Entrance Conductor or Equivalent Area for Parallel Conductors[a] (AWG/kcmil) | | Size of Grounding Electrode Conductor (AWG/kcmil) | |
|---|---|---|---|
| **Copper** | **Aluminum or Copper-Clad Aluminum** | **Copper** | **Aluminum or Copper-Clad Aluminum[b]** |
| 2 or smaller | 1/0 or smaller | 8 | 6 |
| 1 or 1/0 | 2/0 or 3/0 | 6 | 4 |
| 2/0 or 3/0 | 4/0 or 250 | 4 | 2 |
| Over 3/0 through 350 | Over 250 through 500 | 2 | 1/0 |
| Over 350 through 600 | Over 500 through 900 | 1/0 | 3/0 |
| Over 600 through 1100 | Over 900 through 1750 | 2/0 | 4/0 |
| Over 1100 | Over 1750 | 3/0 | 250 |

# Ground Electrode conductors (2)

| $S_{\text{line conductor}}$ | $S_{\text{line conductor}}$ (mm²) | $S_{\text{GEC}}$ | $S_{\text{GEC}}$ (mm²) | $S_{\text{EC}}$ (mm²) | $S_{\text{EC}}$ (mm²) IEC trade sizes |
|---|---|---|---|---|---|
| 1 | 2 | 3 | **4** | 2 | **2.5** |
| #6 or smaller | 13.3 | #8 | **8.36** | 13.3 | **16** |
| #4 | 21.15 | #8 | **8.36** | 16 | **16** |
| #3 | 26.67 | #8 | **8.36** | 16 | **16** |
| #2 | 33.62 | #8 | **8.36** | 16 | **16** |
| #1 | 42.41 | #6 | **13.3** | 21.2 | **25** |
| #1/0 | 53.49 | #6 | **13.3** | 26.74 | **35** |
| #2/0 | 67.43 | #4 | **21.15** | 33.71 | **35** |
| #3/0 | 85.01 | #4 | **21.15** | 42.5 | **50** |
| #4/0 | 107.2 | #2 | **33.62** | 53.6 | **70** |
| 250 | 127 | #2 | **33.62** | 63.5 | **70** |
| 350 | 177 | #2 | **33.62** | 88.5 | **95** |
| 400 | 203 | #1/0 | **53.49** | 101.5 | **120** |
| 500 | 253 | #1/0 | **53.49** | 126.5 | **150** |
| 600 | 304 | #1/0 | **53.49** | 152 | **185** |
| 700 | 355 | #2/0 | **67.43** | 177.5 | **185** |
| 800 | 405 | #2/0 | **67.43** | 202.5 | **240** |
| 900 | 456 | #2/0 | **67.43** | 228 | **240** |
| 1000 | 507 | #2/0 | **67.43** | 253.5 | **300** |
| 1250 | 633 | #3/0 | **85.01** | 316.5 | **-** |

# Ground Electrode conductors (3)



# Conclusions

- Careful determination of the specific earthing system adopted in the system being designed, which may vary with/within the country and/or the application.
- Fault-loops do not necessarily include the actual earth, therefore the terms earth/ground as applied to conductors should be used accordingly to prevent confusion.
- IEC yields larger minimum cross-sectional areas of protective/earthing conductors than NEC.

# IAS WEBINAR SERIES
# Questions and Answers

January 6th, 2016
Presenter: Dr. Massimo Mitolo, ESI Inc.
Title: Understanding NEC and IEC in the matter of bonding and grounding of low-voltage power systems

If you have any question for the presenter:
Use the Webex Q&A tab to send your question to the moderator

# IAS WEBINAR SERIES CONCLUSION

We thank the presenter, Massimo Mitolo,
and we thank you for your attention

This session was recorded and will be posted on line at:
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Next webinar: February 3rd, 2016
Presenter: Prof. Georges Zissis, Université de Toulouse, France
Title: Advances in Lighting Systems Technologies:
Revolutions, Drawbacks and Strategies