MEASUREMENTS ON ELECTRIC INSTALLATIONS in theory and practice

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1. EUROPEAN STANDARDS ABOUT MEASUREMENT INSTRUMENTS

To assure the conditions for safe usage of electrical energy, safety of electric installations, safety testing and maintenance of them, many great efforts were done into the preparation of appropriate standards. The changes on the existing standards which were well known to the producers and as well to the users of the measurement equipment, were quite frequent during the preparing for the unified standard. Although the general safety standard IEC 1010-1 and later harmonized European standard EN 61010 treated the general safety of electrical measurement instruments, the safety viewpoint for the using of these instruments at low-voltage installations was missing. To make an arrangement for unified principles of treating measurement instruments for the field line of measurements at the electric installations up to 1000 V a.c. and 1500 V d.c., IEC and CENELEC prepared and issued together the family of standards EN 61557 which in a great number follow the German standards of family DIN VDE 0413. The EN 61557 has brought the important solution at this field line. For the national committees of individual countries of European Union the new standards express as follows:
The consideration of the new standard signified the introduction of some changes at the construction or in the production for the producers of measurement instruments. As per agreement and because each change needs the definite time to come into operation, the settled term for the introduced changes was 1 December, 1997.
METREL also took into consideration demands of the new standard when developing the newest family of measurement instruments.

EN 61557 standard is divided into a few parts, each part deals with the safety at the determined measurement at the electric installation as follows:

- **EN 61557 Part 2**  
  **Insulation Resistance**

- **EN 61557 Part 8**  
  **Insulation monitoring devices in IT earthing systems**

- **EN 61557 Part 3**  
  **Fault Loop Impedance**

- **EN 61557 Part 7**  
  **Phase sequence**

- **EN 61557 Part 4**  
  **Continuity of Earth Connections and Equipotential Bonding**

- **EN 61557 Part 5**  
  **Earth Resistance**

- **EN 61557 Part 6**  
  **Residual Current Devices (RCD) in TT and TN earthing systems**

Let’s see the main requirements of the separate parts of EN 61557 standard regarding the realization of measurements and construction of measurement instrument.
EN 61557 Part 2  Insulation Resistance

- The maximum error should not exceed +/- 30%.
- DC test voltage should be used.
- In case of 5 μF capacitor connected in parallel with measured resistance \( R_i = \frac{U_n \cdot 1000 \, \Omega}{V} \), test result should not differ from the one without capacitor, more than 10%.
- The test voltage shall not exceed the value of 1,5 \( \cdot U_n \).
- The test current flowing to tested resistance of \( U_n \cdot 1000 \, \Omega/V \) should be at least 1 mA.
- The test current shall not exceed the value of 15 mA, while a.c. component shall not exceed 1,5 mA.
- External a.c. or d.c. voltage of up to 1,2 \( \cdot U_n \) connected to test equipment for 10s shall not damage the equipment.

EN 61557 Part 3  Fault Loop Impedance

- The maximum error should not exceed +/- 30%.
- Test instrument shall give an indication if resistance of test leads is compensated.
- Contact voltage higher than 50 V should not appear during the measurement or the voltage must be terminated within 30 ms.
- External voltage of up to 120% of nominal mains voltage, connected to test equipment, should not damage the equipment or cause any danger for an operator as well as potential fuse in test equipment should not blow.
- External voltage of up to 173% of nominal mains voltage, connected to test equipment for 1 min, should not damage the equipment or cause any danger for an operator, but potential fuse in test equipment may blow.
Measurements on electric installations in theory and practice

**EN 61557 Part 4  Earth Connection or Equipotential bonding Resistance**

- The maximum error should not exceed +/- 30%.
- AC or DC test voltage within 4 up to 24 V may be used.
- The test equipment should enable reversing of test voltage polarity in case of DC test voltage.
- Test current should be higher than 200 mA within minimum measurement range.
- Minimum measurement range shall include the range 0,2 up to 2 Ω.
- Resolution of 0,01 Ω shall be assured at digital instruments while clear indication which limit is exceeded shall be present at simple instruments.
- In case of compensated test leads or additional external resistance, this must be indicated.
- External voltage of up to 120% of nominal mains voltage, connected to test equipment, should not damage the equipment or cause any danger for an operator, but potential fuse in test equipment may blow.

**EN 61557 Part 5  Earth Resistance**

- The maximum error should not exceed +/- 30% under the following conditions:
  - Noise voltage of 3 V / 400 Hz, 60 Hz, 50 Hz, 16,66 Hz or d.c. is connected between E (ES) and S test terminals.
  - Resistance of auxiliary probes is 100 kΩ or 50 kΩ (whichever value is lower).
- AC test voltage should be used.
- The test voltage should be lower than 50 V$_{eff}$ (70 V$_p$), or test current should be lower than 3,5 mA$_{eff}$ (5 mA$_p$), or test signal should be present less than 30 ms.
- Test instrument must indicate exceeded resistance of auxiliary test probes.
- External voltage of up to 120% of nominal mains voltage, connected to test equipment, should not damage the equipment or cause any danger for an operator as well as potential fuse in test equipment should not blow.
The test shall be carried out using AC sine test current.

Test equipment should enable Contact voltage measurement and displaying it or at least indication of exceeded limit value. The measurement may be carried out with or without auxiliary test probe. In case of Tripping current measurement, Contact voltage shall be scaled to the Tripping current (not to nominal value) and compared with limit value.

The error of Contact voltage measurement should be within 0 up to +20 % of limit value.

Test equipment should enable Trip out time measurement and displaying it or at least indication of exceeded limit value.

When a test is carried out at $0.5 \cdot I_N$, the test shall last at least 0.2 s, RCD should not trip during the test.

Test instruments intended to test RCDs with nominal differential current of 30 mA or less should enable also the tests at $5 \cdot I_N$ where duration is limited to 40 ms. This limit is not to be respected if contact voltage is lower than limit value (50 or 25V).

The error of Trip out time measurement should not exceed +/-10 % of limit value.

Test equipment should enable Tripping current measurement and displaying it or at least indication of exceeded limit value.

Test current at Tripping current measurement should be within $I_N$ and $1.1 \cdot I_N$.

Test current when testing RCD with halved nominal differential current, must be within $0.4 \cdot I_N$ and $0.5 \cdot I_N$.

The error of Tripping current measurement should not exceed +/-10 % of nominal differential current.

Declaration of errors is valid for normal conditions as follows:

- There are no voltages at PE conductor.
- Mains voltage is stable during the measurement.
Measurements on electric installations in theory and practice

- There are no leakage currents on tested installation.
- Value of mains voltage during the measurement should be within 85% and 110% of nominal mains voltage.
- Resistance of potentially used auxiliary probe is within the range declared by the producer of test equipment.
- Contact voltage should not exceed 50 V$_{\text{eff}}$ (70 V$_{p}$) during any test, or test current should not exceed 3,5 mA$_{\text{eff}}$ (5 mA$_{p}$), or the voltage should last less than 30 ms.
- External voltage of up to 120% of nominal mains voltage, connected to test equipment, should not damage the equipment or cause any danger for an operator as well as potential fuse in test equipment should not blow.
- External voltage of up to 173% of nominal mains voltage, connected to test equipment for 1 min, should not damage the equipment or cause any danger for an operator, but potential fuse in test equipment may blow.
EN 61557 part 7  Phase sequence

- Test instrument should assure clear indication of phase sequency within voltage range from 85 up to 110 % of nominal mains voltage and within frequency range from 95 up to 105 % of nominal frequency.
- Test instrument should enable either clear acoustic indication even in present noise sound of 75 dB or clear visual indication (visible from the distance of 50 cm) even at present external illumination of 30 up to 1000 lx.
- Indication of phase sequency shall be continuous.
- Test instrument shall be portable even during the test is running on. It should be produced of isolation materials in double insulation classification.
- Leakage current if one or two test leads are connected to ground while other test leads are connected to phase voltage, should be lower than 3,5 mA (at 110 % of nominal mains voltage).
- External diameter of test leads shall be at least 3,5 mm, conductor section at least 0,75 mm² with diameter of separate wires max. 0,07 mm. Double insulation should be used at test leads.

As it can be seen from above said, EN 61557 regulation offers quite exact requirements for construction of measurement instruments. Some requirements are just adapted, some are completely new in comparison with previous regulation. That is why it is highly important, all end users as well as distributors to verify accordance of test equipment to the EN 61557 regulation.
2. EUROPEAN STANDARDS ABOUT ELECTRIC INSTALLATIONS

This domain is on international level covered by IEC 60364-x regulation while on European level mentioned regulation is issued in harmonized form as HD 384-x standard. Individual countries have their own national regulations, let’s see a few of them.

- **Germany**................. VDE 0100 - x (it is mostly identical with individual parts of European harmonized regulation HD 384 - x).
- **England**................. BS 7671: Requirements for Electric installations
  IEE Wiring Regulations
  16 th edition
  interpretation brochures:
  HB 10011
  HB 10116 ÷ HB 10121
  HB 10123
- **Austria**.................. ÖNORM B 5430 ÷ ÖNORM B 5435
- **France**................... NF C15 - 100
- **Spain**.................... UNE 20 - 460 - x - x
- **Italy**.................... CEI 64 - 8
- **Finland**.................. SF S 5825
- **Norway**.................. TH 30995
3. GENERALLY ABOUT THE ELECTRIC INSTALLATION

See the figure below to make clear which installation will be discussed in continuation. The figure shows limit line between electrical energetical network and electric installation in building.

**Fig. 1.** Division between the electric installation and energetic network

*CC ...................... Connection cabinet*
*DC ...................... Distribution cabinet*
Measurements on electric installations in theory and practice

Some measurements which are carried out at the installation include also a part of the energetic network and source (e.g. Line and Fault Loop Impedance measurement, Earth Resistance measurement at the TN systems etc.)

The realization of electric installation is determined by standards. Generally the installations are divided into more groups regarding the usage, the voltage shape, the kind of earthing system etc.)

Concerning the usage of installations, they are divided into:

- **Low-voltage installations in buildings** for a.c. voltages up to 250 V towards the earth (residential premises, business rooms, lodging houses, schools, public places, rural buildings etc.)
- **Low-voltage installations in industry** for the a.c. voltages up to 600 V towards the earth or d.c. voltages up to 900 V (electromotive drives, electromechanic processing machines, galvans, heating systems etc.)
- **Installations for safe voltages**, this is the voltage up to 50 V a.c. or up to 120 V d.c.( telephony, public address systems, aerial network, intelligent installations, safety systems, speech devices, local network etc.)

Concerning the voltage shape the installations can be the following:

- **Installations for a.c. voltages**
- **Installations for d.c. voltages**
Concerning the used Earthing system (neutral point of energetic transformer and accessible conductive parts of loads and appliances), the installations can be divided as follows:

a) **TN-C - system**

![TN-C System Diagram](image)

- Neutral point of energetic transformer is earthed
- Accessible conductive parts are connected to common PEN conductor

**Fig. 2. TN-C - system**

b) **TN-S - system**

![TN-S System Diagram](image)

- Neutral point of energetic transformer is earthed
- Accessible conductive parts are connected to PE conductor

**Fig. 3. TN-S - system**
c) TN-C-S - sistem

![TN-C-S System Diagram]

- Neutral point of energetic transformer is earthed
- Accessible conductive parts are connected partially to common PEN conductor and partially to protection PE conductor

Fig. 4. TN-C-S – system
When installing TN-C-S – system it is important to know, that N and PE conductors should not be connected together again once PEN conductor is separated to N and PE.

d) TT - system

![TT System Diagram]

- Neutral point of energetic transformer is earthed
- Accessible conductive parts are connected directly to autonomous earthing

Fig. 5. TT - system
e) IT - system

- Neutral point of energetic transformer is not earthed
- Accessible conductive parts are earthed

Fig. 6. IT – system
4. MEASUREMENTS ON ELECTRIC INSTALLATIONS IN BUILDINGS – SHORT PRESENTATION

HOW TO ENSURE THE CONDITIONS FOR THE SAFETY AND THE QUALITY OF ELECTRICAL INSTALLATIONS

ACCORDING TO DEMANDS OF STANDARDS;
TESTING AND REPORTING WITH
FOREFRONT EQUIPMENT OF TECHNICAL & TECHNOLOGICAL ACHIEVEMENTS
Measurements on electric installations in theory and practice

To ensure the safety and the quality of the installation, means:

- their good and quality build-in,
- first inspection and testing before and after connection,
- inspections, testing and reports after each intervention, reconstruction or service,
- and regular examination of periodical inspections, testing and reports.

On the other hand, there is important thing to ensure correct reciprocal connectivity of different types of installation inside objects:

- Low Voltage Electric Installation
- Safety Voltages Installation PELV, SELV
- EIB installation
- Telecommunication Installation
- LAN network
- Installation of machines and appliances, which are connected on those installations

Dangerous situation on the Low Voltage Electrical Installation can appear during operation, maintenance or service. Wrong binding, bad connections, damaged connected appliances or cables are the main reason of many fatality on the electrical installations. The basic protection against direct or indirect contact of the human body with mains voltage can be damaged, the safety conditions can become worst and worst or the reason for the fire starting can appear.

Because of the chemical or mechanical influence during the operation there could increase resistance of conductors, increase the loops and lines impedance or recession of insulation.
Examination with the visual inspection–accordance with the project:
- recognizing the built-in equipment and denomination of it,
- existing of structures, schematic diagrams, ...
- test reports of built-in equipment,
- execution of MPE (main potential equalization),
- correct lying and connections of conductors,
- existing of protection devices in accordance with the project,
- risk of fire, present of moisture, wooden parts, water, pans, hospitals...

Examination with the measurements-accordance with the standards:
- insulation resistance measurement,
- continuity of conductors and PE conductor,
- earth resistance measurement,
- impedance of lines and protected loops,
- RCD / Fi protected devices testing,
- contact voltages
- three phase sequence testing
- dangerous voltage drops on machines
- discharging time of connected loads and machines
- withstanding test of dielectric of materials
- telecommunication and LAN networks – attenuation, cross talk, wire map testing and protocol of transferred data
Measurements on electric installations in theory and practice

INSULATION RESISTANCE MEASUREMENT

Insulation resistance shall be measured on:
1. Phase conductors,
2. Phase and PE conductors,
3. Phase and neutral conductors,
4. Neutral and PE conductors
5. Insulation of walls and floors of insulated non conductive or semi conductive rooms
6. Insulation of ground cables

Examples:
- Phase conductor lamp
- Phase conductor appliance
- Phase conductor PE
- Conductors between each
- Coax cable shield middle
- Isolation of gas
- Floor
- Wall

Measurement voltages and minimal allowed insulation resistances:

- 100 V .................. 0.100 MΩ Telecommunication installations
- 250 V .................. 0.250 MΩ Extra low voltage electric installations
- 500 V .................. 0.500 MΩ Low voltage electric installations (U_n<500 V), floor and wall resistances, insulation resistances of switch boards etc.
- 1000 V ................. 1.000 MΩ Low voltage electric installations (U_n>500 V), floor and wall resistances, insulation resistances of switch boards etc.
CONDUCTOR CONTINUITY MEASUREMENT

Automatic trip out mains voltage, in case of present hazardous contact voltage, is one of the most common protections used on electric mains installations. One of three basic requirements at this type of protection is connection of accessible metal parts to grounding system. This way, electric system is protected against appearance of hazardous contact voltage and in case of anyway present hazardous contact voltage, the user of electric appliance is protected against electric shock due to immediate automatic switching off mains voltage.

Examples:
- MPE (Main Potential Equalizing)
- PE terminals at mains outlets
- Heat or gas installation
- Water installation
- Lamp and appliance housings
- Lightning system
Measurements on electric installations in theory and practice

Contact voltage caused by fault on installation or appliance may be seriously dangerous for the user!

Measurements of low Ω resistance are carried out when testing connections between electric conductors,
protection earth conductors and appliances,
protection earth conductors and grounding system etc..

Maximal value of resistance shall be calculated, as it is often not defined by regulation.

Anyhow, maximal resistance of additional potential equilizing system is defined. Resistance between
two metal parts, which are connected together by potencial equilizing conductor must be:

\[
R \leq \frac{50}{I_a}
\]

where :

R – Max Resistance between two accessible metal parts connected together using additional potential
equilizing conductor

I_a - Current, which assures tripping out protection device namely:

\[
I_a = I_{nr} \quad \text{.... residual current protection devices (RCDs)},
\]

\[
I_a = \text{Nominal working current} \quad \text{.... overcurrent protections (fuses)}
\]

In case of RCD protection devices, \( I_a \) is equal to **nominal differential current**, while in case of
overcurrent protection devices (fuses), \( I_a \) is the current, which causes melting and thus **blowing of involved fuse within 5 s** (the current is to be found in appropriate table for a centain type of fuse).

At automatic installation fuses, \( I_a \) is the current, which ensurens reliable **tripping out involved automatic fuse**
(at B type of automatic installation fuses \( I_a \) is equal to 5 x \( I_n \), at C type \( I_a \) is equal to 10 x \( I_n \), etc.).
Earth resistance of accessible metal parts is one of three the most important requirements when protecting electric installations, connected appliances and users of the appliances by means of automatic trip out mains voltage. Maximal allowed earth resistance depend on type of earth (working earth, protection earth or lightning earth). Earth is also necessary measure when protecting electric installations against over-voltages.

When measuring earth resistance, influence of electro-chemical effect is compensated using AC test voltage. Properly selected frequency of test voltage (METREL’s patent) will reduce the influence of leakage currents resulted by 50 Hz mains voltage to the test result. Most of the test instruments use U - I test method which bases on the principle of measuring voltage drop and test current. Earth resistance measurements can be carried out using two, three or four wire test system.

**Two wire test system** is used in case there is no place to drive auxiliary test rods and well grounded terminal is available. When measuring earth resistance in TT system of installation, power transformer’s working earth brought via neutral conductor N is used as one terminal. The same method is acceptable also when measuring earth resistance on open connection of parallel lightning system at bigger buildings.

**Three wire test system** is more suitable when measuring lower earth resistance, as the system compensates resistance of auxiliary earthing system like working earth system of power transformer.

**Four wire test system** is similar to the three wire one, and it also compensates eventual contact resistance between current generator terminal (alligator of black test lead) and tested terminal.

**Current clamp test system** is suitable when measuring separate earth resistance of parallel earthing system without disconnecting tested earth branch.
Measurements on electric installations in theory and practice

Two wire test system
Measurements on electric installations in theory and practice

Two wire test system on open connection of parallel earthing system In that case parallel connection of resistances $R_1$, $R_2$, $R_3$ and $R_4$ is used as auxiliary test terminal.

As an independent auxiliary test terminal can be used also:
- Gas installation system.
- Railway rail system.
- Water installation system (metal) etc.
Measurements on electric installations in theory and practice

Three wire test system
Earth Resistance Measurement - Current Clamp Method

Quite often, earthing system consists of more parallely connected earth bars (for example lightning system or basic earthing system of complex building etc.). Advantage of the EARTH RESISTANCE TESTER produced by METREL is, that current clamp method could be used and no disconnection of tested earth bar is to be realized.
Earth resistivity measurement is usually carried out when testing quality of soil in order to use this information for further designing of earthing system (necessary length of earth bars as well as deepness of the bars). Usually Wenner’s method is used for the measurement, where earth resistivity is calculated as follows:  

\[ \rho = 2 \cdot \pi \cdot a \cdot R \]
Measurements on electric installations in theory and practice

Fault Loop Impedance Measurement

Protection of electric installations, connected appliances and users of the appliances against electric shock, bases on automatic trip out mains voltage. Other types of protection are usually used only for individual appliances or individual rooms. In TN system of installation, all accessible metal parts are connected to neutral conductor N via protection earth conductors PE and thus to ground by means of earthing system of power transformer.

TT system, all the accessible metal parts are connected to Basic Grounding system of the building via protection earth conductor.

In case of short circuit between phase conductor and accessible metal part, short circuit current of the fault loop flows and involved overcurrent protection device must blow.

As RCD devices are usually used as a protection elements in TT system, safety conditions are checked measuring $R_E$. The resistance $R_E$ is to be measured using two, three or four wire test system or clamp system.
LINE IMPEDANCE MEASUREMENT

The measurement of line impedance is important as the result can be used for:

1. Evaluation of overcurrent protection system.
2. Locating of too high line impedance.
3. Locating of too high voltage drop between power transformer and a load.

Overcurrent protection system must be checked in compliance with two general conditions:

\[ I_B \leq I_n \leq I_M \]

and

\[ I_2 \leq 1.45 \cdot I_M \]

where:

- \( I_B \) ..... current, which tested current loop is designed to,
- \( I_n \) ..... nominal current of protection device,
- \( I_M \) ..... max. allowed continuous conductor current,
- \( I_2 \) ..... current, which assures reliable trip out of protection device.
RCD protection switches are usually used to protect users of electric appliances in TT and TN system, while they are rarely used in IT system. RCDs are indispensable in TT system of installation. In some current loops they are required by regulations (outlets in bathrooms, outlets at building sites, current loops in fire endangered rooms etc.).

**In TN system,** fault current supplied by phase voltage is driven through fault appliance to protection earth conductor and then through PEN conductor to neutral terminal of power transformer. Impedance of this loop is called fault loop impedance and the following condition must be ensured:

\[ Z_s \cdot I_{i,n} \leq U_0 \]

(for example: impedance of fault loop protected by RCD protection device with rated differential current of 30 mA could be as high as 1666 \( \Omega \), while actual values are lower than 2 \( \Omega \)).

**Protection system is to be checked. RCD protection device must trip out mains voltage at nominal differential current within 0.4 s.**

**In TT system,** fault current supplied by phase voltage is driven through fault appliance to protection earth conductor PE and then to ground via basic ground resistance. The current is driven to grounding system of power transformer and thus to neutral terminal of the transformer. Total impedance of the fault loop consists of more serial impedances, where the major part presents resistance of Basic Grounding system:

\[ R_E \cdot I_{i,n} \leq 50 \]

It is obvious, that protection system can be checked measuring the resistance of Basic Grounding system. The measurement must be done using AC test current as DC current could cause some electro-chemical effects at the surface of test roods and earth bar, which may disturb the measurement.
Testing of RCD Protection Devices in TN System
Testing of RCD Protection Devices in TT System

Measurements on electric installations in theory and practice
PHASE ROTATION TEST

In some cases it is very important to connect three phase appliance (three phase motors incorporated) correctly to three phase mains system, as the wrong phase sequence could cause some damage at the appliance and danger situation for the user.
### 5. MEASUREMENTS ON ELECTRIC INSTALLATIONS IN BUILDINGS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Allowed deviation</th>
<th>Needed correction of measurement result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation Resistance</td>
<td>+/- 30 %</td>
<td>R × 0.7</td>
</tr>
<tr>
<td>Fault Loop Impedance</td>
<td>+/- 30 %</td>
<td>Z × 1.3</td>
</tr>
<tr>
<td>Resistance of protection conductors, conductors for main and additional equalizing and earthing conductors</td>
<td>+/- 30 %</td>
<td>R × 1.3</td>
</tr>
<tr>
<td>Earth Resistance</td>
<td>+/- 30 %</td>
<td>R × 1.3</td>
</tr>
<tr>
<td>Contact voltage</td>
<td>+/- 0 % of $U_L$</td>
<td>R + 5V ($U_L$ = 25V)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R + 10V ($U_L$ = 50V)</td>
</tr>
<tr>
<td>RCD Trip out time</td>
<td>+/- 10 % of $t_L$</td>
<td>R + 0.1$t_L$ (standard RCD)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R + 0.1$t_L$ maks. (Sel. RCD)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R − 0.1$t_L$ min. (Sel. RCD)</td>
</tr>
<tr>
<td>RCD Tripping current</td>
<td>+/- 10 % of $I_{\Delta N}$</td>
<td>R + 0.1$I_{\Delta N}$ (upper limit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R − 0.1$I_{\Delta N}$ (lower limit)</td>
</tr>
</tbody>
</table>

Table 1. Correction of measurement results
5.1. **INSULATION RESISTANCE  EN 61557-2**

Appropriate Insulation Resistance between live parts and accessible environment (active accessible conductive parts) is a basic safety parameter which protects against direct or indirect touch of human body with mains voltage. Insulation Resistance between live parts which prevents short circuits or leakage currents, is also important.

![Electrical diagram with symbols and equations](image)

*Fig. 8. An example of bad insulation in connection box for permanent connection of a load and resulting fault voltage \( U_f \)*

\[
U_f = U_c + U_s = I_f \cdot R_E
\]
Generally about Insulation Resistance measurement

Measurements of Insulation Resistance are to be carried out before the first connection of mains voltage to the installation. All switches shall be closed and all loads disconnected, enabling the whole installation to be tested and test result not to be influenced by any load.

Measurement principle is presented in the figure below:

Fig. 9. Insulation Resistance measurement principle

U-I method is used.
5.1.1. Measurement of Insulation Resistance between conductors

- Separately all three phase conductors L1, L2 and L3 against neutral one N.
- Separately all three phase conductors L1, L2 and L3 against protection conductor PE.
- Phase conductor L1 separately against L2 and L3.
- Phase conductor L2 against L3.
- Neutral conductor against protection conductor PE.

Fig. 10. An example of Insulation Resistance measurement between the PE and other conductors using the Eurotest 61557, Instaltest 61557 or Earth – Insulation Tester

Notes!
- Switch off mains voltage before starting the measurements!
- All switches should be closed during the test!
- All loads should be disconnected during the test!
The lowest values of insulation resistances are defined by regulations and are presented in the table below.

<table>
<thead>
<tr>
<th>Nominal mains voltage</th>
<th>Nominal d.c. test voltage (V)</th>
<th>Lowest allowed Insulation Resistance (MΩ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safe low voltage</td>
<td>250</td>
<td>0,25</td>
</tr>
<tr>
<td>Voltage up to 500 V except safe low voltage</td>
<td>500</td>
<td>0,5</td>
</tr>
<tr>
<td>Over 500 V</td>
<td>1000</td>
<td>1,0</td>
</tr>
</tbody>
</table>

**Table 2.** The lowest allowed values of Insulation Resistance measured between mains conductors
5.1.2. **Resistance measurement of non-conductive walls and floors**

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

Protection conductor PE which could drive dangerous fault voltage down to the ground potential, is not allowed to be present in non-conductive rooms. Non-conductive walls and floor protect the operator in case of basic insulation fault.

![Measurement electrode diagram](image-url)  

**Fig. 11.** Measurement electrode
Measurements on electric installations in theory and practice

The value of test voltage shall be:
- 500 V ............... nominal mains voltage against ground is lower than 500 V
- 1000 V ............ nominal mains voltage against ground is higher than 500 V

The value of measured and corrected test result (see the chapter 5.) must be higher than:
- 50 kΩ ............. nominal mains voltage against ground is lower than 500 V
- 100 kΩ .......... nominal mains voltage against ground is higher than 500 V
5.1.3. Resistance measurement of semi-conductive floors

In some cases like explosive-safe areas, inflammable stuff store-houses, lacquer rooms, sensitive electronic equipment production halls, fire endangered areas etc., floor surface with a certain conductivity is required. In such cases the floor successfully prevents arising of static electric and drives any low-energy potentials to ground. In order to achieve appropriate resistance of the floor, semi-conductive material should be used. Resistance shall be tested using Insulation Resistance tester with test voltage within 100 up to 500 V.

A special test electrode defined by regulation is to be used, see the figure below.

Fig. 13. Test electrode
Measurements on electric installations in theory and practice

Measurement procedure is presented on the figure below. The measurement is to be repeated a few times on different locations and an average of all results shall be taken.

**Fig. 14. Measurement of semi-conductive floor resistance**

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

**Attention!**
- It is advised the measurement to be carried out using both polarities of test voltage and an average result to be taken.
- Wait until test result is stabilized!
5.1.4. Insulation Resistance measurement on ground cables - 30 GΩ

The measurement is to be carried out the same way as between conductors on installation, except the test voltage shall be 1000 V because of high demanding conditions that such a cable should withstand. Insulation Resistance test shall be performed between all conductors at disconnected mains voltage. Because of high Insulation Resistance values, Earth – Insulation Tester is recommended to be used. The instrument offers measurements up to 30 GΩ.

![Fig. 15. Insulation Resistance on ground cable measurement using the Earth – Insulation Tester](image)
5.2. CONTINUITY OF PROTECTION CONDUCTORS, CONDUCTORS FOR MAIN AND ADDITIONAL EQUALIZING AND EARTHING CONDUCTORS EN 61557-4

Above mentioned conductors are important part of protection system which prevents arising of dangerous fault voltages (dangerous from aspect of duration as well as absolute value). Of course, these conductors can successfully serves to its purpose only if they are well dimensioned and properly installed (connected). That is why it is important to test the continuity and bond resistances.

Generally about the measurement

The measurement is, according to regulations, allowed to be carried out using either a.c. or d.c. test voltage with its value within 4 and 24 V. Test instruments produced by METREL use d.c. test voltage and U-I method. Principle of the measurement is presented on the figure below.

Because of two test voltage polarities, two subresults are available as follows:
Measurements on electric installations in theory and practice

Result $+ = \frac{U}{I} = R_x$ $+$ ...... switch is in full-line position (fig. above)
Result $- = \frac{U}{I} = R_x$ $-$ ...... switch is in interrupted-line position (fig. above)

where:
$U$................. Voltage drop measured by the V-meter on the unknown resistance $R_x$.
$I$................. Test current driven by the battery $U_b$ and measured by the A-meter.

Presentation of practical measurement

Fig. 17. Continuity measurement between MPEC and PCC
Measurements on electric installations in theory and practice
5.3. ADDITIONAL EQUALIZING  EN 61557- 4

In case main equalizing is not sufficient enough to prevent arising of dangerous fault voltages, additional equalizing is to be applied. Let's see an example of main and additional equalizing on the figure below.

How to ascertain the need for additional equalizing
In order to ascertain the need for additional equalizing, resistance of protection conductor for main equalizing from active accessible conductive part to the MPEC (PCC) is to be measured, see the figure below.

Fig. 21. Protection conductor measurement in order to ascertain the need for additional equalizing
\[ R \leq U_L / I_a \]

**Fig. 22.** Checking of efficiency of additional equalizing
Measurement of the Contact voltage at Short-circuit current against passive accessible conductive parts

Fig. 23. Measurement of Contact voltage at Short-circuit current against passive accessible conductive parts using the Eurotest 61557 test instrument
5.4. LOW RESISTANCES

The function is welcomed when maintaining electric installations and electric appliances, checking fuse condition, searching for different connections etc. Advantage of the function against the one for testing of protection conductors according to EN 61557 (described in previous chapter) is, that the function is continuous (low test current and no reversing of test voltage polarity) and is intended for quick tests. Test instruments Eurotest 61557, Instaltest 61557 and Earth — Insulation Tester all offer this function.

Let's see the measurement principle presented on the figure below.

\[ R_x = \frac{U}{I} \]
What is the Earth Resistance

This is the electrical resistance of the earthing electrode which the electric current feels during its running through the earthing part to ground. It consists from the surface of earthing electrode (oxides on the metal surface) and the resistance of earth (material) mainly near the surface of earthing electrode.

Fig. 25. Earthing electrode
**Fig. 26. Voltage apportion across the Earth Resistance - voltage funnel**
Measurement principle using classic four-terminal, two-probe method

Fig. 27. Measurement principle and apportion of test voltage
Measurements on electric installations in theory and practice

**Calculation of required distance between tested earthing system (simple rod or simple band electrode):**

Basis for the calculation is depth of simple rod electrode or diagonal dimension of band earthing system.

- **Distance from tested earthing electrode to current measurement probe C2** = depth (rod electrode) or diagonal (band electrode) × 5
- **Distance to voltage measurement probe P2 (62%)** = Distance C2 × 0.62
- **Distance to voltage measurement probe P2 (52%)** = Distance C2 × 0.52
- **Distance to voltage measurement probe P2 (72%)** = Distance C2 × 0.72

Example: Band type earthing system, diagonal = 4 m.

C2 = 4 m × 5 = 20 m
P2 (62%) = 20 m × 0.62 = 12.4 m
P2 (52%) = 20 m × 0.52 = 10.4 m
P2 (72%) = 20 m × 0.72 = 14.4 m
5.5.1. Measurement of simple rod earthing electrode

\[
\text{Result} = \frac{U}{I} = R_E
\]

where:
\[U\] ...................... Voltage measured by internal V-meter between P1 and P2 test terminals.
\[I\] ...................... Test current drived to tested loop between C1 and C2 test terminals.
The measurement is fairly simple due to the fact, that the earthing electrode can be considered as a point electrode and it is connected to no other electrode. Distances between the tested electrode and test probes (current and potential) depend on the depth of tested electrode.

**Used 4-lead connection, supported by METREL test instruments is much better than 3-lead one, as it brings no problems concerning contact resistance between test clips and usually rusty surface of tested electrode.**

Measurement probes are usually driven to ground in line with the tested electrode or in equilateral triangle.
5.5.2. Measurement of simple band earthing electrode

**Fig. 29.** Earth Resistance measurement of simple band electrode

Result = $U \div I = Re$

where:

$U$ ................. Voltage measured by internal V-meter between P1 and P2 test terminals.

$I$ ................. Test current driven to tested loop between C1 and C2 test terminals.
The measurement is quite similar to previous one, except the electrode can not be considered as a point electrode, but length of used band is to be considered. On basis of the length, appropriate distance from tested electrode to both test probes must be calculated and used, see the figure above. Measurement probes are usually driven to ground in line with the tested electrode or in equilateral triangle.

5.5.3. Measurement at the complex realization of earthing system with more parallel electrodes

Two important data are existing in such systems:

- Common resistance of earthing system \( R_{E\text{tot}} \) which is equal to the parallel connection of individual earthing electrodes. Sufficient common low Earth Resistance meets the requirements for a successful protection against the electrical shock in case of load's faultness, but it may not offer the successful protection at the atmospheric discharging through the lightning conductor.

- Resistance of the individual earthing electrode \( R_{E1}...R_{En} \). Individual earthing resistances have to be low enough when the earthing system is intended for protection against the atmospheric discharging. The atmospheric dischargings
**Measurement of total Earth Resistance**

a) *Classic four-lead, two-probe method*

![Diagram of measurement setup](image)

**Fig. 30.** Measurement of total Earth Resistance of complex earthing system using classic four-lead, two-probe method

Result = $\frac{U}{I} = R_{E1}///R_{E2}///R_{E3}///R_{E4} = R_{Etot}$
b) Rodless method using two test clamps

Let’s see the model of such earthing system and connection of test instrument.

Fig. 31. Measurement of total Earth Resistance by using two test clamps
**Particular Earth Resistance measurement**

There are more ways to measure Earth Resistance of particular earthing electrode. The way which best fits to actual earthing system, and is of course supported by available test instrument, is to be used.

a) *Measurement with mechanical disconnection of tested particular earthing electrode and using classic 4-lead 2-probe test method*

![Diagram of Earth Resistance measurement](image)

**Fig. 33.** Earth Resistance measurement of particular earthing electrode

**Result** = \( \frac{U}{I} = R_{E4} \)
Measurements on electric installations in theory and practice

b) Measurement with mechanical disconnection of tested particular earthing electrode and using classic 4-lead 2-point test method

If the number of total earthing electrodes is high enough, then a simplified, probeless method can be used, see the figure below. Tested particular electrode is to be mechanically interrupted, all the other electrodes will be used as auxiliary ones. Total Earth Resistance of auxiliary electrodes is much lower than tested particular one.

Result = $R_{E4} + (R_{E1} // R_{E2} // R_{E3})$

Fig. 34. Simplified probeless measurement
c) Measurement using classic 4-terminal 2-probe test method in combination with test clamp

Fig. 35. Earth Resistance measurement using one test clamp

Fig. 36. Substitutional electric circuit diagram of previous practical example
d) Probeless measurement using two test clamps

Both Eurotest 61557 and Earth – Insulation Tester can carry out the measurement even in presence of high noise signals namely, they both use a special patented technical solution.

Fig. 38. Substitutional electric circuit diagram of previous practical example

\[ \text{Result} = R_{E4} + (R_{E3} \parallel R_{E2} \parallel R_{E1}) \]
5.6. SPECIFIC EARTH RESISTANCE (RESISTIVITY)
EN 61557- 5

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

Fig. 41. Presentation of Specific Earth Resistance
Measurement of Specific Earth Resistance

Measurement principle is presented on the figure below.
Measurements on electric installations in theory and practice

Result = 2 \pi a \frac{U}{I} = \rho

Using different distances between test probes, material at different depths is measured. As bigger the distance is, as deeper level of ground material is measured.

<table>
<thead>
<tr>
<th>Type of ground material</th>
<th>Specific Earth Resistance in ( \Omega m )</th>
</tr>
</thead>
<tbody>
<tr>
<td>sea water</td>
<td>0.5</td>
</tr>
<tr>
<td>lake or river water</td>
<td>10 – 100</td>
</tr>
<tr>
<td>plough earth</td>
<td>90 – 150</td>
</tr>
<tr>
<td>concrete</td>
<td>150 – 500</td>
</tr>
<tr>
<td>wet gravel</td>
<td>200 – 400</td>
</tr>
<tr>
<td>fine dry sand</td>
<td>500</td>
</tr>
<tr>
<td>lime</td>
<td>500 – 1000</td>
</tr>
<tr>
<td>dry gravel</td>
<td>1000 – 2000</td>
</tr>
<tr>
<td>stoney ground</td>
<td>100 – 3000</td>
</tr>
</tbody>
</table>

**Table 3.** Orientational values of Specific Earth Resistances for a few typical ground materials

Practical measurement using test instrument Eurotest 61557 or Earth – Insulation Tester is shown on the figure below.
5.7. CONNECTION OF PROTECTION CONDUCTOR PE AT MAINS PLUG

The Eurotest 61557 will do this test whenever operator’s finger touches PE test probe near-by the START key.

Let's see the test principle.
5.8. **RCD PROTECTION DEVICES**   **EN 61557- 6**

Such a protection is successful if RCD device is installed correctly if the installation is correctly dimensioned and if Earth Resistance value is under allowed limit value for installed RCD device.

![Diagram](image)

**Fig. 46. Schematic presentation of the RCD protection device**

L1, L2, L3, N ............ Input terminals for connection of energetic network.  
L1', L2', L3', N'  
Output terminals for connection to installation in building.
Measurements on electric installations in theory and practice

- **AC type**, sensitive to alternating differential current. This is the most frequently used type due to the fact that most of installations supply loads with alternating current.

![AC type diagram](image)

*Fig. 47. Shape of differential current, AC type of RCD is sensitive to*

- **A type**, sensitive besides to alternating current, also to half or full-wave rectified a.c. current. It is rarely used in practice as there are not a lot of installations that supply connected loads with such current (e.g. d.c. motors, galvanization plants etc.)

![A type diagram](image)

*Fig. 48. Shape of differential current, A type of RCD is sensitive to as well*
• **B type**, sensitive besides to alternating and half or full-wave rectified a.c. current, also to pure or nearly pure d.c. current. It is rarely used in practice as there are not a lot of installations that supply connected loads with pure d.c. current (e.g. full-wave rectified three-phase voltage etc.)

**Fig. 49.** Shape of differential current, B type of RCD is sensitive as well

Regarding required trip out time of RCD protection devices, two types are offered namely:
- Standard type (undelayed trip out)
- Selective type (delayed trip out)
5.8.1. Contact voltage

What is the contact voltage
Contact voltage is the voltage which arises in case of faulty load on active accessible parts and can be bridged over by human body.

b) Measurement of Contact voltage using auxiliary test probe
Principle of the measurement is presented on the two figures below.
5.8.2. Trip out time

What is the Trip out time

Trip out time $t_\Delta$ is time needed by the RCD to trip at nominal differential current $I_{\Delta N}$.

Maximal allowed values of Trip out time are defined by EN 61009 standard and are listed in the table below:

<table>
<thead>
<tr>
<th>Type of RCD</th>
<th>$I_{\Delta N}$</th>
<th>$2I_{\Delta N}$</th>
<th>$5I_{\Delta N}^*$</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>0,3 s</td>
<td>0,15 s</td>
<td>0,04 s</td>
<td>max. allowed value</td>
</tr>
<tr>
<td>Selective</td>
<td>0,5 s</td>
<td>0,2 s</td>
<td>0,15 s</td>
<td>max. allowed value</td>
</tr>
<tr>
<td></td>
<td>0,13 s</td>
<td>0,06 s</td>
<td>0,05 s</td>
<td>min. allowed value</td>
</tr>
</tbody>
</table>

* Test current of 0,25A shall be used instead of $5I_{\Delta N}$ in case nominal differential current $I_{\Delta N} \leq 30$ mA.
5.8.3. **Tripping current**

*What is the Tripping current*

This is the lowest differential current $I_\Delta$ which can still cause tripping out RCD.

*Allowed range of Tripping current value* is prescribed by IEC 61009 standard and depends on type of RCD (AC, A or B) as follows:

- $I_\Delta = (0.5 \text{ up to } 1) \times I_{\text{n}}$ ............ AC type
- $I_\Delta = (0.35 \text{ up to } 1.4) \times I_{\text{n}}$ ........ A type
- $I_\Delta = (0.5 \text{ up to } 2) \times I_{\text{n}}$ ............ B type

*Measurement of tripping out current*
5.8.4. Earth Resistance (external source of test voltage)

<table>
<thead>
<tr>
<th>Nominal differential current $I_{an}$ (A)</th>
<th>0.01</th>
<th>0.03</th>
<th>0.1</th>
<th>0.3</th>
<th>0.5</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. allowed Earth Resistance value at $U_L = 50$ V (Ω)</td>
<td>5000</td>
<td>1666</td>
<td>500</td>
<td>166</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>Max. allowed Earth Resistance value at $U_L = 25$ V (Ω)</td>
<td>2500</td>
<td>833</td>
<td>250</td>
<td>83</td>
<td>50</td>
<td>25</td>
</tr>
</tbody>
</table>
5.9. FAULT LOOP IMPEDANCE and \( I_{pSc} \) \hspace{1cm} EN 61557-3

If current loops (fuse loops) are protected by over-current protection devices (fuses), then Fault loop impedance \( Z_s \) should be measured. The Fault loop impedance should be low enough in order potential fault current \( I_f \) to interrupt installed protection device within prescribed time interval in case of faulty load.

Fault loop impedance in TN- system consists of the following partial impedances:

- Impedance of power transformer’s secondary
- Phase conductor resistance from power transformer to fault location
- Protection conductor resistance from fault location to power transformer

![Fig. 55. Presentation of Fault loop in TN- system](image-url)
Fault loop impedance in TT- system consists of the following partial impedances:

- Impedance of power transformer’s secondary
- Phase conductor resistance from power transformer to fault location
- Protection conductor resistance from fault location to earthing electrode
- Earth Resistance $R_E$
- Ground resistance from earthing electrode $R_E$ to power transformer
- Resistance of power transformer’s earthing system $R_o$

**Fig. 56.** Presentation of Fault loop in TT- system
Measurements on electric installations in theory and practice

Max. allowed Fault loop impedances in case of used melting fuses type gG in installation with nominal mains voltage \( U_{L-N} = 220 \) V are presented in the next table.

<table>
<thead>
<tr>
<th>Nominal current of over-current protection device (A)</th>
<th>gG 0,4 s</th>
<th>gG 5s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( I_a ) (A)</td>
<td>( Z_s ) (( \Omega ))</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>13,7</td>
</tr>
<tr>
<td>4</td>
<td>32</td>
<td>6,8</td>
</tr>
<tr>
<td>6</td>
<td>47</td>
<td>4,6</td>
</tr>
<tr>
<td>10</td>
<td>82</td>
<td>2,6</td>
</tr>
<tr>
<td>16</td>
<td>110</td>
<td>2,0</td>
</tr>
<tr>
<td>20</td>
<td>147</td>
<td>1,4</td>
</tr>
<tr>
<td>25</td>
<td>183</td>
<td>1,2</td>
</tr>
<tr>
<td>32</td>
<td>275</td>
<td>0,8</td>
</tr>
<tr>
<td>40</td>
<td>320</td>
<td>0,6</td>
</tr>
<tr>
<td>50</td>
<td>470</td>
<td>0,4</td>
</tr>
<tr>
<td>63</td>
<td>550</td>
<td>0,4</td>
</tr>
<tr>
<td>80</td>
<td>840</td>
<td>0,2</td>
</tr>
<tr>
<td>100</td>
<td>1020</td>
<td>0,2</td>
</tr>
<tr>
<td>125</td>
<td>1450</td>
<td>0,1</td>
</tr>
</tbody>
</table>

*Table 6.* Max. allowed Fault loop impedances in case of used gG melting fuses

\( I_a \)............. Fault loop current which already assure tripping of protection device.
In some countries, gL type of over-current protection devices is known instead of gG one. Let’s see corresponding table for the gL protection devices constructed according to VDE 0636 used in installation with $U_{L-N} = 220$ V.

<table>
<thead>
<tr>
<th>Nominal current of over-current protection device (A)</th>
<th>$gL_{0.2}$ s</th>
<th></th>
<th>$gL_{5}$ s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$I_a$ (A)</td>
<td>$Z_s$ (Ω)</td>
<td>$I_a$ (A)</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>11.0</td>
<td>9.21</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>5.5</td>
<td>19.2</td>
</tr>
<tr>
<td>6</td>
<td>60</td>
<td>3.7</td>
<td>28.0</td>
</tr>
<tr>
<td>10</td>
<td>100</td>
<td>2.2</td>
<td>47</td>
</tr>
<tr>
<td>16</td>
<td>148</td>
<td>1.5</td>
<td>72</td>
</tr>
<tr>
<td>20</td>
<td>191</td>
<td>1.2</td>
<td>88</td>
</tr>
<tr>
<td>25</td>
<td>270</td>
<td>0.8</td>
<td>120</td>
</tr>
<tr>
<td>32</td>
<td>332</td>
<td>0.7</td>
<td>156</td>
</tr>
<tr>
<td>35</td>
<td>367</td>
<td>0.6</td>
<td>173</td>
</tr>
<tr>
<td>40</td>
<td>410</td>
<td>0.5</td>
<td>200</td>
</tr>
<tr>
<td>50</td>
<td>578</td>
<td>0.4</td>
<td>260</td>
</tr>
<tr>
<td>63</td>
<td>750</td>
<td>0.3</td>
<td>351</td>
</tr>
<tr>
<td>80</td>
<td>—</td>
<td>—</td>
<td>452</td>
</tr>
<tr>
<td>100</td>
<td>—</td>
<td>—</td>
<td>573</td>
</tr>
<tr>
<td>125</td>
<td>—</td>
<td>—</td>
<td>751</td>
</tr>
<tr>
<td>160</td>
<td>—</td>
<td>—</td>
<td>995</td>
</tr>
</tbody>
</table>

*Table 7. Max. allowed Fault loop impedances in case of used gL melting fuses*
Measurements on electric installations in theory and practice

Max. allowed Fault loop impedances in case of used automatic fuses type B, C and K in installation with nominal mains voltage $U_{LN} = 220$ V are presented in the table below.

<table>
<thead>
<tr>
<th>Nominal current of over-current protection device (A)</th>
<th>Type of automatic fuse B</th>
<th>Type of automatic fuse C</th>
<th>Type of automatic fuse K</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_a=5 \cdot I_n$ (A)</td>
<td>$Z_s (\Omega)$ (0,2s)</td>
<td>$I_a=10 \cdot I_n$ (A)</td>
<td>$Z_s (\Omega)$ (0,2s)</td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>-------------------------</td>
<td>-------------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>6</td>
<td>30</td>
<td>60</td>
<td>90</td>
</tr>
<tr>
<td>10</td>
<td>50</td>
<td>100</td>
<td>150</td>
</tr>
<tr>
<td>16</td>
<td>80</td>
<td>160</td>
<td>240</td>
</tr>
<tr>
<td>20</td>
<td>100</td>
<td>200</td>
<td>300</td>
</tr>
<tr>
<td>25</td>
<td>125</td>
<td>250</td>
<td>375</td>
</tr>
<tr>
<td>32</td>
<td>160</td>
<td>320</td>
<td>480</td>
</tr>
<tr>
<td>35</td>
<td>175</td>
<td>350</td>
<td>525</td>
</tr>
<tr>
<td>40</td>
<td>200</td>
<td>400</td>
<td>600</td>
</tr>
<tr>
<td>50</td>
<td>250</td>
<td>500</td>
<td>750</td>
</tr>
<tr>
<td>63</td>
<td>315</td>
<td>630</td>
<td>945</td>
</tr>
</tbody>
</table>

Table 8. Max. allowed Fault loop impedances in case of used automatic fuses type B, C and K
Fault loop impedance measurement

The two figures below are presenting measurement principle and practical connection of test instrument.

Fig. 57. Measurement principle
5.10. **LINE IMPEDANCE and Prospective Short-circuit current**

Line Impedance is impedance measured between phase L and neutral N terminals on single-phase system or between two phase terminals on three-phase system. The Line Impedance is to be measured when checking ability of installation to supply for example high power loads when verifying installed over-current brakers etc. The Impedance consists of the following partial impedances:

- Impedance of power transformer secondary
- Resistance of phase conductor from power transformer to tested place
- Resistance of neutral conductor from power transformer to tested place

5.10.1. **Line Impedance between the phase and neutral terminals**

![Diagram of Line Impedance measurement between the phase L1 and neutral N terminals]

*Fig. 59. Measurement principle of Line Impedance measurement between the phase L1 and neutral N terminals*
5.10.2. Line Impedance measurement between two phase conductors
5.11. *N–PE LOOP RESISTANCE*

Up-to-date test instruments, with built in modern electronics, can measure resistance even between the neutral N and protection PE conductors in spite of possible high current in neutral conductor. The current which is driven by phase voltages through different linear and non linear loads, causes voltage drops of extremely irregular (non sine wave) shape. The voltage drops interfere with test voltage and thus disturb the measurement. Internal test voltage (approx. 40V, a.c., <15 mA) is used, as there is no mains voltage between neutral and protection conductors.

Important advantage of this measurement against Fault Loop one (L – PE) is, that RCD surely does not trip during the measurement, due to low test current (<15 mA). Test instrument Eurotest 61557 uses special *(patented)* measurement principle to filter test signal and thus assures correct measurement results.

**What can be the message of the measurement**

As there is no mains voltage between the N and PE terminals which could be used as a test voltage, instrument must generate internal one. The voltage may be either d.c. or a.c. Instrument Eurotest 61557 uses a.c. test voltage, measurement is done on basis of U-I method according to the figure below.

\[
\text{Result} = \frac{U_t}{I_t} = R_{N-PE}
\]
5.11.1. Measurement of N–PE loop resistance in TN- system

5.11.2. Measurement of N–PE loop resistance in TT- system

Fig. 65. Resistance measurement between neutral and protection conductor in TT- system

Result 1 = \( R_N + R_{PE} + R_E + R_O \)
Measurements on electric installations in theory and practice

\[ \text{Result 2} = Ipsc = 230V \cdot 1,06 / (R_N + R_{PE} + R_E + R_O) \]

As it could be presumed, that resistance \( R_E \) is much higher than the sum of all other resistances, the following can be put down:

\[ \text{Result 1} \approx R_E \]
\[ \text{Result 2} = Ipsc \approx 230V \cdot 1,06 / R_E \]

5.11.3. Measurement of N–PE loop resistance in IT- system

As it could be seen from the figure above, there is no galvanic connection between the neutral and protection conductor in IT- system. Test result is thus very high (it can be even out of display range), pointing out IT- system is involved.
5.12. PHASE ROTATION  EN 61557- 7

How to measure the phase rotation

1. phase (referential); result is 1 2 3
2. phase (comparative); result is 2 1 3

Fig. 67. Measurement principle
5.13. MEASUREMENT OF VOLTAGE, FREQUENCY AND CURRENT

5.13.1. Voltage and frequency measurement

5.13.2. Current measurement
5.14. VARISTOR OVERVOLTAGE PROTECTION DEVICES

- In connection cabinets at the input of mains voltage (the devices prevents spreading of energetic overvoltages)
- In distribution cabinets of individual installation units.
- Just near by connected electrical loads (equipment).

Breakdown voltage may drop. Because of that reason they may be destroyed by mains voltage itself.
They may break totally. The protection function is thus lost completely.
Test instruments like Eurotest 61557, Eurotest 61557 or Earth – Insulation Tester can do the undestructable tests of varistor overvoltage protection devices using test voltage of 50 up to 1000 V.

Measurement principle is represented in the figure below.

**Fig. 73. Measurement principle**
5.15. TRACING OF ELECTRICAL INSTALLATION

- Recognition of protective element (fuse) responsible for a certain current loop.
- Location of short circuit.
- Location of conductor interruption.
- Tracing of a certain conductor under mains voltage.
- Tracing of a certain voltage-free conductor (not connected to mains voltage).

Measurement instrument Eurotest 61557 or Eurotest 61557 in combination with hand-held detector, can solve all the problems listed above.

- **Inductive mode** Instrument operates on installation under mains voltage (it loads mains voltage)
- **Capacitive mode** Instrument operates on voltage-free installation (it imposes its own signal)

### a) Recognition of protective element in installation under mains voltage - inductive

**Fig. 74.** Connection of test instrument to phase and neutral conductors of electric appliance
Measurements on electric installations in theory and practice

Test instrument loads connected mains voltage i.e. it generates current test pulses of a certain frequency from phase terminal to neutral one. The current causes adequate electro-magnetic field around the connected conductors which can be detected by hand-held detector. This way the detector recognizes involved protection element (fuse).

If involved fuse of a certain mains socket is to be recognized, test instrument shall be connected directly to the socket according to the figure below.
b) Recognition of protective element in voltage-free installation - capacitive

**Fig. 76.** Recognition of protection element at voltage-free (auxiliary earth probe or PE terminal is used as referential terminal)

The same measurement can be done if test instrument is connected directly to mains socket according to the figure below.
c) Location of short circuit between phase and neutral conductor

Set detector to inductive mode of receiving.
d) Location of short circuit between phase and protection conductor

Set detector to inductive mode of receiving.

**Attention!**
Check the value of Earth Resistance $R_e$ before carrying out presented procedure. Max. value of the $R_e$ is 50 ohms, otherwise the procedure may be dangerous!

*Fig. 79. Connection of test instrument in order to locate short circuit between phase and protection conductor*
e) Location of current loop (conductor) interruption

Set detector to capacitive mode of receiving signal.

Fig. 80. Connection of test instrument in order to locate interruption of current loop