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STANDARDS GUIDE

EN 62305

MEASUREMENTS PERFORMED USING THE MRU-200, MRU-120, MRU-105, MRU-106, MRU-21, AND MRU-20 GROUNDING RESISTANCE METERS

EN 60364-6

MEASUREMENTS USING THE MPI-525, MPI-520, MPI-508, MPI-505, AND MPI-502 INSTALLATION PARAMETER METERS

Guide for the EN 62305 standard

I Measurements performed using the MRU-200, MRU-120, MRU-105, MRU-106, MRU-21, and MRU-20 grounding resistance meters:

Guide for the EN 60364-6 standard

II Measurements using the MPI-525, MPI-520, MPI-508, MPI-505, and MPI-502 installation parameter meters:

Chapter I. Measurements performed using the MRU-200, MRU-120, MRU-105, MRU-106, MRU-21, and MRU-20 grounding resistance meters - EN 62305.

1.Introduction

Earth resistance measurements significantly differ from other measurements performed to assess the protection against electric shock. They require a thorough knowledge about the construction of the earthing system, the phenomena occurring during the measurements and methods for managing difficult field conditions. Persons performing tests and measurements of ground systems must have appropriate knowledge and measuring equipment able to support such complicated task.

In 2008, the following standards were introduced EN 62305-1 Protection against lightning. Part 1: General principles and EN 62305-2 Protection against lightning. Part 2: Risk management. These standards included a description of damages and losses caused by lightning, the classification levels of lightning protection and lightning parameters. They also defined the term of earthing impedance.

In 2009 other parts of the standard were published - EN 62305-3 Protection against lightning. Part 3: Physical damage to structures and life hazard and EN 62305-4
Lightning protection. Part 4: Electrical and electronic systems within structures.
These standards set the requirements and ways of practical implementation, which relate to the proposed lightning protection systems, maintenance methods and assessment of correct assembly.

Requirements described in the above standards, indicating the necessity of measuring earthing impedance, correspond to the functions of the new meter created by SONEL SA - MRU-200. This device allows you to perform measurements of earth resistance not only using a technical method (low frequency) but also by the impulse method compliant with the definition presented in EN 62305. The offer of SONEL SA includes many devices to test earth resistance and soil resistivity – from simple ones designed for less demanding customers to more sophisticated models used in fully professional applications and in all technical conditions.

The most advanced meter model is MRU-200 - currently it is the only meter in the world, which is able to perform measurements of earth resistance using all known methods including the impulse method (option to select one of the three types of measuring edges). The offer also includes measures MRU-120, MRU-105 (the successor to the well-known MRU-101 meter), and MRU-21.

2. Earthing measurements

2.1 Earthing types

An earthing is an intentionally made connection between a device or electrical installation and a metal object located in the ground called an earth electrode.

Depending on the task of earthing, we may distinguish the following types of earthing: protective, operational and lightning protection (functional).

Depending on the components used in the construction of earth electrodes – they are divided into natural and artificial earth electrodes.

Natural earth electrodes may include: metal water pipes, metal elements embedded in the foundations, elements of concrete reinforcement located in the ground and other metal parts having good contact with the ground.

Artificial earth electrodes may include: sections, rods, wires, cables, steel plates or strips, coated with a conductive protective coating (anti-corrosion), entered in the ground horizontally (horizontal earth electrodes) or vertically (vertical earth electrodes).

Earth electrodes may be made as single horizontal or vertical elements (centred earth electrodes) or as complex systems consisting of the earth electrodes arranged in different configurations (ground rings, grids, radial earth electrodes). Earth electrodes in the form of a complex system are installed in order to provide low earthing resistance.

When installing earth electrodes, users should pay attention to the electrochemical potentials of individual system components. When the system will include the combination of a natural earth electrode in foundation (steel in concrete) and an artificial earth electrode, located outside of the foundation, made of galvanized steel, then the difference of electrochemical potentials between these elements will be approx. 1V. As a result of this difference a current will flow, causing the corrosion of steel located in the ground. Earth electrodes of such construction can not be used - they should be made of steel covered with a copper layer or copper or stainless steel.

2.2 Factors influencing the quality of earthing point

Earth resistance generally depends on soil resistivity. So it is obvious that a good grounding in areas of high resistivity (e.g. sandy grounds, wood areas) is difficult and requires far more resources than in wetlands with low soil resistivity.

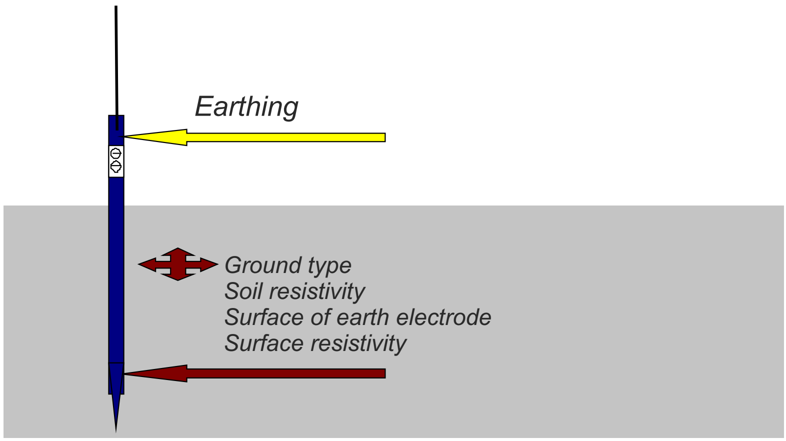


Fig. 1 Factors influencing the value of earthing resistance

Measurement of ground resistivity, performed in the design phase, are essential for optimal selection of the elements of earthing system and its depth in the ground in order to ensure desired earth resistance. These measurements considerable shorten the time of completion the whole project and optimize its costs. In most cases, the deeper earth electrodes are buried in the ground the lower is their resistance. Moreover, the deeper earth electrodes are buried in the ground, the greater is the stability of earthing resistance during its operation due to the limited influence of external factors (seasonal changes, rain).

Proper earthing should provide:

- low level of its assumed resistance (impedance),

- the lowest variability of resistance (impedance) over time,
- maximum corrosion resistance of earth electrode elements.

2.3 Factors affecting the accuracy of measurements

During the measurements of earthing resistance, we measure current flowing through the tested earthing and the voltage drop in this earthing. Using Ohm's law we calculate the value of earthing resistance. Earthing resistance is measured with AC, due to the electrolytic nature of the ground conductivity.

2.3.1 Effect of stray currents

Earth resistance measurement accuracy depends on many factors. The main factors causing measurement errors are stray currents (with mains frequency and its harmonics). During the measurement of operational earthing it is recommended to use the measuring current frequency as close to the mains frequency as possible - but it has to be different from 50 Hz and its harmonics. Fulfilling this requirement is very difficult in practice and causes very high design requirements of the meter. Only the best producers are able to fulfil this condition, and of course all SONEL SA meters are able to do it. Metering circuits of these instruments perfectly cope with interfering currents present in the ground, with mains frequency and harmonic frequencies. MRU-200 meter has a function for analyzing interference voltages and automatically selects appropriate measurement frequency to match interference currents. Test current generated in SONEL SA meters has a value above 200mA (excluding MRU-21) and together with a sophisticated noise filtration system it provides the highest resistance to interference voltages with an amplitude up to 24V AC (i.e. 68V_{p-p})

2.3.2 Effect of auxiliary electrodes

The resistance of auxiliary electrodes affects the additional measurement error. The bigger it is, the greater is its influence on the measurement result. The person performing the measurements, knowing the value of the resistance of auxiliary electrodes, may intervene in the case when this resistance is too high and may try to reduce it by entering longer electrodes into the ground, wetting the ground or entering the electrodes in a different location. The person may also use the existing earthing (if there are any) e.g., metal lamp posts, etc. Instruments offered by SONEL SA indicate the resistance of auxiliary probes, automatically calculate their effect on the additional error and allow users to perform measurements even with their considerable resistances – it makes them unique among all the meters for testing the earth resistance.

2.3.3 Effect of ground moisture

A very large impact on earthing resistance measurements has a degree of ground moisture. Measurements performed after the rain will indicate a much lower value of earthing resistance. If measurements cannot be made during normal ground moisture, correction coefficients should be applied.

Depending on the current ground moisture and the type of an earth electrode, the measurement results must be multiplied by an appropriate coefficient presented in Table 1. The coefficient K_p ranges from 1.1 to 3. Coefficients presented in the Table facilitate correction of seasonal changes in earthing resistance.

Table 1. Values of correction coefficient - K_p

Earth electrode type	Correction coefficient K_p depending on soil moisture		
	dry	wet	very wet
Deep, vertical earth electrode at the depth greater than 5m (below the surface)	1,1	1,2	1,3
As above but at the depth ranging from 2.5 - 5m	1,2	1,6	2,0
Horizontal earth electrode at depth of approx. 1m	1,4	2,2	3,0

It may be assumed that:

- for measurements performed within 2 to 3 days after rainfall,
- for measurements performed from September to October (the greatest resistance of earth electrodes during the year) in Europe,

there is no need to apply correction coefficients.

2.4 Accuracy of measurements vs. measurement range of the meter

Instruments, depending on the measured earthing systems, their nature and characteristics should be chosen to allow to perform measurements compliant with the relevant parts of EN 61557 standard:

- EN 61557- Part 4 "Resistance of earth connection and equipotential bonding"
- EN 61557- Part 5 "Resistance to earth".

It is required that the total measurement error is not above 30%. Most frequent mistake made by users is not taking into account the measurement range of the meter. This leads to accepting the results that are outside the range of measurement for assessing the suitability of tested facility. Measurement range of a meter defines the measuring range in which measurement error is within acceptable limits.

Very often, users of the instruments do not pay attention to the measurement range, usually checking only displayed values and the resolution of the meter. Often they can not calculate the measurement error basing on data provided by the manufacturer. It may happen that the results will have the measurement error above the value of the allowable error. The measurement range of the meter determines the range of its application.

Currently, manufacturers of measuring instruments are required to state measurement ranges on the meters, taking into account the error limit values specified in EN 61557. This obligation enables users to quickly compare error parameters of different devices and evaluate their suitability for various applications.

For example, while measuring the continuity of protective connections and equipotential bonding with MRU-200 meter the value is displayed with a resolution of 0.001 Ω with the accuracy for the range 0.000 ... 3.999 Ω ± (2% +4 digits), which provides the a measurement range compliant to EN 61557-4: 0.045 ... 19.9 k Ω. For the measurements of earthing resistance by 3 - and 4-pole, the measurement range according to EN 61557-5 is 0.100Ω... 19.9 kΩ. This means that the results of the measurements within these limits have an accuracy better than 30% and may be entered into an adequate report. Measurement abilities of SONEL SA meters are among the best in the world.

3. Measurements of Lightning Protection Systems according to EN 62305 standard

3.1 Sources and types of damage to a structure

The lightning current is the source of damage. The following situations shall be taken into account, depending on the position of the point of strike relative to the structure considered:
- S1: flashes to the structure;
- S2: flashes near the structure;
- S3: flashes to the services connected to the structure;
- S4: flashes near the services connected to the structure.

As result, the lightning can cause three basic type of damages
- D1: injury of living beings due to touch and step voltages;
- D2: physical damage (fire, explosion, mechanical destruction, chemical release) due to lightning current effects including sparking;
- D3: failure of internal systems due to LEMP.

In the standard the following types of loss are considered:
- L1: loss of human life;
- L2: loss of service to the public;
- L3: loss of cultural heritage;
- L4: loss of economical value (structure and its content, service and loss of activity).

3.2 Protection measures

Protection measures to reduce injury of living beings due to touch and step voltages:
– adequate insulation of exposed conductive parts;
– equipotentialization by means of a meshed earthing system;
– physical restrictions and warning notices.

Equipotentialization is not effective against touch voltages. An increase of the surface resistivity of the soil inside and outside the structure may reduce the life hazard.

Protection measures to reduce physical damage:

a) for structures
  - lightning protection system (LPS), when surge protective devices (SPD) are installed equipotentialization is a very important measure to reduce fire and explosion danger and life hazard.

b) for services
  - shielding wire (For buried cables, a very effective protection is given by metal ducts).

Protection measures to reduce failure of electrical and electronic systems:

a) for structures
  – LEMP protection measures system (LPMS) consisting of the following measures to be used alone or in combination:
    • earthing and bonding measures;
    • magnetic shielding;

• line routing;
• "coordinated SPD protection".

b) for services

– surge protective devices (SPDs) at different locations along the length of the line and at the line termination;

– magnetic shields of cables.

3.3 Lightning protection levels (LPL)

EN 62305-1 standard introduces four lightning protection levels (I to IV). For each LPL a set of maximum and minimum lightning current parameters is fixed (see Table 2)

Table 2. Maximum values of lightning parameters according to LPL

First short stroke			**LPL**			
Current parameters	**Symbol**	**Unit**	**I**	**II**	**III**	**IV**
Peak current	I	kA	200	150	100	
Short stroke charge	Q_{short}	C	100	75	50	
Specific energy	W/R	MJ/Ω	10	5,6	2,5	
Time parameters	T_1/T_2	μs/μs	10/350			
Subsequent short stroke			**LPL**			
Current parameters	**Symbol**	**Unit**	**I**	**II**	**III**	**IV**
Peak current	I	kA	50	37,5	25	
Average steepness	di/dt	kA/μs	200	150	100	
Time parameters	T_1/T_2	μs/μs	0,25/100			
Long stroke			**LPL**			
Current parameters	**Symbol**	**Unit**	**I**	**II**	**III**	**IV**
Long stroke charge	Q_{long}	C	200	150	100	
Time parameter	T_{long}	s	0,5			
Flash			**LPL**			
Current parameters	**Symbol**	**Unit**	**I**	**II**	**III**	**IV**
Flash charge	Q_{flash}	C	300	225	150	

Table 3. Minimum values of lightning current parameters together with the related rolling sphere radius LPL

Interception criteria			**LPL**			
	Symbol	**Unit**	**I**	**II**	**III**	**IV**
Minimum peak current	I	kA	3	5	10	16
Rolling sphere radius	r	m	20	30	45	60

3.4 Lightning protection zones (LPZ)

Protection solutions such as LPS, shielding wires, magnetic shields and SPD determine lightning protection zones (LPZ).

LPZ inwards of the protection measure are characterized by significant reduction of

LEMP (lightning electromagnetic impulse) than that outwards of the LPZ.

With respect to the threat of lightning, the following LPZs are defined:

- LPZ 0A zone where the threat is due to the direct lightning flash and the full lighting electromagnetic field. The internal systems may be subjected to full or partial lightning surge current;
- LPZ 0B zone protected against direct lightning flashes but where the threat is the full lightning electromagnetic field. The internal systems may be subjected to partial lightning surge currents;
- LPZ 1 zone where the surge current is limited by current sharing and by SPDs at the boundary. Spatial shielding may attenuate the lightning electromagnetic field;
- LPZ 2, ..., n zone where the surge current may be further limited by current sharing and by additional SPDs at the boundary. Additional spatial shielding may be used to further attenuate the lightning electromagnetic field.

In general, the higher the number of an individual zone, the lower the electromagnetic environment parameters. The standard defines detailed rules for designing LPS's in the above zones.

3.5 Protection of structures

3.5.1 Protection to reduce physical damage and life hazard

The structure to be protected shall be inside an LPZ 0B or higher. This is achieved by means of a lightning protection system (LPS).

An LPS consists of both external and internal lightning protection systems.

The functions of the external LPS are:

- to intercept a lightning flash to the structure (with an air-termination system),
- to conduct the lightning current safely to earth (with a down-conductor system),
- to disperse it into the earth (with an earth-termination system).

The function of the internal LPS is to prevent dangerous sparking within the structure, using either equipotential bonding or a separation distance (and hence electrical isolation) between the LPS components and other electrically conducting elements internal to the structure. Four classes of LPS (I, II, III, IV) are defined as a set of construction rules, based on the corresponding LPL.

Where surface resistivity of the soil outside, and of the floor inside the structure is not sufficiently high, life hazard due to touch and step voltages is reduced:

– outside the structure, by insulation of the exposed conductive parts, by equipotentialization of the soil by means of a meshed earthing system, by warning notice and by physical restrictions;
– inside the structure, by equipotential bonding of services at entrance point into the structure.

3.5.2 Protection to reduce the failure of internal systems

The protection against LEMP to reduce the risk of failure of internal systems shall limit:

- overvoltages due to lightning flashes to the structure resulting from resistive and inductive coupling;
- overvoltages due to lightning flashes near the structure resulting from inductive coupling
- overvoltages transmitted by lines connected to the structure due to flashes to or near the lines;
- magnetic field directly coupling with internal systems.

3.6 Surges due to lightning at different installation points

3.6.1 Surges due to flashes to the structure

For dimensioning of conductors, Surge protective devices (SPDs) and apparatus, the threat due to surges at the particular installation point of these components should be determined. Voltage surges can arise from lightning currents and from induction effects into installation loops. The threat due to these surges must be lower than the withstand levels of the components used.

When conducted to earth, the lightning current is divided between the earth termination system, the external conductive parts and the lines, directly or via SPDs connected to them.

This division of the lightning current depends on the number of parallel paths, conventional earthing impedance for underground parts, or their earth resistance, where overhead parts connect to underground, for overhead parts and the conventional earthing impedance of the earth-termination system.

Earthing impedance is defined in the standard as a ratio of the peak values of the earth-termination voltage and the earth-termination current which, in general, do not occur simultaneously.

Earthing impedance corresponds to the impedance (impulse earthing resistance), measured with MRU-200 meter .

Table 4 presents earthing impedance values Z and Z1, related to the class of LPS, assuming that:

Z - is the conventional earthing impedance of the earth-termination system,

Z1 - is the conventional earthing impedance of the external parts or lines running underground.

Table 4. Conventional earthing impedance values Z and Z1 - according to the resistivity of the soil

ρ Ωm	Z1 Ω	Conventional earthing impedance related to the class of LPS Z Ω		
		I	II	III - IV
≤ 100	8	4	4	4
200	11	6	6	6
500	16	10	10	10
1000	22	10	15	20
2000	28	10	15	40
3000	38	10	15	60
NOTE Values reported in this table refer to the conventional earthing impedance of a buried conductor under impulse condition (10/350μs).				

3.6.2 Surges due to induction effects

Surges due to induction effects from magnetic fields, generated either from nearby lightning flashes or from lightning current have a typical current waveform of 8/20μs.

3.7 Maintenance due to inductive effects

3.7.1 Inspection of LPS (lightning protection system)

The aim of the inspection is ensuring that:

a) lightning protection device is compatible with the design based on the EN 62305,
b) all elements of LPS are in good condition, are able to meet the design tasks and are not corroded,
c) all service equipment or structures installed after the LPS assembly are included in the LPS.

3.7.2 Sequence of inspections

Inspections shall be carried out in accordance with par. 7.1 of EN 62305-3 standard:

- during the construction of the object to check the built-in components,
- after installing the LPS,
- periodically, taking into account the nature of the protected object i.e. the risk of corrosion and the class of LPS,
- after changes or repairs, or when it is known that the object was struck by lightning.

During periodical inspections it is particularly important to check:

- deterioration of the elements: air terminal, cables and connections and their corrosion
- corrosion of earth electrodes,
- the value of earth resistance of earthing,
- condition of connections, including equipotential bondings and fixings

3.7.3 Intervals between LPS inspections

A visual inspection of the LPS should be carried out at least once a year. For areas where there are significant changes in weather and exceptional weather conditions, it is advisable to carry out inspections more frequently than stated in Table 5 .

Table 5. Maximum intervals between LPS inspections

Protection level	Inspections (years)	Full inspection (years)	Full instection of critical equipment (years)
I i II	1	2	1
III i IV	2	4	1

NOTE! LPS used in objects with explosion risk should be visually inspected every 6 months. Electrical tests on the installation should be performed once a year. An exception from the annual inspection plan is the inspection carried out every 14-15 months, in locations where it is considered beneficial to test earthing resistance at different times of the year in order to capture the seasonal changes.

Intervals between LPS inspections should be determined according to the following factors:
- classification of the protected structure, considering particularly the result of losses,
- LPS class ,
- local environment, e.g. in corrosive atmospheres the intervals should be short,
- materials of individual components of lightning protection device,
- type of surfaces to which LPS elements are attached ,
- soil properties and the associated rate of corrosion,
- mechanical exposure.

In the case of critical environmental conditions, mechanical stresses, the full inspection should be performed every year.

In the case of resistance changes greater than in the design, when the resistance increases between inspections, improving the LPS must be considered.

3.8 Procedure of LPS inspection

The aim of the inspection is to ensure that LPS in all respects meets the requirements of EN 62305 standard.

The inspection includes:
- checking technical documentation,
- visual inspection,
- checking and testing LPS,
- preparing the inspection report.

Checking the technical documentation consists in verifying its completeness, compliance with standards and conformity with as-built designs.

The visual inspection is performed to check whether:
- the design is in line with EN 62305,
- LPS is in good condition,
- there are any loose connections and accidental breaks in the cables and connections of LPS,
- parts has been weakened due to corrosion, especially at the ground level,
- all connection to grounding electrodes are intact,
- all visible wiring and components of LPS are fixed to the mounting surfaces,
- changes were introduced in the protected facility, that requiring additional protection,
- there are any signs of damage to LPS and the SPD,
- equipotential bonding were correctly made and the continuity tests were performed ,
- insulation gaps are as required.

3.8.1 Checking and testing of LPS

Checking and testing of LPS include the visual inspection and should be supplemented by the following activities:
- verification of continuity, especially in those elements that were not visible during the assembly and are not available for current inspection,
- measurement of earthing resistance for both: the system of earth electrodes and separate earth electrodes with an adequate inspection (test) report.

Measurements at high frequency (earthing impedance) are possible both during assembling and repairing the earthing system in order to compare the designed earthing system with the requirements.

Earthing resistance of each local earth electrode must be measured and where it is reasonable the system of earth electrodes should be subject to measurements. Each local earth electrode should be measured separately with the testing point between the outlet cable and each earth electrode in a disconnected state. Resistance to ground of the earth electrode systems as a whole should not exceed 10Ω. If there is a significant increase in the value of earth resistance, the cause of this increase should be found and repair activities should be carried out.

During the measurements in the rocky ground, earth electrode of the foundation should be placed in a concrete foundation, because (despite its reduced efficiency) it acts as an equipotential bonding. Conductors and the foundation earth electrodes should be connected, via test terminals, to additional earth electrodes.If no foundation earth electrode was made use a ground ring instead. If the earth electrode can not be installed in the ground and must be placed on its surface, it should be protected against mechanical damage. Radial earth electrodes, lying on or near the surface of the earth surface should be (to ensure their mechanical protection) covered with stones or embedded in concrete. Requirement of 10Ω in rocky areas is not applicable this case.

It is obligatory to inspect all cables, connections and connectors, or to measure their galvanic continuity. If the system of earth electrodes does not fulfil the requirements or inspection is not possible due to the lack of information, the system should be improved by installing additional earth electrodes or installing a new system.

3.9 Test / Inspection documents

In accordance with the requirements of EN 62305, the inspection of LPS should produce a report. The report should be stored together with the design report of LPS and previous maintenance and test reports of LPS.

LPS inspection report should contain information on:

- general condition of air terminals (wires and other elements),
- general level of corrosion and corrosion protection measures,
- the condition of fixing the cables and components of LPS,
- measurement of earthing resistance of earth electrodes,
- any deviations from EN 62305 standard,
- documentation of all changes and development of LPS, and any changes to the object. In addition, structural drawings of LPS should be checked along with its design description,
- obtained test results.

4. Methods used in earth resistance and earth impedance meters

Earth resistance measurements are performed with:

- the technical method,
- the technical method with clamps for measuring multiple earthing,
- the two-clamp method for measurements without auxiliary electrodes,
- the impulse method (impedance measurement).

Depending on the nature of the measured earth resistance, measurements shall be carried out for earthing resistance measurement or impulse method, corresponding to the earthing impedance compliant with EN 62305.
Earth resistance measurements are made with test current with a frequency close to the mains frequency (e.g. working earthing). Earth impedance measurements are made using current with the shape corresponding to the shape of lightning (for lightning earthing).

SONEL SA offers meters that provide options for measurements with different methods.

The offer of SONEL SA includes MRU-200 and MRU-120 meters that allow users to apply most of the known methods of measurement:

- 2-pole method (2p) - measurement of continuity of protective connections and equipotential bondings,
- 3-pole method (3p) - measurement of earth resistance by the technical method
- 4-pole method (4p) - which eliminates the influence of the test cable resistance on the measurement result ,
- 3p-method with clamp - allowing multiple earthing resistance measurement without disconnecting the test connection,
- Two-clamp method - allowing the measurement of earth resistance without auxiliary electrodes.

The meters have a function of ground resistivity measurements. Additionally, MRU-200 meter also has the option of impulse measurement method – used to check impedance earthing according to the requirements of EN 62305 for the measurement of lightning and earth leakage currents (damaging) using clamp.

MRU-200 and MRU-120 meters enable users to perform measurements in networks with a nominal frequency of 50 Hz or 60 Hz. Additionally, MRU-200 may perform measurements for 16 2/3Hz and 400Hz. Selection of measurement frequency (125Hz or 150Hz) may be made manually by the person performing the measurements (for MRU-200 and MRU-120 meters) or automatically by the meter based on the analysis of interference voltage (for MRU-200). MRU-200 meter has the best metrological parameters (the measurement resolution from 0.001 Ω, measurement range according to IEC61557 from 0.100 Ω).

MRU-105 and MRU-106 meters perform measurements with the following methods:

- 2-pole method (2p),
- 3-pole method (3p),
- 4-pole method (4p),
- 3p method with clamp,

In addition, it is possible to measure soil resistivity. The meter allows the measurement in the network at frequency of 50Hz (MRU-105) or 60Hz (MRU-106).

MRU-21 performs measurements with the following methods:
- 2-pole method (2p),
- 3-pole method (3p), with the resistance of auxiliary electrodes equal to 50 kΩ

Additionally, it is possible to measure the continuity of the protective and equipotential bonding with current of 200mA and option of auto-zeroing the resistance of test cables.

All the meters during the test also measure the earth resistance of auxiliary electrodes and analyze their impact on the value of additional error. Interference voltage is also measured. All the meters allow users to measure the earth resistance with interference voltages up to 24V.

4.1 Two-pole (2p) method - measuring the continuity of the protective and equipotential bonding

EN 62305 requires to test the connections wires of the earth electrodes. These tests are especially important when earthing wires are not visible. Such measurement shall be carried out in accordance with EN 61557 - Part 4, "Resistance of earth connection and equipotential bonding." Under this standard the minimum test current is not less than 200mA and the voltage at the open terminals shall be within 4 ... 24V. These conditions are met during the measurements performed with MRU-200, MRU-120, MRU-105, MRU-106, MRU-21 meters.

The method of measuring the continuity of the protective and equipotential bonding is shown in Fig.2.

The meter allows the use of cables of different lengths. In order to avoid the influence of their resistance on measurement results – these cables may be auto-calibrated. During the calibration, the resistance of test leads is measured and it is not added to the resistance measured - thus there is no additional measurement error.

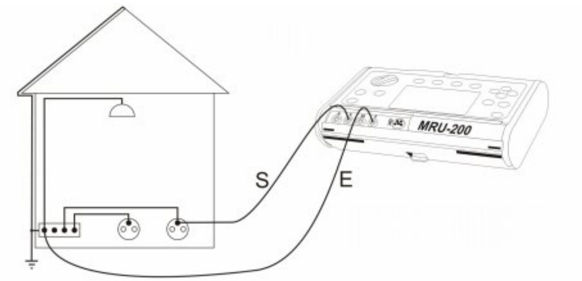


Fig . 2 Measurement of the continuity of the protective and equipotential bonding - 2p method

4.2 Two-pole (2p) method – measurement of earth resistance

2p method may also be used to measure the earth resistance. If the earthing system is known and there is a single earthing, where resistance value is known, the measurement result will be the sum of earth resistances of: the measured earthing and the one, where the value is known.

4.3 Three-pole (3p) method – (potential drop)

For measuring earth resistance the technical method is most commonly used and it is often called the potential drop method. During this measurement, the voltage drop is measured on the earthing along with the current that flows through it. The Ohm's law is used to calculate the resistance.

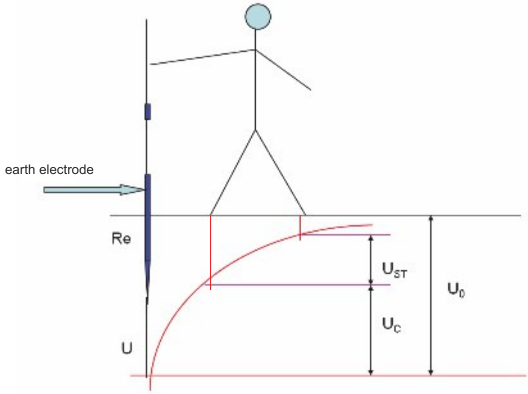


Fig. 3 Distribution of voltage around the earthing (U_C- touch voltage , U_{ST}- step voltage)

Fig. 3 presents the distribution of voltage around the earthing for fault current.

Fig. 4 presents the technical method of measuring earth resistance. Earth resistance R_E is measured. In order to perform measurement place two additional auxiliary electrodes:

- H electrode, to allow the force of current flow in the circuit:
    - earth electrode measured R_E→meter→current electrode E→ground,
- S electrode, to measure the voltage drop measured grounding resistance by flowing current.

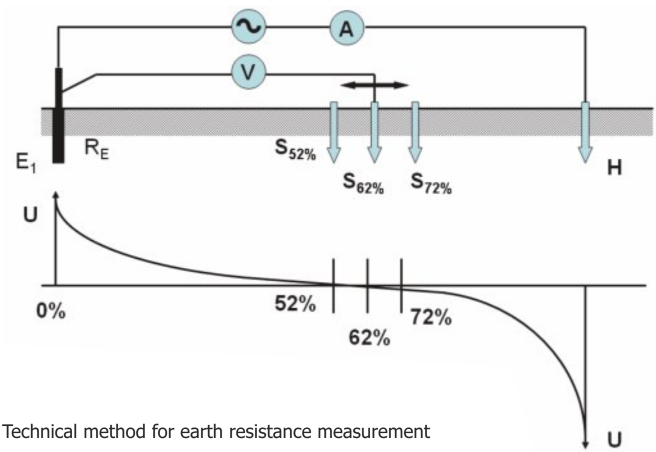


Fig. 4 Technical method for earth resistance measurement

Electrodes are placed in one line. Voltage electrode is placed midway between the electrodes. In this method, it is important to arrange auxiliary electrodes in order to obtain the place of zero potential - then the voltage drop be correctly measured on the grounding. The greater the distance between the measured earthing and electrode current H, the wider is the area of zero potential. To check whether a place potted voltage electrode was chosen correctly it is necessary to perform two additional measurements. If, after moving the voltage electrode in the direction of measured earthing and toward the current electrode (typically a few meters), the difference between the results is insignificant, then it may be assumed that the location of electrodes was chosen properly. The arithmetic mean of three results is the measured value of earth resistance.

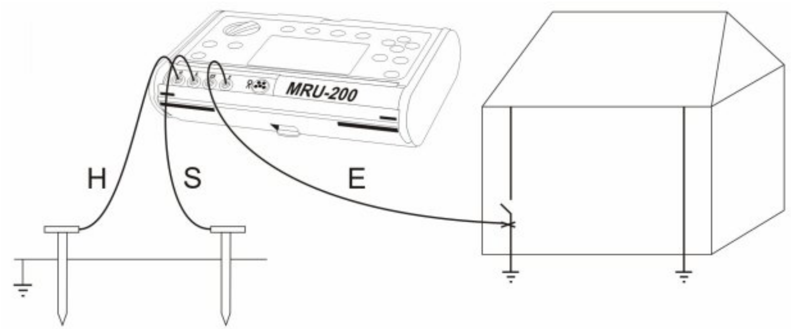


Fig. 5. 3p method for measuring earth resistance

When, after moving the electrodes the results will significantly different from each other, move the electrodes (usually in the direction of the current electrode H) or increase the distance between the electrodes. If that does not work, it is necessary to arrange the electrodes in the other direction. The reason for the problems with the earthing measurements may be in for example water pipes located in the ground (current flows through metallic connections).

In practice the entire length of the test leads/wires is used (in case of MRU-200 meter it is 50m for current electrode and 25m for voltage electrode). 3 p method of measuring earth resistance is presented in Fig. 5.

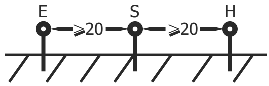
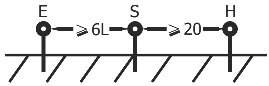
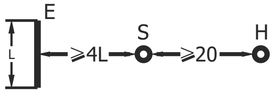
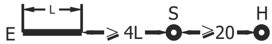
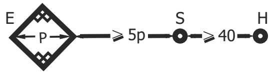
For measurement of widely spaced earth electrodes substantial length of test leads is required. In such cases, connects leads/wires are used and they are placed on spools (spools are designed for such connections).

For multiple measurements of earthing - disconnect test connection. Otherwise, the measurement will be the resultant resistance of the whole system.

At the time of measurement, MRU-200, MRU-120, MRU-105, MRU-106 and MRU-21 meters also measure the value of the interference voltage. Additionally, MRU-200 meter has an automatic selection of measuring frequency depending on the frequency of stray currents.
The highest quality of this meter allow users to measure of earth resistance in the most demanding conditions and for very small values of earthing.

The recommended distances between the auxiliary electrodes for measuring earth resistance are presented in Table 5.

Table 5. Recommended distances between auxiliary electrodes

Auxiliary electrode structure	**Minimum distances (m) or relative distances when the probe is applied in line with the tested electrode E**
Tested electrode E single vertical length L ≤3m	
Tested electrode E vertical length L≥3m	
Tested electrode E horizontal length L≤3m	
Tested electrode E horizontal length L≥10m	
Tested electrode E multiple – electrodes of square shape with diagonal p	

4.4 Four-pole (4 p) method

Four-pole method (4p) is used to measure earthing elements, when the required accuracy is high. In 3p method the displayed value is the sum of the measured ground resistance and resistance of test leads between E terminal of the meter and the measured earth electrode. In 4p method, the fourth wire, connected between ES terminal and the measured earth electrode, eliminates the effect of lead resistance measurement. Just as in 3p method, it is necessary to disconnect the control connection (otherwise it will measure the resistance of the whole earthing system). The method of measuring earthing resistance with 4 poles is presented in Fig. 6.

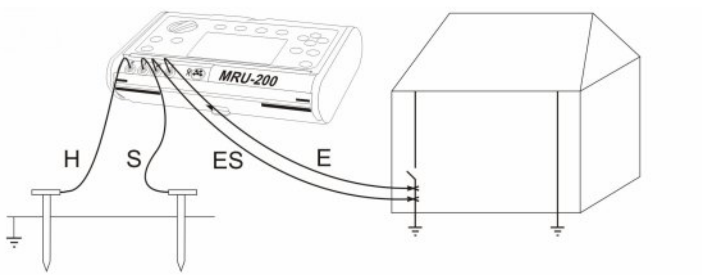


Fig. 6 Earth resistance measured with 4p method.

4.5 3p method with clamp

In measuring practice, often it is necessary to measure multiple earthing resistance when there is no possibility of disconnecting the control connection. The only possibility option in such cases is applying 3p method with clamps. This method uses two auxiliary electrodes, as in 3p method. As the control connection is not open, test current from E terminal of the meter flows through both the tested earthing and other earthing elements. To determine the current which flows through the tested earthing, measuring clamps are used. Basing on the measured voltage drop on the tested earth electrode and on measured current values, the meter calculates the value of earth resistance. When performing the measurement, pay attention to correctly place the clamps. They should be installed below the connection of E lead/wire. During the measurement only a part of generated current flows through the tested earth electrode. The rest of the test current flows through the other components of the earthing system. To ensure the highest accuracy, use clamps of the highest quality. The measurement range achieved by MRU-200 is 0.120 ... 1.99 k Ω. The method of 3p measurement is presented in Fig. 7

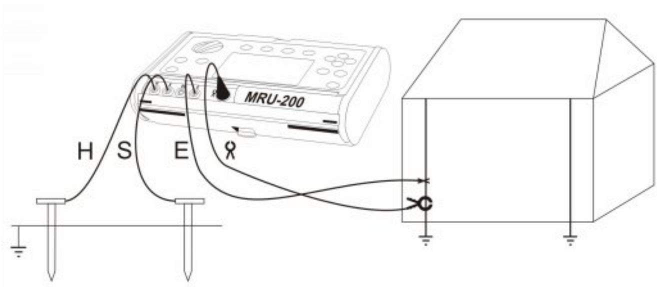


Fig. 7 The method of 3p measurement.

4.6 Two-clamp method

For a long time measurements of earth resistance in urban areas cause huge problems. To perform the measurement of earth resistance, it is necessary to generate current and then to calculate the resistance value basing on the voltage drop. In the city centre, where the buildings are very close to each other, often there is no way to enter auxiliary electrodes into the ground. In such conditions, two-clamp method may be applied. The principle of the two-clamp measurement method is shown in Fig. 8. The aim of measurement is to measure the earth resistance of the earthing electrode R_{E1}. to which other earthing electrodes are connected with resistances R_{E2}, R_{E3} ... R_{E6}. This method uses transmitting clamp (N-1) and receiving clamp (C-3). Transmitting clamp is used to generate a voltage in the circuit. Current flowing in the circuit depends on the values of circuit resistance - the lower the resistance value, the greater the current. Receiving clamp measures the current flowing in the circuit. On this basis the value of earth resistance is calculated. To make 2-clamp method possible, the circuit must be closed to enable the current flow. Therefore the measurement of one, open earth electrode is not possible in this method. To perform the measurement, a single earth electrode should be connected to another.

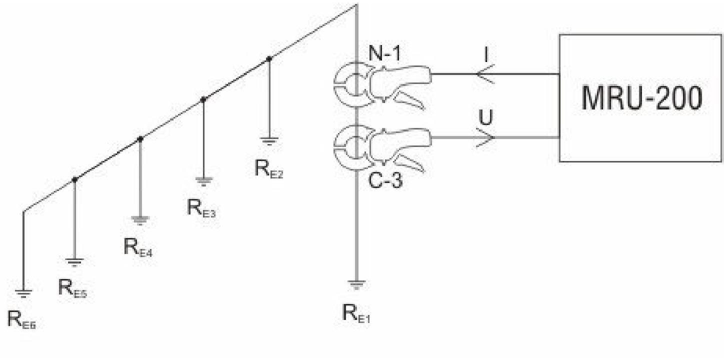


Fig.8 Two-clamp method used for earth measurements.

System of earth electrodes presented in Fig.8 was replaced by a substitute diagram shown in Fig. 9

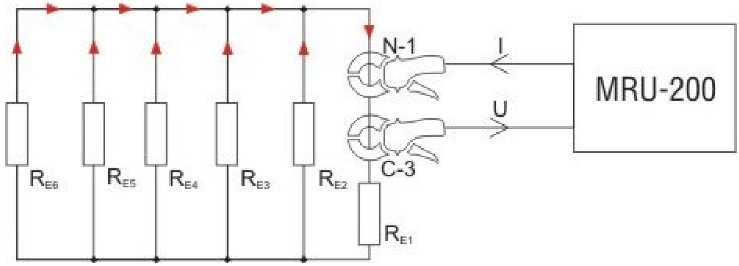


Fig.9 Two-clamp method used for earth measurements – a substitute diagram for circuit shown in Fig.8.

The substitute diagram shows the value of R_{E1} earth resistance. As is apparent from the formula below, the value displayed is composed of the measured ground R_{E1} and the resultant of other electrodes connected in parallel.

$$R_E = R_{E1} + \frac{1}{\frac{1}{R_{E2}} + \frac{1}{R_{E3}} + \frac{1}{R_{E4}} + \frac{1}{R_{E5}} + \frac{1}{R_{E6}}}$$

Thus the obtained value of earth resistance will be overestimated (positive measurement error). This is the error of the method. Since the resultant resistance of the other parallel earth electrodes (i.e. measurement error) will decrease with the increasing number of earth electrodes, it is recommended to perform measurements using this method in systems with multiple earth electrode.

Example

Measuring the resistance of the earth electrode as in Fig. 9 with R_{E1}=10Ω, with earth electrodes R_{E2}=R_{E3}=R_{E4}=R_{E5}=R_{E6}=10Ω, the value displayed by the meter will be R_E=10Ω + 2Ω= 12Ω. It may be seen that the measurement has an additional error of 2Ω.

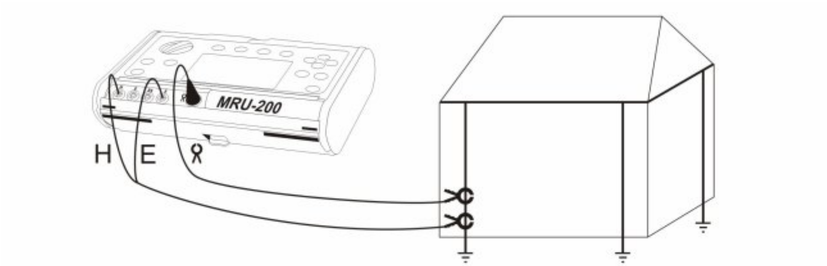


Fig. 10 Two-clamp method used for earth measurements

Because operational earthing work at 50Hz of mains frequency, it is recommended to perform measurements with test signal of a frequency as close to 50Hz as possible. SONEL SA meters (MRU-200, MRU-120) provide such option - for the 50Hz of mains frequency the measurement is made with the current at frequency of 125Hz (150Hz for the 60Hz networks). This involves sophisticated metering circuit of the meter, but these measurements best reflect the results for a frequency of 50Hz. Additionally important is the internal diameter of the clamp to be able to perform measurements of earth resistance for example on a band iron. For N-1 and C-3 clamp inner diameter is 52mm (2 inches). The method of two-clamp measurement is shown in Fig.10. When measuring with two-clamp method it is irrelevant whether the transmitting clamp is at the top or bottom. Important is the distance between the clamp, in order to avoid the influence of transmitting clamp on the receiving clamps. The recommended minimum distance is 30cm.

4.7 Measurements on lightning protection earthing

Designing and constructing earthing for lightning protection is different from methods applied for operational earthing used, for example, for protection against electrocution. Details are defined in EN 62305 - lightning protection. This standard introduces the concept of earthing impedance. Earthing impedance is defined as ratio of the peak values of the earth-termination voltage and the earth-termination current which, in general, do not occur simultaneously. This earthing impedance measured by MRU-200 meter - is called the impulse resistance R_d. Earthing (e.g. a band iron buried in earth) for mains frequency (50Hz) may be modelled as the resistance. Impedance in this case is equal to resistance (Fig. 11).

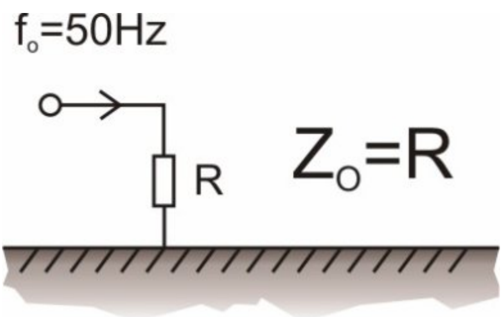


Fig. 11 Electrical model of a conductor buried in ground for mains frequency

Completely different is the model of the same conductor in the ground for the lightning stroke. For high frequencies, corresponding to the lightning discharge, the conductor should be considered as a transmission line. Then the conductor inductance and capacitance to the ground begin to play a significant role. Considering the conductor as a pure resistance in this case is a mistake. Such a system has the impedance, depending not only on its resistance , but also on its orientation in the ground. Electrical model for the lightning stroke is shown in Fig. 12.

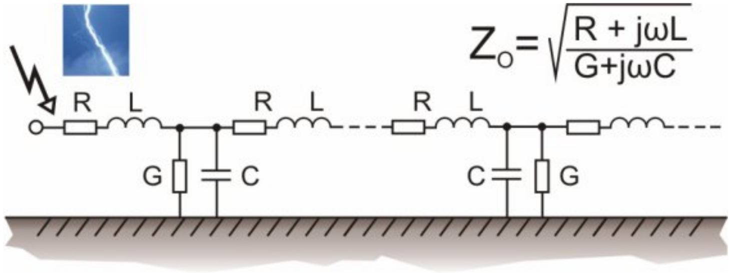


Fig.12 Electrical model of a conductor buried in ground for the lightning stroke

As indicated by the model, the largest share of the lightning current discharge is taken by the initial part of the earthing. Inductive reactance of the wire is the reason for which the further parts of the earthing have less influence on discharging the lightning to the ground.
The manner of arranging air terminals, conductors and earth electrodes is very important for effective lightning protection and should therefore be made in accordance with the requirements of EN 62305.

4.8 Impulse method

Measurements on lightning protection earthing should be performed in a manner as close as possible to the conditions occurring at the time of lightning stroke. To fulfil this requirement, the test current should have a shape which is created by the lightning stroke. The shape of the test pulse is shown in Fig. 13.

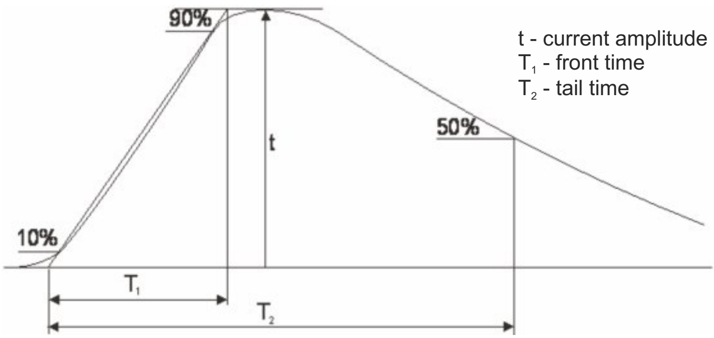


Fig.13 Parameters of short impulse (shape of the test impulse for the impulse method with MRU-200 meter)

The meter during the measurement generates a series of pulses with a given shape and amplitude of 1.5 kV and currents up to 1A. The device enables users to perform measurement with one out of three following impulse shapes:

- 4μs/10μs,
- 8μs/20μs,
- 10μs/350μs.

10μs/350μs impulse corresponds to the first short stroke, according to EN 62305 (see Table 2). Impulse shape of 8μs/20μs stroke corresponds to stroke resulting from the effects of inductive magnetic fields generated by the lightning current in the external LPS or by a nearby lightning discharge. The shorter the impulse selected for measurement, the greater is the effect of reactance.

The impulse method used in measurements in earthing elements differs from the technical method of 4p, which uses test frequencies similar to the mains frequency.
Applying the 4 p method eliminates the influence of impedance of the test lead/wire connected to the meter. A shielded cable is used for the measurement to eliminate the effect of noise on the measurement result. It is important that the screen of this cable is connected to E terminal of the meter. During the measurement test leads must be totally unwound and cannot be located on reel in order to prevent additional inductance. During the impulse measurement auxiliary electrodes must be arranged differently than in 4p method. To avoid inducing a voltage in S conductor by current flow in the H conductor - S conductor should be separated from H.
It is recommended that the cable wires are at angles greater than 60°.

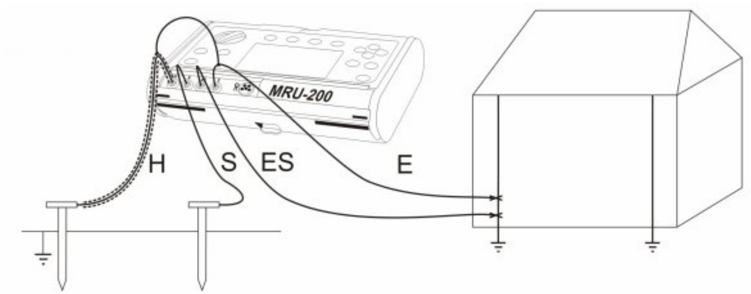


Fig.14 The method of connecting test leads/wires during the impulse method

5. Measuring ground resistivity

Designing new earthing systems should take into account local ground conditions. The most important earth parameter is the soil resistivity. Low soil resistivity means easier way of installing an earthing which fulfils pre-defined requirements. Rocky and sand areas, require complex earthing systems and higher costs in order to achieve an appropriate resistance value.

Resistivity model is presented as a cube with dimensions of 1m x 1m x 1m, filled with soil, while electrodes are located on opposite. Such a cube is connected to the voltage. Ratio of the voltage to the flowing current determines resistivity

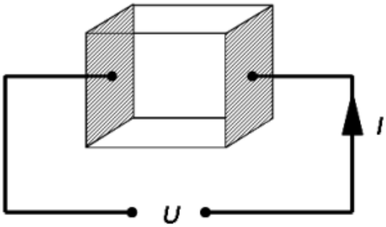


Fig.15 Model of ground resistivity (cube 1m x 1m x1m)

MRU-200, MRU-120, MRU-105 and MRU-106 meters measure the ground resistivity applying the Wenner's method (Fig. 16).

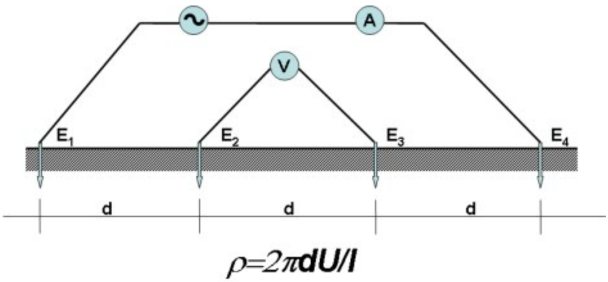


Fig. 16 Method for ground resistivity measurement (Wenner's method)

In this method the four probes are placed in a line at equal distances (Fig.17).

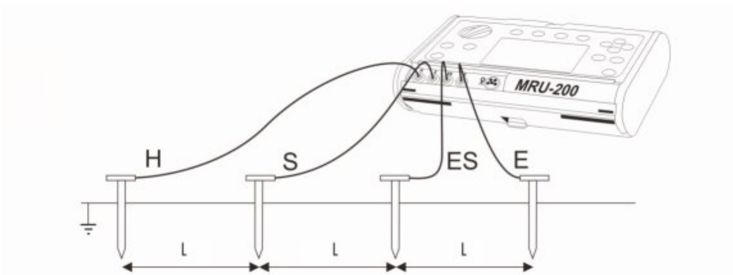


Fig.17 Method for ground resistivity measurement

Characteristic for Wenner's method is proportional relationship between the distance between probes and the depth to which the flowing current penetrates the ground. This relationship allows users to define the range of the depth at which the resistivity is measured and it amounts to about 0.7 of the distance between the probes. Performing a series of resistivity measurements, while changing the distance between the probes, we can determine approximately at what depth the lowest resistivity occurs. This knowledge is of crucial importance for material savings during the construction of earth electrodes.

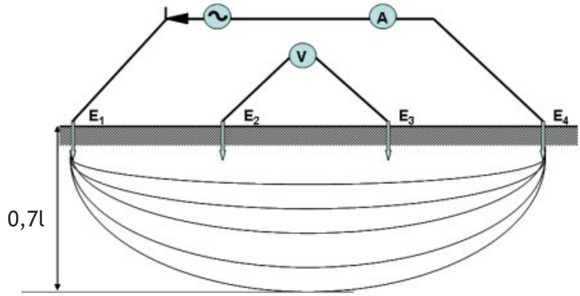


Fig. 18 The relationship between the distance the electrodes and the depth in which the ground resistivity is measured .

Example:

In order to determine the ground resistivity in the area of its frost penetration zone (approx 0.7 m), the probe must be spaced at 1m distance. After the measurement is done the electrodes must be rotated by 90° in relation to the first measurement. Similar measurement results are evidence of the homogeneity of the ground and the accuracy of tests. Water pipes or other metal parts buried in the ground may impact the ground resistivity measurements. This will be indicated by significant differences in results obtained in a series of resistivity measurements with the auxiliary probes directed in different directions. In such case it is necessary to change the place of an examination by replacing the probes and entering them into the ground a few meters from the place where the measurement is difficult.

Ground resistivity measurements enable users to determine the optimum depth at which vertical elements of earthing system should be buried into the ground. This saves both time and materials used to construct grounding systems.

Chapter II. Measurements of electric system parameters using combined measuring instruments - EN 60364-6.

1. Introduction

The standard HD60364-6 defines requirements pertaining to acceptance inspections and periodic inspections of electrical systems. Also, it defines requirements pertaining to reporting of inspection results.

SONEL S.A. is the manufacturer of electric system parameter measuring instruments MPI-502, MPI-505, MPI-508, MPI-520, and MPI-525.

The present publication is intended to present the way these measuring instruments can be used to perform measurements in accordance with the aforementioned standard.

In specific situations where measurements must be performed with special equipment, SONEL S.A. can provide measuring instruments intended to perform measurements, among others, of:

- short circuit loops (to include the strong-current short circuit loop impedance meter MZC-310S with resolution of 0.1 mΩ, which is intended to perform measurements among others in transformer stations);
- insulation resistance with measurement voltage up to 5 kV and measurement range up to 5 TΩ, e.g. in cables and transformers (MIC-5000);
- grounding resistance and soil resistivity using a two-clamp method (MRU-120 and MRU-200) and the impulse method (MRU-200);
- low resistances (micro-ohmmeters) with measurement resolution of 0.1 μΩ (MMR-630);
- power supply quality (PQM-701 analyzer).

2. Legal requirements concerning the performance of measurements

The HD 60364-6:2008 standard defines two types of inspections:

- acceptance inspections;
- periodic inspections.

According to this standard, every system must be inspected during assembly, after assembly, and before handover to the user. The acceptance inspection must include comparison of the measurements results with the relevant criteria defined, among others in the multi-sheet IEC 60364 standard, so as to check if the requirements given there have been met. In the case of enlargement or modifications of existing systems, the same full scope of tests must be performed as in the case of a new system.

During the performance of the measurements, precautions must be observed to make sure that the inspection will not cause a hazard to persons or pets and that it will not cause damage to the property and equipment even if the tested loop is defective.

The person performing the inspection should be properly qualified and competent with regards to inspections. It must be emphasized that the person performing the inspection is responsible for preparing the system for tests, for conducting the tests, and for proper assessment of the test results (E and D license).

An acceptance inspection consists of a visual inspection and a test. A visual inspection must be performed before the test, before the power supply of the system is switched on.

A periodic test consists of activities necessary to determine if the system and all its components are in a condition that enables their continued operation..

3. Frequency of periodic inspections

The frequency of periodic inspections must be determined taking into account:
- the type of the system and equipment;
- the application and operation of the system;
- the frequency and quality of maintenance;
- the impact of weather conditions to which the system is exposed.

According to the current Construction Law, electric and lightning-protection systems must be tested at least once every five years.
It is recommended that the periodic inspection report define the date of the next required periodic inspection. Shorter inspection intervals are required in the case of:
- work stations or premises with the risk of electric shock, fire, or explosion caused by degradation;
- work stations or premises where both low- and high-voltage systems are present;
- municipal facilities;
- construction sites (absolutely mandatory in the case of a TN-S system);
- safety systems (e.g. emergency lighting).

Regardless of the requirements defined in the standard, good engineering practices intended to ensure effective electric shock protection and insulation resistance require observing inspection intervals given in Table 1.

Table 1. Types and frequency of measurements.

Premise type	Inspection interval	
	Electric shock protection effectiveness	Insulation resistance
With caustic fumes	at least 1 per year	at least 1 per year
With explosion hazard	at least 1 per year	at least 1 per year
Open space	at least 1 per year	at least 1 every 5 years
With very high humidity, approx. 100%, Intermittent humidity of 75-100%	at least 1 per year	at least 1 every 5 years
Hot, with air temperature above 35°C	at least 1 per year	at least 1 every 5 years
With fire hazard	at least 1 every 5 years	at least 1 per year
Constituting a hazard to people (ZL I, ZL II, ZL III)	at least 1 every 5 years	at least 1 per year
With a dusty atmosphere	at least 1 every 5 years	at least 1 every 5 years
Others not listed above	at least 1 every 5 years	at least 1 every 5 years

4. Selection of measuring instruments for the tests

The measuring instruments and devices must be selected in compliance with the respective parts of the EN 61557 standard:

- EN 61557 - Part 1 „General requirements"
- EN 61557 - Part 2 „Insulation resistance"
- EN 61557 - Part 3 „Loop impedance"
- EN 61557 - Part 4 „Resistance of earth connection and equipotential bonding"
- EN 61557 - Part 5 „Resistance to earth"
- EN 61557 - Part 6 „Effectiveness of residual current devices (RCD) in TT, TN and IT systems"
- EN 61557 - Part 7 „Phase sequence"
- EN 61557 - Part 10 „Combined measuring equipment for testing, measuring or monitoring of protective measures"

The permissible values of measurement errors given in the above standards are shown in Table 2.

Table 2. Permissible values of measurement errors acc. to the EN 61557 standard.

Measured value	Permissible measurement error
Insulation resistance	30%
Loop impedance	30%
Resistance of earth connection and equipotential bonding	30%
RCD tripping current	10%
Touch voltage	20%

Currently manufacturers of measuring instruments are required to provide on the instruments information on the measurement range, taking into account the permissible error values given in Table 2. Previously, the ranges given in the user's manuals of measuring devices were the displayed value ranges. As an example, in the measuring device MPI-525 (MPI-520, MPI-508, MPI-505, MPI-502), the displayed value range for loop impedance measurements is 0.00-1999 Ω, with error of ±(5% of the measured value + 3 digits). According to the EN 61557 standard, the permissible loop impedance measurement error is 30%. In the case of measurement using 1.2 m long measuring cables, the measurement range is 0.13 – 1999 Ω. This means that the measurement results in this range have measurement error lower than 30% and may be included in the measurements report. In the case of measurement results below 0.13 Ω, another meter (a special one) must be used to measure loop impedance. A SONEL S.A. meter that can be used is MZC-310S. Its range of displayed values is 0.0-1999 mΩ. The measurement range for the MZC-310S meter, according to the EN 61557 standard, is 7.2-1999 mΩ.

5. Safety of measurements – categories of measuring instruments

Measuring instruments are subjected to the working voltage and temporary exposures from the circuit they are connected to during the measurement or test.

When the measuring device is used for system testing, the temporary exposures can be estimated based on the location in the system in which the measurements are being performed.

According to the EN 61010-1 standard, circuits are divided into the following measurement categories:

- measurement category IV (CAT IV) – measurements performed at a low-voltage system source; examples are measurements of equipment at overcurrent protection devices;

- measurement category III (CAT III) – measurements performed in systems in buildings; examples are measurements performed at distribution boards, automatic switches, electrical system conductors, to include cables, busbars, connectors, power outlets in systems and equipment intended for industrial applications and other equipment, e.g. fixed motors permanently connected with to stationary systems;

- measurement category II (CAT II) – measurements performed in circuits that are directly connected with low-voltage systems; examples are measurements in home appliances, portable tools, etc.;

- category I (CAT I) – measurements performed in circuits that are not connected directly to a power supply system.

Another way to characterize a meter is to provide the maximum voltage-to-earth value. For example the MPI-520 meter has measurement category IV with the maximum voltage-to-earth value being 300 V; consequently, it is described as CAT IV 300 V meter. This means that it can be used to perform measurements even at building cable connections with maximum voltage-to-earth value of 300 V and that there are no problems with using it for 230 V phase voltages (phase-to-phase voltage of 400 V). Category IV 300 V is the equivalent of category III 600 V (CAT III 600 V).

6. System arrangements

Low-voltage power distribution systems (up to 1 kV) can be divided into the following arrangements:

- TN-C;
- TN-S;
- TN-C-S;
- TT;
- IT.

The first letter stands for the way the neutral point of the transformer is connected to the earth:
- T means that the neutral point of the transformer is connected to the earth directly;
- I means that the system is insulated from the earth or is connected with the earth through impedance.

The second letter indicates the way the accessible conductive parts of the equipment grounding are connected to the earth:
- T indicates a direct electrical connection between the equipment and the earth (T - terra - ground);
- N indicates a direct electrical connection between the equipment and a grounded point in the power supply system.

The subsequent letters, if any, indicate the presence of the neutral conductor and the protection earth conductor. S (separate) indicates that the protection function is provided by the PE conductor, which is separate from the neutral conductor.
C (common) indicates that one conductor (the PEN conductor) performs two functions: the neutral conductor and the protective conductor.

The TN-C system

In the TN-C system arrangement, the neutral point of the transformer is grounded, the accessible conductive parts of equipment are connected to earth through the power supply system with the combined PEN conductor. It must be emphasized that such a system can be used only if the cross-section of the PEN conductor is at least 10 mm2. (Note: “Old” systems are not TN-C systems. Currently, they are considered as unclassified).

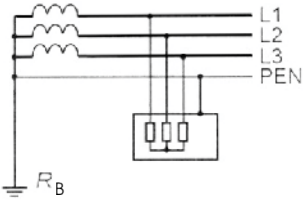


Fig. 1. The TN-C system

The TN-S system

In the TN-S system arrangement, the neutral point of the transformer is grounded and the accessible conductive parts of equipment are connected to earth through the PE conductor.

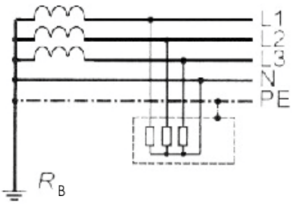


Fig. 2. The TN-S system

The TN-C-S system

In the TN-C-S system arrangement, the neutral point of the transformer is grounded and the accessible conductive parts of equipment are connected to earth through the power supply system: in part through the dedicated PE conductor and in part, closer to the transformer, through the combined PEN conductor.

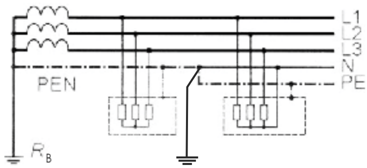


Fig. 3. The TN-C-S system

The TT system

In the TT system arrangement, the neutral point of the transformer is grounded and the conducting parts of equipment are connected with protective conductors to grounding electrodes that are independent of the working earthing.

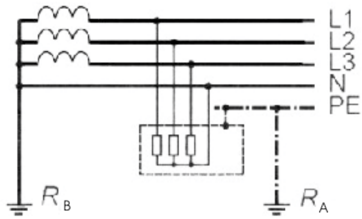


Fig. 4. The TT system

The IT system

In the IT system arrangement, the neutral point of the transformer is insulated and the accessible conducting parts of equipment are connected with protective conductors to grounding electrodes.

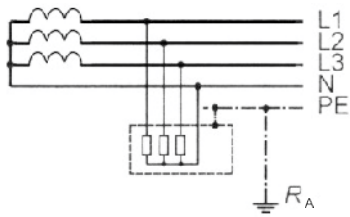


Fig. 5. The IT system

7. Types of measurements conducted during acceptance and periodic inspections

During the performance of acceptance and periodic inspections, depending on the needs, the following measurements must be performed in the order specified below (acc. to the HD 60364-6 standard):

a) continuity of conductors;
b) resistance of the electric system's insulation;
c) protection with SELV, PELV, or electric separation;
d) resistance/impedance of floors and walls;
e) autonomous switching off of the power supply;
f) supplementary protection;
g) polarity check;
h) phase sequence check;
i) functional and operational tests;
j) voltage drop.

If any of the tests are failed, the test, together with the preceding test if the detected defect may influence its results, must be repeated after the cause of the defect is eliminated.

7.1 Continuity of conductors

According to the standard, the electric continuity inspection must be performed in the case of protection conductors in main and supplementary equipotential bonding and active conductors in ring circuits.
According to the EN 61557-4 standard, the continuity test must be performed with current above 300 mA. Also, with the meter clamps open, the voltage must be in the range of 4-24 V. The required accuracy of the measurement is above 30%.

The method of performance of continuity checks with the MPI-525 (MPI-520, MPI-508, MPI-505, and MPI-502) meter is shown in Figure 6. The test is performed with direct current, with parameters meeting the requirements of the standard. The test must be performed twice, in each direction of current flow. The test result is the arithmetic mean value.

The measurement range of the meters according to the IEC 61557-4 standard is 0.12-400 Ω. This is a range where the accuracy of the measurement is higher than 30%, i.e. the result of the measurement can be included in the report.

Fig. 6. Method of conductor continuity inspection.

Due to the frequent need to use measurement cables with various lengths, the meter has the AUTOZERO function for calibration of the measurement cables.

7.2 Resistance of the electric system's insulation

Resistance of insulation must be measured between active conductors and the protective conductor connected to the earthing system. The active conductors may be connected together for this measurement. In the TN-C system, the measurement must be performed between the active conductors and the PEN conductor. Measurements must also be performed between the ungrounded protective conductors and the earth. In premises where a fire hazard is present, the measurements must be performed between the active conductors. The test voltage values depend on the nominal voltage in the circuit and are shown in Table 3. The table also shows the minimum values of insulation resistance for the respective cables.

The MPI-525 meter can be used to conduct measurements with the following voltage values: 50 V, 100 V, 250 V, 500 V, 1000 V, and 2500 V.

The MPI-520 meter can be used to conduct measurements with the following voltage values: 50 V, 100 V, 250 V, 500 V, and 1000 V.

The MPI-508 meter can be used to conduct measurements with the following voltage values: 250 V, 500 V, and 1000 V.

The MPI-505 meter can be used to conduct measurements with the following voltage values: 100 V, 250 V, 500 V, and 1000 V.
If there is any likelihood that the surge protection devices (SPD) or other devices can influence the results of the measurements or may become damaged, such devices must be disconnected before

the insulation resistance measurements are performed. If it is impossible to disconnect such devices (e.g. if the surge protection devices are integrated into fixed power sockets), then in the respective circuit the test voltage must be reduced to 250 V DC; however, the insulation resistance value must be at least 1 MΩ.

Table 3. Minimum values of insulation resistance.

Nominal circuit voltage (V)	**Test voltage DC (V)**	**Insulation resistance (MΩ)**
SELV and PELV	250	≥0,5
Up to and including 500 V, to include FELV	500	≥1,0
Above 500V	1000	≥1,0

Figure 7 shows the way the cables must be connected during insulation resistance tests.

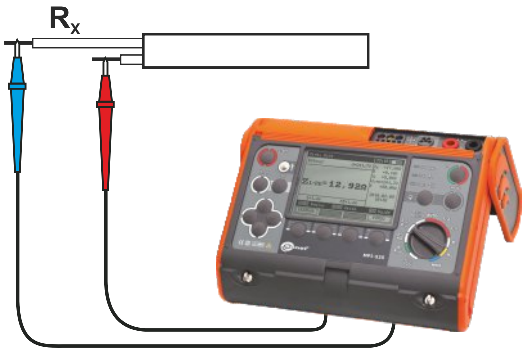


Fig. 7. Insulation resistance measured with the MPI-525 meter.

The MPI-520 meter can be used to measure insulation resistance in power supply sockets using a power supply system plug.

Fig. 8. Insulation resistance measured in a power supply socket with a UNI-Schuko plug (MPI-520).

In the case of 3-, 4-, and 5-core cables, the measurements can be much easier if one uses the AutoISO-1000C adapter (for MPI-508 and MPI-520) or AutoISO-2500 (for MPI-525). The meter performs all the measurements by itself and the results can be stored in its memory.

Fig. 9. Measurement of insulation resistance in multi-core cables using the AutoISO-2500 adapter.

7.3 Protection with SELV, PELV, or electric separation

Protection with SELV

It is necessary to measure the insulation resistance between the active parts of the SELV circuit and the active parts of other circuits and the earth. The measured insulation resistance values should be in line with those given in Table 3.

Protection with PELV

It is necessary to measure the insulation resistance between the active parts of the PELV circuit and the active parts of other circuits. The measured insulation resistance values should be in line with those given in Table 3.

Protection with electric separation

It is necessary to measure the insulation resistance between the active parts of one circuit and the active parts of other circuits and the earth. The measured insulation resistance values should be in line with those given in Table 3.

Resistance/impedance of floor and wall insulation

At least three measurements must be performed in the same premise; one at the distance of approx. 1 m from the accessible foreign conducive part located in the premise. The other measurements must be performed at larger distances. The measurements must be performed at the nominal resistance to earth and frequency. In the case of a DC system measurement with nominal voltage not larger than 500 V, the insulation resistance must be measured with the test voltage of at least 500 V; in the case of systems with nominal voltage greater than 500V, the test voltage must be at least 1000 V DC.

7.4 Protection with an automatic power supply shutdown

TN systems

According to the HD 60364-4-41 standard, in the case of TN systems the following condition must be met:

$Z_s \times I_a \leq U_o$ where:

Z_s is the loop impedance;

I_a is the current that causes automatic power supply shutdown in the time given in Table 4, with the reservations given in the HD 60364-4-41 standard;

Table 4. Maximum shutdown times.

System	50V < Uo ≤ 120V		120V < Uo ≤ 230V		230V < Uo ≤ 400V		Uo > 400V	
	a.c.	d.c.	a.c.	d.c.	a.c.	d.c.	a.c.	d.c.
TN	0,8 s	Note 1	0,4 s	5 s	0,2 s	0,4 s	0,1 s	0,1 s
TT	0,3 s	Note 1	0,2 s	0,4 s	0,07 s	0,2 s	0,04 s	0,1 s

Note 1: The shutdown may be required for reasons other than electric shock protection.

In the case of distribution circuits and circuits with overcurrent circuit breakers, for currents over 32 A, the permitted maximum shutdown time is 5 s.

In accordance with the standards, the inspection is performed by:
- measuring the loop impedance;
- checking the characteristics of the effectiveness of the protective device.

In the case of overcurrent circuit breakers, a visual inspection is required (checking the nominal current, the type of the breaker, the settings for the short-delay and no delay tripping of the circuit breakers). In the case of RCD devices, a visual inspection and measurements are required.

In accordance with the EN 61557-3 standard, the measurements of the loop impedance must be performed with measurement error below 30%. The MPI-525, MPI-520, MPI-508, MPI-505, and MPI-502 meters make it possible to perform measurements of a short-circuit loop using cables of different lengths. Table 5 shows the measurement ranges of the meters (the intervals for which the measurement error is below 30%, which enables including the results in the measurements report).

Table 5. Short-circuit loop measurement ranges for the MPI-525, MPI-520, MPI-508, MPI-505, and MPI-502meters.

Measurement cable	Measurement range Z_s
1,2 m	0,13...1999Ω
5 m	0,17...1999Ω
10 m	0,21...1999Ω
20 m	0,29...1999Ω
WS type plug - UniSchuko adapter	0,19...1999Ω

Measurements are possible in system systems with voltages:
- 110/190V,
- 115/200V,
- 127/220V,
- 220/380V,
- 230/400V,
- 240/415V.

The meters enable measurements at any voltage in the range of 95-440 V.

The meters enable measuring loop impedance in L-PE, L-L, and L-N circuits. The measurements can be performed using a measurement cable with a power supply system plug. The meters have an L-PE loop impedance measurement function in circuits protected with residual current devices (RCD) without tripping the circuit breaker.

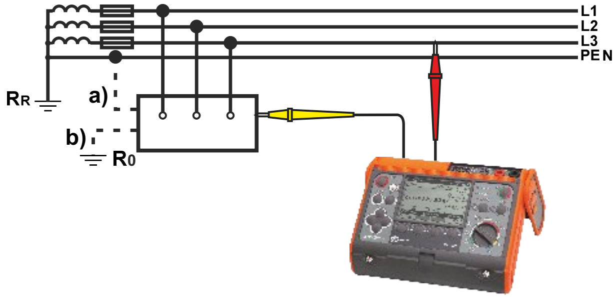


Fig. 10. Measurement of the loop impedance in the case of: a) a TN system; b) a TT system.

The meter displays both the measured loop impedance and the expected short-circuit current. Using the time-current characteristics for the tested circuit breakers and the anticipated short-circuit current, one can read the tripping time of the circuit breaker. By comparing the tripping time determined based on the band characteristics of the circuit breaker with the maximum time given in Table 4, one can determine if the requirements given in the standard have been met.

For example, Figure 11 shows the time-current characteristics of the system circuit breaker of the S-190 series. The characteristics of the S-190 type C circuit breaker indicate that for short-circuit current higher than 10 times the nominal current, the tripping time will be within the limits given in Table 4.

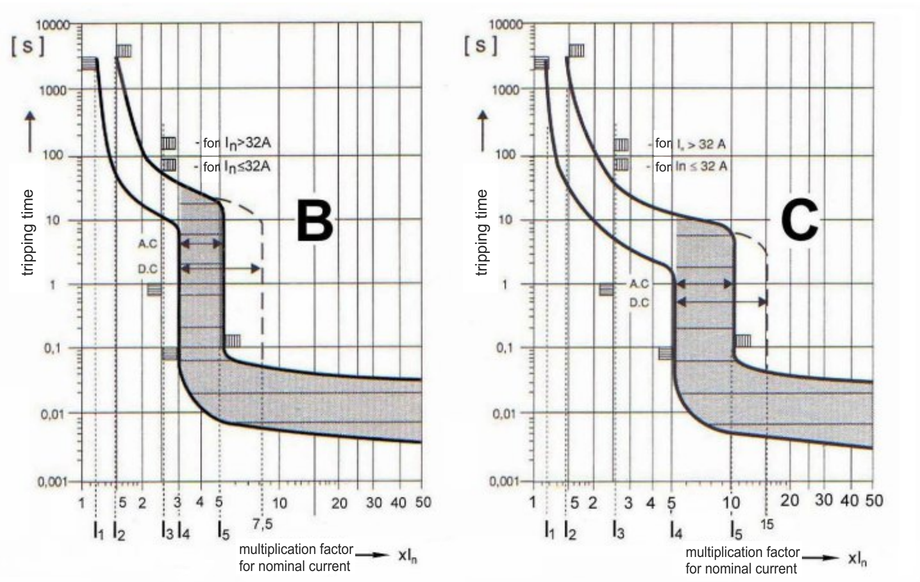


Fig. 11. Time-current characteristics of the system circuit breakers of the S-190 series, type B and C.

If SONEL PE4 software is used to prepare measurement reports, after the type of the circuit breaker has been selected and the results of the loop impedance measurements have been entered, the software automatically evaluates the conformance to the requirement that protection is to be provided with automatic power supply shutdown. The effectiveness of the automatic shutdown using RCD circuit breakers must be checked with properly selected meters in accordance with the EN 61557-6 standard.

The meters also have a function for testing RCD circuit breakers. the MPI-525 and MPI-520 meters can be used to test all kinds of RCD devices of the AC, A, and B type (AC and A type in the case of the MPI-508, MPI-505, and MPI-502 meters), with residual current values of 10 mA, 30 mA, 100 mA, 300 mA, 500 mA, and 1000 mA. Also, one can perform tests of short-delay, instantaneous, and selective RCD devices. In the case of such tests, one can select the multiplication factor for the nominal current ($I_{\Delta n}$) of the circuit breaker during the tripping time measurements. The possible values are 0,5 $I_{\Delta n}$, $I_{\Delta n}$, 2 $I_{\Delta n}$ i 5 $I_{\Delta n}$.

Figure 12 shows the measurements of the tripping time for an RCD device.

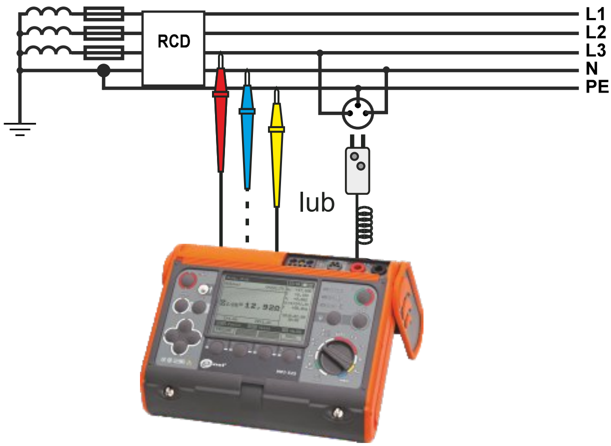


Fig. 12. Measurements of the tripping time for an RCD device.

The measured tripping time value must conform to the values given in Table 4. In observance of good engineering practices, one can perform an evaluation in accordance with the IEC/EN 6008 standard. The tripping times for currents equal to the nominal value of the RCD device are shown in Table 6.

Table 6. Maximum tripping time for RCD circuit breakers for nominal currents ($I_{\Delta n}$)

Type of RCD device	Maximum tripping time
Short-delay, instantaneous	300 ms
Selective	500 ms

One must test the RCD device for its characteristic forms of current. For example, a B type RCD device must be tested for pulsating sinusoidal current required by the meter, pulsating current with a base of direct current, and direct current for both a rising and a falling edge.

During the measurements of tripping times and currents for RCD devices, the devices become tripped. This leads to the need to switch the RCD devices on after every measurement.

In order to avoid multiple walks between the measurement point where the meter is connected and the RCD device, the MPC-525, MPI-520, and MPI-508 meters are provided with the AUTO function. This function allows for programming a sequence of measurements of an RCD device which includes measuring the tripping current, the tripping times for 0.5 $I_{\Delta n}$, $I_{\Delta n}$, 2 $I_{\Delta n}$ and 5 $I_{\Delta n}$ both for a rising edge and a falling edge, and also measuring the ZL-PE loop impedance. After the meter is connected to the measuring point and the measurements start, one must only switch on the RCD device several times until the measurement sequence is completed. There is no need to press the START button in the meter. The measured values are stored in the meter's memory.

The MPI-525, MPI-520, MPI-508, MPI-505, and MPI-502 meters also enable approximate measurements of tripping current and time of a circuit breaker with simultaneous tripping of the RCD device. In this mode, the meter gradually increases the test current and displays the current at which the circuit breaker became tripped and the tripping time for this current value.

The TT system

In the case of TT systems, where protection is provided using RCD devices in accordance with the HD 60364-4-41 standard, the tripping times must conform to the values given in Table 4.

Tripping time equal to 1 sec is allowed in distribution systems and circuits with protections above 32 A. RCD tripping time is measured with currents 5 times greater than the nominal current of the RCD device (5 $I_{\Delta n}$). Similar to the TN system, one can use the MPI-525, MPI-520, MPI-508, MPI-505, and MPI-502 meters, which enable measuring the tripping time.

Also, the following condition must be met: $R_A \times I_{\Delta n} \leq 50V$, where:

R_A is the sum of resistance of the grounding and the protective conductor for the accessible conducting parts of the short-circuit loop;
$I_{\Delta n}$ is the nominal current of the RCD device.

Table 7 shows the maximum values of the grounding resistance for different values of the $I_{\Delta n}$.

Table 7. Maximum grounding resistance values for different RCD devices.

Nominal current of the RCD device ($I_{\Delta n}$)	**10 mA**	**30 mA**	**100 mA**	**300 mA**	**500 mA**	**1000 mA**
R_A for 50V	5000W	1667W	500W	167W	100W	50W

The grounding resistance R_A can be measured using the MPI-525, MPI-520, MPI-505, and MPI-502 meter in the arrangement shown in Figure 10.
The condition will be met if the measured resistance value is lower than that given in Table 7. If resistance R_A is known, instead the loop impedance Z_S can be measured.

According to the HD 60364-4-41 standard, in TT systems where protection is ensured by using overcurrent circuit breakers, the following condition must be met

$Z_s \times I_a \leq U_o$ where:

Z_S is the loop impedance;
I_A is the current that causes automatic power supply shutdown in the time given in Table 4, with the reservations given in the HD 60364-4-41 standard. Tripping time equal to 1 s is allowed in distribution systems and circuits with protections above 32 A.
U_O is the nominal value of AC or DC voltage to earth.

Loop impedance in TT systems can be measured with the MPI-525 meter (MPI-520, MPI-508, MPI-505, and MPI-502). Loop impedance measurement in a TT system is shown in Figure 10. Besides the loop impedance, the meters also show the expected short-circuit current value. Based on the time-current characteristics of the overcurrent circuit breakers, one can read, for the expected short-circuit current, the tripping time for the overcurrent device and compare it to the required time.

If the SONEL PE4 software is used to prepare the measurement report, then after the overcurrent protection device has been selected and the measured expected short-circuit current has been entered, the software automatically evaluates the compliance with the automatic power supply shutdown condition.

The IT system

In IT systems, the following conditions must be met:

- in the case of AC systems: $R_A \times I_d \leq 50V$

- in the case of DC systems: $R_A \times I_d \leq 120V$, where:

R_A is the sum of resistance of the grounding and the protective conductor for the accessible conducting parts; I_d is the fault current for the first ground fault.

This condition must be checked by calculating or measuring the I_d current for the first ground fault of the phase conductor or the neutral conductor. The measurement must be performed only when calculations are not possible due to the lack of some parameters. During the measurement, one must be careful, so as to avoid the risk of double ground fault. If during the second ground fault in another circuit there are conditions similar to those pertaining to the TT system, then the same tests must be performed as in TT systems. If during the second ground fault in another circuit there are conditions similar to those pertaining to the TN system, then the same tests must be performed as in TN systems. When measuring the loop impedance, one must establish a connection with negligibly low impedance between the neutral point of the system and the protective conductor, preferably in the installation connection or, if that is not possible, at the measurement point.

7.5 Grounding resistance measurement

Grounding resistance is most often measured using a technical method. The method is described in Annex B to the HD 60364-6 standard. In this method, two ancillary electrodes are used. One electrode (H) enables the flow of current forced by the current meter and the other electrode (S) is used to measure the voltage drop in the tested earth electrode.

This method is used to measure grounding resistance with the MPI-525 and MPI-520 meters (Figure 13).

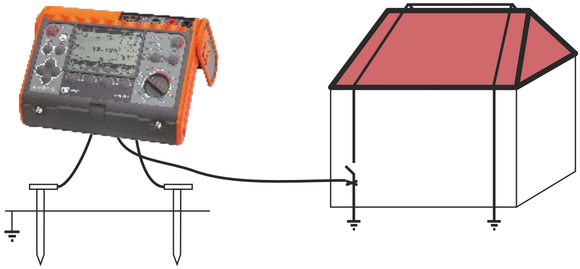


Fig. 13. Measurement of grounding resistance using the MPI-525 (MPI-520) meter.

The ancillary H electrode should be driven into the ground at the appropriate distance which depends on the size of the measured earth electrode. The S electrode should be located in the middle of the distance between E and H. In order to check the correct placement of the electrode, one must move the S electrode 6 meters towards the earth electrode and then 6 meters towards the H electrode. If the 3 results are approximately the same, then the average of the three measurements is assumed to be the grounding resistance. If the results are different, the measurements must be repeated. This means that the S electrode is not places at a zero potential location. In such a situation, the distance between E and H must be increased or the direction of the ancillary electrodes must be changed.

Before the measurements are taken, the MPI-525 (MPI-520) meter measures the interference voltage in the ground. The meter enables performing measurements at very large values of interference voltage (up to 24 V). The measurement current is 20 mA. The measurement voltage for measuring the grounding resistance can be selected to have the value of 25 V or 50 V. The value of 25 V is recommended for measurements in farmland (presence of animals). The measurements enable determining the grounding resistance and measuring the resistance of the ancillary electrodes.

If the location of the installation prevents placing two ancillary electrodes, then the standard allows for measuring loop resistance or using the two-clamp method. In such a case, one can use the special meter for grounding resistance and soil resistivity measurements, i.e. the MRU-200 meter made by SONEL S.A. The meter enables measuring the grounding resistance using all the known methods:

- the three-wire method (3p), as in the case of MPI-525 (MPI-520); the four-wire method (4p);
- the 3p method (Figure 14) using additional MRU-200, MRU-120, and MRU-105 measurement clamps (one can perform measurements of multiple ground electrodes without disconnecting the control connections);

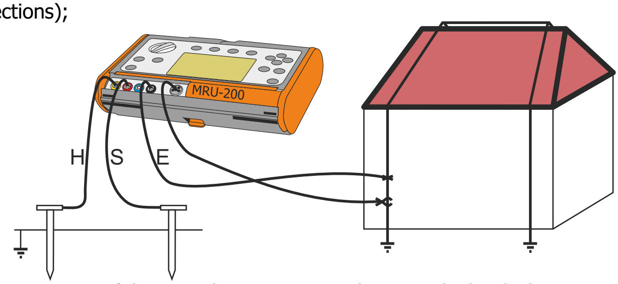


Fig. 14. Measurement of the grounding resistance – the 3p method with clamps.

- the two-clamp method (MRU-200, MRU-120) when ancillary electrodes cannot be used, with the exception of perimeter grounding electrodes);

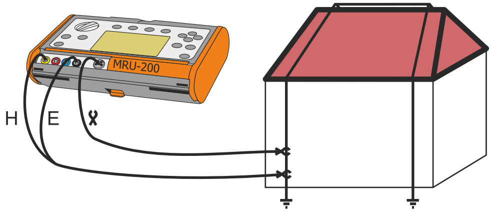


Fig. 15. Measurement of grounding resistance using the two-clamp method.

- the impulse method (MRU-200) (Fig. 16)

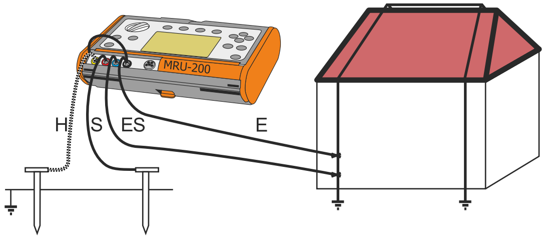


Fig. 16. Measurement of grounding resistance using the impulse method with the MRU-200 meter.

Also, it is possible to measure the leakage current using clamps and to measure the ground resistivity (MRU-200, MRU-120, and MRU-105).

The impulse method is used to measure the grounding impedance of:

- structures with explosion and fire hazard;
- sports facilities, cranes, and smokestacks;
- large grounding systems where other methods cannot be used.

In the impulse method, a current impulse is used, with shape similar to that of a lightning (Figure 17). The meter allows for selecting the shape of a T1/T2 impulse with the following parameters: 4 μs/10 μs, 8 μs/20 μs, or 10 μs/350 μs.

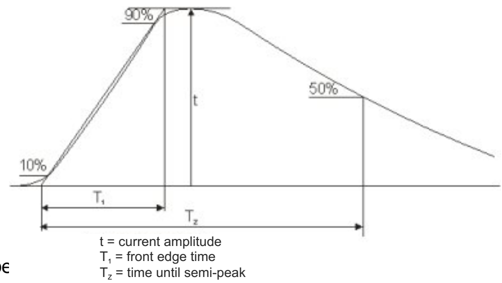


Fig. 17. Shape

The use of this shape of current results in the results of the grounding resistance measurements similar to those for resistance measurements for lightning strikes. During a lightning strike, only a part of the grounding electrode conducts the lightning current. In large grounding systems, the impulse grounding resistance can be many times larger than the resistance measured using other methods.

7.6 Supplementary protection

The effectiveness of measures implemented as a part of supplementary protection can be checked by way of visual inspections and measurements. If supplementary protection uses RCD devices, then one must use a meter that meets the requirements given in the EN 61557-6 standard. Such requirements are met by meters MPI-525, MPI-520, and MPI-508 made by SONEL S.A.

7.7 Polarity check

If the regulations prohibit using unipolar connectors in the N conductor, one must check if all such connectors are connected only to the phase conductors. This check can be performed using the volt meter of the MPI-525, MPI-520, and MPI-508 meters, as shown in Figure 18.

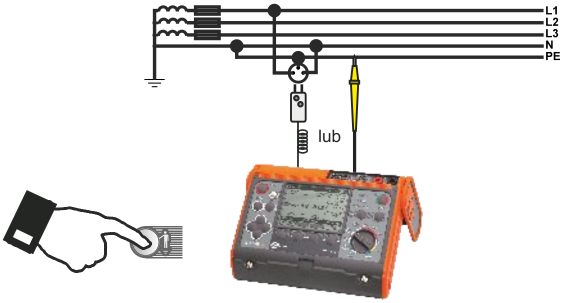


Fig. 18. Checking the correct connection of the PE conductor using the MPI-525 (MPI-520, MPI-508) meter.

7.8 Phase sequence check

In multi-phase circuits, one must check the phase sequence. For this purpose, meters MPI-525, MPI-520, MPI-508, and MPI-505 can be used, as shown in Figure 19.

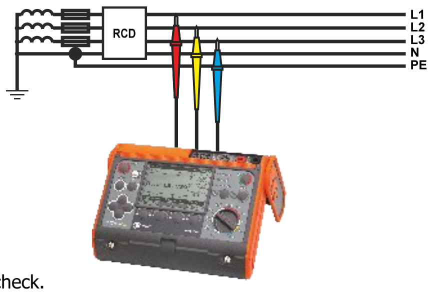


Fig. 19. Phase sequence check.

When the phase sequence is correct, the display of the meter will show phase rotation to the right (clockwise). The meter also measures the interphase voltage.

7.9 Functional testing

Distribution boards, control stations, control devices, interlocks, and drives must undergo functional tests intended to check if they are assembled correctly and if their settings are conformant to the relevant standards. If necessary, one must check the operation of the protection devices so as to make sure that they have been installed correctly and that their settings are correct.

7.10 Voltage drop

According to the HD 60364-5-52 standard, it is recommended that the voltage drop between the power supply source and the appliance circuits be less than 4% of the nominal power supply voltage. Only in the case of motor startup, voltage drops larger than 4% are allowed.
The voltage drop value can be determined by measuring the circuit loop impedance or on the basis of a diagram given in Annex D to the HD 60364 standard.

III Measurement reports

Reports must be prepared from testing of new, extended, or modified installations, as well as from periodic inspections.

Acceptance reports must include details of the tested installation, to include the results of the visual inspection and the measurements. Any defects or shortcomings found during the inspection must be eliminated before the contractor declares that the installation meets the requirements of the PN-HD 60364 standard.

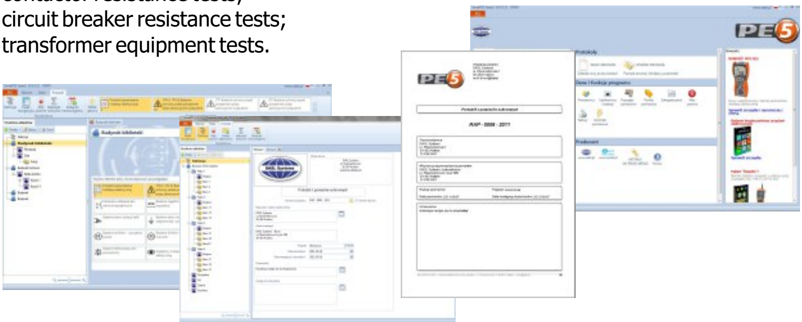
If the acceptance report pertains to a modified or expanded installation, it can contain an instruction to repair or improve the installation. The entries in the report must identify each circuit and its protective devices, as well as the results of tests and measurements.

An acceptance report must include the names of persons responsible for the safety, construction, and testing of the installation, taking into account the individual responsibility of those persons in relation to the person who ordered the work. An acceptance report must include recommendations concerning the time interval between the acceptance inspection and the periodic inspection. Similar information must be provided in the periodic inspection report.
Reports must be prepared and signed, or certified in other ways, by persons who are competent to perform the inspections.

SONEL PE5 software

The software enables automatic preparation of reports to document the following types of measurements:
- automatic shutdown effectiveness tests (TN-S, TN-C, TN-C-S, TT, IT);
- RCD device parameters tests;
- circuit insulation condition tests (TN-S, TN-C, TN-C-S, TT, IT);
- electric cables insulation condition tests;
- comprehensive measurement points tests;

- lightning-protection systems and grounding condition tests;
- conductor continuity tests;
- closed- and open-winding motor insulation resistance tests;
- contactor resistance tests;
- circuit breaker resistance tests;
- transformer equipment tests.



Automatic calculations and evaluation of entered results. Work with files (no need to archive and dearchive the reports).

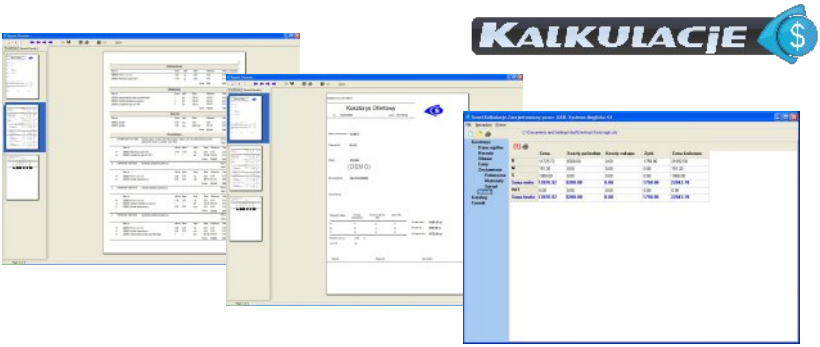
Additional features of the software:

- modern software interface;
- possible printout of abridged reports;
- adding drawings and photographs below report tables;
- creation of user's views of report tables;
- cooperation with meters made by Sonel S.A.;
- importing data from drawings made in Sonel Schematic software and their automatic inclusion in the reports;
- additional options related to edition of tables;
- saving the reports in the PDF format; possibility to enter an image with a seal and a signature;
- entering combined measurement points – a set of repeated measurement points, assembled by the user, entered into the table at one time;
- series filling out of the columns with values – the user can highlight a part of a column or the entire column and fill it with a series of data;
- data analysis – the software analyzes the data entered by the user and evaluates its conformance to the requirements;
- possibility to change the descriptions in the table headings; determination of accuracy and rounding up; hiding of columns; creation of user's own keys to headings;
- additional functions that facilitate preparation of reports and reduce the time needed to prepare them, which lowers the costs related to preparation of documentation;
- a calendar function – cyclic reminders of the need to perform measurements in specific facilities;
- ongoing updates over the Internet (manual or automatic);
- technical assistance (by phone or Internet).

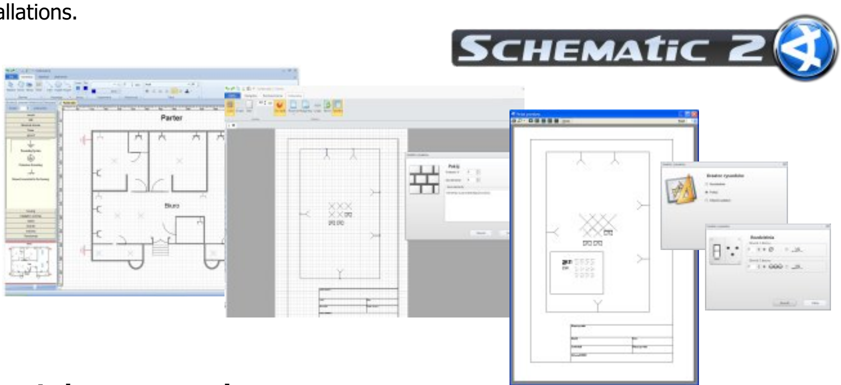
Equipment requirements:

- operating system: Windows 2000, Windows XP, Windows Vista (32 and 64-bit), Windows 7 (32 and 64-bit).

Sonel Kalkulacje software is intended for performing test calculations. Thanks to its simple structure, it does not require extensive knowledge of cost estimates. It works with the Sonel PE5 software to automatically generate cost estimates based on reports.



Sonel Schematic software is intended to make sketches, plans, and diagrams of electrical installations.



IV Laboratory services

The testing and calibrating laboratory of SONEL S.A. offers calibration tests and certificates for the following devices:

- meters for circuit breaker and protection device tests:
  insulation resistance tests, grounding resistance and impedance tests, short-circuit loop tests, residual current device parameters tests, and combined meters tests including functional tests of such devices;
- electric equipment safety meters;
- low resistance meters;
- voltmeters, ammeters (including clamp ammeters), resistance meters, and multimeters;
- light intensity meters;
- thermovision cameras;
- pyrometers.

A calibration certificate is a document that confirms the compliance of the parameters declared by the manufacturer of a tested instrument with the state-required standard, with information on the uncertainty of the measurement.

According to the ISO 10012-1 standard, Annex A "Quality assurance requirements for measuring equipment. Metrological confirmation system for measuring equipment", SONEL S.A. recommends periodic metrological inspections of its equipment to be conducted **every 13 months.**

Note:

In the case of equipment used for tests related to electric shock protection, the person performing the tests must be absolutely sure that the equipment is in good working order. Tests performed with meters that are out of order may result in an erroneous evaluation of the effectiveness of the protection of human health and lives.

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http://www.en.sonel.pl

Sonel offers broad range of training:

MPI-520/SONEL PE5: Operating, measurements with multi-function MPI-520 meter, and issuing test reports with SONEL PE5 software.

MPI-508 and SONEL PE5 software: Operating, measurements with multi-function MPI-511/ MPI-508 meters, and issuing test reports with SONEL PE5 software.

MRU 200 / SONEL PE5 software: Operating, measurements with earthing resistance and ground resistivity MRU-200 meter, and issuing test reports with SONEL PE5 software.

KT-384, KT-160, KT-160A, KT-150, KT-140 thermovision cameras: Operating, measurements with thermovision cameras and issuing reports with Sonel ThermoAnalyze software.

PQM-701 and SonelAnalysis software: Operating, recording with PQM-701 power supply quality analyser and issuing analysis reports with SonelAnaliza software.

PAT-805, PAT-800 and SonelPAT software: Operating, measurements with PAT-800, PAT-805 electrical safety meters, and issuing reports with the SonelPAT software.

Measuring techniques: Cycle of training courses on measuring techniques, regulations, standard and operating SONEL meters.

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