HANDBOOK

Guide for Testing and Verification of Low Voltage Installations

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Guide for testing and verification of low voltage installations

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1 Introduction

1.1 Scope

This guide is intended for electricians who deal with measurements on low-voltage electrical installations.
The main purpose of this document is:

- To stress the importance of testing of safety of electrical installations. Potential dangers and appropriate protective measures are described.
- Testing methods are described. Different test types (initial, maintenance, periodic, visual inspections, measurements) are covered.
- Supporting documentation (inspection & test protocols) is described.
- New testing technologies (preparing, proper documentation of results) are described. The advantages of new innovative measuring equipment are presented.
- The document is related to the latest edition of technical standards IEC 60364 and IEC 61557 (both published in 2007).

2 General about electrical installations

This documents mainly deals with LV installations, the final part of the electrical power supply network (items 6 and partly 5 on figure below)

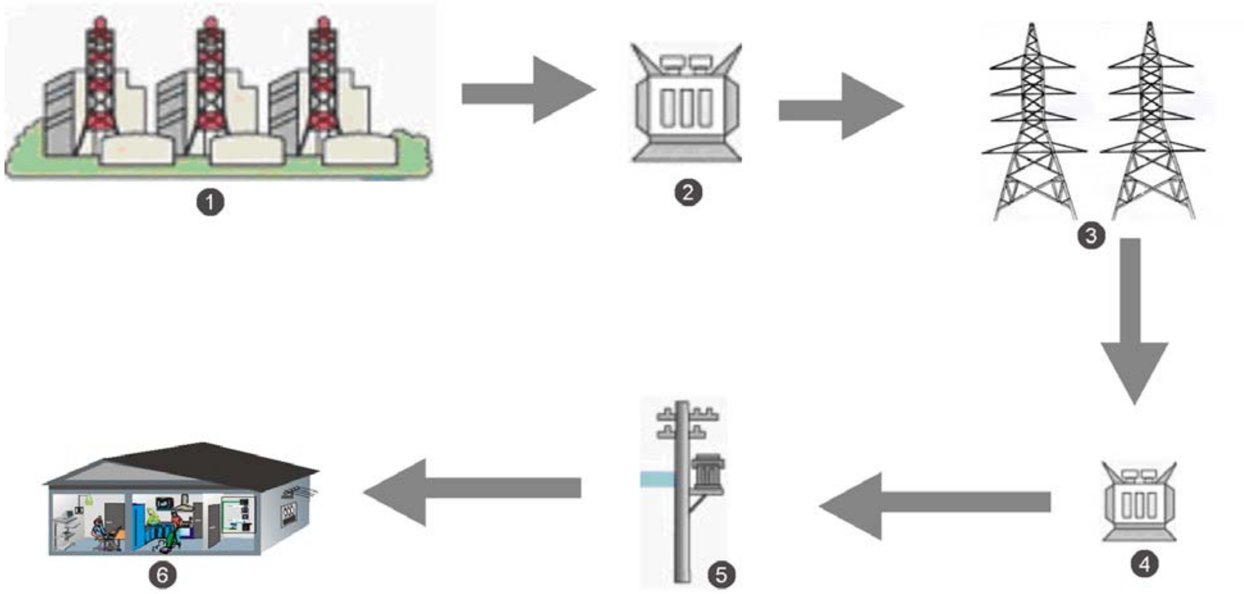


Fig.1: *Electrical power system 1*

The complete power supply system consists of:
1. Electrical power stations (where electricity is produced);
2. HV substation (step up the voltage for transmission);
3. Transmission lines (distribute energy to area where power is needed);
4. MV (intermediate) substation (transforms HV to MV);
5. Distribution transformer (transforms MV to LV, typical 400V, 600V), overhead lines (distributes electricity to home, plants, etc;
6. Buildings (consumer of electricity).

2.1 Electrical installation types concerning voltage shape

Concerning voltage shape the installations can be as follows:
- AC voltage installations, and
- DC voltage installations.

In general electrical power installations can carry AC or DC electricity:

Supply type	**Note**
Alternate (AC)	AC type voltage enables simpler voltage transformation and creation of rotational field in poly-phase systems.
Direct (DC)	Mostly used for local installations. Examples are installations with DC power sources (photo-voltaic cells, accumulators). Rarely used in larger systems.

Symbols:

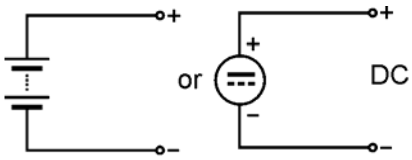


Fig. 2: *Direct current power source*

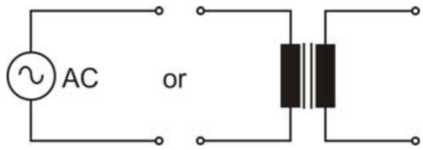


Fig. 3: *Alternate current power source*

2.2 Electrical installation types concerning earthing system

Any installation must contain appropriate protective measures against excessive leakage currents and touch voltages in case of a fault. Any power supply system with nominal voltages above 50V must include an earthing arrangement.
The standard IEC 60364-1 defines and describes different types of the installations regarding earthing arrangement.
Meaning of description:
The first letter describes the earthing arrangement at the power source:

T Direct earthing at power source (Latin terra = earth).
I Phase conductors are isolated from the earth or connected to earth via impedance.

The second letter describes the way of earthing exposed conductive parts at the installation.

T Direct earthing of installation via earth electrode.
N Exposed conductive parts are connected (via PE or PEN conductor) to the earthing at power source.

2.2.1 TT system

The TT system is earthed at the source of supply. Accessible conductive parts are earthed locally (e.g. at the installations entry point).

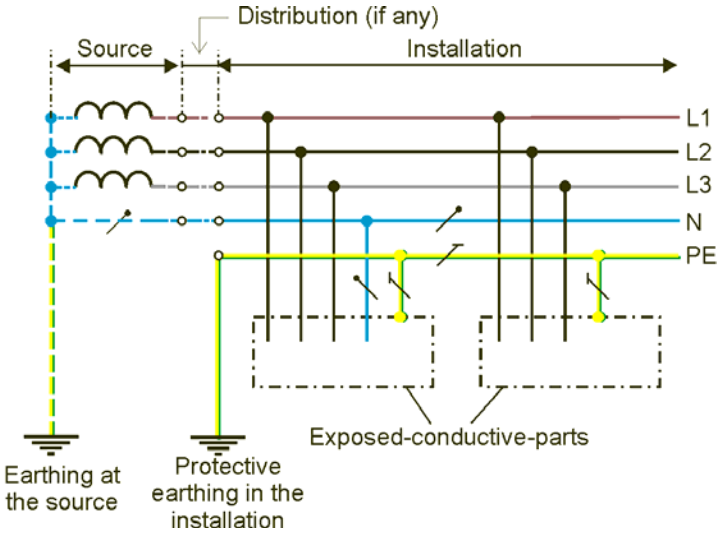


Fig. 4: *TT system*

All line conductors are fuse protected. The system can contain additional RCD protection. If there is no RCD installed the earth, the resistance shall be low enough to trip-out the fuse in case of a fault. Earthing resistance can vary from almost 0 Ω to several hundred Ω depending on the quality of installation's protective earthing and fault protection.

2.2.2 TN system

A TN system is earthed at power source and/or distribution points. Exposed conductive parts are connected (earthed) to the points via the PE or PEN conductor. PEN conductor serves as supply and protective conductor at the same time. All line conductors are fuse protected.

2.2.2.1 TN-S system

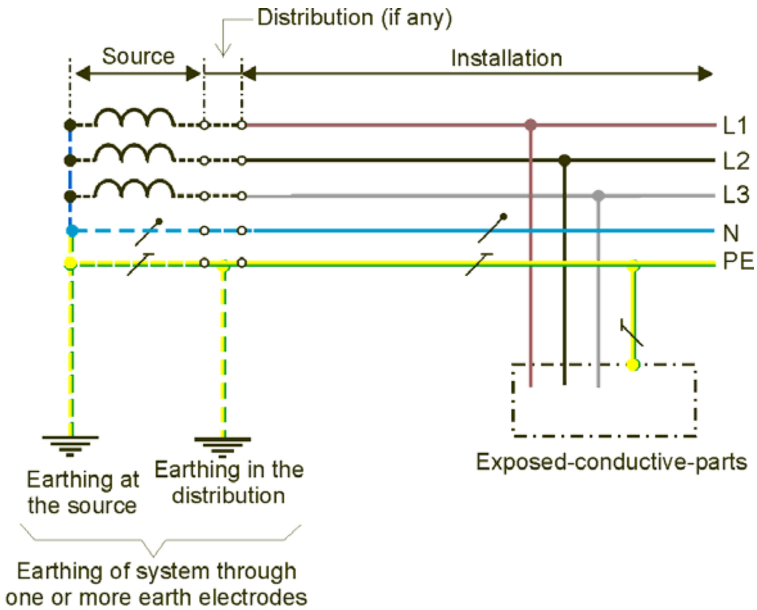


Fig. 5: *TN-S system*

In TN-S (**S**=separated) systems the PE and N (if applied) conductors are separated. The PE conductor serves for protection purposes only.
All line conductors are fuse protected. The system can contain additional RCD protection. The earthing resistance is usually low enough because of low PE conductor resistance and good earthing at the source and distribution points.

2.2.2.2 TN-C system

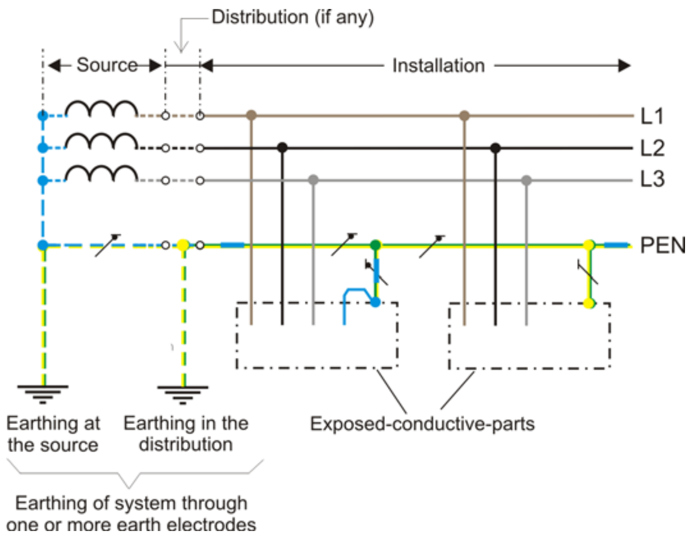


Fig. 5: *TN-C system*

TN-C (**C**-common) system comprises one common PEN conductor for the complete supplying system. PEN conductor serves for protection purposes and is carrying load currents.
All line conductors are fuse protected. The earthing resistance is usually low enough because of low PEN conductor resistance and good earthing at the source and distribution points. Additional RCD protection would not be effective.

2.2.2.3 TN-C–S system

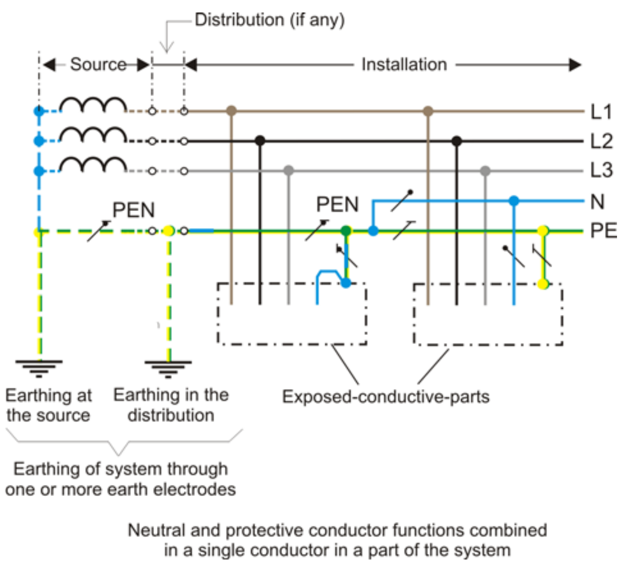


Fig.6: *TN-C-S system*

In TN-C-S systems exposed conductive parts are partly connected to the PE conductor and partly to the PEN conductor.

All line conductors are fuse protected. The earthing resistance is usually low enough because of low PEN and PE conductor resistance and good earthing at the source and distribution points. Additional RCD protection can be applied where N and PE conductors are separated.

2.2.3 IT system

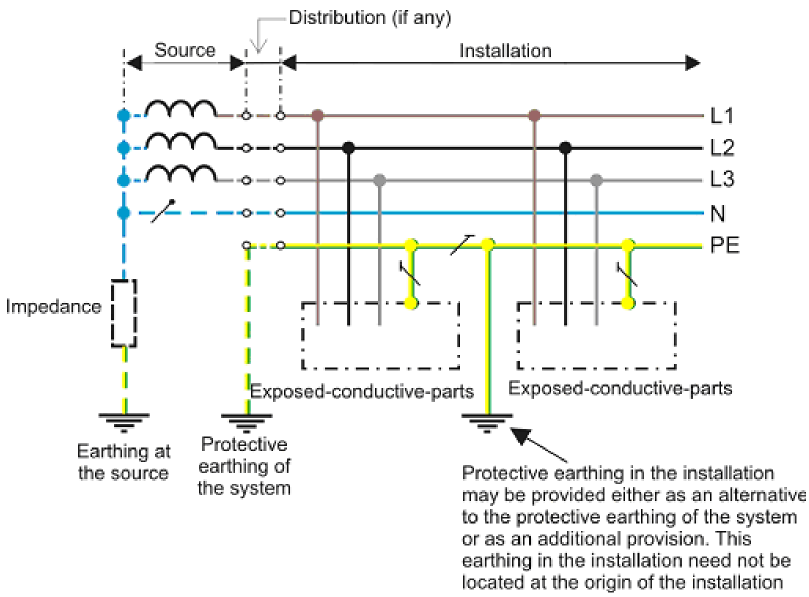


Fig. 7: *IT system*

The IT system has the supply part of the power source separated from earth or is earthed through a sufficient high impedance at source. Exposed conductive parts are autonomously earthed or connected to the PE conductor and locally earthed at the installation input.
The IT system is often used in medical rooms, chemical industry, explosive areas etc. The main advantage is that in case of the first fault (between phase and earth) the system still works safely.
All line conductors are fuse protected. In IT system IMDs and RCMs are often installed to detect insulation faults and to trigger an alarm before the supply must be disconnected. RCDs are only partly applicable.

For more information about IT installations refer to METREL's handbook *Measurements on IT power installation*.

2.2.4 RLV system

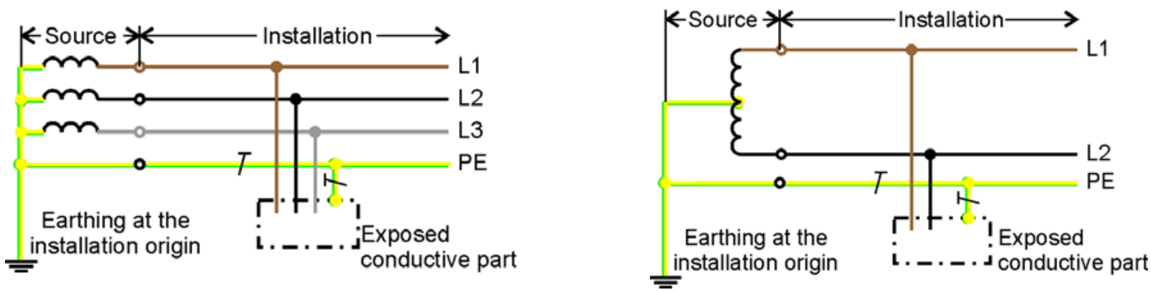


Fig. 8: *3-Phase and 2-Phase RLV systems*

In RLV (reduced low voltage) system the PE is placed in the middle point of the source. As a result, in an 110V RLV system any L - PE voltage is close to the safety touch voltage limit (63.5V in a 3-phase and 55V in a 2-Phase system). In general the RLV system can be considered as very safe.
All line conductors are fuse protected. The RLV system can contain additional RCD protection.

2.3 Electrical installation types concerning number of phases

Installation systems have usually 1, 2 or 3 line conductors.
The 1-Phase system is simpler and less demanding (materials, components).
The 3-Phase a.c. system is the most convenient one for supplying powerful rotating machines and large loads (power is divided among more conductors, generation of rotary field).
Figures below show some most popular 1, 2 and 3-Phase systems.

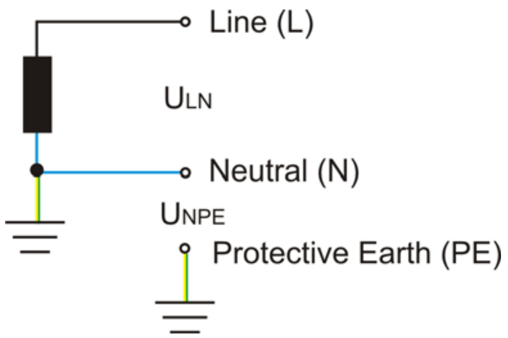


Fig.9: *Standard Single-Phase AC system*

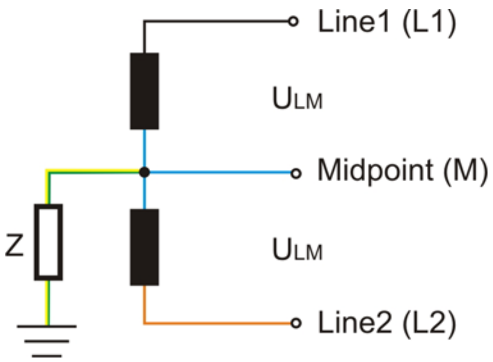


Fig.10: *2-Phase AC system (IT type example)*

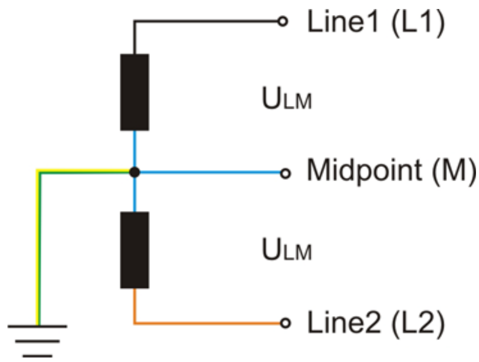


Fig. 11: *2-Phase AC system (RLV type example)*

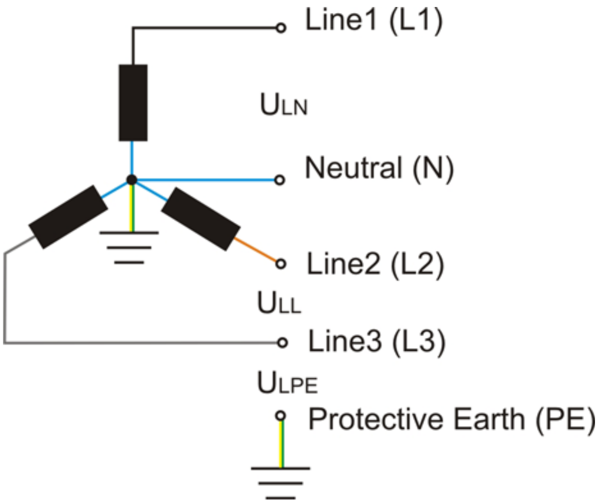


Fig.12: *3-Phase AC star system*

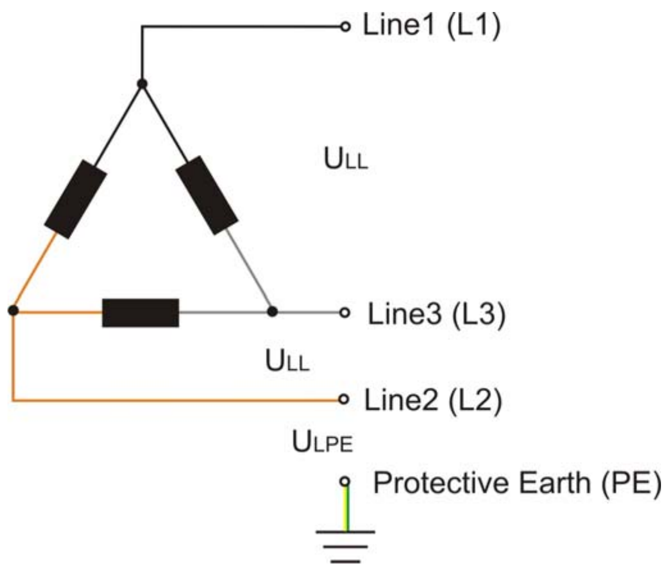
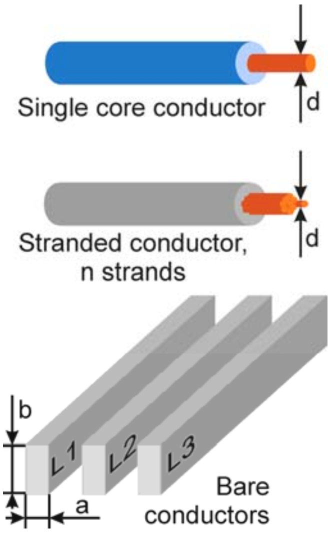


Fig.13: *3-Phase AC triangle connection*

2.4 Components forming electrical installations

Assembling components

Conductors



Conductors are typically made of copper because of its low specific resistance.
The main parameter of a conductor is rated current. It depends on conductor size and application.
Maximum current density for copper conductors is 10 A/mm^2. If the conductor has no space for cooling or the currents are ≥100 A then decreased density of 1 A/mm^2 must be considered.
In general the PE conductor has to withstand the same current as the current carrying conductors.
Cross section of typical conductor shapes:

Single core	Stranded	Bare
d^2pi/4	nd^2pi/4	ab

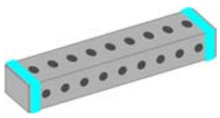
n....number of individual strands in conductor.

See annex C for information about relations between rated current and cross-sections for single core PVC insulated cable.

PE collector bar

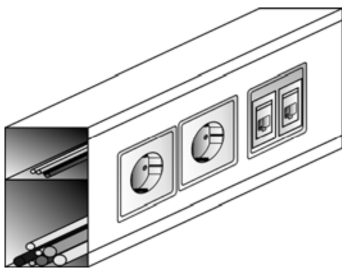
PE collector bar is intended for connection of PE conductors. It is yellow/green marked.

N collector bar



N collector bar is intended for connection of N conductors. It is blue marked.

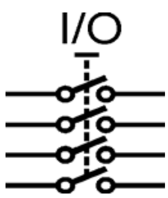
Conduit



Holder and protection for installation conductors. It is made of plastic or metal. Metal conduit must be bonded to PE. Signal, control or communication lines must have separate conduit to prevent crosstalk from supply conductors.

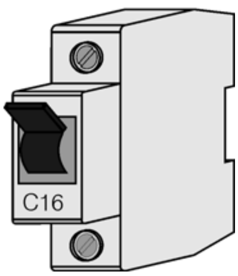
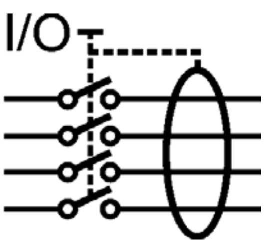
Disconnection components

Circuit breakers (switch)



Component for disconnecting complete or part of the installation from its supply. It usually disconnects all line and neutral conductors. The breaker must be clearly marked and must be easy to access.
Parameters are:

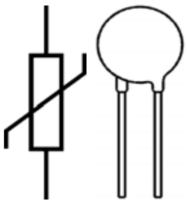
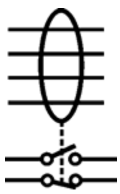
- *Rated contact voltage*: Maximum working voltage of circuit breaker.
- *Rated contact current*: Maximum current of circuit breaker.

	
Fuses  Melting fuses  Automatic fuse 	A component intended for over current protection of the installation. Fuses can be of melting or electromagnetic (automatic) types. Important fuse parameters are: - *Rated current* I_N: maximum continuous current that could flow without breaking the fuse. - *Rated voltage* U_N: maximum voltage that the fuse withstands. In case the rated voltage is lower then the applied voltage then the fuse could keep conducting after disconnection because of a voltage breakthrough. - *Breaking current* I_A: minimum current that is required for breaking the fuse in required period. - *Arc breaking current*: maximum current for which the fuse operates. If current through the fuse is higher then the fuse could keep conducting after disconnection because the arc cannot be distinguished, especially in case of inductive load currents. It is very important that the right fuse is selected and installed in the protected circuit. Under dimensioned fuses will cause frequent breaking during normal operation Over dimensioned fuses will probably not correctly disconnect the supply in case of a fault. This can cause severe consequences.
RCD 	Residual current device trips out if current difference through it exceeds $I_{\Delta N}$. They are composed of a differential current monitor connected to a circuit breaker. Main parameters are: - *Rated residual current* ($I_{\Delta N}$): the nominal current difference that triggers the in built circuit breaker to disconnect the protected circuit. RCD will trip-out when the residual current is between $I_{\Delta N}/2$ and $I_{\Delta N}$. - *Residual current waveform*: the shape of residual current that the RCD is sensitive to. Types are AC, A and B. - *Time delay (selective)*: Standard RCDs are non-delayed. The residual current must flow through the RCD for a longer time to trip out time delayed (selective) types. This enables to

<table>
<tr>
<td>
</td>
<td>install more sensitive RCDs in installation sub circuits (e.g. bathroom) without influencing each other.
- Rated contact voltage: Maximum working voltage to be applied to the RCD.
- Rated contact current: the maximum current through the RCD (any conductor).
Note: see Appendix A for more information about RCDs and similar devices.</td>
</tr>
</table>

Other protection components

<table>
<tr>
<td>Surge protective devices

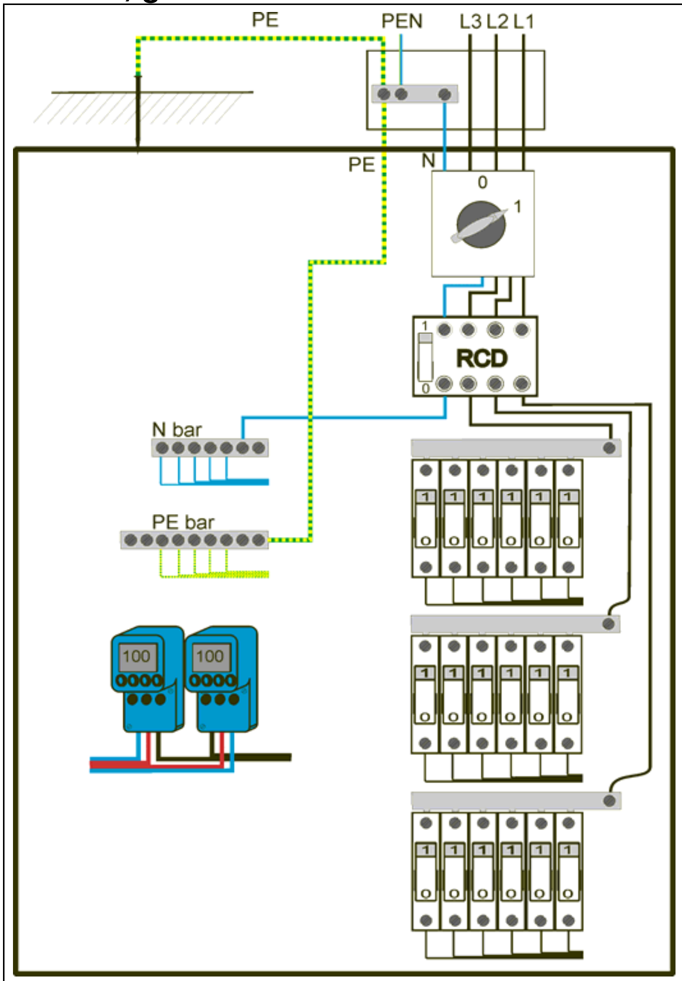
Varistor

Gas discharge tube, surge arresters
  </td>
<td>Surge protective devices can absorb energy of short over voltages (switch off of inductive loads, lighting). They are intended to prevent the installation and electronic equipment.
Main parameters are:
- Rated voltage: the maximum continuous voltage that the surge protective device withstands without conducting. Most manufacturers mark the components with r.m.s. value but some of them mark them with rated DC test voltage. Relation between the DC and r.m.s values is: $U_{rms} = U_{DC}/1.6$.
- Rated absorption energy or maximum current: the highest energy value during transient that the device can absorb in rare repetitive manner. The device will be damaged in case that current or absorbed energy during transient, e.g. lightning, are higher than the rated.
The device will be effective only in case of sufficient line/loop impedances. Components with higher absorption energy or current must be selected for lower line/ loop impedance.</td>
</tr>
<tr>
<td>RCM

</td>
<td>Residual current monitor monitors residual currents. They are composed of a differential current monitor (similar to that in an RCD) and an alarm indicator. The alarm is activated when residual current exceeds the preset threshold level.
Main parameters are:
- Threshold residual current (I_{Δ}): the current difference that triggers the in built alarm. Usually presetable ($I_{\Delta N}$ value, delay).
- Rated current voltage and current: same as for RCDs.</td>
</tr>
</table>

IMD

Insulation monitoring device monitors the insulation resistance between supply conductors and PE. They are composed of an insulation measuring device (monitor) and an alarm indicator. The alarm is activated when the insulation resistance drops below the preset threshold level.
Main parameters are:

- *Threshold insulation resistance*: minimum insulation resistance / impedance that triggers the in built alarm. It is usually presetable.
- *Rated voltage:* Maximum working voltage to be applied to the IMD.

Boards, gears

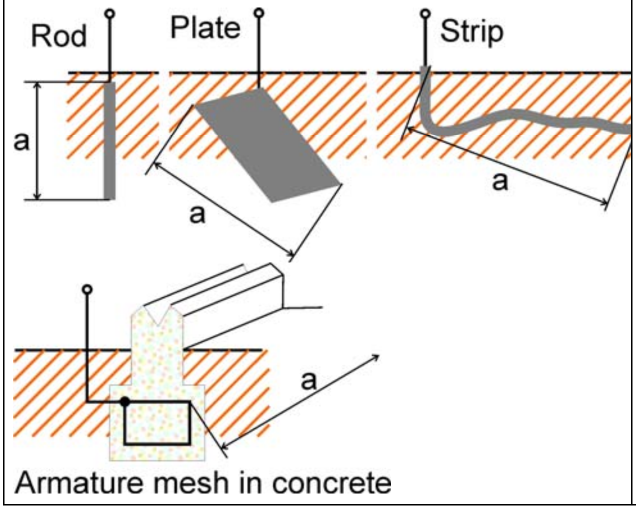


Distribution board
A board where incoming power circuit is distributed over building segments. It contains indicators, circuit breakers, RCDs, fuses...

Fuse box
A board containing mainly fuses for selective protection of sub circuits.

Switchboard, switchgear
Similar as distribution board, containing also devices for controlling and monitoring purposes.

Earthing components

Earth electrode 	In the soil depleted metal part like plate, rod or strip, intended for earthing of the power source, distribution point, installation, exposed metal part to earth. Earth electrodes for making main earthings, lighting systems Parameter a represents maximum dimension of the electrode and is used for calculations and measurements

Other

Electricity measuring equipment 	Equipment intended for measuring and registering of consumed electrical energy. All line conductors must be connected for measurement of power consumption. It can have additional inputs for connections of control equipment.

2.5 Marking of installation components

Marking of conductors
Tables 1, 2, 4 and 4 show conductor markings and abbreviations as defined in IEC standards.

Designated conductors	Equipment terminal marking	Marking by graphical symbols for use on equipment [b]
AC conductors		
Line 1 (L1)	U	
Line 2 (L2)	V [a]	
Line 3 (L3)	W [a]	
Mid-point conductor (M)	M	
Neutral conductor (N)	N	
DC conductors		
Positive (L+)	+	
Negative (L-)	-	
Protective conductors (PE)	PE	
PEN conductor (PEN)	PEN	
PEL conductor (PEL)	PEL	
PEM conductor (PEM)	PEM	
Protective bonding conductor (PB)[C]	PB	
Earthed (PBE)	PBE	
Unearthed (PBU)	PBU	
Functional earthing conductor (FE)[d]	FE	
Function bonding conductor (FB)	FB	

Notes:
a Only necessary in systems with more than one phase.
b The graphics shown correspond to the symbols in IEC 60417
c A protective bonding conductor will in most cases be a protective bonding conductor earthed. It is not necessary to designate these with PBE in those cases where both a distinction between a protective bonding conductor earthed and a protective bonding conductor unearthed are used, a clear distinction between them shall be made, preferably applying the designations PBE and PBU.
d Neither the designation FE nor the graphical symbol 5018 of IEC 60417 shall be applied for conductors or terminals having a protective function.

Table 1: *Markings on conductors and equipment (IEC 60445)*

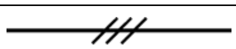
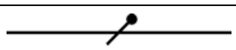
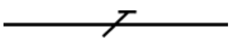
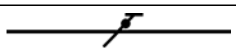
	Group of line conductors (L1..L3)
	Neutral (N), midpoint conductor (M)
	Protective earth conductor (PE)
	Combined protective earth and neutral conductor (PEN)

Table 2: *Markings of conductors in installation schematics*

Three-phase conductor markings were modified during the time. The following table lists old markings compared to existing ones.

Supply conductors	
Existing	Old
L1	R
L2	S
L3	T

Equipment conductors			
Single three-phase connections		Multiple three-phase connections	
Existing	Old	Existing	Old
U	U	U1	U
V	V	V1	V
W	W	W1	W
		U2	X
		V2	Y
		W2	Z

Table 3: *Three-phase conductors (old and new markings)*

Conductor type	Marking	Colour
Line1	L1	Black or brown or grey
Line2	L2	
Line3	L3	
Neutral	N	Blue
Midpoint	M	
Protective	**PE**	**Green-yellow***
Protective+ Neutral	PEN	Green-yellow with blue markings at terminals or blue with yellow-green markings at terminals.
Line+	L+	The standard does not prefer colours but most often the red indicates L+ and black or blue L-.
Line-	L-	

Table 4: *Conductor colours (IEC 60445)*

Note:
Green-yellow colour is intended for protective earth conductors only and must not be used for any other purpose.

3 Regulations and standards

3.1 Directives, regulations

In general electrical installations are well covered by regulations (design, testing, safety etc). In most countries law regulates a thorough and well-documented maintenance of electrical installations during its complete lifetime.
Most important regulations that regulate the field of electrical installations are:

- EU directives, they are obligatory on the whole EU territory.
- National laws, regulations, guidance's (e.g. health safety laws, code of practices)
- Technical standards, reports, articles (IEC, IEEE, white papers that are included in regulations). Standards must be considered and are becoming obligatory if they are quoted in laws and regulations.

A detailed citation of national regulative is beyond the scope of this guide.

3.2 Standards

Standards are technical documents that are covering (e.g. design, maintenance, testing, verification) particular technical fields or products. They are very important as:

- They assure a unified and comparable system worldwide.
- They reflect the acknowledged state of technique.

Main standards that relates to safety and testing of electrical installations and are listed in this chapter.

Standards are produced by various standardization organizations worldwide, e.g.: IEC, IEEE, CENELEC, CEN, ISO, IEE, ETSI, DIN, VDE, JST, BSI, AST, ANSI…
IEC (International Electrotechnical Comitee) is the largest international standardization organization for electro technique. Its technical comities and working groups are continuously accompanying particular technical fields and prepare new (IEC) standards or editions.

Beside international standardization organizations there are national standard organizations or institutes. They ratify international standards on the national level. Sometimes they also generate theirs own standards if the international standards are not considered as sufficient.

CENELEC is an organization for harmonization of electrotechnical standards between EU countries. After an IEC standard is harmonized on the European level it is released as an EN standard with the same numbering.

Table 5 shows most important standards related to electrical installations.

Note:
Local standards are mostly based on IEC standards and this is the reason that standards in this guide are referred to the IEC.

3.2.1 Low voltage electrical installations

IEC generic standards

IEC 60364-1	Low-voltage electrical installations Part 1: Fundamental principles, assessment of general characteristics, definitions	
IEC 60364-4 series	Low-voltage electrical installations Part 4: Protection for safety	
	Section 41: Protection against electric shock	
	Section 42: Protection against thermal effects	
	Section 43: Protection against over current	
	Section 44: Protection against voltage disturbances and electromagnetic disturbances	
IEC 60364-5 series	Electrical installations of buildings Part 5: Selection and erection of electrical equipment	
	Section 51: Common rules	
	Section 52: Wiring systems	
	Section 53: Protection, isolation, switching, control and monitoring	
	Section 54: Earthing arrangements, protective conductors and protective bonding conductors	
	Section 55: Other equipment	
	Section 56: Safety services	
IEC 60364-7 series	Electrical installations of buildings – Part 7: Requirements for special installations or locations	
IEC 62305 series	Protection against lightning	
IEC 61201	Touch voltage threshold values for protection against electric shock	

Table 5: *Generic IEC standards for electrical installations*

EU and national generic standards

HD 384 series	Harmonization documents related to application of some IEC 60364 series standards.
DIN/VDE 0100 series	With IEC 60364 series harmonized German standards for electrical installations
BS 7671 series	With IEC 60364 series harmonized UK standards for electrical installations
AS/NZS 3018	Australian /New Zealand standard for Electrical installations – Domestic installations
IEEE Std. 80	IEEE Guide for Safety in AC Substation Grounding (US)
IEEE Std. 142	IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems (US)
EN 50110-1	Operation of electrical installations
EN 50110-2	Operation of electrical installations (national annexes)

Table 6: *Generic standards for electrical installations*

3.2.2 Components in electrical installations

IEC standards

IEC/TR 60755	General requirements for residual current operated protective devices
IEC 61008 series	Residual current operated circuit-breakers without integral over current protection for household and similar uses (RCCBs)
IEC 61009 series	Residual current operated circuit-breakers with integral over current protection for household and similar uses (RCBOs)
IEC 60269 series	Low-voltage fuses
IEC 60445	Basic and safety principles for man-machine interface, marking and identification - Identification of equipment terminals and conductor terminations
IEC 60446	Basic and safety principles for man-machine interface, marking and identification - Identification of conductors by colours or alphanumeric
IEC/TR 61818	Application guide for low-voltage fuses

Table 7: *IEC standards for components in electrical installations*

3.2.3 Testing and monitoring safety of electrical installations

IEC standard

IEC 60364-6	Low-voltage electrical installations - Part 6: Verification

Table 8*: IEC standard for testing, verification and monitoring of electrical installations*

EU and national standards

AS/NZS 3017	Australian /New Zealand standard: Electrical installations - Testing and inspection guidelines
ES 59009	Inspection and testing of electrical installations in domestic properties (CENELEC)
IEEE Std. 81	IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System Part 1: Normal Measurements

Table 9*: Standards for testing, monitoring, verification of electrical installations*

Test & measurement equipment

IEC 61557 series	Electrical safety in low-voltage distribution systems up to 1000 V ac and 1500 V dc—Equipment for testing, measuring, or monitoring of protective measures

Table 10: *T&M equipment*

See chapter 4.3.1 for more information about the standards of series IEC 61557.

4 Safety of electrical installations

4.1 Substitute circuits of electrical installations

Figure 14 shows a detailed equivalent circuit of electrical installation.
The components (resistors, capacitors) represent:

- Important safety relevant installation parameters.
- Parameters that are measured when verifying safety.

The meaning of components is described in table 11.

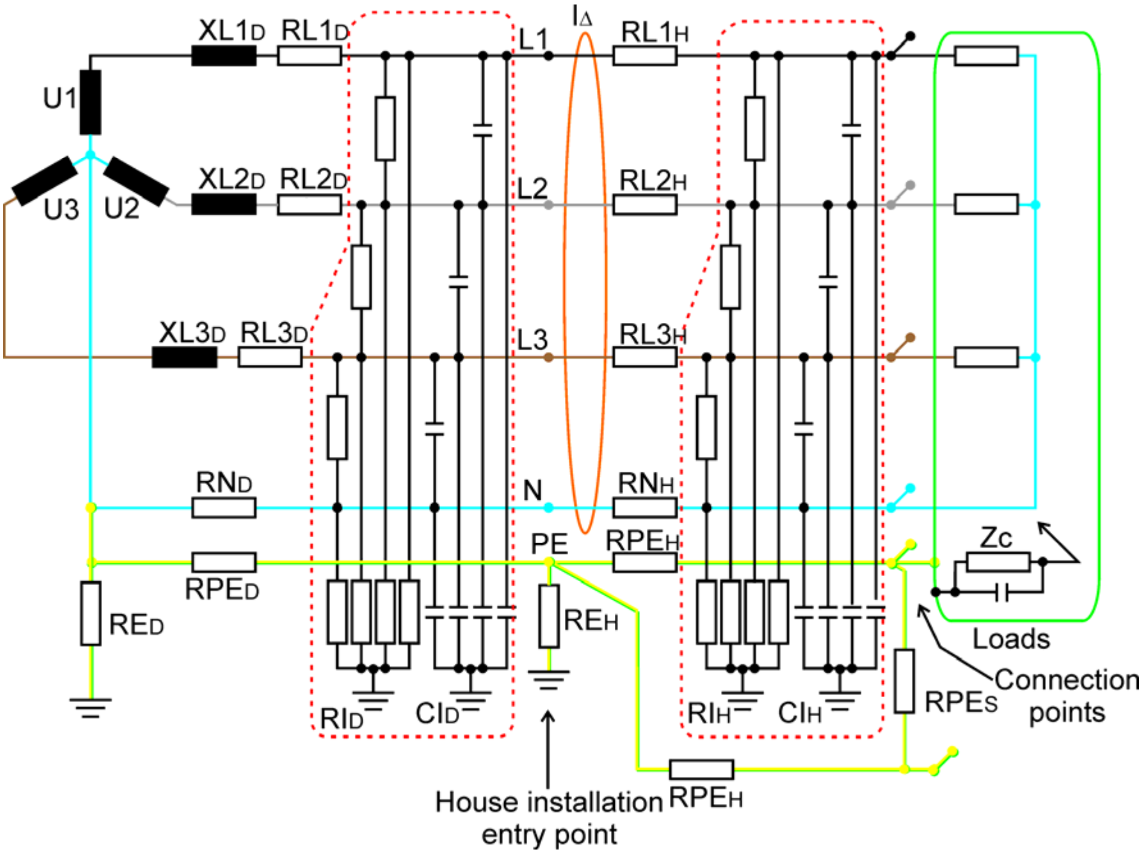


Fig.14: *Equivalent circuit of low voltage electrical installation*

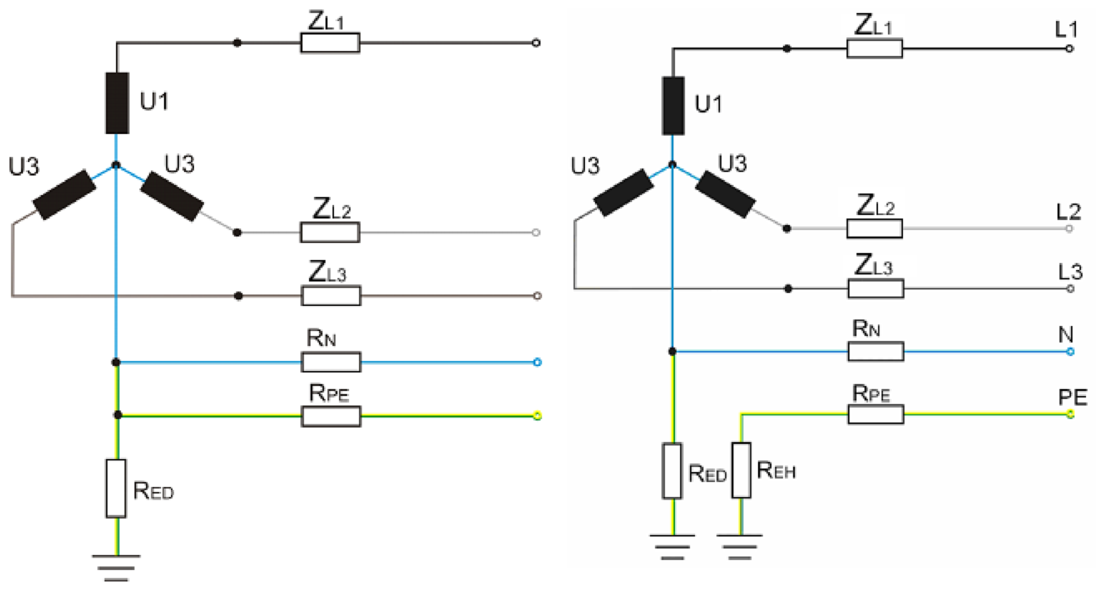
Supply part (distribution part)	
U1, U2, U3	Line (source) voltages.
XL1D, XL2D, XL3D RL1D, RL2D, RL3D	Impedance at the origin (entry point) of house installation. Impedances consists of: - Distribution wiring resistances; - Source resistance (impedance of distribution transformer, transformed impedances of complete energy system).
RND	Resistance of distribution neutral wiring.
RPED	Resistance of distribution PE wiring.
RED	Earthing resistance at distribution origin.
RID, CID	Impedance of connected equipment between any two wires and from each wire to earth on distribution side.

Installation (final) part	
$RL1_H$, $RL2_H$, $RL3_H$	Resistances of installation’s line conductors.
RN_H	Resistance of installation’s neutral conductors.
RPE_H	Resistance of installation’s PE wiring.
RE_H	Earthing resistance of installation.
RPE_S	Resistance of supplementary bonding.
RI_H, CI_H	Insulation resistances and capacitances between any two wires of house installation and from each wire to earth, containing also capacitances of reactive energy compensating systems.
I_Δ	Differential leakage current at house entry point.
R1L, R2L, R3L	Load resistances.
Zc	Insulation impedances in consumers comprising insulation resistances and capacitances, EMC components, etc.
Connection points	In general this are wall socket and other connection terminals of the installation.

Table. 11: *Legend of components*

Figure 15 shows simplified TN and TT substitute circuits of electrical installation that is more often used:

- XL_D, RL_D, RL_H are summarized to ZL.
- RN_D, RN_H are summarized to RN.
- RPE_D, RPE_H are summarized to RPE.
- RI_D, CI_D, RI_H, CI_H are not shown.



TN supply system *TT supply system*

Fig.15: *Standard equivalent circuit of low voltage electrical installation (TN/TT)*

Description and markings described in this chapter are used later in this document.

4.2 Dangers

Electrical installation is a source of many dangers. Two most often dangers are:

- Overheating through excessive thermal dissipation or insulation fault on installation components and electrical equipment.
- Excessive touch voltage on accessible conductive parts and consequentially dangerous current through human body.

Both problems can have fatal consequences! Accidents are still happens daily!
Table 12 shows the number of accidental deaths because of electricity in Germany. The number is still considerable although Germany has one of the strictest safety regulations and has made an important progress in last decades. Unfortunately the trends are not so positive in countries where the regulations are less strict or are not considered. The cost and consequences of accidents and damages caused by impaired electrical installation exceeds the investments in proper design, maintenance and testing by far.

	Year 1950	Year 1975	Year 2000
Population	10 Mio	60 Mio	80 Mio
Consumption of electricity	50 TWh	300 TWh	500 TWh
Number of accidental deaths caused by electricity	270	215	100

Table. 12: *Accidental deaths in Germany because of electric shock*

(source VDEW Frankfurt)

4.2.1 Dangerous body currents

In this chapter the dangers of fault voltages and consequentially currents through the human body are described. Even relatively small currents in range of miliampers can be dangerous! The time the fault current flows through the body is also important.

Graph on fig. 16 shows the current/ time relations and influence to human body
Field 1: no problems, just perception
Field 2: strong reaction, muscle contractions, pain, “can’t let go” threshold
Field 3 (possibly fatal): respiration problems, heart fibrillation, heart paralysis.
Field 4 (likely fatal): organ burns, heart paralysis.

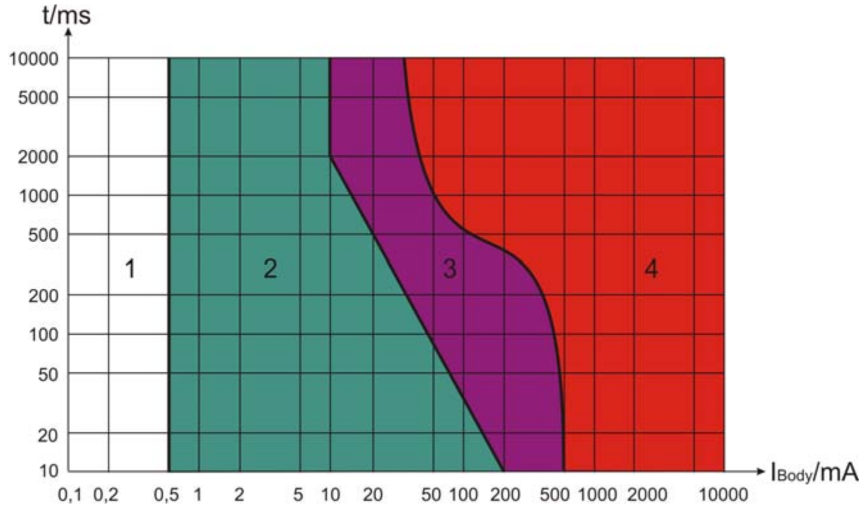


Fig. 16: *Body current / exposure time danger relations*

Standard IEC 61140 defines following maximum allowed time / contact voltage relations:

Maximum time of exposure	Voltage
>5s to ∞	$U_C \leq 50V_{AC}$ or $\leq 120V_{DC}$
< 0.4s	$U_C \leq 115V_{AC}$ or $\leq 180V_{DC}$
< 0.2s	$U_C \leq 200V_{AC}$
< 0.04s	$U_C \leq 250V_{AC}$

Table 13: *Fault voltage / maximum time durations*

It can be seen that the time limits in table 13 are closely related with limit disconnection times for over current and residual current protection devices.

4.2.1.1 Requirements for disconnection of protection devices in different installation systems

Disconnection of fault voltage in due time is one of the primary protective measures in electrical installation. Equations in this chapter define the conditions for disconnection of protection devices (fuses, RCDs) for typical installation systems.

Line (short circuit) loop (TN, TT, IT, RLV)
(Z_{L1-N}, Z_{L2-N}, Z_{L3-N}, Z_{L1-L2}, Z_{L1-L3}, Z_{L2-L3})

Over current protection:

$$Z_{LN} \cdot I_a \leq U_0 \qquad U_0 = U_{LN} \qquad \text{Eq. 1}$$

$$Z_{LxLy} \cdot I_a \leq U_0 \qquad U_0 = U_{LL} \qquad \text{Eq. 2}$$

I_a .... Current causing disconnection of supply in rated time.
U_0.......... System voltage U_{LN} or U_{LL}.
Z_{LN} .... Line impedance Z_{LN}.
Z_{xx} .... Line impedance Z_{L1L2} or Z_{L1L3} or Z_{L2L3}.

Fault loop (TT, RLV)
(Z_{L1-PE}, Z_{L2-LPE}, $Z_{L3-LPE,}$ U_{CL})

Over current protection:

$$Z_{LPE} \cdot I_a \le U_0 \quad \textit{Eq. 3}$$

Protection against excessive touch voltage:

$$R_A \cdot I_a \le U_{CL} \quad \textit{Eq. 4}$$

I_a .... A current causing disconnection of supply in rated time. If a RCD is installed at the origin of installation then $I_a = I_{\Delta N}$
*U_0.......... System voltage to earth U_{LPE}**
Z_{LPE}....... Fault loop impedance
U_{CL}........ Limit contact voltage on exposed conductive parts
R_A .... Resistance of protective earthing $R_A = R_E + R_{PE}$ *(earth probe resistance plus PE wiring resistance)*
** in 110V RLV systems U_{LPE} is 55V or 63.5V.*

Fault loop (TN-S)
(Z_{L1-PE}, Z_{L2-PE}, Z_{L3-PE}, U_{CL})

Over current protection:

$$Z_{LPE} \cdot I_a \le U_0 \quad \textit{Eq. 5}$$

Protection against excessive touch voltage:

$$R_{PE} \cdot I_a \le U_{CL} \quad \textit{Eq. 6}$$

I_a .... A current causing disconnection of supply in rated time. If a RCD is installed at the origin of installation than $I_a = I_{\Delta N}$
U_0.......... System voltage to earth
Z_{LPE}....... Fault loop impedance
U_{CL}........ Limit contact voltage on exposed conductive parts
R_{PE}........ Resistance of PE wiring

Fault loop (TN-C)
(Z_{L1-PE}, Z_{L2-PE}, Z_{L3-PE}, U_{CL})

Over current protection:

$$Z_{LPE} \cdot I_a \le U_0 \quad \textit{Eq. 7}$$

Protection against excessive touch voltage:

$$R_{PEN} \cdot I_a \le U_{CL} \quad \textit{Eq. 8}$$

I_a .... A current causing disconnection of supply in rated time. If a RCD is installed at the origin of installation then $I_a = I_{\Delta N}$
U_0.......... System voltage to earth
Z_{LPE}....... Fault loop impedance
U_{CL}........ Limit contact voltage on exposed conductive parts
R_{PEN}...... Resistance of PEN wiring

Fault loop (TN-C-S)
(Z_{L1-PE}, Z_{L2-PE}, Z_{L3-PE}, U_{CL})

Over current protection:

$$Z_{LPE} \cdot I_a \leq U_0 \qquad \text{Eq. 9}$$

Protection against excessive touch voltage:

$$(R_{PEN} + R_{PE}) \cdot I_a \leq U_{CL} \qquad \text{Eq. 10}$$

I_a .... *A current causing disconnection of supply in rated time.* If a RCD is installed at the origin of installation then $I_a = I_{\Delta N}$
U_0.......... *System voltage to earth*
Z_{LPE}....... *Fault loop impedance*
U_{CL}........ *Limit contact voltage on exposed conductive parts*
R_{PEN}...... *Resistance of PEN wiring (C-part)*
R_{PE}........ *Resistance of PE wiring (S-part)*

Fault loop (IT)
(Z_{L1-PE}, Z_{L2-LPE}, Z_{L3-LPE}, U_{CL})

Protection against excessive touch voltage:

$$R_A \cdot I_{SF} \leq U_{CL} \qquad \text{Eq. 11}$$

I_{SF} .... *A current flowing into PE in case of first fault. Where RCD is applied then* $I_{SF} = I_{\Delta N}$
R_A .... *Resistance of protective earthing* $R_A = R_E + R_{PE}$ *(earth probe resistance plus PE wiring resistance)*
U_{CL}........ *Limit contact voltage on exposed conductive parts*

Table 14 lists disconnection times for final circuits.

Supply system	Nominal voltages						
	50 V < U_0 ≤ 120 V	**120 V < U_0 ≤ 230 V**		230 V < U_0 ≤ 400 V		U_0 > 400 V	
	a.c.	**a.c.**	d.c.	a.c.	d.c.	a.c.	d.c.
	Disconnection times in [s]						
TN, IT	0.8	**0.4**	5	0.2	0.4	0.1	0.1
TT, IT	0.3	**0.2**	0.4	0.07	0.2	0.04	0.1

Table 14: *Disconnection times according to IEC 60364-4-41*

4.2.2 Other dangers

In this chapter most frequent dangerous problems on electrical installations are described.

4.2.2.1 Fault voltage, contact voltage, fault current, body currents

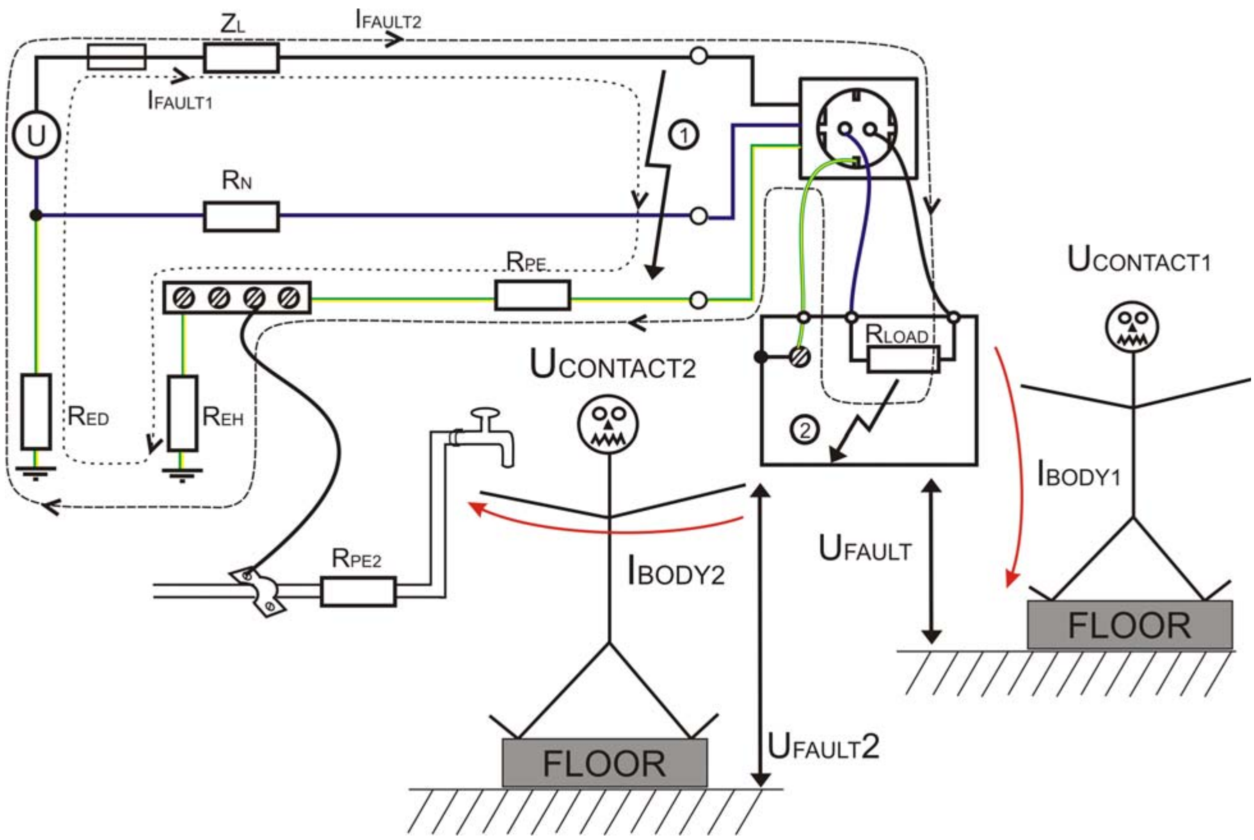


***Fig. 17:** Origin of fault voltages and currents*

Figure 17 shows how dangerous fault voltages and currents occur:

- An insulation failure occur somewhere in the installation, e.g.:
  - between line and PE conductors 1.
  - inside connected electrical equipment 2.
- Because of the fault a fault current starts to flow.
- If the earthing resistance of the electrical installation is too high (defective PE wiring, improper earthing etc.)
  AND/ OR
  if the protection devices are not effective (wrong type, size etc),
  the fault voltage on exposed conductive pars (metal housings, water pipes etc) can exceed the safe level (voltage size and duration are to be considered).
- If the conductive part with fault voltage would be touched a part of the fault current would flow through the body. Magnitude of the body current depends on the following resistances: fault resistance, body resistance, contact resistance, floor resistance, earthing resistances...

Relations:

$$U_{FAULT} = I_{FAULT} \cdot (R_{PE} + R_{EH}),\ \textit{must be below 50V (25V)} \qquad \text{Eq. 12}$$

$$U_{CONTACT1} = U_{FAULT} \cdot \left(\frac{R_{BODY}}{R_{BODY} + R_{FLOOR} + R_{CONTACT}} \right) \qquad \text{Eq. 13}$$

$$U_{CONTACT2} = U_{FAULT} \cdot \left(\frac{R_{BODY}}{R_{BODY} + R_{PE2} + R_{CONTACT}} \right) \qquad \text{Eq. 14}$$

U_{FAULT} .... *Voltage on exposed metal earth against earth.*
$U_{CONTACT}$ ... *Part of the fault voltage the body is exposed to.*
I_{FAULT}......... *Current through the fault loop, a part can flow through the human body.*
I_{BODY}.......... *Current through the body.*
R_{BODY}........ *Resistance of body.*
R_{FLOOR}....... *Additional (insulation) resistance of floor.*
$R_{CONTACT}$ ... *Additional (insulation) resistance of shoes, gloves, etc.*

Note:
Fault / leakage currents are not necessarily a result of a failure in the installation. Leakage currents can be caused by input EMC filters of electronic equipment. Of course they must stay under predefined safety levels otherwise they can cause trip-out of RCDs and other troubles.

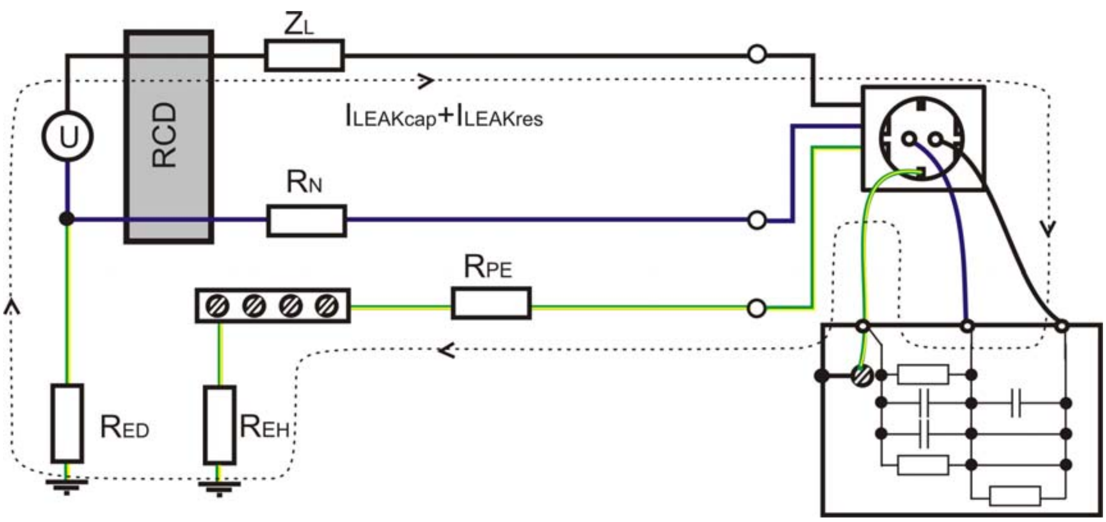


Fig. 18: *Origin of leakage currents*

4.2.2.2 Overheating

On figure 19 it can be seen how local overheating can occur:

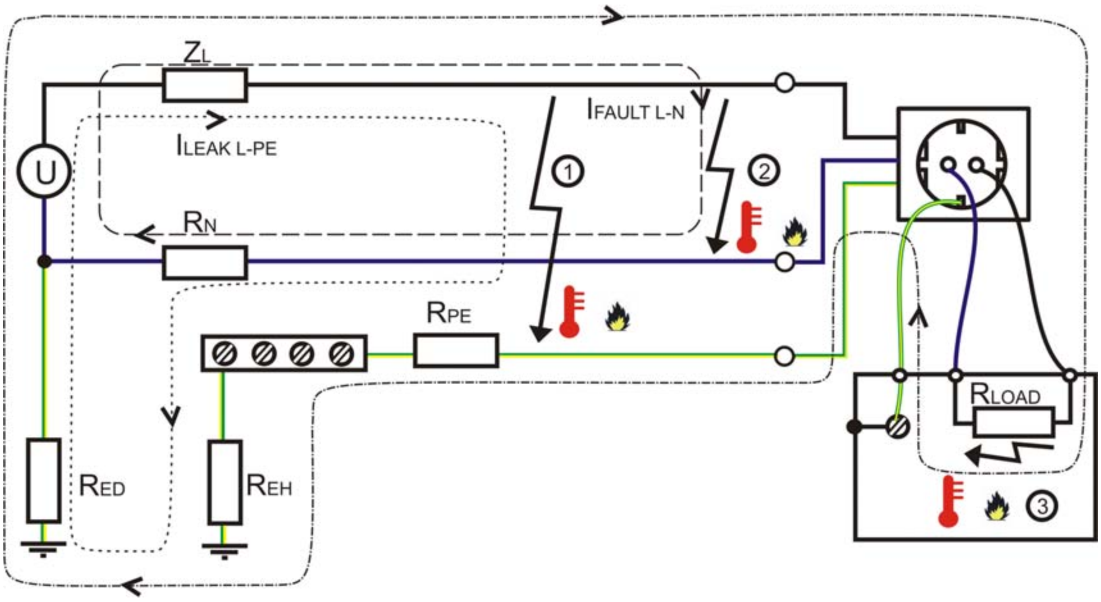


Fig. 19: *Origin of overheating*

- An failure occur somewhere in the installation, e.g.:
  - Insulation failure between phase and PE 1, phase and neutral conductors 2.
  - Failure of electrical equipment 3 (short circuit, interruptions, malfunction etc.)
- As a result a fault current starts to flow. If installation or parts of electrical equipment are not intended for sizes of the fault current they become to overheat. Consequentially this can result in fire.

4.2.2.3 Lightning struck

Lightning presents a serious danger for the electrical installation and connected electrical equipment in lot of geographic areas.
The figure below shows an example how a lightning struck can cause fire and fault voltages all over the electrical installation (because of an improper lightning system).

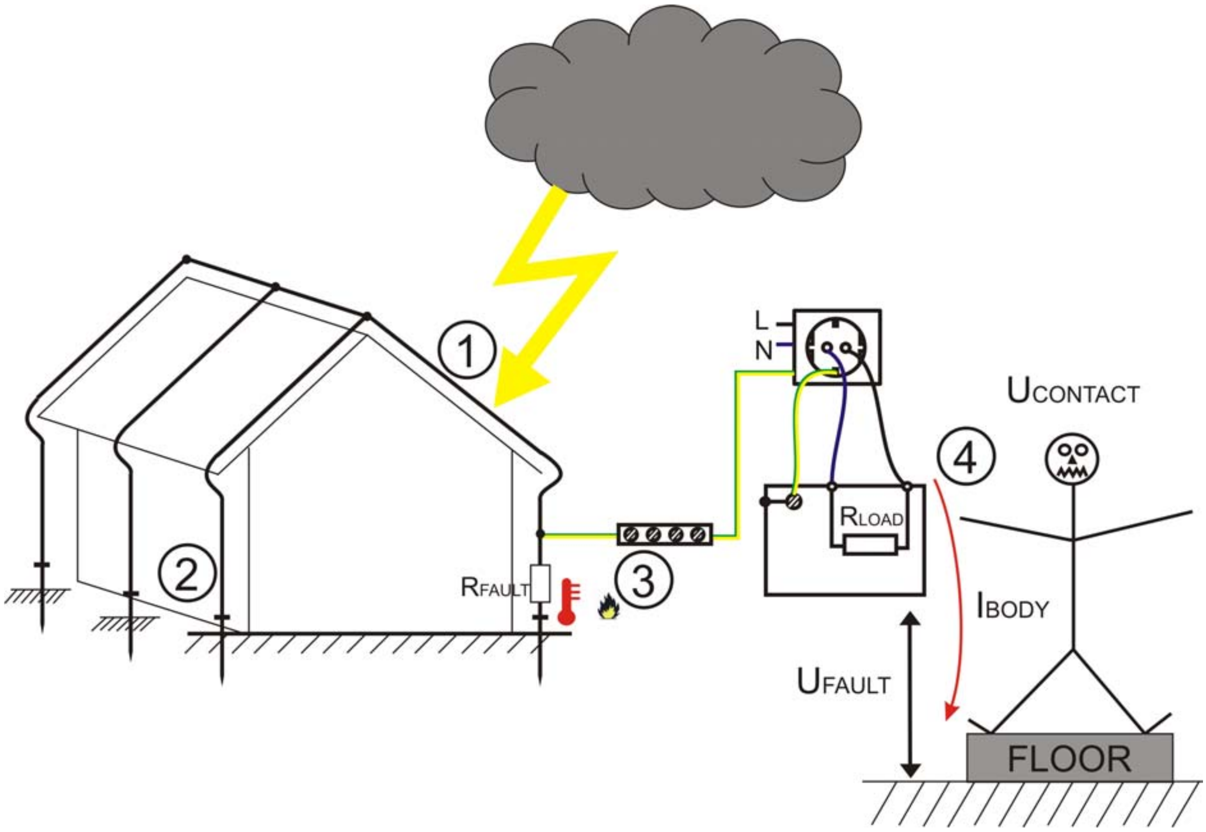


Fig. 20: *Origin of danger through a lightning struck*

- The object's lighting system suffered a direct lightning struck 1
- In a proper lightning system the high voltages caused by the released energy is correctly drained into earth 2. The impulse voltage between earth and PE collector bar stays relatively low.
- However, in a faulty lightning system (e.g. with faulty rods) uncontrolled high-energy impulse over voltages can occur on exposed accessible conductive parts (PE conductors, metal bonded parts) 3. The high-energy impulses enter the electrical installation via the conductors; overheating and dangerous fault voltages can occur all over the installation 4, not only at the point of the struck.

Note:

- Non-direct struck can have similar consequences. The high voltage transients can travel long distances over electrical conductors and enter the installation through any conductor (L, N or PE).

4.2.2.4 Faults in electrical installations- summary

Table 15 shortly summarizes typical faults on installations.

Fault	Often fault reasons	Potential dangers	Typical protective measures	Measurement
Insulation fault	- Degradation of insulation material, old materials; - Moisture, dirt; - Careless assembling of installation components (lights, equipment); - Damaged insulation layers.	- Sparking, local overheating and fire (if enough energy) - Fault currents if PE is involved - Voltage on exposed metal parts	- IMDs - Isolation of conductors, - Sufficient clearance and creepage distances, barriers	INSULATION, IEC 61557-2
Fault current (1) **Leakage current** **Contact voltage**	- Insulation faults with PE or exposed conductive parts involved. - Filter capacitors and resistors in connected equipment.	- Electric shock because of excessive body currents if exposed metal part is touched. Body currents can flow to earth or between two exposed metal parts. - Especially dangerous if earthing is impaired.	- RCDs, RMDs - Low earthing resistance	RCD tests + UC IEC 61557-6 Clamp leakage current IEC 61557-13* Low Ω IEC 61557-2 Earth IEC 61557-3,5
Fault current (2)	- Low resistance path (failure) between line and PE - Bad assembling, failure of electrical equipment	- Electric shock (view fault current (1)) AND - Fault currents that are much higher then the nominal capability of wiring and installation /equipment components (shorts, breakthroughs etc) – can cause overheating, fire. - Especially dangerous if improper protective devices are installed.	- Fuses, RCDs - Low enough earthing resistance	ZLOOP/ IPFC IEC 61557-3
Short circuit current	- Low resistance path between line / line or line / neutral. - Bad assembling, failure of electrical equipment	- Fault currents that are much higher then the nominal capability of wiring and installation /equipment components (shorts, breakthroughs etc) – can cause overheating, fire. - Especially dangerous if improper protective devices are installed.	- Fuses	ZLINE/ IPSC IEC 61557-3
* Standard in preparation				

Table 15: *Summary of dangers in electrical installations*

4.3 Test equipment for electrical installations

Only special test equipment should be used for testing electrical installations.
Safety considerations for installation testers are higher than for other electrical equipment:

- The testers are daily used on live electrical installations, often on unprotected boards, outlets, switches, or in other difficult conditions.
- Some tests are performed with high voltages and currents. This voltages and currents must not cause any danger on the installation under no circumstances.
- The test instruments must have high immunity against EMC and other noise on the supply system.
- The user must know and consider the safety precautions given by the manufacturer.

This chapter contains general information regarding test equipment for electrical installation.

4.3.1 Accordance to directives and standards

Electrical installations testers must meet the requirements of the standards listed in table 16.
European LVD and EMC directives are referencing to the harmonized standards based on IEC 61010 and IEC 61326 series. Accordance to these standards is obligatory and confirmed by the manufacturer or importer with the CE mark.
The IEC 61557 series defines additional safety aspects and measuring accuracy or electrical installation testers. Most national regulatives are referencing to it.

Safety and electromagnetic compatibility

IEC 61010-1	Safety requirements for electrical equipment for measurement, control and laboratory use - Part 1: General requirements
IEC 61010-31	Safety requirements for electrical equipment for measurement, control and laboratory use - Part 31: Particular requirements for hand-held probe assemblies for electrical measurement and test
IEC 61326 series	Electrical equipment for measurement, control and laboratory use – EMC requirements

Additional safety requirements, accuracy and operation

IEC 61557 series	Electrical safety in low voltage distribution systems up to 1000 V a.c. and 1500 V d.c. - Equipment for testing, measuring or monitoring of protective measures
IEC 61557-1	General requirements
IEC 61557-2	Insulation resistance
IEC 61557-3	Loop impedance
IEC 61557-4	Resistance of earth connection and equipotential bonding
IEC 61557-5	Resistance to earth
IEC 61557-6	Effectiveness of residual current devices (RCD) in TT, TN and IT systems
IEC 61557-7	Phase sequence
IEC 61557-8	Insulation monitoring devices for IT systems
IEC 61557-9	Equipment for insulation fault location in IT systems

IEC 61557-10	Combined measuring equipment for testing, measuring or monitoring of protective measures
IEC 61557-12	Performance measuring and monitoring devices (PMD)

Table 16: *Standards for installation testers and monitoring devices*

4.3.2 Equipment markings and specifications

Table 17 includes safety related markings on measuring equipment.
The markings inform about conditions in which the instrument is intended to be used.

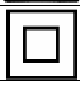
Marking	Description
	***Caution, see note***! (Usually user manual) The symbol can relate to complete or a part of test equipment.
	***Caution, possibility of electric shock!*** Equipment can produce hazardous voltages.
	***Protection by double insulation*** Double insulation is typical for installation testers.
600 V CAT III	Overvoltage category. Defines protection level against over voltages.
Pollution degree 2	Influence of pollution. Influences protection level against over voltages.
IP 42	Protection by enclosure Defines protection against environmental conditions.

Table 17: *Markings on installation testers*

4.3.3 Instrument accuracy, calibration, re-calibration

Proved accuracy and consistency of test instruments during its complete lifetime is required for verification purposes. In this chapter activities to assure this are described.

Accuracy

- Instruments must be designed and approved according to the IEC 61557 standards.

Valid calibration of the instrument

- New instrument must be provided with a valid calibration certificate from the manufacturer.
- Calibration certificates from accredited laboratories are the most valuable ones. Accredited laboratories are subjected to a very strict control, their results can be considered as absolutely accurate and traceable.

Regular re-calibration

- Proper re-calibration date must be defined.
- Recommended re-calibration date by use the manufacturer should be considered.
- In case of daily use or if the instrument is used in harsh conditions (higher number of tests than normal, moisture and high temperature) the recalibration period should be shorter.
- National or other regulatives for recalibration periods should be strictly considered.

Informal accuracy checks
Between recalibrations there are some good practices to maintain confidence in the test instrument:

- Daily (weekly) comparative cross checks with other test instruments.
- Daily (weekly) comparative measurements on known reference points with known values.
- Use of simple field calibration units (e.g. Eurocheck MI2099 from METREL).

METREL calibration laboratory
All installation testers produced by METREL are calibrated in METREL accredited calibration laboratory. More information is available on METREL web sites.

4.3.4 Overvoltage category

Especially in high power (transformer stations, industrial plants) installations transient over voltages (fast transients and surges) and high (current) energy breakdowns can become very destructive.
Reasons for transients and consequentially breakdowns are:

- Direct or indirect lightning struck.
- Fast changes/interruptions of current in the power system (switching on/off motors, transformers, large loads, failures, reaction of protective devices).

Over voltages can travel along the distribution/ installation wiring. As a result, failure at remote location can cause problems too.
If the electrical equipment cannot sustain the transient, the transient/ surge voltage can act as an ignition for a breakdown. The consequences depend on the fault loop impedance.
In a domestic environment breakdowns usually cause the tripping of protective devices without making serious problems. At the origin of installation a breakdown can have more severe consequences because the fault impedances are lower. It can cause burnings and severe damage all around the fault.
Both, breakdowns and over voltages are more likely to occur:

- On installations that are delivering more power (usually near to the origin).
- On outside conductors that are more susceptible for all kinds of electromagnetic disturbances.

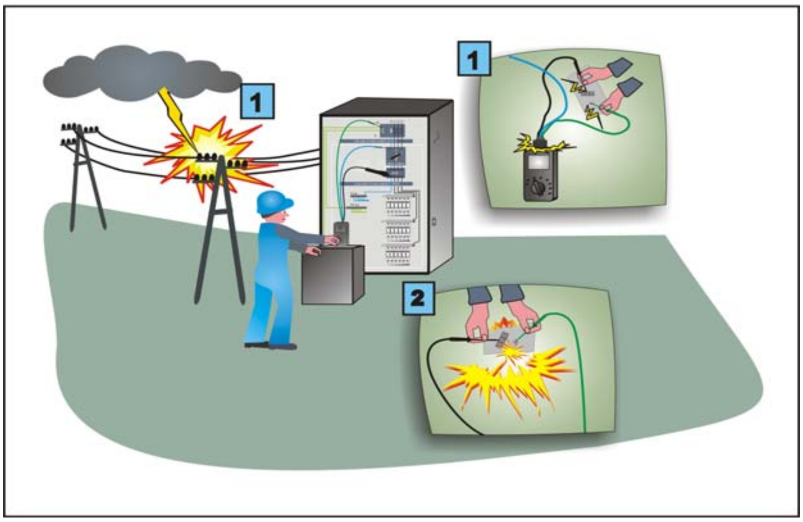


Fig 21: *Origin and consequences of a breakdown*

Fig 22: *Photo of breakdown of test equipment*

Overvoltage protection categories of installation
The standard IEC 60364-4 includes the definition of overvoltage categories (Section 44: Protection against voltage disturbances and electromagnetic disturbances). They are defined on base of installation impedances, proximity to the installation origin and installed protective elements. For each declared category/voltage the maximum amplitude of transient voltages to be expected during the measurement (on electrical installation, equipment, etc.), is defined, see fig. 23.

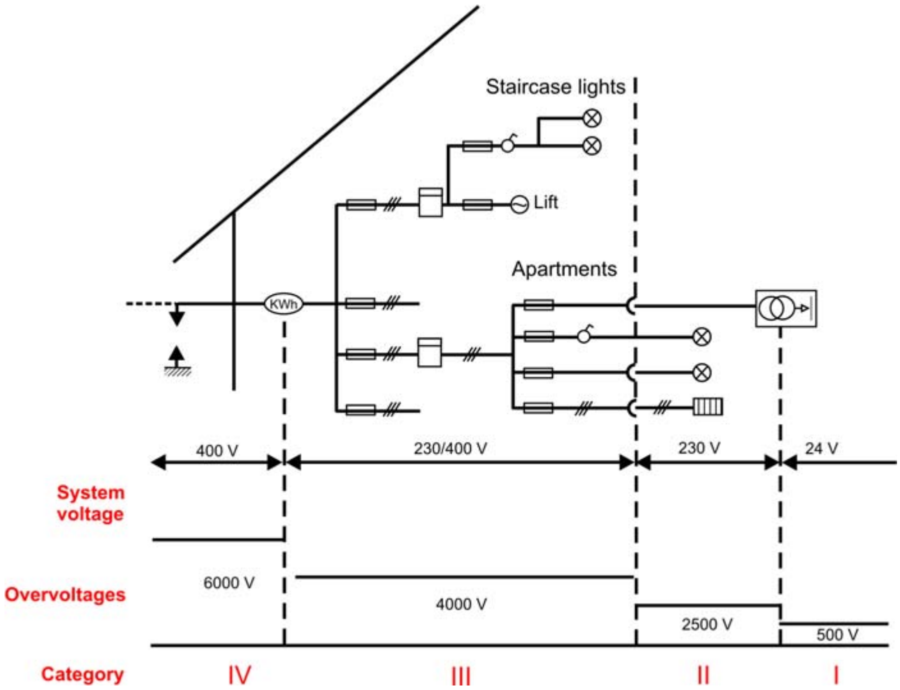


Fig. 23: *3 Over voltages acc. to IEC 60364*

CAT IV environment
Origin of installation, utility transformers, all outside conductors, energy counters, protective devices on primary sides and electricity meters are classified as CAT IV environment.

CAT III environment
Distribution boards, machinery, main switching devices close to the switchgears, industrial installations and high current circuits/outlets close to the DB are classified as CAT III environment.

CAT II environment
Outlets, lighting switches and connections in buildings and outlets at a distance more than 10 m from a CAT III source are classified as CAT II environment.

CAT I environment
Electronics on secondary side of supply transformers, electrical equipment with supply voltage separation and low voltage outputs are classified as CAT I environment.

Overvoltage categories of electrical installation testers
As installation testers are often used at the power source and at the installation's origin a high protection against over voltages is important.

The standard IEC 61010-1 also considers over voltages. The minimum protective measures for measuring equipment for all installation overvoltage categories are defined. The measuring instruments should stay safe if they are exposed to the maximum expected transient voltage on the installation. Most installation testers are designed to sustain over voltages expected in CAT III environment. Only few models with improved protection circuitry are designed for CAT IV environment. As they include additional protective measures over voltages there must be a higher overvoltage to provoke a breakdown.

Modern installation testers should be declared as at least 300V CAT IV!

Overvoltage protection category as defined in IEC 60664-1 and IEC 61010-1 for line – earth	Transient test voltage
CAT II 600 V	4000 V
CAT III 300 V	
CAT III 600 V	6000 V
CAT IV 300 V	
CAT III 1000 V	8000 V
CAT IV 600 V	

Table 18: *Overvoltage protection categories for installation testers*

Other protection measures in high voltage environment
Besides using a high protection-class measuring instrument, the user must also take care about the accessories (test leads, tips, crocodiles, clamps), especially if performing tests in a CAT IV environment. The accessory should be at least of the same category as the equipment.
Since accessories are subjected to wear, damage etc it is a good practice to use accessories with a higher protection class than the instrument.

Although considering all safety precautions the test equipment can still fail (breakdowns through unexpected transients, etc)
Therefore the user:

- Should wear insulated gloves, safety glasses, flame resistance clothes,
- Should wear insulated boots and stand on nonconductive floor,
- Should not wear metal jewellery, watches,
- If possible the instrument should not be hanged around the neck or be in the hand,
- If in doubt should always assume that the circuit is live,
- etc.

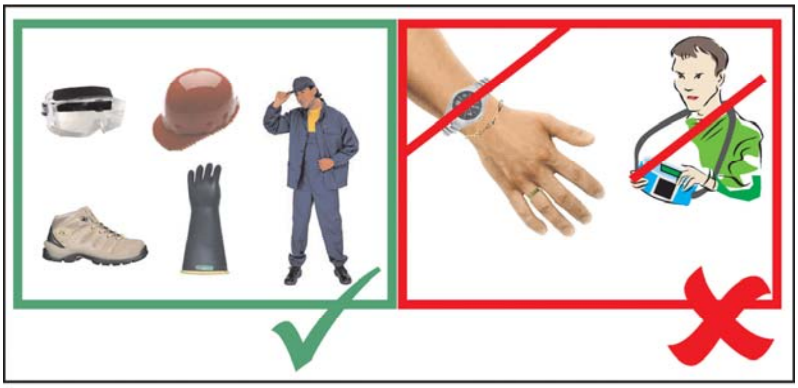


Fig 24: *Other protective measures for working in CAT IV environment*

Note:
For more information about over voltages refer to METRELs article *Electrical installation testers: CAT IV or CAT III?* available on METREL's web pages.

4.3.5 Pollution degree

Dust and other pollutants collect on surfaces, outside of the equipment but also inside, penetrating through the openings. Dust in combination with humidity forms a layer that reduces insulation. Three pollution degrees are defined:

Pollution degree 1	No pollution or only dry, non-conductive pollution occurs. The pollution has no influence.
Pollution degree 2	Normally only non-conductive pollution occurs. Occasionally, however, a temporary conductivity caused by humidity condensation must be expected.
Pollution degree 3	Conductive pollution occurs, or dry, non-conductive pollution occurs which becomes conductive due to humidity condensation is expected.

Table 19: *Pollution degrees acc. to standard IEC 60664.*

Pollution degree 2 is the standard one applied for electrical installation testers.

4.3.6 Protection by enclosure

The IP factor defines following:

- Protection of persons against dangerous voltage inside the instrument,
- Protection against penetration of solid parts (sand, dust),
- Protection against penetration of water.

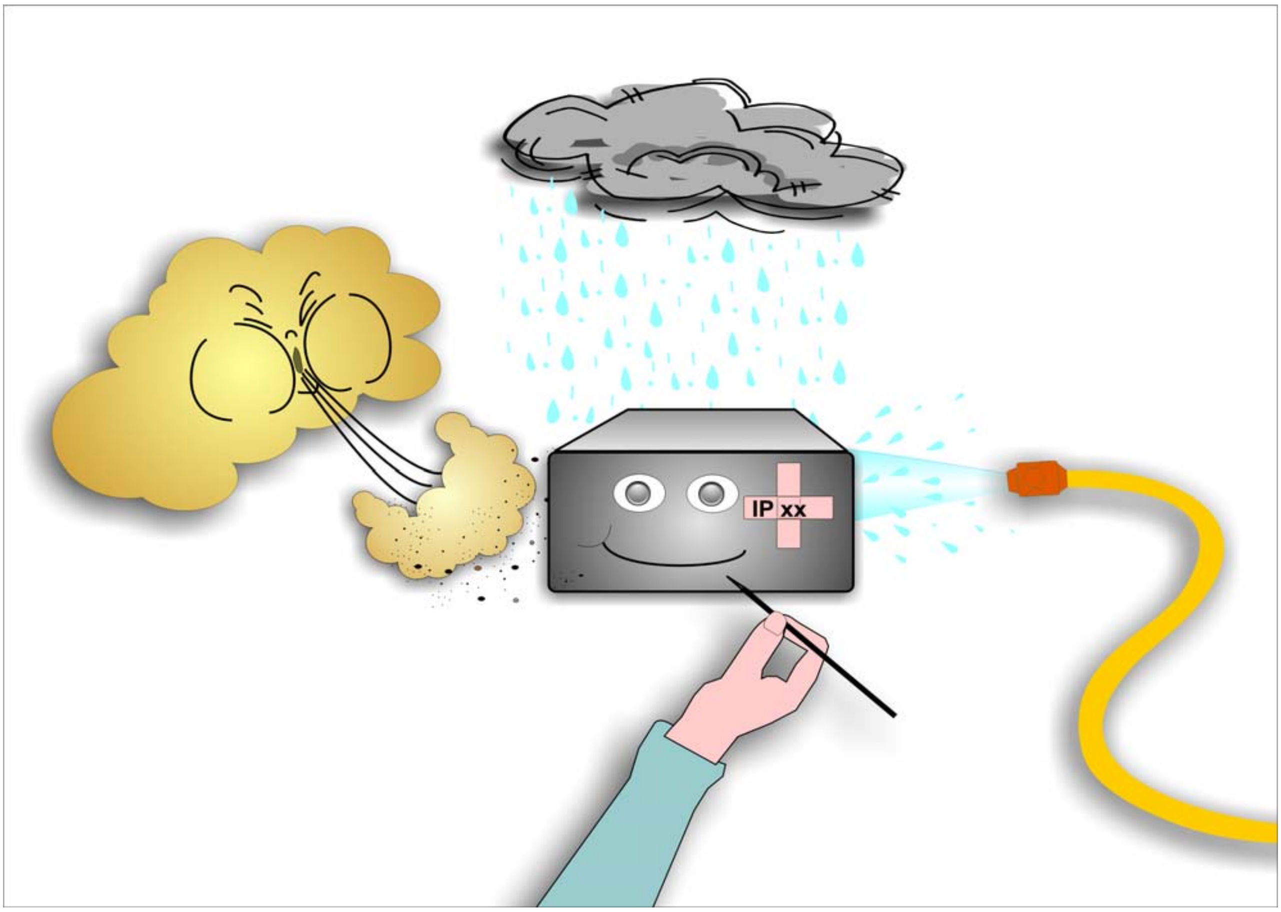


Fig. 25: *IP factor – Protection by enclosure*

The meaning of first and second IP numbers is described in table 20 (as defined in IEC 60529).

Protection against **solid foreign objects**

IP code	Description
IP **0**x	Non-protected.
IP **1**x	Protected against solid foreign objects of 50 mm diameter and greater.
IP **2**x	Protected against solid foreign objects of 12.5 mm diameter and greater.
IP **3**x	Protected against solid foreign objects of 2.5 mm diameter and greater.
IP **4**x	Protected against solid foreign objects of 1 mm diameter and greater.
IP **5**x	Dust protected.
IP **6**x	Dust tight.

Protection against **ingress of water**

IP code	Description
IP x**0**	Non-protected.
IP x**1**	Protected against vertically falling water drops.
IP x**2**	Protected against vertically falling water drops when enclosure is tilted up to 15 º.
IP x**3**	Protected against spraying water.
IP x**4**	Protected against splashing water.
IP x**5**	Protected against water jets.
IP x**6**	Protected against powerful water jets.
IP x**7**	Protected against the effects of temporary immersion in water.
IP x**8**	Protected against the effects of continuous immersion in water.

Table 20: *IP protection according to standard IEC 60529*

Minimal requirement for installation testers is IP 40. That is normally enough if the instrument is not used outside. IP 41 is the standard IP degree for electrical installation testers.

5 Electrical installations safety management

The term installation safety management summarizes all necessary activities that must be taken to assure the safety of electrical installations through its complete lifetime. For a safe and proper operation of electrical installation, it has to be properly designed, assembled, brought into operation and maintained. Each of these steps should be verified, validated and documented.
Figure 26 summarizes activities for assuring a safe and working electrical installations.

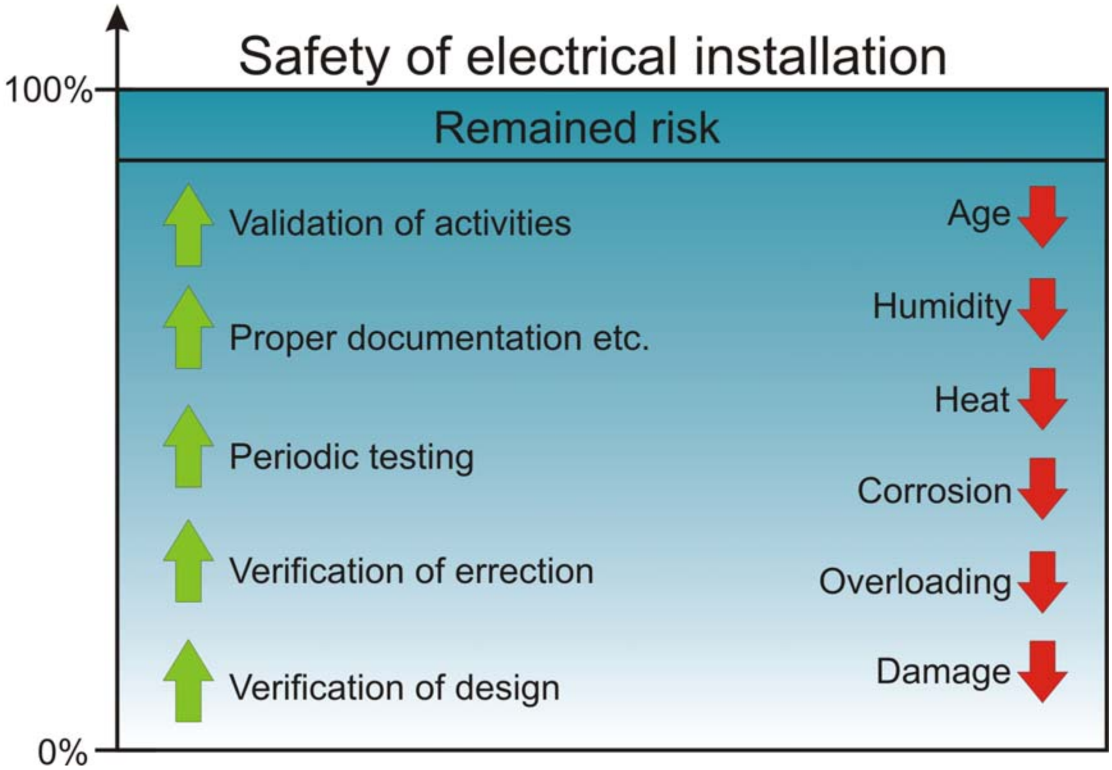


Fig 26: *Safety management*

Verification means confirmation of a technically skilled person (electrician, installer).
Validation means confirmation by an authority body (inspector).

Electrical installation shall be verified and validated at each of following stages:
- After design
- After assembly for erection,
- After modification,
- Periodically

Assembly, modifications and periodic verifications should be supported by visual inspection and measurements.

5.1 Design verification

The purpose of design verification is to verify that the design of a new installation or a modification corresponds to the project documentation. The verification shall confirm that all safety measures and other requirements are taken into account.

5.2 Verification after assembly (initial verification)

The purpose of initial verification is to prove that the assembly of the installation was made properly and according to the project documentation.
The complete installation has to be verified thoroughly, in full details. The verification consists of visual inspection and testing. Both steps have to be documented well. A verification report should be provided.
Refer to chapter 8.1.1 for more information about initial verification.

5.3 Maintenance (after modifications, additions, alterations, service) testing

Maintenance means each modification or change on the installation in operation. Typical maintenance works are changing installation components, adding new connection points, adding new circuits, altering existing circuits and points etc. Verification usually includes a thorough check (similar as for initial verification) of the modified installation parts and fast check/ inspection of existing (no-modified) parts.
The purpose of the verification after maintenance is to verify the performed works and to check that installation's performance remains within specified limits. All verification steps have to be documented well. A verification report (simpler form) should be provided.
Refer to chapter 8.1.1 for more information about verification after maintenance.

5.4 Periodic (recurrent) testing

Periodic tests are to be carried out to determine whether the installation is in satisfactory condition after a certain period.
The periodic testing should consist of inspection and testing as far as reasonably practicable. As it must often be performed without disturbing the regular operation of the installation or some parts are not accessible it is not as strict as other tests. Therefore it is important:

- That the extent of the test is agreed between the contractor and customer,
- That the limitations of the test are clearly described and documented,
- That there are no unnecessary limitations.

5.4.1 Retest period

A competent person should define the time interval to the next periodic verification. IEC 60364-6 recommends following time intervals for periodic checking.

Period	***Installations***
Longer (e.g. 10 years)	- Dwellings Note: electrical installation shall be verified when occupancy of dwelling is changed.
4 years	Typical period for most installation groups.

Shorter	- Working places or locations where degradation leads to risk of electric shock, fire or explosion. - Working places or locations with both, high voltage and low voltage installation. - Communal facilities. - Construction sites. - Safety installations.

Table 21: *Recommended Intervals for periodic test*

Note:

- The recommended periods are the maximal intervals. They are used if the installation is subjected to normal conditions and use.
- Shorter periods can be defined due to particular circumstances. In this case the reason should be specified.
- National regulatives must be considered. They can recommend other periods.

6 Inspections and tests

6.1 Inspections

Visual inspection is an important and effective part of the verification of installation. Visual inspection can discloses many faults that cannot be found by testing.
The visual inspection should be always carried out before testing.

Scope:
The inspection should verify:
- That the components of the installation are in accordance (size, operation) with the project documentation.
- That the components are installed correctly and carefully.
- That the components are in compliance with safety requirements of the relevant equipment standard (marking, certification, manufacturer info).
- That the safety provisions are in accordance with the project documentation.
- That there are no visible damages that could impair safety.

References
The minimal requirements for the content of visual inspection are listed in:
- IEC 60364-6 (chapter 61.2),
- ES 59009 (CENELEC countries).

6.1.1 Required content for visual inspection – IEC 60364

Inspection shall include at least the checking of following, where relevant:
a) Method of protection against electric shock (Part 4-41).
b) Presence of fire barriers and other precautions against propagation of fire and protection against thermal effects (Part 4-42 and Clause 527 of Part 5-52).
c) Selection of conductors for current-carrying capacity and voltage drop (Part 4-43 and Clauses 523 and 525 of Part 5-52).
d) Choice and setting of protective and monitoring devices (Part 5-53).
e) Presence and correct location of suitable isolating and switching devices (Clause 536 of Part 5-53).
f) Selection of equipment and protective measures appropriate to external influences (Clause 422 of Part 4-42, 512.2 of Part 5-51 and Clause 522 of Part 5-52).
g) Neutral and protective conductors correctly identified (514.3 of Part 5-51).
h) Single-pole switching devices connected in the line conductors (Clause 536 of Part 5-53).
i) Presence of diagrams, warning notices or other similar information (Clause 514.5 of Part 5-51).
j) Identification of circuits, over current protective devices, switches, terminals, etc. (Clause 514 of Part 5-51).
k) Adequacy of connection of conductors (Clause 526 of Part 5-52).
l) Presence and adequacy of protective conductors, including main and supplementary equipotential bonding conductors (Part 5-54).
m) Accessibility of equipment for convenience of operation, identification and maintenance (Clauses 513 and 514 of Part 5-51).

Inspection shall include all particular requirements for special installations or locations.

Inspection methodology:
Inspection / visual checking shall be done first before any measurement. The inspection shall be performed in following order:

- Visual inspection of installation's input,
- Visual inspection at distribution board,
- Visual inspection of final circuits.

Initial inspection
Each point of complete installation shall be inspected visually. Mechanical fastenings should be checked. The complete installation shall be disconnected from supply during the inspection.
Inspection after modification or repair
The part(s) of installation that was repaired or modified shall be thoroughly inspected as during initial inspection. Observed parts of the installation shall be disconnected from supply.
Periodic and maintenance inspection
The part(s) of the installation that has to be maintained and periodic verified shall be inspected. In this case the installation is normally not disconnected from supply.

Results:
IEC 60364-6 specifies a detailed checklist for the visual inspection (see chapter 8.1.5 for more information). A note must be assigned for each item in the report. All checked items must pass; each failed item has to be repaired until all pass. Results can be noted as:

PASS	Item was checked and result is satisfactory.
FAIL	Item was checked and result is unsatisfactory.
LIMITED	Inspection was performed in a limited manner. Extent of limitation must be described.
NOT APPLICABLE	Item is not applicable in the particular inspection.

6.2 Tests

6.2.1 Insulation resistance

Scope of test
This test discloses insulation faults caused by pollution, moisture, deterioration of insulation materials etc. Insulation resistance of electrical installation is represented with the parameter R_{IH} on the substitute circuit on fig. 14.

References:
Limits, methodology: IEC 60364-6 (chapter 61.3.3, table 6A)
Measuring instruments: IEC 61557-2

Measuring principles / limits:
Insulation resistance shall be measured between

- Line conductors

- Line and PE conductors
- Line and neutral conductors.
- Neutral and PE conductors

Table 22 shows limit values for electrical installations acc. to IEC 60364-6.

Nominal circuit voltage	Test voltage d.c. V	Insulation resistance MΩ
SELV and PELV	250	≥ 0.5
Installations with nominal voltages up to and including 500 V, including FELV	500	≥ 1.0
Above 500 V	1000	≥ 1.0

Table 22: *Insulation resistance - limits*

Notes:

- Capacitances in the installation (cables, connected equipment) can cause capacitive leakage currents, represented as C_{IH} in the substitute circuit on fig. 14. The capacitive portion of the impedance is not considered in the insulation test as it is carried out with DC current.
- In normal cases the insulation resistance is far higher than predefined limits, especially in new installations. When the result is close to or less than the required minimum insulation resistance:
  - Repeat the measurement with a longer measurement time or perform a couple of test.
  - Check that loads / consumers are disconnected and/or switched off, surge protective devices are removed, lights are switched off.
  - If there are signs of dust and humidity clean and dry critical parts.
- If surge protective devices cannot be removed, than the test voltage could be reduced to 250 V_{DC}. In this case the insulation resistance limit shall be at least 1 MΩ (IEC 60364-6).
- Test individual sub circuits to find the problematic location (by disconnecting of circuit breakers, removing fuses…).

6.2.1.1 Insulation of complete installation

Under following conditions the insulation resistance test of the complete installation can be performed:

- Installation must be disconnected from the input mains during the insulation test; main switch = OFF.
- All sub circuits must be involved; other switches/fuses/RCDs are ON.
- All loads (motors, electrical equipment, lamps) must be physically disconnected.

If all installation wiring is included in the test and the result is a PASS it can be claimed that insulation tests of any sub items (individual circuits, switchboard) will pass too.
This test is usually performed in the switchboard, although it could be performed from any connection point with accessible L (L1, L2, L3), N, and PE conductors.
In case of a fault individual circuits shall be checked.

Notes:
- Some national regulatives do not recognize this test as sufficient. In this case insulation resistance should be tested at every connection point of final circuits.
- For periodic testing it is sometimes impossible to switch OFF all loads between L and N. If allowed the Insulation L-N test should be skipped in this case.

6.2.1.2 Insulation resistance of individual circuits / items

Especially during troubleshooting insulation resistance of individual installation parts are checked. In this case appropriate fuses / switches should be switched OFF in order to isolate the observed installation part.

Connection diagrams

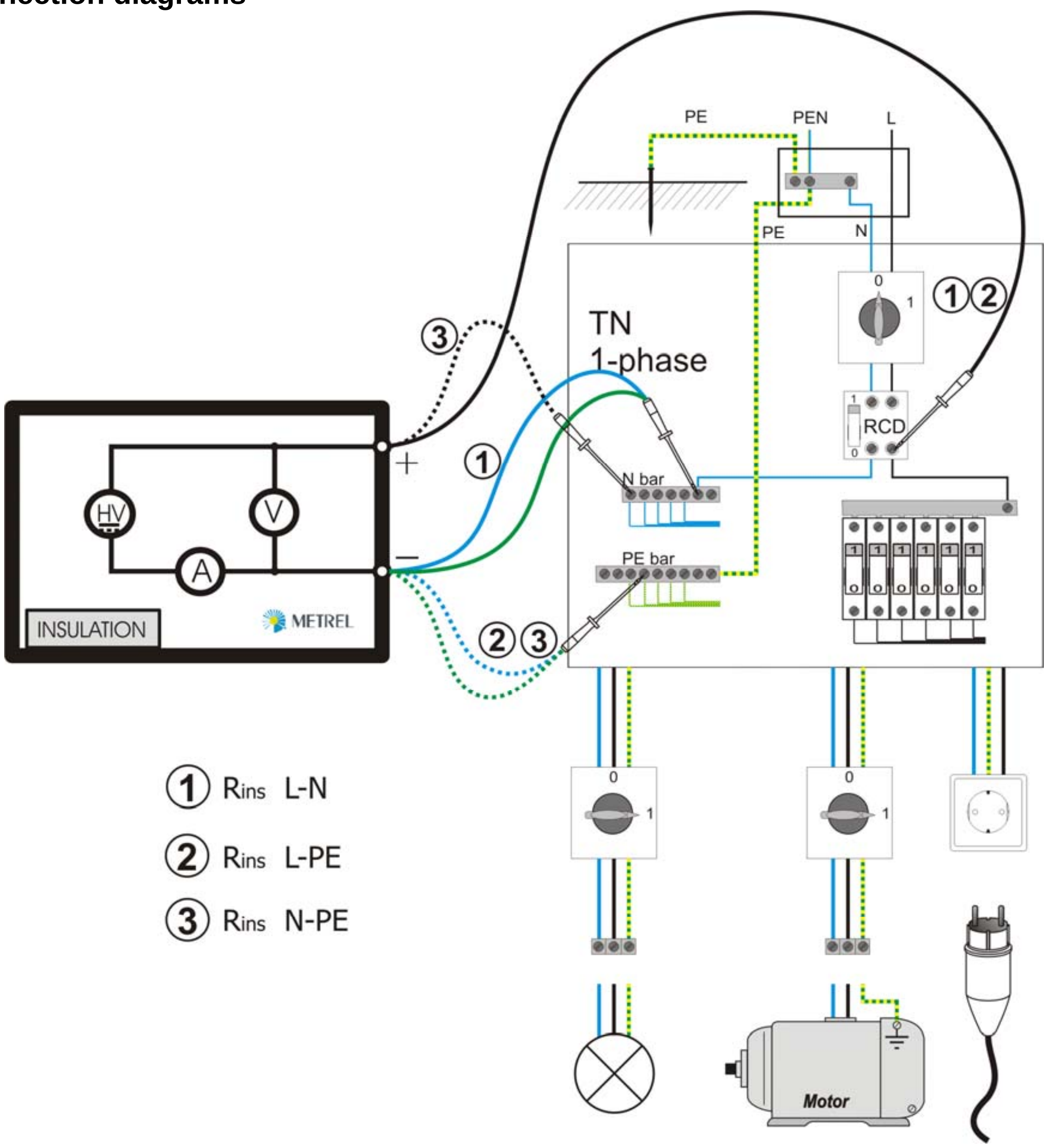


***Fig.27:** Complete insulation test performed on switchboard*

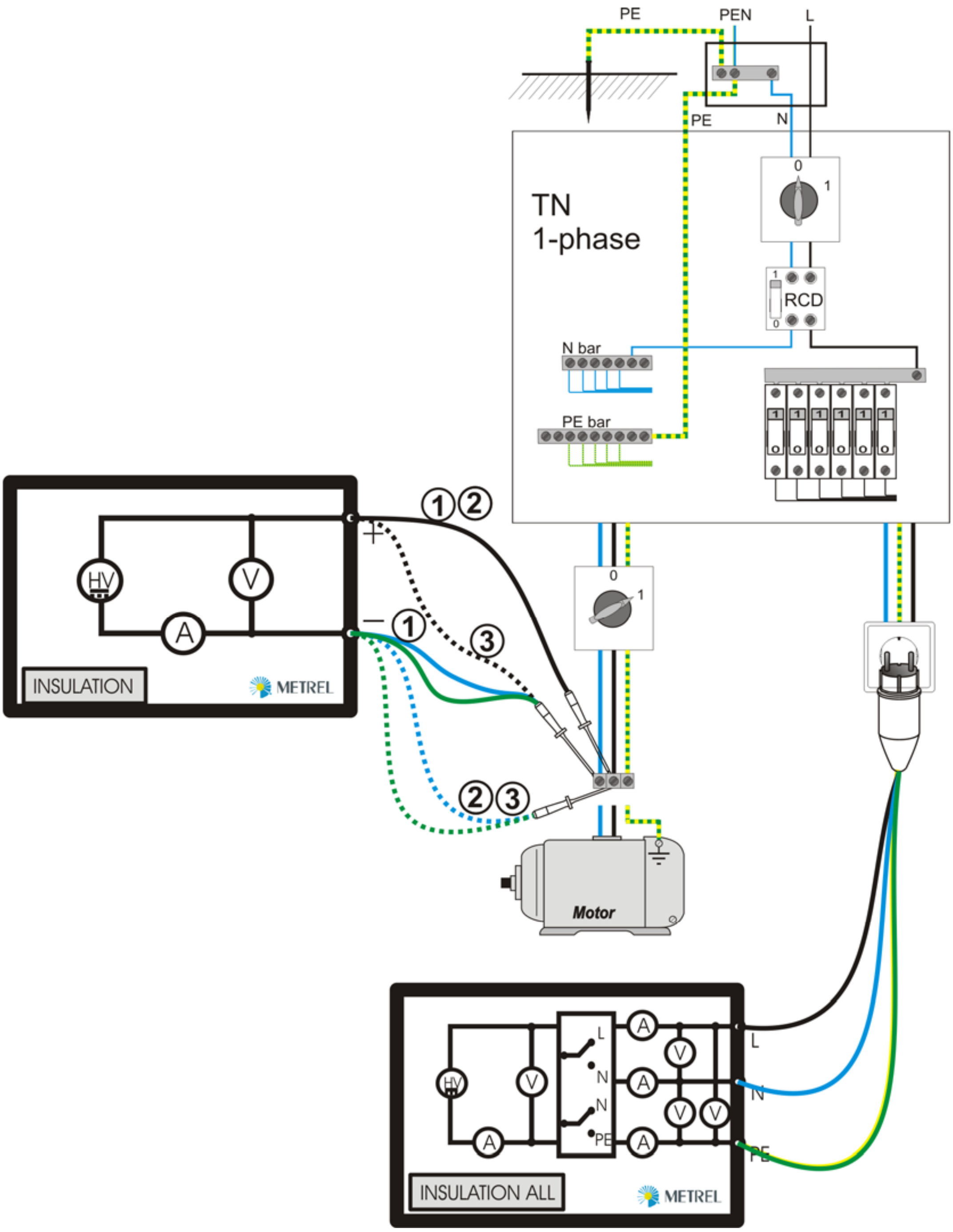


Fig 28: *Complete insulation test at connection point; on outlet (Insulation ALL feature)*

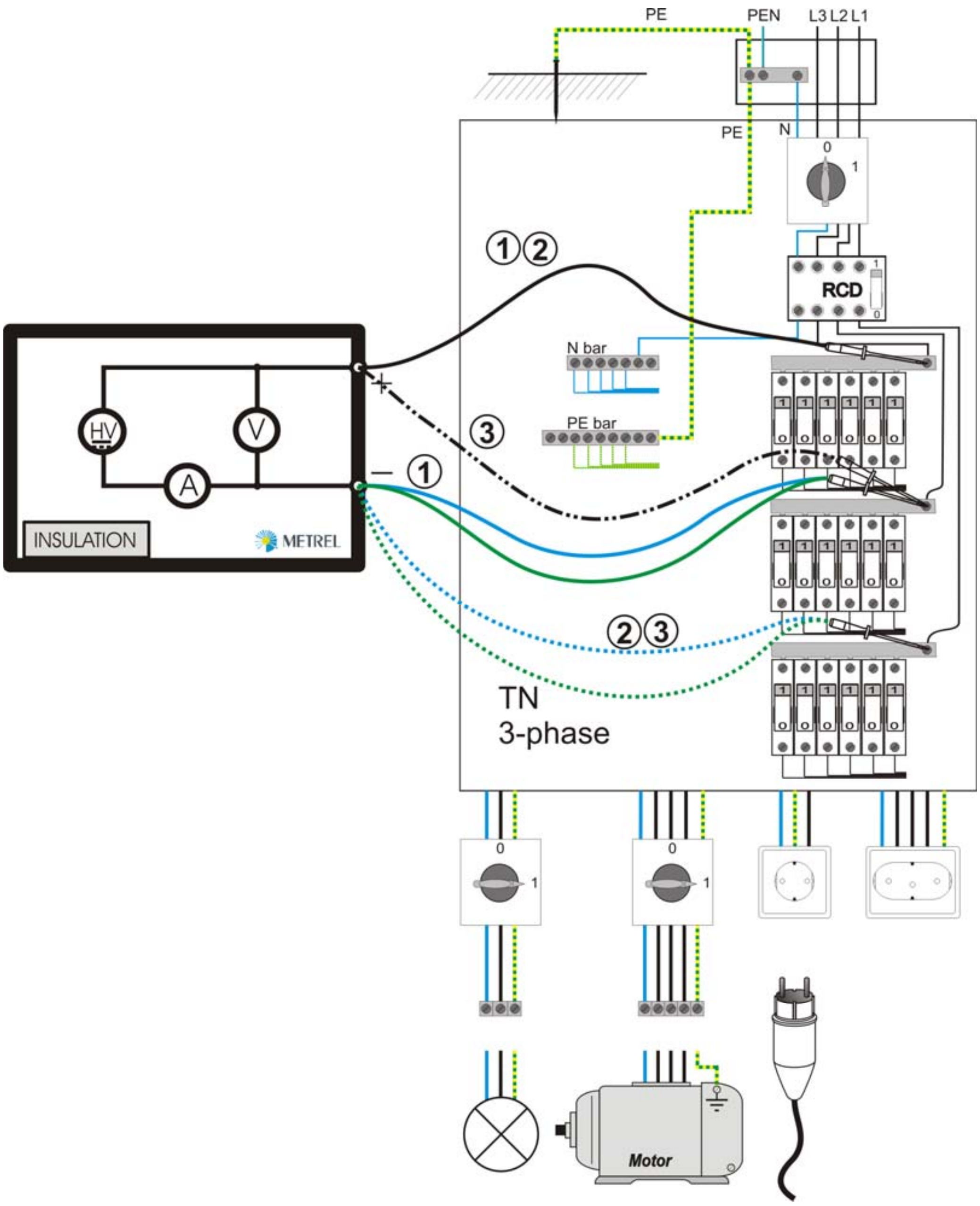


Fig.29: *Complete phase - phase insulation test performed on switchboard*

METRELs hint:

- METREL installation testers Eurotest AT, XA have inbuilt the “Insulation ALL” function. With this function a 3-port insulation test (L-N, L-PE, N-PE or L1-L2, L1-L3, L2-L3) can be performed in one step. This is a very time saving feature especially if measuring insulation on outlets (see figure 28)
- METREL installation testers Eurotest AT, XA include the parameter “Type of insulation test”. Options are:
  - L-N, L-PE, N-PE, L-PE N-PE (recommended if loads between L and N can not be disconnected),
  - L-N L-PE (recommended if N-PE connection can not be interrupted),
  - ALL.

Setting these parameters simplifies the creation of the verification report.

6.2.2 Continuity of protective conductors and equipotential bonding

Scope of test

Continuity of main protective conductors
Protective conductors connect exposed conductive parts with earthing arrangements. Appropriate PE bonding assures a firm connection of exposed conductive parts with the earthing arrangement. The main protective earth wiring consists of:

- PE conductors that connect PE terminals (outlets, fixed connection points, electrical equipment) and main PE bar.
- PE conductors that connect external conductive parts (water installation, antennas, heating system etc) with the main PE bar.

The continuity test confirms that PE connections and additional equipotential bondings are functioning. PE conductors are presented with parameters R_{PEd}, R_{PEh}, R_{PES} on the substitute circuit on figure 14.

Equipotential bonding
Equipotential bonding assures a low contact voltage between two metal parts that can be touched simultaneously.
Equipotential bonding is to be applied:

- Between exposed conductive parts that are connected to earth through different PE connections.
- If there is other exposed conductive parts at a distance lower then 2.5 m.
- R_{PEmain} is too high (see Eq. 18)
- In bathrooms, showers, swimming pools and similar places the equipotential bonding is performed by default (IEC 60364-701)

Additional equipotential bonding is presented with parameters R_{PES} on the substitute circuit on figure 14.

References:
Methodology: IEC 60364-6 (chapter 61.3.2), table 6A
Measuring instruments: IEC 61557-4

Measuring principles / limits:

Problem of parallel paths
Before carrying out a continuity test it should be checked that there are no additional parallel paths between test site and PE bar. If they exist they should not to be used as a part of the PE bonding system.
Parallel conductive paths can be very problematic especially if they are not a part of the electrical system on purpose:

- Because of them the actual PE connection can not be checked correctly,
- They can change the resistance or they can even be removed without warning!

Example
A typical example that is causing many problems is old installations where the pipeline system is uncontrolled connected to the PE wiring. If the tubes are interrupted with plastic components and the actual PE conductor is not intact this results in a serious safety failure.

In general at least at initial verification the existence and integrity of PE conductors should be checked very thoroughly by inspection and measurement.
If unknown parallel paths could be problematic the best solution is to disconnect the measured connection at the PE bar during the test.

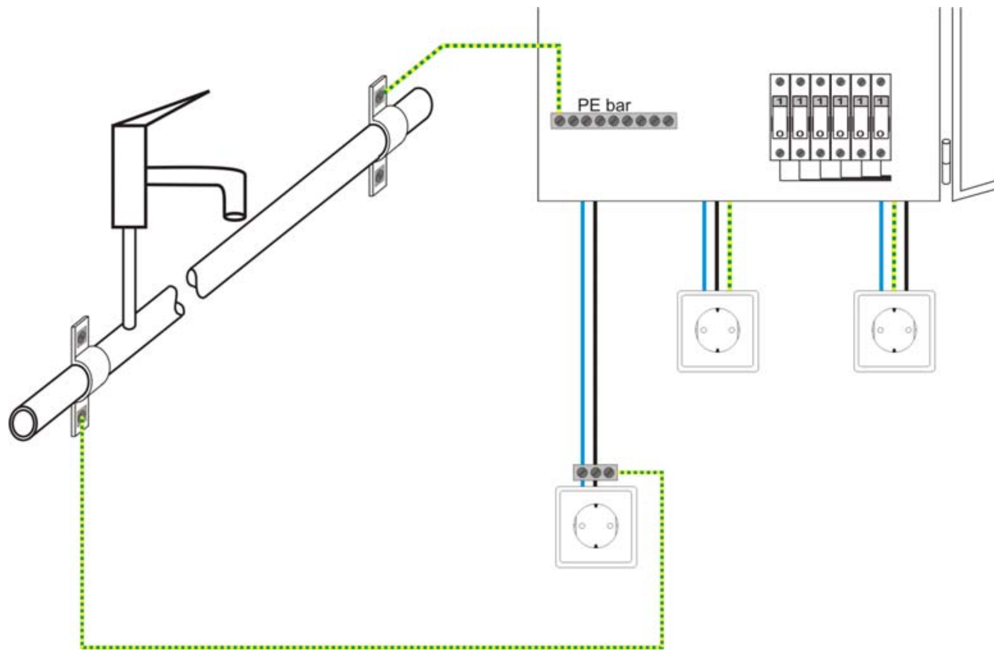


Fig. 30: *Example of non-allowed parallel bonding paths*

Note:
The problem of parallel paths is treated different in different countries. For instance in UK the PE conductor must be disconnected from the installation during the test. For initial verifications alternative test methods are not allowed at all.

6.2.2.1 The standard Continuity test

The standard continuity measurement is performed between main PE collector and exposed metal parts (PE terminals on outlets, switches, fixed connections, PE connection of water installation, CATV, lighting system connection, external antenna...).
In general the resistance shall be as low as possible and in accordance with conductor's length and cross-section.

$$R_{CON} = \rho \frac{l}{A} [\Omega] \qquad \textit{Eq. 15}$$

R_{CON}.......... *Conductor's resistance*
ρ............... *Specific resistance of conductor's material (for Cu: 0.0172 $\Omega mm^2/m$)*
l................ *Length of conductor [m]*
A .... *Cross-section of conductor [mm^2].*

Table 33 in Appendix B includes typical conductor resistances, for different lengths and sizes.
As exact calculation of conductor's resistance is rather difficult, 1.0 Ω, 2.0 Ω or similar values are often considered as the limit values.

Notes:

- If the resistance is higher than expected on base of conductor's size and length this can be a result of a serious connection problem and must be checked!
- If the resistance is lower than expected on base of conductor's size and length this can be a result of an unknown parallel path and must be checked!
- For the standard measurement (sometimes very long) prolongation tests are used. In this case the resistance of measuring leads must be subtracted from the result (this feature is usually integrated in installation testers).
- *Problem of parallel paths must be considered.*

6.2.2.2 Measuring continuity in TN systems – the LOOP N-PE test

In TN systems N and PE conductors are connected at the NPE bar at the installation origin (TN-C, TN-C-S) or at power source (TN-S).
Measuring the resistances between N and PE terminals (often called N_PE loop resistance) at test site can simplify the continuity test. Following results are obtained:

In a TN-C-S, TN-C systems:

$$R_{NPE} = R_{Nh} + R_{PEh} \, [\Omega] \qquad \textit{Eq. 16}$$

In a TN-S system:

$$R_{NPE} = R_{Nh} + R_{PEh} + R_{Nd} + R_{PEd} \, [\Omega] \qquad \textit{Eq. 17}$$

R_{NPE} .... N-PE loop resistance
R_{NH}, R_{ND},R_{PEH}, R_{PED}.... Portions of the N-PE loop resistance (see fig. 14)

Expected results:

- If cross-sections of N and PE conductors are the same the expected result is ca. two times higher than the result acc. to Eq. 16.
- If the cross-sections of PE conductor is lower than that of the N conductor than the expected result is slightly higher than result according to eq. 17.

This method is simpler than the standard method because the long extension test leads (see fig. 31) from main PE bar to tested connection point are not needed.

Drawbacks of this method are:

- In case of parallel paths the results are wrong.
- Additional connections between N and PE conductors in the installation also influence the results.
- National regulative must be checked if this measurement is allowed/recommended.

<u>METRELs hint:</u>
METREL installation testers EUROTEST AT, XA can perform the N_PE loop test between instrument's N and PE test terminals. This makes testing with the plug test cable on outlets possible.

6.2.2.3 Equipotential bonding test

Equipotential bonding must be performed if:

$$R_{PEmain} \cdot I_a > U_{C\lim} \qquad \text{Eq. 18}$$

R_{PEmain} ...... *Continuity of main PE bonding*
U_{Clim} .... *Limit contact voltage (usually 50V)*
I_a .... *A current causing disconnection of supply in rated time period. If a RCD is installed at the origin of installation then* $I_a = I_{\Delta N}$

The measurement is performed between two exposed metal parts closer than 2.5 m. Following condition must be fulfilled

$$R_{EB} < \frac{U_{C\lim}}{I_a} \qquad \text{Eq. 19}$$

R_{EB}............ *Resistance between bonded conductive parts*

Connection diagrams

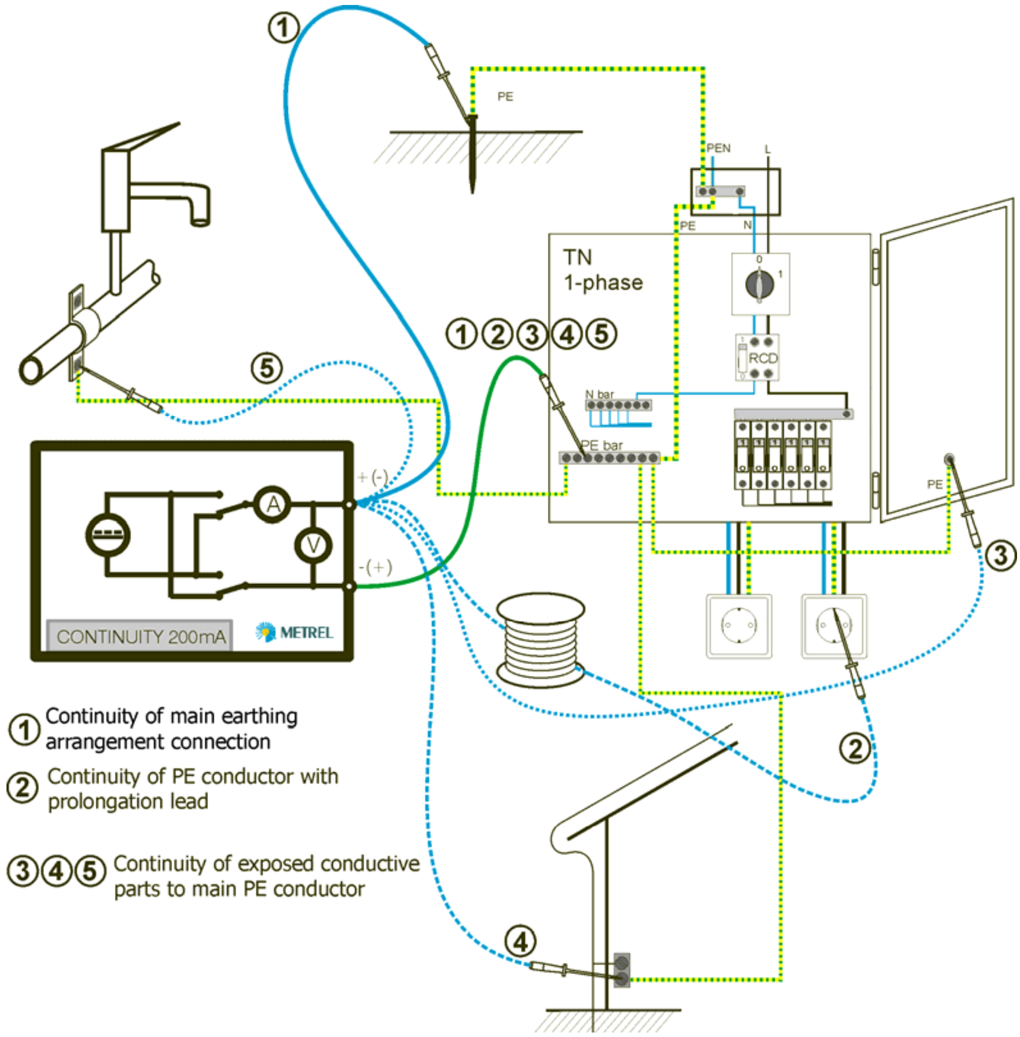


Fig. 31: *Standard continuity test*

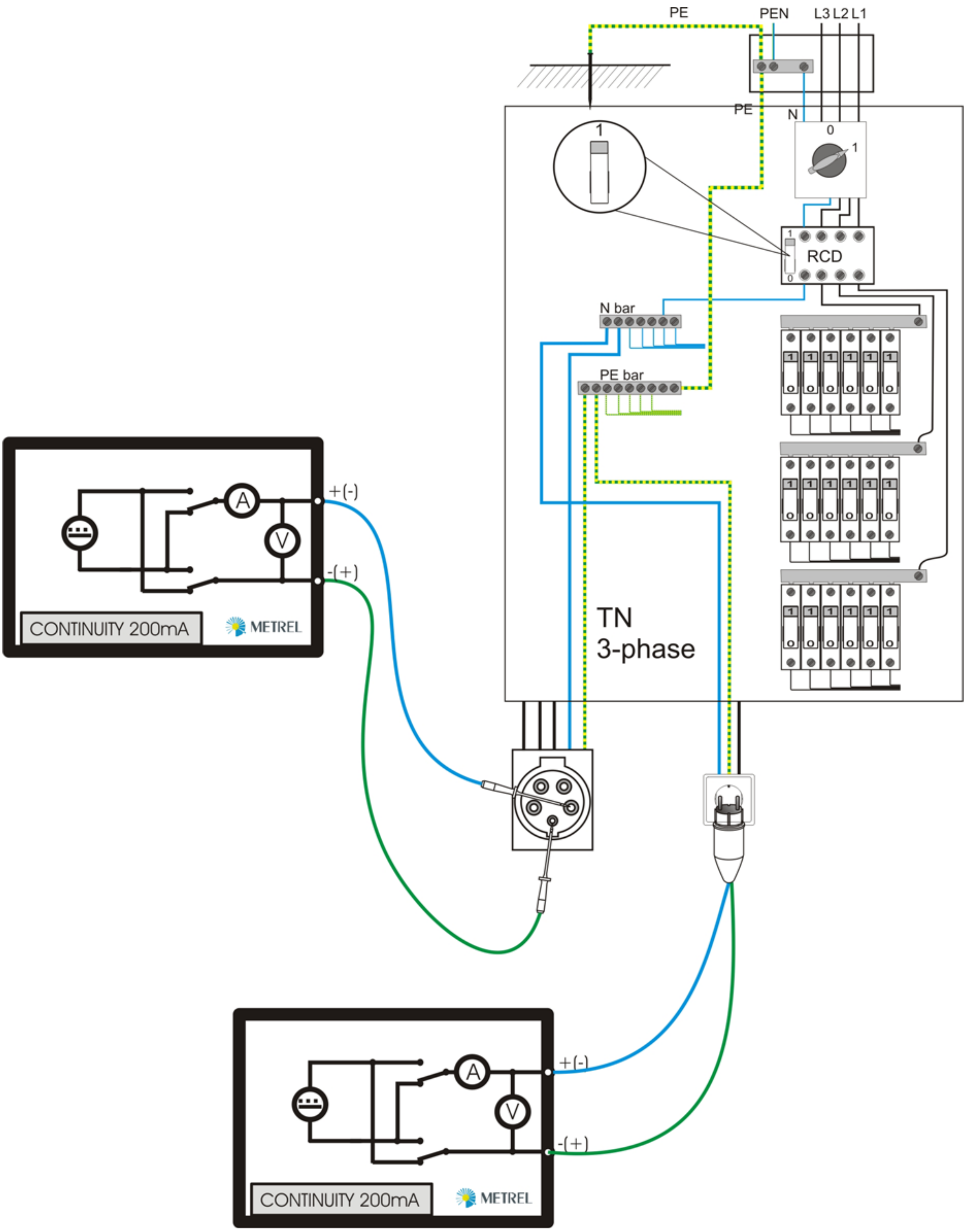


Fig.32: *NPE loop test*

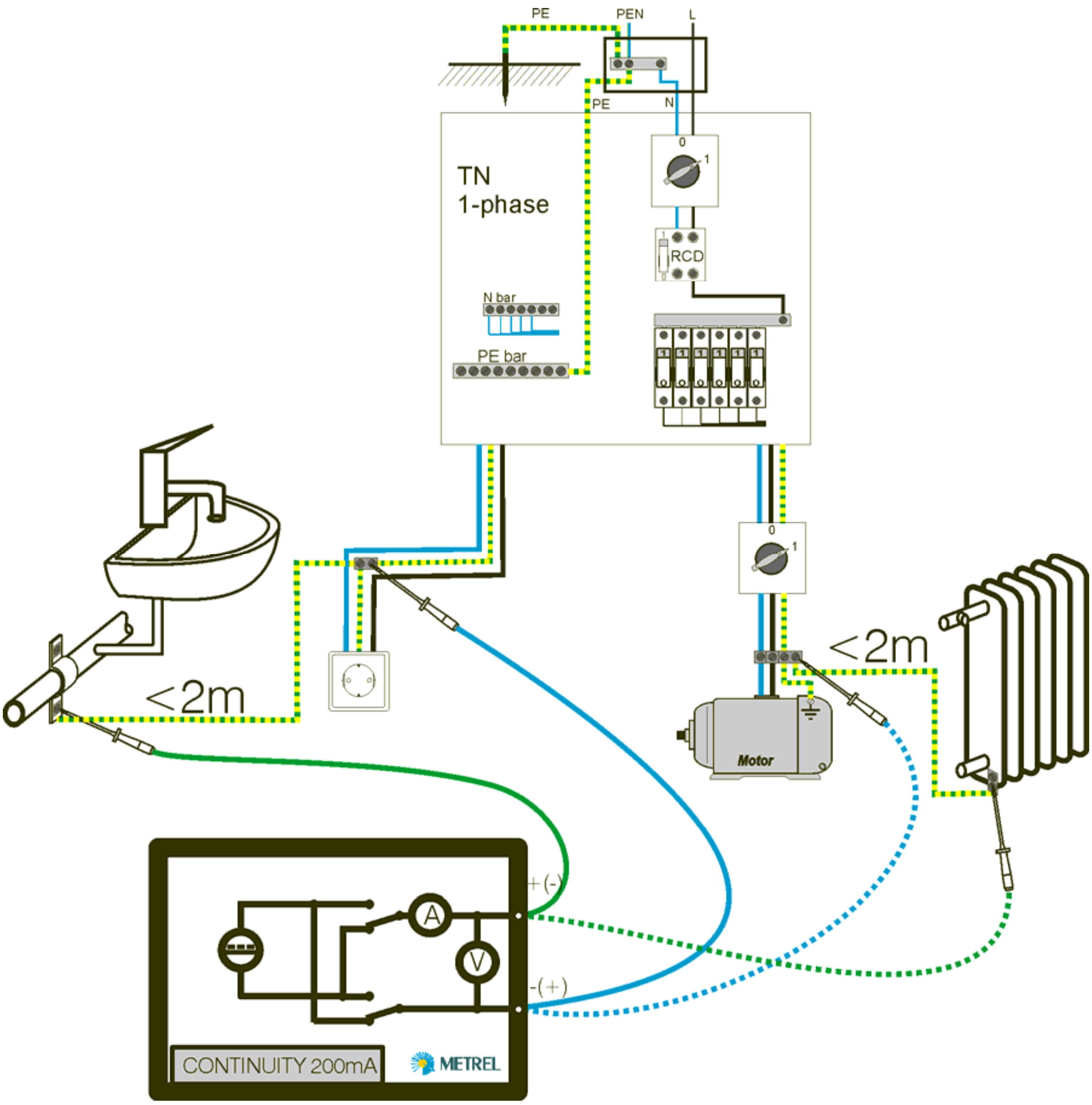


Fig.33: *Equipotential bonding*

6.2.3 Earth resistance

Scope of test
Earthing of exposed conductive parts assures that the voltage on them stays below dangerous level in case of a fault. In the installation substitute circuit on fig. 14 R_{EH} and R_{ED} represent the earthing resistances.

Main earthing
The installation/ distribution point/ power source is earthed via the so-called main earthing. The earthing is realized with metal electrode(s) depleted in the soil. The size and complexity of the earthing arrangement depends on the application (size of object, soil resistivity, maximum allowed earthing resistance etc).
In TN installations the earthing is realized at the source and/or distribution points. The earthing resistances are usually very low (below 1Ω).

TT installations have their own main earthing. The resistances are usually higher than in TN systems (from few Ω up to several hundred Ω). Because of this dangerous fault voltages and body currents can occur at relatively low fault currents. Therefore TT systems usually have additional RCD protection.

Lighting systems
Another application of earthing are lightning protection systems. The lighting rods of a lighting system must have relatively low resistances (between 1 Ω and 10 Ω to prevent the installation/buildings before a direct lighting struck. Lighting systems can be very large.

What is Earth Resistance?
An earthing electrode depleted into ground has a certain resistance, depending on its size, surface of the earthing electrode (oxides on the metal surface) and the soil resistivity around the electrode.
The earthing resistance is not concentrated in one point but is distributed around the electrode.
If a fault current flows into the earthing electrode a typical voltage distribution occur around the electrode (the “voltage funnel”). It can be seen that the largest part of the voltage drop is concentrated directly around the earth electrode (see figure 34).
Fig. 17 shows how fault, step and contact voltages occur as a result of fault currents flowing through the earthing electrode in the ground.
The fault and contact voltages are described in chapter 4.2.2.1.
Close to earthing electrodes or in case of large fault currents into ground the step voltage must be considered to.

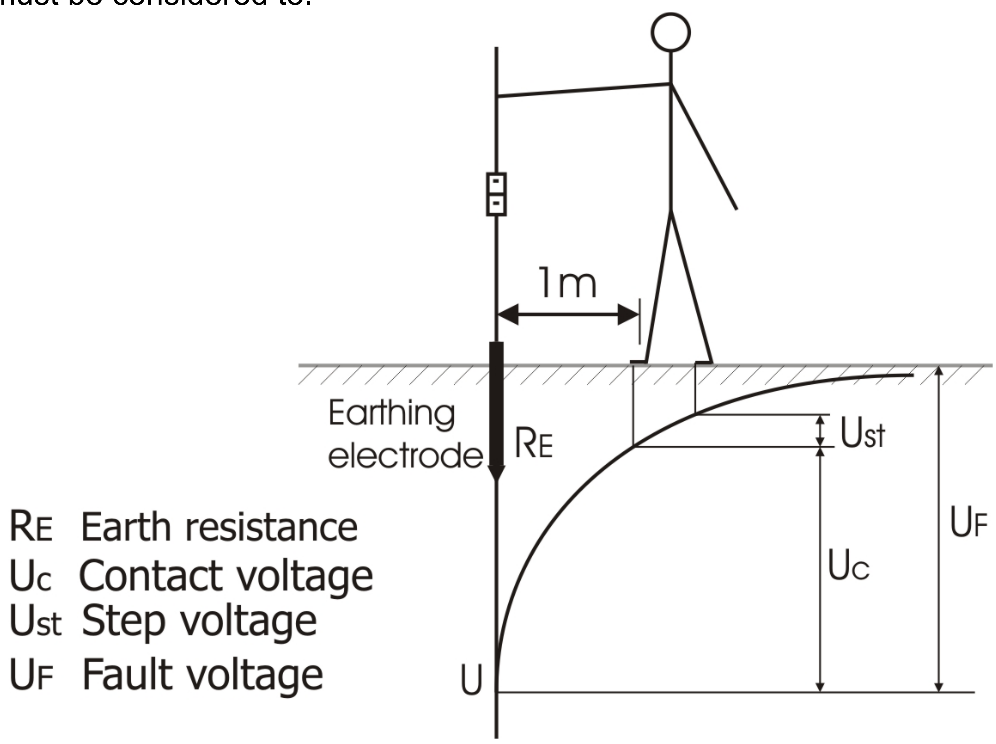


Fig. 34: *Fault, contact and step voltage at earthing electrode*

References:
Limits, methodology: IEC 60364-6 (chapter 61.3.6.2)
Measuring instruments: IEC 61557-5

Measuring principles / limits:
Measuring earthing resistance can be a very complex task. Earthing systems can be large, many local systems can be connected together under or above ground level etc. That is why the selection of an appropriate test method and test instrument is very important. Most important test methods are described later in this chapter.

Limit resistance
For main earthing following condition must be fulfilled:

$$R_{EH} < \frac{U_{C\lim}}{I_a} \qquad \textit{Eq. 20}$$

R_{EH}............ *Main earthing resistance*
U_{Clim}.......... *Limit contact voltage (usually 50V)*
I_a.............. *Current causing disconnection of supply in rated time period.* If a RCD is installed at the origin of installation then $I_a = I_{\Delta N}$.

Individual rods of a lighting system must have a relatively low resistance (between 1 Ω and 10 Ω.

Measuring total and selective earthing resistances
Large earthing systems and lighting protection systems have more than one earthing point. In this case particular earthing points must be tested.
A model of earthing system with multiple earthing points can be presented with a simple connection of resistors connected in parallel. Each resistor represents the earthing resistance of one earthing point. According to the model:
- Total (global, system) earthing resistance is the parallel resistance of (R_{E1}, R_{E2}, R_{E3}, R_{E4}...),
- Individual (partial, selective) earthing resistances are R_{E1}, R_{E2}, R_{E3}, R_{E4}...

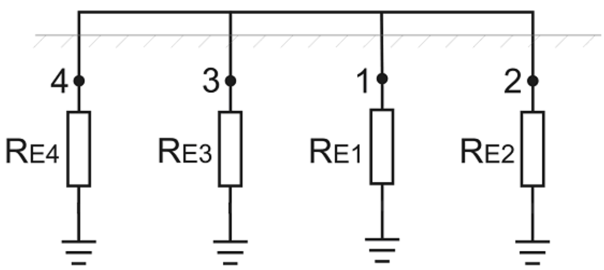


Fig. 35: *Substitute circuit of an earthing system with multiple earthing points*

6.2.3.1 Two wire earthing resistance test, internal generator, no probes,

The two-wire test can be used if there is a well-grounded auxiliary terminal available (e.g. source/ distribution earthings via the neutral conductor). The main advantage of this method is that no test probes are needed for the test. The method is fast and relatively reliable.

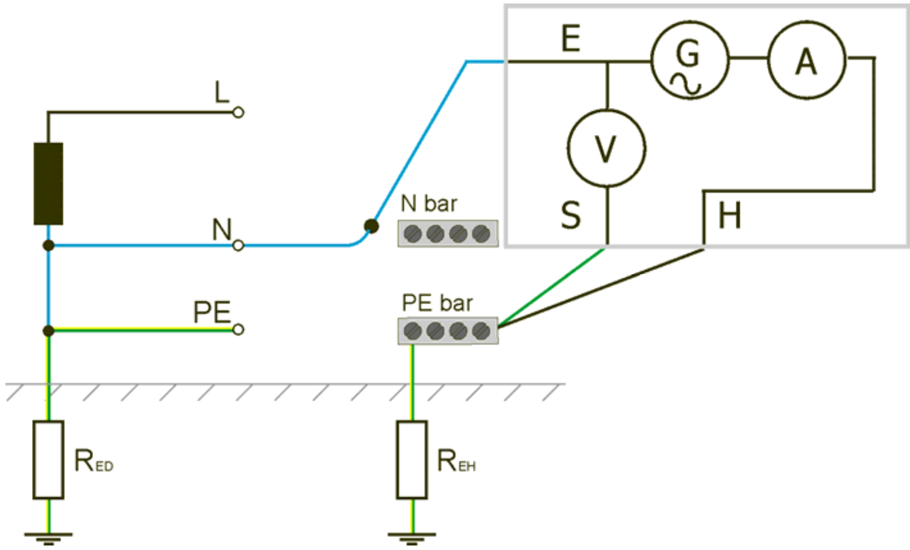


Fig. 36: *Total earthing measurement – two-wire test*

In the example on fig. 36 following resistance is measured:

$$R_{EARTH\_2W} = R_{Nd} + R_{Eh} + R_{Ed} \ [\Omega] \qquad \textit{Eq. 21}$$

$R_{EARTH\_}2W$ .....Result of two-wire earthing resistance test

Usually the resistances R_{Ed} and R_{Nd} are much lower than R_{Eh}. In this case the result can be considered as ≈ R_{Eh}.

Notes:

- Applicable for TT systems if the measured installation's earthing resistance is higher than the (well grounded) auxiliary one
- Not applicable for TN and IT systems!
- Applicable in urban areas if there is no appropriated place for test probes
- Applicable in areas where different local and main earthings are connected together, making the earthing system very large
- No need to use test probes.

6.2.3.2 Earth loop test, external source, no probes

In TT systems with the loop resistance test according to IEC 61557-3 the following loop resistance is measured:

$$R_{LOOP} = R_{Lh} + R_{Eh} + R_{Ed} + R_{T} \ [\Omega] \qquad \textit{Eq. 22}$$

If the total earth resistance of R_{EH} is higher than the resistance R_{ED} and the return path (resistance of L conductors, secondary of power transformer) then the result can be considered as ≈ R_{EH}.
See chapter 6.2.4 for more information about fault loop testing.

Notes:
- Applicable for TT systems, where the measured installation's earthing resistance is higher than the (well grounded) auxiliary one.
- Not applicable for TN and IT systems!
- Applicable in urban areas if there is no appropriate place for test probes.
- Applicable in areas where different local earthings are connected together, making the local earthing system very large.
- No need to use test probes.

6.2.3.3 Three / four wire earthing resistance test, internal generator, two probes

The three-wire test is the standard earthing resistance test method. It is the only choice if there is no well earthed auxiliary terminal available. The measurement is performed with two earthing probes.
The drawback if using three wires is that the contact resistance of E terminal is added to the result.

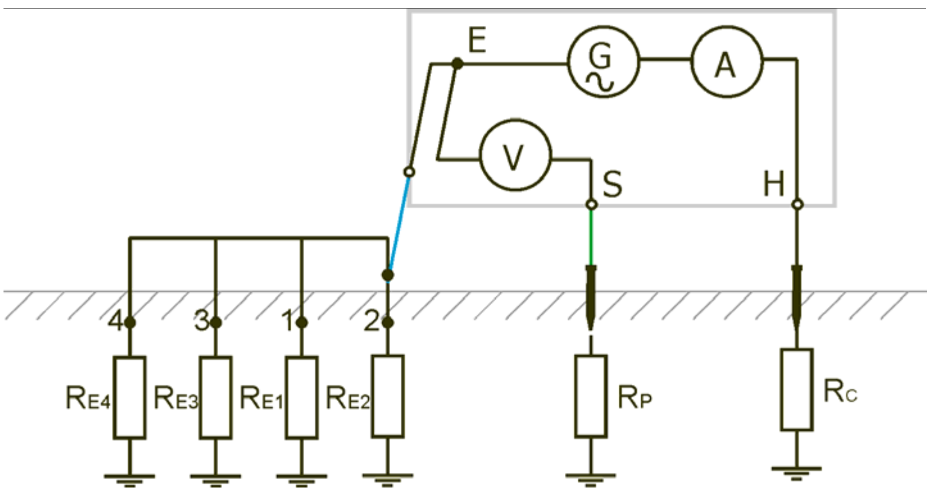


Fig. 37: *Total earthing measurement (3 wires) – standard method*

The advantage for using of four-wire system is that the leads and contact resistances between measuring terminal E and tested item do not influence the measurement.

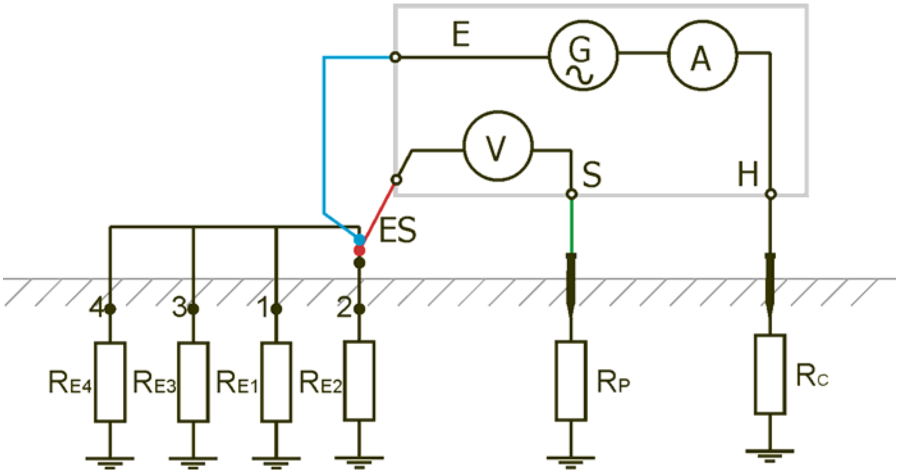


Fig. 38: *Total earthing measurement(4 wires) – standard method*

In the example on fig. 38 the following resistance is measured:

$$R_{EH} = U_V / I_{gen} \quad \text{Eq. 23}$$

$$I_{gen} = I_{RE1} + I_{RE2} + I_{RE3} + I_{RE4} \quad \text{Eq. 24}$$

U_V .... Voltage drop on earthing resistance, measured between S and ES
I_{gen}........... Test current of measuring instrument

Notes:

- Method enables accurate results from 0Ω up to several 1000 Ω.
- Method is not suitable for very large or connected earthing systems because test probes must be then placed at very long distances from the measured object.
- Positioning of test probes is described later in this chapter.

- If measuring individual earthing resistances the measured rod (point) must be disconnected from the system.
- In TN systems incoming PE (PEN) conductor must be disconnected !

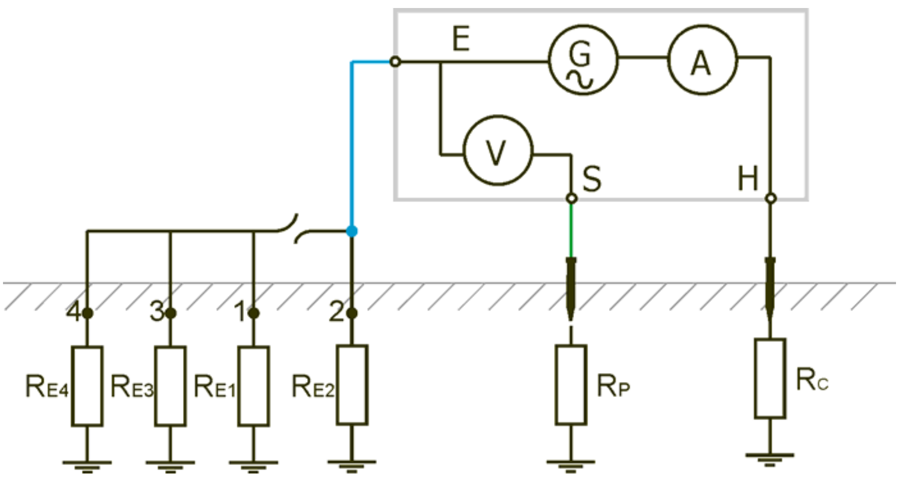


Fig. 39: *Selective earthing measurement – standard method*

$$I_{gen} = I_{RE2}$$ *Eq. 25*

According to eq. 25 the test current flows only through the partial resistance R_{E2} in this case R_{E2} is measured.

Notes:
- Accurate results from 0Ω, no limitation regarding number of points
- Not suitable for very large or connected earthing systems because test probes must be then placed at very long distances from the measured object.
- Disconnection is rather complicated, test methods with current clamps are simpler
- Positioning of test probes in described later in this chapter.

6.2.3.4 Earthing resistance test with current clamp and two probes

This measurement is applicable for measuring earth resistances of individual earthing points in an earthing system. The earthing rods do not need to be disconnected during measurement.

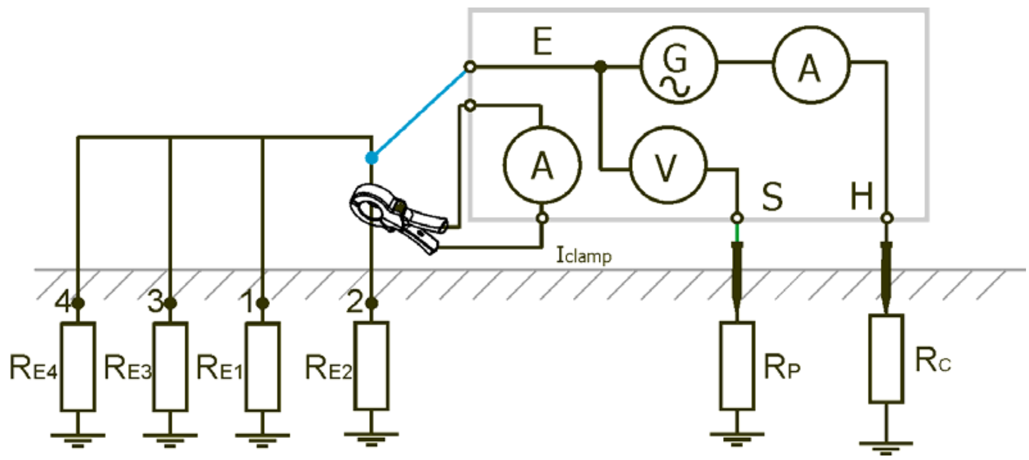


Fig. 40: *Selective earthing measurement – method with one current clamp*

In the example on fig. 40, the following resistance is measured:

$$R_{E2} = \frac{U_V}{(I_{clamp} \cdot N)} = \frac{U_V}{I_{RE2}}$$ *Eq. 26*

$$I_{clamp} = \frac{\left(R_{E1} \| R_{E2} \| R_{E3} \| R_{E4} \ldots\right)}{R_{E2}} \cdot I_{gen}$$ *Eq. 27*

I_{clamp} .... Current through clamp
N............. Clamp current transformation ratio
I_{gen}........... Test current of measuring instrument

The partial current I_{RE2} (see fig. 40) is measured with current clamps.

Notes:

- Not suitable for very large or connected earthing systems because test probes must be placed at very long distances from the measured object in this case.
- In large systems the measured partial current is only a small portion of the test current I_{gen}. The measuring accuracy for small currents and immunity against noise currents must be considered! METREL's installation testers display appropriate warning in this case.
- For systems with more than several 10 rods this method is not recommendable.
- The method has no real advantages compared to the test system with two current clamps.
- Positioning of test probes in described later in this chapter.

6.2.3.5 Earthing resistance test with two current clamps

This measurement system is used when measuring earth resistances of grounding rods, cables etc, under- earth connections etc. The measuring method needs a closed loop to be able to generate test currents.

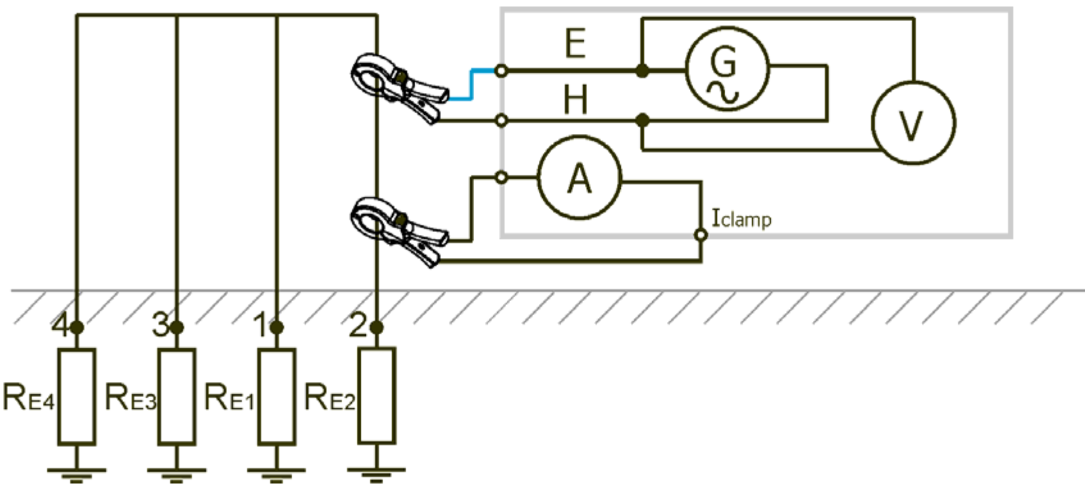


Fig. 41: *Total earthing resistance measurement with two current clamps*

The driver clamp injects a voltage in the earthing system. The injected voltage generates a test current in the loop.
According to the example on fig. 41 individual earthing resistance is measured:

$$R_{E2} + \left(R_{E1} \| R_{E3} \| R_{E4} \ldots\right) = \frac{U_{generator} \frac{1}{N}}{I_{clamp}} \qquad \textit{Eq. 28}$$

$U_{generator}$... Internal voltage source of test instrument, driving voltage for driver clamps
I_{clamp} .... Current through sense clamps
N .... Driver clamp transformation ratio

If the total Earth Resistance of the electrodes RE1, RE3 and RE4 connected in parallel is much lower than the resistance of tested electrode RE2, then the result can be considered as ≈ RE2

Other individual resistances can be measured by embracing other electrodes with the current clamps.

Notes:

- Applicable in complex earthing system with numerous parallel earthing electrodes.
- Applicable for measuring earthing resistance in transformer stations.
- Especially suitable in urban area.
- No disconnection of measured electrodes.
- Applicable for measuring selective and main earthings resistances.
- Very fast measurement; no need to place measurement probes and to separate the measured electrodes.
- Very accurate for resistances below 10 Ω. Measuring range is limited up to several 10 Ω. At higher values the test current drops to few mA. The measuring accuracy for small currents of and immunity against noise currents must be considered! METREL's installation testers display appropriate warnings in this case.
- The minimum distance between driver and sense clamps is at least 30 cm (unless they are shielded).

Functionality and placing of test probes

For a standard earthing resistance two test probes (voltage and current) are used. Because of the voltage funnel it is important that the test electrodes are placed correctly. More information about principles described in this document can be found in the handbook: *Grounding, bonding, and shielding for electronic equipments and facilities*.

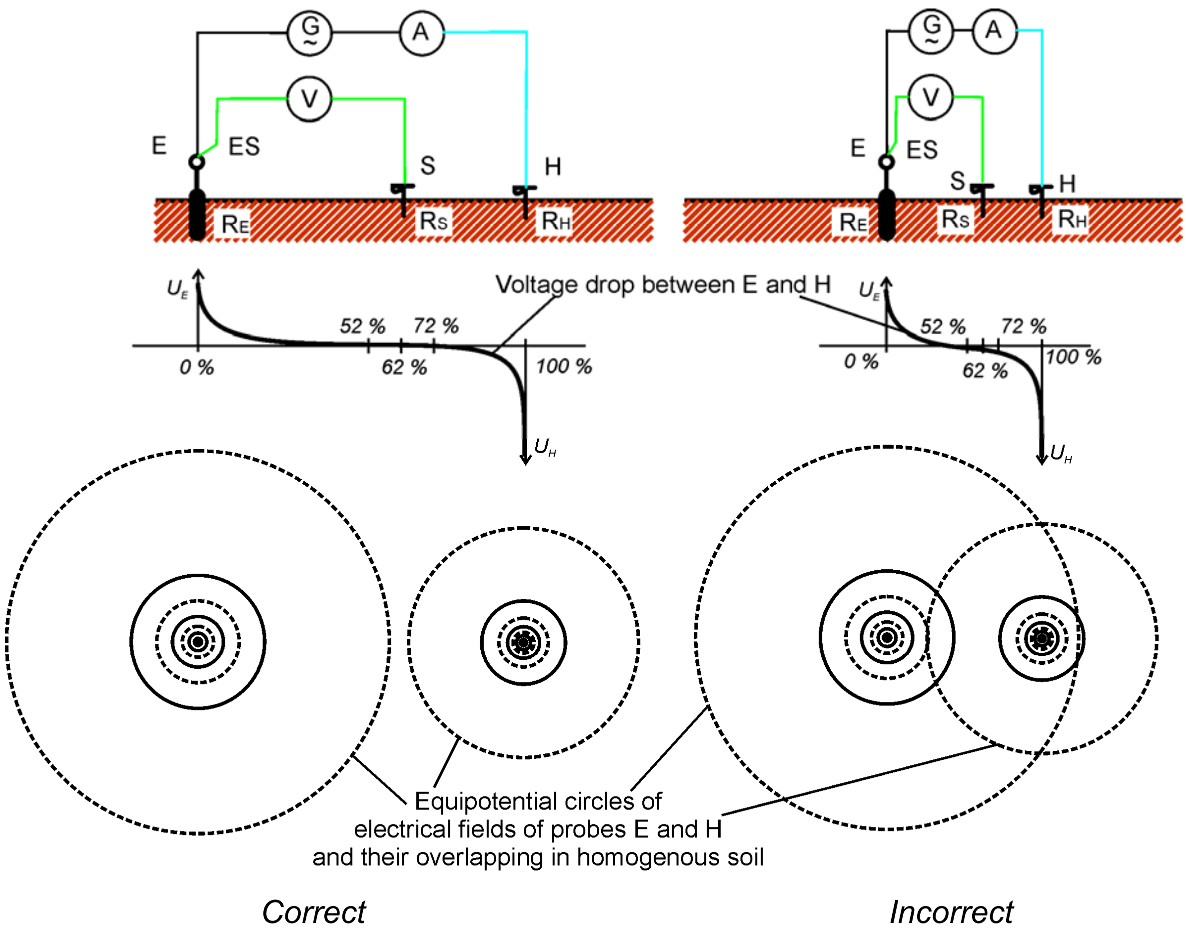


Fig. 42: *Placement of probes*

Probe E is connected to the earthing electrode (rod).
Probe H serves to close the measuring loop. The voltage between probe S and E is the voltage drop on the measured resistance. Correct placing of probes is essential. If the S probe is placed to close to the earthing system then too small resistance will be measured (only a part of the voltage funnel would be seen).
If the S probe is placed to close to the H probe the earthing resistance of voltage funnel of the H probe would disturb the result.
It is most important that the size of the earthing system shall be known for the correct test probe placement. Parameter a represents the maximum dimension of the earthing electrode (or a system of electrodes) and can be defined acc. to fig. 43.

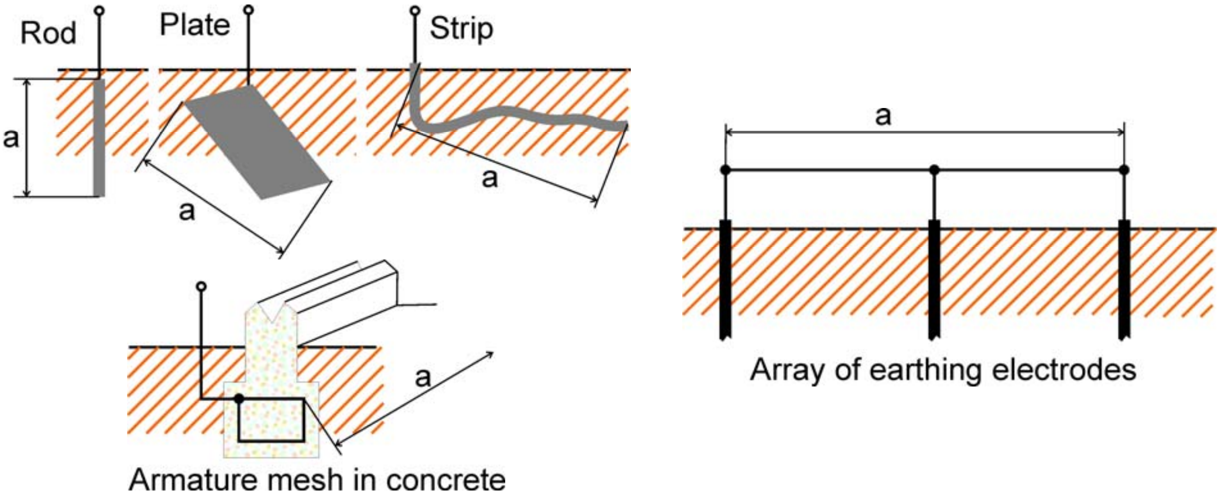


Fig. 43: *Definition of parameter a*

Straight-line placement

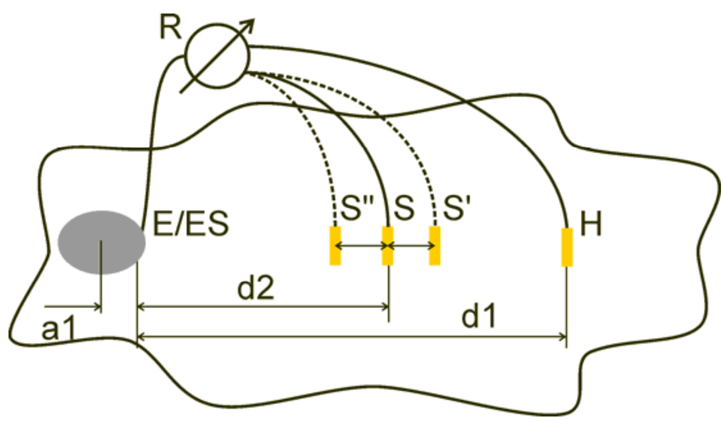


Fig. 44: *Straight-line placement*

After the maximum dimension a of an earthing system is defined then measurements can be performed by proper placement of test probes. A measurement with three placements of test probe S (S'',S, S') is intended to verify that the selected distance d1 is long enough.

- Distance from tested earthing electrode system E/ES to current probe H shall be d1 ≥ 5a,
- Distance from tested earthing electrode system E/ES to potential probe S shall be:

$$d_2 = 0.62d_1 - 0.38a_1 \, [\Omega] \qquad \textit{Eq. 29}$$

a1............ distance between connection point of earthing system and centre of the same.

Measurement 1

- Distance from earthing electrode E/ES to voltage probe S shall be: d2.

Measurement 2

- Distance from earthing electrode E/ES to voltage probe S shall be: $d_2 = 0.52d_1 - 0.38a_1$ (S”).

Measurement 3

- Distance from earthing electrode E/ES to voltage probe S shall be: $d_2 = 0.72d_1 - 0.38a_1$ (S’).

In case of a properly selected d1 the result of measurements 2 and 3 are symmetrical around the result of measurement 1. The differences (measurement 2- measurement 1, measurement 3 - measurement 2) must be lower than 10 %. Higher differences or non-symmetric results mean that the voltage funnels influence the measurement and the d1 should be increased.

Notes:

- Initial accuracy of measured resistance to earth depends on distance between electrodes d1 and size of earthing electrode a. It can be seen in table 23.

d1/a	Error [%]
5	10
10	5
50	1

Table 23: *Influence of d1/a ratio to initial accuracy*

- It is advisable for the measurement to be repeated at different placements of test probes.
- The test probes shall also be placed in the opposite direction from tested electrode (180° or at least 90°). The final result is an average of two or more partial results.
- According to IEC 60364-6 the distances S’-S (measurement 2) and S’’-S (measurement 3) shall be 6 m.

Equilateral placement

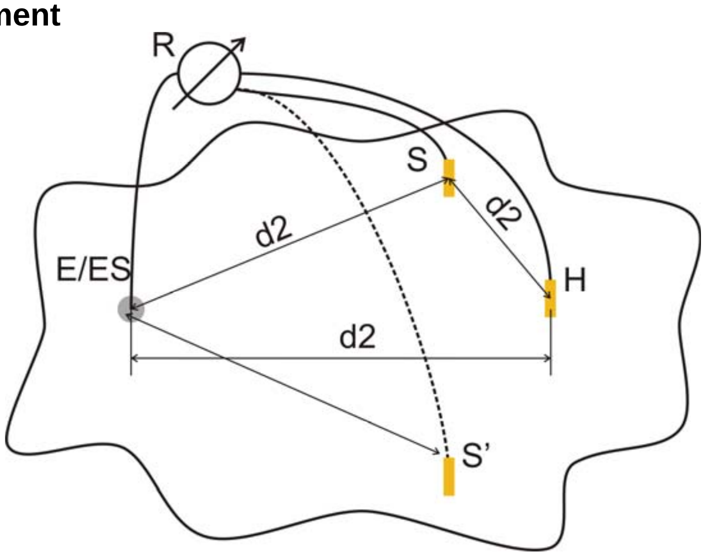


Figure 45: *Equilateral placement*

Measurement 1
Distance from tested earthing electrode to current probe H and voltage probe S should be at least: d2= 5·a
Measurement 2
Distance from earthing electrode to voltage probe S (S'): d2, contrary side regarding to H.

The first measurement is to be done at the S and H probes placed at a distance of·d2. Connections E, probes H and S should form a equilateral triangle
For the second measurement the S probe should be placed at the same distance d2 on the contrary side regarding to the H probe. Connections E, probes H and S should again form a equilateral triangle. The difference between both measurements shall not exceed 10%. If a difference in excess of 10% occurs, distance d2 should be proportionally increased and both measurements repeated. A simple solution is only to exchange test probes S and H (can be done at the instrument side). The final result is an average of two or more partial results.
It is advisable for the measurement to be repeated at different placements of test probes. The test probes shall be placed in the opposite direction from tested electrode (180° or at least 90°).

Test probe resistances
In general test probes should have a low resistance to earth. In case the resistance is high (usually because of dry soil) the H and S probes can significantly influence the measurement result. A high resistance of H probe means that most of the test voltage drop is concentrated at the current probe and the measured voltage drop of the tested earth electrode is small. A high resistance of S probe can form a voltage divider with the internal impedance of the test instrument resulting in a lower test result. Test probe resistance can be reduced by:

- Watering in the vicinity of probes with normal or salty water.
- Depleting electrodes under dried surface.
- Increasing test probe size or paralleling of probes.

METREL test equipment displays appropriate warnings in this case, according to IEC 61557-5. All METRELs earth testers measure accurate at probe resistances far beyond the limits in IEC 61557-5.

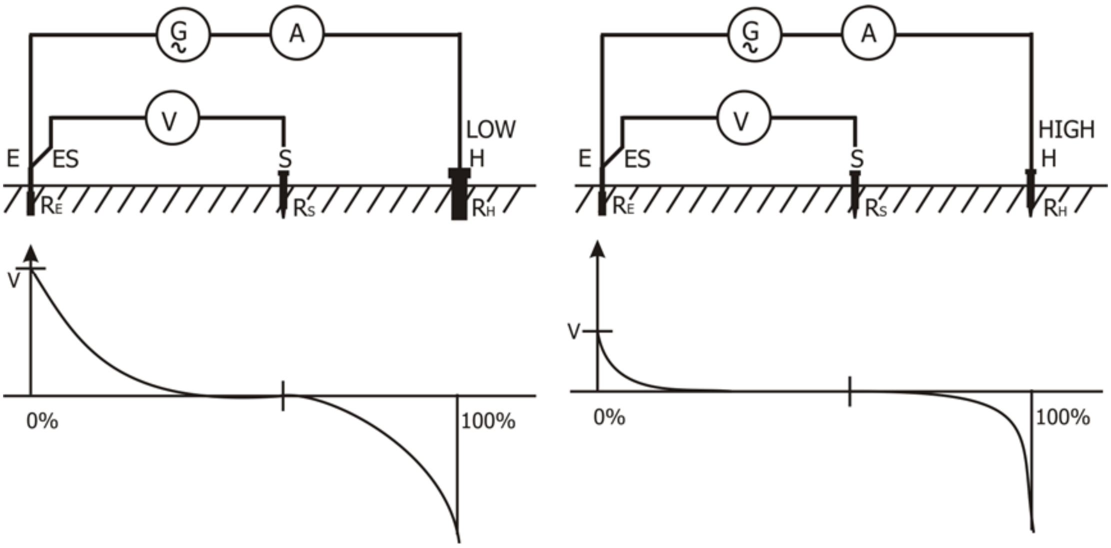


Fig. 46: *Different measured voltage drops at low and high probe resistance*

Connection diagrams

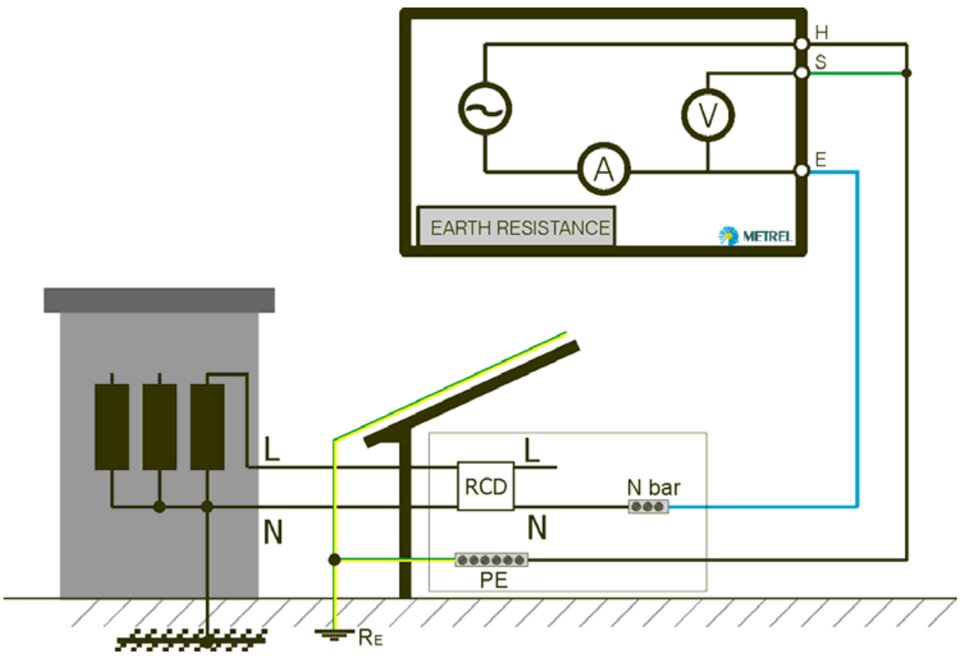


Fig. 47: *Two-wire test (only for TT systems), no probes*

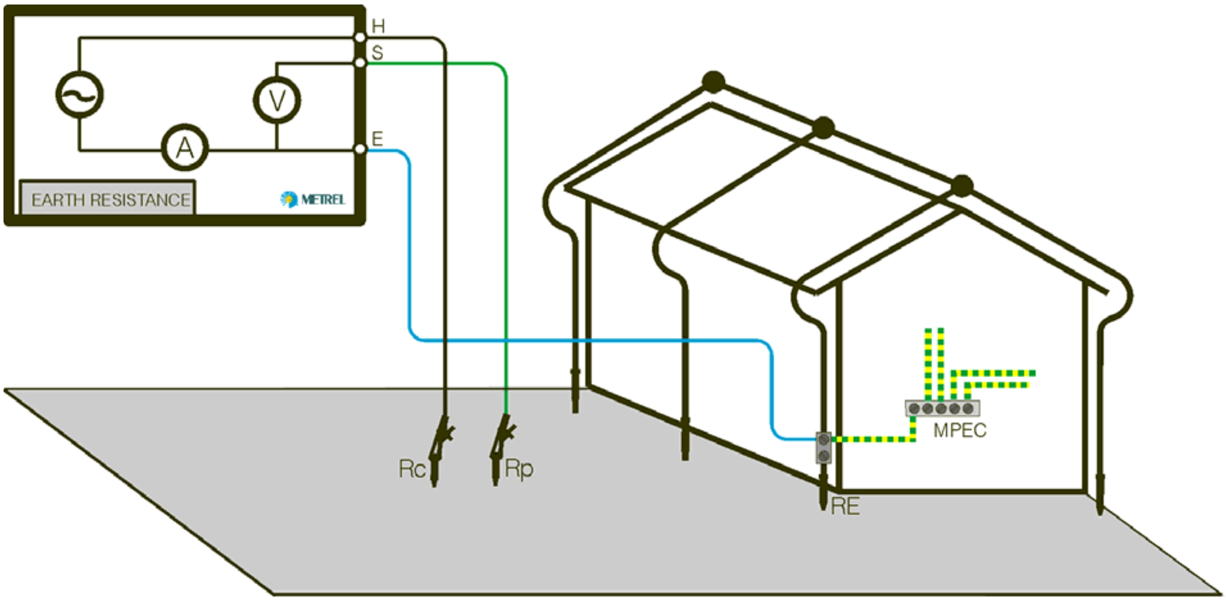


Fig. 48: *Three wire test, two probes, and straight-line placement of probes*

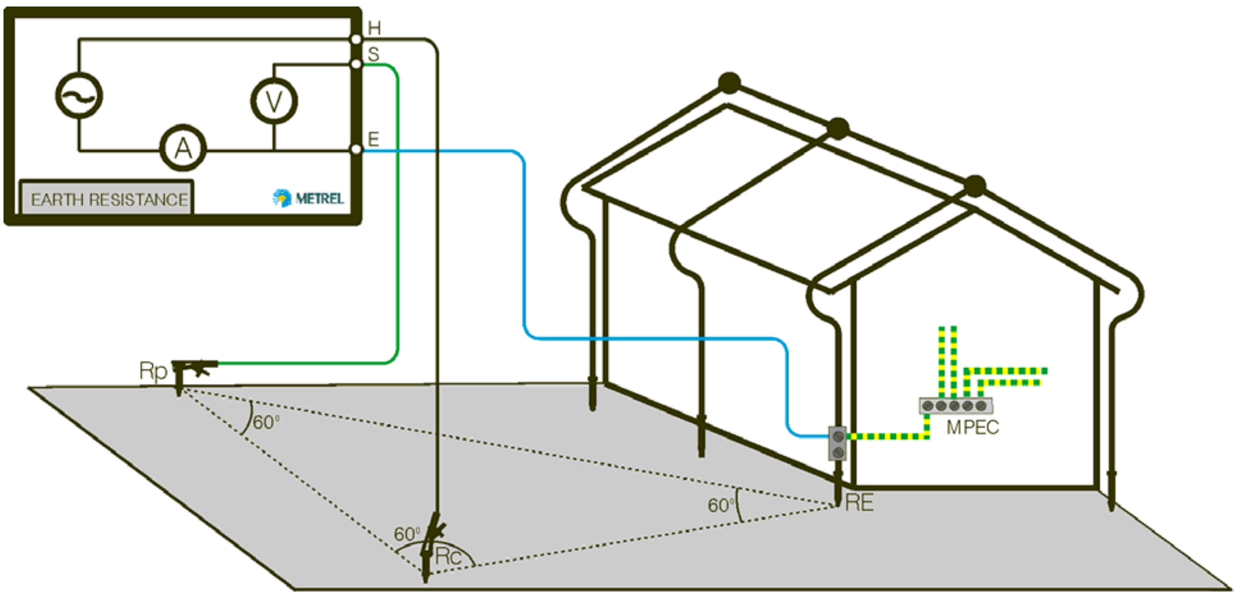


Fig. 49: *Three-wire test, two probes, and equilateral placement of probes*

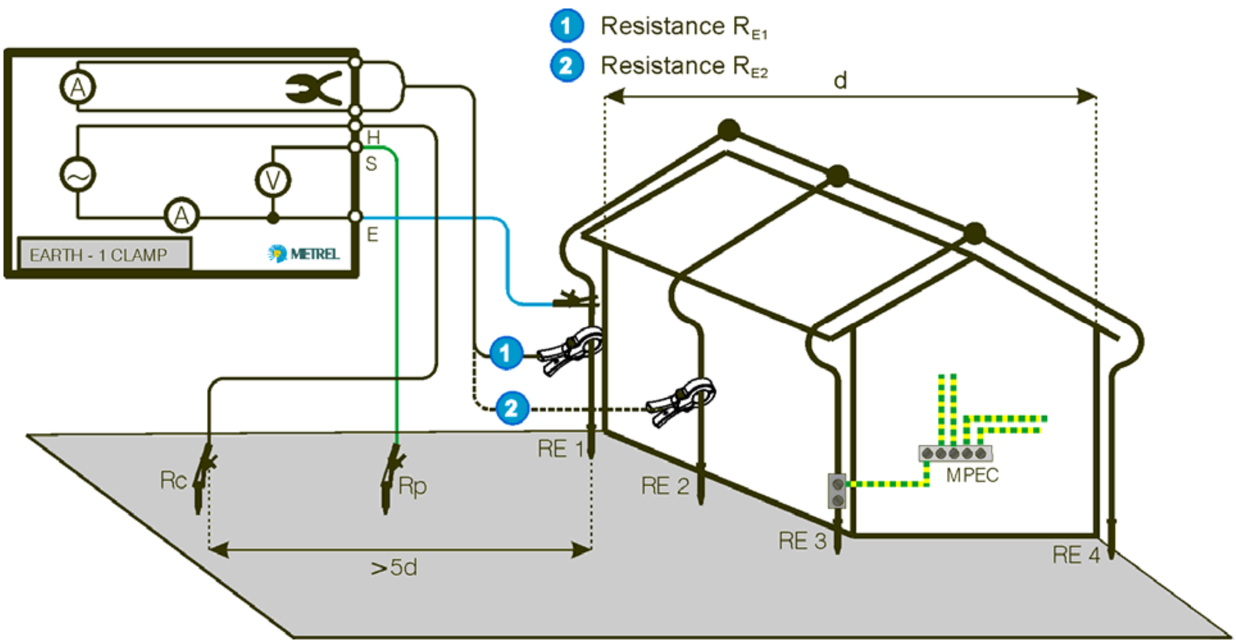


Fig. 50: *Test system with current clamp and two probes*

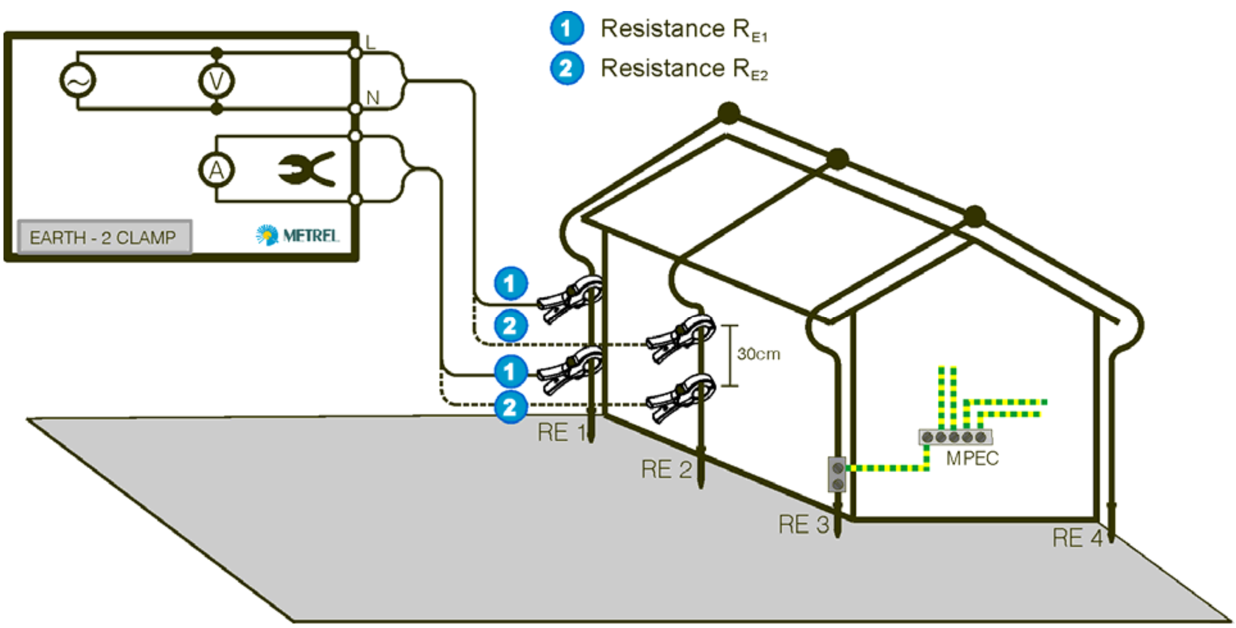


Fig. 54: *Test system (individual earthing rods) with two current clamps*

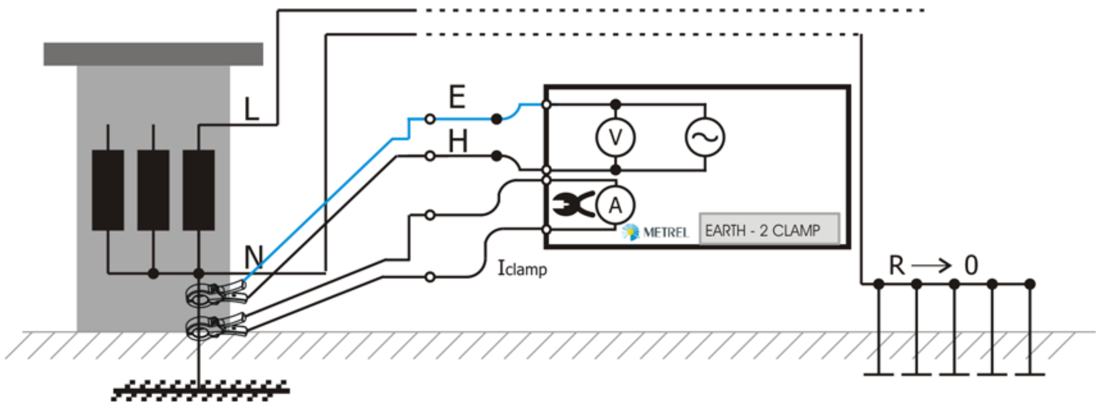


Fig. 55: *Transformer's resistance to earth measurement with two current clamps*

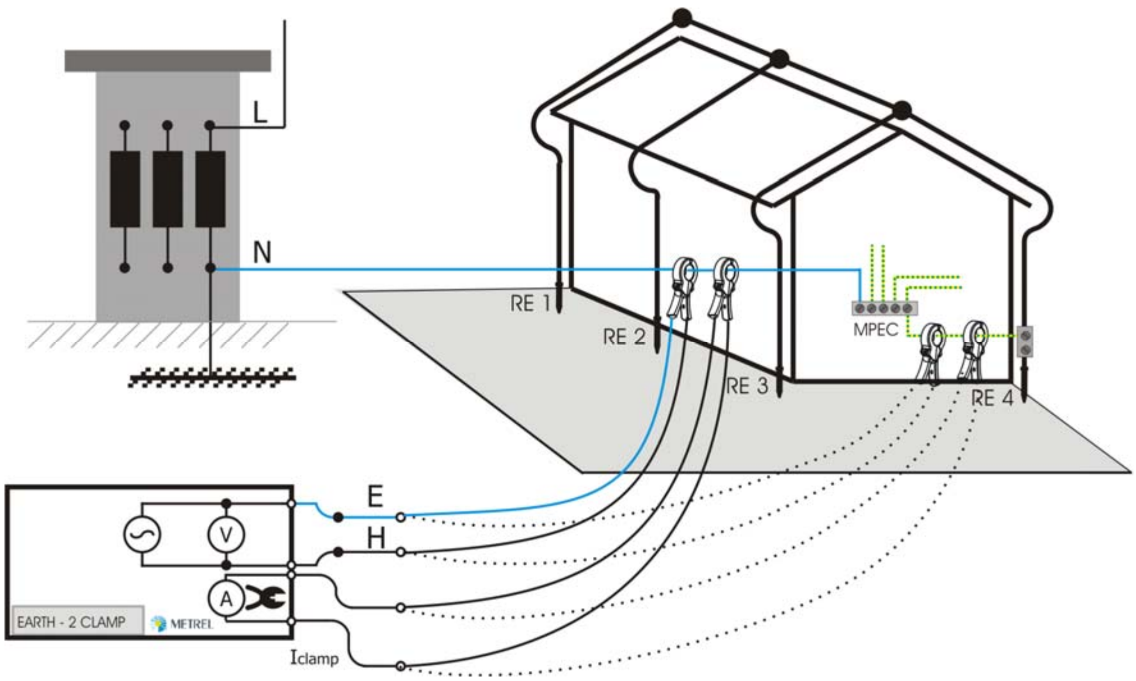


Fig. 56: *Measurement of resistance to earth of object with two current clamps in TN system*

6.2.4 Loop impedance

Scope of test

This test is intended to:

- *Verify effectiveness of installed over current and/or residual current disconnection devices.*
- *Verify fault loop impedances, prospective fault currents, and fault voltage values.*

Fault loop, fault impedance and prospective fault current in TN systems

In TN systems the fault loop Z_{LPE} consists of:

- Z_T (power transformer secondary impedance)
- Z_L (phase wiring from source to fault)
- R_{PE} (PE / PEN wiring from fault to source)

The fault loop impedance is the sum of impedances and resistances that forms the fault loop.

$$Z_{LPE} = Z_L + R_{PE} + Z_T \qquad \text{Eq. 30}$$

The prospective fault current I_{PFC} is defined as:

$$I_{PFC} = \frac{U_{LPE}}{Z_{LPE}} > I_a \qquad \text{Eq. 31}$$

U_{LPE} is the nominal supply voltage. I_{PFC} must be higher than I_a (current for rated disconnection time) of the over current disconnection device.
The fault loop impedance should be low enough e.g. prospective fault current high enough that installed protection device will disconnect the fault loop within the prescribed time interval. Limit values for I_{PFC} and Z_{LPE} depend on selected fuse type, size and required trip out time.

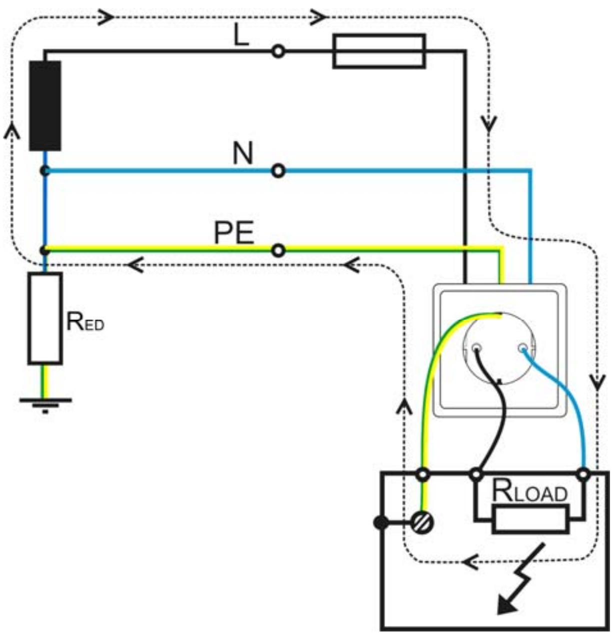


Fig. 57: *Fault loop in TN system*

Fault loop, fault impedance and prospective fault current in TT systems
In TT systems the fault loop consists of:

- Z_T (power transformer secondary impedance),
- Z_L (phase conductor from source to fault),
- R_{Eh}+R_{PEh} (earthing resistance of installation with PE conductor from fault to earthing point),
- R_{Ed} (earthing resistance of source/ distribution point).

The fault loop impedance is the sum of impedances and resistances that forms the fault loop.

$$Z_{LPE} = Z_L + R_{Eh} + R_{Ed} + Z_T \qquad \text{Eq. 31}$$

RCD devices are usually used as protection elements in TT system. In case of a short circuit or high leakage current between phase and PE a dangerous contact voltage occurs on accessible metal parts. If the voltage exceeds 50 V the RCD must trip out:

$$Z_{LOOP} < \frac{50V}{I_{\Delta N}} = \frac{U_C}{I_{\Delta N}} \qquad \textit{Eq. 32}$$

U_C .... Contact voltage
Z_{LOOP}....... Loop impedance
$I_{\Delta N}$ .... Nominal trip out current of RCD

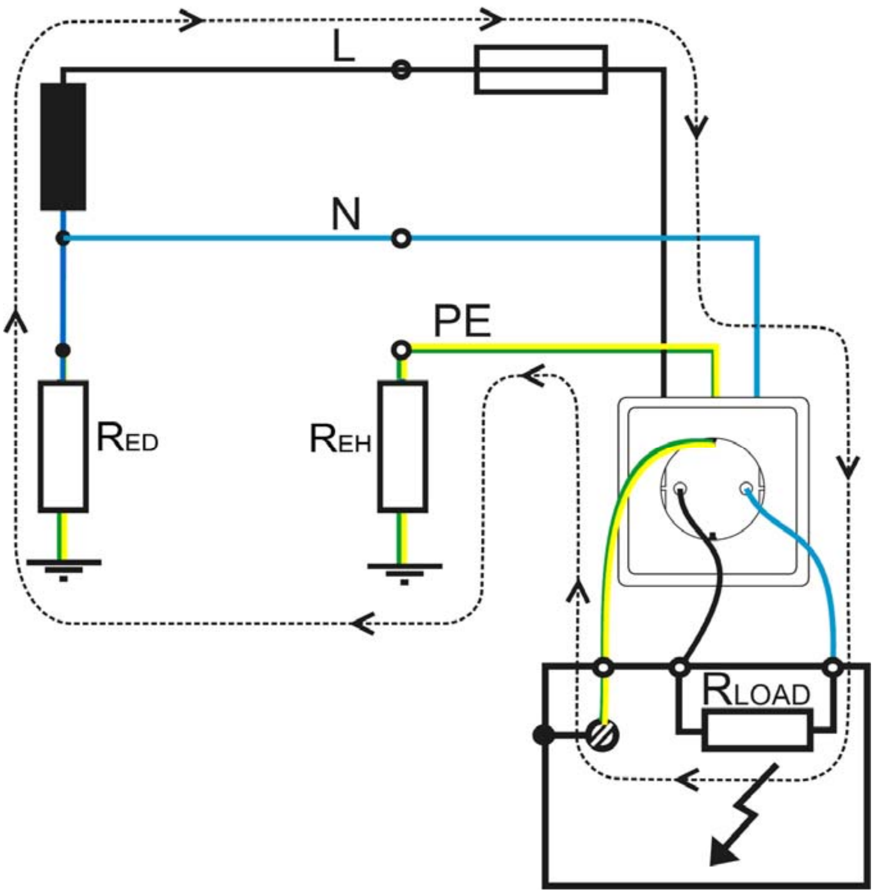


Fig. 58: *Fault loop in TT system*

References:
Limits, methodology: IEC 60364-4 (chapter 61.3.6.3)
Measuring instruments: IEC 61557-3

Measuring principles / limits:

Loop impedance/ loop resistance
Fault loop impedance includes the resistive and inductive part of the fault loop. The main part of inductivity comes from the power transformers inductances.
The main resistance part comes from copper wiring in the loop (conductors, transformer wiring) and earthing resistances (in TT systems).
In general the inductive part can be neglected if loop impedance > 0.4 Ω.

In applications where the measurement is carried out in close proximity to the power transformer (< 50m) the inductivity can be of a similar value than the resistance part. In this case it is very important to consider the impedance result because the fault loop resistance result is lower and can lead to a wrong judgement.

Example:
Internal resistance (R_L+ R_{PE}) of the TN distribution system is 0.25 Ω,
stray inductance X_L of distribution transformer is 0.4 mH (0.13 Ω at 50 Hz),
loop impedance of the system is 0.28 Ω.
I_{PFC} based on resistance measurement: 828 A (at 207V).
I_{PFC} based on impedance measurement:739 A
It can be seen that if measuring only resistance can lead in a wrong selection or verification of installed fuse!

Prospective fault current scaling factor

The condition I_{PFC} > I_a must be fulfilled also for the worst conditions (highest temperature of conductors, lowest supply voltage).
To consider this the measured value of I_{PFC} should be decreased for an appropriate factor.

$$I_{PFCcalculated} = I_{PFCmeasured} * (scaling.factor) \qquad \text{Eq. 33}$$

$I_{PFCmeasured}$ ....*Measured result with measuring instrument*
$I_{PFCcalculated}$ ....*Calculated result that considers worst condition*

The worst case conditions can be considered also by correction of the limit values. In this case there is no need to correct the measured results.

$$I_{PFClimit} = I_a / (scaling\ factor) \qquad \text{Eq. 34}$$

I_a ....*Current causing disconnection of supply in rated time period.*
$I_{PFClimit}$..............*Calculated limit that considers worst condition*

Note:

- For right value of scaling factor national regulative must be considered.
- A typical scaling factor is 0.64 (0.8 for influence of supply voltage and 0.8 for influence of conductors’ temperature).

6.2.4.1 Standard loop measurement

The test instrument is connected to the mains voltage (between phase and PE conductors) and strongly loads the mains voltage over a short period of time. The voltage drop caused by the test current is measured by V-meter. The phase delay between test current and mains voltage is also measured. On the basis of the measured results the test instrument calculates the fault loop impedance Z_{LPE}.

$$Z_{LPE} = \frac{U_{UNLOADED} - U_{LOADED}}{U_{LOADED} / R_{LOAD}} = \frac{\Delta U}{I_{test}} \qquad \text{Eq. 35}$$

ΔU........... *Measured voltage drop*
I_{test}........... *Test current*

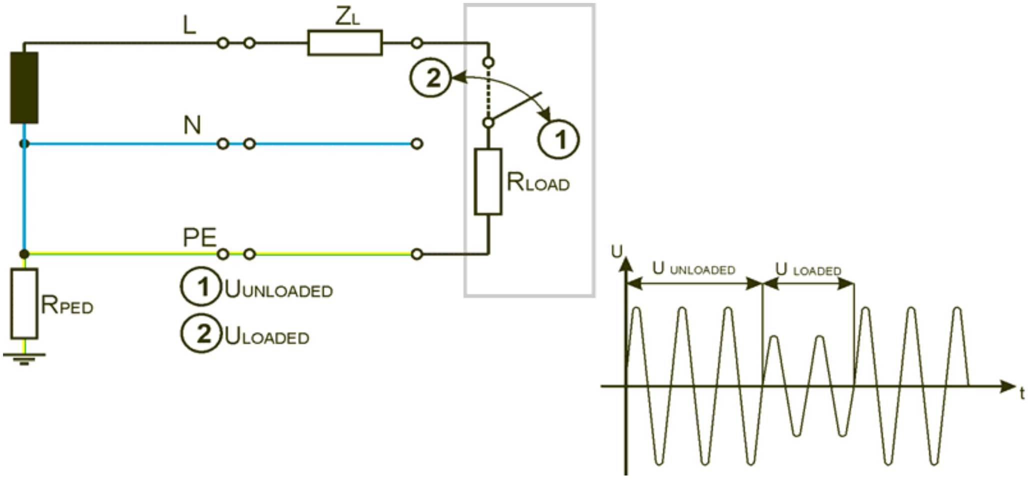


Fig. 59: *Loop impedance measurement –standard method*

6.2.4.2 Measurement of Z_{LOOP} in RCD protected TN systems

In TN systems with over current protection and additional RCD protection the following problem occurs:
As the condition $I_{PFC} > I_a$ must be fulfilled, the measured impedances are low (typically <1.5 Ω). The test current must be small to avoid tripping out the RCD. For a 30mA RCD the test current <15mA.
The measured voltage drop caused by the small test current is very small – as a result even small voltage fluctuations can seriously influence the results. Voltage fluctuations are mainly caused by load variations and switch on/off events on the mains.
To solve this problem advanced measuring techniques must be used that are beyond the scope of this test.

Example:
TN installation with Z_{LPE}=1.00Ω is protected with a 30mA RCD.
Let's assume that the 230V supply voltage is fluctuating for 0.5% during the measurement. The measurement is performed with a 15mA test current in order to not trip out the RCD.
Acc. to Eq. 35 the measured voltage drop is $I_{test} \cdot Z_{LPE}$ = 15mV.
0.5% of 230V means 1.15V.

The example shows that the voltage drop caused by fluctuation is 77 times higher than the measured signal!

Note:
- The advanced loop test is often offered beside the standard test (named R_S, “TripLock”, 15mA Loop etc.)
- The test principle, accuracy, stability of the so called “non tripping test” differs significantly among different installation testers. The user should check the real accuracy of this test before purchasing a new installation tester as this feature is more and more important.
- METREL installation testers have one of the best solutions on the market. METREL permanently works on improvements of this test.

Limit values – protection with over current devices
If the installation is protected with over current devices following condition must be fulfilled:

$$I_{PFC} > I_a \qquad \text{Eq. 36}$$

I_{PFC}.......... *Actual prospective fault current.*
I_a............. *Current for rated disconnection time) of the over current disconnection device.*

Optionally a proper scaling factor should be considered (see eq. 34)

Note:

- The I_a values for standard fuse types (NV, gG, B,C,K,D) can be found in METREL installation tester User Manuals.

Fuse type	Fuse trip-out time	Fuse current rating	Min. prospective short- circuit current (A)
B	200 ms	6 A	30
B	200 ms	10 A	50
B	200 ms	16 A	80
B	200 ms	20 A	100

Table. 24: *Cut-out of the Fuse table (source Eurotest XA User Manual)*

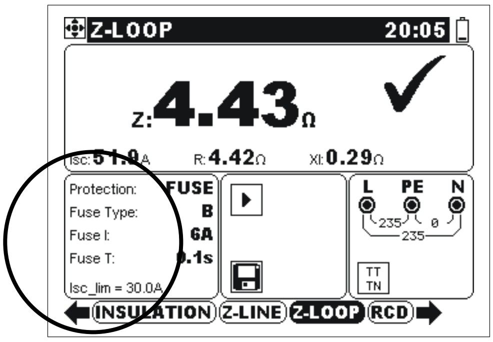


Fig. 60: *Limit values/parameters/ PASS/FAIL in Eurotest installation tester*

<u>METREL's hint</u>

- In most of METREL installation testers fuse parameters and scaling factor can be set. This allows to define the Z_{LOOP} / I_{PFC} limits on field.

Limit values – protection with residual current devices

If the installation is protected with RCD devices following condition must be fulfilled:

$$Z_{LPE} < \frac{U_{CL}}{I_{\Delta N}} \qquad \text{Eq. 37}$$

U_{CL}.......... *Contact voltage*
Z_{LPE}......... *Loop impedance*
$I_{\Delta N}$ .... *Nominal trip out current of RCD*

The following table presents the calculated maximum allowed values of loop resistance (earthing resistances), for different RCDs.

Max. allowed Earth Resistance value (Ω)	Nominal differential current $I_{\Delta N}$ (A)					
Limit contact voltage U_{CL} (V)	0,01	0,03	0,1	0,3	0,5	1
50	5000	1666	500	166	100	50
25	2500	833	250	83	50	25

Table. 25: *Limit Z_{LPE} values for RCD protected installations.*

Note:

- In TT installation systems the earthing resistance R_{EH} represents the main part of the loop impedance. Therefore the loop test can be suitable for measuring earthing resistance of objects, systems etc.
- Limit values in table 25 are also earthing resistance limits in TT installation systems.
- If the RCD is installed downstream the installation and parts of wiring are not protected than the limit for over current protection must be considered. A typical example is a socket with integrated RCD.

Connection diagrams

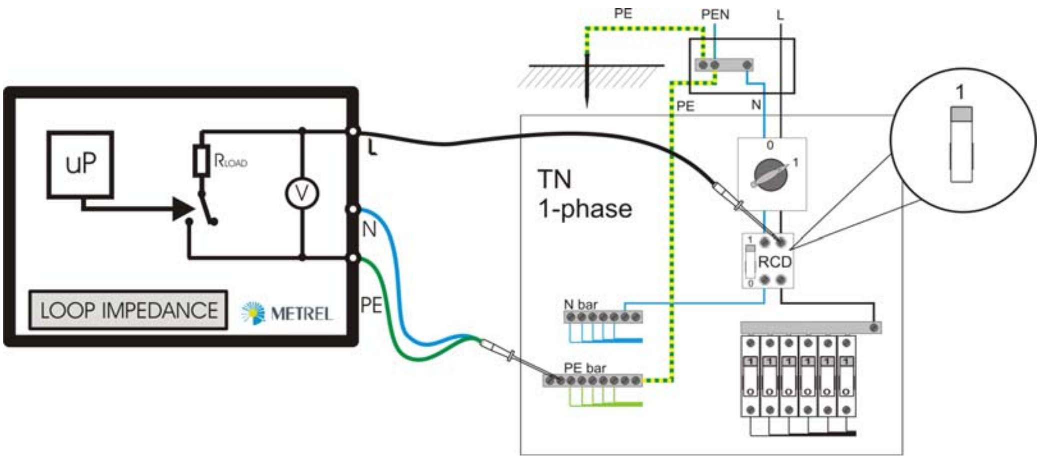


Fig.61: *Loop impedance at origin of 1-phase installation*

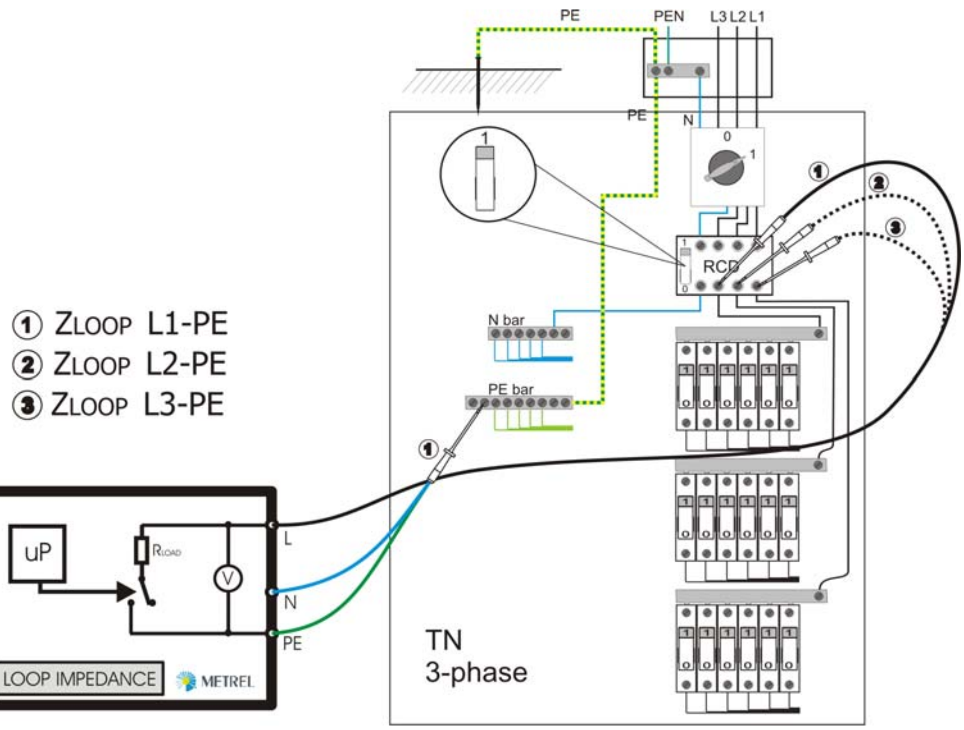


Fig.62: *Loop impedance at origin of 3-Phase installation*

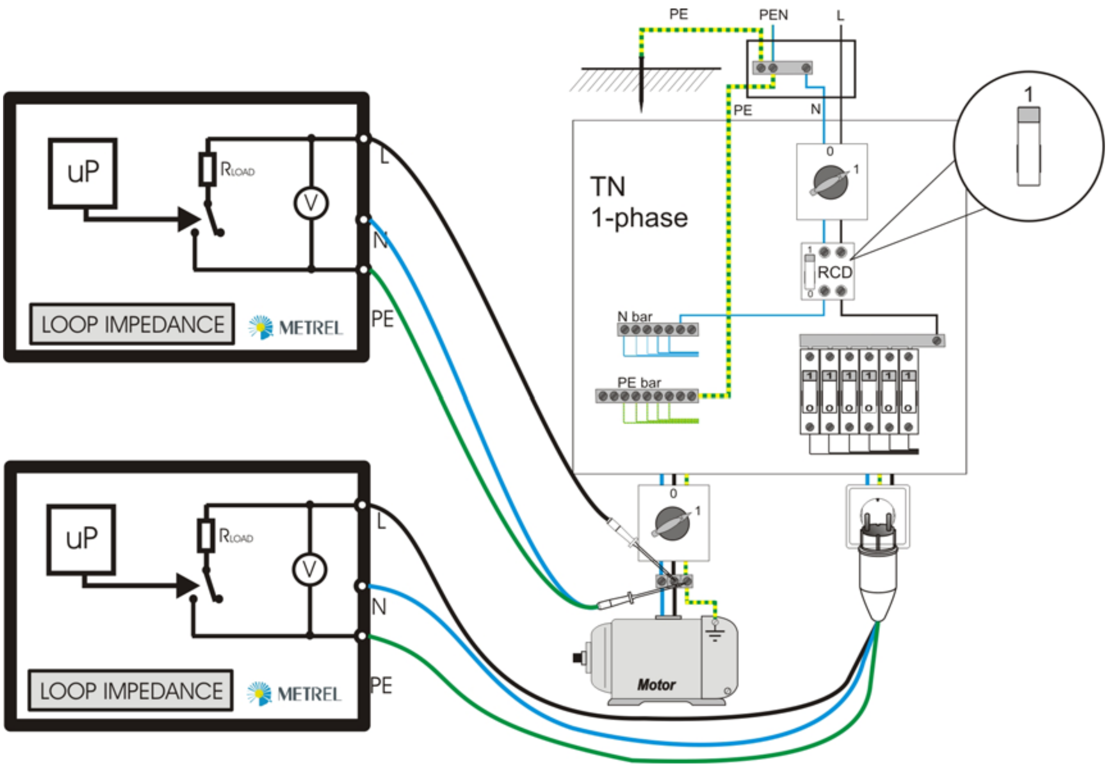


Fig.63: *Loop impedance at 1-phase outlet and connection point*

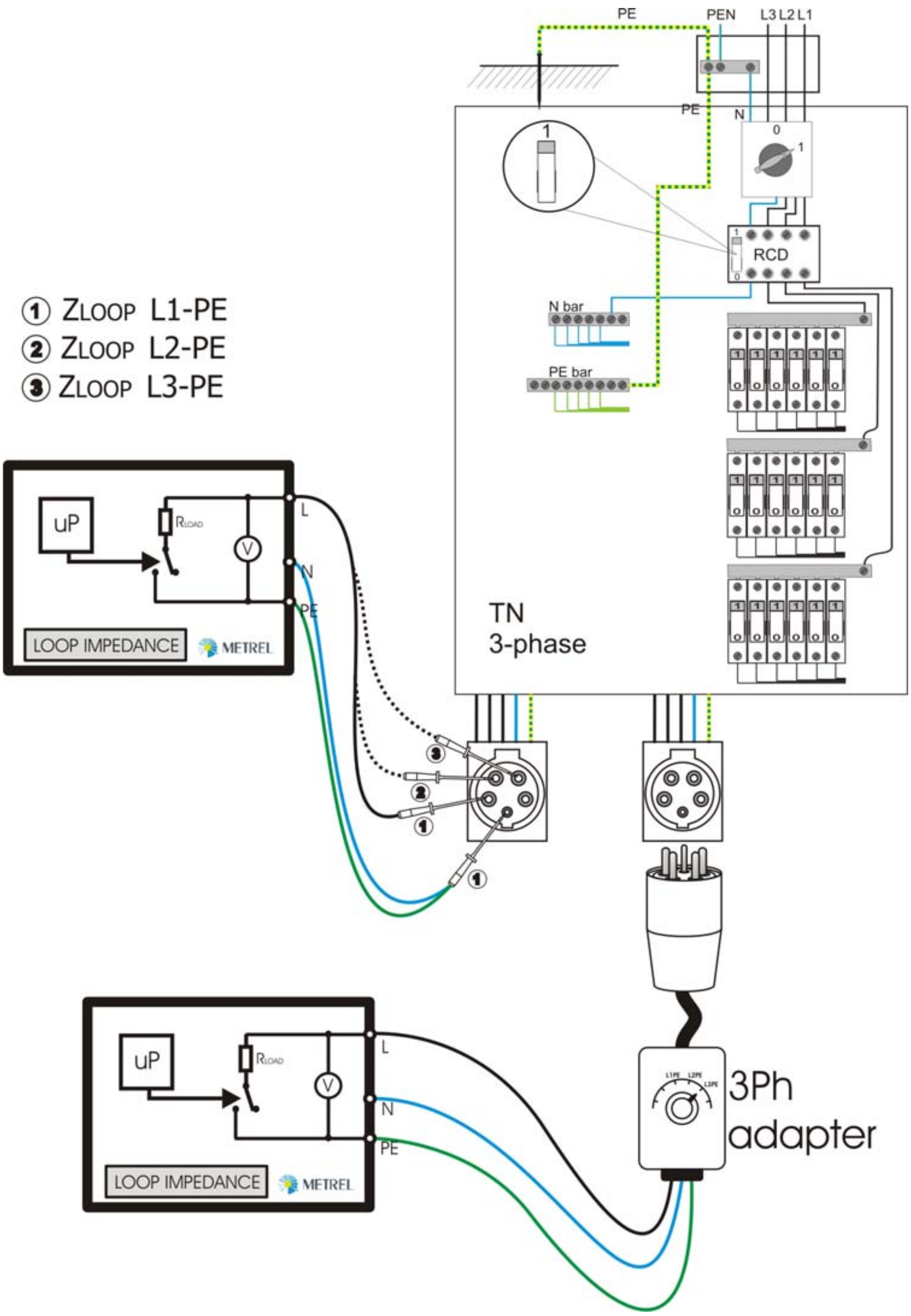


***Fig.64:** Loop impedance measurement at 3-phase outlets*

6.2.5 Line impedance

Scope of test

Scope of this test is:

- To verify effectiveness of installed over current devices.
- To verify internal impedance for supplying purpose (voltage drop / IEC 60364-6, chapter 61.3.11).

Short circuit line – neutral impedance and prospective short circuit current

The line- neutral short circuit loop consists of:

- Power transformer secondary impedance Z_T,
- Z_L (phase wiring from source to fault),
- Z_N (neutral wiring from source to fault),

he line to neutral impedance is the sum of impedances and resistances that forms the line to neutral loop. In three phase system there are three line-neutral impedances (Z_{L1-N}, Z_{L2-N}, Z_{L3-N}).

$$Z_{LN} = Z_L + Z_N + Z_{TLN} \qquad \textit{Eq. 38}$$

The prospective short circuit current I_{PSC} is defined as:

$$I_{PSC} = \frac{U_{LN}}{Z_{LN}} \qquad \textit{Eq. 39}$$

I_{PSC} must be higher than I_a (current for rated disconnection time) of the over current disconnection device.

The line-neutral impedance should be low enough e.g. prospective short circuit current high enough that installed protection device will disconnect the short circuit loop within the prescribed time interval. Limit current and impedance depend on selected fuse type, size and required trip out time.

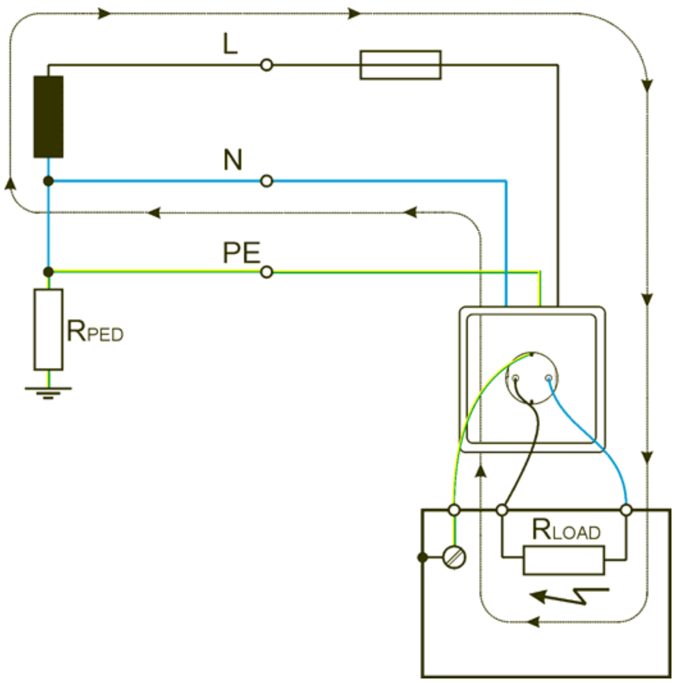


Fig. 65: *Short circuit current between Line and Neutral*

Short circuit line – line impedance and prospective short circuit current

The line-line short circuit loop consists of:

- Power transformer secondary impedance Z_T,
- Z_{Lx} (first phase wiring from source to fault),
- Z_{LY} (second phase wiring from source to fault).

The line-line impedance is the sum of impedances and resistances that forms the line-line loop. In three-phase system there are three line-line impedances (Z_{L1-L2}, Z_{L1-L3}, Z_{L2-L3}).

$$Z_{LxLy} = Z_{Lx} + Z_{Ly} + Z_{TLL} \qquad \text{Eq. 40}$$

The prospective short circuit current I_{PSC} is defined as:

$$I_{PSC} = \frac{U_{LxLy}}{Z_{LxLy}} = \frac{U_{LN} \cdot \sqrt{3}}{Z_{LxLy}} \qquad \text{Eq. 41}$$

I_{PSC} must be higher than I_a (current for rated disconnection time) of the over current disconnection device.
The line – line impedance should be low enough e.g. prospective short circuit current high enough that installed protection device will disconnect the short circuit loop within the prescribed time interval. Limit current and impedance depend on selected fuse type, size and required trip out time.

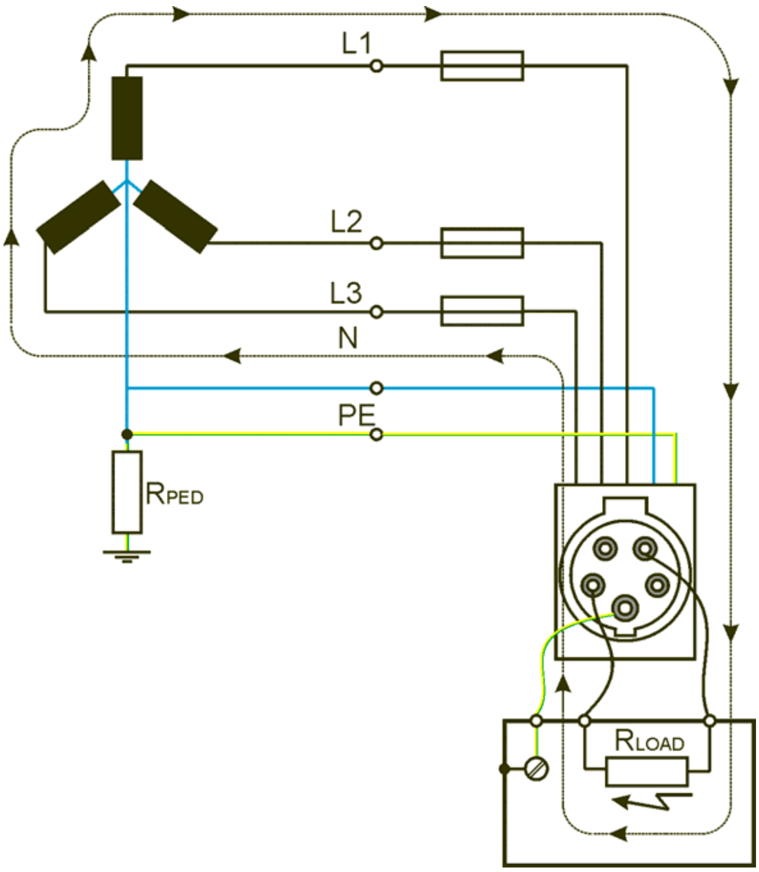


Fig. 66: *Short circuit current between two Phase conductors*

References:
Limits, methodology: IEC 60364-6 (chapter 61.3.11)
Measuring instruments: IEC 61557-3

Measuring principles / limits:

Line impedance/ line resistance:
Line impedance includes the resistive and inductive part in the short circuit loop. The main part of inductivity comes from the power transformers inductances. The resistance part mainly comes from copper wiring in the loop (transformer, phase and neutral conductors).
In general the inductive part can be neglected if the loop impedance > 0.4 Ω.
In applications where the measurement is carried out in close proximity to the power transformer (< 50m) the inductivity can be of a similar value than the resistance part. In this case it is very important to consider the impedance result because the line resistance result is lower and can result in wrong judgements.

Prospective short circuit current scaling factor
Same principles as for Prospective fault circuit current scaling factor is used.
See chapter 6.2.4 for more information.

6.2.5.1 Line impedance measurement

The measurement principle is the same as for the Loop impedance measurement (see chapter 6.2.4) except the measurement is carried out between L, N or Lx, Ly terminals

$$Z_{LINE} = \frac{U_{UNLOADED} - U_{LOADED}}{U_{LOADED} / R_{LOAD}} \qquad \textit{Eq. 42}$$

$Z_{LINE} = Z_{LN}$ *or* Z_{LxLy}

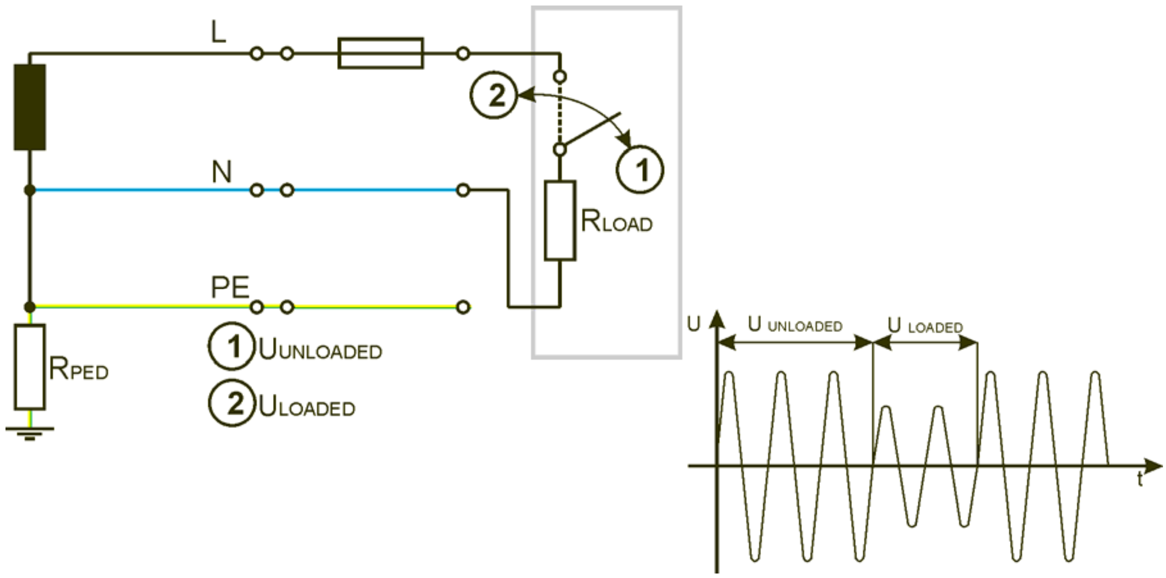


Fig 67: *Line impedance Z_{LN} measurement*

Limit values:

Following condition must be fulfilled:
$I_{PSC} > I_a$
I_a is current for rated disconnection time of the over current disconnection device.
Optionally a proper scaling factor should be considered.

Same fuse tables can be used for comparison for prospective fault currents (see chapter 6.2.4.2). Most of METREL installation testers have the parameters included (same as for the loop impedance test).

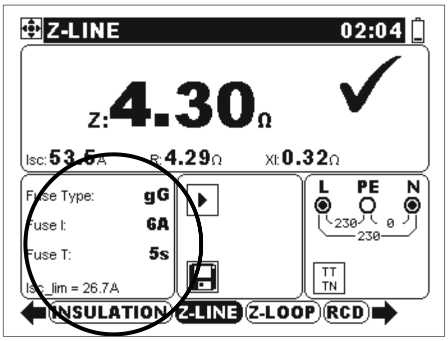


Fig. 68: *Limit values/parameters/ PASS/FAIL in EurotestAT*

<u>METREL's hint</u>

- In most of METREL installation testers fuse parameters and scaling factor can be set. This allows to define the Z_{LINE} / I_{PSC} limits on field.

Connection diagrams

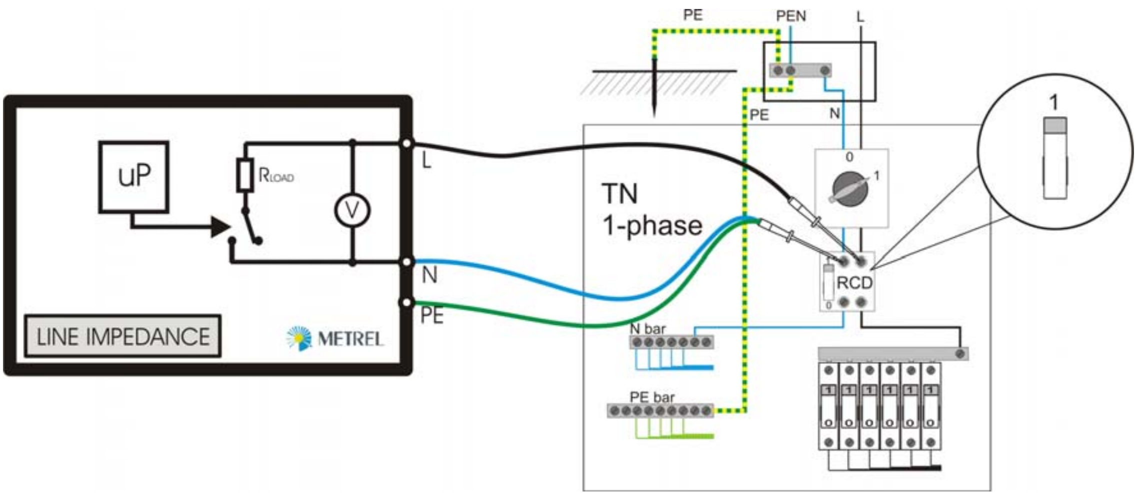


Fig. 69: *Line impedances at origin of 1-phase installation*

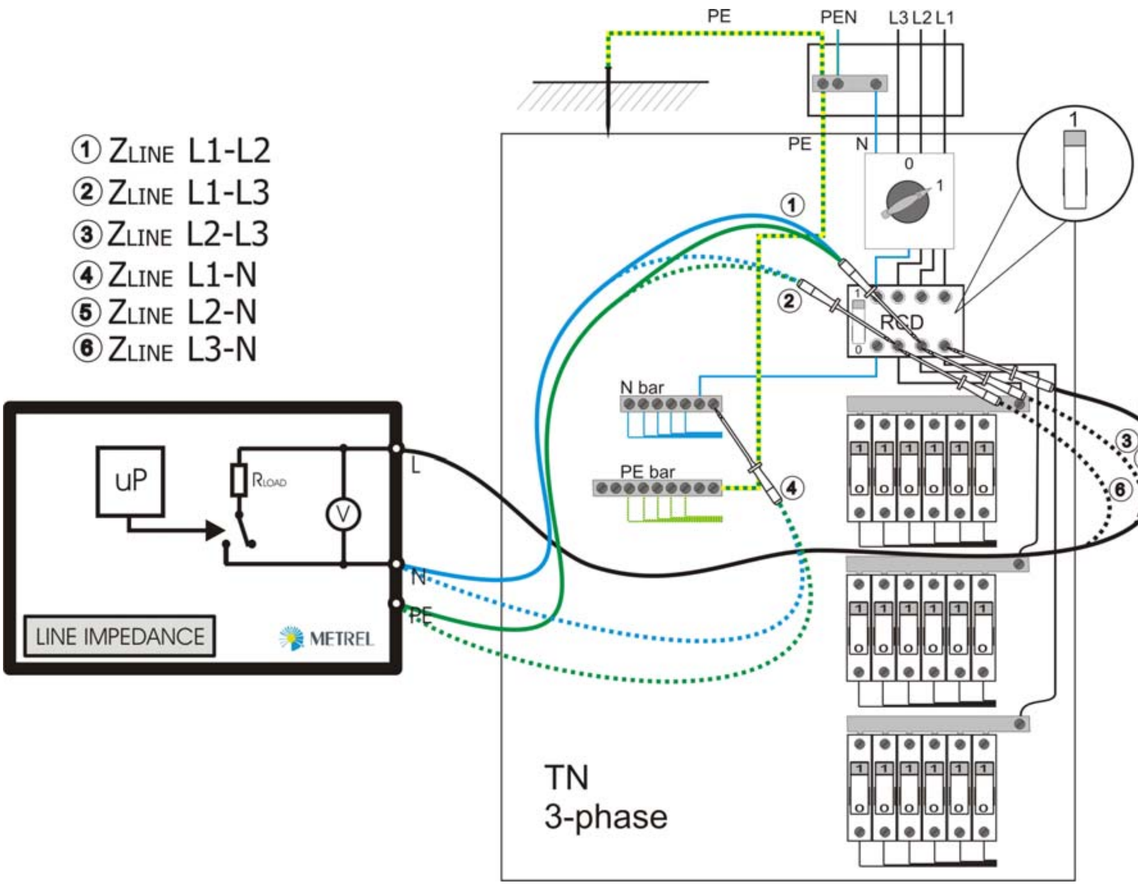


Fig. 70: *Line impedances at origin of 3-phase installation*

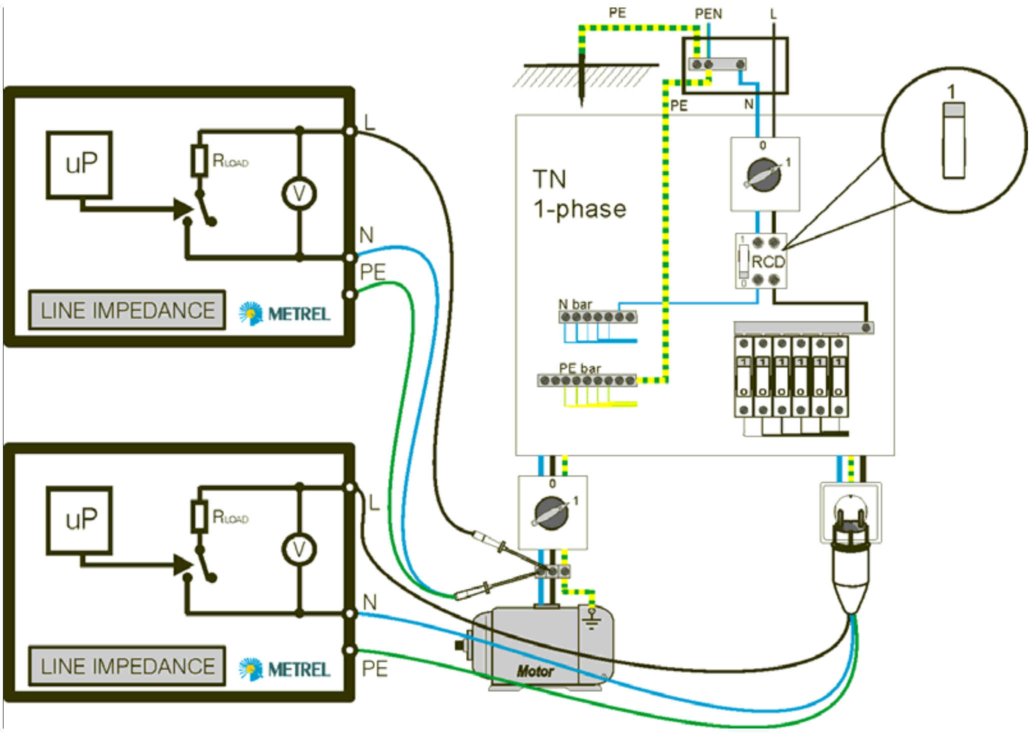


Fig.71: *Line impedance at 1-phase outlet, connection points*

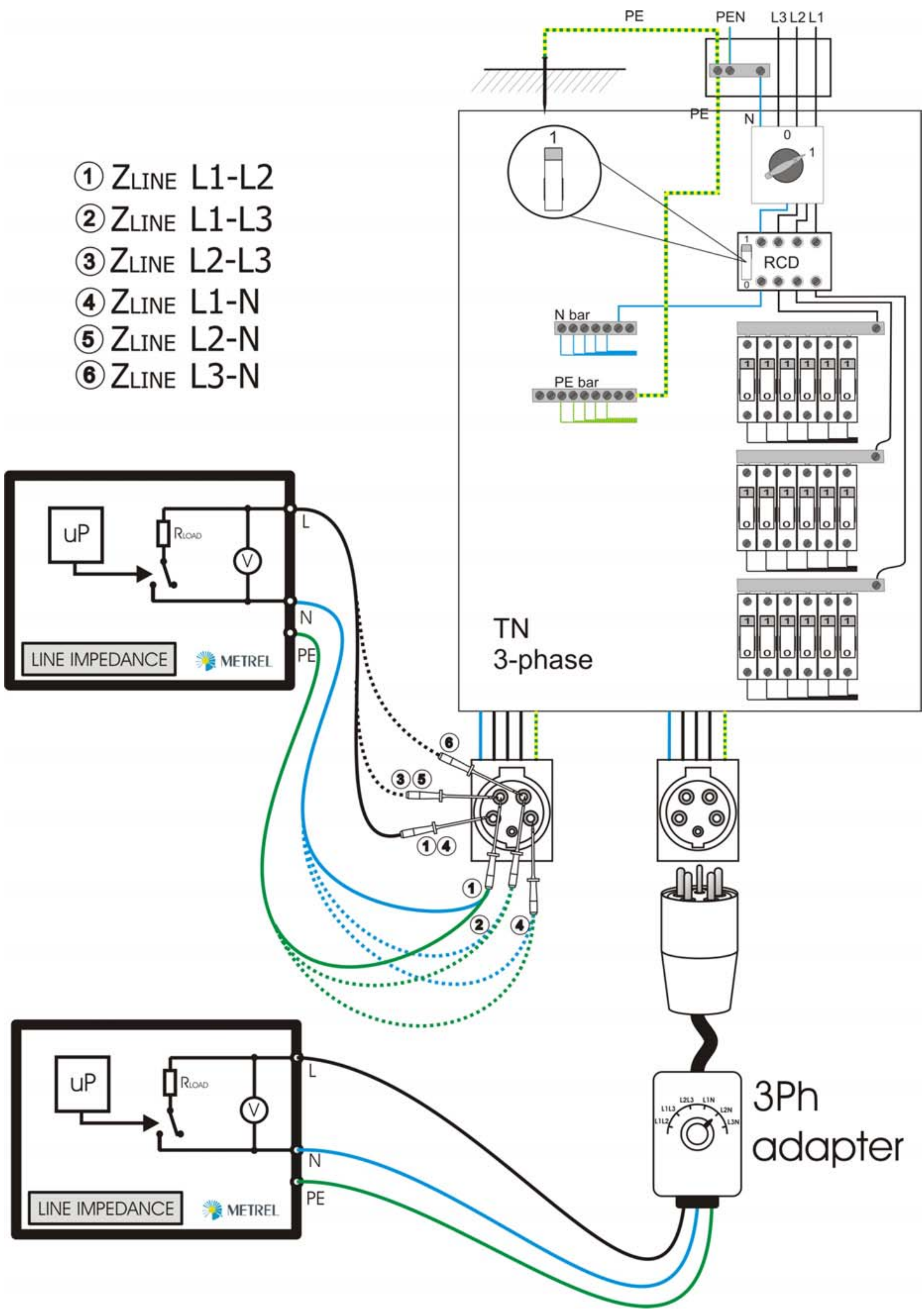


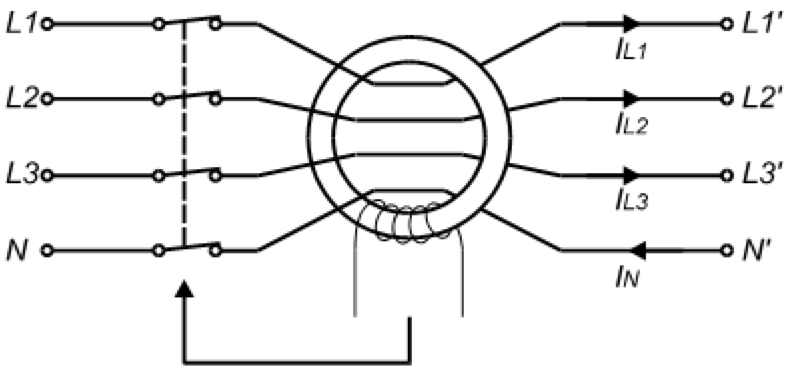
***Fig. 72:** Line impedance at 3-phase outlets*

6.2.6 RCD test

Scope of test
RCD devices are used as protection against dangerous fault voltages and fault currents. In TT systems relatively leakage (fault) currents between phase and PE conductor can result in a dangerous contact voltage on exposed metal parts.
Scope of this test is:

- to verify effectiveness and proper operation of the residual current disconnection devices (RCDs).
- to verify disconnection times and trip out currents of RCDs
- to verify that there are no or limited present fault currents in the installation. The sum of present fault current and measuring instrument test current can trip out the RCD.

RCDs- residual current protection devices
RCDs work on the basis of a difference between the phase currents flowing to different loads and the returning current flowing through the neutral conductor (optional). If the difference is higher than the tripping current of the installed RCD protection device, the device will trip and thereby switch off the mains voltage. The differential current must flow to ground as a leakage current (via insulation or capacitive coupling) or as a fault current (via faulty insulation or partial/total short circuit between live parts and accessible conductive parts).



$I_\Delta = I_{L1} + I_{L2} + I_{L3} - I_N$

Fig. 73: *Schematic representation of the RCD protection device*

RCD types
Regarding shape of fault current there are three basic types of RCD. Table 26 shows how different RCD types response on different differential current shapes.

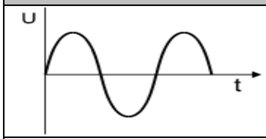
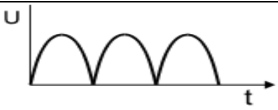
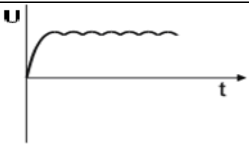
	AC type 	**A type** 	**B type** 
	✓	✓	✓
	No response	✓	✓
	No response	No response	✓

Table 26: *Sensitivity of different RCDs*

It can be seen that:
- AC type RCDs protect only against AC leakage currents.
- A type RCDs protect against AC and pulsating DC leakage currents.
- Only B type RCDs protects electrical installation against all types of leakage currents including smooth DC leakages.

RCD's of type AC are the simplest one. However as a lot of electronic devices can produce pulsating or pure DC fault currents the meaning of A and B-type RCDs is increasing in last time. A type is becoming the standard RCD type in a lot of European countries. B type is the most universal type and obligatory in special environments.

Regarding required trip out time of RCD protection devices, two types are available:
- **Standard type** (instantaneous trip out)
- **Selective type** (delayed trip out), marked with **S**

RCDs of selective type have a delayed trip out response (several 10ms). If an installation is protected with more RCDs they are usually installed at the input side of the installation. Standard type RCDs are installed downstream of selective RCDs. This connection allows a selective trip out of only that installation part where the fault occurred.
See Appendix A for more information about types, installation and operation of RCD devices.

References:
Limits/ methodology: IEC 60364-4 (chapters 61.3.6.1 and 61.3.7)
Measuring instruments: IEC 61557-6
RCD devices - general: IEC 61008-1, IEC 61009-1, IEC 62423, IEC/TR 60755

Measuring principles / limits:
Following parameters are to be tested in an RCD test:
- Contact voltage Uc,

- Earth Resistance R_E,
- Non-tripping test,
- Trip out time t∆ test (usually at 1 I·∆N and 5·I∆N) at 0º and 180º phase,
- Tripping current I∆.

RCD testing principle
The test instrument is connected to the mains voltage (between line and PE conductors) and loads the mains voltage with the selected test current I∆. Typical test current values are:

- 0.45·I∆N for no-tripping tests,
- 1.05 I∆N and 5.25 I∆N for trip out time tests,
- Increasing current ramp for trip out current test (between 0.2 and 1.1 I∆N).

Voltage drop is measured for the contact voltage/earth resistance tests:

$$U_C=(U_{UNLOADED}-U_{LOADED}), \text{ at } I\Delta N \qquad \textit{Eq. 43}$$

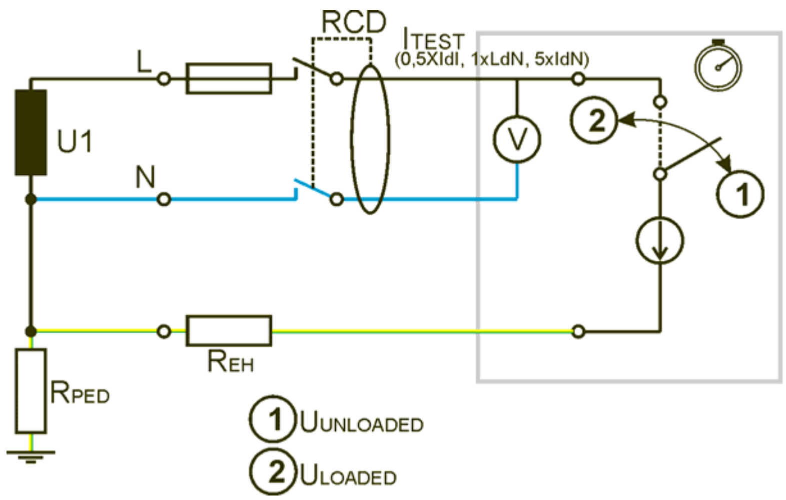


Fig. 74: *RCD tests - measuring principle*

6.2.6.1 No-tripping test, contact voltage, fault loop resistance tests

Test results obtained with no-tripping test:

- Fault loop resistance R_{LOOP},
- Contact voltage U_C,
- Verification of correct operation of the RCD (no trip out),
- Confirmation that there is no existing leakage current in the installation at the time of measurement (no trip out).

Contact voltage
The contact voltage is not allowed to exceed 50V. Following condition must be fulfilled:
U_C < 50V (at $I_{\Delta N}$).

Earth resistance
In TT systems the installation earthing resistance (R_{EH}) usually comprises the main part of the loop impedance. Conditions acc. to eq. 44 must be fulfilled. Contact voltage shall not exceed 50 V at RCD trip out.

$$R_E < \frac{U_{C\lim it}}{I_{\Delta N}}$$ *Eq. 44*

U_{Climit}....... Limit contact voltage (usually 50V)
R_E .... Main earthing resistance
$I_{\Delta N}$ .... Nominal trip out current of RCD

For earth resistance limit values see table 25.

No trip out test
For the no trip out test the test passes if the RCD does not trip out.

6.2.6.2 Trip out time test

Test results obtained with trip out time test:

- Verification of correct operation of the RCD
  - Successful trip out,
  - Trip out time $t_{\Delta N}$ at $I_{\Delta N}$ lies inside predefined limits.

Test results obtained with the ramp current test:

- Verification of correct operation of the RCD
  - Successful trip out,
  - Current IΔ and trip out time tΔ @ IΔ (current at which RCD tripped out) lie inside predefined limits.

RCD test results - limits

Trip out time at 0.5, 1, 2, 5$I_{\Delta N}$
For the trip-out test the test passes if the RCD trips out inside the time defined in table 27.

RCD type	RCD test current			
	½×$I_{\Delta N}$ *)	$I_{\Delta N}$	2×$I_{\Delta N}$	5×$I_{\Delta N}$
General RCDs (non-delayed)	No trip out	t_Δ < 300 ms	t_Δ < 150 ms	t_Δ < 40 ms
Selective RCDs (time-delayed)	No trip out	130 ms < t_Δ < 500 ms	60 ms < t_Δ < 200 ms	50 ms < t_Δ < 150 ms

Table 27: *Trip-out times according to IEC 60364-4-41.*

Note:

- Preferred trip out times, trip out test measurement time and test current sizes differ slightly in some other standards.
- METREL installation testers EUROTEST enable selecting different standards for RCD tests. The limits, test times and current size are adapted automatically to the selected standards.

6.2.6.3 Trip out current test

Trip out current I_{Δ}
A continuously rising residual current (see Fig. 75) is intended for testing the threshold sensitivity for RCD trip-out. The test the passes if the RCD trips out at currents according to table 28.

RCD type	Slope range		Waveform
	Start value	End value	
AC	$0.2 \times I_{\Delta N}$	$1.0 \times I_{\Delta N}$	Sine
A ($I_{\Delta N} \geq 30$ mA)	$0.35 \times I_{\Delta N}$	$1.4 \times I_{\Delta N}$	Pulsed
B	$0.5 \times I_{\Delta N}$	$2.0 \times I_{\Delta N}$	

Table 28: *Trip-out currents according to IEC/TR 60755*

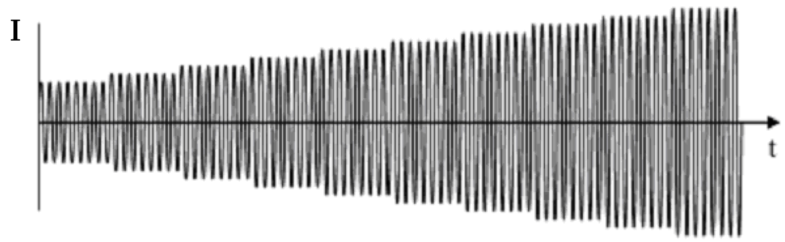


Fig. 75: *Current shape for trip out current measurement*

Connection diagrams

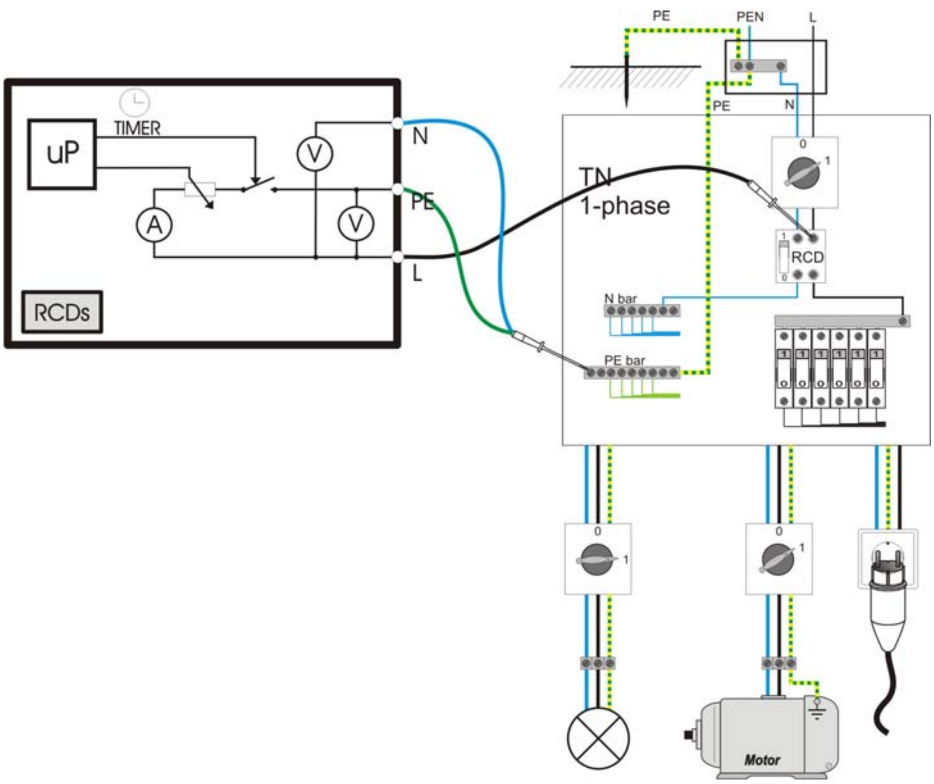


Fig. 76: *RCD test at switchboard*

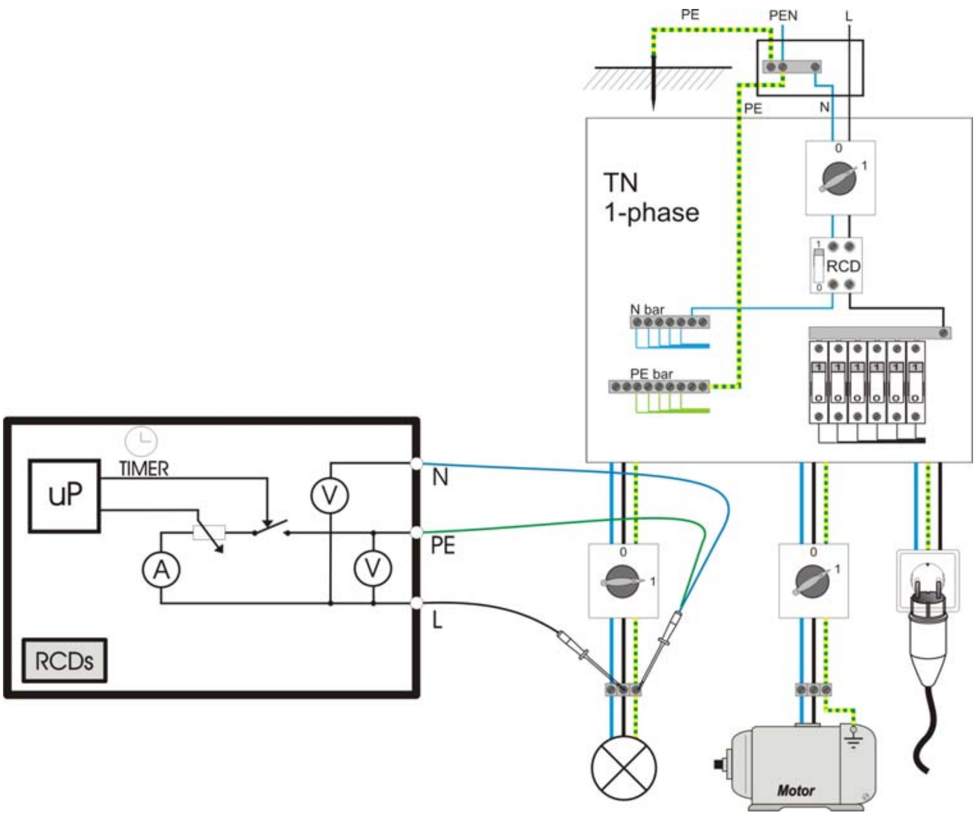


Fig. 77: *RCD test at outlet and connection point*

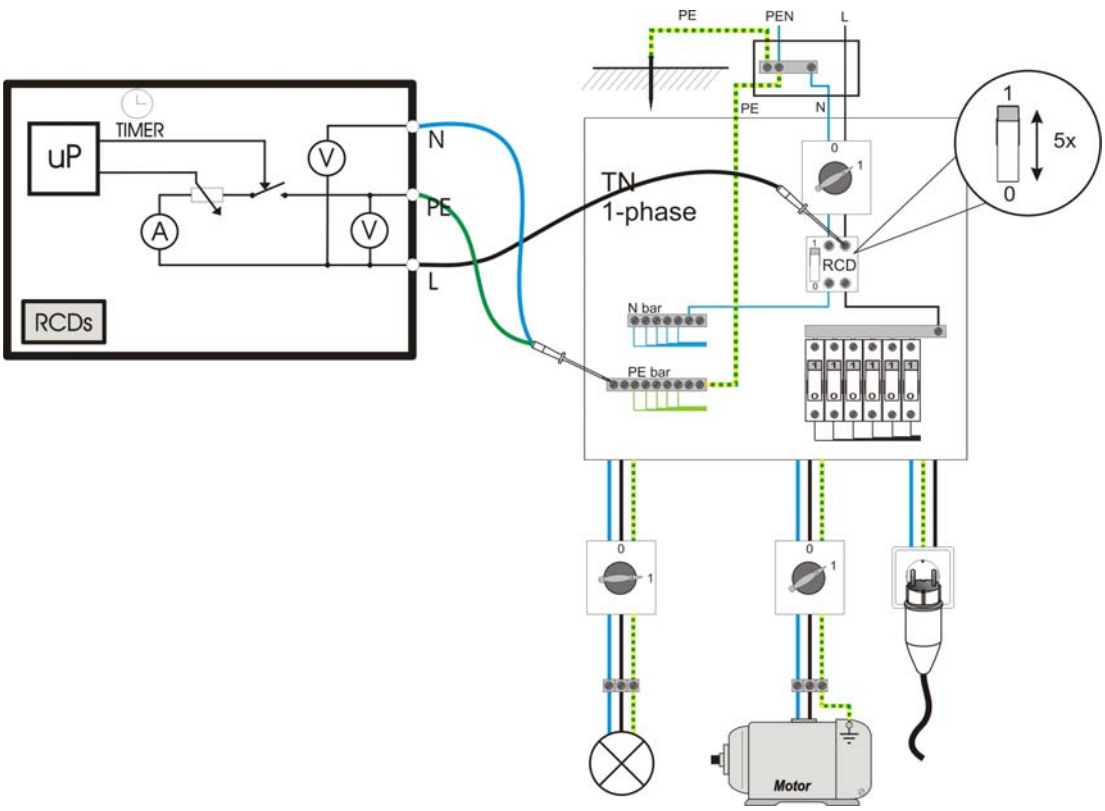


Fig. 78: *RCD test at switchboard (RCD Auto feature)*

METRELs hint:
METREL installation testers have inbuilt the "RCD AUTO" function. With this function all relevant RCD tests can be carried out in one step. It is a very simple and time saving feature.

6.2.7 Phase sequence

Scope of test
Line voltages in AC multi-phase systems are delayed to each other in predefined order. This order defines direction of rotation of motors and generators.
In three-phase system line voltages are shifted for 120 ° between each other; changing any two lines between each other will change direction of rotation.
In practice we often deal with the connection of three-phase loads (motors and other electro-mechanical machines) to three-phase mains installation. Some loads (ventilators, conveyors, motors, electro-mechanical machines, etc.) require an exact phase rotation and some may even be damaged if the rotation is reversed. This is why it is advisable to test phase rotation before connection is made.

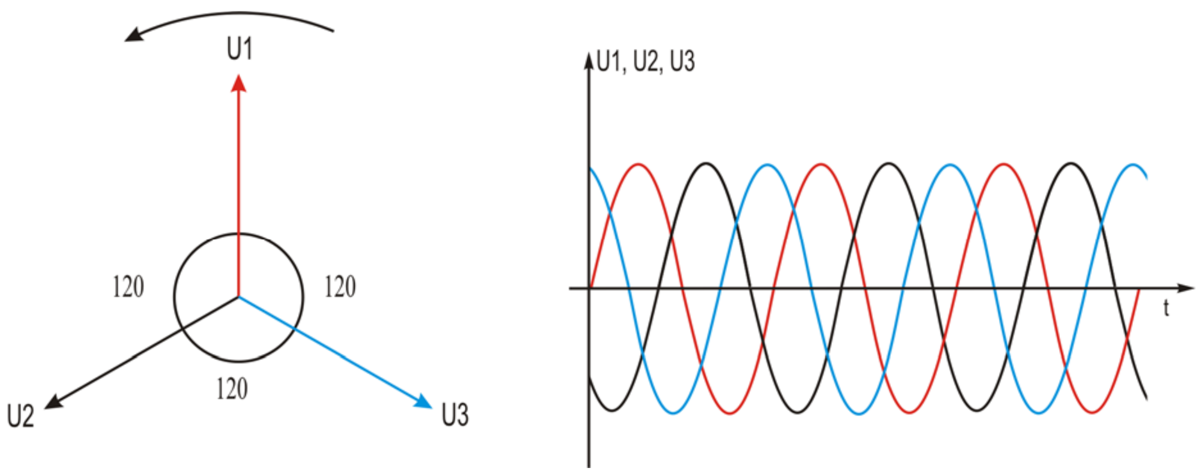


Fig.79: *3-phase voltage diagrams*

References:
Methodology: IEC 60364-6 (chapter 61.3.9)
Measuring instruments: IEC 61557-7

Measuring principles / limits:
The test instrument compares all three phase-phase voltages concerning amplitude and phase delay. Phase rotation is determined on that basis. If necessary, two phase conductors must be exchanged between each other in order to reverse the phase rotation.
The test can be done comparatively with respect to a reference mains outlet.

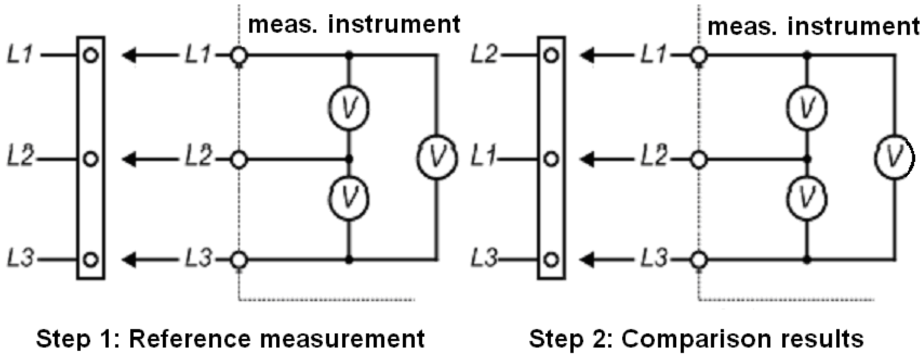


Fig 80: *Rotary field measuring principle*

Testing procedure:
First, phase rotation on the reference mains outlet should be measured, where behaviour of a specific machine (e.g. direction of phase rotation) is known. The direction should be noted.
Measurement should to be repeated on an unknown mains outlet and both results compared.
If necessary, two line conductors must be exchanged between each other in order to reverse the phase rotation.

Results:
Pass means that the connection is prepared for clockwise (c.w., indication of METREL installation testers is 1.2.3) rotation. Fail means opposite direction (counter clockwise, c.c.w., indication is 2.1.3 or 3.2.1). In this case two line conductors shall be changed between each other to receive pass.

Connection diagrams

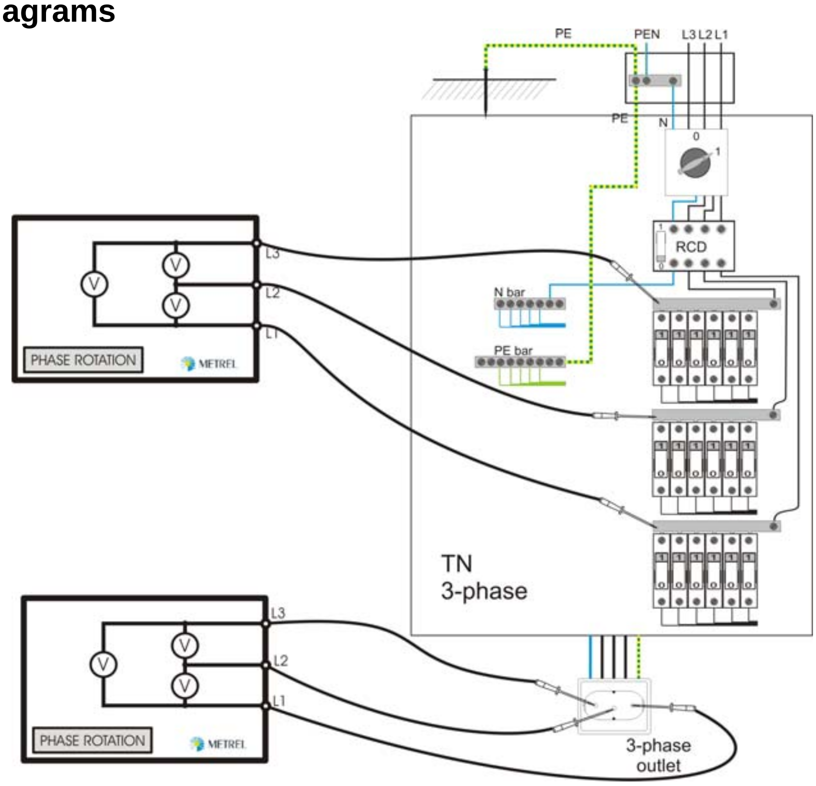


Fig 81: *Rotary field test*

7 Modern working principles for verification of installations

A complete verification of an electrical installation consists of a lot of activities.
New innovative working technologies developed by METREL enable to perform verifications of installations faster, more efficient and accurate than with standard approaches. This new technologies and practices are described in this chapter.
The flowcharts on fig. 82 and fig. 83 show activities and time consumption for verification of a middle sized domestic electrical installation.
They assume that well-made project documentation is available and the electricians carried out the installation works without making big failures.
It can be seen that using the proposed technologies and practices can save a lot of time.

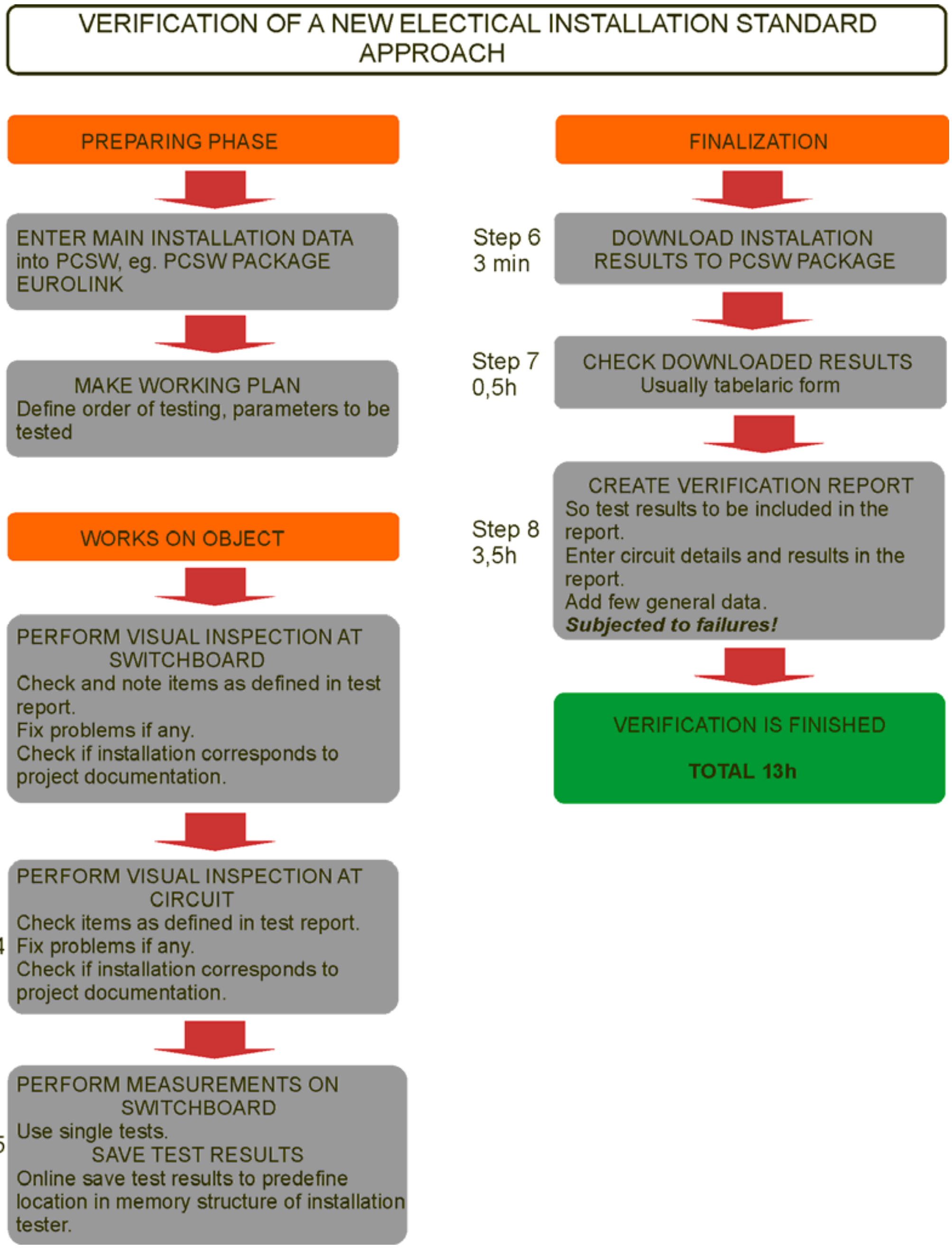


Fig. 82: *Verification flowchart – standard approach*

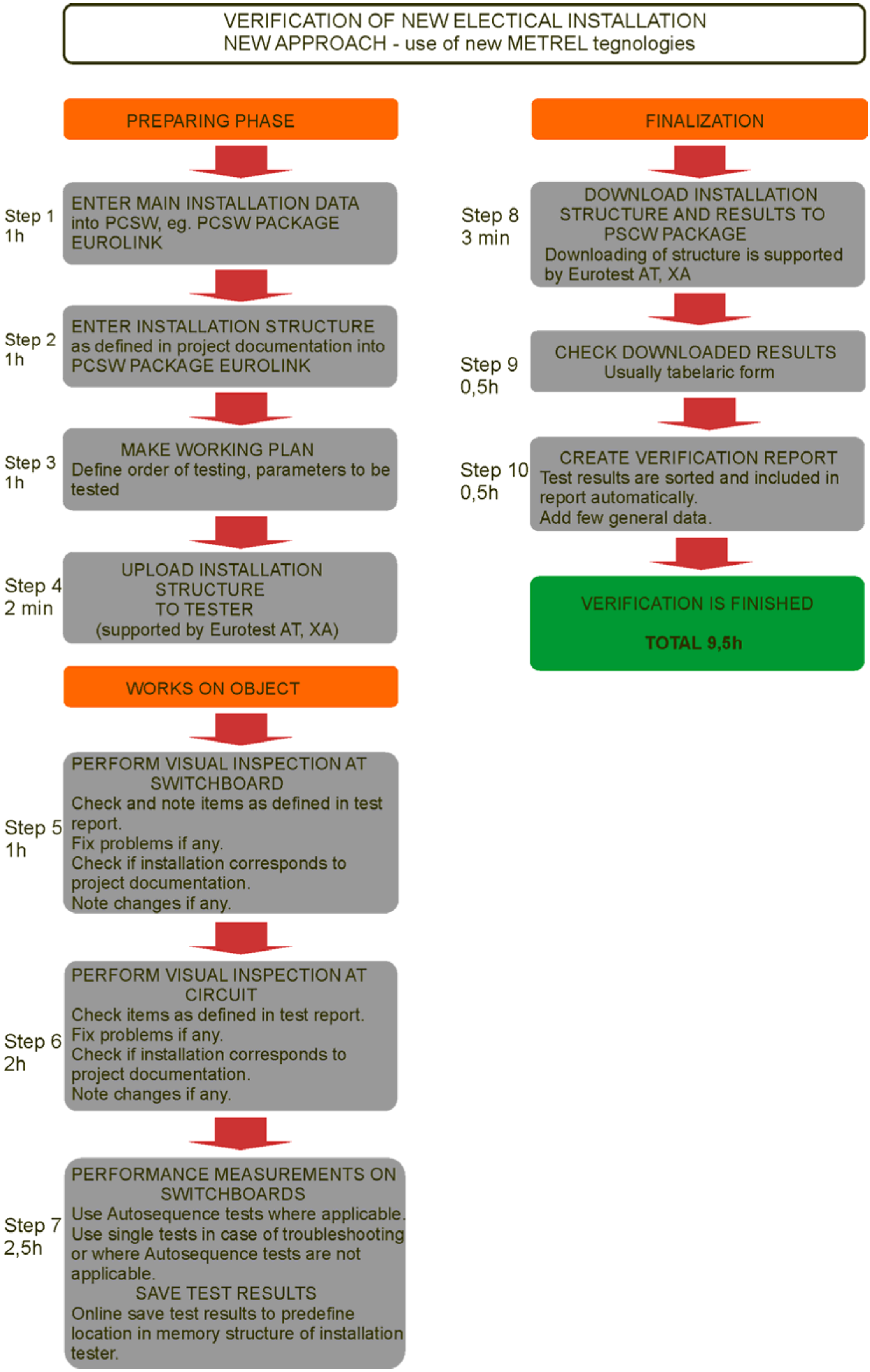


Fig. 83: *Verification flowchart – new proposed approach*

7.1 Working stages

7.1.1 Preparing phase

The preparing phase includes activities before getting on the object to be tested.

Overview of project documentation

- Estimation of amount of work for verification (on base of installation size)
- Overview of documentation:
  - Is it complete?
  - Is it understandable?

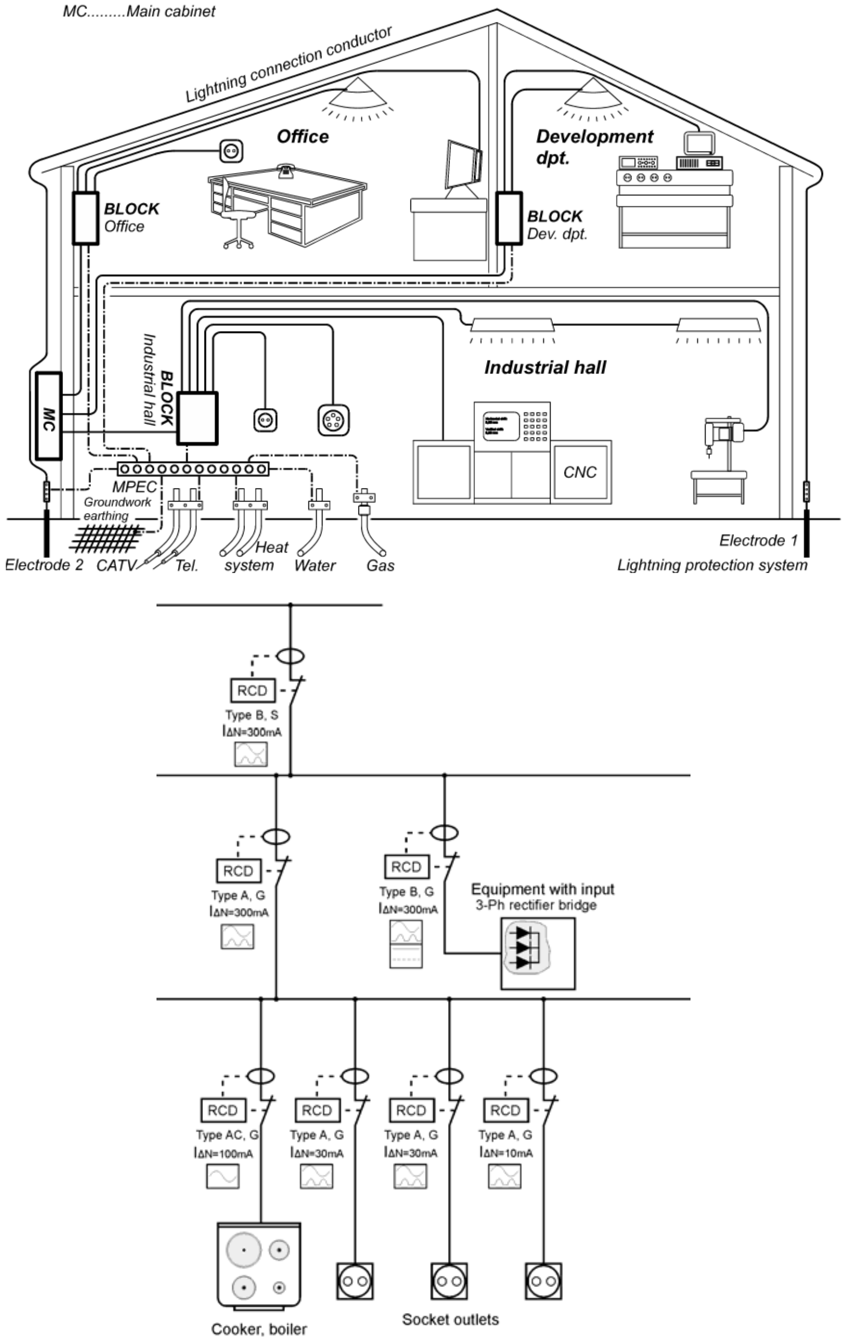


Fig. 84: *Cut-outs of a project documentation*

Make a working plan

- Define resources (how many instruments, materials, electricians are needed) to carry out the verification,
- Define order and amount of testing (switchboards, circuits),
- Check if any special measuring equipment /accessories/ skills are needed.

Open a new project in PCSW (EurolinkPRO), create and upload the installation structure to an installation tester (Eurotest AT,XA).

The same installation structure as in project documentation can be created with METREL PCSW packages and uploaded to the measuring instrument (see fig. 85). By doing this the instrument reconfigures its memory organization so that it corresponds to the structure of the measured installation. The structure elements include attributes like switchboard, circuit, earth bonding, names etc

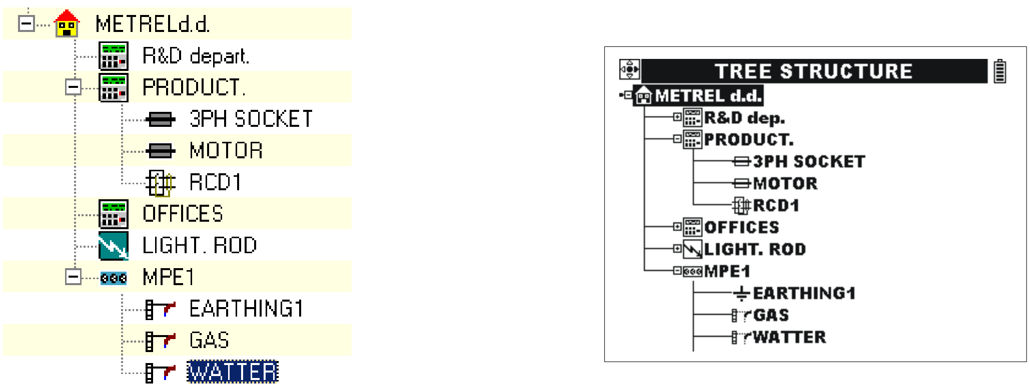


***Fig. 85:** Example of installation structure created with Eurolink PCSW and downloaded to Eurotest AT installation tester*

The advantage of this technology is that each measuring result will include the exact information where it belongs to e.g.: a switchboard, circuit, earth bond connection. This significantly simplifies further steps of verification:

Advantages on the test site:

- The user does not need to care where and how to store the results. It is obvious where in the installation structure individual measurements belong.
- Measured and stored results are easy to access and recall.
- It is easier to check if all needed measurements were performed e.g. if some measurements are missing
- Simpler manipulation with the installation tester.

Advantages when making the test report:

- Automatic creation of verification report

See more information about building up a proper installation structure in chapter 7.2.

7.1.2 Works on the object

In general sequence of works is following:

Visual inspection
Inspection / visual checking shall be done first before any measurement.
For more information regarding visual inspection view chapter 8.1.5.

Measurements

Test sequence - the standard approach
The standard approach assumes that after inspection some tests are made before electricity is applied or with appropriate installation parts disconnected from supply. With the “no supply” tests, the basic safety against direct contact can be confirmed.

Measurements with supply off (“dead” tests)
- Main and supplementary PE connections.
- Insulation resistances
- Main earthing
- Connection and Polarity test (in some countries)

The measurements should start at the installation origin, proceeding on the switchboards up to the most remote circuit connection points.
Care must be taken that during the tests all switches, fuses etc are switched ON or OFF adequately. Measured results must be saved.

If the no-supply tests passed the verification can proceed with measurements with supply on.

Measurements with supply on (“live” tests):
- RCD tests
- Line and Loop impedances (prospective currents)
- Rotary field tests
- Functional testing of switchgears, assemblies etc.

The measurements should start at the installation origin, proceeding on the switchboards up to the most remote circuit connection points.
Care must be taken that during the tests all switches, fuses etc are switched ON or OFF adequately. Test results must be saved.

Alternative measuring methods and sequences
As the standard approach is relatively time demanding many faster alternative measurements and methods were developed.
<u>Important note !</u>
- **Alternative measurement procedures are not considered as regular in all countries!**
- **It depends on regulations and practices in individual countries which alternative measurement procedures are valid.**
- **This guide does not determine the validity of the described alternative methods in individual countries.**

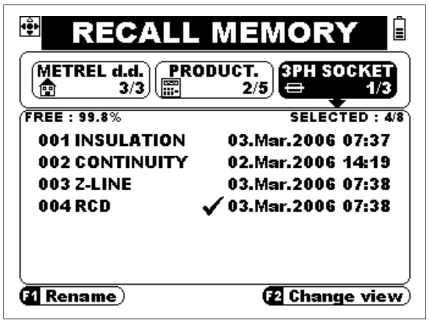
Some (alternative) measurements that can significantly reduce the overall test time by:

- Performing insulation resistance test for complete installation in one step (view chapter 6.2.1.2 for more information).
- Performing the continuity test between N and PE terminals in TN systems (verification of PE conductor continuity) with the N-PE loop test (view chapter 6.2.2.2 for more information).
- Verification of operation (trip out tests) of RCD at switchboard. Only no-tripping RCD tests (U_C etc) are measured then on circuits.

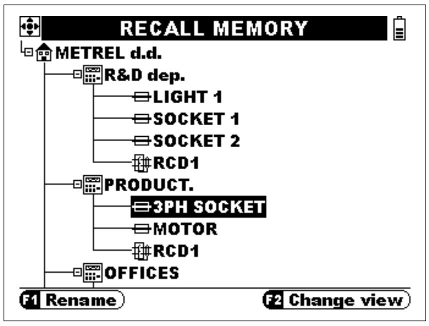
Other solutions for reducing the overall verification time

- Measurements can be carried much faster with the use of ***AUTOSEQUENCE©*** procedures. See chapter 7.3 for more information.
- If measuring parameters (limit values, parameters of installed fuse etc) are correctly set, checking PASS's/FAIL's on the field is possible. The EUROTEST instruments enable on site evaluation of all test results, including of Z_{LINE} and Z_{LOOP} results (as they have the fuse table integrated) – see chapters' 6.2.4, and 6.2.5 for more information.
- Insulation ALL tests (see chapter 6.2.1.2 for more information)
- RCD AUTO test (see chapter 6.2.6.3 for more information)

At the end of this working phase all measurement results are stored in the instrument's memory. In METREL installation testers Eurotest AT, XA beside test results relevant test point attributes and parameters are stored too.



Basic view



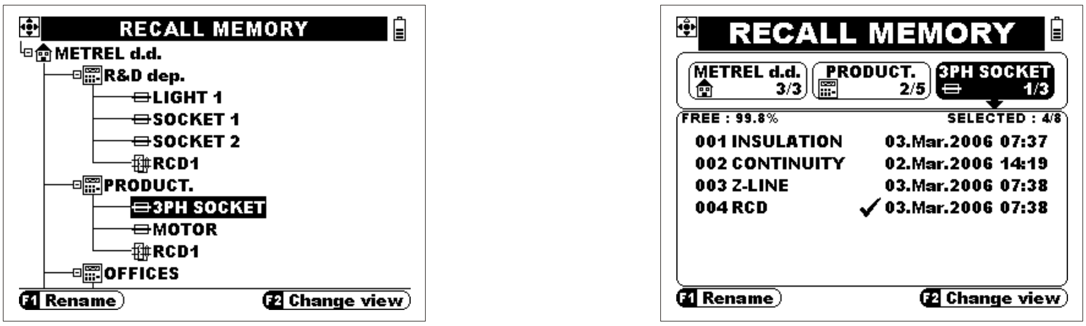
Tree structure view

Fig. 86: *EurotestAT, XA have stored test results, parameters and installation attributes*

7.1.3 Finalization

Download of measuring results and installation structure to PCSW package and check them

After the results and structure are downloaded in the PCSW they should be checked first. EurolinkPRO offers a simple table form for viewing test results.



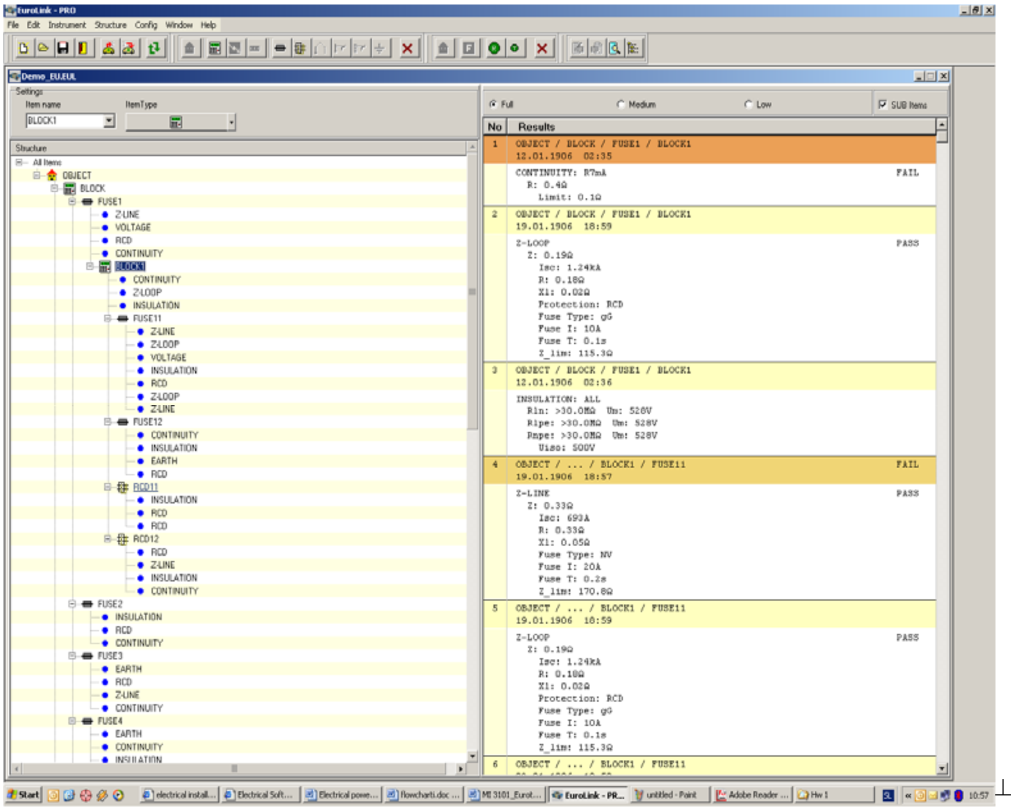


Fig. 87: *Stored test results, parameters and installation attributes downloaded back to the PCSW EurolinkPRO; results in table form*

Creation of verification report

Verification report has to be created on base of project data and test results.
Each test result must have attached following data to be included in the verification report:
Test site information

- Exact meaning in the installation structure (block, circuit, MPE etc)
- Name of place

Measurement parameters/limits

- All parameters needed for PASS/FAIL decision. FAIL results can not be included in a verification report.
- Date and time of measurement (optional)

Steps of creation

Entering general installation and project data

Type of installation, customer and operator data, data of origin of installation etc. must be documented in the verification report.

See chapter 8.1.1 for more information.

PASS/FAIL evaluation of all results

All results in the protocol must be PASS. Each test result must be compared against predefined limits.

Sorting of results

On test places with more than one test points only worst results are to be documented. For instance a circuit can consist of many outlets. The highest impedance, highest RCD trip out time, highest PE bonding resistance lowest insulation resistance etc. are going in the protocol.

If only test results (without parameters) are available and the PASS/FAIL evaluations and sorting must be made manually this is a complicated and time demanding job. METREL offers different tools to simplify and speed up the creation.

Automatic creation of verification report with METREL tools

METREL installation testers and EurolinkPRO PCSW include features that support automatic creation of the verification report.

Attachment of relevant data to the test results

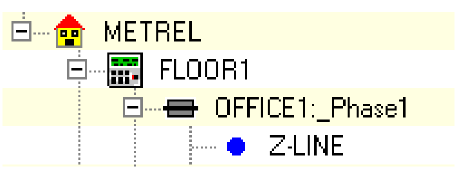
Test site information can be edited with the Eurolink PCSW during the making of installation structure (before or after testing)

Measurement parameters/ limits are set with the Eurotest testers before carrying out the test.

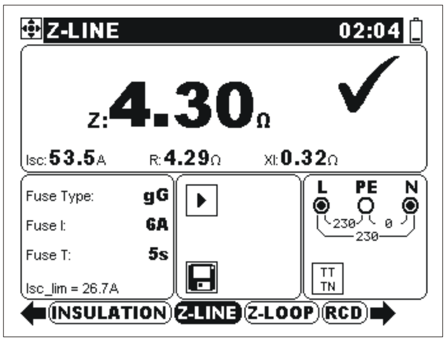
PASS/FAIL evaluation is displayed beside each test result. This enables an on-site result control.

Example

The example below shows the attributes for a particular ZLINE measurement with a result of 4.30Ω/53.5A.

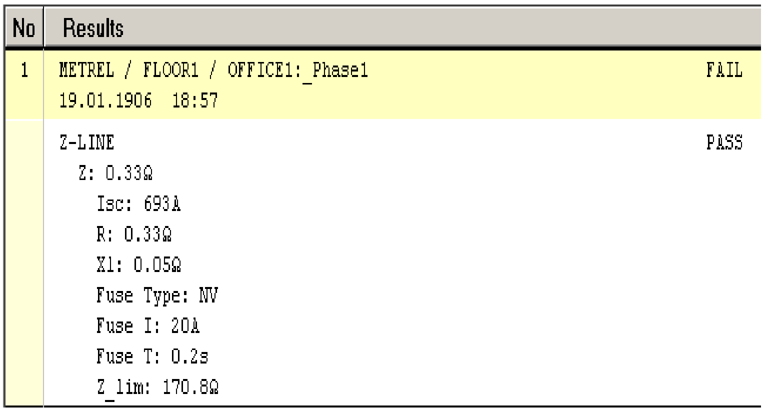


Location: FUSE
Name: OFFICE1_Phase1



Fuse type: gG
Fuse I_N:6A
Fuse t: 5s
I_{SCLIM}: 26.7A
Status: PASS

Fig. 88: *Example of attached data to a test result*



No	Results	
1	METREL / FLOOR1 / OFFICE1: _Phase1 19.01.1906 18:57	FAIL
	Z-LINE Z: 0.33Ω Isc: 693A R: 0.33Ω Xl: 0.05Ω Fuse Type: NV Fuse I: 20A Fuse T: 0.2s Z_lim: 170.8Ω	PASS

Fig. 89: *Example of a test result with all belonging attributes for verification*

Automatic evaluation and sorting of result
If test results and data include all information for the verification report than the verification report can be created automatically.
METREL EurolinkPRO PCSW has the creation rules integrated. With this tool the most demanding manual filling of circuit details completely falls out.

METREL verification reports are described in chapter 8.

Documentation of reports
Beside the verification report the complete Eurolink project should be saved.

Eurolink *.EUL file includes:

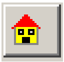
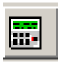
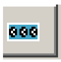
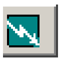
- Installation structure with attributes and original names
- All test results with belonging parameters and PASS/FAIL decisions
- Verification report

The installation structure can be reused for periodic verifications or serve as a starting point for another project. For periodic tests on unmodified installations the most of the preparing phase falls away.

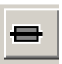
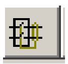
7.2 Installation structure

PCSW EurolinkPRO includes a tool for creation arbitrary electrical installation structures. Any electrical installation designed according to IEC 60364 can be created with the elements available. All installation structure elements can be renamed.
The created installation structure can be up/downloaded to METREL installation testers Eurotest AT and XA. Modifications of the structure with test instruments on site are possible.

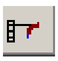
Main installation structure elements

Symbol	Name	Description
	OBJECT	Location where all the measurements will be carried out. Example: METREL factory
	BLOCK	Distribution board, switchboard Example: Distribution board 1
	MPE	Main potential equalizer Example: MPE DB 1
	LIGHTING	Lighting rod of lighting system Example:METREL factory lighting system

Elements of a BLOCK

Symbol	Name	Description
	FUSE	FUSE (CIRCUIT) Example: KITCHEN Phase 1
	RCD	RCD Example: main RCD

Elements of a MPE

Symbol	Name	Description
	CONNECTION MPE	Main earth bonding Example: CATV
	EARTHING	Main or local earthing Example: main earthing electrode

Elements of a LIGHTING

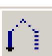
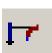
Symbol	Name	Description
	ELECTRODE	Particular electrode of lighting system Example: METREL factory lighting electrode #11
	CONNECTION ELECTRODE	Connections to the lighting electrode Example: underground connection #11

Table 29: *Installation structure components*

In general the installation structure is an open type structure. Each measurement can be stored under any installation item/ location. The open structure is flexible and allows the operator to customize the stored data according to its needs.

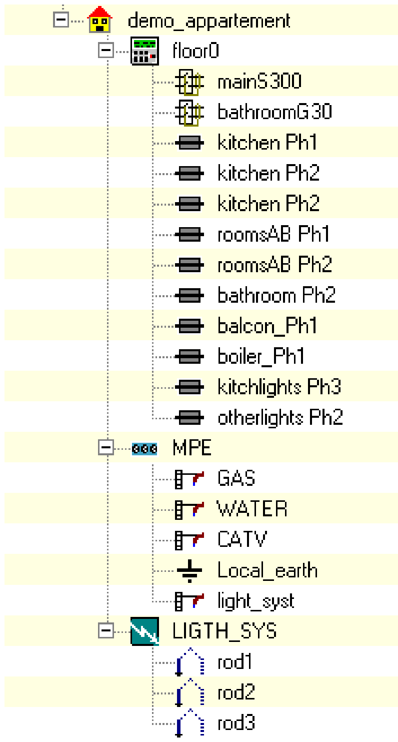


Fig. 90: *Example of an installation structure with all installation structure elements*

The installation structure and test results forms the basis for creation of verification reports. If the operator considers some simple rules, METREL technologies enables this step to be performed automatically.

Main rules for creation of verification reports

- Results of measurements at outlets, switches, and connection points in the same circuit should be all stored under the same FUSE installation structure element. Worst case R_{ISO}, Z_{LINE}, Z_{LOOP}, RCD t, U_C, R_{PE} results will be searched and stored in the protocol. If they are stored to any other installation structure element than FUSE will not be imported in the verification protocol.
- The FUSE installation structure element should not be divided into subitems.
- It is important that the measurement parameters in the same circuit are not changed.
- Measurements not relevant for the verification report can be stored in the same installation structure element than relevant results. They can be viewed, printed out etc but will be ignored in the protocol creation steps.
- In the RCD installation structure element the results of the RCD operation tests should be stored in the switchboard. The same RCD can be stored at outlets as a part of the FUSE installation structure element.
- Test results of primary and main disconnection devices can be stored under the BLOCK or OBJECT installation structure element. However test results must be manually entered in verification report.

Note:

- The rules above are valid for standard METREL verification report that is subjected to changes.

- The PCSW EurolinkPRO must consider a much larger set of rules for the automatic creation of reports. Exact rules are beyond the scope of this guide.
- Report creation rules and installation structure elements for other verification protocols provided by METREL can significantly differ.
- *Contact METREL for help on creation of verification reports.*

7.3 Autosequence

In this chapter the new *AUTOSEQUENCE©* technology is described. AUTOSEQUENCE© is a tool that supports carrying out a set of measurements in pre-programmed sequences. It offers a faster and more accurate measuring. The technology is especially efficient on sites where a large number of equal tests must be performed as fast as possible.

Main advantages of the AUTOSEQUENCE© technology:

- Measurements are performed faster – more measurements can be executed sequentially.
- Measurements are performed in an easier, safer and more accurate manner (less operation with the instrument).
- Easy setup of test parameters (fuse type/characteristic/size, limits, RCD type) PASS and FAIL decisions for individual and group of tests.
- Names, comments, hints, descriptions, names can be applied with a user-friendly editor.
- A database of popular sequences is available from METREL.

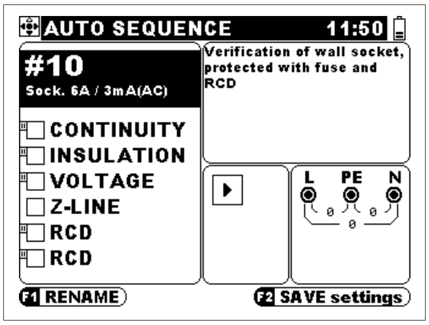


Fig. 91: *Pre-programmed sequences*

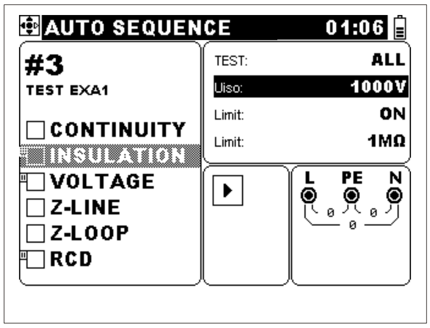


Fig. 92: *Easy setup of parameters*

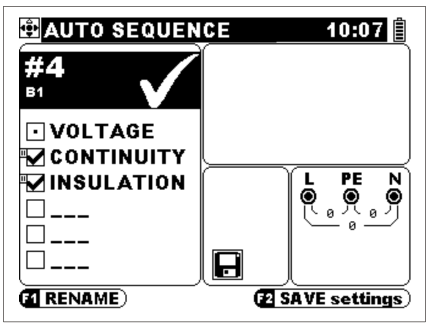


Fig. 93: *PASS's, FAIL'*

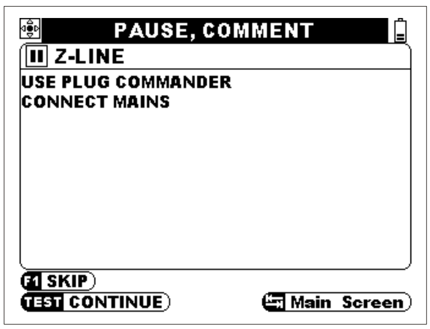


Fig. 94: *Online warnings, notes*

How the sequential measurement is performed?

Preparing:
Any sequential measuring procedure can be pre-programmed.
However the simplest option is to use pre-programmed sequences offered by METREL. Only fuse and RCD type must be then selected on the field.
Performing the measurements:
Individual measurements are performed automatically in a sequential manner. The installation tester cares on line for proper connection on the measured item and checks for correct measuring and safety conditions (voltages, impedances etc) on the installations.

Depending on the application the procedures can be performed with or without stopping. Pauses (e.g. for reconnection) can be pre-programmed if needed.
Check results
At the end of test:

- Measuring results, parameters and PASS/FAIL are displayed for each test
- Overall PASS/FAIL of the sequence is displayed

Comparison of Electrical Installation's Safety Testing Procedures

The example below shows the major benefits if using the AUTO SEQUENCE ® testing procedures.

 **Type of inspection**	Automatic testing procedure with instrument operating by patented ***AUTO SEQUENCE ®***	Standard c testing procedure with any instrument operating by means of **Rotary Switch, Keys**
Initial inspection of installation with settings of the Instrument and **Switch Board Testing of:** • Visual inspection • Z line / Z loop • Continuity • Earth resistance **and 10 Outlets Testing of:** • L/N/PE voltage polarity test • Z line / Z loop • Continuity • RCD dt, dI, Uc • Insulation L-N-PE	**Number of operations:** • Settings x 2 • Re-connecting x 12 • Testing x 11 • Checking x 11 • Saving x 11 **Total number of operations 47.** **Operating time for skilled electrician:** • <5 min. at SB • <1 min. at each Outlet **In Total less than 15 minutes.** Operating time for unskilled electrician: • 5 min. at SB • 1 min. at each Outlet **In Total less than 15 minutes.**	**Number of operations:** • Settings 4 + 10x10 • Re-connecting 4 + 10x10 • Testing 4 + 10x10 • Checking 4 + 10x10 • Saving 4 + 10x10 **Total number of operations 520.** **Operating time for skilled electrician:** • 5 minutes at SB • 3 min. at Outlet **In Total more than 35 minutes.** Operating time for unskilled electrician: • 10 min. at SB • 5 min. at each Outlet **In Total more than 60 minutes.**

Periodic inspection of installation with settings of the Instrument and **Switch Board Testing of:** • Visual inspection • Z line / Z loop • Continuity • Earth resistance • RCD dt, dI, Uc • Insulation L-PE/N-PE **and 10 Outlets Testing of:** • L/N/PE voltage polarity test • Z line / Z loop • Continuity • RCD Uc	**Number of operations:** • Settings x 2 • Re-connecting x 12 • Testing x 11 • Checking x 11 • Saving x 11 **Total number of operations 47.** **Operating time for skilled electrician:** • <10 min. at SB • <1/2 min. at each Outlet **In Total less than 15 minutes.** **Operating time for unskilled electrician:** • 10 min. at SB • 1/2 min. at each Outlet **In Total less than 15 minutes.**	**Number of operations:** • Settings 6 + 10x7 • Re-connecting 6 + 10x7 • Testing 6 + 10x7 • Checking 6 + 10x7 • Saving 6 + 10x7 **Total number of operations 380.** **Operating time for skilled electrician:** • 10 minutes at SB • 2 min. at Outlet **In Total more than 30 minutes.** **Operating time for unskilled electrician:** • 20 min. at SB • 4 min. at each Outlet **In Total more than 60 minutes.**

Results:

- Less operations (setting of functions, parameters, limits manipulation, reconnections) are needed to complete the task.
- The measurements are completed faster. The time savings increase with more demanding applications
- Lower skilled users can use the instrument in more demanding applications (the sequences can be preset before by a higher skilled person). The possibility to make mistakes is lower

It can be easily shown that similar improvements can be obtained for almost any measuring procedure.

Examples of popular autosequences

Verification of 1 phase TN-C(S) distribution board

Performed tests: ZLINE, IPSC, ZLOOP, IPFC, RCD tΔN at 1x IΔ, RCD tΔN at 5x IΔ, RCD IΔ, UC, Continuity 200mA, RISO

Application: Initial verification, periodic tests of installations. Suited for TN earthing systems.

Description of sequence:

With this test all defined safety parameters on a 1-phase switchboard are checked and compared to predefined limits – insulation resistances, functionality and protection effectiveness of RCD and fuses. For TN-C system the connection between N and PE bars is checked.

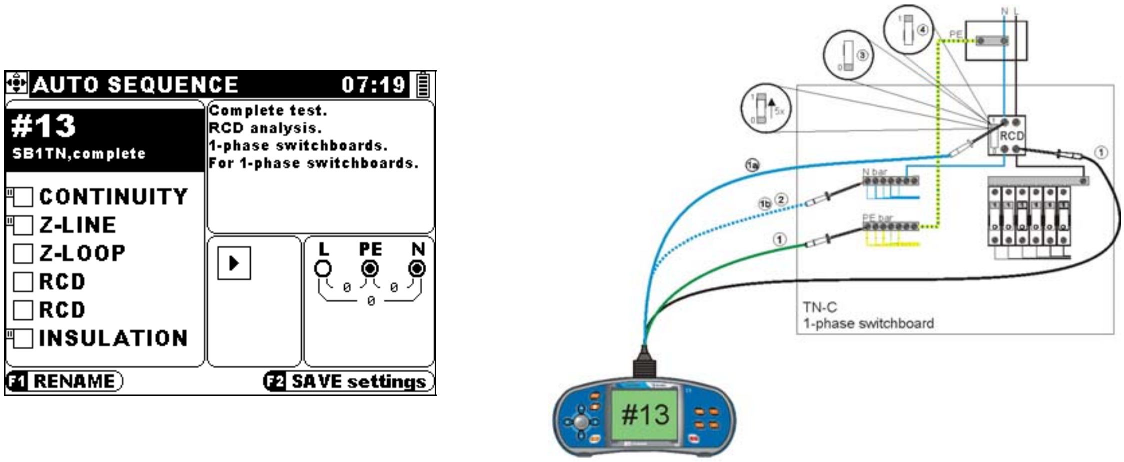


Fig. 95: *Autosequence setup and connection diagram, example 1*

Safety check of 1 phase outlet

Performed tests: Z_{LINE} , I_{PSC}, Z_{LOOP}, I_{PFC}, Continuity 7mA, RCD U_C

Application: Fast safety check of outlet. Suited for TN earthing systems, no tripping of RCD.

Description of sequence:

In this test the effectiveness of installed over current disconnection device (fuse) is checked.

Line/ fault loop impedances, prospective short/ faults currents and contact voltage at $I_{\Delta N}$ are measured. Test results are compared to limits from fuse data base.

The resistance of N-PE loop is measured to check the continuity of the PE conductor.

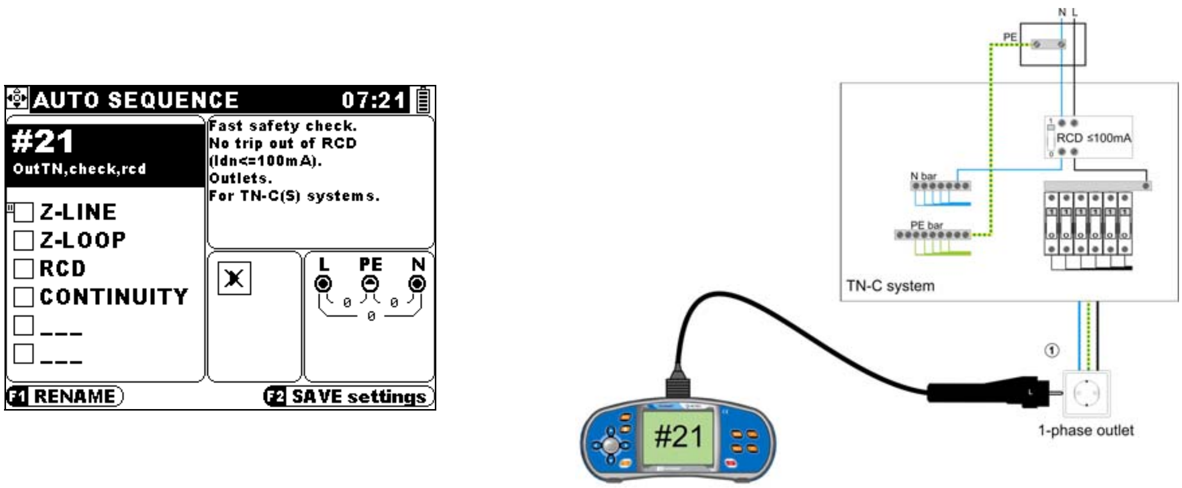


Fig. 96: *Autosequence setup and connection diagram, example 1*

For more information about autosequences see METREL’s handbook *Guide through Autosequences*.

8 Verification Reports

The purpose of verification reports is to:

- Ensure that the electrical installation is safe to put into operation
- Ensure that it is likely that the installation will remain safe until the next periodic inspection
- Prove that the inspection and testing were performed according to the regulations
- Prove that the inspection and testing were performed by a skilled and competent person
- Get a record with all necessary information regarding safety
- Provide a material prove in case of an accident

Verification report forms
There is no international standard verification report form available.
The content and outlook of the verification forms differs significantly between different countries. METREL provides different appropriate verification report forms for almost all countries worldwide.

8.1 IEC 60364-6: 2006 verification report proposal

The IEC 60364-6:2006 includes a verification report proposal in its informative annexes F and H. This proposal is a very good example with all items which modern verification report should include. In this chapter individual parts of the proposal are highlighted. The parts are the same or similar as that in actual METREL verification reports.

8.1.1 Description of the installation / project data

Description of the installation for verification

NOTE Particularly suitable for domestic installations.

Type of verification:
Initial verification
Periodic verification

Client name and address:

Installation address:

Installer name and address:

Installation:
New Modification
Extension Existing

Name of inspector:

Description of installation work:

Date of inspection: Signature: ....

Identification of instruments used:

Type	Model	Serial number

Fig. 97: *IEC 60364-6 verification report proposal – description of installation*

Type of verification

<u>Initial verification</u>

The initial verification takes place upon completion of a new installation or completion of additions or of alterations to existing installations.

Purpose of initial verification is a complete and thorough safety check before putting the installation in operation.

<u>Periodic verification</u>

The periodic verification takes place to be sure that the safety of the users is not put at risk and that the installation is still in a safe and serviceable condition.

The procedures for periodic verification can differ from place to place. This is because some parts of the installation can not be accessible or allowed to be disconnected from the mains. The extent of the periodic verification and limitations, if any, should be determined between the client and inspector. Both parties should not agree on unnecessary limitations.

If documentation of former (initial, periodic) verifications is not available the extent of periodic verifications must be increased.

Client name and address
The name and address of the person or organisation that engaged the contractor to carry out the installation work.

Installation address
The complete address of the installation including the postcode.

Installer name and address
The name and address of the person(s) or organisation that carried out the installation work.

Installation
New – if the whole installation has been installed as new
Extension – if the existing installation is extended with one or more new circuits
Modification – if one or more exiting circuits were modified (extended, changed components etc)
Existing – verification performed on an existing installation

Name of inspector
Name of a competent person responsible for inspecting and testing.

Description of installation work
A clear description of the work carried out. Extent of the installation covered by this report. Important field as the contractor is taking responsibility for this work.

Date of inspection, signature
Signature of inspector and date when verification was carried out.

Identification of instruments used
Measuring instruments and monitoring equipment and methods shall be chosen in accordance with relevant parts of IEC 61557. The instrument(s) type model and serial number must be noted. The test equipment must be regularly calibrated.

8.1.2 Description of incoming supply characteristics

Supply characteristics and earthing arrangements			Tick boxes and enter details, as appropriate
Earthing arrangements Supply authority Consumer's earth electrode	Number and type of live conductors	Nature of supply parameters	Incoming supply protective device characteristics
System types TN-C TN-C-S TN-S TT IT	a.c d.c. 1-phase, 2-wire (LN) 2-pole 1-phase, 3-wire (LLM) 3-pole 2-phase, 3-wire (LLN) other 3-phase, 3-wire (LLL) other 3-phase, 4-wire (LLLN) other	Nominal voltage, U/U_o (1)..................V Nominal frequency, f (1).....................Hz Prospective highest short-circuit current, I_{cc} (2)............. ....kA External earth fault loop impedance,Z_e (2).......................Ω NOTES (1) By enquiry (2) By enquiry, or by measurement or by calculation	Type:.................. Nominal current rating:..........A RCD sensitivity, where applicable ....mA
Alternative source of supply (to be detailed on attached schedules)			

Fig. 98: *IEC 60364-6 verification report proposal – supply characteristics and earthing arrangements*

Earthing arrangements / Supply authority/ Consumer's earth electrode

<u>System type</u>

The installation's earthing arrangement should be entered here. In case that different earthing arrangement is used in a part of the installation this must be noted.

<u>Alternative source of supply</u>

Where there are more supply sources (e.g. public supply and a generator) this should be noted.

Number and type of live conductors

Number of incoming live conductors (including N) and type of voltage (ac, dc) are entered here.

Nature of supply parameters

<u>Nominal voltages:</u>

U (phase to phase) and U_0 (phase to earth) voltages are entered here.

<u>Nominal frequency:</u>

Nominal frequency is entered here (usually 50Hz or 60Hz)

<u>Prospective highest short-circuit current I_{CC}</u>

This is the largest fault or short circuit current that can occur in the installation. This is the highest of the prospective currents between phase-phase, phase-neutral, phase-earth. Measurements should be performed in the switchboard on incoming points of the installation.

External earth fault loop impedance Z_E:
Z_E is the fault loop impedance of the distribution site. It should be measured at the installation entry point.
The purpose of this test is to verify the integrity of the main earthing. Therefore the incoming PE conductor must be disconnected from all other installation's earthing connections to prevent from parallel paths.

Incoming supply protective device characteristics
Type, nominal current rating
Type and nominal value of the primary over current protective device (fuse) should be entered here. It should be checked by inspection that the markings on the device corresponds to the project documentation.
RCD sensitivity
RCD's (if installed) nominal trip out current should be entered here.

8.1.3 Description of consumer earthing arrangement (electrode, wiring)

Details of consumers earth electrode (where applicable)			
Type	Material		
	Cu	Fe	Other
Foundation earth electrode Ground earth electrode Rod Tape Other:			
Location:			
Resistance to earth:.......................................Ω			
NOTE In existing installations where the above information cannot be ascertained, this fact should be noted.			

Fig 99: *IEC 60364-6 verification report proposal – details of consumers earth electrode*

This field must be fulfilled only if verifying a TT or IT system.

Type
Enter a description of the main earth electrode.

Location
Location should be described so that the electrode can be find for periodic tests.

Resistance to earth
The main earthing resistances should be entered here. It is important that parallel earthing paths are not influencing the result.

Earthing and main bonding conductors			
Earthing conductor:	material......................	csa[1]...................... mm²	connection verified
Main equipotential bonding conductors:	material......................	csa...................... mm²	connection verified
To incoming water and/or gas service		To other elements:..	
Supplementary equipotential bonding			
Bathrooms/showers:	material......................	csa...................... mm²	connection verified
Swimming pools:	material......................	csa...................... mm²	connection verified
Other: (please state)	material......................	csa...................... mm²	connection verified
1) csa: conductor cross-section area.			

Fig. 100: *IEC 60364-6 verification report proposal – main and supplementary bonding*

Earthing and main bonding conductors
Enter the conductor characteristics (material, cross-section) of PE earthing wiring here. Describe all main PE connections.
Confirm verification by visual inspection and testing.

Supplementary equipotential bonding
Enter the conductor characteristics (material, cross-section) of the supplementary equipotential bonding. Describe all performed supplementary bondings.
Confirm verification by visual inspection and testing.

8.1.4 Description of main isolation / protective devices

Isolation and protective devices at the origin of installation				
	Type	No. of poles	Ratings	
Main switch				V
				A
Fuse or circuit breaker			I_n	A
			I_{cn}, I_{cu}, I_{cs}	kA
RCD			I_n	A
			$I_{\Delta n}$	mA

Fig. 101: *IEC 60364-6 verification report proposal – insulation*

Describe components that are installed at the installation origin here.

Type
Type of the insulation / protective device should be entered here. It should be checked by inspection that the markings on the device corresponds to the project documentation.

<u>No. of poles</u>
Number of poles should be entered here. Check that all line and neutral conductors are disconnected.
<u>Ratings</u>
Nominal voltage / current / residual current values of the components should be entered here. It should be checked by inspection that the ratings corresponds to the project documentation.

8.1.5 Description of visual inspection

The proposed form contains a sample list of installation elements that must be visually inspected. Each element should be visually inspected. Compliance with product standards must be visible (markings, labels, technical documentation).
The results of the inspection must be noted. For initial verifications all items must pass.

Form for inspection of electrical installations
(see examples in Clause G.2)

G.1 Form for inspection of electrical installations

NOTE Particularly suitable for domestic installations.

A Protection against direct contact

	Item	Compliance (NOTE 1)	Comments
i	Insulation of live parts		
ii	Barriers		
iii	Enclosures		

B Equipment

	Equipment	Selection (NOTE 2)	Erection (NOTE 1)	Comments
i	Cables			
ii	Wiring accessories			
iii	Conduits			
iv	Trunking			
v	Distribution equipment			
vi	Luminaires			
vii	Heating			
viii	Protective devices RCD, CBs, etc.			
ix	Other			

C Identification

	Item	Presence	Correct location	Correct wording	Comments
i	Labelling of protective devices, switches and terminals				
ii	Warning notices				
iii	Danger notices				
iv	Identification of conductors				
v	Isolation devices				
vi	Switching devices				
vii	Diagrams and schedules				

NOTE 1 Enter C if it complies with (national) installation standard, NC if it does not comply.

NOTE 2 Visible indication of compliance with the appropriate product standard. In case of doubt, a declaration of conformity with the standard needs to be obtained from the manufacturer (e.g. from the catalogues).

More detailed sample list of various items. It can be seen that the visual inspection must be carried out thoroughly and that a lot of details have to be checked.

G.2 Examples of items to be checked when carrying out an installation inspection

General

Good workmanship and proper materials have been used

Circuits to be separate (no interconnection of neutrals between circuits)

Circuits to be identified (neutral and protective conductors in same sequence as line conductors)

Disconnection times likely to be met by installed protective devices

Adequate number of circuits

Adequate number of socket-outlets provided

A Protection against direct contact

Insulation of live parts

Barriers (check for adequacy and security)

Enclosures have suitable degree of protection appropriate to external influences

Enclosures have cable entries correctly sealed

Enclosures have unused entries blanked off where necessary

……..

B Equipment

1 Cables and cords

Non-flexible cables and cords

Correct type

Correct current rating

Non-sheathed cables protected by enclosure in conduit, duct or trunking

……..

2 Wiring accessories (luminaires – see below)

General (applicable to each type of accessory)

Visible indication of compliance with the appropriate product standard, where required in the relevant product standard

Box or other enclosure securely fixed

....

3 Conduits

General

Visible indication of compliance with the appropriate product standard, where required in the relevant product standard

....

4 Trunking

General

Visible indication of compliance with the appropriate product standard, where required in the relevant product standard

Securely fixed and adequately protected against mechanical damage

....

5 Distribution equipment

Visible indication of compliance with the appropriate product standard, where required in the relevant product standard

Suitable for the purpose intended

Securely fixed and suitably labelled

....

6 Luminaires

Lighting points

Correctly terminated in a suitable accessory or fitting

Not more than one flex unless designed for multiple pendants

Flexible support devices used

....

7 Heating

Visible indication of compliance with the appropriate product standard

Class 2 insulation or protective conductor connected

....

8 Protective devices

Visible indication of compliance with the appropriate product standard, where required in the relevant product standard

RCDs provided where required

Discrimination between RCDs considered

....

9 Other

C Identification

Labelling

Warning notices

Danger notices

Identification of conductors

8.1.6 Description of circuit details and test results

Reporting for verification

Table H.1 – Model form for cicuit details and test results schedule

INFORMATION REGARDING DISTRIBUTION BOARD (1)																								
Description:					Ref.:					Manufacturer														
Rated voltage, U_n: V			Nominal current, I_n: A				Fréquence: Hz			Protection IP degree:						Short-circuit withstand capability of distribution board, I_{cc} kA								
MAIN SUPPLY TO DISTRIBUTION BOARD (6)																								
Protective device:				Type:		Rating, I_n: A				Short circuit capacity rating kA				RCD: mA		I_{cp}: kA (2)		Z_s: W			CSA supply condition Section: L= mm²; PE= mm²			
CIRCUIT DETAILS										TEST RESULTS														
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Circuit n°.	Description Room served	Number of points	Fonc-tion	Connec-tion load	Cables/Cond.		Circuit protection			Circuit characteristics			Insulation resistance				RCD				Touch voltage	Polar-ity test	PE conti-nuity	Remarks+ national requirements
					Type	Section-L/PE	I_n (A)		Type	Z_s	I_p (A)		MΩ				I_n	I_{dn}	T_d					
			(5)	kW (9)		mm²	Fuse	Dis-jonct.		Ω	L-N	L-PE	N-PE	L1-PE	L2-PE	L3-PE	A	mA	(3) (4)	(7)	(8)	(3)		

NOTES

(1) By enquiry (manufacturer, name plate or technical doc.)

(2) By measurement or calculation

(3) Enter C if complies or NC if does not comply

(4) Complete test where appropriate shall be performed including touch voltage and tripping time at rated current

(5) Enter appropriate function code (see opposite)

(6) Only to be completed if the distribution board is not connected directly to the origin of the installation

(7)

(8) Only required where supplementary equipotential bonding has been installed in accordance with 413.1.3.6

(9) Record connected load where readily identifiable

Abbreviations

L Line

T_d Test trip time

Z_s Fault loop impedance

CSA Cross-sectional area

I_{cp} Prospective short-circuit current at main busbars of distribution board r.m.s. value

I_p Measured short-circuit current at end of consumer supply line. For socket outlets circuits, measurement shall be made at each S/O and to record only the worst case

I_{cw} Short-circuit withstand of equipment

Function code (for column 4)

C	Cooking	W/H	Water heating
S/O	Socket outlet	S/H	Storage heaters
UFH	Under floor heating	Li	Lighting
H	Heating	HP	Heat pump

Information regarding distribution board

General technical information about distribution board (description, model, reference, manufacturer, rated voltage, nominal current, frequency, IP protection, short circuit current capability) should be entered here.

The data can be found in project documentation or manufacturer data.

Main supply to distribution board
This field is filled only if the distribution board is a sub-distribution board. This means that it is not connected to the origin of installation.
The characteristic of incoming supply must be entered here, similar as for the incoming supply.

Circuit details
Number
Successive number of the circuit.
Description
Name of the circuit.
Number of points
Indicates size of the circuit. Points are socket, switches, fixed connection points etc.
Function code
Indicates primary function of devices connected to the circuit.
Cables / conductors
Indicates type and cross-section of supply and PE conductors.
Circuit protection
Fuse for protection of the circuit should be described here (nominal current and type).

Test results
Circuit characteristics
Highest measured line or loop (whichever is higher) impedance Z_s in circuit is entered here.
Lowest measured prospective short circuit current I_p (LN) in circuit is entered here.
Lowest measured prospective fault circuit current I_p (LPE) in circuit is entered here.
Insulation resistance
Lowest measured insulation resistance between neutral and PE conductors R_{ins} (NPE) in circuit is entered here.
Lowest measured insulation resistance between any of the phase and PE conductors R_{ins} (L1PE, L2PE, L3PE) in circuit is entered here.
RCD
The nominal carrying current I_n and nominal differential current $I_{\Delta N}$ of the RCD (that protects the circuit) are entered here.
In the T_d field, the highest measured trip out time at $I_{\Delta N}$ and the highest measured contact voltage in the circuit are entered.
Touch voltage
This test should be performed where supplementary equipotential bonding was performed. Highest measured touch voltage or compliance mark is entered here.
Polarity
Compliance of correct polarity of circuit's conductors (L, N, PE) on all measured points is entered here.
PE continuity
Highest measured PE resistance in circuit or compliance mark is entered here.

9 METREL installation testers

Comparison table	EurotestXA	EurotestAT	EurotestXE	EurotestEASI	Eurotest 61557	Instalcheck	Insulation/Continuity	$Z_{Line\ Loop}$/RCD	Earth
Ordering No.:	MI 3105	MI 3101	MI 3102	MI 3100	MI 2086	MI 2150	MI 3121	MI 3122	MI 3123
Main features									
Voltage Monitor/TRMS	• / •	• / •	• / –	• / –	• / •	• / –	• / •	• / •	
Phase SEQUENCE EN 61557-7	•	•	•	•	•	•		•	
Continuity EN 61557-4	•	•	•	•	•		•		
Automatic polarity exchange, 200 mA	•	•	•	•	•		•		
Low current continuous 7 mA DC	•	•	•	•		•	•		
Resistance test through shuko N-PE	•	•							
Insulatio N - IEC/ EN 61557-2									
50 / 100 /250 / 500 /1000 V	50 ... 1000 V	50 ... 1000 V	100 ... 1000 V	100 ... 1000 V	50 ... 1000 V	500 V	50 ... 1000 V		
Automatic test between L-N-PE pairs	•	•							
ISFL	•		•						
LINE/LOOP EN 61557-3	•	•	•	•	•	•		•	
Impedance L-L, L-N and L-PE, Ipsc, Ipfc	•	•	•	•	•			•	
R and Xi calculations	•	•			•				
High accuracy RCD TRIP LOCK loop impedance	•	•	•	•	•	•		•	
IT system line/loop	•	•	•	•	•				
IT system first fault loop	•		•						
Built-in Fuse base characteristics	•	•	•	•				•	
PASS/FAIL evaluation of result	•	•	•	•		•		•	
RCD EN 61557-6	•	•	•	•	•	•		•	
RCD type	A, AC, B	A, AC, B	A, AC	A, AC	A, AC	AC		A, AC	
RCD AUTOTEST	•	•	•	•	•			•	
Trip-out time t, Uc (IΔN)	•	•	•	•	•	•		•	
Trip-out current ID	•	•	•	•	•	•		•	
EARTH EN 61557-5	•	•	•		•				•
Two wire earth resistance	•	•	•		•				•
Three wire earth resistance	•	•	•		•				•
Two clamps earth/loop resistance	•				•				•
One clamp earth/loop resistance	•				•				•
Specific Earth resistance	Optionaly	Optionaly			•				•
Current Clamp TRMS	•		•		•				•
Clamp leakage current	•		•		•				•
AUTO SEQUENCE ®	•	•				•			
Automatic test of insulation	ALL L-N-PE	ALL L-N-PE				L-PE, N-PE			
Automatic test of RCD	•	•	•	•					
AUTO SEQUENCE ® on SwitchBoard	•	•							
AUTO SEQUENCE ® on Circuit	•	•				•			
Automatic evaluation of complete safety	•	•							
Preparing results for verification reports	•	•							
Smart commands, comments, icons, instructions, ...	•	•							
Sensor	•		•		•				
Lux	Optionaly		Optionaly		Optionaly				
Other	•	•	•	•	•	•	•	•	•
Power					•				
Energy					•				
Harmonics					•				
Line Tracer	Optionaly	Optionaly			Optionaly				
Touch electrode	•	•	•	•	•	•		•	
Evaluation PASS/FAIL results	•	•	•	•	•	•	•	•	•
Frequency	15 - 500 Hz	15 - 500 Hz	45 - 65 Hz	45 - 65 Hz	45 - 65 Hz		15 - 500 Hz	15 - 500 Hz	
Voltage systems support	440 / 230 / 110 V	440 / 230 / 110 V	440 / 230 / 110 V	440 / 230 / 110 V	440 / 230 / 110 V	440 / 230 / 110 V		440 / 230 / 110 V	
Reduced low voltage system support	55 / 65 V	55 / 65 V	55 / 65 V	55 / 65 V	55 / 65 V				
Earthing system support	TN / TT / IT	TN / TT / IT	TN / TT / IT	TN / TT / IT	TN / TT / IT	TN / TT		TN / TT	
On line Warnings	•	•	•	•	•	•	•	•	•
HELP menus	•	•	•	•	•	•	•	•	•
Communication ports	•	•	•		•		•	•	•
RS 232	•	•	•		•		•	•	•
USB	•	•	•		•		•	•	•
Accessories	•	•	•	•	•	•	•	•	•
Plug commander	•	•			•		Optionaly	Optionaly	
Tip commander 2 wire	Optionaly	Optionaly	•	•	Optionaly			Optionaly	
PC Software	Profesional PRO	Profesional LITE	Standard		Profesional PRO		Profesional PRO	Profesional PRO	Profesional PRO
Querty keypad csreen	•	•							

10 Appendix A – RCDs (operation, selection, installation)

This appendix provides additional information about residual current devices.

10.1 RCD selection table according to their sensitivity

Table 1 is a selection table for RCDs. It shows sensitivity of different RCD types for typical fault current shapes.

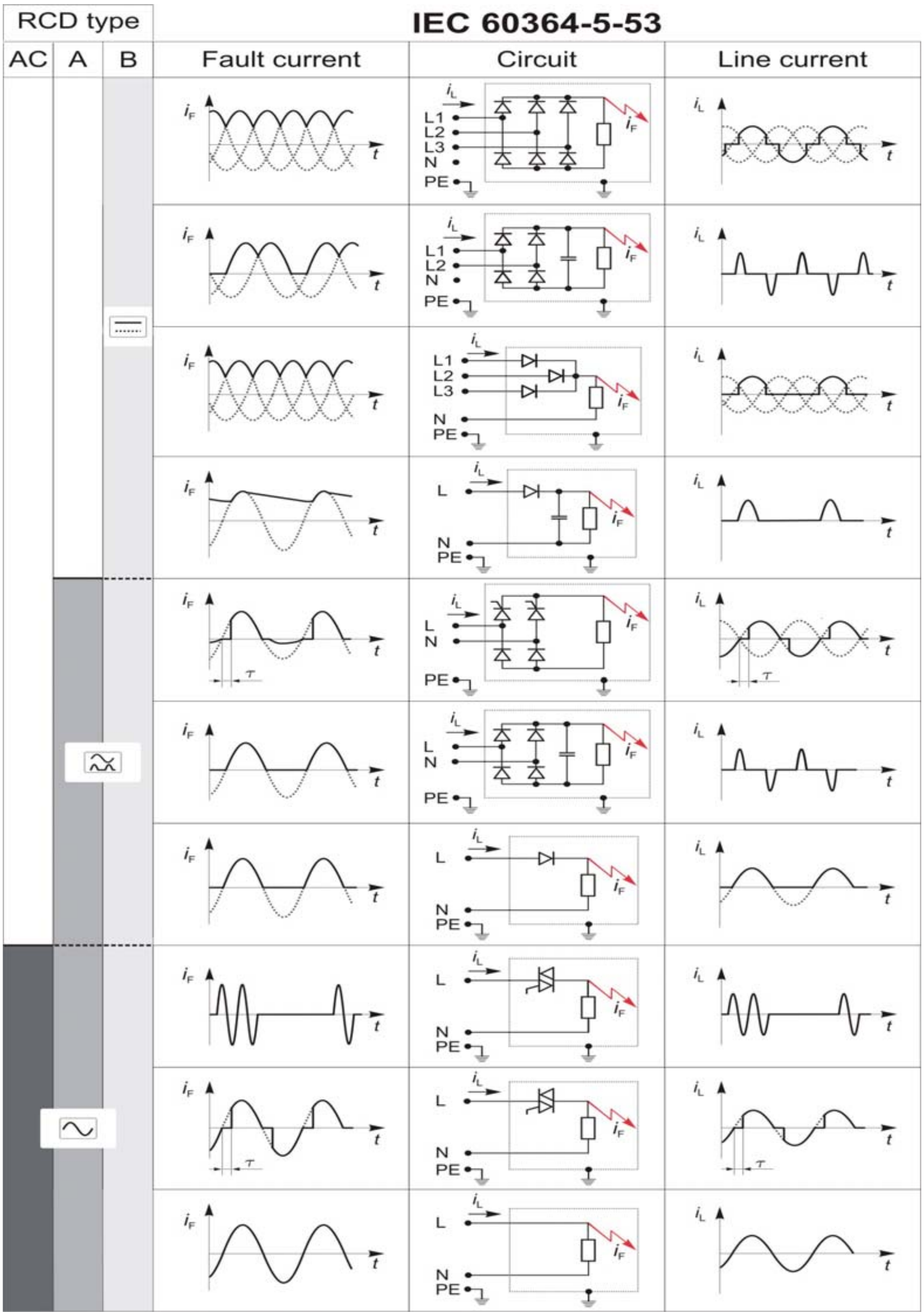


Table 31: *Sensitivity of different RCD types*

10.2 RCD discrimination principle

Where the installation is protected by more than one RCD than the discrimination principle is applied. The advantage of using multiple RCDs is that if a fault occurs only the RCD nearest to the fault will trip and other installation parts will not be affected.
In this case the main RCD is usually a delayed (selective) type RCD (100mA or 300mA). If RCDs downstream the main RCD have 30mA sensitivity this will ensure the correct discrimination.
Figure 102 show an example of correct RCD discrimination in an installation with multiple RCDs.

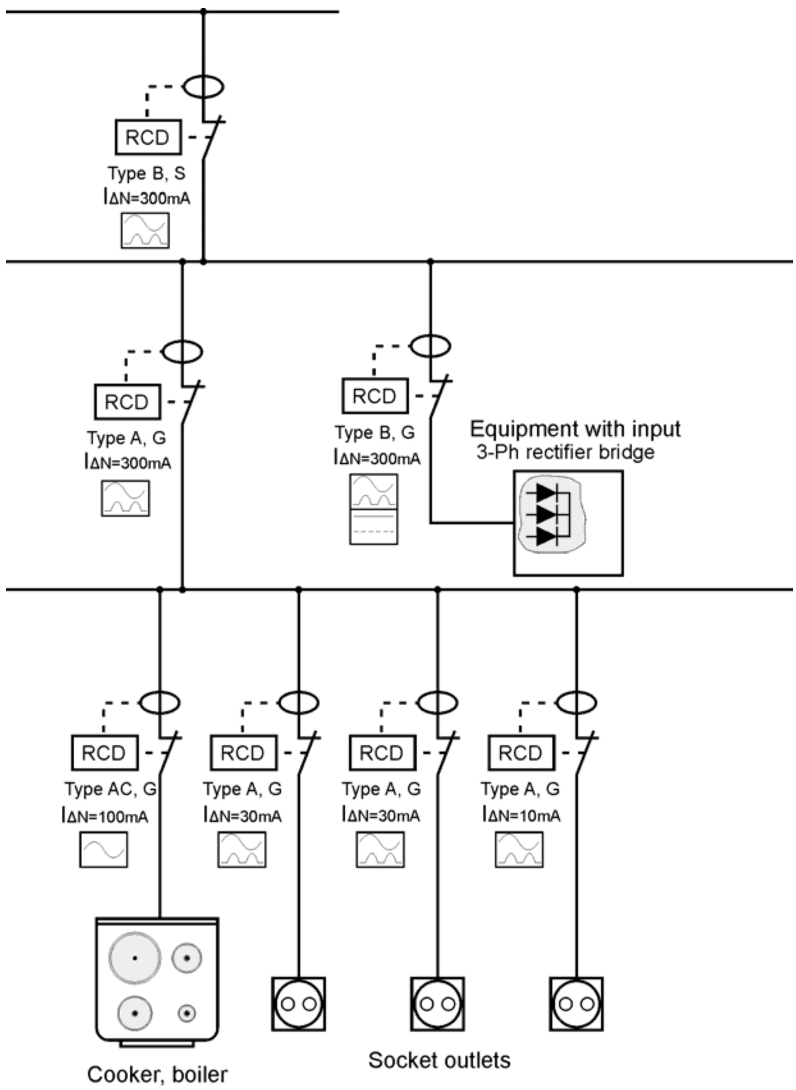


***Fig. 102**: Example of multiple RCDs in the installation*

10.3 RCD product types

Many different names are associated with residual current devices.

Main types			
Short	**Type**	**Description**	**Usage**
RCD	Residual Current Device	This is a generic term for the entire range of RCDs.	General
RCBO	Residual current operated circuit-breaker (RCCB) with integral over current protection.	This is basically an over current circuit breaker (such as an MCB) with an RCD function added to it. It has two functions, to provide protection against earth fault currents and to provide protection against overload currents.	Consumer units, Distribution boards.
RCCB	Residual current operated circuit-breaker without integral over current protection.	This is basically a mechanical switch with an RCD function added to it. Its only function is to provide protection against earth fault currents.	Consumer units, Distribution boards.

Less known types			
Short	**Type**	**Description**	**Usage**
CBR	Circuit-breaker incorporating residual current protection.	Over current protective device incorporating residual current protection.	Distribution boards in large installations.
SRCD	Socket-outlet incorporating an RCD.	A socket-outlet or fused connection unit incorporating a built-in RCD.	Often installed to provide supplementary protection against direct contact for portable equipment used out of doors.
PRCD	Portable residual current device.	A PRCD is a device that provides RCD protection for any item of equipment connected by a plug and socket. Often incorporates over current protection.	Plugged into an existing socket-outlet. PRCDs are not part of the fixed installation
SRCBO	Socket-outlet incorporating an RCBO.	Socket-outlet or fused connection unit incorporating an RCBO.	Often installed to provide supplementary protection against direct contact for portable equipment used out of doors.

Table 32: *RCD types*

11 Appendix B – Single core copper wires

This appendix contains resistance and typical maximum currents for single core copper wires, insulated with thermoplastic (70 °C, PVC), non-armoured, with or without sheath.

	Maximum current		Resistance of conductor related to length of				
Cross-section	2 conductors Single-phase	3 or 4 conductors Three-Phase	1 m	2 m	5 m	10 m	100 m
[mm^2]	[A]	[A]	[mΩ]	[mΩ]	[mΩ]	[mΩ]	[mΩ]
0.75	10.1	9	22.9	45.9	114.7	229.3	2293.3
1	13.5	12	17.2	34.4	86	172	1720
1.5	17.5	15.5	11.5	22.9	57.3	114.7	1146.7
2.5	24	21	6.9	13.8	34.4	68.8	688
4	32	28	4.3	8.6	21.5	43	430
6	41	36	2.9	5.7	14.3	28.7	286.7
10	57	50	1.7	3.4	8.6	17.2	172
16	76	68	1.1	2.2	5.4	10.8	107.5
25	101	89	0.7	1.4	3.4	6.9	68.8
35	125	110	0.5	1	2.5	4.9	49.1
50	151	134	0.3	0.7	1.7	3.4	34.4
70	192	171	0.2	0.5	1.2	2.5	24.6
95	232	207	0.2	0.4	0.9	1.8	18.1
120	269	239	0.1	0.3	0.7	1.4	14.3
150	300	262	0.1	0.2	0.6	1.1	11.5
185	341	296	0.1	0.2	0.5	0.9	9.3
240	400	346	0.1	0.1	0.4	0.7	7.2
300	458	394	0.1	0.1	0.3	0.6	5.7
400	546	467	<0.1	0.1	0.2	0.4	4.3
500	626	533	<0.1	0.1	0.2	0.3	3.4
630	720	611	<0.1	0.1	0.1	0.3	2.7

Table 33: *Maximum currents related to cross-section and number of current carrying conductors and typical resistances at different lengths at 25 °C*

Give maximum current limits are conservative. They are considering the maximum operating temperature of the insulating material and skin effect.

The positive temperature coefficient of copper $\alpha = 0.004041 / °C$ means that (specific) resistance of wire increases with temperature. Resistance dependence to temperature T is: $R = R_{ref}(1 + \alpha(T - T_{ref}))$ with R_{ref} as reference resistance at temperature T_{ref}.

Table 34 show resistances of 100m wire of typical cross-sections, at different temperatures.

Temperature	Specific resistance	Resistance of 100 m copper conductor of different cross-section					
		1 mm^2	1.5 mm^2	2.5 mm^2	4 mm^2	6 mm^2	10 mm^2
[°C]	Ωm	Ω	Ω	Ω	Ω	Ω	Ω
0	0.0155	1.55	1.03	0.62	0.39	0.26	0.15
5	0.0158	1.58	1.05	0.63	0.4	0.26	0.16
10	0.0162	1.62	1.08	0.65	0.4	0.27	0.16
15	0.0165	1.65	1.1	0.66	0.41	0.27	0.16
20	0.0168	1.68	1.12	0.67	0.42	0.28	0.17
25	0.0172	1.72	1.15	0.69	0.43	0.29	0.17
30	0.0175	1.75	1.17	0.7	0.44	0.29	0.18
35	0.0179	1.79	1.19	0.71	0.45	0.3	0.18
40	0.0182	1.82	1.21	0.73	0.46	0.3	0.18
45	0.0185	1.85	1.24	0.74	0.46	0.31	0.19
50	0.0180	1.89	1.26	0.76	0.47	0.31	0.19
55	0.0192	1.92	1.28	0.77	0.48	0.32	0.19
60	0.0196	1.96	1.3	0.78	0.49	0.33	0.2
65	0.0199	1.99	1.33	0.8	0.5	0.33	0.2
70	0.0202	2.02	1.35	0.81	0.51	0.34	0.2
75	0.0206	2.06	1.37	0.82	0.51	0.34	0.21
80	0.0209	2.09	1.39	0.84	0.52	0.35	0.21
85	0.0213	2.13	1.42	0.85	0.53	0.35	0.21
90	0.0216	2.16	1.44	0.86	0.54	0.36	0.22
95	0.0219	2.19	1.46	0.88	0.55	0.37	0.22
100	0.0223	2.23	1.49	0.89	0.56	0.37	0.22

Table 34: *Specific resistance of cooper and resistances of 100 m conductor versus temperature*

Increasing of resistance with temperature is important for defining of prospective short circuit currents and touch voltages at rated operating conditions. Measurements are usually made at room temperature (20 °C) but working temperature is higher for rated loading (e.g. 70 °C). This means that resistance of wiring is higher for factor of: $\frac{R_{70°C}}{R_{20°C}} = 1.2$. When dealing with short circuit currents then 80 % of the value measured at 20 °C has to be taken into account.

12 Appendix C Dimensions of conductors

This appendix describes some basic information about size of conductors in electrical installations in general and earthing systems. Reference standards are IEC 60364-5-52 for wiring systems in general and IEC 60364-5-54 for earthing arrangements, protective conductors and protective bonding conductors.

Minimum cross-sections of conductors in fixed installations

Conductors type	Intention of circuit	Conductor	
		Material	Cross-sectional area [mm^2]
Cables and insulated conductors	Power and lighting circuits	Copper Aluminium	1.5 2.5
	Signalling and control circuits	Copper	0.5
Bare conductors	Power circuits	Copper Aluminium	10 16
	Signalling and control circuits	Copper	4

Table 35: *Minimum cross-sectional areas of conductors*

Cross-section area of neutral conductor shall be as follows:

Type of circuit	Cross-section area of neutral conductor
Single-phase, two-wire	The same as line conductor
Poly-phase, single-phase three-wire $S_{Cu} \leq 16$ mm^2, $S_{Al} \leq 25$ mm^2	
Poly-phase $S_{Cu} \leq 16$ mm^2, $S_{Al} \leq 25$ mm^2	- Reduced according to expected maximum neutral current including harmonics, and - Protected according to 431.2 of IEC 60364-4-43, and - At least equal to 16 mm^2 (Cu) / 25 mm^2 (Al)

Table 36: *Cross-sectional areas of neutral conductors*

Minimum cross-section of protective conductors

Minimum value is defined as:
- Selected according to IEC 60949 or
- For disconnection time less than 5 s:

$$S = \frac{\sqrt{I^2 t}}{k} \qquad \text{Eq. 45}$$

Where are:
S .... Cross-sectional area [mm^2]
I.............. Prospective fault current that can flow through protective device [A]
t.............. Protective device operating time for automatic disconnection [s]

k.............. A value incorporating protective conductor material, insulation, temperature, see table 37.

Examples for 70 °C PVC insulated protective conductors

Protective conductor type	**Material of conductor**		
	Copper	Aluminium	Steel
Insulated, not incorporated in cables and not bunched with other cables	143	95	52
Bare, in contact with cable covering, not bunched with other cables	159	105	58
A core incorporated in cable or bunched with other cables or insulated conductors	115	76	42

Table 37: *k factor for calculation of minimum cross-sectional areas of protective conductors*

Minimum cross-section area of protective conductors related to line conductor:

Cross-sectional area of line conductor [mm^2]	Minimum cross-sectional area of protective conductor [mm^2]	
	The same materials as line conductors	Material, different to line conductors
S≤16	S	$\frac{k1}{k}S$
16<S≤35	16	$16\frac{k1}{k}$
S>35	$\frac{S}{2}$	$\frac{k1}{k}\frac{S}{2}$

Table 38: *Minimum cross-sectional areas of protective conductors related to line conductors*

Where are:

k.............. A value incorporating protective conductor material, insulation, temperature and is defined above, and

k1............ Similar to k but for line conductor.

Example for PVC insulated line conductor:

Conductor material	**k1**
Copper	115
Aluminium	76

Table 39: *k1 factor for table 38*

Additional requirement for minimum cross-sectional area [mm^2] of protective conductors

Protective conductor type	Conductor material				
	Copper		Aluminium		Steel
	Protected	Unprotected	Protected	Unprotected	-
Is not part of cable or is not in common enclosure with line conductor	2.5	4	16	16	-
Main equipotential bonding and connected to main earthing terminal	6		16		50
Protected: protection against mechanical damage is provided, Unprotected: protection against mechanical damage is not provided.					

Table 40: *Minimum cross-sectional areas of protective conductors*

Minimum cross-sectional areas [mm^2] of earthing conductors that are buried in the soil

Earthing conductor	Mechanically protected		Mechanically unprotected	
Protected against corrosion	Copper	Steel	Copper	Steel
	2.5	10	16	16
Not protected against corrosion	Copper		Steel	
	25		50	

Table 41: *Minimum cross-sectional areas of buried earthing conductors*

PEN conductors

They may be used only in fixed installations. Minimum cross-sectional areas are:

Conductor material	**S[mm^2]**
Copper	10
Aluminium	16

Table 42: *Minimum cross-sectional areas of PEN conductors*

- It is not permitted to connect the neutral conductor to any other earthed part of the installation (e.g. protective conductor from PEN conductor);
- It is permitted to form more than one neutral conductor more than one protective conductor from PEN.
- Cross-sectional area reduction can be applied as is defined for neutral conductor.

13 APPENDIX D: Other electrical measurements

In this appendix some special and less often used installation measurements are described.
For further information refer to METREL's handbook *Electrical installations in theory and practice*.

13.1 Insulation resistance measurements of non- and semi-conductive rooms

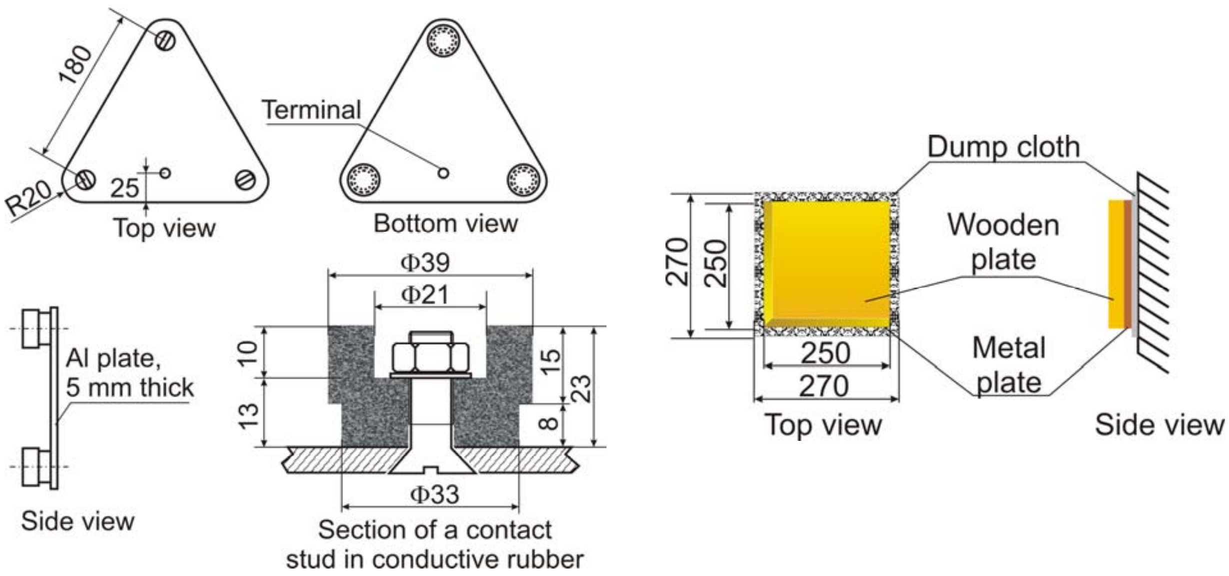
13.1.1 Resistance measurement of non-conductive walls and floors

There are certain situations where it is desirable for a room to be totally isolated from the Protective Earth conductor (e.g. for conducting special tests in a laboratory etc.). These rooms are regarded as an electrically safe area and the walls and floor should be made of non-conductive materials. The arrangement of any electrical equipment in those rooms should be of such a manner that:

- It is not possible for two live conductors, with different potentials, to be touched simultaneously in the case of a basic insulation fault.
- It is not possible for any combination of active and passive accessible conductive parts to be touched simultaneously.

A protection conductor PE that could drive a dangerous fault voltage down to the ground potential is not allowed in non-conductive rooms. Non-conductive walls and floors protect the operator in case of a basic insulation fault.

The resistance of non-conductive walls and floors shall be measured using the procedure described below. Special measurement electrodes described below are to be used.



Recommended *Optional*

Fig. 102: Measurement electrode according to IEC 60364-6

The measurement is to be carried out between the measurement electrode and the protection conductor PE, which is only accessible outside of the tested non-conductive room.
To create a better electrical contact, a wet patch (270 mm × 270 mm) shall be placed between the measurement electrode and the surface under test. A force of 750N (floor measurement) or 250N (wall measurement) shall be applied to the electrode during the measurement.

The value of test voltage shall be:
- 500 V where the nominal mains voltage with respect to ground is lower than 500 V
- 1000 V where the nominal mains voltage with respect to ground is higher than 500 V

The value of the measured and corrected test result must be higher than:
- 50 kΩ where the nominal mains voltage with respect to ground is lower than 500 V
- 100kΩ where the nominal mains voltage with respect to ground is higher than 500V.

Notes
- It is advisable that the measurement to be carried out using both polarities of test voltage (reversed test terminals) and the average of both results be taken.
- Wait until the test result is stabilized before taking the reading.

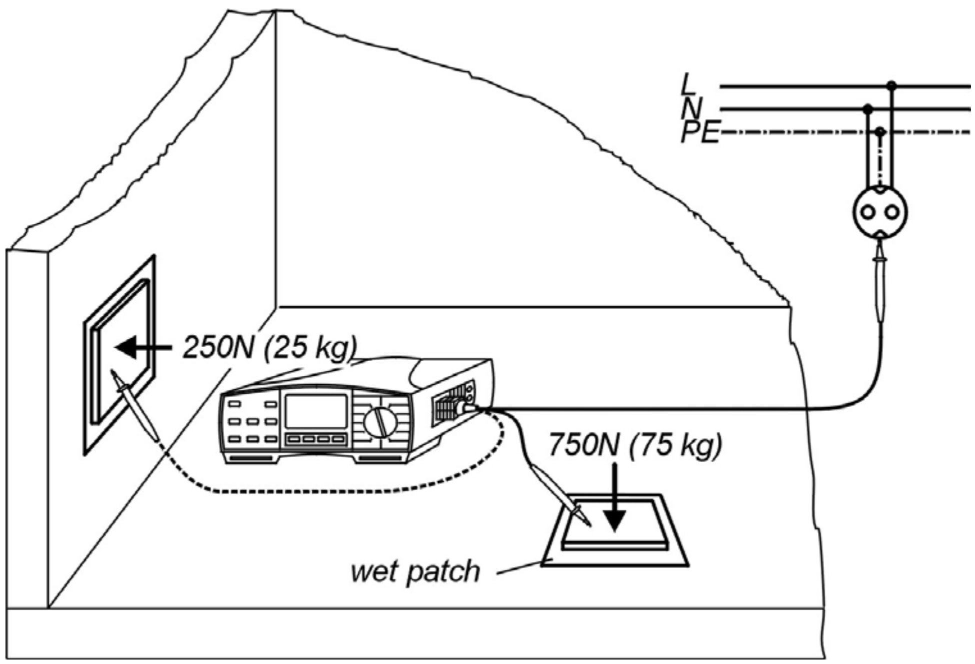


Fig. 103: *Resistance of walls and floor measurement.*

13.1.2 Resistance measurement of semi-conductive floors

In some instances such as explosive-safe areas, inflammable material storehouses, lacquer rooms, sensitive electronic equipment production factories, fire endangered areas etc., a floor surface with a specific conductivity is required. In these cases the

floor successfully prevents the build-up of static electricity and drives any low-energy potentials to ground.
In order to achieve the appropriate resistance of the floor, semi-conductive material should be used. The resistance should be tested using an Insulation Resistance tester with a test voltage within 100 up to 500 V.
A special test electrode defined by regulation is to be used, see the figure below.

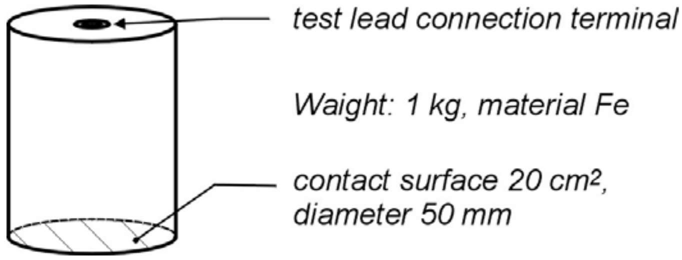


Fig. 104: *Test electrode*

Measurement procedure is presented on the figure below. The measurement should be repeated several times at different locations and an average of all the results taken.

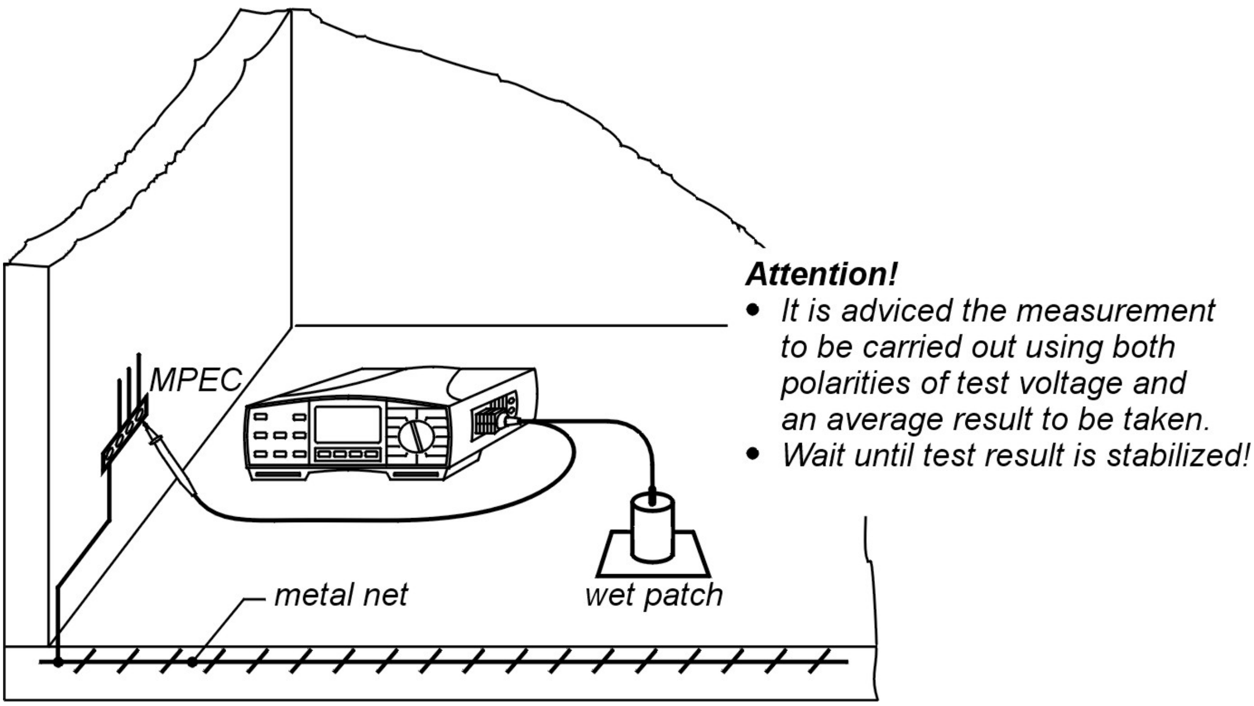


Fig. 105: *Measurement of semi-conductive floor resistance*

The measurement is to be carried out between the test electrode and metal network installed in the floor, which is usually connected to the protection conductor PE. Dimension of the area, where measurements are to be applied, should be at least 2 × 2m.

13.2 Specific earth resistance (resistivity) EN 61557- 5

What is Specific Earth Resistance?
It is the resistance of ground material shaped as a cube 1 × 1 × 1 m, where the measurement electrodes are placed at the opposite sides of the cube, see the figure below.

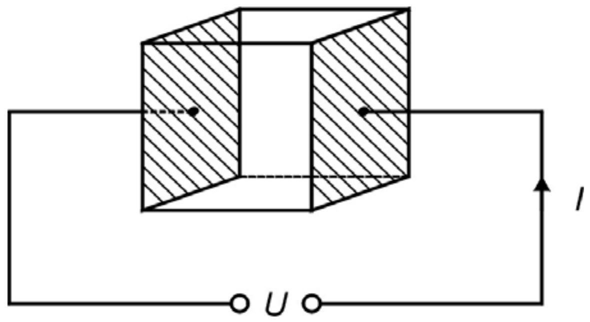


Fig. 106: *Presentation of Specific Earth Resistance*

Measurement of Specific Earth Resistance
The measurement is carried out in order to assure more accurate calculation of earthing systems e.g. for high-voltage distribution columns, large industrial plants, lightning systems etc.
AC test voltage should be used because of possible electro-chemical processes in the measured ground material if a DC test voltage is used.
Specific Earth Resistance value is expressed in Ωm, its absolute value depends on structure of the ground material
Measurement principle is presented on the figure below.

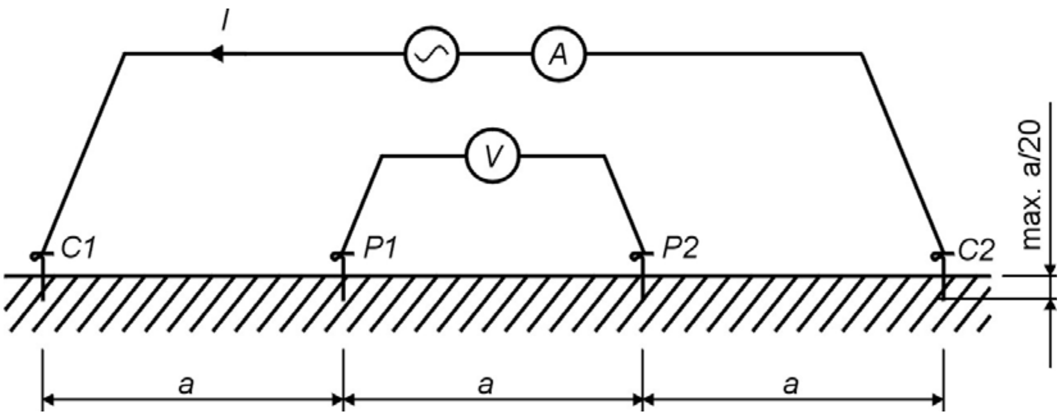


Fig. 107: *Measurement principle*

$$\rho = 2 \pi a U / I$$ *Eq. 46*

a.............. Distance between test probes.
U............. Voltage between test probes P1 and P2, measured by the V-meter.
I............... Test current, driven by an a.c. generator and measured by the A-meter.
ρ.............. Specific Earth Resistance.

The above equation is valid if the test probes are driven to ground at maximum a/20.

In order to reach more objective results it is advisable that the measurement be repeated in different directions (e.g. 90° with regard to the first measurement) and an average value taken.
Using different distances between the test probes means that the material at different depths is measured. Because the bigger the distance is, then the deeper level of ground material is measured.

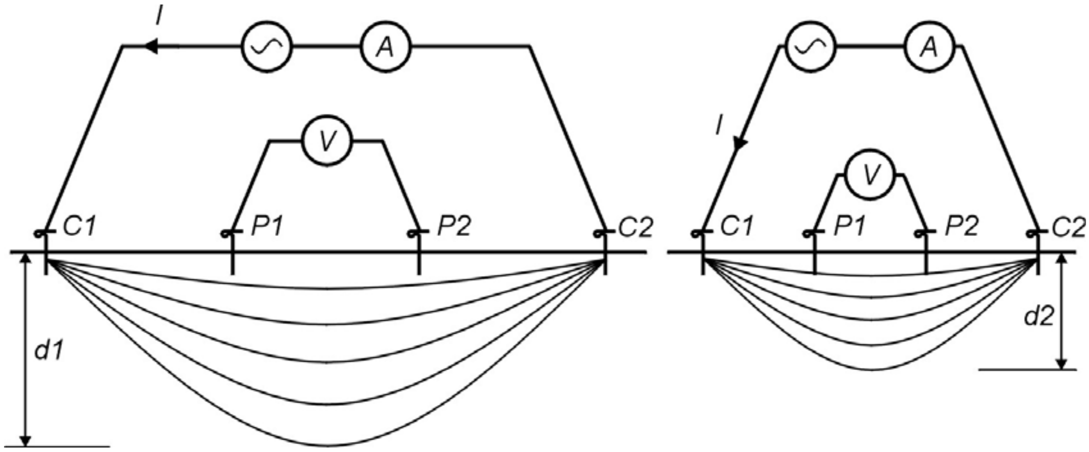


Fig. 108: *Influence of the distance a to measured depth*

d1........... Depth involved at larger distance a between test probes.
d2........... Depth involved at smaller distance a between test probes.

The earthing electrode should be sited at a place and depth where the lowest Earth Resistance will be reached (or at least a reasonable compromise shall be achieved), this is why test results obtained at different depths are to be taken.
Also a structure of the ground material can be roughly defined by measuring the Specific Earth Resistance.
The table below is representative of the orientation values of Specific Earth Resistances for a few typical ground materials.

Type of ground material	Specific Earth Resistance in Ωm
sea water	0,5
lake or river water	10 – 100
ploughed earth	90 – 150
concrete	150 – 500
wet gravel	200 – 400
fine dry sand	500
lime	500 – 1000
dry gravel	1000 – 2000
stony ground	100 – 3000

Table 43: *Orientation values of Specific Earth Resistances for a few typical ground materials*

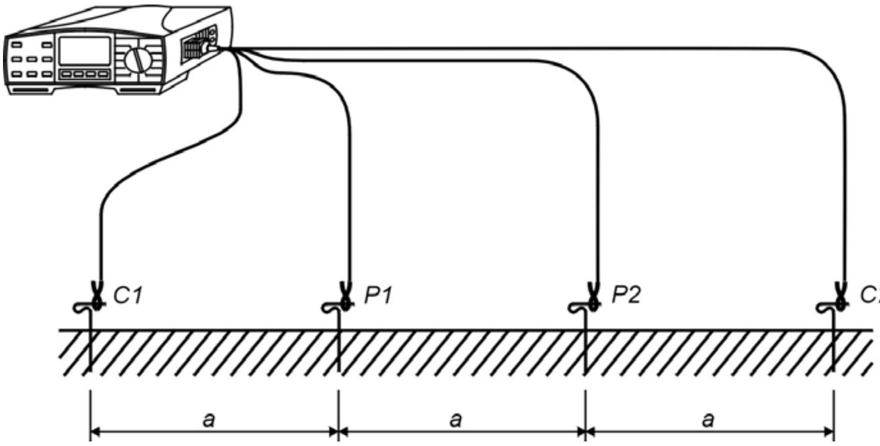


Fig. 109: *Practical measurement of Specific Earth Resistance*

13.3 Overvoltage protection devices

Over-voltage protection devices are usually used to protect highly sensitive electronic equipment against lightning effects. The protection is most needed in areas where atmospheric discharges are often present. Examples of actual loads to be protected are PC computers, printers, telephone exchanges etc. The protection devices are either permanently installed in an electrical installation or inserted into a mains installation adjacent to the protected equipment (a part of the mains plug, extension etc.).

To ensure the most effective protection the devices are usually installed in several stages namely:

- In connection cabinets at the input of the mains voltage (the devices prevents the spread of supply over voltages)
- In distribution cabinets of individual installation units.
- Adjacent to connected electrical loads (equipment).

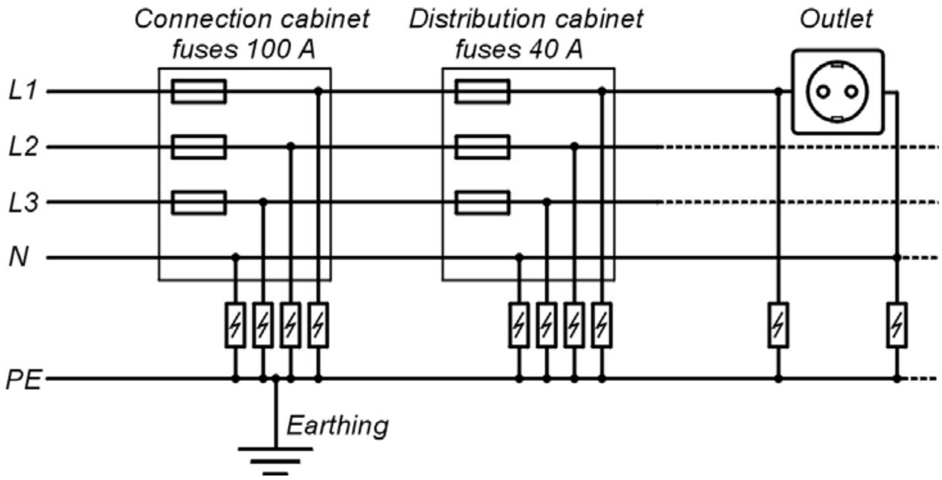


Fig. 110: *Connection of multi-stage protection*

The construction of protection devices is very diverse. They may consist of varistors only, gas arresters, fast diodes, solenoids, capacitors or a combination of these and other different protection elements etc.

The devices may, due to the absorption of high-voltage pulses, change their characteristics in two ways:

- Breakdown voltage may drop. Because of that reason they may be destroyed by the mains voltage itself.
- They may break totally. Therefore the protection function is lost completely.

Test instruments such as EurotestAT, Eurotest XA can do non-destructive tests of varistor overvoltage protection devices using test voltage of 50 up to 1000 V.
Measurement principle is represented in the figure below.

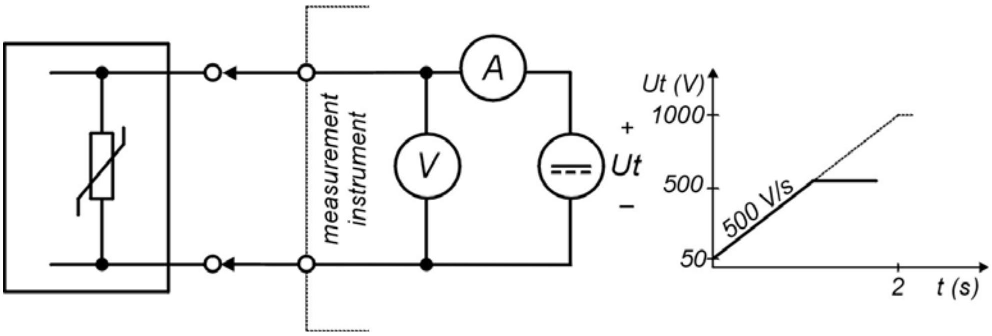


Fig. 111: *Measurement principle*

A DC generator increases the test voltage with the slope of 500 V/s while A-meter measures forward current. As soon as the current reaches the value of 1 mA (the threshold current), the generator stops to generate the test voltage and the last voltage is displayed (breakdown voltage).
The user should compare the displayed test voltage with the nominal one noted at the device's enclosure and change the device if needed.
The protection device is considered to be defective in the following circumstances:

- If it is open circuit (displayed result >1000 V). There is no protection function left.
- If the displayed breakdown voltage is too high (displayed value is, for example, double the nominal value). The protection is partially corrupted and it may allow too high over voltages.
- If the displayed breakdown voltage is too low (displayed value is close to the nominal mains voltage). The mains voltage may cause total destruction of the device in the near future.

Note

- The test is to be done at voltage-free protection device.
- Tested device should be removed from the installation before testing it in order that other loads connected to the installation do not influence the test.

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