Electrical Safety and Quality Application Trainer

MI 3399

Instruction manual with exercises

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1 Introduction

Electrical Safety and Quality Application Trainer MI 3399 is a multipurpose trainer facility platform, suited for middle level technical schools, training centres and independent organizations who wish to evaluate people's competency and improve practical and theoretical knowledge of their listeners. The MI 3399 is ideally suited for training and education of larger groups of people as well as for independent practice.
The MI 3399 Application Trainer ensures absolute safety for the user. Protection circuits are monitoring potential dangerous contact voltages permanently and trip out the board automatically in case of error.
It simulates real low voltage electrical installation, special electrical installations for medical surgery rooms, mobile installations on vehicles, grounded and ungrounded TN / TT / IT systems, earthing and grounding points, LPS lightning protection system, three phase voltage and power quality situations, PAT and Machine training module, photovoltaic training module and much more. Major elements like fuses, RCD protection switches, outlets, alarms etc. are incorporated.
Simulation of possible errors is bringing the know-how about troubleshooting, maintaining, and caring out different measurements of electro-installation. It is aimed as well to be used at sale-demonstration rooms for presentation of electro-installation testers and their application.
The MI 3399 is foldable for simplified transport. The MI 3399 is designed to easy assemble with only two screws on the site for training, seminar or fairground. The dimensions of the single set are 210 cm (H) x 125 cm (L) x 125 cm (W).

Applications:

- Education, trainings and seminars with theoretical and practical exercising and testing for upgrading knowledge of a professional's competence.
- Education and practical training of electrical contractors about safety procedures, measuring methods and knowledge.
- Demonstration on how to use different measurement instruments and testers.

The MI 3399 Electrical Safety & Quality Application Trainer set enables several main training modules and courses:

- LV Electrical Installation Safety Trainer Module
- TN / TT / IT Earthing Systems Trainer Module
- Lightning Protection Trainer, Surge Protection Trainer Module
- Special Installations and Locations Safety Trainer Module
- Vehicles and Mobile Units Safety Trainer Module

Additionally there are several optional modules available:

- Power and Voltage Quality Trainer Module
- Appliances and Machines Safety Trainer Module
- Photovoltaic Systems Trainer Module
- LAN & Telecommunication Installations Quality Trainer Module

Modules are supported with Handbooks, Posters, Charts, Presentations, Exercises, Catalogues of Knowledge and Catalogues of Exam plus Approved Certificate optionally when separate training module is localized.

2 Description of MI 3399 Application Trainer set modules

All modules are fully functional once the Application Trainer MI 3399 is powered ON.

2.1 AD1 MI 3399 – EIS Electrical Installation Safety Trainer

EIS Electrical Installation Safety Trainer sub-modules:
- Low Voltage Electrical Installation Safety Trainer
- TN / TT / IT Earthing Systems Trainer
- Lightning Protection trainer, Surge Protection Trainer
- Special Installations and Locations Safety Trainer

This module comes together with the following equipment:
- MI 3152 ST Eurotest XC - Multifunctional Installation Tester
- MI 3110 EurotestIM - Special Installation Tester
- MI 3242 MicroOhm 2A-Earth Bonding 4-wire
- MI 3121H 2,5 kV HV Insulation Analyser
- MI 3123 Smartec - Earth/Clamp Tester
- MI 2014 Cable Scanner - LAN Cable Tester
- MD 9272 Leakage Clamp TRMS with Power & Harmonics
- A 1018 Current Clamp - (low range, leakage)
- A 1019 Current Clamp
- S 2009 Test lead set, 2m, 4pcs
- 25 pcs Guide for testing and verification of low voltage installations
- 25 pcs Guide for measurements on IT power installation
- 25 pcs Chart Verification on Low-voltage electrical installations
- Poster Verification on Low-voltage electrical installations
- Poster Medical Sites
- Poster Fire Brigades

Electrical Safety and Quality Application Trainer Package Set enables performing of the following tests:
- Continuity of PE conductors
- Earth Bonding 4-wire (with MI 3242)
- Insulation resistance
- HV Insulation Analysing, PI, DAR factors (with MI3121H)
- Line impedance
- Loop impedance
- RCD testing (Contact voltage, trip-out time, trip-out current, Autotest)
- IMD, ELM, RCM leakage and insulation monitors adjustment and test
- Earth resistance (4-wire, 3-wire, 2-wire, two current clamps)
- Specific earth resistance
- Lightning protection loops and legs resistance
- Surge protector test
- Leakage current
- Phase rotation
- AUTOSEQUENCE® procedure for TN, TT or IT earthing system.

More than 65 different measurements and testing methods could be demonstrated all in accordance to IEC 61557 and IEC 60364-6 (insulation resistance, continuity of PE conductors, earth resistance, specific earth resistance, line and loop impedance, phase rotation, leakage current, RCD testing, voltage and frequency and other).
The most significant elements are integrated: RCDs of different types, Fuses, PE equalization bars, 1-phase and 3-phase sockets, various grounding systems (TT, TN, IT), Surge protector, IMD insulation monitor and more.
More than 20 different errors can be set where problems on the field could be analysed and troubleshooting procedures trained.

2.2 AD2 MI 3399 – PQA Power and Voltage Quality Trainer

This module comes together with the following equipment:

- MI 2892 Power Master - Power Quality Analyser
- 25 pcs Guide for modern Power Quality Analysing Techniques
- 25 pcs Chart Power Quality Analysing and troubleshooting procedures

Power Quality Simulator Package Set enables performing of the following tests:

- Periodics Recording
- Min., Max., Avg. graphs
- Phase Diagram
- Harmonics Recording
- Frequency Measurement
- Voltage Quality Recording
- Voltage Events Recording
- Dips, Swells, Sags, Interruptions
- Waveforms
- Transients
- Inrushes
- Flickers
- Voltage asymmetry

2.3 AD3 MI 3399 – PAT Appliances & Machines Safety Trainer

This module comes together with the following equipment:

- MI 3309 BT DeltaPAT
- A 1488 BT Label Printer Able (with battery charger and one role of labels)
- 25 pcs Guide for verification of electrical safety of machines
- 25 pcs Guide for Electrical Equipment Testing
- 25 pcs Chart Testing and verification of Electrical Equipment
- Poster Portable appliances and electrical equipment testing

Appliances/ Machines/ Switchboard Package Set enables performing of the following tests and fault simulation:

- Continuity of Equipotential Bonding
- Insulation Resistance
- PE Leakage Current

- Substitute Leakage Current
- Touch Leakage Current
- Polarity of Cables
- Functional Operation
- AUTOSEQUENCE® Procedure

Examples are on following electrical equipment simulators:
- Portable appliance of class I (flat iron)
- Portable appliance of class II (radio receiver)
- Portable appliance of class I (extension drum)
- Portable appliance of class I (coffee machine)
- Portable appliance of class I (washing machine)
- Low voltage switchgear
- Electrical machine
- IEC cord

2.4 AD4 MI 3399 – PV Photovoltaic Systems Trainer

This module comes together with the following equipment:
- MI 3109 PS EurotestPV Pro Set
- 25 pcs Guide for measurements on PV systems

Photo Voltaic Package Set enables performing of the following tests:
- PV string insulation Resistance,
- Bonding Resistance of PV panel metallic support to Protective Earthing,
- PV string U/I Characteristics,
- PV string D.C. Current,
- PV string D.C. Power,
- Irradiance,
- Temperature on PV Panels,
- Inverter output A.C. Current,
- Inverter output A.C. Voltage,
- Inverter output A.C. Power,
- Inverter and PV system efficiency.

3 Unpacking of Application trainer

Figure 3-1: Unpacking the Application trainer (1).

Remove the bottom cover.

Figure 3-2: Unpacking the Application trainer (2).

Remove the upper cover.

Figure 3-3: Unpacking the Application trainer (3).

Remove the top and side covers.


Figure 3-4: Unpacking the Application trainer (4).

Prepare the MI 3399 to dig it up on wheels. Check all the wheels first. Clean the area around. Take care about enough space for operators.

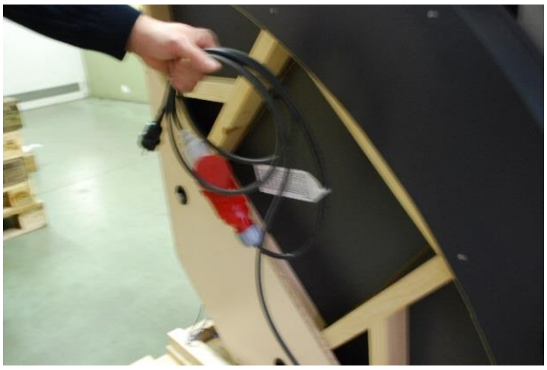


Figure 3-5: Unpacking the Application trainer (5).

Take care of the Main Plug cable. Put it in a safe location. Do not step on it and do not put the MI 3399 on the cable when manoeuvring.

Figure 3-6: Unpacking the Application trainer (6).

Dig up the top part of MI 3399. Additional help is needed to protect the MI 3399 during this step to put it on wheels gently.


Figure 3-7: Unpacking the Application trainer (7).

Remove screws from the backside of the MI 3399. Save the screws for later fitting of corner's walls (Fig.10).

Figure 3-8: Unpacking the Application trainer (8).

Remove the last part of the transport case. For any further transport, this transport case would be needed. Please keep safe all the parts of transport case in dry environment condition.


Figure 3-9: Unpacking the Application trainer (9).

Prepare the bottom part. Find two wires below the cover. Connect the blue and black banana to the blue and black plugs on the bottom side of the MI3399. Fit the corner's bottom part to the corner's wall.

Use the long screws from the transport case and fit the walls to the bottom part.

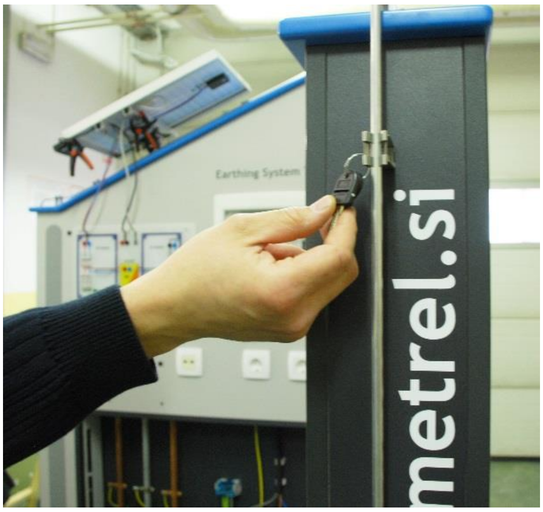


Figure 3-10: Unpacking the Application trainer (10).

Find the key of the corner's draw connected to the lightning leg.

Figure 3-11: Unpacking the Application trainer (11).

Open the draw. Find the table desk beside the draw and take it out.

Figure 3-12: Unpacking the Application trainer (12).

Find the additional parts inside the draw. Mount the plastic holders on the wall.

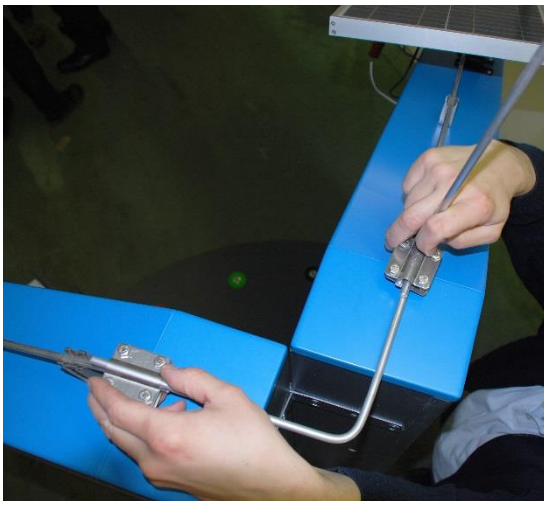


Figure 3-13: Unpacking the Application trainer (13).

Connect together the upper part of lightning conductors. Use the enclosed junctions and screws.

4 Description of the MI 3399 Application Trainer

4.1 Technical data

Mains connection	3-phase (4 m) type 3P+N+PE or one-phase type, using a 1-phase adapter (2 m).
Width	125 cm x 125 cm
Height	220 cm
Mass	240 kg approx., 350 with packaging
Fixing to a table:	by means of two screws (distance between fixing holes is 700 mm)
Respected standards	EN 61010-1 (safety) EN 50081-1 (EMC) N 50082-1 (EMC)
Test sockets	1-phase with PE terminal 3-phase (3L+N+PE)
Protection classification	CLASS I (PE terminal connected to metal housing)
Fuse protection	Fuse B 10

Table 4-1: Technical data.

4.2 Connection to mains voltage

Before connecting the MI 3399 Application Trainer to the mains installation, the following must be checked by the operator:

- That the PE terminal is present at mains outlet which is to be used for connection of the board.
- That there are no damages noticed at the outlet (mechanical damages, broken contacts etc.).
- That there are no damages present at the board's plug and at the board itself (damaged outlets, mechanical damages of other elements etc.)
- That there is a RCD protection switch I_{Δ}=30 mA (or any other protection switch) involved in mains installation to be used for disconnecting the MI 3399 in case of fault (recommendation).

The Application Trainer can be connected to nominal voltage of 230 V and 110 V. in either case the MI 3399 has full testing capabilities.

⚠ **Attention!**

- The socket where the MI 3399 is plugged-in must be earthed, since the Application Trainer tests for presence of voltage between the N and PE conductors. The Application Trainer will start only if the measured voltage is below 25 V regardless if the MI 3399 is installed in a 230 V or 110 V system.
- The board is allowed to be used only in presence of properly educated person-trainer or teacher when using it in schools.
- Use only attached original material (defined technical specifications) for carrying out required connections on front panel of the board.

- **Use the test outlets on MI 3399 walls for test purpose only and not for supplying different loads (radio, cooker, lamp etc.) because the components inside the board (wiring, switches, contacts, resistors etc.) are dimensioned for test purpose only.**
- To supply additional loads or instruments use the F0/1 outlet. This outlet is connected in parallel to mains and not through electronic circuits.
- Do not short accessible contacts at one-phase or three-phase outlets.

4.2.1 Connection to a 1-phase outlet

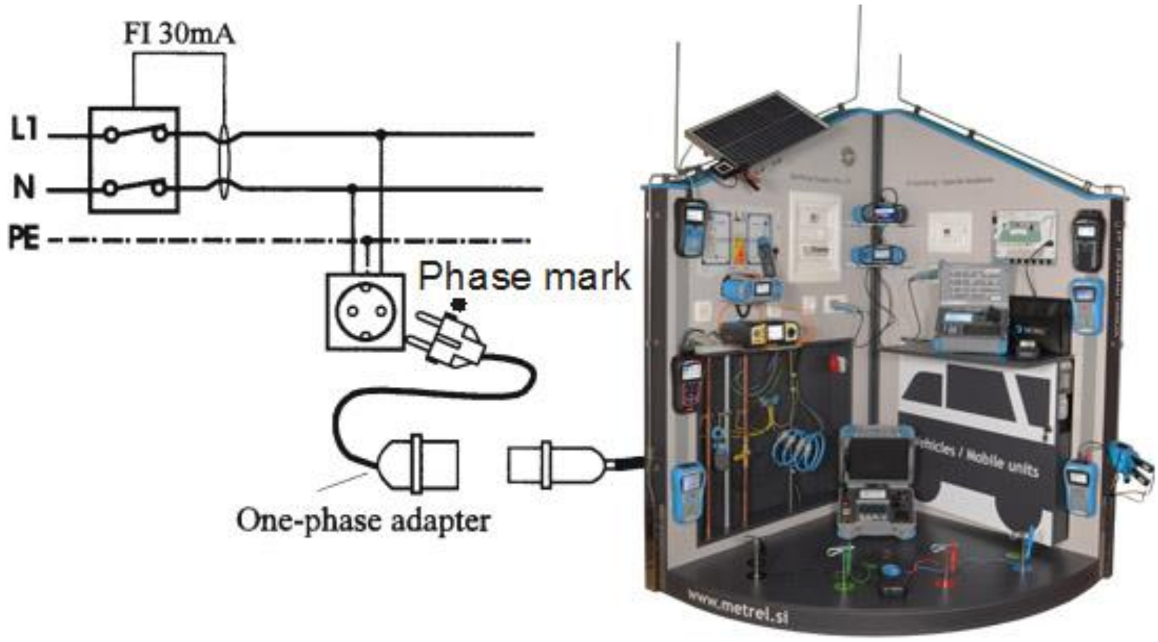


Figure 4-1: Connection of the Application Trainer to one-phase outlet.

After connecting the MI 3399 to the wall outlet check if lights L1, L2 and L3 are ON. Turn the Application Trainer ON by switching the circuit breaker on the bottom of the error switch panel (4 in Figure 4-4: Parts of the Application Trainer explained.). When the switch is turned ON, lights L1, L2 and L3 should light up.
If lights L1, L2 and L3 do not light up, check chapter 4.2.3 Error handling for further information.

4.2.2 Connection to a 3-phase outlet

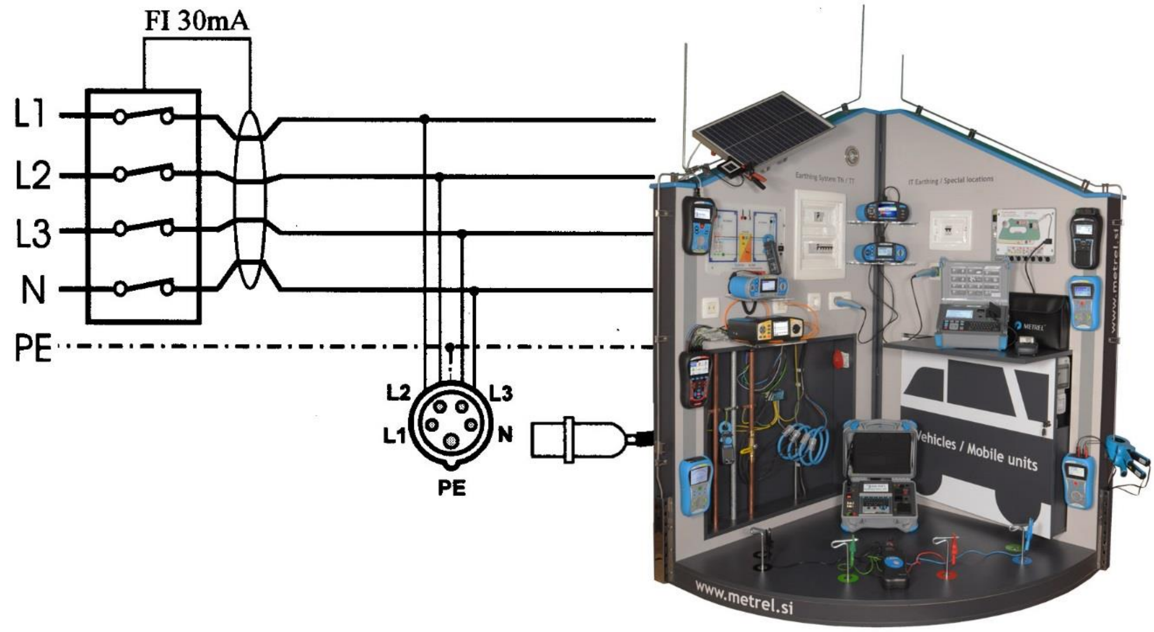


Figure 4-2: Connection of the Application Trainer to 3-phase outlet.

After connecting the MI 3399 to the wall outlet check if lights L1, L2 and L3 are ON. Turn the Application Trainer ON by switching the circuit breaker on the bottom of the error switch panel (4 in Figure 4-4: Parts of the Application Trainer explained.). When the switch is turned ON, lights L1, L2 and L3 should light up.
If lights L1, L2 and L3 do not light up, check chapter 4.2.3 Error handling for further information.

4.2.3 Error handling

Note: The equipment contains a special input protection circuit.

This circuit checks if any voltage is present between N and PE conductors to ensure that correct pins on the plug are connected to the correct conductors (L to L, N to N, PE to PE). The circuit decides this based on the measured voltage between N and PE points:

- If the measured voltage is **below 25V**[1], the **MI 3399 will start**. Lights L1, L2 and L3 will turn on.
- If the measured voltage is **above 25V**, the **MI 3399 will not start**. Lights L1, L2 and L3 will not show. In this case, the N and L positions must be changed.
  - In case a **1-phase outlet** is used, simply **rotate the plug**.
  - In case a **3-phase outlet** is used, check if the socket has the conductors correctly connected. If not fix the wall outlet.

Attention! Please ensure minimum of 20 s between unplugging the Application Trainer and plugging it in again for safety reasons.

[1] Note that line impedance does not have any effect powering ON/OFF the MI 3399. It does have an effect on the line impedance (Z_{Line}) measurement conducted in the Application Trainer.

If the MI 3399 still will not start check the rest of the installation to see whether conductors L and PE are also switched.

- Before any radical changes are made on the socket, first check if the circuit breaker at the bottom of the error switch box is switched on. If not, turn it on and check the lights again. If the MI 3399 still does not work, check the installation.

This will enable that the protection circuit is working correctly.

4.3 Front panel

Figure 4-3: Front panel.

4.4 Basic parts of the Application Trainer

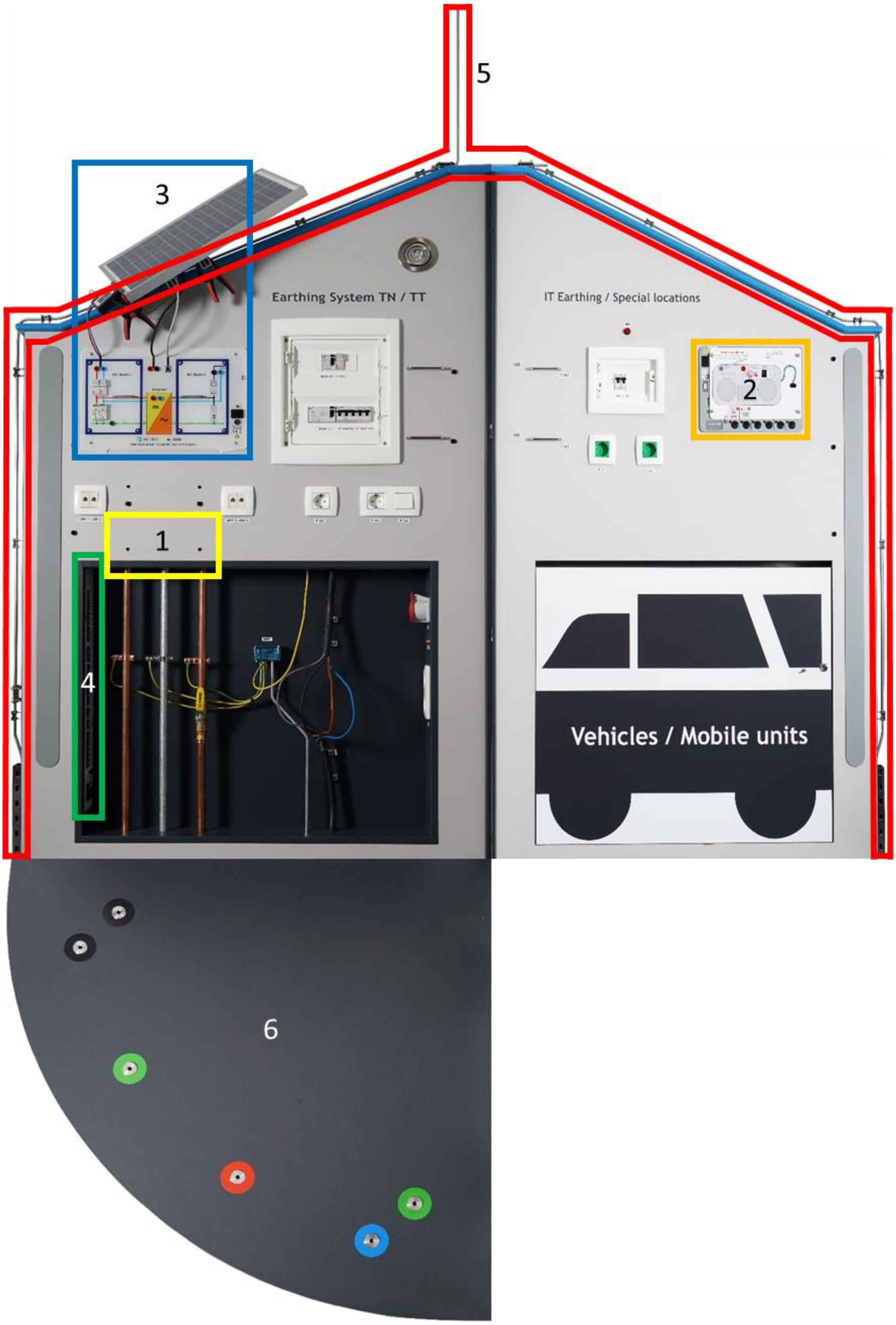


Figure 4-4: Parts of the Application Trainer explained.

The application trainer consists of four training modules and an error switch panel:

- Electrical installations module, which is further comprised of the following sub-modules (the whole module except parts 1, 2 and 3):
  - TN/TT module (complete left side of the MI 3399 with exception of 1 and 3)
  - IT module (complete left side of the MI 3399 with exception of 2), which further consists of:
    - the medical part
    - the vehicle part (e.g. fire trucks, police vehicles, …)
  - Lightning system with air terminals, down conductors and lightning rod sinks (5).
  - Earthing system (6).
- Power analysis module (1).
- Portable appliance testing (PAT) module (2).
- Photovoltaics module (3).
- Error switch panel (4) with:
  - Error switches S1 – S33.
  - Circuit breaker dubbing as an ON/OFF switch.
  - TN/TT switch

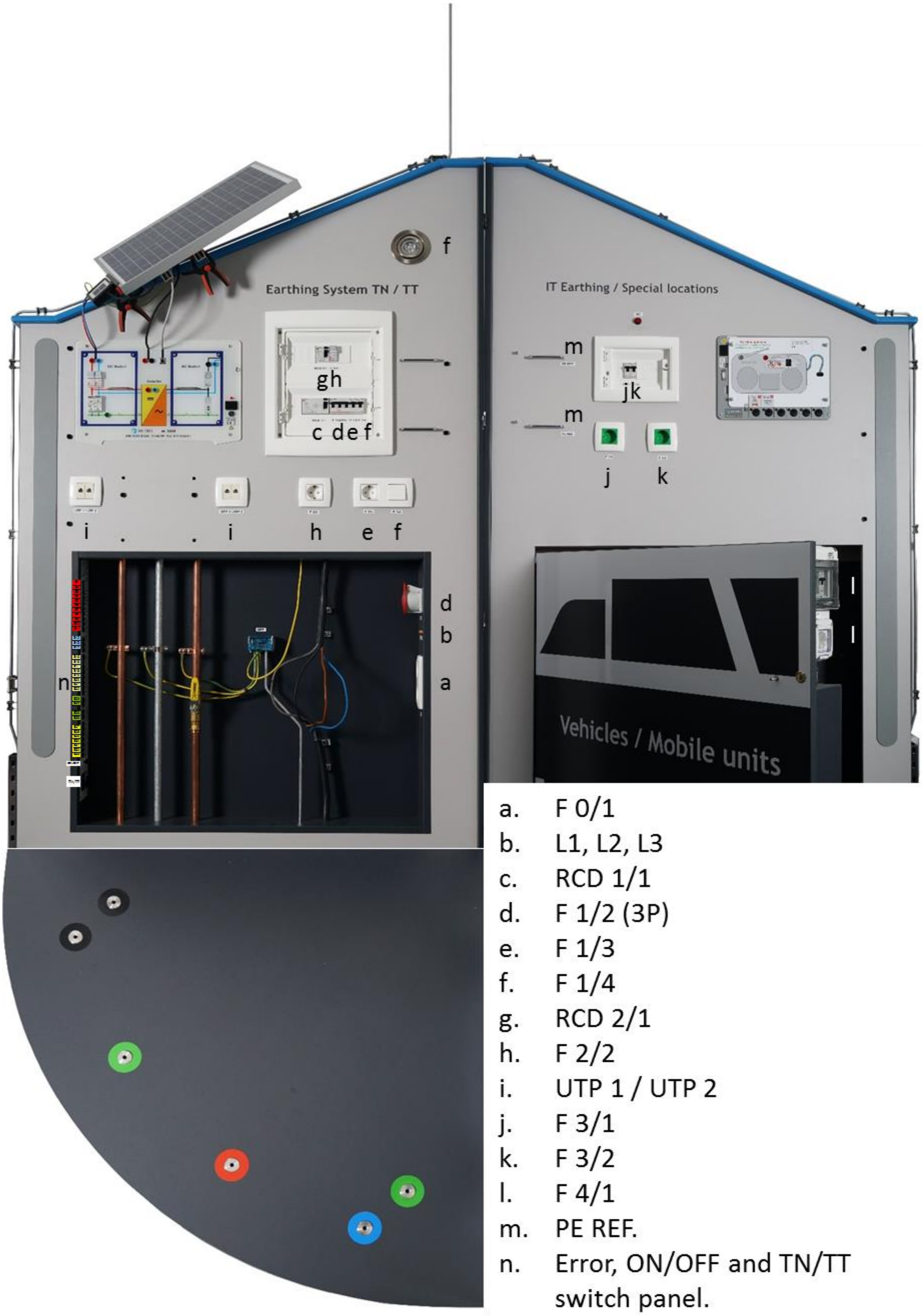
A very important part of the MI 3399 is the error switch panel (4), the part where error switches are installed. Here it is possible to set errors:

- On the electrical installation module and its sub-modules (middle part of 4).
- On power analysis module (upper part of 4).

At the very bottom of the error switch panel are:

- An electrical circuit breaker which has two functions:
  1. It protects the Application Trainer from over current faults.
  2. **It powers ON the Application Trainer (MI 3399).**

The location of all RCDs, fuses, circuit breakers, sockets and switches is shown in Figure 4-5: Location of RCDs, fuses, circuit breakers, sockets and switches.



a. F 0/1
b. L1, L2, L3
c. RCD 1/1
d. F 1/2 (3P)
e. F 1/3
f. F 1/4
g. RCD 2/1
h. F 2/2
i. UTP 1 / UTP 2
j. F 3/1
k. F 3/2
l. F 4/1
m. PE REF.
n. Error, ON/OFF and TN/TT switch panel.

Figure 4-5: Location of RCDs, fuses, circuit breakers, sockets and switches.

4.5 Meaning of abbreviations on MI 3399 Application Trainer

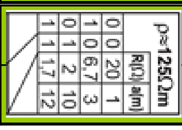
3 Phase / 1 Phase	Mains Plug
F 0 / 1	Direct Power Sockets
3-pin / 12V	Charging Sockets
SB 1/2	Earthing Systems TN/TT
SB 3	IT Earthing / Special locations
LPS	Lightning Protection System
F 0/1 outlet	Bypass outlet - connected in parallel to mains and not through electronic circuits **for supplying different loads and instruments**.
F 1/2	Three phase Outlet **for test purpose only and not for supplying different loads!**
F 1/3 2/2 3/1 3/2	Single phase Outlets **for test purpose only and not for supplying different loads!**
F 1/4	Light Circuit
UTP	LAN sockets for testing communication network parameters, errors, faults and distances to the faults and crosstalk.
N-PE	TN/TT Open / Short switch to simulate real conditions on both types of earthing systems.
Pipes	Pipes of water, Gas and Heating systems are connected to MPE through switches and resistors to simulate safety conditions close to limit values.
Gas Pipe Surge protection	Gas pipe has insulator in between field pipe and in-building pipes. The Surge protection shows good example to make system safe in case of lightning strike.
MPE	Main Potential Equalizing
●	Re Auxiliary rod 1 (Inner Ring)
●	Re Auxiliary rod 2 (Inner Ring)
●	Ro Current probe 1 (Outer Ring)
●	Ro Potential probe 1 (Outer Ring)
●	Ro Potential probe 2 (Outer Ring)
●	Ro Current probe 2 (Outer Ring)

4.6 Adjustments of the Application Trainer parameters

Values of measurement parameters in case the switch is in **ON** or in **OFF** position are available in the table below.

Exercises	Switch	Function	Site of error	ON	OFF
Power simulator	S1	Dip	Output on Power Simulator connection plate	138 V dip, 5 periods long each 10 seconds	Normal 3-phase system sinusoidal shape, inductive character
	S2	Swell		276 V swell 5 periods long each 10 seconds	
	S3	Interrupt		0 V interrupt 5 periods long each 10 seconds	
	S4	Capacitive load & energy		capacitive switching, nonlinear	
	S5	Harmonics		Voltage harmonics: 3rd harmonic:5%, 5th harmonic: 5%, 7th harmonic: 5% Current harmonics: 3rd harmonic:15%, 5th harmonic: 15%, 7th harmonic: 15%	
	S6	Unbalance		U1 = 240 V, U2 = 230 V, U3 = 220 V, I1 = 900 A, I2 = 1000 A, I3 = 1100 A	
	S7	Flicker		Pst_{U1} = 1, Pst_{U1} = 1.5, Pst_{U1} = 1.8	
	S8	Inrush		1700 A 200 msec duration, every 10 second	
	S9	Transient		420 Vpk, length < 3 msec, every 10 sec	
	S10	Phase (switch) failure		L2 and L3 interchanged	
	S11	Wrong instrument connection		Voltage, Current, Power, frequency phase angle sequence	

Table 4-2: List of parameters' adjustments on Application Trainer (part 1).

Exercises	Switch	Function	Site of error	ON	OFF
Line Impedance	S12	Z LINE	TN/TT F1/2 L3/N outlet (3-ph.)	> 10 Ω	< 2 Ω
	S13	Z LINE	TN/TT F2/2 L1/N outlet	> 10 Ω	< 2 Ω
	S14	Z LINE	TN/TT F1/3 L3/N outlet	> 10 Ω	< 2 Ω
PE Connection	S15	R LOW / IMD	IT F3/1 PE outlet	> 20 Ω	< 1 Ω
	S16	ISFL / IMD	IT F3/2 ISFL	approx. 6 mA (@ 230 V) approx. 3 mA (@ 115 V)	< 1.3 mA
	S17	R LOW	IT PE ref.	approx. 3.3 Ω	< 1 Ω
	S18	R LOW	TN/TT F1/4 PE light	> 20 Ω	< 1 Ω
	S19	R LOW / Z LOOP	TN/TT F1/2 PE outlet (3-ph.)	approx. 3.4 Ω	< 1 Ω
	S20	R LOW / Z LOOP	TN/TT F2/2 PE outlet	> 2.3 Ω	< 2 Ω
	S21	R LOW	MPE / PE Gas	approx. 2.2 Ω	< 1 Ω
	S22	R LOW	MPE / PE Heat inst.	approx. 3.3 Ω	< 1 Ω
Earth Resistance R_E	S23	R_E (classic method 3w)	Basic grounding in TT	approx. 3.3 Ω	approx. 2.6 Ω
	S23 + S24	R_E (classic method 3w)	Basic grounding in TT	approx. 9.8 Ω	approx. 2.6 Ω
	S24	R_E (classic method 3w)	Basic grounding in TT	approx. 4.8 Ω	approx. 2.6 Ω
		R_E (2 - clamps method)	Basic grounding in TN (on Main PE wire) Lightning rod 1 Lightning rod 2	approx. 10 Ω approx. 22 Ω approx. 10 Ω	approx. 3.6 Ω approx. 5 Ω approx. 10 Ω
ρ	S25	RO (resistivity 4w)			
	S26	RO (resistivity 4w)			

ρ≈125Ωm			
		R(Ω)	a(m)
0	0	20	1
1	0	6.7	3
0	1	2	10
1	1	1.7	12

Table 4-3: List of parameters' adjustments on Application Trainer (part 2).

Exercises	Switch	Function	Site of error	ON	OFF
Insulation resistance	S27	R_{ISO}	IT F3/1 L1/L2 outlet	approx. 0.45 MΩ	> 200 MΩ
	S28	ISFL/IMD	IT F3/1 L1/PE outlet	approx. 3 mA	< 1 mA
	S29	I_{Δ}	TN/TT F2/2 L1/PE outlet	approx. 5.1 mA (@230 V) approx. 2.5 mA (@115 V)	< 3.5 mA
	S30	R_{ISO}	TN/TT F1/2 L1/PE outlet (3-ph.)	capacitive 1.45 MΩ	> 200 MΩ
	S31	R_{ISO} / VARISTOR	TN/TT SPD GAS / PE	shorted	U_{SPD} approx. 150 V
	S32	R_{ISO}	TN/TT F1/2 L2/N outlet (3-ph.)	approx. 0.45 MΩ	> 200 MΩ
	S33	R_{ISO}	TN/TT F1/2 L1/L2 outlet (3-ph.)	approx. 0.45 MΩ	> 200 MΩ
Electrical Equipment Safety	Err1	Loose contact of PE conductor	Error value	0.84 Ω	0.02 Ω
		Earthed metal part (2) and PE pin on socket (3)	Earth Bond	0.84 Ω	0.02 Ω
	Err2	Insulation fault	Error value	106 kΩ	>20 MΩ
		L and PE pins on socket (3)	Insulation 500 V DC	0.106 MΩ	>20 MΩ
			Leakage 230 V, 50 Hz	2.17 mA	0.00 mA
			Subleakage	2.17 mA	0.00 mA
	Err3	Excessive capacitive current	Error value	33 nF	/
		L and PE pins on socket (3)	Insulation 500 V DC	> 20 MΩ	> 20 MΩ
			Leakage 230 V, 50 Hz	2.12 mA	0.00 mA
			Subleakage	2.12 mA	0.00 mA
	Err4	Insulation fault	Error value	238 kΩ	> 20 MΩ
		Accessible isolated metal part (1) and L pin on socket (3)	Insulation 500 V DC	0.238 MΩ	> 20 MΩ
			Touch Leakage 230 V	0.97 mA	0.00 mA
			Subleakage	0.97 mA	0.00 mA
	Err5	Functional fault	Functional	interruptions	/
		Functional	Functional	interruptions	/
	Err6	Crossed L and N wire	Polarity	L, N crossed	/
		Polarity	Polarity	L, N crossed	/
	Err7	Insulation fault	Error value	238 kΩ	30 MΩ
		Isolated accessible metal part (3) and L, pin on socket (2)	Insulation 500 V DC (probe)	0.237 MΩ	13 MΩ
			Touch Leakage 230 V AC	0.97 mA	0.00 mA
			Subleakage (probe)	0,97 mA	0.00 mA
	Err8 Err9	Insulation fault	Error value	1.88 MΩ	> 20 MΩ
		L (3) and PE (4) input connections	Insulation 1000 V DC	1.880 MΩ	> 20 MΩ
			Withstanding 1000 V AC	0.6 mA	0.1 mA
	Err9	Excessive charge on filter capacitors	Error value	100 nF	4.7 nF
				100 MΩ	100 MΩ
		L and N on input connection (3)	Discharging time	cca. 9 sec	cca 0.4 sec

* Err buttons position selected according to the selected equipment simulator.

Table 4-4: List of parameters' adjustments on Application Trainer (part 3).

5 Maintenance

5.1 Cleaning

Use soft patch slightly moistened with water or alcohol to clean the surface of the **Application trainer** and leave it to dry totally after cleaning.
Do not use liquids based on petrol!
Do not spill cleaning liquid over the Application trainer!

5.2 Service

In case of any board malfunction or if there is any damage noticed at the board, the board must be serviced by a competent service department. Contact your dealer or producer of the board for further information.

Producer's contact details:

Address:	METREL d.d. Ljubljanska 77 SI-1354 Horjul Slovenia, Europe
Tel.:	+386 1 755 82 00
Fax.:	+386 1 754 92 26
URL:	http://www.metrel.si
E-mail:	metrel@metrel.si

U	ISO	RLOW	RCD	LOOP	LINE	EARTH	OTHER

AD 1 - MI 3399
EIS Electrical Installation Safety Trainer

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1 Basic theory about LV Electrical Installations Safety and Measurements

Basic theory needed for successful completion of exercises is described in this chapter.

For a more detailed theoretical explanation, please see the Metrel’s Handbook **Guide for testing and verification of low voltage installations**.

For a more detailed explanation on how to navigate to a specific device setting, please refer to the appropriate instruction manual of the device used.

1.1 TN system

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

1.1.1 TN-S system

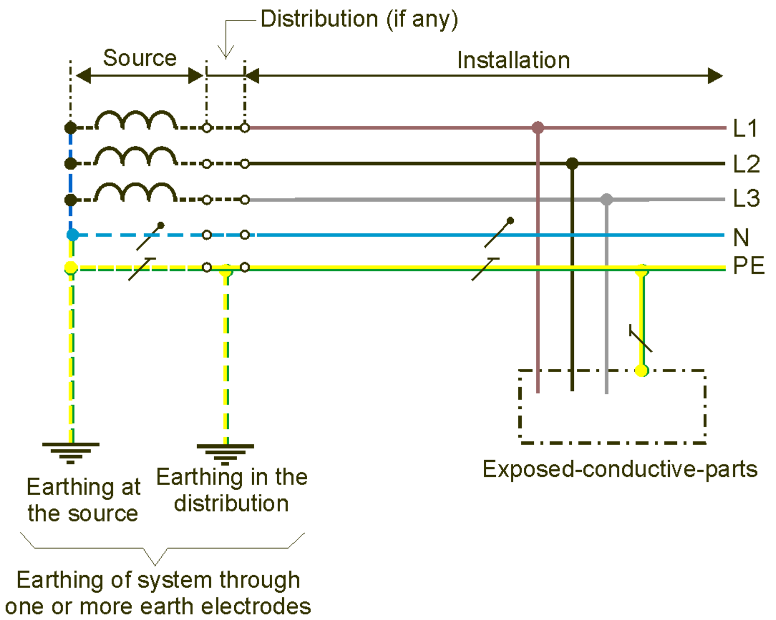


Figure 1-1: TN-S system

In TN-S (S=separated) systems the PE and N (if applied) conductors are separated. The PE conductor serves for protection purposes only.

All line conductors are fuse protected. The system can contain additional RCD protection. The earthing resistance is usually low enough because of low PE conductor resistance and good earthing at the source and distribution points.

1.1.2 TN-C system

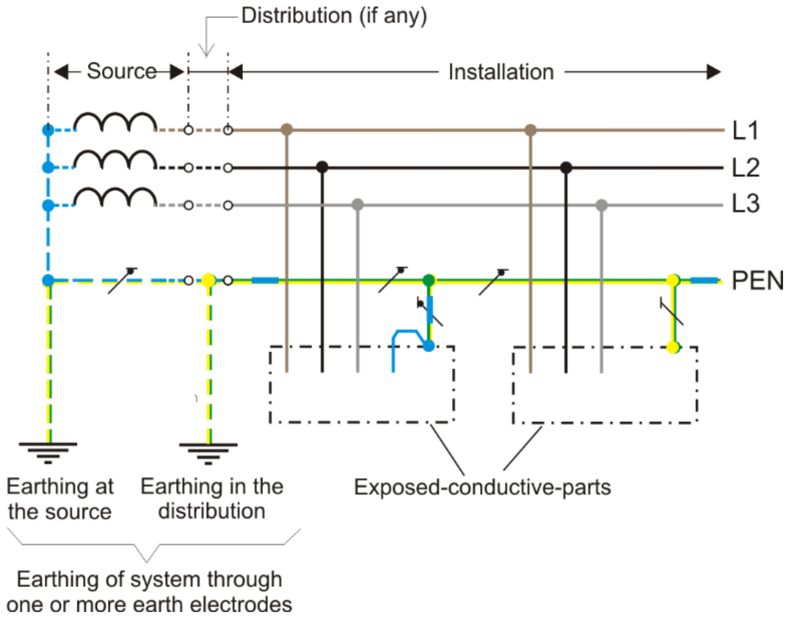


Figure 1-2: TN-C system

TN-C (C-common) system comprises one common PEN conductor for the complete supplying system. The PEN conductor is used for protection purposes and is carrying load currents.

All line conductors are fuse protected. The earthing resistance is usually low enough because of low PEN conductor resistance and good earthing at the source and distribution points. Additional RCD protection would not be effective.

1.1.3 TN-C-S system

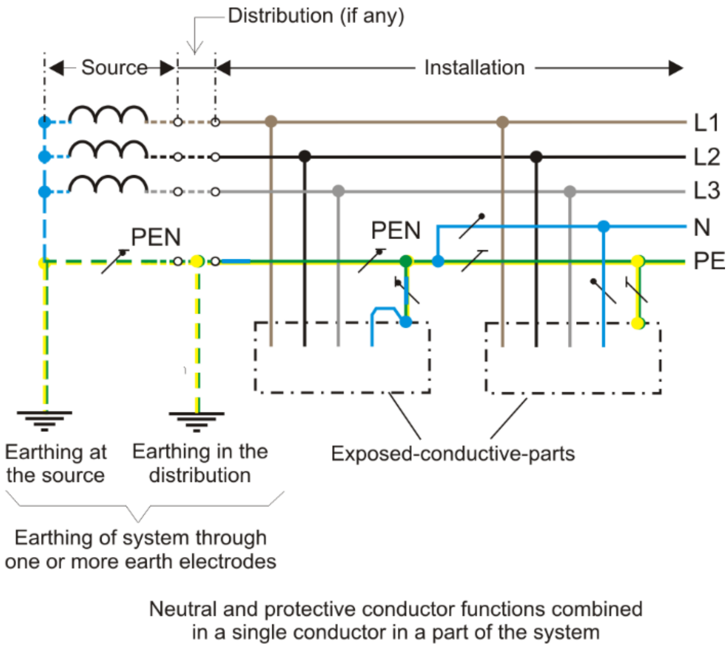


Figure 1-3: TN-C-S system

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

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

The Line and Loop Impedances can simply be measured at each end of the circuit:

- **Line impedance in a TN system:**

$Z_{Line} = Z_{Line\ conductor} + Z_{Transformer} + Z_{Neutral\ conductor} + Z_{Local\ neutral\ conductor}$

- **Loop impedance in a TN system:**

$Z_{Loop} = Z_{Line\ conductor} + Z_{Transformer} + Z_{Neutral\ conductor} + Z_{Local\ PE\ conductor}$

In case the continuity is good for all conductors – Line, Neutral and PE – then Line and Loop Impedance in TN system are basically the same.

1.2 TT system

In TT system, all accessible metal parts are connected to basic grounding system of the building via protection earth conductor PE. Safety conditions are checked by measuring earth resistance R_E.

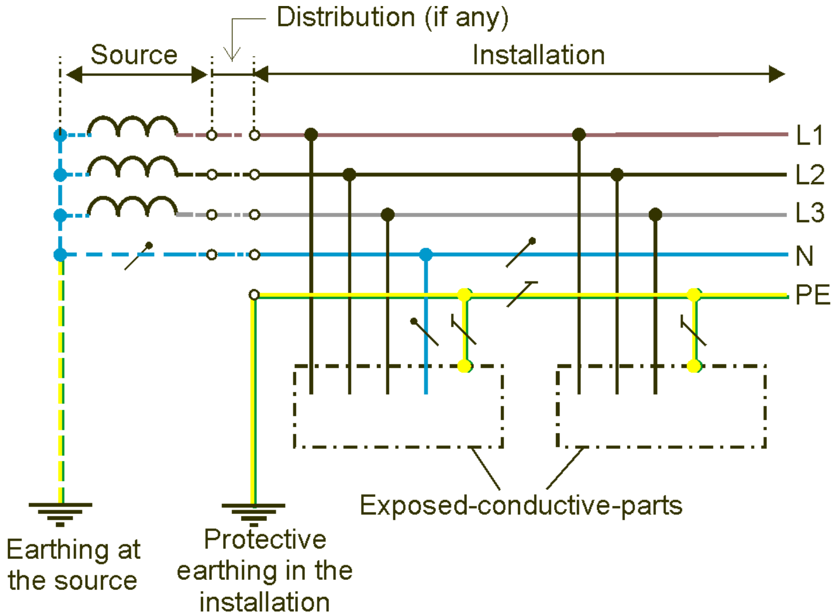


Figure 1-4: TT system

Fault loop impedance in a TT system consists of the following partial impedances:

- Impedance of power transformer's secondary.
- Phase conductor impedance from power transformer to fault location.
- Protection conductor impedance from fault location to earthing electrode.

- Earth Resistance R_E.
- Ground resistance from earthing electrode R_E to power transformer.
- Resistance of power transformer’s earthing system R_O.

The Line and Loop Impedances can simply be measured at each end of the circuit:

- **Line impedance in a TT system:**

$$Z_{Line} = Z_{Line\ conductor} + Z_{Transformer} + Z_{Neutral\ conductor} + Z_{Local\ neutral\ conductor}$$

- **Loop impedance in a TT system:**

$$Z_{Loop} = Z_{Line\ conductor} + Z_{Transformer} + R_{O\ transformer\ earthing} + R_{Earth\ of\ the\ object} + Z_{Local\ PE\ conductor}$$

Line Impedance in TT system is much lower than Loop Impedance because of the fault loop current flowing through the ground.

1.3 IT system

The IT system has the supply part of the power source separated from earth or is earthed through a sufficient high impedance at the source. Exposed conductive parts are autonomously earthed or connected to the PE conductor and are locally earthed at the installation input.

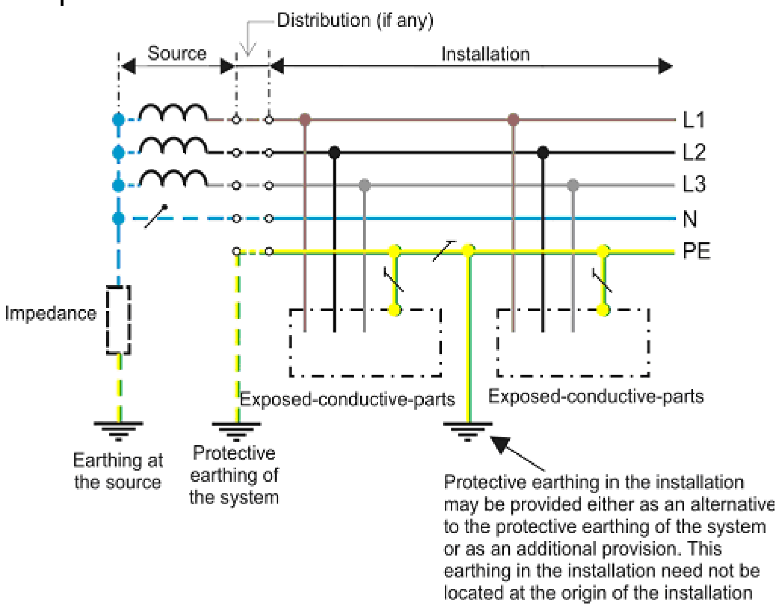


Figure 1-5: IT system

Fault loop impedance in IT- systems is not in function until a first fault occurs. After the first fault, the system must generate a sound and visual alarm and start operating as a TN or TT system.

The Line Impedances can simply be measured at each end of the circuit:

- **Line impedance in an IT system:**

$Z_{Line} = Z_{Line\ conductor} + Z_{Transformer} + Z_{Neutral\ conductor} + Z_{Local\ neutral\ conductor}$

- **Loop impedance in an IT system:**

Z_{Loop} = OPENED LOOP (results are in the high range, usually over 35 kOhm)

All line conductors are fuse protected. IMDs and RCMs are often installed in an IT system to detect insulation faults and to trigger an alarm before the supply must be disconnected. RCDs are only partly applicable.
IT systems are usually installed in:

- Medical surgery rooms and hospitals.
- Emergency lighting in communal facilities.
- Emergency vehicles (fire trucks, ambulance vehicles,…) where the PE conductor is connected to the chassis of the vehicle itself.
- Ships.
- Computer power supply systems.
- Chemical industry.
- Mining industry.
- Explosive atmospheres, chemical industry[2].

The main advantage is that in case of the first fault (between phase and earth) the system still works safely.

1.4 Ensurance of Safety

1.4.1 Line impedance

The Line impedance result between the line and neutral conductor can show the ability of the built in conductors to supply the high power loads. Verification of installed over-current breakers is possible by comparing the characteristics with calculated short circuit current.
After pressing the START key the instrument loads the installation between L, N or L_x, L_y terminals (see Figure 1-6) and measures loaded (Figure 1-6: switch position **1**) and unloaded (Figure 1-6: switch position **2**) voltages. The result is obtained by the following formula (simplified form).

$$Z_{LINE} = \boldsymbol{Z_{LN}} = \frac{\boldsymbol{U_{Unloaded} - U_{Loaded}}}{\boldsymbol{U_{Loaded}/R_{Load}}}$$

[2] See Metrel's Handbook **Guide for measurements on IT power installation** for more information.

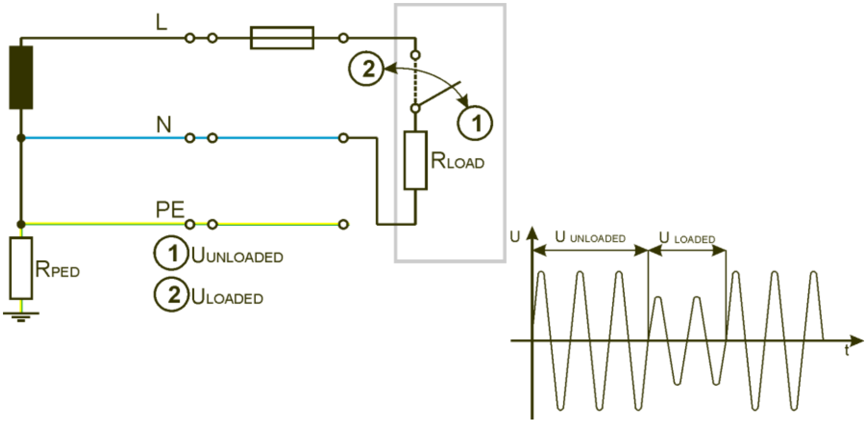


Figure 1-6: Line impedance (Z_{LN}) measurement – standard method

1.4.2 Fault Loop impedance

The Fault loop impedance should be low enough in order to enable the potential fault current to interrupt installed protection device within prescribed time interval in case of faulty load.

After pressing the START key the instrument loads the installation between L and PE terminals (see Figure 1-7) and measures loaded (Figure 1-7: switch position **1**) and unloaded (Figure 1-7: switch position **2**) voltages. The result is obtained by the following formula (simplified form).

$$R_{LOOP} = \boldsymbol{R_{L-PE}} = \frac{\boldsymbol{U_{Unloaded} - U_{Loaded}}}{\boldsymbol{U_{Loaded} / R_{Load}}}$$

If phase delays are measured, loop impedance $Z_{L\text{-}PE}$ can be calculated as:

$$\mathbf{Z_{L\text{-}PE} = R_{L\text{-}PE} + j\omega L_{L\text{-}PE}}$$

$$\boldsymbol{Z_{L-PE}} = \frac{\boldsymbol{U_{Unloaded} - U_{Loaded}}}{\boldsymbol{U_{Loaded} / R_{Load}}} = \frac{\boldsymbol{\Delta U}}{\boldsymbol{I_{test}}}$$

where

ΔU – Measured voltage drop
I_{test} – Test current

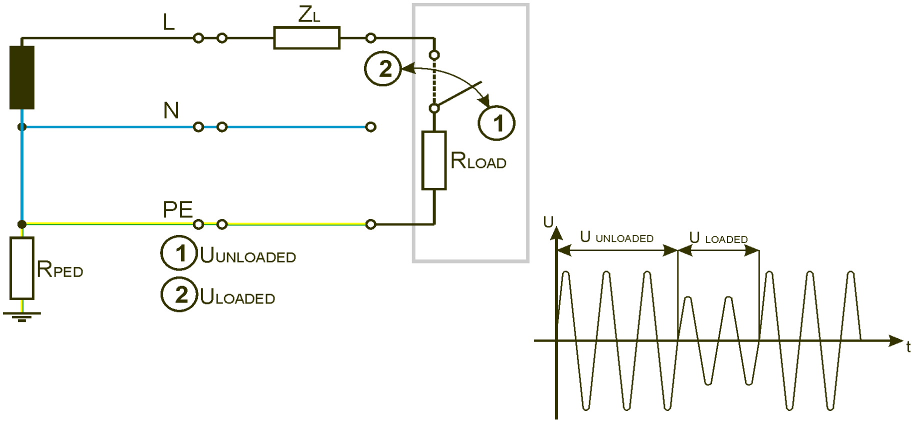


Figure 1-7: Loop impedance measurement – standard method

Some Examples of evaluation of the Loop impedance result:

- If all fuses in the fuse box are B10, than the results of the Loop impedance on all circuits should not exceed the value of **4,4 Ω**.
- If all fuses in the fuse box are C10, than the results of the Loop impedance on all circuits should not exceed the value of **2,2 Ω**.
- If the built-in fuses are mixed up - some of the fuses are gG16, some of them are B20, B16 and C10, than the results of the Loop impedance on all circuits should not exceed the value of the most critical one, which is in our case **2,0 Ω**.

If there is no presence of RCD, the limit values of the Earth resistance are the same as for the Loop impedance – valid for TN and TT type of installation.
In case that the Loop impedance result is higher than the limit, next possible solutions are recommended:

- Tracing of possible bad contacts in the tested mains socket.
- Tracing of possible bad contacts in lines L and PE from the fuse box to the mains socket.
- Changing of the built-in fuse with the lower nominal current.
- Changing of the cross-section of the built-in wires.

1.4.3 Comparison Line and Fault Loop impedances

The evaluation of the results of the Line and Loop impedance and its comparison is very important to evaluate the way of troubleshooting:

- Line and Loop impedances are equal ($Z_{LOOP} = Z_{LINE}$). If both impedances are:
  - **Over the maximum allowed limit**, then there are possible bad contacts on the Line (L) conductor.
    - If there are no bad contacts present, then the cable from the fuse box to the tested point is too long or its cross-section is too week. Replacement of the cable with **higher cross-section** of the wires is recommended
    - In case that there is no need to use the power with nominal current of the built-in fuse, the **fuse can be replaced** with the one with lower nominal current and cable could stay the same.

- **Within allowed limits and all outlets produce the same result**, then we may conclude that TN earthing system is being tested.

- Loop impedance is much higher than Line impedance ($Z_{LOOP} >> Z_{LINE}$):
  - If such impedances are present on all measured outlets, then we may conclude that TT earthing system is being tested.
  - If TT earthing system is not present, then there is an error on the PE conductor.
- Loop impedance is much lower than Line impedance ($Z_{LOOP} << Z_{LINE}$):
  - There is an error on the Neutral conductor.

Maximum allowed Line and Fault loop impedances to ensure the trip-out ability with built-in fuses type B, C or gL-gG in the installation with nominal mains voltage U_{L-N} = 230 V are presented in the example table below.

Nominal current of over-current protection device (A)	Type of automatic Fuse B		Type of automatic Fuse C		Type of Fuse gG	
	Ia=5·In (A)	**Zs (Ω) (0,2s)**	**Ia=5·In (A)**	**Zs (Ω) (0,2s)**	**Ia (A)**	**Zs (Ω) (0,4s)**
2	10	22	20	11	16	13,7
4	20	11	40	5,5	32	6,8
6	30	7,3	60	3,65	47	4,6
10	50	4,4	100	2,2	82	2,6
16	80	2,8	160	1,4	110	2,0
20	100	2,2	200	1,1	147	1,4

Table 1-1: Maximum allowed fault loop impedances in case of used melting fuses type B, C and gG[3]

Fuse trip-out times depend on the characteristics of a built-in fuse or RCD.

Circuit type	**Trip-out time**
Explosive	100 ms
3-phase	200 ms
1-phase	400 ms
Fixed connection	5 s

Table 1-2: Fuse trip-out times

Where an installation is protected with a RCD, special measuring techniques are used to avoid tripping out the RCD during the test.

1.4.4 RCD

Installation of RCDs is:

- Mandatory in TT systems.
- Optional in TN systems, though European countries today typically install RDCs also on these types of systems.

[3] See Metrel's Handbook **Guide for testing and verification of low voltage installations** for more parameters/limits.

- Optional in IT systems in each circuit as additional protection in case a second fault occurs after first already present.

1.4.4.1 RCD trip-out time test

With the trip-out time test, the correct operation of the RCD is verified. Conditions:

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

Trip-out times are measured at 0.5 $I_{\Delta N}$, 1 $I_{\Delta N}$, 2 $I_{\Delta N}$ and 5 $I_{\Delta N}$.
For the trip-out test to pass the RCD must trip-out according to the limits defined in Table 1-3.

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

Table 1-3: Trip-out times according to IEC 60364-4-41

1.4.4.2 RCD trip-out current test

With the trip-out current test, the correct operation of the RCD is verified. Conditions:

- Successful trip out,
- Current I_{Δ} and trip out time t_{Δ} @ I_{Δ} (current at which RCD is tripped out) lie inside predefined limits.

A continuously rising residual current I_{Δ} is intended for testing the threshold sensitivity for RCD trip-out. The test passes if the RCD trips-out at currents according to 2.4.

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

Table 1-4: Trip-out currents according to IEC/TR 60755

1.4.4.3 RCD trip-out contact voltage test

With the trip-out contact voltage test, the correct operation of the RCD is verified. Conditions:

- Successful trip out,
- Measured earth resistance of the object must be lower than described in 1.4.5 Earth Resistance and Contact Voltage.

1.4.5 Earth Resistance and Contact Voltage

The actual contact voltage is calculated from the measured earth resistance and trip-out current. In order to get valid measurements the correct RCD settings have to be selected.

Additional protection against too high contact voltage (U_{CL} – contact voltage limit) is ensured, but only in case that earth resistance of the object is low enough.

Nominal differential current $I_{\Delta n}$ (mA)	**10**	**30**	**100**	**300**	**500**	**1000**
Max. allowed Earth Resistance value at U_{CL} = 50 V (Ω)	5000	1666	500	166	100	50
Max. allowed Earth Resistance value at U_{CL} = 25 V (Ω)	2500	833	250	83	50	25

Table 1-5: Maximum allowed earth resistance (Z_{L-PE}) values for RCD protected installations

Note:
- In TT installation systems the earthing resistance R_E represents the main part of the loop impedance. Therefore the loop test can be suitable for measuring earthing resistance of objects, systems etc.
- If the RCD is installed downstream, the installation and parts of wiring are not protected. In this case the limit for over current protection must be considered. A typical example is a socket with integrated RCD.
- If a RCD device is not present then the selected limit must be set according to the used fuse characteristic.

Some Examples of evaluation of the Earth resistance value:
- In case the RCD Nominal differential current is 500mA and Max. allowed contact voltage is 50V, the Max. allowed Earth resistance value is **100 Ω**.
- In case the RCD Nominal differential current is 30mA and Max. allowed contact voltage is 25V, the Max. allowed Earth resistance value is **833 Ω**.

In case that the Earth resistance value is higher than the limit, the next possible solutions are recommended:
- Tracing of possible bad contacts in the tested mains socket.
- Tracing of possible bad contacts in the PE conductor from the fuse box to the mains socket.
- Tracing of possible bad earthing of the object or no earthing at all.

Where the Earth resistance of the object is within the allowed values, the additional test of RCD is needed to ensure the safety protection:
- Trip out Time of RCD in case of fault leakage current flows the same as nominal differential current of RCD should be within 300ms.

- Trip out Time of RCD in case of fault leakage current flows 5x nominal differential current of 30mA RCD should be within 40ms.

1.4.6 Insulation

To ensure the complete safety of the installation, one of the main protections against electroshock of hazardous voltage needs to be tested. The visual inspection is necessary and the test of insulated parts must be done on each separated circuit.

For this type of testing the installation must be prepared in such a way that **no voltage is present** and **no loads are connected**. The insulation test starts after the RCD trips out for that reason.

The insulation test must be done with a voltage higher than possible present line voltage and the **test voltage must be higher than 500V.**
The value of the insulation resistance must be **higher than 1 MΩ.**

1.4.7 Continuity

The basic protection against electroshock of hazardous voltage is ensured by potential equalizing and earth bonding of all accessible metal parts of the installations in the surrounding. The visual inspection is necessary and the test of R_{LOW} or R_{PE} need to be measured between MPE, remote PE or reference PE points to PE conductors, conductive parts and housing of connected loads. The test current must be at least 200 mA, AC or DC.

The results should never be higher than **2 Ω**. Recommended results for special installations are **1 Ω** or lower.

In installations without RCD protection, results must be low enough to ensure trip-out ability of live installation in case of a fault. The same conditions must be fulfilled as in the case of fault loop measurement – referencing to Table 1-1 and Table 1-2.

2 Measurements on electrical installations in practice

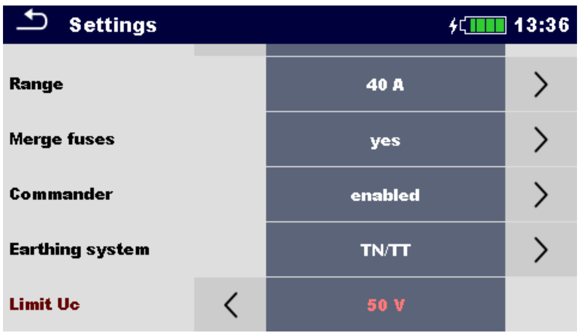
This chapter describes basic principles of measuring electrical installations in buildings in TN, TT and IT earthing systems. Although the sequence of measurements follows a logical order from impedance toward earth resistance, the correct order when conducting a first inspection of installations (and recommended order at periodical testing) is as follows:

1. Continuity testing (R_{LOW})
2. Insulations resistance (R_{ISO})
3. Line impedance (Z_{LINE})
4. Fault loop impedance (Z_{LOOP})
5. RCD testing
6. Earth resistance testing
7. IMD and ISFL testing
8. Voltage testing

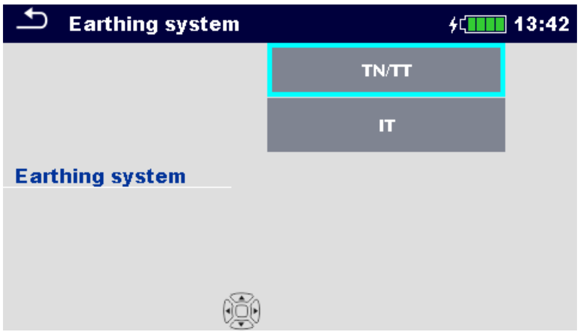
2.1 Instrument's general settings

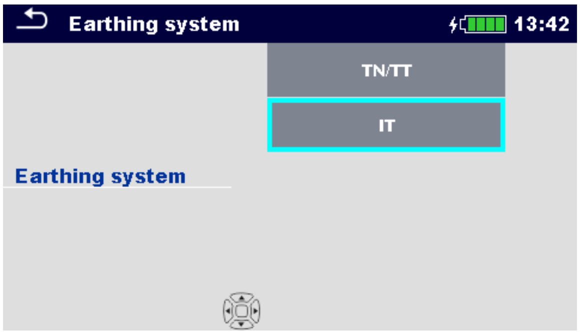
Depending on the earthing system being tested the appropriate system must be also set on the instrument. To do so:

1. Power on the device used for testing and navigate to the settings menu. Scroll down to the bottom of the menu where the Earthing system may be selected. The chosen value can be either **TN/TT** or **IT**.



2. If the earthing system used is TN or TT, select the **TN/TT** option. If the earthing system used is IT, select the **IT** option.



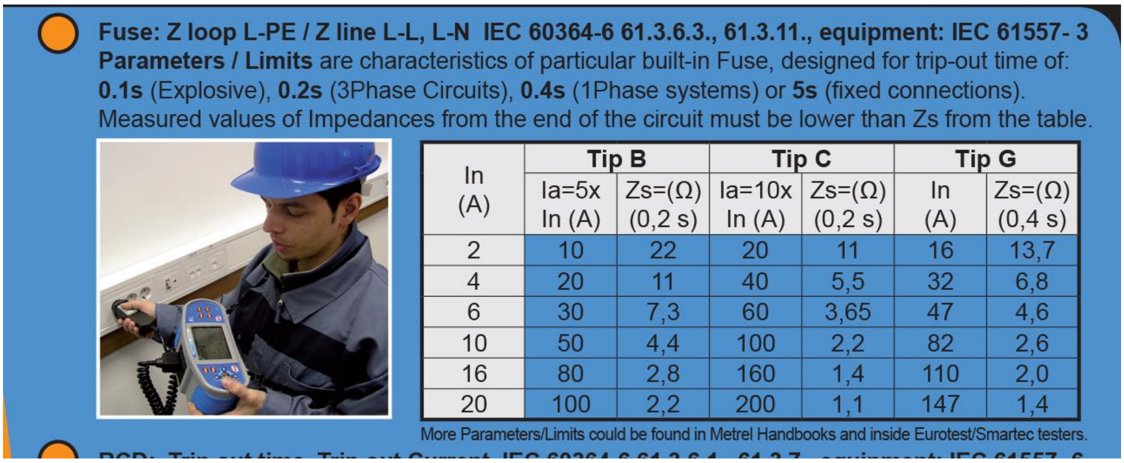


3. Exit settings.

2.2 Line impedance measurement

Line impedance is measured in a loop comprising of mains voltage source and line wiring (between the line and neutral conductors or between lines on a 3-phase system). Scope of the line impedance test is:

- To verify effectiveness of installed over current disconnection devices.
- To verify internal impedance for supplying purpose.
- To verify too high (excessive) internal line impedance for supplying purpose. This causes too high voltage drop between power transformer and a load.



Fuse: Z loop L-PE / Z line L-L, L-N IEC 60364-6 61.3.6.3., 61.3.11., equipment: IEC 61557- 3
Parameters / Limits are characteristics of particular built-in Fuse, designed for trip-out time of: **0.1s** (Explosive), **0.2s** (3Phase Circuits), **0.4s** (1Phase systems) or **5s** (fixed connections).
Measured values of Impedances from the end of the circuit must be lower than Zs from the table.

In (A)	Tip B		Tip C		Tip G	
	Ia=5x In (A)	Zs=(Ω) (0,2 s)	Ia=10x In (A)	Zs=(Ω) (0,2 s)	In (A)	Zs=(Ω) (0,4 s)
2	10	22	20	11	16	13,7
4	20	11	40	5,5	32	6,8
6	30	7,3	60	3,65	47	4,6
10	50	4,4	100	2,2	82	2,6
16	80	2,8	160	1,4	110	2,0
20	100	2,2	200	1,1	147	1,4

More Parameters/Limits could be found in Metrel Handbooks and inside Eurotest/Smartec testers.

Figure 2-1: Chart reference for line impedance measurements

Figure 2-2: Measuring Z_{Line} in the Application Trainer with the schuko commander

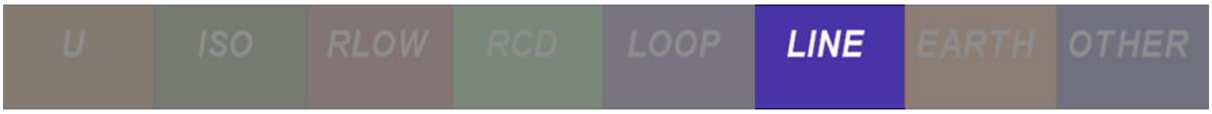
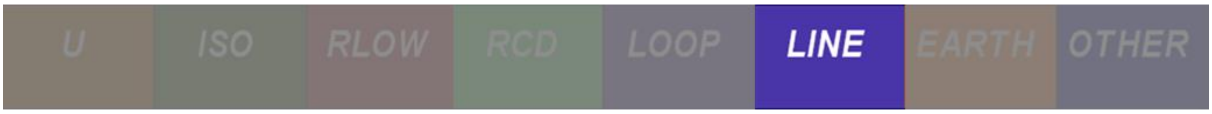


Figure 2-3: Measuring Z_{Line} in Application Trainer's switchboard with cables

Figure 2-4: Measuring Z_{Line} in the Application Trainer with the schuko commander on an IT system

2.2.1 Background of measurements

Line impedance includes the resistive and inductive part in the short circuit loop. The main part of inductivity comes from the power transformers' inductances.
The resistance part mainly comes from copper wiring in the loop (transformer, phase and neutral conductors).
In general the inductive part can be neglected if the loop impedance > 0.4 Ω.
In applications where the measurement is carried out in close proximity to the power transformer (< 50m) the inductivity can be of a similar value than the resistance part.



In this case it is very important to consider the impedance result because the line resistance result is lower and can result in wrong judgements.

2.2.2 Line impedance

Faults (bad contacts, corrosion) or improper installation design are the most often reason for too high line impedances and wrong installed fuses.
Safety conditions are checked by measuring line impedance (Z_{LINE} or R_{LINE}) e.g. prospective short circuit current I_{PSC}. Limit currents and impedance usually depend on fuse type, size and required trip out time.
Line resistance or line impedance can be measured. The resistance measurement returns only the resistive part of the loop. The impedance measurement considers the inductive part too. In general impedance measurement is preferred if the measurement is performed close to the transformer or on the installation with high rated currents. In this case the contribution of the inductive part is relatively high.

2.2.2.1 Short circuit line – neutral impedance and prospective short circuit current

The line-neutral short circuit loop consists of:

- Z_T – power transformer secondary impedance,
- Z_L – phase wiring from source to fault and
- Z_N – neutral wiring from source to fault.

The line to neutral impedance is the sum of impedances and resistances that forms the line to the neutral loop.

$$\mathbf{Z_{LINE} = Z_L + Z_N + Z_T}$$

In a 3-phase system there are three line-neutral impedances (Z_{L1-N}, Z_{L2-N} and Z_{L3-N}).

$$Z_{LINE} = \mathbf{Z_{LN} = Z_L + Z_N + Z_{TLN}}$$

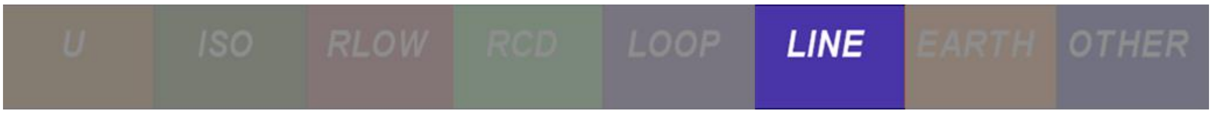
The prospective short circuit current I_{PSC} is defined as:

$$\boldsymbol{I_{PSC}} = \frac{\boldsymbol{U_{LN}}}{\boldsymbol{Z_{LN}}} > \boldsymbol{I_a}$$

where

- U_{LN} – rated fault loop voltage or nominal supply voltage.

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



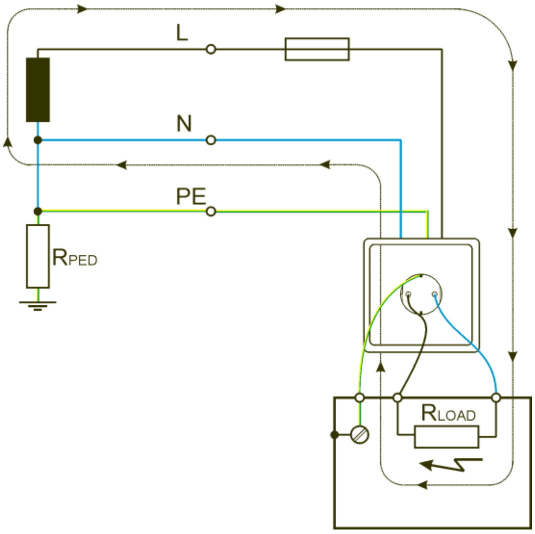


Figure 2-5: Short circuit current between Line and Neutral

2.2.2.2 Short circuit line – line impedance and prospective short circuit current

The line-line short circuit loop consists of:

Z_T – power transformer secondary impedance,
Z_{Lx} – first phase wiring from source to fault,
Z_{LY} – second phase wiring from source to fault.

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

$$Z_{LINE} = \mathbf{Z_{Lx-Ly} = Z_{Lx} + Z_{Ly} + Z_{TLL}}$$

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

$$I_{PSC} = \frac{U_{LxLy}}{Z_{LxLy}} = \frac{U_{LN} \cdot \sqrt{3}}{Z_{LxLy}} > I_a$$

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

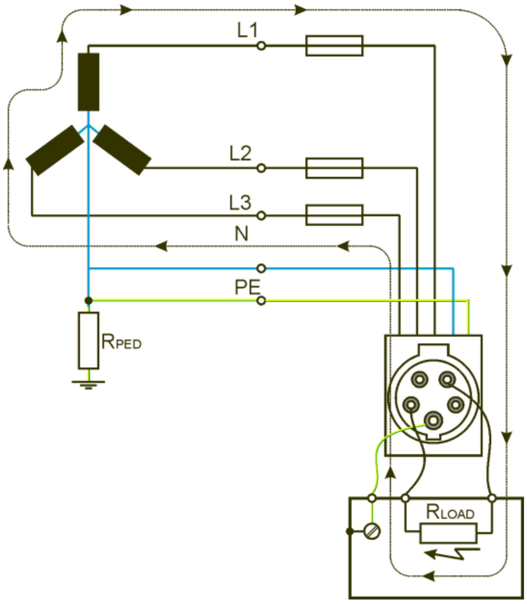


Figure 2-6: Short circuit current between two Phase conductors

2.2.2.3 Voltage drop

During the Z_{LINE} measurement the fuse before the measured circuit is the one referenced to. When measuring Z_{LINE} on the supply conductor, the fuse prescribed by the electrical distributor is considered. When measuring Z_{LINE} on the circuit the fuse installed before that circuit is considered. The difference between both measurements must not be greater than 3%.
After the reference impedance (Z_{REF}) has been determined the actual voltage drop test may be performed. The voltage drop is calculated as follows:

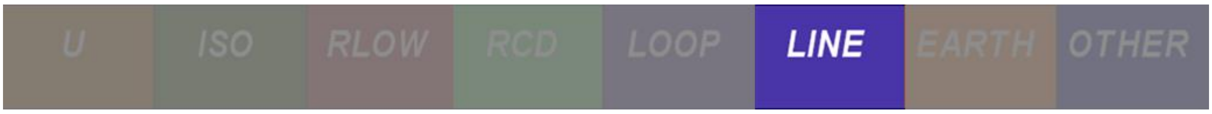
$$\Delta U[\%] = \frac{(Z - Z_{REF}) \cdot I_N}{U_N} \cdot 100 < 3\%$$

where:

- ΔU – Voltage drop,
- Z – Measured line impedance,
- Z_{REF} – Reference line impedance,
- I_N – rated current of selected fuse,
- U_N – nominal voltage (see Table 2-1).

U_N	Input voltage range (L-N or L1-L2)
110 V	93 V <= UL-N < 134 V
230 V	185 V <= UL-N <= 266 V
400 V	321 V < UL-L <= 485 V

Table 2-1: Nominal voltage table



2.2.3 Exercises

2.2.3.1 Exercise No. 2.2-1: dU, Z_{L-N} and I_{PSC} measurement on the supply side

Measuring connection topology

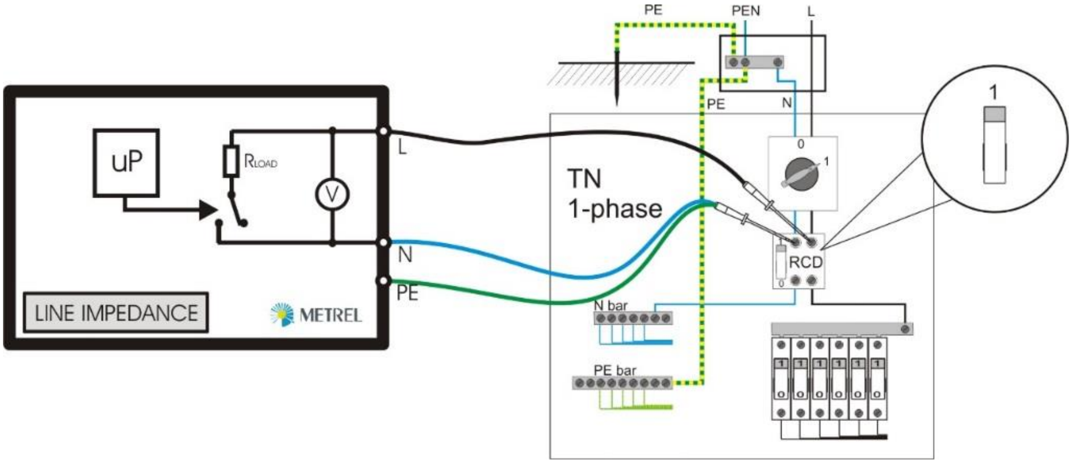


Figure 2-7: Topology in a 1-phase TN system on the supply side

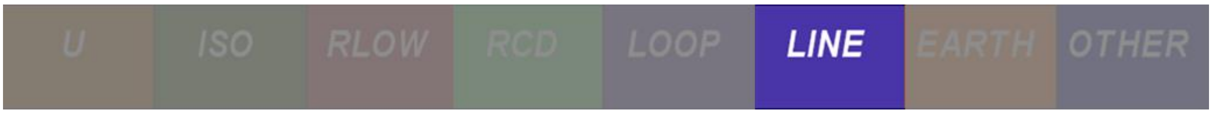
Measuring procedure

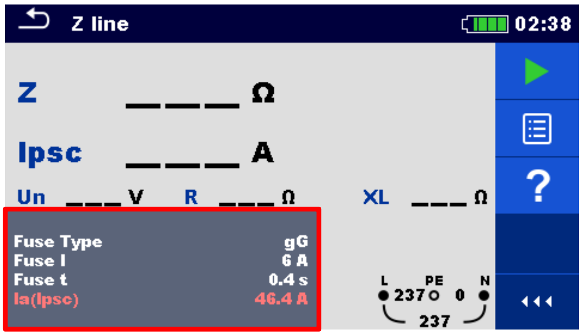
1 To measure the line impedance select the line impedance measurement $\mathbf{Z_{L-L,\,L-N}}$ (**Z line**) which measures impedance between phase and neutral conductors.

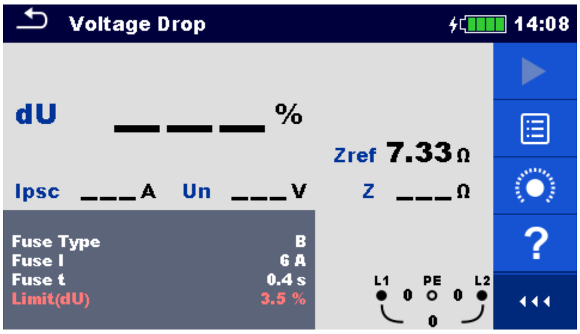
The line impedance measured at the supply side is actually the reference line impedance (Z_{REF}).
To measure the voltage drop select the voltage drop measurement **dU**.

If the voltage drop is measured at this test point then, the drop should actually be 0,0% since the measured and reference impedances should be the same.

2 To get correct readings during measurement select the appropriate fuse settings (fuse type, size and trip-out time) by clicking in the bottom left dark grey corner.



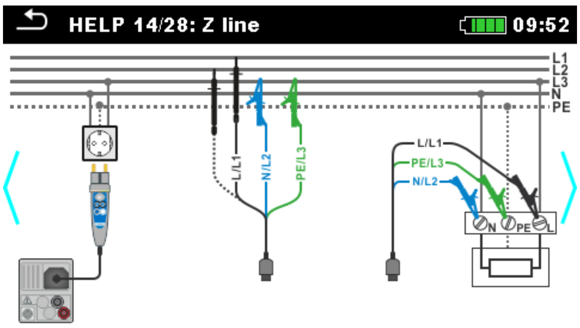




Typically, in a TN or TT system inside a residential building with a 1-phase system a 6A gG fuse is used. Settings for each system are shown below

Whenever a fuse parameter setting is changed, the prospective short circuit current (I_{PSC}) limit is set automatically.

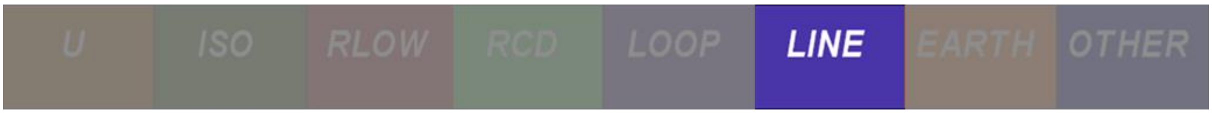
3 If a schuko commander is to be used, plug the commander into the appropriate outlet. If the cables are used, connect all cables appropriately – the PE cable to the PE conductor, the N cable to the N conductor and the phase cable to a phase conductor (L1, L2 or L3).



4 Press the **START** key.

Expected results

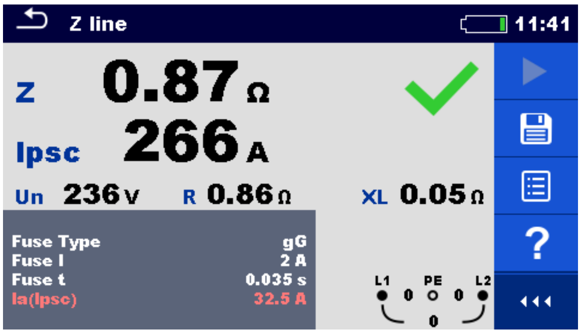
The prospective short circuit current (I_{PSC}) is calculated as:

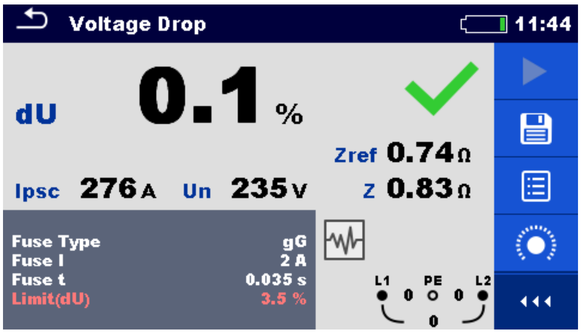


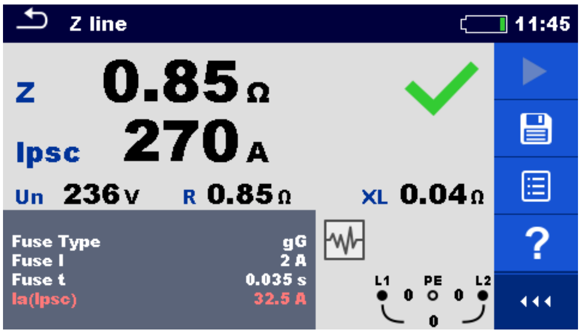
$$I_{PSC} = \frac{U_N}{Z_{MEASURED}}$$

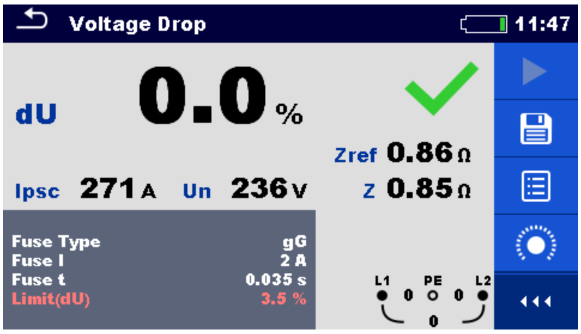
where:

U_N – nominal value, determined according to the measured voltage (U_{L-N}).









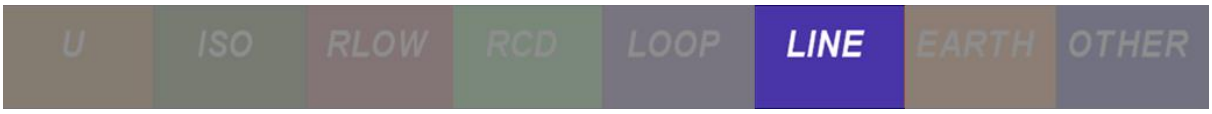
In a 1-phase TN/TT system the maximum allowed impedance result for a 6A gG type fuse with 400ms trip-out time is **4,6 Ω**[4]. If a 3-phase TN/TT system is used a 6A B type fuse with 200ms trip-out time is used. In this case the allowed impedance is **7,3 Ω**.

As is seen from the screens above the impedance, voltage drop and I_{PSC} are within limits and the test is marked as passed.

Expected results with a simulated error

It is not possible to simulate an error in the Application Trainer on the supply side.

[4] See chapter 1.4 Ensurance of Safety for more details on fuse trip-out times and impedances.



2.2.3.2 Exercise No. 2.2-2: dU, Z_{L-N} and I_{PSC} measurement on the socket side

Measuring connection topology

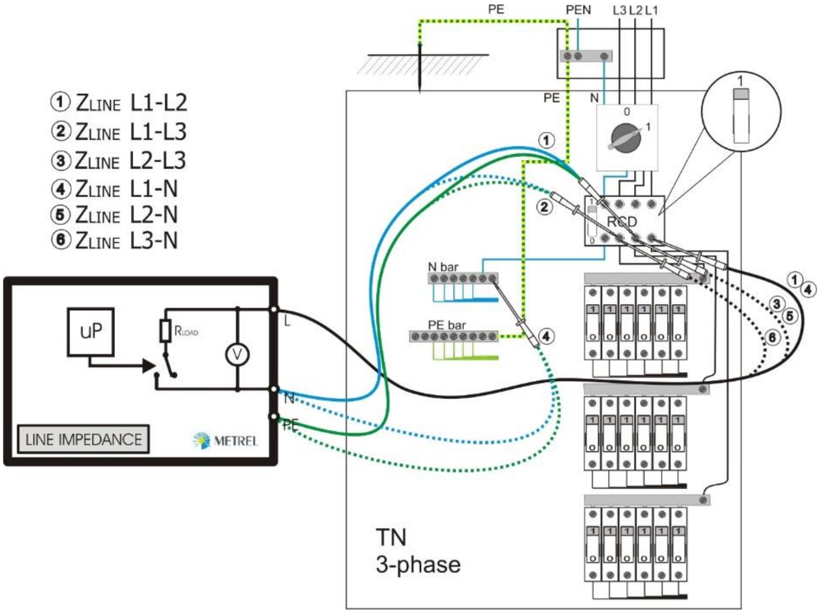


Figure 2-8: Topology in a 3-phase TN system on the outlet side

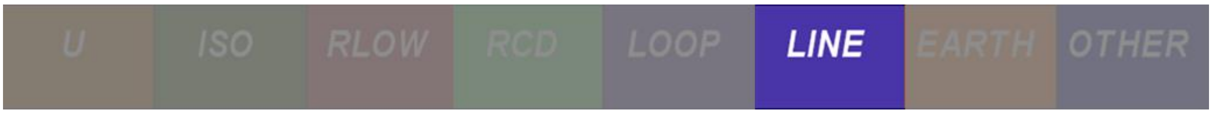
Measuring procedure

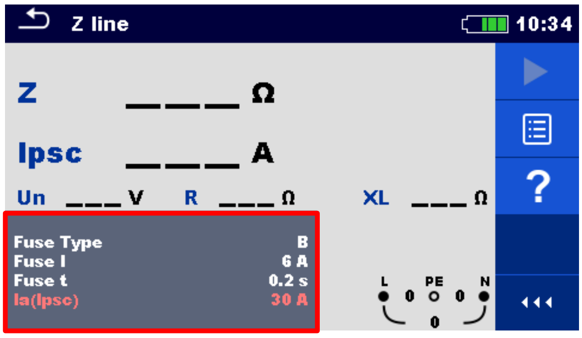
1 To measure the line impedance select the line impedance measurement $\mathbf{Z_{L-L,\ L-N}}$ (**Z line**) which measures impedance between phase and neutral conductors.

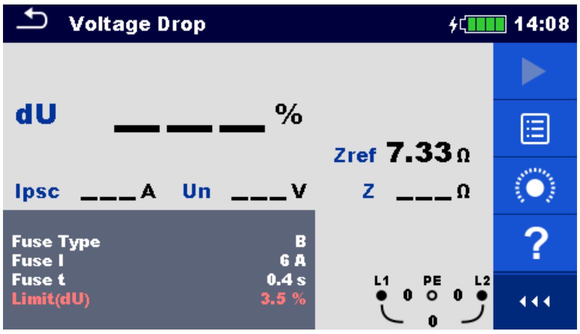
The line impedance measured at the supply side is actually the reference line impedance (Z_{REF}).
To measure the voltage drop select the voltage drop measurement **dU**.

If the voltage drop is measured at this test point then, the drop should actually be 0,0% since the measured and reference impedances should be the same.

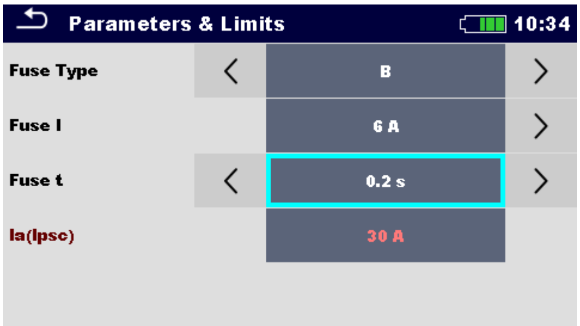
2 To get correct readings during measurement select the appropriate fuse settings (fuse type, size and trip-out time) by clicking in the bottom left dark grey corner.



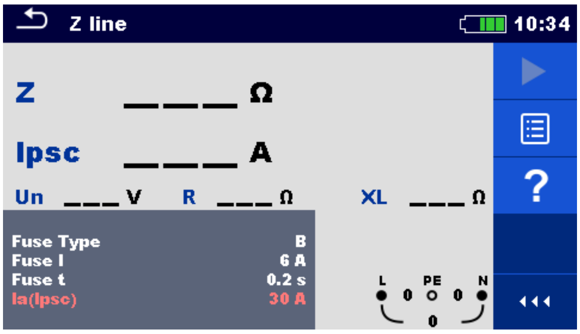




E.g. if we use a B6 fuse inside a residential building with a 3-phase system the following fuse settings should be set:



3 Whenever a fuse parameter setting is changed, the prospective fault current (I_{PSC}) limit is set automatically.



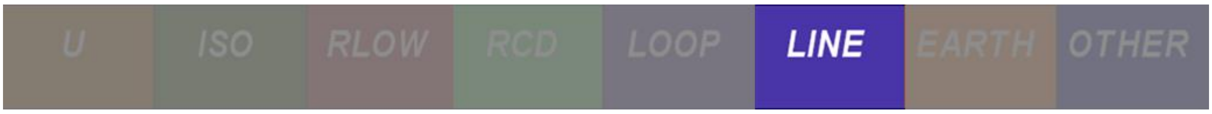
4 If the commander is to be used, plug the commander into the appropriate schuko outlet. If the commander is not used connect the L_x and L_y cables to the appropriate conductors.

5 Press the **START** key.

Expected results

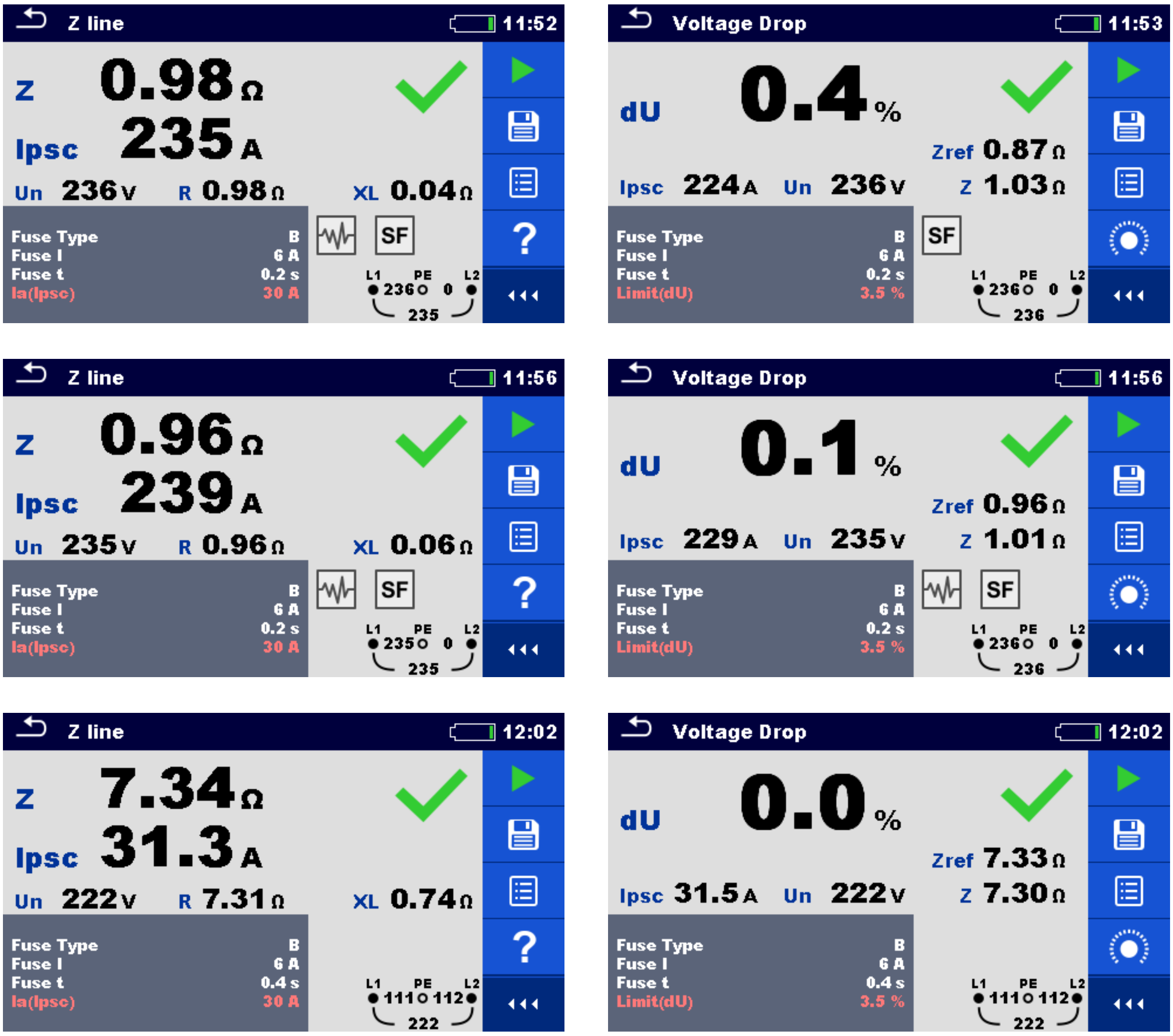
The prospective short circuit current (I_{PSC}) is calculated as:

$$I_{PSC} = \frac{U_N}{Z_{MEASURED}}$$



where:

U_N – nominal value, determined according to the measured voltage (U_{L-N}).



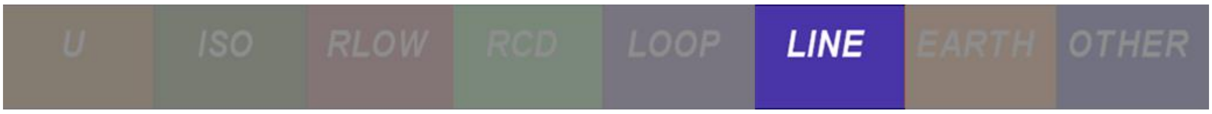
In a 3-phase TN/TT system the maximum allowed impedance result for a 6A B type fuse with 200ms trip-out time is **7,3 Ω**[5]. If a 1-phase TN/TT system is used then 6A gG type fuse with 200ms trip-out time is used. In this case the allowed impedance is **4,6 Ω**.

As is seen from the screens above the impedance, voltage drop and I_{PSC} are within limits and the test is marked as passed.

Expected results with a simulated error

During the test we add an error in the circuit introducing an additional 10Ω to the wiring simulating a wiring error in a TN/TT earthing system. The Application Trainer does not support error simulation on an IT earthing system. To simulate an error on a 3-phase TN/TT system (as per our example) enable the switch **S14** in the Application Trainer:

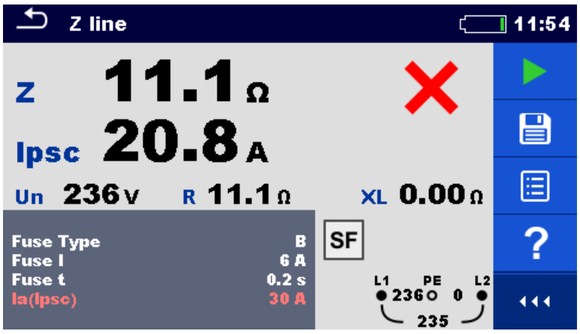
[5] See chapter 1.4 Ensurance of Safety for more details on fuse trip-out times and impedances.

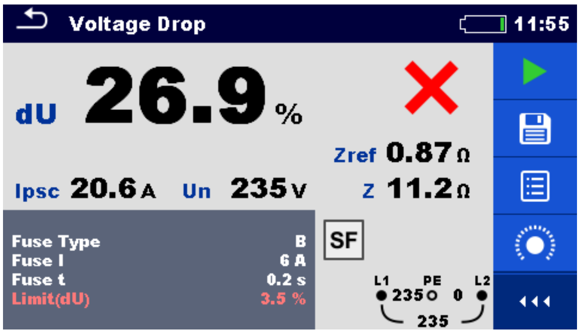


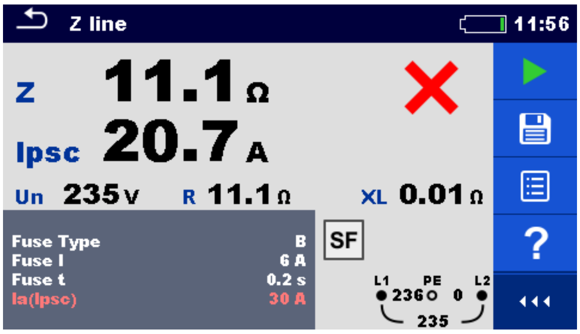
Exercises	Switch	Function	Site of error	ON	OFF
Line Impedance	S12	Z LINE	TN/TT F1/2 L3/N outlet (3-ph.)	> 10 Ω	< 2 Ω
	S13	Z LINE	TN/TT F2/2 L1/N outlet	> 10 Ω	< 2 Ω
	S14	**Z LINE**	**TN/TT F1/3 L3/N outlet**	**> 10 Ω**	**< 2 Ω**

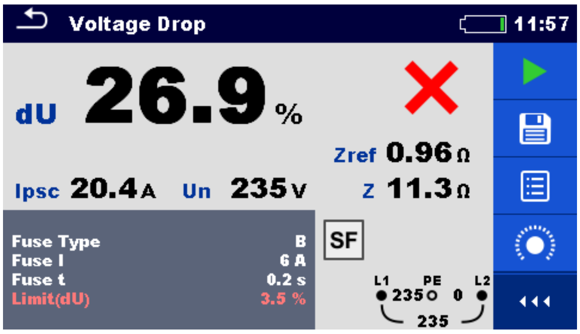
Figure 2-9: Simulated error on a 3-phase TN or TT system

The result is that the test fails since the measured impedance is higher than the maximum allowed (**7,3 Ω**) for this type of fuse.







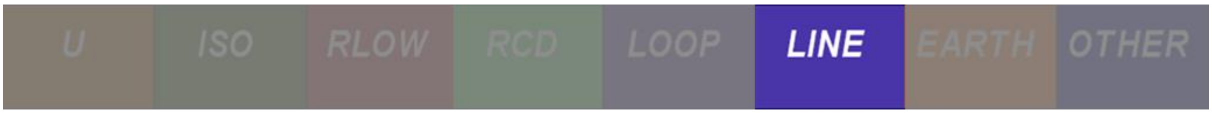


2.2.3.3 Exercise No. 2.2-3: dU, Z_{L-N} and I_{PSC} measurement on the socket side in an IT earthing system

The IT system has the supply part of the power source separated from earth or is earthed through a sufficient high impedance at the source. The line impedance depends on the size of the system and size of the transformer used:

- A small system requires a smaller transformer, which results in a higher reference line impedance.
- A large system requires a larger transformer, which results in a lower reference line impedance.

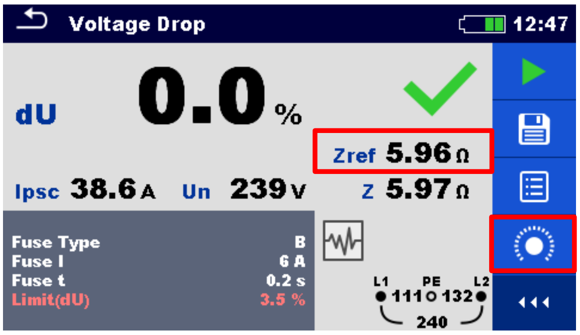
This exercise is done on the Application Trainer whose reference line impedance is approximately 7 Ω.



Measuring procedure

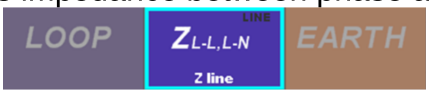
1 First the reference line impedance has to be measured. This is done by using the voltage drop measuring function **dU**.

To measure the reference line impedance in an IT system first click on the reference line impedance measurement button. Then press the start measurement button to measure the actual voltage drop.



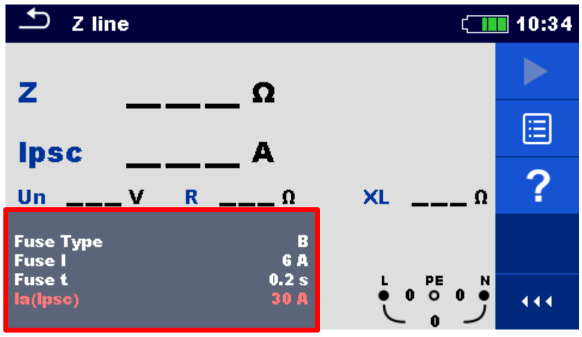
The reference line impedance should be done only on the one socket outlet which is selected as the reference one. All subsequent voltage drop measurements are then based on that reference line impedance.

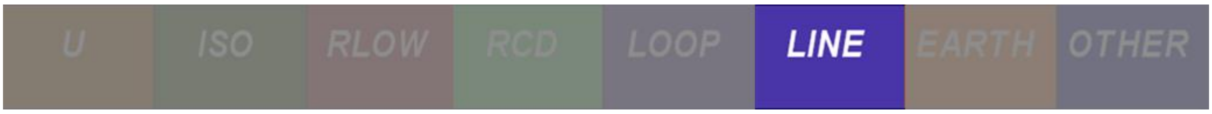
2 To measure the line impedance select the line impedance measurement **Z$_{L-L, L-N}$** (**Z line**) which measures impedance between phase and neutral conductors.



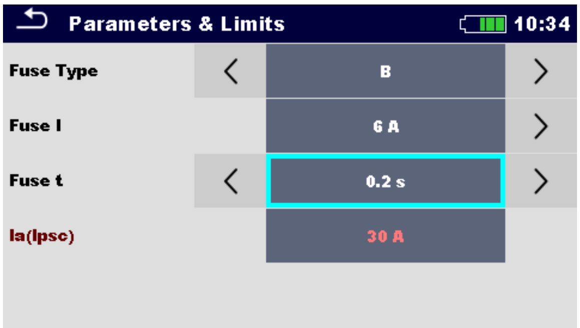
The line impedance measured at the supply side is actually the reference line impedance (Z_{REF}).

3 To get correct readings during measurement select the appropriate fuse settings (fuse type, size and trip-out time) by clicking in the bottom left dark grey corner.

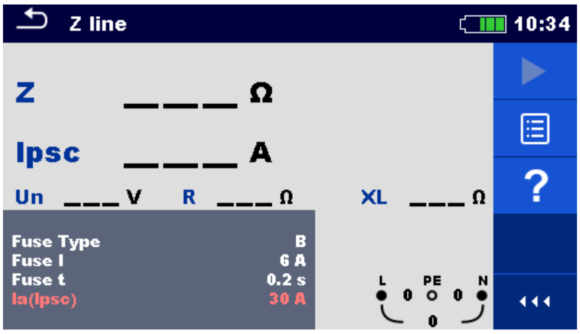




E.g. if we use a B6 fuse inside a residential building with a 1-phase IT system the following fuse settings should be set:



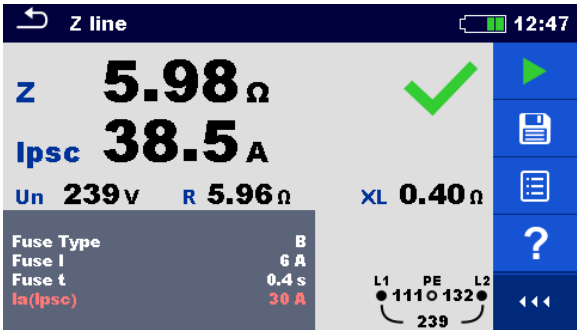
4 Whenever a fuse parameter setting is changed, the prospective fault current (I_{PSC}) limit is set automatically.

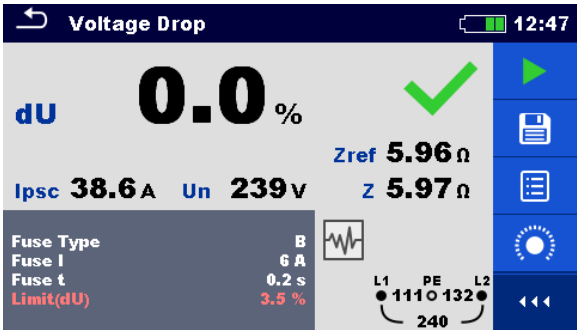


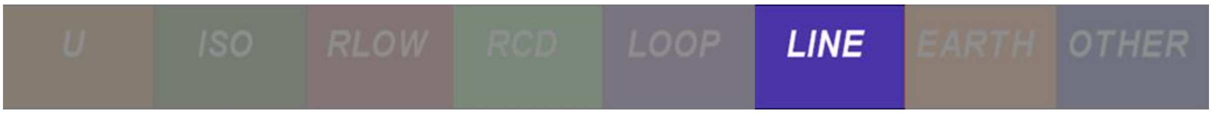
5 If the commander is to be used, plug the commander into the appropriate schuko outlet. If the commander is not used connect the L_x and L_y cables to the appropriate conductors.

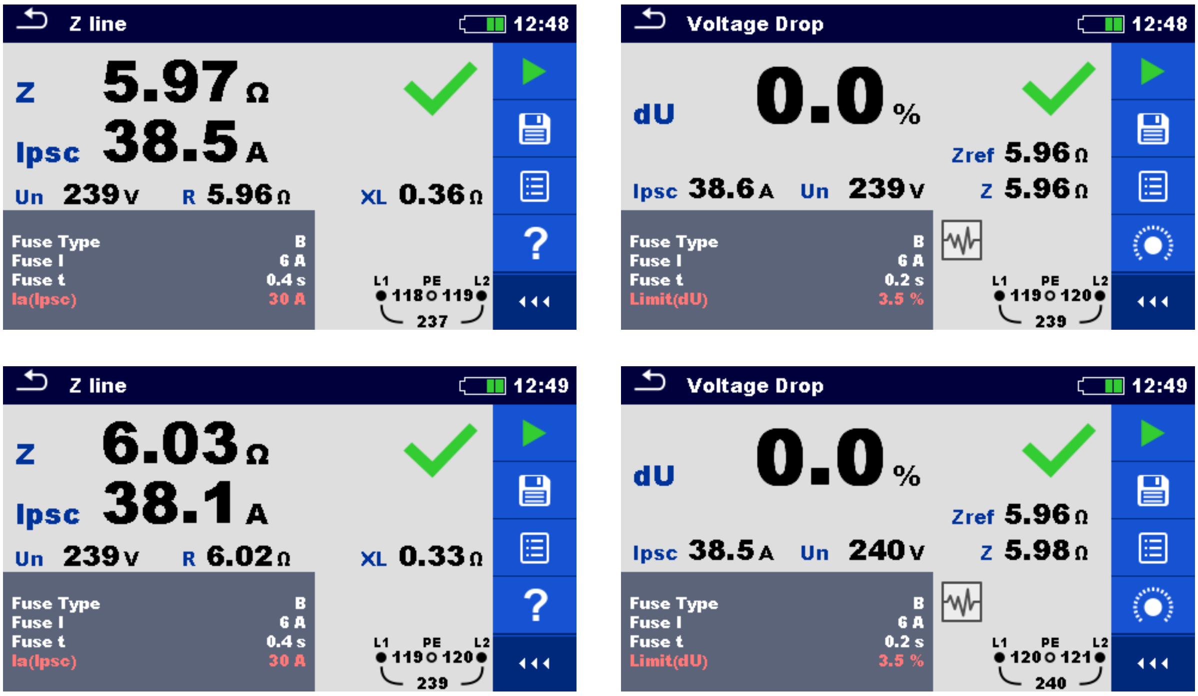
6 Press the **START** key.

Expected results









Since no faults in the IT system were present, all tests passed.

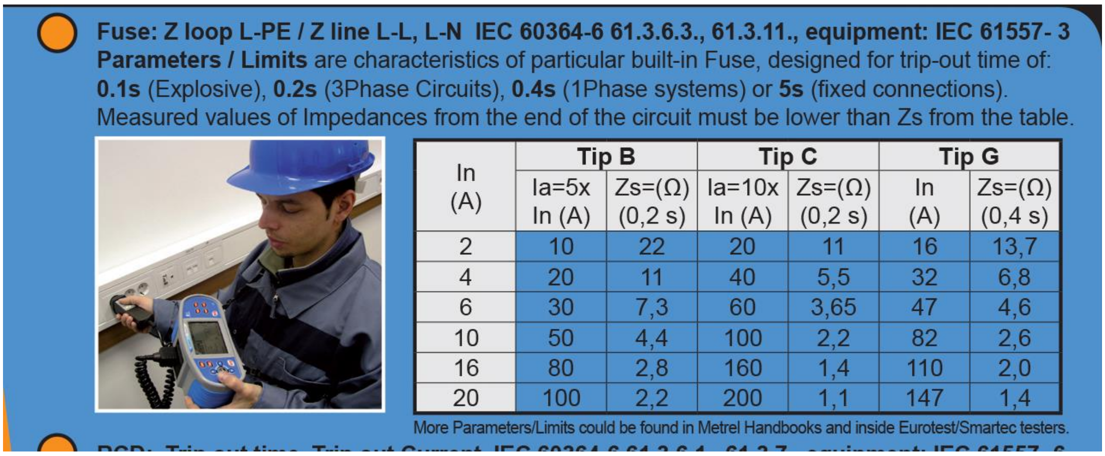
Expected results with a simulated error

It is not possible to simulate errors in an IT system in the Application Trainer.

2.3 Fault loop impedance measurement

Fault loop is a loop comprising mains source, line wiring and PE return path to the mains source. Scope of loop impedance test is:

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



Fuse: Z loop L-PE / Z line L-L, L-N IEC 60364-6 61.3.6.3., 61.3.11., equipment: IEC 61557- 3
Parameters / Limits are characteristics of particular built-in Fuse, designed for trip-out time of: **0.1s** (Explosive), **0.2s** (3Phase Circuits), **0.4s** (1Phase systems) or **5s** (fixed connections).
Measured values of Impedances from the end of the circuit must be lower than Zs from the table.

In (A)	Tip B		Tip C		Tip G	
	Ia=5x In (A)	Zs=(Ω) (0,2 s)	Ia=10x In (A)	Zs=(Ω) (0,2 s)	In (A)	Zs=(Ω) (0,4 s)
2	10	22	20	11	16	13,7
4	20	11	40	5,5	32	6,8
6	30	7,3	60	3,65	47	4,6
10	50	4,4	100	2,2	82	2,6
16	80	2,8	160	1,4	110	2,0
20	100	2,2	200	1,1	147	1,4

More Parameters/Limits could be found in Metrel Handbooks and inside Eurotest/Smartec testers.

Figure 2-10: Chart reference for fault loop impedance measurements – TN system

Limits: Where no RCD, select limit from the FUSE characteristics, test by Z loop. Where RCD:

Nominal Differntial current IΔN (mA)	10	30	100	300	500	1000
R earth (Ω) max. (Uc<25 V)	2500	833	250	833	50	25

Figure 2-11: Chart reference for fault loop impedance measurements – TT system

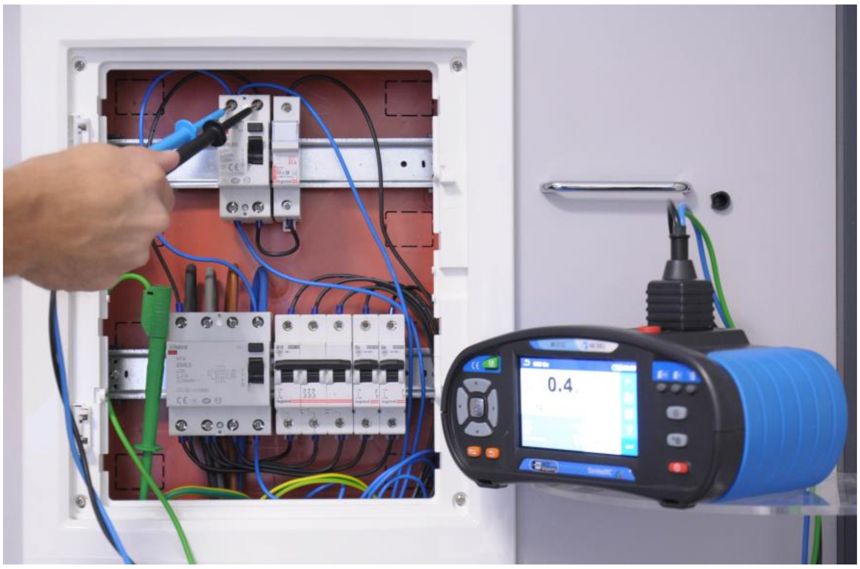


Figure 2-12: Measuring Z_{Loop} in Application Trainer's switchboard with cables on the supply side (before the RCD)

Figure 2-13: Measuring Z_{Loop} in the Application Trainer with the schuko commander

2.3.1 Background of measurements

Fault loop impedance includes the resistive and inductive part of the fault loop. The main part of inductivity comes from the power transformers inductances.
The main resistance part comes from copper wiring in the loop (conductors, transformer wiring) and earthing resistances (in TT systems).
In general the inductive part can be neglected if loop impedance > 0.4 Ω.
In applications where the measurement is carried out in close proximity to the power transformer (< 50m) the inductivity can be of a similar value than the resistance part. In this case it is very important to consider the impedance result because the fault loop resistance result is lower and can lead to wrong judgement.

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

In TN systems the fault loop Z_{L-PE} consists of:

- Z_T – power transformer secondary impedance,
- Z_L – phase wiring from source to fault impedance,
- R_{PE} – PE / PEN wiring from fault to source resistance.

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

$$Z_{LOOP} = \mathbf{Z_{L-PE} = Z_L + R_{PE} + Z_T}$$

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

$$I_{PFC} = \frac{U_{L-PE}}{Z_{L-PE}} > I_a$$

where

U_{L-PE} – rated fault loop voltage or nominal supply voltage.

Overcurrent disconnection device must be designed to trip out in case of an earth fault, i.e. short circuit of line to earth (PE). This means I_{PFC} must be higher than I_a (current for rated disconnection time) of the over current disconnection device.
The fault loop impedance should be low enough e.g. prospective fault current high enough that installed protection device will disconnect the fault loop within the prescribed time interval. Limit values for I_{PFC} and Z_{L-PE} depend on selected fuse type, size and required trip out time.

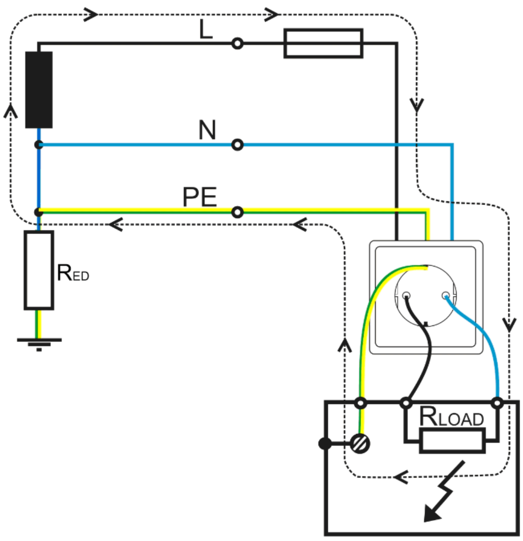


Figure 2-14: Fault loop in 1 phase TN system

2.3.1.2 Fault loop, fault impedance and prospective fault current in TT systems

In TT systems the fault loop consists of:

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

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

$$Z_{LOOP} = \mathbf{Z_{L-PE} = Z_L + R_{Eh} + R_{Ed} + Z_T}$$

In case of a short circuit or high leakage current between phase and PE conductor a dangerous contact voltage occurs on accessible metal parts. The voltage must stay below 50 V (25 V for aggravating conditions) otherwise the RCD must trip out:

$$Z_{L-PE} < \frac{U_C}{I_{\Delta N}} = \frac{50\,V}{I_{\Delta N}}$$

where

U_C – contact voltage,
$Z_{L\text{-}PE}$ – loop impedance,
$I_{\Delta N}$ – nominal trip out current of RCD.

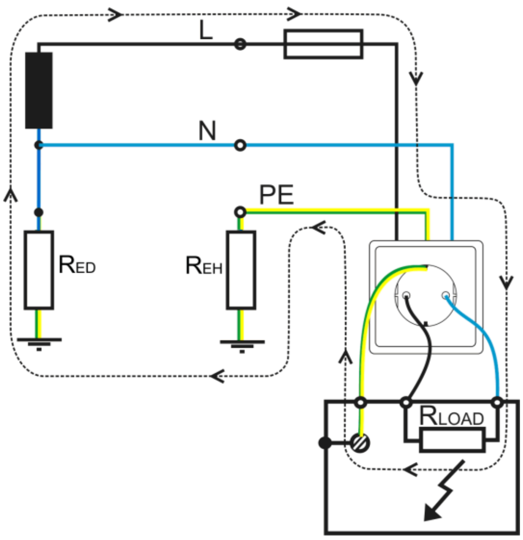


Figure 2-15: Fault loop in TT system

2.3.1.3 Fault loop, fault impedance and prospective fault current in RCD protected TN and TT systems

In TT and TN systems where RCD is used a different function for measuring the fault loop impedance is used - $\mathbf{Z_{S\ RCD}}$.

If the installation is protected with over current devices, the following condition must be fulfilled:

$$\mathbf{I_{PFC} > I_a}$$

where:

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

In this case the measured impedances are low (typically < 1.5Ω). The test current must be small to avoid tripping out the RCD. The function introduces a small test current (<

15mA) for all types of RCD available (10 mA … 1 A). This way we ensure that either type of RCD will not be tripped during the measurement.
The measured voltage drop caused by the small test current is very small – as a result, even small voltage fluctuations can seriously influence the results. Voltage fluctuations are mainly caused by load variations and switch on/off events on the mains.
To solve this problem advanced measuring techniques must be used that are beyond the scope of this test.

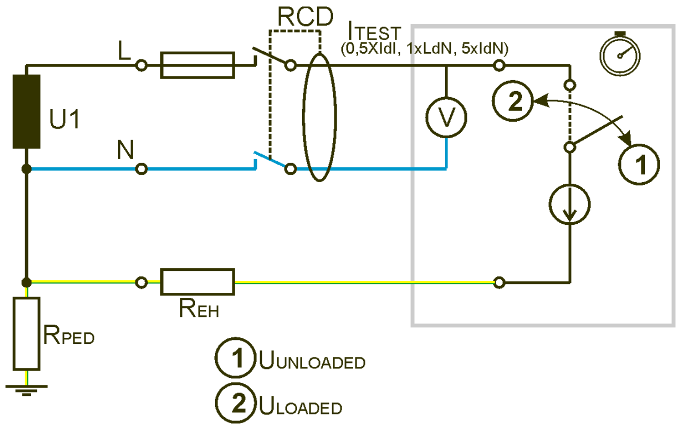


Figure 2-16: Loop impedance measurement in a RCD protected system

2.3.2 Exercises

2.3.2.1 Exercise No. 2.3-1: $Z_{L\text{-}PE}$ and I_{PFC} measurement on the supply side

Measuring connection topology

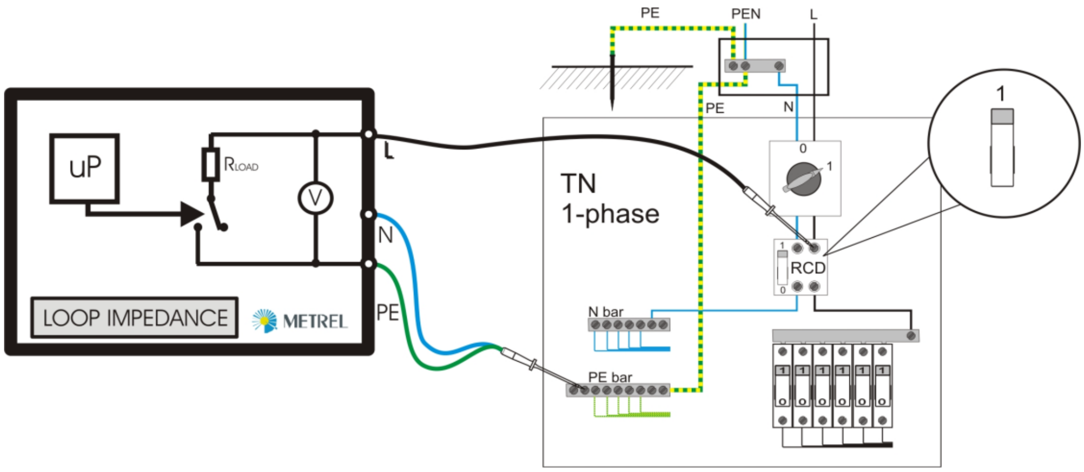


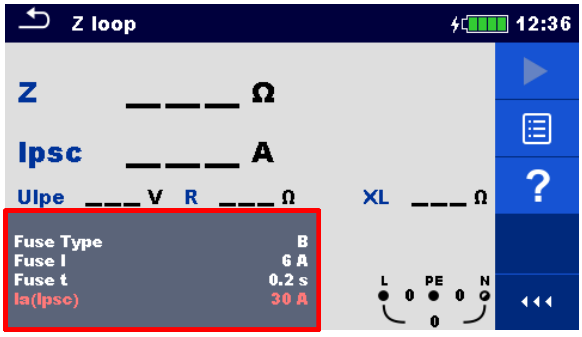
Figure 2-17: Topology in a 1-phase TN system on the supply side

Even though there is a RCD installed the Z_{LOOP} function may be used without fear of tripping the RCD since the measurement is taking place on the supply side (Figure 2-17) where the circuit is not yet protected by the RCD.

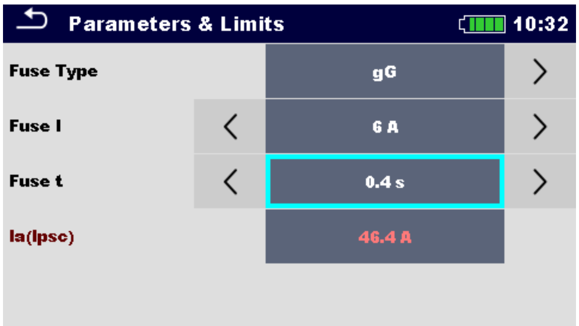
Measuring procedure

1 Select the fault loop impedance measurement **Z_{L-PE}** (**Z loop**) which measures impedance between phase and earth. When selecting this measurement one must be sure that a TN system without RCD is used. If a RCD in a TN system is used, this measurement will cause the RCS to trip. In this case the Z_S ($Z_{S\ RCD}$) option should be considered. It is only possible to perform a Z_{LOOP} measurement in a RCD protected system if the test is done on the supply side as is the case of this exercise.

2 To get correct readings during measurement select the appropriate fuse settings (fuse type, size and trip-out time) by clicking in the bottom left dark grey corner.

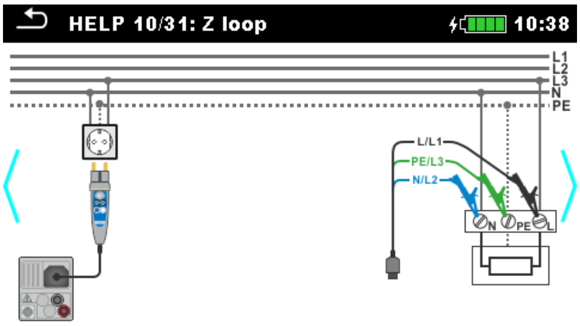


Typically, in a TN system inside a residential building with a 1-phase system a 6A gG fuse is used.



Whenever a fuse parameter setting is changed, the prospective fault current (I_{PSC}) limit is set automatically.

3 If a schuko commander is to be used, plug the commander into the appropriate outlet. If the cables are used, connect all cables appropriately – the PE cable to the PE conductor, the N cable to the N conductor and the phase cable to a phase conductor (L1, L2 or L3).



4 Press the **START** key.

Expected results

This test should only be used in TN systems that do not have a RCD installed. If a RCD is installed in a TN system the $Z_{S\ RCD}$ function should be used in order not to trip the RCD.

The prospective fault current (I_{PSC}) is calculated as:

$$I_{PFC} = \frac{U_N}{Z_{MEASURED}}$$

where:

U_N – nominal value, determined according to the measured voltage (U_{L-PE}).

The measured $\mathbf{Z_{LOOP}}$ parameter is actually the reference impedance (Z_{REF}) since all measurements are done on the supply side. In a TN system the measured values $\mathbf{Z_{LOOP}}$ and $\mathbf{Z_{LINE}}$ should be equal (see chapter 1.4.3 for more details). In a TT system the difference between $\mathbf{Z_{LOOP}}$ and $\mathbf{Z_{LINE}}$ represents the earth resistance (R_E) which is approximately 3 Ω.

Expected results with a simulated error

It is not possible to simulate an error in the Application Trainer on the supply side.

2.3.2.2 Exercise No. 2.3-2: $Z_{L\text{-}PE}$ and I_{PFC} measurement on the socket side – RCD protected

Measuring connection topology

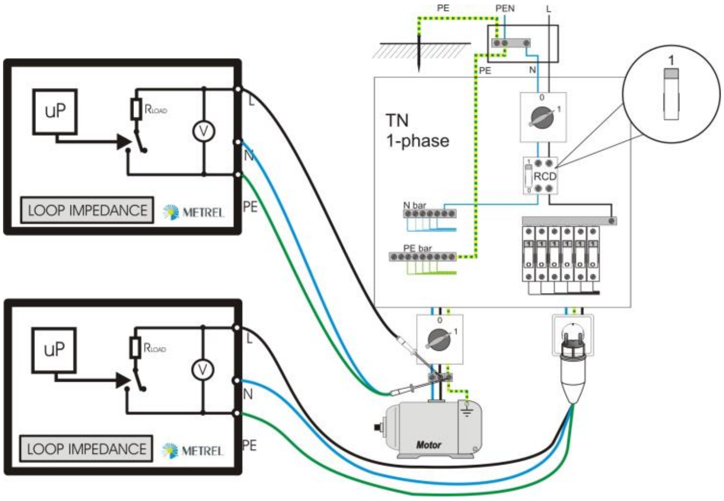


Figure 2-18: Topology in a 1-phase TN system on the circuit side

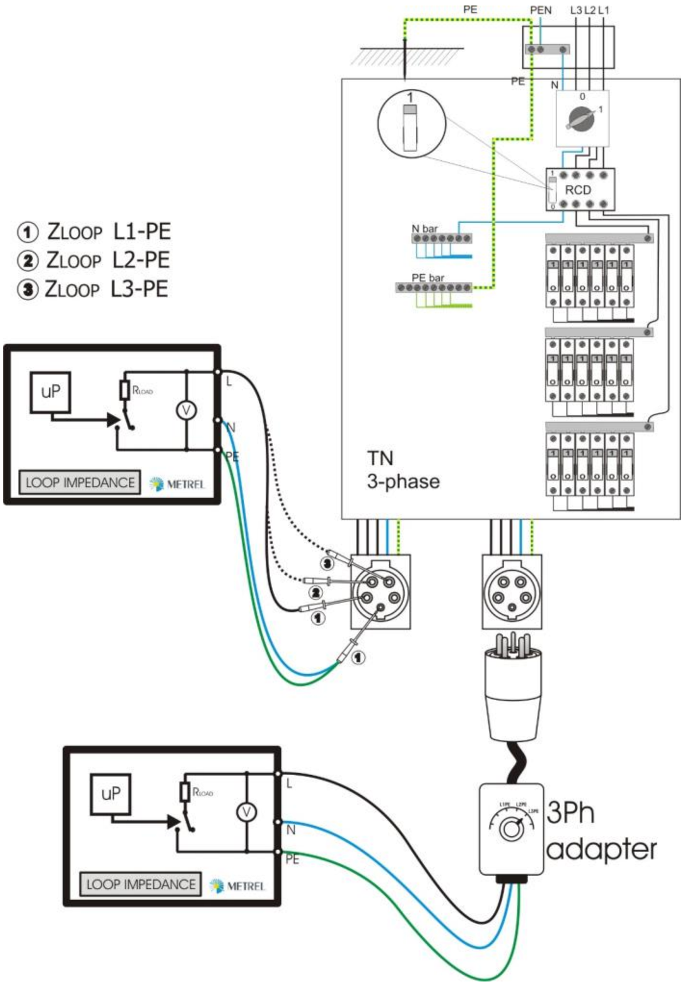


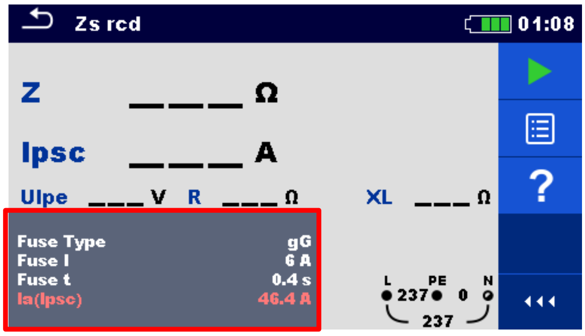
Figure 2-19: Topology in a 3-phase TN system on the circuit side

Since the measurement is taking place on the circuit side (after the RCD) the correct function for performing this kind of measurement is the $Z_{S\ RCD}$ function which will not trip the RCD.

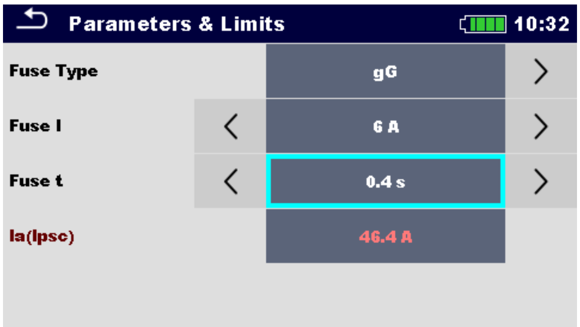
Measuring procedure

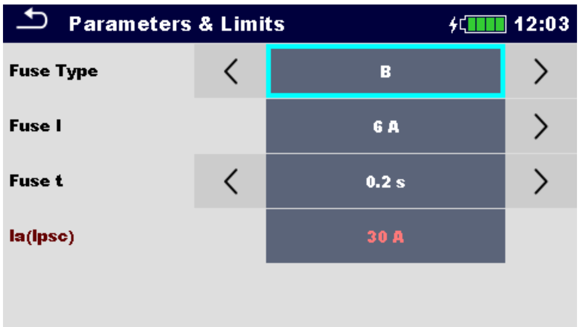
1 Select the fault loop impedance measurement $\mathbf{Z_{S\ RCD}}$ for a RCD protected system that measures impedance between phase and earth. This way the RCD will not be tripped during the fault loop impedance measurement

2 To get correct readings during measurement select the appropriate fuse settings (fuse type, size and trip-out time) by clicking in the bottom left dark grey corner.



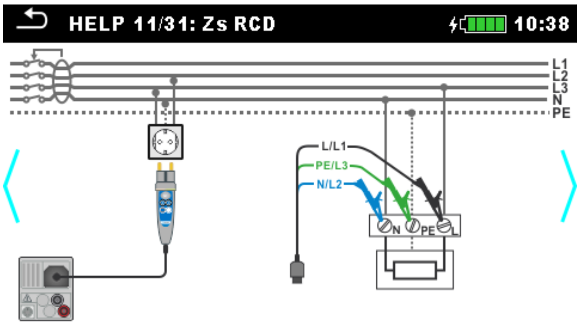
In a TN system inside a residential building with a 1-phase system a 6A gG fuse is typically used whereas in a 3-phase system a B6 fuse is used. Settings for each type of fuse are shown below.





Whenever a fuse parameter setting is changed, the prospective fault current (I_{PSC}) limit is set automatically.

3 If a schuko commander is to be used, plug the commander into the appropriate outlet. If the cables are used, connect all cables appropriately – the PE cable to the PE conductor, the N cable to the N conductor and the phase cable to a phase conductor (L1, L2 or L3).



4 Press the **START** key.

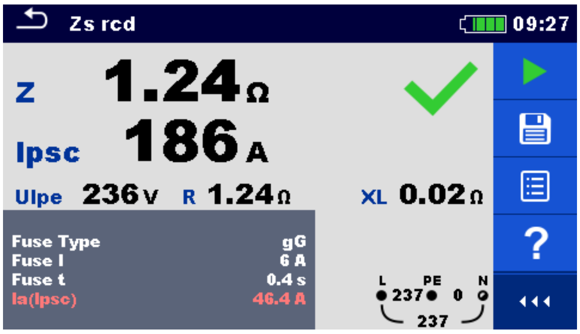
Expected results

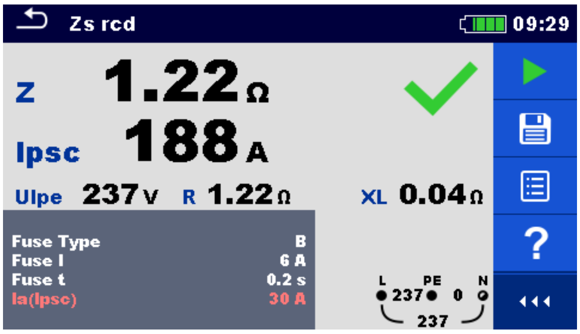
The prospective fault current (I_{PSC}) is calculated as:

$$I_{PFC} = \frac{U_N}{Z_{MEASURED}}$$

where:

U_N – nominal value, determined according to the measured voltage ($U_{L\text{-}PE}$).





In a 1-phase TN system the maximum allowed impedance result for a 6A gG type fuse with 400ms trip-out time is **4,6 Ω** whereas in a 3-phase TN system the maximum allowed impedance result for a 6A B type fuse with 200ms trip-out time is **7,3 Ω**[6].
As seen from both screens the impedance and I_{PSC} are both within limits and the tests are marked as passed.

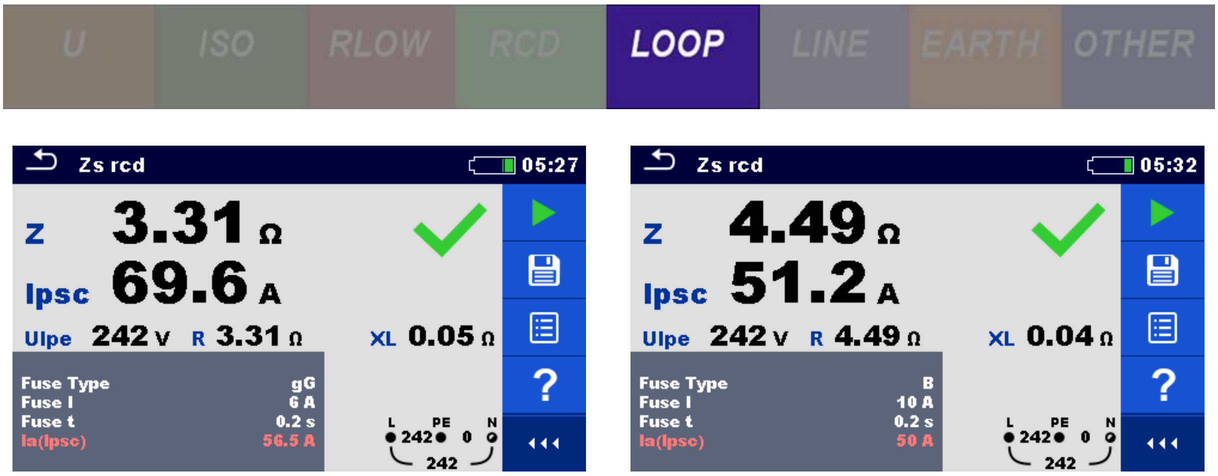
Expected results with a simulated error

During the test we add an error on the PE conductor by enabling switch **S20** in the Application Trainer. Toggling this switch introduces additional resistance on the PE conductor on a 1-phase TN earthing system.

Exercises	Switch	Function	Site of error	ON	OFF
PE Connection	S15	R LOW / IMD	IT F3/1 PE outlet	> 20 Ω	< 1 Ω
	S16	ISFL / IMD	IT F3/2 ISFL	approx. 6 mA (@ 230 V) approx. 3 mA (@ 115 V)	< 1.3 mA
	S17	R LOW	IT PE ref.	approx. 3.3 Ω	< 1 Ω
	S18	R LOW	TN/TT F1/4 PE light	> 20 Ω	< 1 Ω
	S19	R LOW / Z LOOP	TN/TT F1/2 PE outlet (3-ph.)	approx. 3.4 Ω	< 1 Ω
	S20	**R LOW / Z LOOP**	**TN/TT F2/2 PE outlet**	**> 2.3 Ω**	**< 2 Ω**
	S21	R LOW	MPE / PE Gas	approx. 2.2 Ω	< 1 Ω
	S22	R LOW	MPE / PE Heat inst.	approx. 3.3 Ω	< 1 Ω

Figure 2-20: Simulated error on PE conductor in a 1-phase TN system

[6] See chapter 1.4 Ensurance of Safety for more details on fuse and RCD trip-out times and impedances.



The result of both test is shown as passed. The correct result of the measurement should be fail since the PE has an error simulated. Because $Z_{S\ RCD}$ is not the proper method for measuring fault loop on a RCD protected system the true fault is not discovered by the device and the device returns a false positive. A better function to measure the resistance in this case would be the R_{PE} function. If a fuse with a higher allowed current were to be used the result would also be shown as failed in this case.

If we simulate an error in the line (L) conductor instead of the PE conductor, the test should fail since we introduce an additional 10Ω to the wiring on the line conductor. This is done by enabling switches **S12** (3-phase), **S13** (1-phase) or **S14** (1-phase) in the Application Trainer.

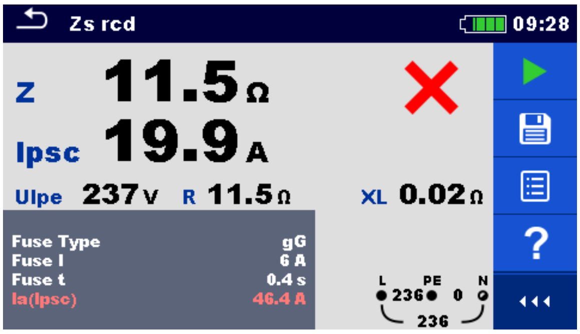
Exercises	Switch	Function	Site of error	ON	OFF
Line Impedance	S12	Z LINE	TN/TT F1/2 L3/N outlet (3-ph.)	> 10 Ω	< 2 Ω
	S13	Z LINE	TN/TT F2/2 L1/N outlet	> 10 Ω	< 2 Ω
	S14	Z LINE	TN/TT F1/3 L3/N outlet	> 10 Ω	< 2 Ω

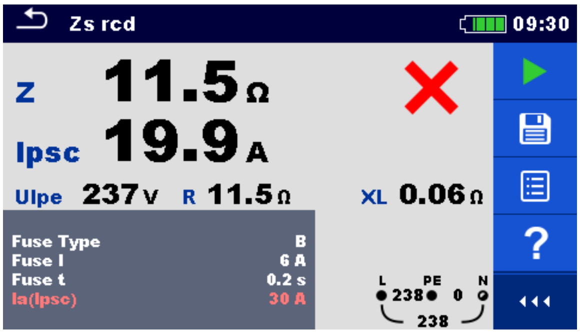
Figure 2-21: Simulated errors on the line conductor

In a 1-phase TN system the maximum allowed impedance result for a 6A gG type fuse with 400ms trip-out time is **4,6 Ω**, whereas in a 3-phase TN system the maximum allowed impedance result for a 6A B type fuse with 200ms trip-out time is **7,3 Ω**[7].
The result is that the test fails since the measured impedance value are higher than the maximum allowed (**4,6 Ω** and **7,3 Ω**) for both types of fuses.

[7] See chapter 1.4 Ensurance of Safety for more details on fuse and RCD trip-out times and impedances.


U
ISO
RLOW
RCD
LOOP
LINE
EARTH
OTHER


Zs rcd
09:28
Z 11.5 Ω
Ipsc 19.9 A
Ulpe 237 V
R 11.5 Ω
XL 0.02 Ω
Fuse Type gG
Fuse I 6 A
Fuse t 0.4 s
Ia(Ipsc) 46.4 A
L PE N
236 0
236


Zs rcd
09:30
Z 11.5 Ω
Ipsc 19.9 A
Ulpe 237 V
R 11.5 Ω
XL 0.06 Ω
Fuse Type B
Fuse I 6 A
Fuse t 0.2 s
Ia(Ipsc) 30 A
L PE N
238 0
238

2.4 Measuring RCD parameters

2.4.1 Background of measurement

RCD protection switches are used to protect users of electric appliances against electric shock caused by fault and leakage currents in the installation. Even relatively small currents are dangerous if resistance to earth and equipotential bonding are relatively high. Typical fault reasons are deteriorated insulation, dirt, moisture, filter capacitors etc.

RCD: Trip out time, Trip out Current IEC 60364-6 61.3.6.1., 61.3.7., equipment: IEC 61557- 6

RCD	RCD trip out at differential current Id (ms)			
	1/2 x IΔN	1 x IΔN	2 x IΔN	5 x IΔN
General	No trip	tΔ < 300	tΔ < 150	tΔ < 40
Selective	No trip	130 x tΔ < 500	60 x tΔ < 200	50 x tΔ < 150

RCD	Slope range (from-to)
∼ AC	0.5 ÷ 1.0 x IΔN
A	0.35 ÷ 1.4 x IΔN
B	0.5 ÷ 2.0 x IΔN

Figure 2-22: Chart reference for line impedance measurements

Limits: Where no RCD, select limit from the FUSE characteristics, test by Z loop. Where RCD:

Nominal Differntial current IΔN (mA)	10	30	100	300	500	1000
R earth (Ω) max. (Uc<25 V)	2500	833	250	833	50	25

Figure 2-23: Chart reference for fault loop impedance measurements – TT system

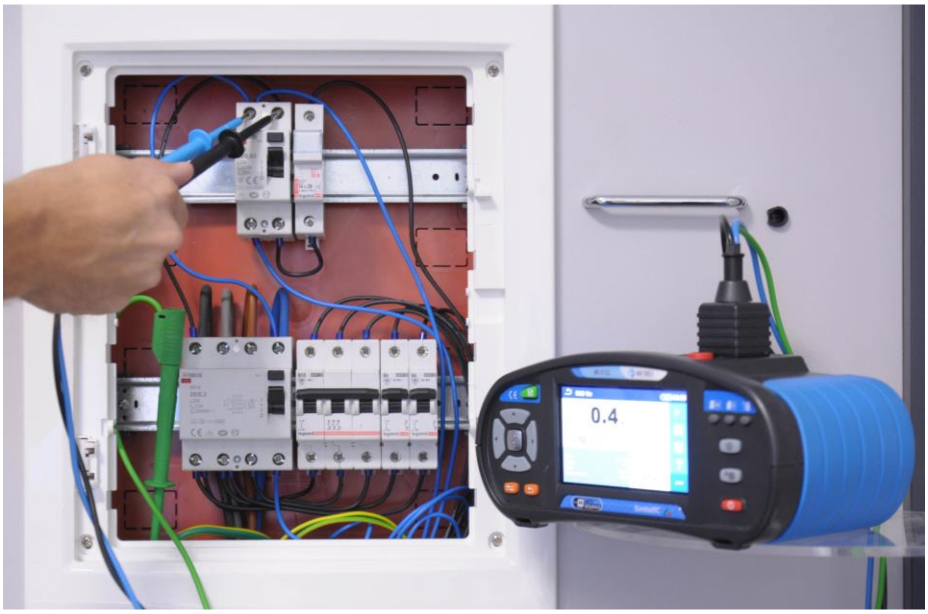


Figure 2-24: RCD measurement in Application Trainer's switchboard with cables on the supply side

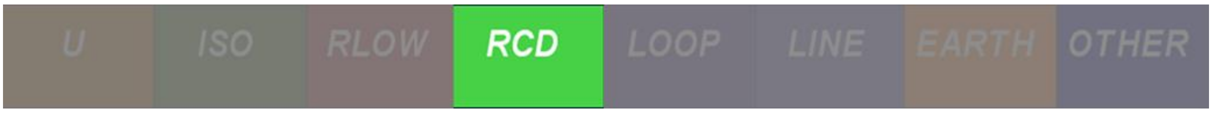


Figure 2-25: RCD measurement in the Application Trainer with the schuko commander

Figure 2-26: RCD measurement in an IT earthing system

2.4.1.1 Function of RCD

In TN systems, fault and leakage currents flow from live conductors to protection earth conductor and then through PEN conductor to neutral terminal of power transformer. The RCD must trip out if the leakage (fault) current exceeds its nominal current:

$$I_{FAULT,\ LEAKAGE} \le I_{\Delta N}$$

It must be assured that the fault and leakage currents do not cause touch voltages higher than conventional safety limit of 50 (25)V.

$$Z_{LOOP} \cdot I_{\Delta N} \leq U_C$$

Allowed touch voltages vary depending on the presence of water in a room/building. Typically, 3 contact voltages are allowed:

- 12 V – for hospitals, saunas.
- 25 V – for rooms where there is presence of water (e.g. bathrooms).
- 50 V – for rooms where there is no presence of water.

Impedances in TN systems are usually much lower than allowed (for example: impedance of fault loop protected by RCD protection device with rated differential current of 30 mA could be as high as 1666 Ω, while actual values are lower than 2 Ω).

In TT systems, fault currents supplied by line voltage flow through the fault to protection earth conductor (PE) and then to ground via the system's earthing resistance. The current is driven to the grounding system of the power transformer and thus to the neutral terminal of the transformer. Total impedance of the fault loop consists of more serial impedances, where the major part presents global resistance of earthing system; other impedances are negligible in comparison with this resistance. The following condition must be fulfilled:

$$R_E \cdot I_{\Delta N} \leq U_C$$

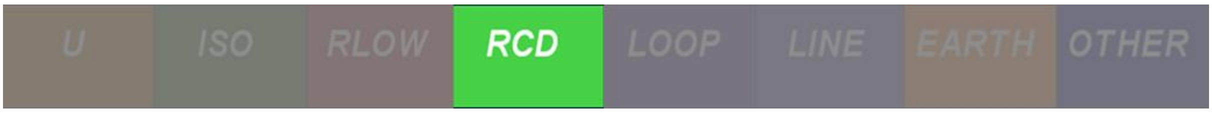
where:

R_E – global earthing resistance in Ω
$I_{\Delta N}$ – nominal differential current of RCD,
U_C – limit contact voltage (50 V or 25 V).

RCD test parameters (test current shape, size) must be set correctly before the test. Disconnection time $t_{\Delta N}$ and actual disconnection currents I_{Δ} are measured. A complete analysis of the proper operation of installed RCD includes:

- disconnection times $t_{\Delta N}$ at ½, 1 and 5 $I_{\Delta N}$
- contact voltage test.

Limit values are defined in appropriate standards and are usually inbuilt in measuring equipment.



2.4.2 Exercises

2.4.2.1 Exercise No. 2.4-1: RCD trip-out time, current and contact voltage measurements

Measuring connection topology

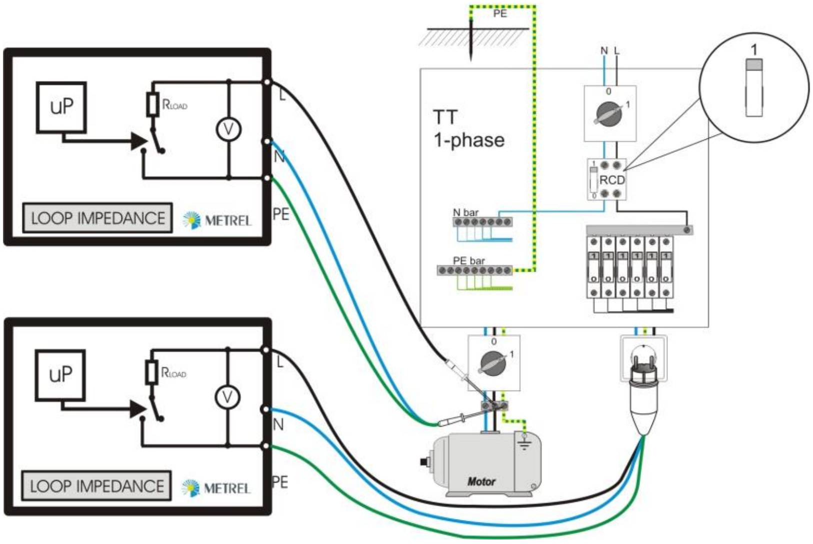


Figure 2-27: RCD measurement in a 1-phase TT system

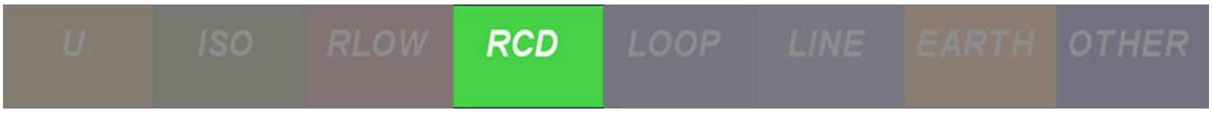
Measuring procedure

1 To measure the contact voltage **U_C** of a TT system select the **RCD U_C** test.

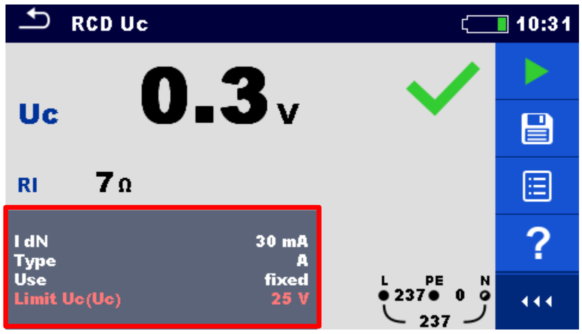
2 To measure the trip-out time **$t_{\Delta N}$** of a TT system select the **RCD t** test.

3 To measure the trip-out current **I_{Δ}** of a TT system select the **RCD I** test.

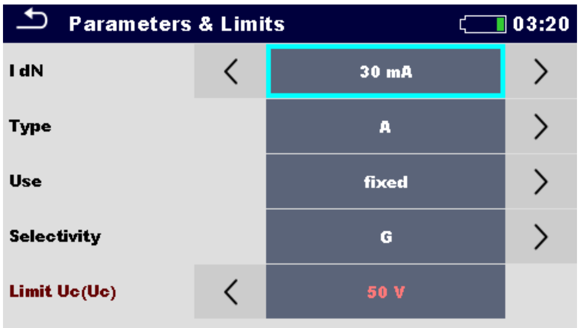
4 To perform all RCD measurements (**U_C**, **$t_{\Delta N}$**, **I_{Δ}**) in one easy step select the **RCD Auto** test.



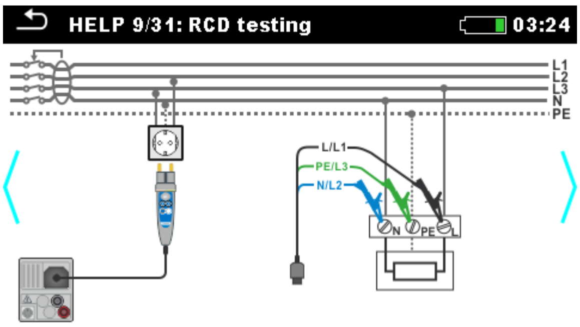
5 Set the RCD test parameters (I_{dN}, current type, selectivity and contact voltage limit) by clicking in the bottom left dark grey corner and selecting the appropriate RCD settings.



In this case we use a 30mA RCD so in a 1-phase TT earthing system which doesn't have water in the proximity. That is why the contact voltage limit may be set to 50 V.



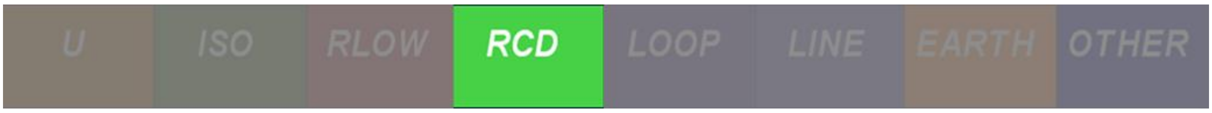
6 If a schuko commander is to be used, plug the commander into the appropriate outlet. If the cables are used, connect all cables appropriately – the PE cable to the PE conductor, the N cable to the N conductor and the phase cable to a phase conductor (L1, L2 or L3).



7 Press the **START** key.

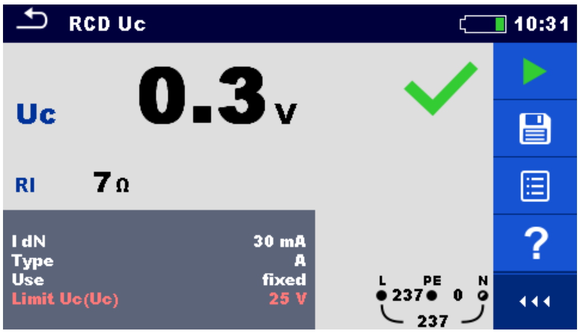
Expected results

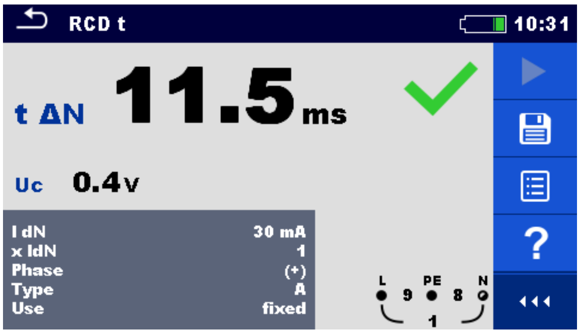
In a normal situation, the contact voltage should be well below 1 V (please see chapter RCD trip-out contact voltage test for more information), whereas the trip-out time and

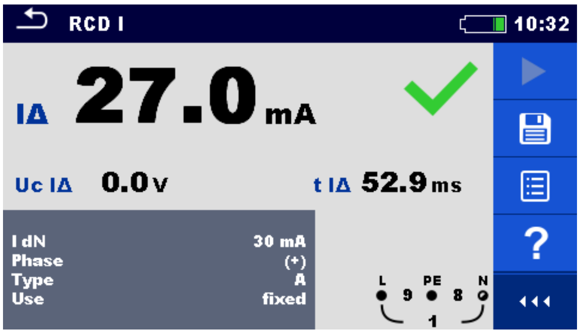


trip-out current should be within limits described in chapters RCD trip-out time test and RCD trip-out current test.

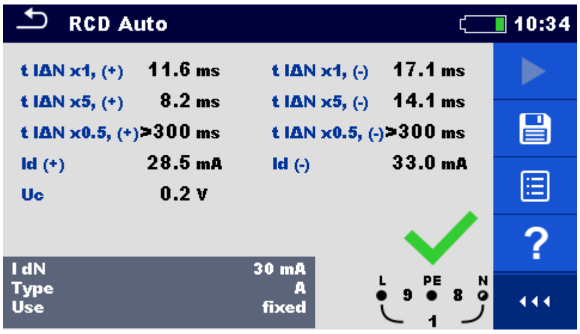
In our case the results we get for all three tests are within the expected limits.





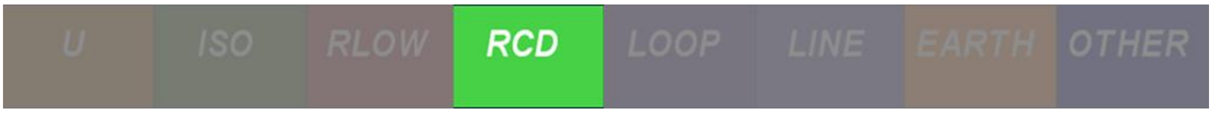


After the trip-out time and trip-out current tests, the RCD is tripped as is the intention of both test. Be sure to reset the RCD before each test.
Instead, all three mentioned test a predefined RCD *AUTO SEQUENCE®* test (**RCD Auto**) can be used. The functionality is that it performs all three test one after another. The tester is only required to reset the RCD every time it is tripped-out to continue testing.



Expected results with a simulated error

RCD testing simulated errors do not produce enough contact voltage to properly display failed results. For this reason no example is given.



2.4.2.2 Exercise No. 2.4-2: RCD trip-out time, current and contact voltage measurements in an IT earthing system

Measuring procedure

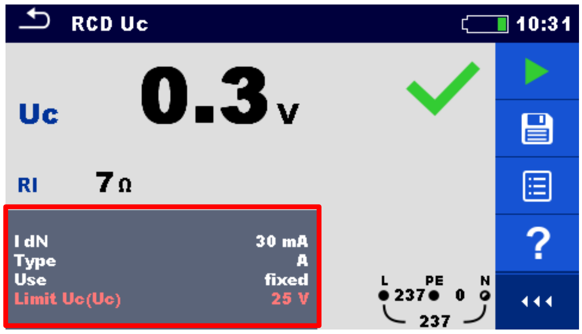
1 To measure the contact voltage **U_C** of a IT system select the **RCD U_C** test.

2 To measure the trip-out time **$t_{\Delta N}$** of a IT system select the **RCD t** test.

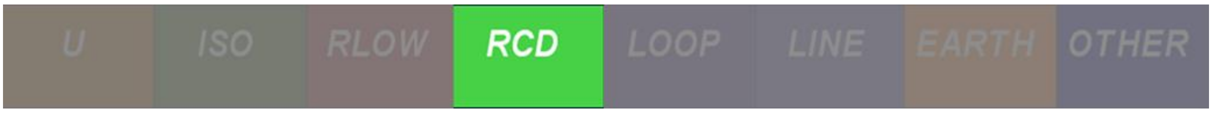
3 To measure the trip-out current **I_{Δ}** of a IT system select the **RCD I** test.

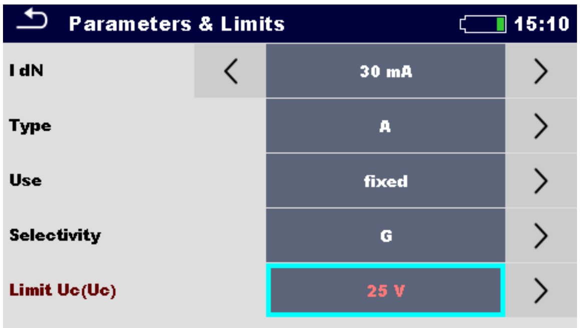
4 To perform all RCD measurements (**U_C**, **$t_{\Delta N}$**, **I_{Δ}**) in one easy step select the **RCD Auto** test.

5 Set the RCD test parameters (I_{dN}, current type, selectivity and contact voltage limit) by clicking in the bottom left dark grey corner and selecting the appropriate RCD settings.



In this case we use a 30mA RCD so in an IT earthing system which has water in the proximity. That is why the contact voltage limit must be set to 25 V.





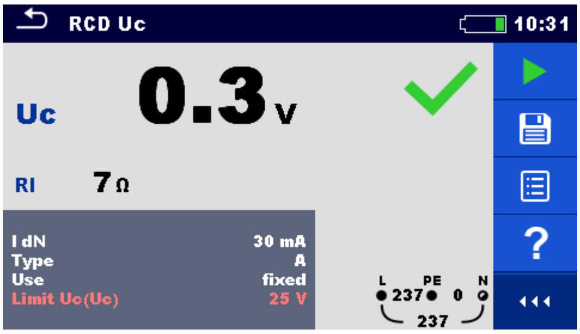
6 To measure RCD functions in an IT earthing system we have to simulate the fault loop. This can be achieved in the Application Trainer by creating a fault loop between two circuits. To create such a situation connect the line (black cable in Figure 2-26) and the neutral (blue cable in Figure 2-26) cables to Line1 and Line2 of the first circuit. Then connect the PE cable (green cable in Figure 2-26) to one of the Line conductors on the second circuit as shown in Figure 2-26.

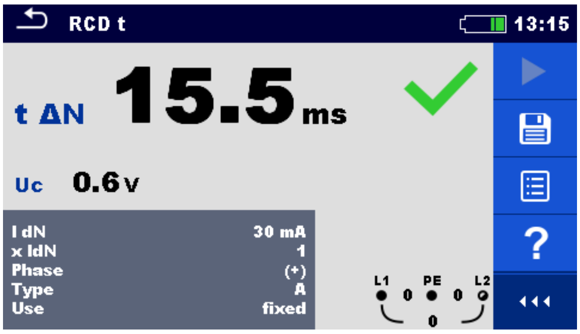
7 Press the **START** key.

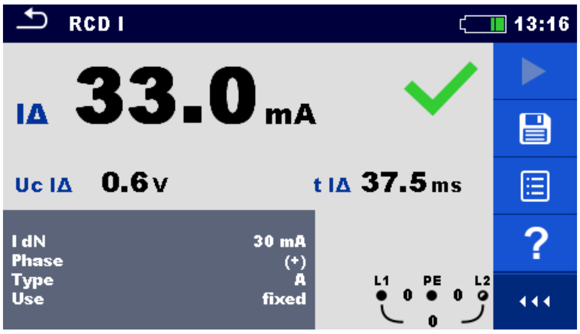
Expected results

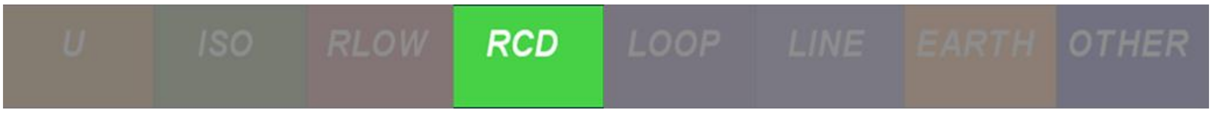
In a normal situation, the contact voltage should be well below 1 V (please see chapter RCD trip-out contact voltage test for more information), whereas the trip-out time and trip-out current should be within limits described in chapters RCD trip-out time test and RCD trip-out current test.

In our case, the results we get for all three tests are within the expected limits.



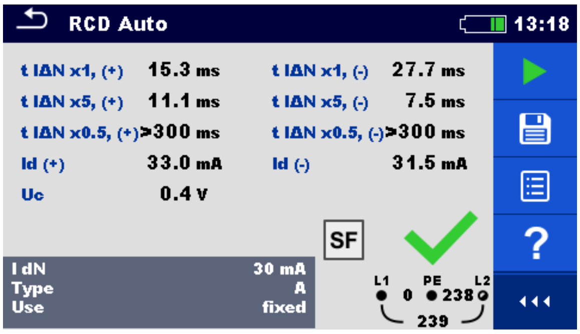






After the trip-out time and trip-out current tests, the RCD is tripped as is the intention of both tests. Be sure to reset the RCD before each test.

Instead of performing all three mentioned tests individually, a predefined RCD *AUTO SEQUENCE*® test (**RCD Auto**) can be used. The auto test performs all three test one after another. The tester is only required to reset the RCD every time it is tripped-out to continue testing.



2.5 Insulation monitor devices and measuring single fault leakage currents

2.5.1 Background of measurement

Figure 2-28: Chart reference for IMD and single fault leakage current measurements

Figure 2-29: Measuring I_{SFL} and IMD in an IT system

2.5.1.1 Single fault leakage current (I_{SFL})

I_{SFL} is used for evaluating the effectiveness of an IT earthing systems that converts to a TT system during a single fault. The purpose of this test is to check if contact voltages stay inside the safety limits during a single fault condition. The leakage/fault currents are increased by a certain amount during the single fault and can rise above the limit values. The calculated result U_{CSF1} returns the expected contact voltage in a single fault.

Typical measurements & calculations:

- I_{SFL1}, I_{SFL2}, I_{SFL3} for individual or group earthing
- U_{CSF1}, U_{CSF2}, U_{CSF3} (calculated) for each individual or group earthing

The earthing resistances of individual and group earthings must be known for the U_{CSF} calculation:

$$U_{CSFx} < (R_{E_{LOCAL}} + R_{PEC_{LOCAL}}) \cdot I_{SFLx} = 50\ (25)\ \mathrm{V}$$

where:

U_{CSF}	– Contact voltages at single fault on earthing (calculated).
I_{SFL}	– Single fault leakage current (measured).
R_{E_LOCAL}	– Earthing resistance of each individual or group earthing (measured).
R_{PEC_LOCAL}	– PE conductor resistance of each individual or group earthing (measured).

2.5.1.2 Insulation monitor device (IMD)

IMDs and other monitoring devices usually include a self-test option for an alarm circuit. The alarm circuit can be double checked by applying an adjustable resistor between line and PE conductors.

When measuring IMD in an IT earthing system, we can either measure the response of the IMD based by lowering resistance or the current in the circuit. In either case, the allowed IMD values are:

- $30\ k\Omega \leq R_{MEASURED} \leq 50\ k\Omega$
- $I_{MEASURED} \leq 4{,}4\ mA$

All measured values in between these limits will not cause the IMD to sound the alarm. All measured values that fall out of these barriers should produce an error.

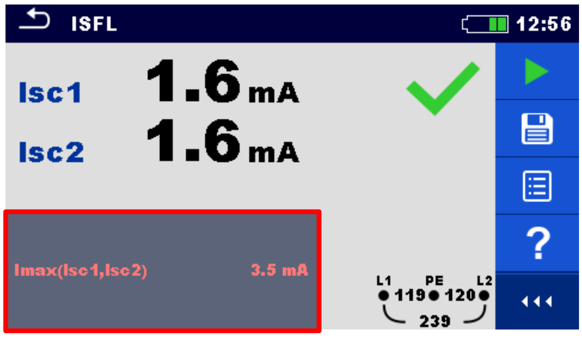
2.5.2 Exercises

2.5.2.1 Exercise No. 2.5-1: Measuring single fault leakage currents (I_{SFL})

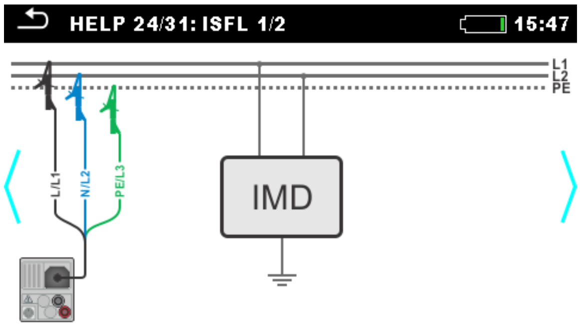
Measuring procedure

1 To measure the single fault leakage currents select first the **I_{SFL}** function in the **Other** section.

2 Set the maximum allowed short circuit current on both lines by clicking in the bottom left dark grey corner.



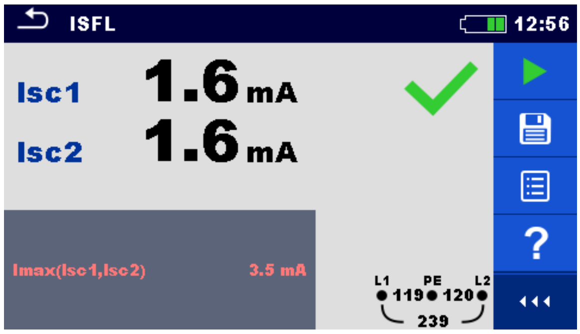
3 If a schuko commander is to be used, plug the commander into the appropriate outlet. If the cables are used, connect all cables appropriately – the PE cable to the PE conductor, the N cable to Line2 and the L cable to Line1.



4 Press the **START** key.

Expected results

In a normal situation when no faults are present, the measured single fault leakage current should be well below the defined limit (3.5 mA) as seen in the picture below.



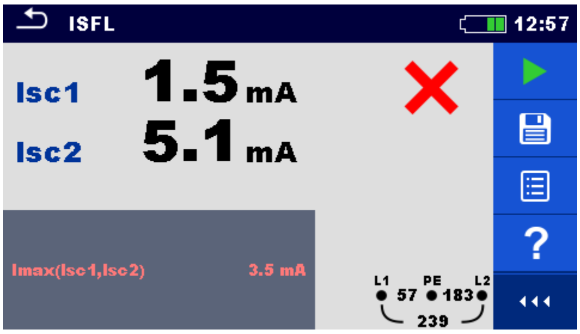
Expected results with a simulated error

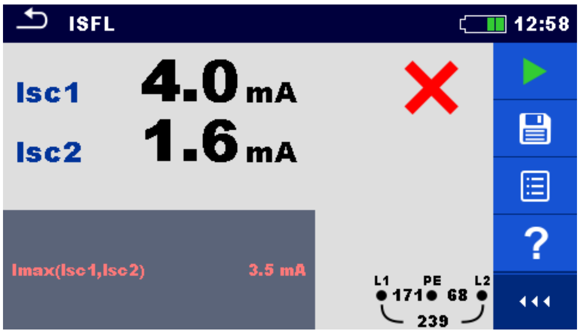
There are to possible errors that can be simulated with the Application Trainer:

- To introduce a single fault leakage current enable the switch **S16**.
- To simulate a fault current between the L1 and the PE conductors enable the switch **S28**.

Exercises	Switch	Function	Site of error	ON	OFF
PE Connection	S15	R LOW / IMD	IT F3/1 PE outlet	> 20 Ω	< 1 Ω
	S16	**ISFL / IMD**	**IT F3/2** **ISFL**	**approx. 6 mA (@ 230 V)** **approx. 3 mA (@ 115 V)**	**< 1.3 mA**
	S17	R LOW	IT PE ref.	approx. 3.3 Ω	< 1 Ω
	S18	R LOW	TN/TT F1/4 PE light	> 20 Ω	< 1 Ω
	S19	R LOW / Z LOOP	TN/TT F1/2 PE outlet (3-ph.)	approx. 3.4 Ω	< 1 Ω
	S20	R LOW / Z LOOP	TN/TT F2/2 PE outlet	> 2.3 Ω	< 2 Ω
	S21	R LOW	MPE / PE Gas	approx. 2.2 Ω	< 1 Ω
	S22	R LOW	MPE / PE Heat inst.	approx. 3.3 Ω	< 1 Ω
Insulation resistance	S27	R_{ISO}	IT F3/1 L1/L2 outlet	approx. 0.45 MΩ	> 200 MΩ
	S28	**ISFL/IMD**	**IT F3/1** **L1/PE outlet**	**approx. 3 mA**	**< 1 mA**
	S29	I_{Δ}	TN/TT F2/2 L1/PE outlet	approx. 5.1 mA (@230 V) approx. 2.5 mA (@115 V)	< 3.5 mA
	S30	R_{ISO}	TN/TT F1/2 L1/PE outlet (3-ph.)	capacitive 1.45 MΩ	> 200 MΩ
	S31	R_{ISO} / VARISTOR	TN/TT SPD GAS / PE	shorted	U_{SPD} approx. 150 V
	S32	R_{ISO}	TN/TT F1/2 L2/N outlet (3-ph.)	approx. 0.45 MΩ	> 200 MΩ
	S33	R_{ISO}	TN/TT F1/2 L1/L2 outlet (3-ph.)	approx. 0.45 MΩ	> 200 MΩ

Figure 2-30: ISFL simulated errors on an IT system





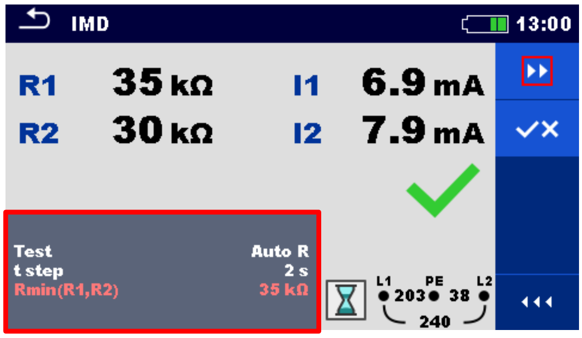
In both cases the measured fault currents increased above the allowed value which means that the contact voltage is above the safety limit during the single fault condition. As expected in such case the tests failed.

2.5.2.2 Exercise No. 2.5-2: Verification of insulation monitor devices (IMD)

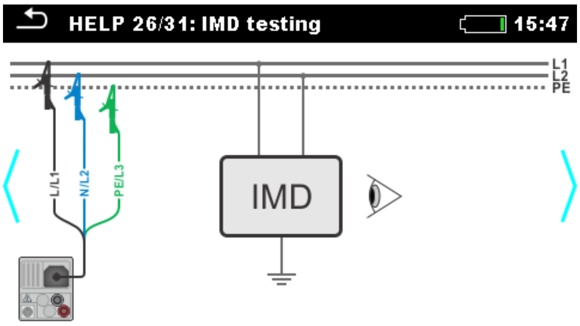
Measuring procedure

1 To measure the single fault leakage currents select first the **IMD** function in the **Other** section.

2 Set the minimum allowed resistance or the maximum allowed short circuit current on both lines by clicking in the bottom left dark grey corner.



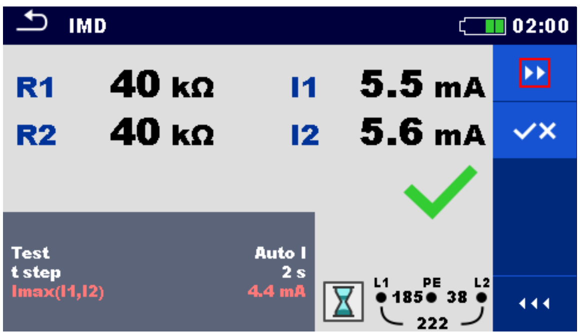
3 If a schuko commander is to be used, plug the commander into the appropriate outlet. If the cables are used, connect all cables appropriately – the PE cable to the PE conductor, the N cable to Line2 and the L cable to Line1.

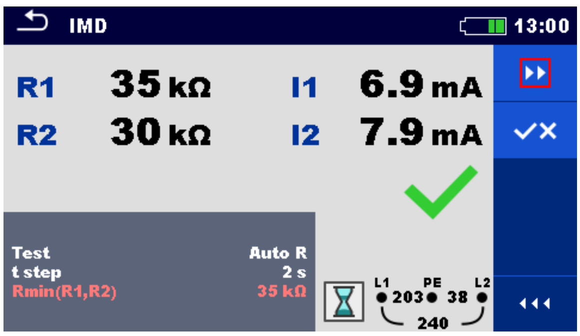


4 Press the **START** key.

Expected results

In a normal situation the IMD issue an alert when the maximum leakage current rises above 4,4 mA (if current is being tested) or the fault resistance falls under 35 kΩ (when earth resistance is being tested). If the alarm sounds within the specified values then the test should be marked as passed, otherwise as failed.





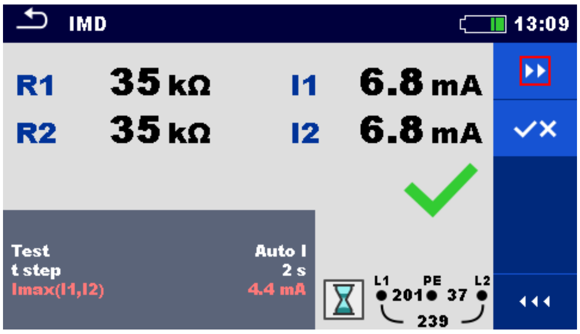
In the left picture we set the maximum allowed leakage current to 4,4 mA. Since we indicated that the alarm sounded when the limit was exceeded the test passed ($I_{MEASURED}$ > 4,4 mA). The same goes for the minimum allowed earth resistance. The IMD alarm sounded after the fault resistance reached 35 kΩ. In both cases it can occur that the button confirming IMD alarm was pressed too late and the device already continued to the next value. In such case, it is recommended to perform both tests manually.

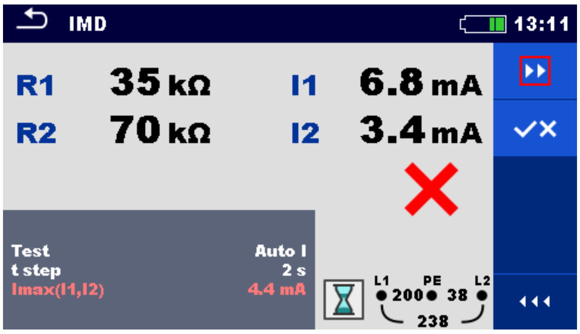
Expected results with a simulated error

When simulating an error on the PE conductor the PE is disconnected from the circuit. In this case, the IMD test shows no difference in measurement. To turn on the PE error enable switch **S15** in the Application Trainer. To simulate the I_{SFL} fault on IMD device enable switch **S16**.

Exercises	Switch	Function	Site of error	ON	OFF
PE Connection	**S15**	**R LOW / IMD**	**IT F3/1** **PE outlet**	**> 20 Ω**	**< 1 Ω**
	S16	**ISFL / IMD**	**IT F3/2** **ISFL**	**approx. 6 mA (@ 230 V)** **approx. 3 mA (@ 115 V)**	**< 1.3 mA**
	S17	R LOW	IT PE ref.	approx. 3.3 Ω	< 1 Ω
	S18	R LOW	TN/TT F1/4 PE light	> 20 Ω	< 1 Ω
	S19	R LOW / Z LOOP	TN/TT F1/2 PE outlet (3-ph.)	approx. 3.4 Ω	< 1 Ω
	S20	R LOW / Z LOOP	TN/TT F2/2 PE outlet	> 2.3 Ω	< 2 Ω
	S21	R LOW	MPE / PE Gas	approx. 2.2 Ω	< 1 Ω
	S22	R LOW	MPE / PE Heat inst.	approx. 3.3 Ω	< 1 Ω

Figure 2-31: IMD simulated errors on an IT system





Since switch S15 disconnects the PE conductor the IMD test does not detect any error, which is correct. It is recommended to perform the single fault leakage currents (I_{SFL}) test and the IMD test one after another to determine whether there is fault in the circuit present.

2.6 Insulation resistance measurement

Figure 2-32: Chart reference for insulation resistance measurements

Figure 2-33: Insulation resistance measurement at the switchboard – all circuits on

Figure 2-34: Insulation resistance measurement at the switchboard – disabling circuits during measurement

2.6.1 Background of measurement

This test discloses insulation faults caused by pollution, moisture, deterioration of insulation materials etc. The insulation resistance shall be measured between

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

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

Table 2-2: Insulation resistance limits

- Capacitances in the installation (cables, connected equipment) can cause capacitive leakage currents. The capacitive portion of the impedance is not considered in the insulation test as it is carried out with DC current.
- In normal cases, the insulation resistance is far higher than predefined limits, especially in new installations. When the result is close to or less than the required minimum insulation resistance:
  - Repeat the measurement with a longer measurement time or perform a couple of test.

- Check that loads / consumers are disconnected and/or switched off, surge protective devices are removed, and lights are switched off.
- If there are signs of dust and humidity, clean and dry critical parts.

- If surge protective devices cannot be removed, than the test voltage could be reduced to 250 VDC. In this case the insulation resistance limit shall be at least 1 MΩ.
- Test individual sub circuits to find the problematic location (by disconnecting of circuit breakers, removing fuses…).

2.6.1.1 Insulation resistance of individual circuits / items

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

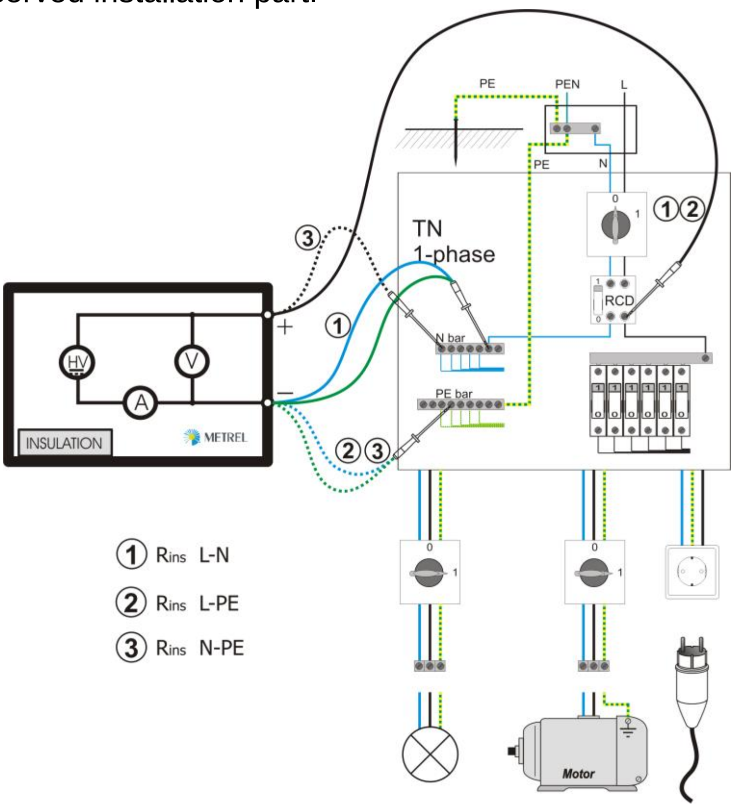


Figure 2-35: *Insulation test performed on switchboard and outlet*

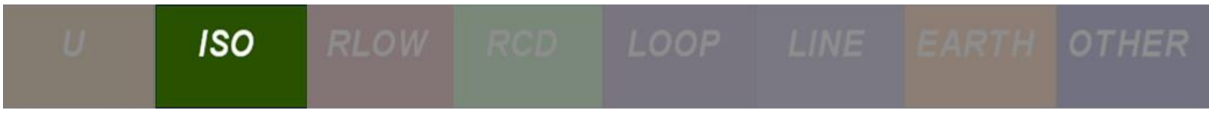
2.6.2 Exercises

Before running any test check if any RCD is present. If a RCD is present, disconnect it or it will not be possible to conduct any tests.

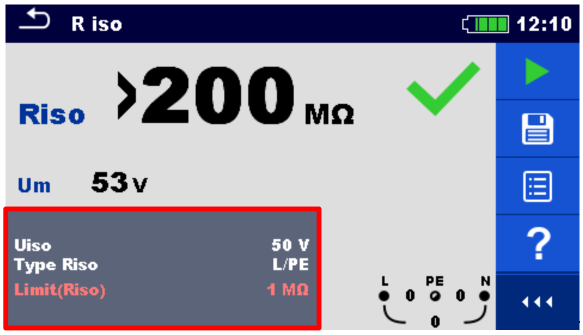
2.6.2.1 Exercise No. 2.6-1: R_{ISO} in a 1-phase outlet in a TN/TT system

Measuring procedure

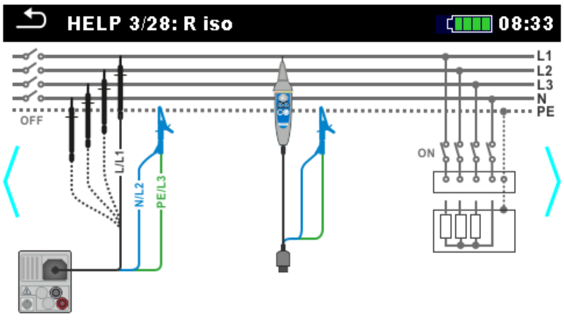
1 To measure the insulation resistance select first the **R_{ISO}** function in the **ISO** section.



2 Set the minimum allowed insulation resistance by clicking in the bottom left dark grey corner.



3 If a schuko commander is to be used, plug the commander into the appropriate outlet. If the cables are used, connect all cables appropriately – the PE cable to the PE conductor, the N cable to Line2 and the L cable to Line1.

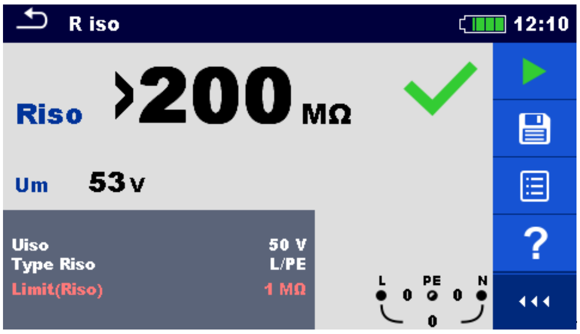


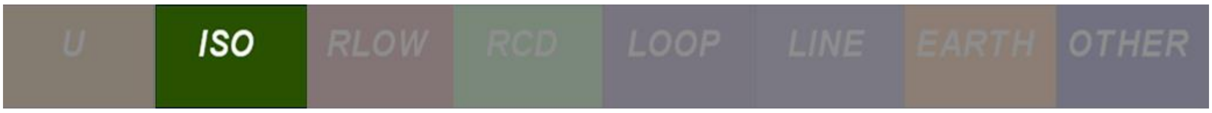
During the measurement, check the insulation resistance between all conductors (L_X-L_Y, L-N, L-PE. N-PE).

4 Press the **START** key.

Expected results

In a normal situation, the insulation resistance in a circuit should be well above 1 MΩ and above 0.5 MΩ in a PELV/SELV environment.



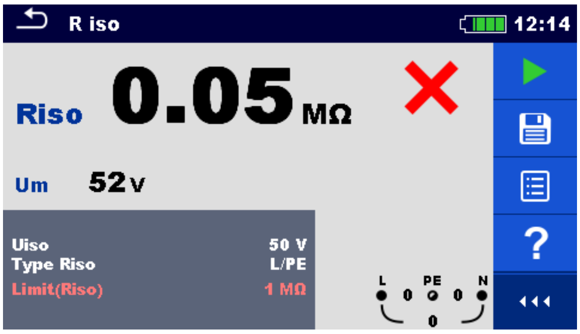


Expected results with a simulated error

Simulate an insulation resistance fault by enabling the switch **S29** in the Application Trainer. The error introduces a fault between the L1 and the PE conductors.

Exercises	Switch	Function	Site of error	ON	OFF
Insulation resistance	S27	R_{ISO}	IT F3/1 L1/L2 outlet	approx. 0.45 MΩ	> 200 MΩ
	S28	ISFL/IMD	IT F3/1 L1/PE outlet	approx. 3 mA	< 1 mA
	S29	**I_{Δ}**	**TN/TT F2/2 L1/PE outlet**	**approx. 5.1 mA (@230 V) approx. 2.5 mA (@115 V)**	**< 3.5 mA**
	S30	R_{ISO}	TN/TT F1/2 L1/PE outlet (3-ph.)	capacitive 1.45 MΩ	> 200 MΩ
	S31	R_{ISO} / VARISTOR	TN/TT SPD GAS / PE	shorted	U_{SPD} approx. 150 V
	S32	R_{ISO}	TN/TT F1/2 L2/N outlet (3-ph.)	approx. 0.45 MΩ	> 200 MΩ
	S33	R_{ISO}	TN/TT F1/2 L1/L2 outlet (3-ph.)	approx. 0.45 MΩ	> 200 MΩ

Figure 2-36: R_{ISO} simulated error between phase and PE conductors

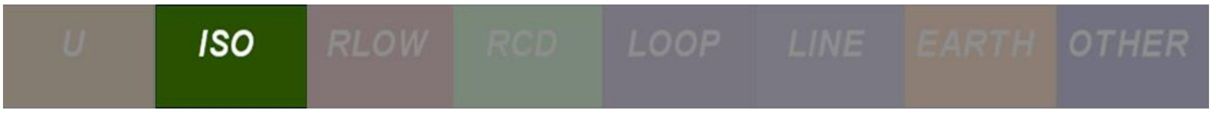


As seen from the picture above the added insulation fault caused the measured insulation resistance is much lower than required. This tells us the wiring should be checked.

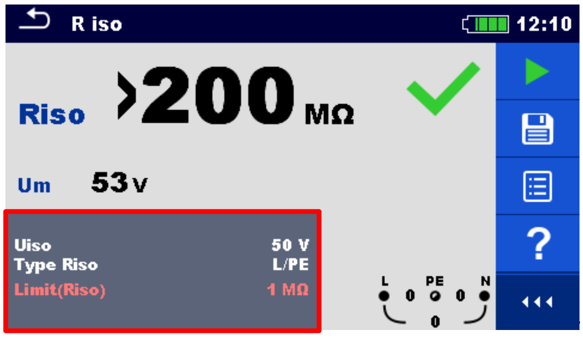
2.6.2.2 Exercise No. 2.6-2: R_{ISO} in a 3-phase TN/TT system on the supply side

Measuring procedure

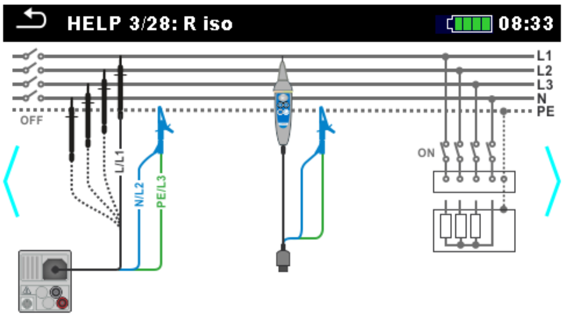
1 To measure the insulation resistance select first the **R_{ISO}** function in the **ISO** section.



2 Set the minimum allowed insulation resistance by clicking in the bottom left dark grey corner.



3 If a schuko commander is to be used, plug the commander into the appropriate outlet. If the cables are used, connect all cables appropriately – the PE cable to the PE conductor, the N cable to Line2 and the L cable to Line1.

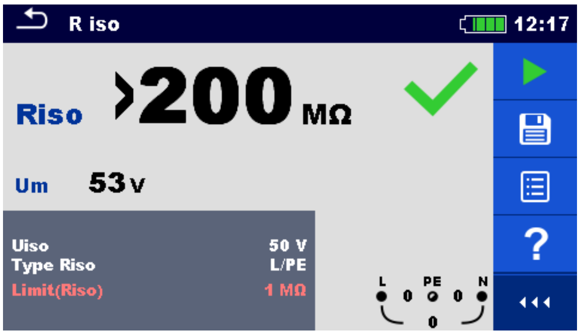


During the measurement, check the insulation resistance between all conductors (LX-LY, L-N, L-PE. N-PE).

4 Press the **START** key.

Expected results

Conduct this measurement at the switchboard. After disabling the RCD measure all possible insulations resistances between all conductors as described above. To verify all circuits connected to this RCD simply perform all tests on the output side of the RCD. If all tests pass then insulation is sufficient between all conductors. In such case the output of the measuring device should show the same result as the picture below.



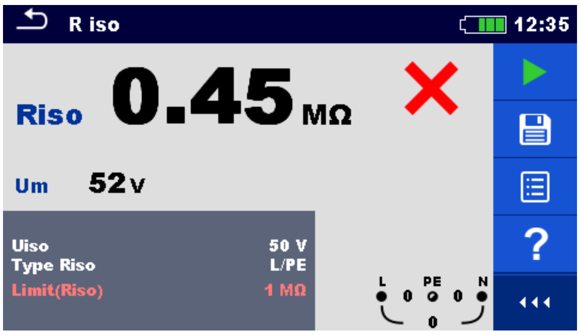
Expected results with a simulated error

In an installation with an insulation error between conductors, the measured insulation resistance usually decreases to approx. 0,45 MΩ. To measure such a situation enable the switch **S32** as indicated in Figure 2-37.

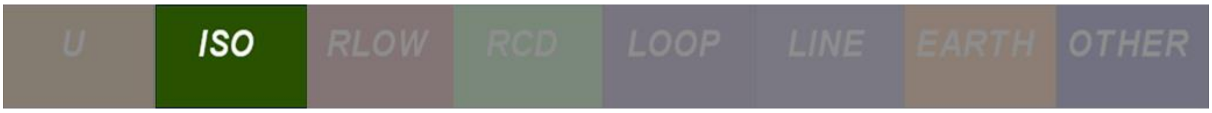
Exercises	Switch	Function	Site of error	ON	OFF
Insulation resistance	S27	R_{ISO}	IT F3/1 L1/L2 outlet	approx. 0.45 MΩ	> 200 MΩ
	S28	ISFL/IMD	IT F3/1 L1/PE outlet	approx. 3 mA	< 1 mA
	S29	I_{Δ}	TN/TT F2/2 L1/PE outlet	approx. 5.1 mA (@230 V) approx. 2.5 mA (@115 V)	< 3.5 mA
	S30	**R_{ISO}**	**TN/TT F1/2 L1/PE outlet (3-ph.)**	**capacitive 1.45 MΩ**	**> 200 MΩ**
	S31	R_{ISO} / VARISTOR	TN/TT SPD GAS / PE	shorted	U_{SPD} approx. 150 V
	S32	**R_{ISO}**	**TN/TT F1/2 L2/N outlet (3-ph.)**	**approx. 0.45 MΩ**	**> 200 MΩ**
	S33	**R_{ISO}**	**TN/TT F1/2 L1/L2 outlet (3-ph.)**	**approx. 0.45 MΩ**	**> 200 MΩ**

Figure 2-37: R_{ISO} simulated error between phase and neutral conductors

The fastest way to find the fault is to measure R_{ISO} at the switchboard in the same way as before (chapter Expected results above). After we see an error in the system, we enable continuous measurement of the measuring device. We now measure only between conductors that show a fault in the circuit simply by disabling all subsequent fuses and RCDs in our measuring subsystem. The fuse/RCD that remains with the fault is the circuit that has the fault.



As seen from the picture above the added insulation fault caused the measured insulation resistance is much lower than required. This tells us the wiring should be checked.

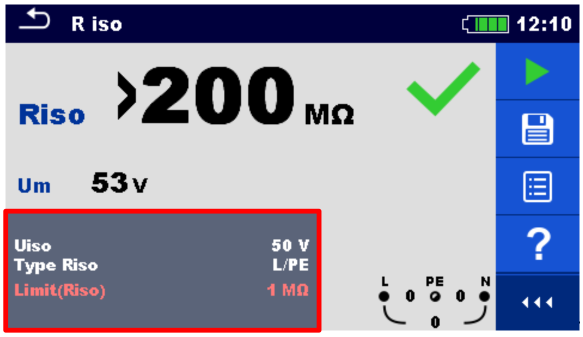


2.6.2.3 Exercise No. 2.6-3: R_{ISO} in an IT system

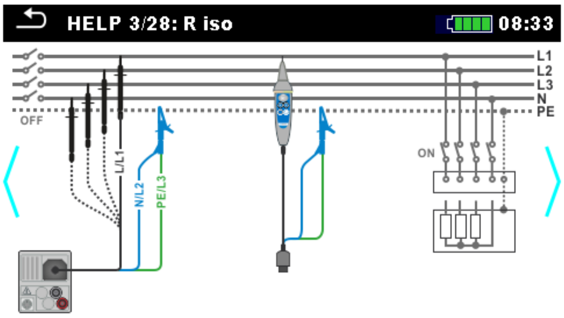
Measuring procedure

1 To measure the insulation resistance select first the **R_{ISO}** function in the **ISO** section.

2 Set the minimum allowed insulation resistance by clicking in the bottom left dark grey corner.



3 If a schuko commander is to be used, plug the commander into the appropriate outlet. If the cables are used, connect all cables appropriately – the PE cable to the PE conductor, the N cable to Line2 and the L cable to Line1.

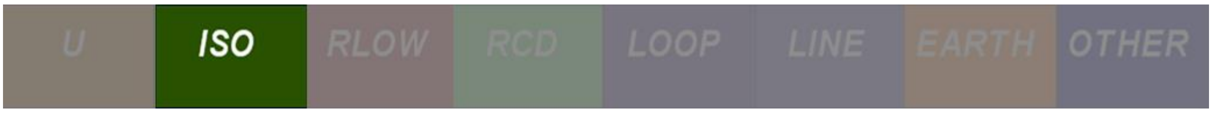


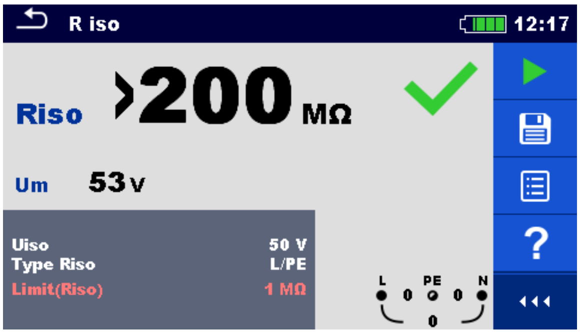
During the measurement, check the insulation resistance between all conductors (L_X-L_Y, L-N, L-PE. N-PE).

4 Press the **START** key.

Expected results

Measuring the insulation resistance in an IT system is done between both Line conductors. Usually the insulation resistance in a circuit is well above 1 MΩ.



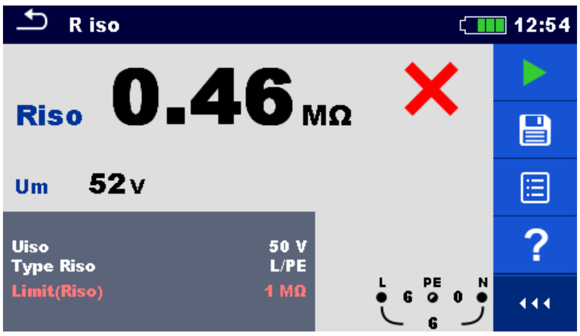


Expected results with a simulated error

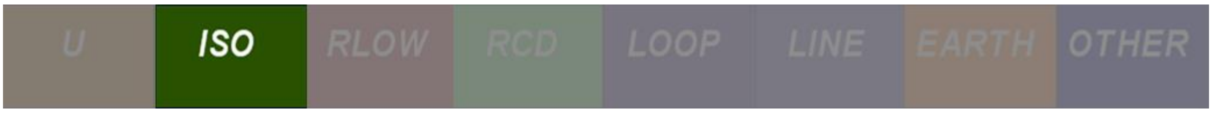
To introduce a fault in the insulation resistance in an IT system enable the switch **S27**. The measured R_{ISO} should now be approx. 0,45MΩ.

Exercises	Switch	Function	Site of error	ON	OFF
Insulation resistance	**S27**	**R_{ISO}**	**IT F3/1 L1/L2 outlet**	**approx. 0.45 MΩ**	**> 200 MΩ**
	S28	ISFL/IMD	IT F3/1 L1/PE outlet	approx. 3 mA	< 1 mA
	S29	I_{Δ}	TN/TT F2/2 L1/PE outlet	approx. 5.1 mA (@230 V) approx. 2.5 mA (@115 V)	< 3.5 mA
	S30	R_{ISO}	TN/TT F1/2 L1/PE outlet (3-ph.)	capacitive 1.45 MΩ	> 200 MΩ
	S31	R_{ISO} / VARISTOR	TN/TT SPD GAS / PE	shorted	U_{SPD} approx. 150 V
	S32	R_{ISO}	TN/TT F1/2 L2/N outlet (3-ph.)	approx. 0.45 MΩ	> 200 MΩ
	S33	R_{ISO}	TN/TT F1/2 L1/L2 outlet (3-ph.)	approx. 0.45 MΩ	> 200 MΩ

Figure 2-38: R_{ISO} simulated error between phase conductors in an IT system



As seen from the picture above the added insulation fault caused the measured insulation resistance is much lower than required. This tells us the wiring should be checked.

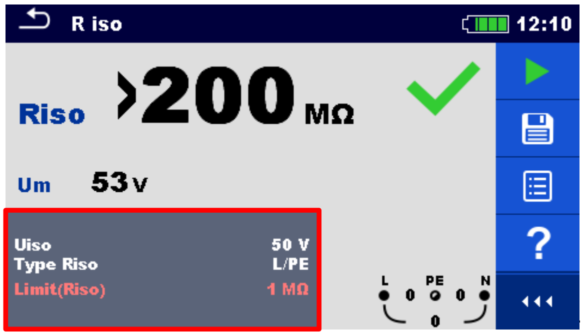


2.6.2.4 Exercise No. 2.6-4: R_{ISO} varistor measurement

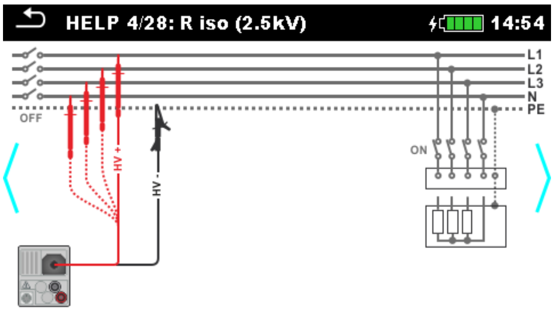
Measuring procedure

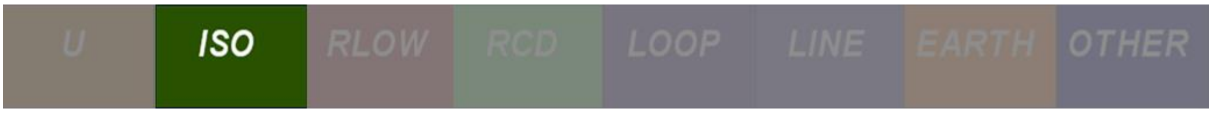
1 To measure the insulation resistance select first the **R_{ISO}** function in the **ISO** section.

2 Set the minimum allowed insulation resistance by clicking in the bottom left dark grey corner.



3 During this test only cables may be used, where the PE and N cable are connected together and connected to the GAS pipe above the varistor. The Line cable is connected to the GAS pipe below the varistor as indicated by the picture below and Figure 2-39.





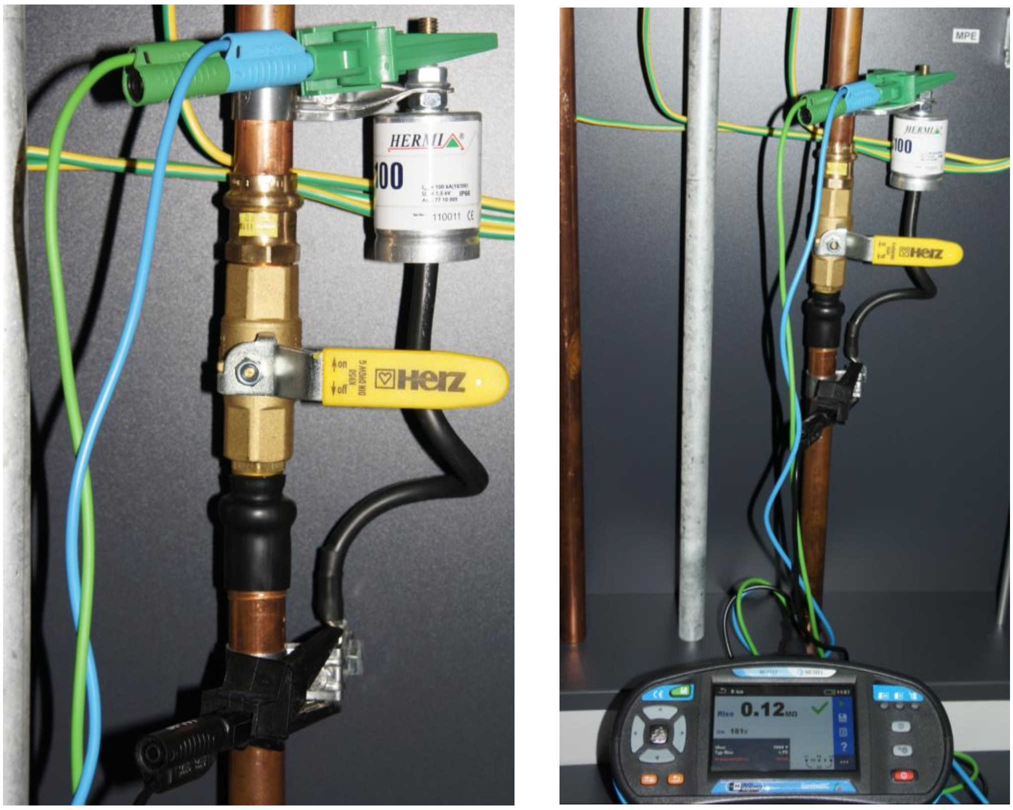
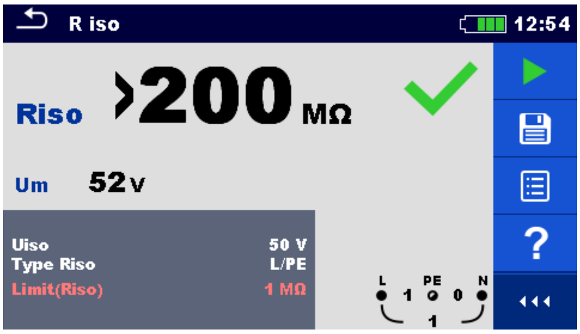


Figure 2-39: Insulation resistance measurement at the varistor

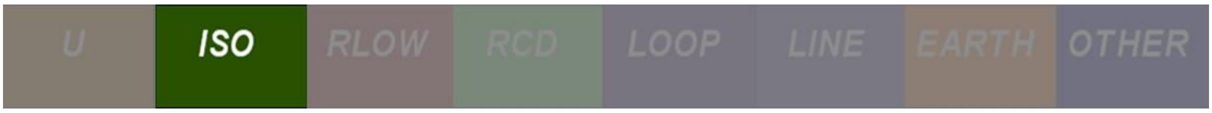
4 Press the **START** key.

Expected results

The point of this exercise is to see if the varistor is performing its function in a building that has gas pipes installed. At low voltage, a varistor has a high electrical resistance and the current flows normally over the gas pipe. In case of overcurrent (e.g. lightning strike) the electrical resistance of the varistor decreases and all the current then flows past the gas pipe thus protecting the building from possible damage (e.g. fire).



Picture above shows normal insulation resistance.

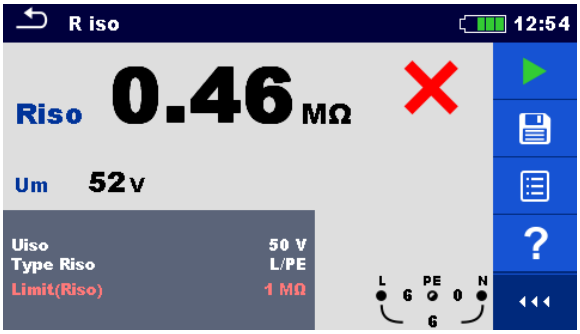


Expected results with a simulated error

In this case, we simulate an error where the cables connected with the varistor have an insulation fault which causes the varistor to not function properly. In worst case such a situation can result in a fire accident.

Exercises	Switch	Function	Site of error	ON	OFF
Insulation resistance	S27	R_{ISO}	IT F3/1 L1/L2 outlet	approx. 0.45 MΩ	> 200 MΩ
	S28	ISFL/IMD	IT F3/1 L1/PE outlet	approx. 3 mA	< 1 mA
	S29	I_{Δ}	TN/TT F2/2 L1/PE outlet	approx. 5.1 mA (@230 V) approx. 2.5 mA (@115 V)	< 3.5 mA
	S30	R_{ISO}	TN/TT F1/2 L1/PE outlet (3-ph.)	capacitive 1.45 MΩ	> 200 MΩ
	S31	**R_{ISO} / VARISTOR**	**TN/TT SPD GAS / PE**	**shorted**	**U_{SPD} approx. 150 V**
	S32	R_{ISO}	TN/TT F1/2 L2/N outlet (3-ph.)	approx. 0.45 MΩ	> 200 MΩ
	S33	R_{ISO}	TN/TT F1/2 L1/L2 outlet (3-ph.)	approx. 0.45 MΩ	> 200 MΩ

Figure 2-40: R_{ISO} simulated error on the varistor cabling



As seen from the picture above the added insulation fault caused the measured insulation resistance is much lower than required. This tells us the wiring should be checked.

2.7 Conductor continuity measurement

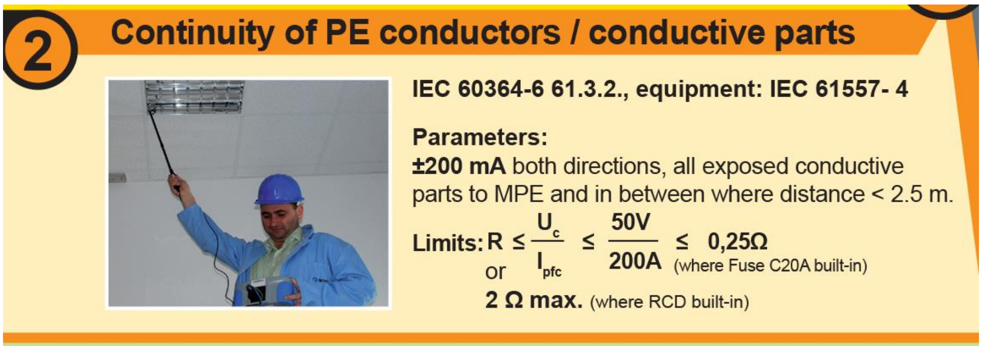


Figure 2-41: Chart reference for continuity measurements

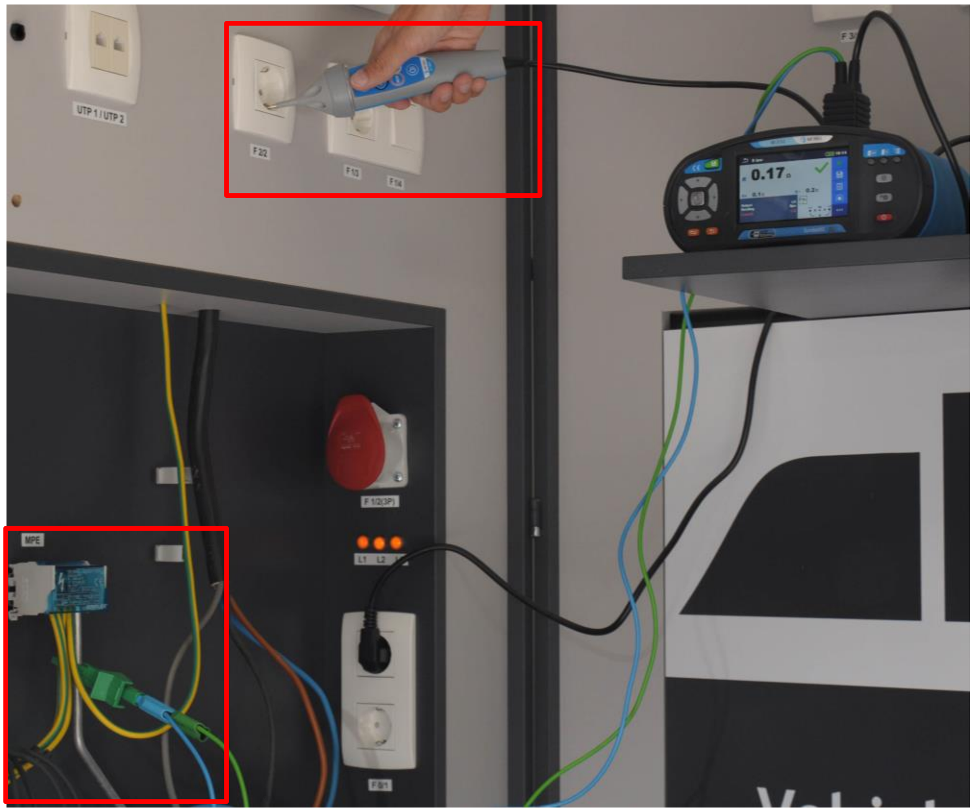


Figure 2-42: Continuity measurement between MPE and socket

Figure 2-43: Continuity measurement between switchboard and socket

2.7.1 Background of measurement

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

$$R_{CON} = \rho \frac{l}{A} \; [\Omega]$$

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

As exact calculation of conductor’s resistance is rather difficult, 1.0 Ω, 2.0 Ω or similar values are often considered as the limit values.

Notes:

- If the resistance is higher than expected on base of conductor’s size and length this can be a result of a serious connection problem and must be checked!
- If the resistance is lower than expected on base of conductor’s size and length this can be a result of an unknown parallel path and must be checked!

- For the standard measurement (sometimes very long) prolongation tests are used. In this case the resistance of measuring leads must be subtracted from the result (this feature is usually integrated in installation testers).
- Problem of parallel paths must be considered.

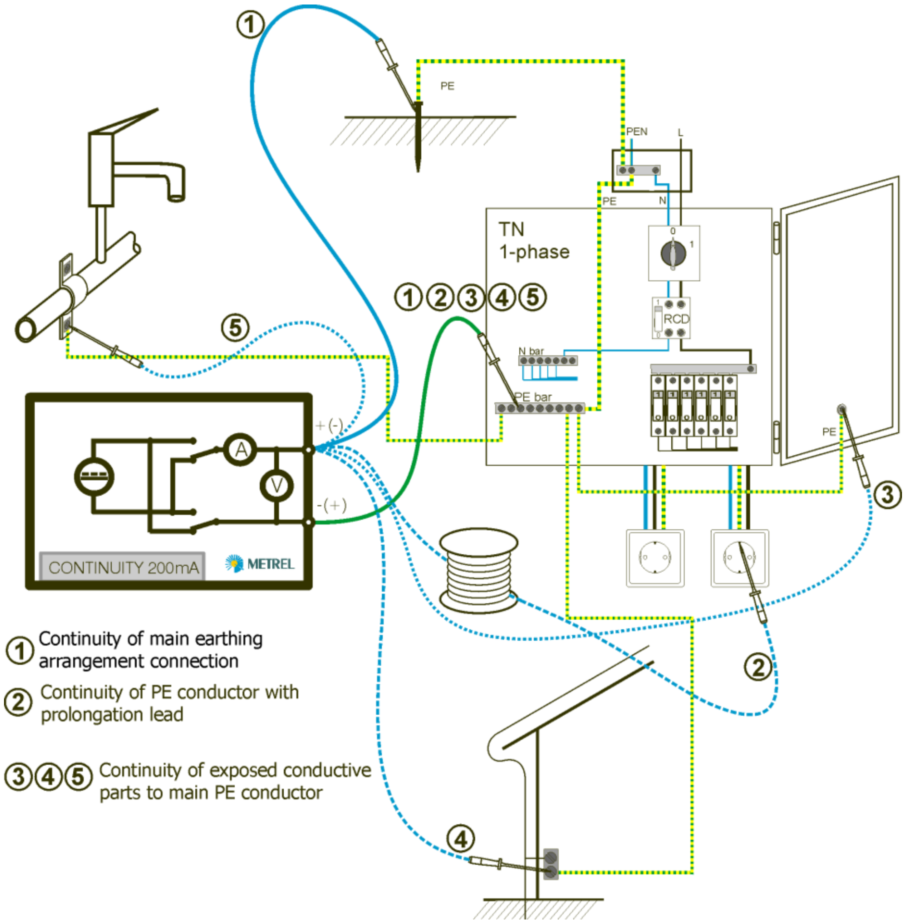


Figure 2-44: *Standard continuity test*

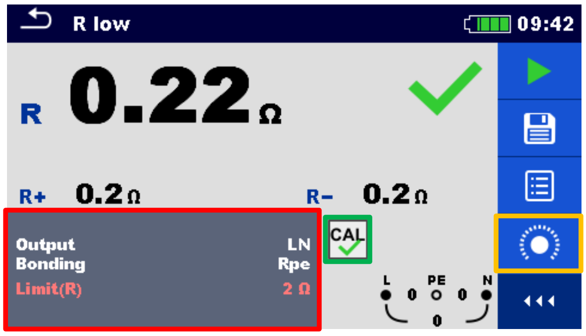
2.7.2 Exercises

2.7.2.1 Exercise No. 2.7-1: Measuring continuity in a TN/TT system

Measuring procedure

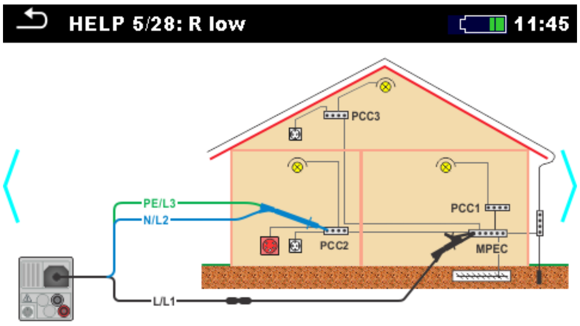
1 To measure the insulation resistance select first the **R200** function in the **continuity (RLOW)** section. This is a DC type of measurement.

2 Set the minimum allowed insulation resistance by clicking in the bottom left dark grey corner.



Before conducting any measurements, the measuring instrument has to be calibrated. First connect the PE a neutral cables together to create a PEN cable, then connect the tips of the PEN and phase cable and run the calibration (right orange square in picture above). This way the resistance of the cables will be removed when measuring conductor continuity. Once the instrument is calibrated a “CAL” icon appears on the screen (middle green square in picture above).

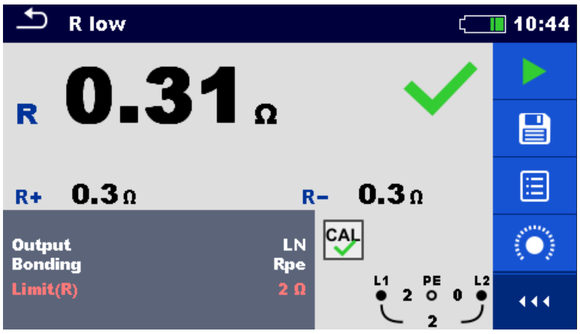
3 During this type of measurement only the cables may be used. Connect the PE a neutral cables together to create a PEN cable and place it on a reference point somewhere in the building (e.g. the MPE). Check all PE wires in all sockets available with the phase cable.



4 Press the **START** key.

Expected results

In a normal situation, the measured continuity resistance must be below 2Ω. This limit always applies when continuity is measured in a RCD protected system. If no RCD is present the allowed continuity resistance is usually much lower since it depends on the fuse used in the measured circuit (e.g. in a circuit protected by a C20A fuse the maximum allowed continuity resistance would be 0,25Ω).



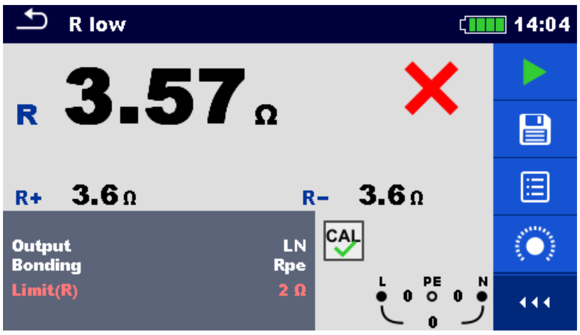
Since continuity was measured in a RCD protected TN system the measured value is regarded as passed.

Expected results with a simulated error

A typical fault when measuring continuity would be if the resistance of PE conductor would be above 2Ω. To simulate such an error enable the switch **S19** in the Application Trainer.

Exercises	Switch	Function	Site of error	ON	OFF
PE Connection	S15	R LOW / IMD	IT F3/1 PE outlet	> 20 Ω	< 1 Ω
	S16	ISFL / IMD	IT F3/2 ISFL	approx. 6 mA (@ 230 V) approx. 3 mA (@ 115 V)	< 1.3 mA
	S17	R LOW	IT PE ref.	approx. 3.3 Ω	< 1 Ω
	S18	R LOW	TN/TT F1/4 PE light	> 20 Ω	< 1 Ω
	S19	**R LOW / Z LOOP**	**TN/TT F1/2 PE outlet (3-ph.)**	**approx. 3.4 Ω**	**< 1 Ω**
	S20	R LOW / Z LOOP	TN/TT F2/2 PE outlet	> 2.3 Ω	< 2 Ω
	S21	R LOW	MPE / PE Gas	approx. 2.2 Ω	< 1 Ω
	S22	R LOW	MPE / PE Heat inst.	approx. 3.3 Ω	< 1 Ω

Figure 2-45: Simulated continuity error



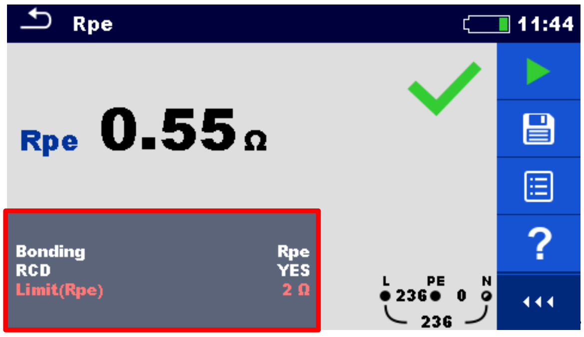
In a TN system the simulated error introduced additional resistance of 3.4 Ω. Since the limit for systems with installed RCD is 2 Ω the test failed. The device correctly interpreted the result.

2.7.2.2 Exercise No. 2.7-2: Measuring R_{PE} continuity in a TN/TT system

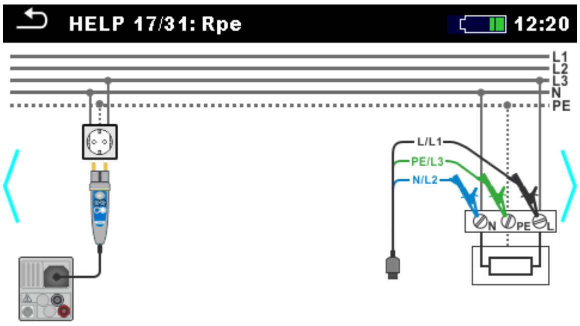
Measuring procedure

1 To measure the insulation resistance select first the **R_{200}** function in the **continuity (RLOW)** section. This is an AC type of measurement.

2 Set the minimum allowed insulation resistance and presence of a RCD by clicking in the bottom left dark grey corner.



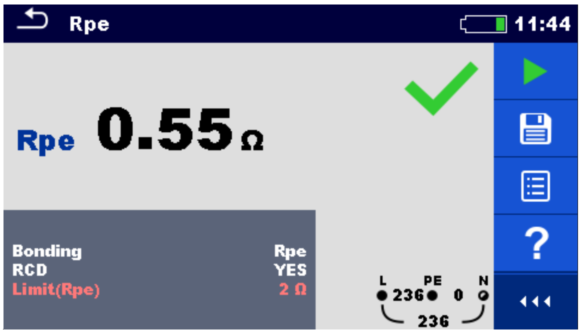
3 During this type of measurement only the shuko commander is used. Plug the commander into the chosen outlet. Here the resistance between neutral and PE conductors is measured.

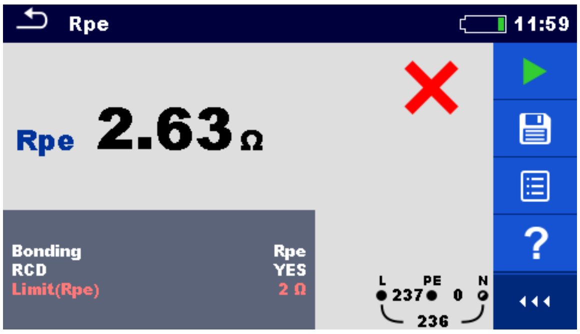


4 Press the **START** key.

Expected results

Depending on the selection of the presence of a RCD the system will switch between measuring methods, i.e. use different current as to not trip the RCD if present. In a both cases the measured continuity resistance must be below 2Ω. The interpretation of the R_{PE} test depends also on the type of earthing system used. In a TN system we measure the resistance of PE conductors, whereas in a TT earthing system we actually measure earth resistance.





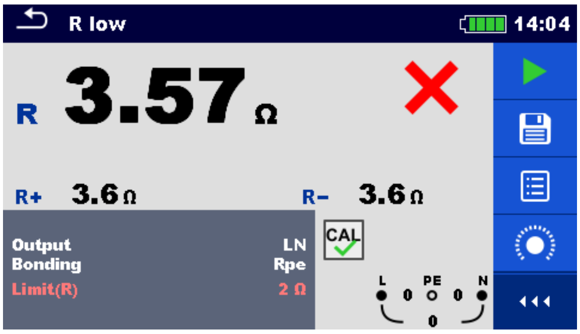
As seen from the results above the measurement in a TN system (left) is below the threshold and the test passed. The test in a TT system (right) is marked as failed. Since this test actually measured earth resistance the test result should be considered as passed regardless of what the device is telling us. The device does not distinguish between TN and TT earthing systems so it cannot predict the type of earthing system used. It is up to the user set the limit for the R_{PE} test in order for the device to correctly interpret the results.

Expected results with a simulated error

A typical fault when measuring continuity would be if the resistance of PE conductor would be above 2Ω. To simulate such an error enable the switch **S19** in the Application Trainer.

Exercises	Switch	Function	Site of error	ON	OFF
PE Connection	S15	R LOW / IMD	IT F3/1 PE outlet	> 20 Ω	< 1 Ω
	S16	ISFL / IMD	IT F3/2 ISFL	approx. 6 mA (@ 230 V) approx. 3 mA (@ 115 V)	< 1.3 mA
	S17	R LOW	IT PE ref.	approx. 3.3 Ω	< 1 Ω
	S18	R LOW	TN/TT F1/4 PE light	> 20 Ω	< 1 Ω
	S19	**R LOW / Z LOOP**	**TN/TT F1/2 PE outlet (3-ph.)**	**approx. 3.4 Ω**	**< 1 Ω**
	S20	R LOW / Z LOOP	TN/TT F2/2 PE outlet	> 2.3 Ω	< 2 Ω
	S21	R LOW	MPE / PE Gas	approx. 2.2 Ω	< 1 Ω
	S22	R LOW	MPE / PE Heat inst.	approx. 3.3 Ω	< 1 Ω

Figure 2-46: Simulated continuity error



In this case we simulated an error which introduced an additional resistance of 3.4 Ω in a TN system. The test failed as expected.

2.8 Earth resistance measurements

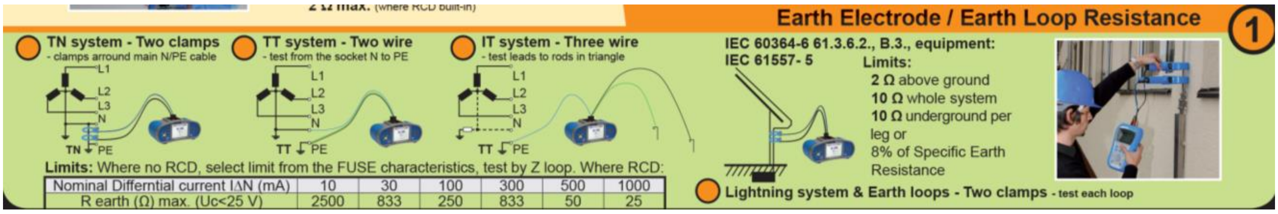


Figure 2-47: Chart reference for earth resistance measurements

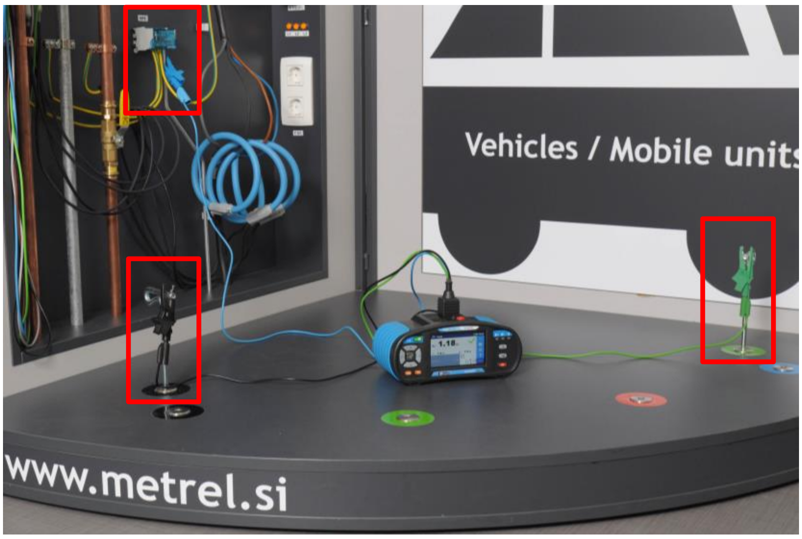


Figure 2-48: Earth resistance measurement using the 3-wire method

Figure 2-49: Earth resistance measurement in a TT system using the 2 clamp method

Figure 2-50: Lightning system testing

2.8.1 Background of measurement

2.8.1.1 Main earthing

The installation/distribution point or power source is earthed via the so-called main earthing. The earthing is realized with metal electrode(s) depleted in the soil. The size and complexity of the earthing arrangement depends on the application (size of object, soil resistivity, maximum allowed earthing resistance etc.).
In TN installations the earthing is realized at the source and/or distribution points. The earthing resistances are usually very low (below 1Ω).
TT installations have their own main earthing. The resistances are usually higher than in TN systems (from few Ω up to several hundred Ω). Because of this dangerous fault voltages and body currents can occur at relatively low fault currents. Therefore, TT systems usually have additional RCD protection.

2.8.1.2 Lighting systems

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

2.8.1.3 Earth loop test, external source, no probes

In TT systems with the loop resistance test the following loop resistance is measured:

$$R_{LOOP} = R_{LH} + R_{EH} + R_{ED} + R_T \; [\Omega]$$

If the total earth resistance of R_{EH} is higher than the resistance R_{ED} and the return path (resistance of L conductors, secondary of power transformer) then the result can be considered as ≈ R_{EH}.

This test is applicable:

- Applicable for TT systems, where the measured installation's earthing resistance is higher than the (well grounded) auxiliary one.
- Applicable in urban areas if there is no appropriate place for test probes.
- Applicable in areas where different local earthings are connected together, making the local earthing system very large.

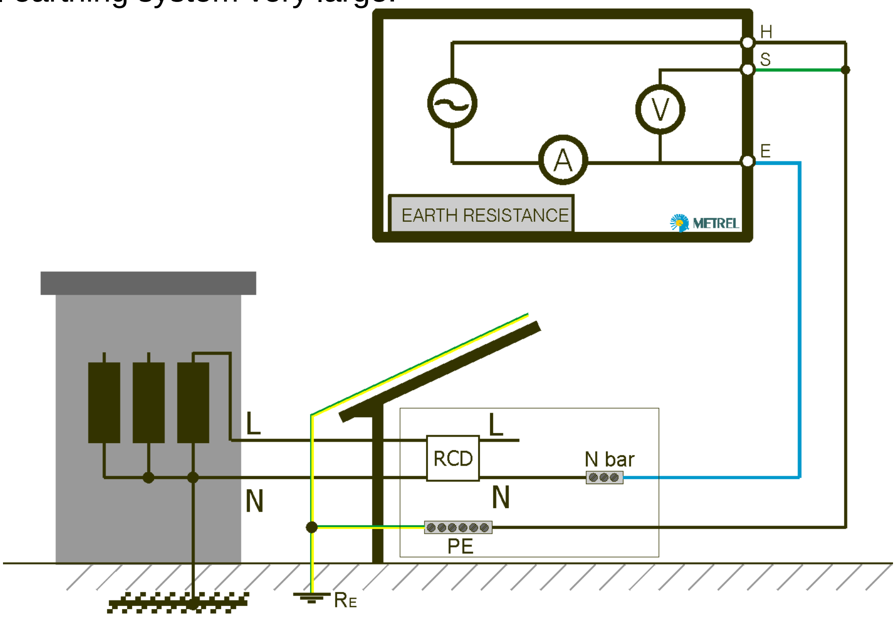


Figure 2-51: Two-wire test (only for TT systems), no probes

2.8.1.4 3-wire earthing resistance test, internal generator, two probes

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

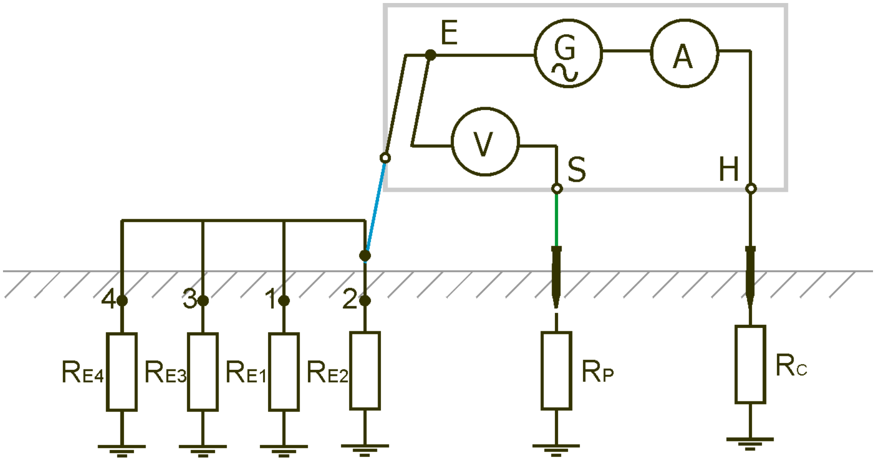


Figure 2-52: Total earthing measurement (3 wires) – standard method

Notes:

- This method enables accurate results from 0 Ω up to several 1000 Ω.
- This method is not suitable for very large or connected earthing systems because test probes must be then placed at very long distances from the measured object.
- If measuring individual earthing resistances, the measured rod (point) must be disconnected from the system.
- In TN systems incoming PE (PEN) conductor must be disconnected!

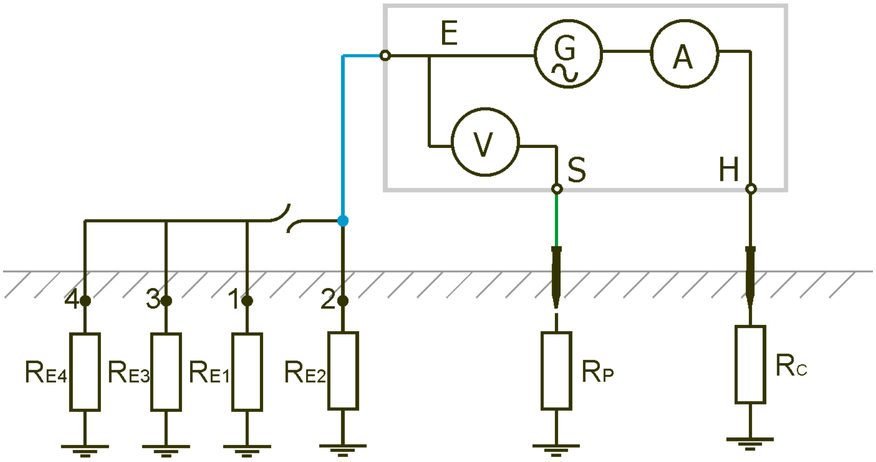


Figure 2-53: Selective earthing measurement – standard method

$$I_{gen} = I_{RE2}$$

The equation above indicates that the test current flows only through the partial resistance R_{E2}. In this case only R_{E2} is measured.

Notes:

- Accurate results from 0 Ω, no limitation regarding number of points.
- Not suitable for very large or connected earthing systems because test probes must be then placed at very long distances from the measured object.

- Used in IT, TT or other not connected earthing systems.

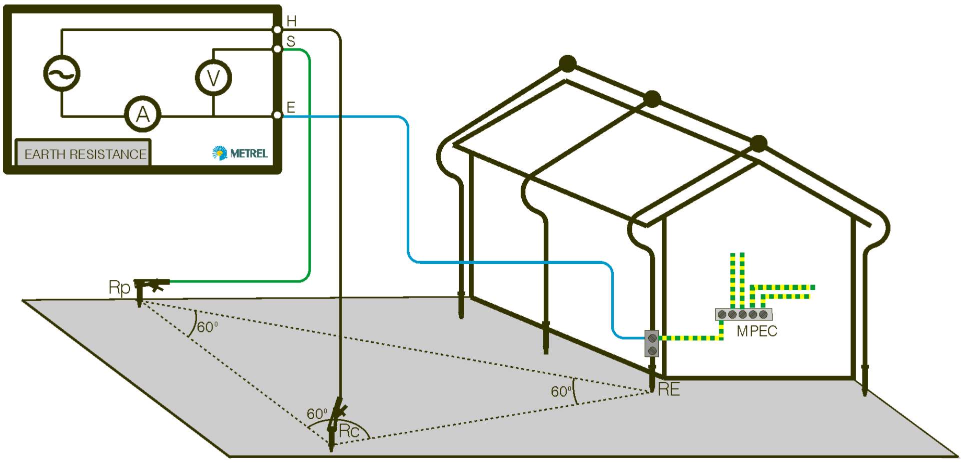


Figure 2-54: Three-wire test, two probes, and equilateral placement of probes

Functionality and placing of test probes

For a standard earthing resistance two test probes (voltage and current) are used. Because of the voltage funnel it is important that the test electrodes are placed correctly. In a 3-wire earthing resistance test an equilateral placement of test probes is used.

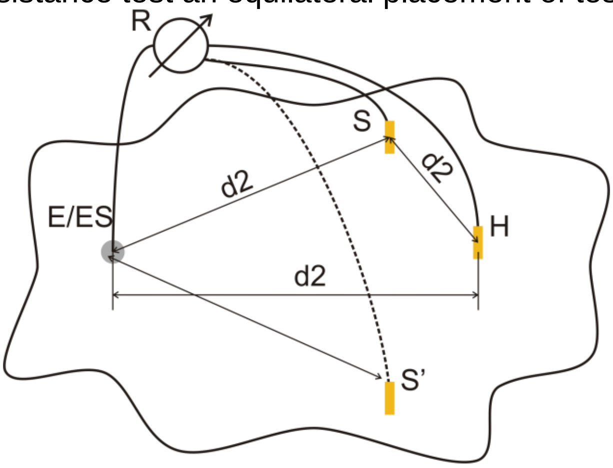


Figure 2-55: Equilateral placement of probes

<u>Measurement 1</u>
Distance from tested earthing electrode to current probe H and voltage probe S should be at least: d2= 5·a

<u>Measurement 2</u>
Distance from earthing electrode to voltage probe S (S'): d2, contrary side regarding to H.

The first measurement is to be done at the S and H probes placed at a distance of·d2. Connections E, probes H and S should form an equilateral triangle.

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

2.8.1.5 Earthing resistance test with two current clamps

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

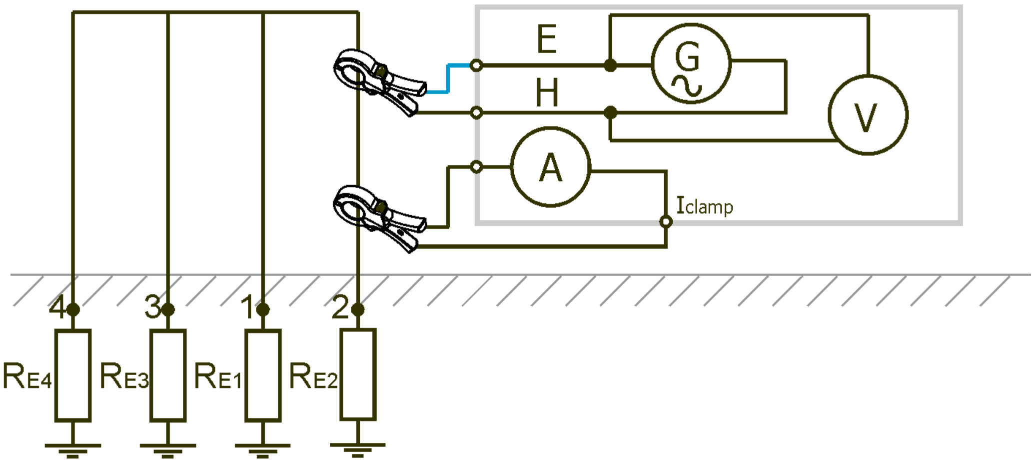


Figure 2-56: Total earthing resistance measurement with two current clamps

The driver clamp injects a voltage in the earthing system. The injected voltage generates a test current in the loop.
Individual earthing resistance is measured as:

$$R_{E2} + (R_{E1} \,||\, R_{E3}||R_{E4} \,...) = \frac{\mathrm{U}_{generator}\,\frac{1}{N}}{\mathrm{I}_{clamp}} \;[\Omega]$$

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

If the total Earth Resistance of the electrodes R_{E1}, R_{E3} and R_{E4} connected in parallel is much lower than the resistance of tested electrode R_{E2}, then the result can be considered as ≈ R_{E21}.

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

Notes:

- Applicable in complex earthing system with numerous parallel earthing electrodes.
- Applicable for measuring earthing resistance in transformer stations.
- Applicable for measuring lightning systems (Figure 2-57).
- Applicable for measuring earthing resistance in TN earthing systems (Figure 2-58).
- Especially suitable in urban area.
- No disconnection of measured electrodes.
- Very fast measurement; no need to place measurement probes and to separate the measured electrodes.
- Very accurate for resistances below 10 Ω.
- The minimum distance between driver and sense clamps is at least 30 cm (unless they are shielded).

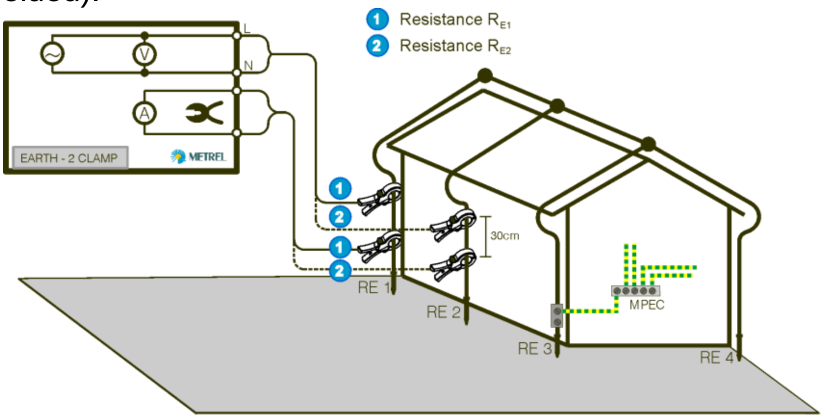


Figure 2-57: Test system (individual earthing rods) with two current clamps

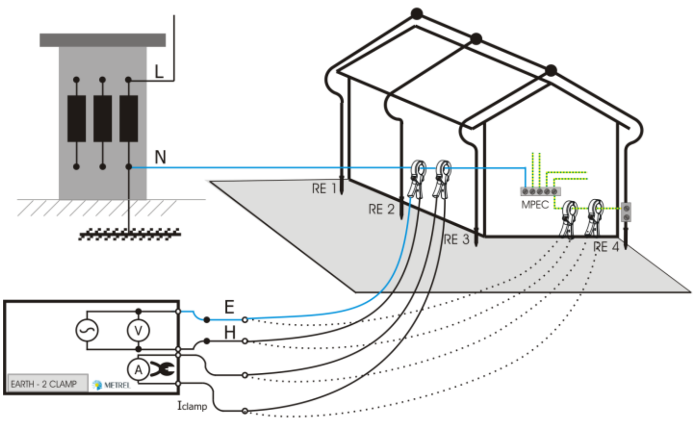


Figure 2-58: Measurement of resistance to earth of object with two current clamps in TN system

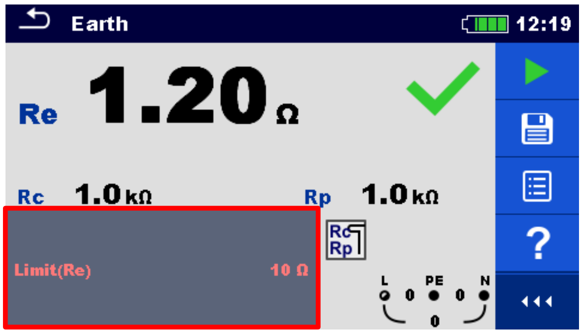
2.8.2 Exercises

2.8.2.1 Exercise No. 2.8-1: Earth Resistance Measurement – three wire method

Measuring procedure

1 To measure the earth resistance select first the **3W (three wire)** function in the **Earth** section.

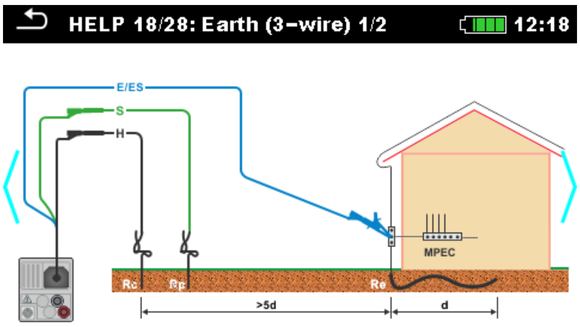
2 Set the maximum allowed earth resistance by clicking in the bottom left dark grey corner.



When setting the limits the following thresholds should be considered:

- **2 Ω** above ground,
- **10 Ω** for the complete system,
- **20 Ω** for a single wire or
- **8%** of the specific earth resistance.

3 During this type of measurement cables in combination with earth probes are to be used. Plug the neutral cable to the PE conductor or the earthing rod. Connect the phase cable to one probe and the PE cable to the other probe. After the measurement is completed reverse the cables connected to both rods in order to exclude any funnel overlap. If the measured resistances are equal (20% to 30% difference is acceptable), funnel overlap is not present.

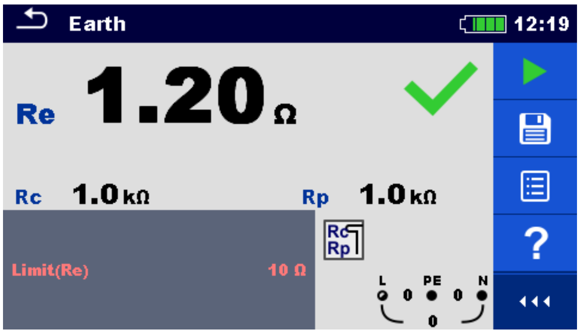


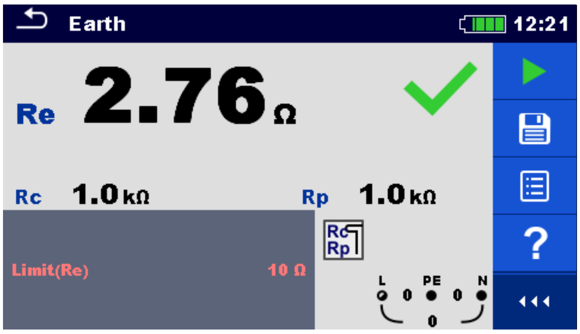
If measuring earth resistance in a TT earthing system, the probes may be replaced with the shuko commander since all measurements may be done via the outlets.

4 Press the **START** key.

Expected results

Expected earth resistance result is below 10Ω. As may be observed from the figure below the result varies whether a TN or TT earthing system is used. The latter usually has 2~3 Ω higher result as it also measures the resistance of the connected transformer.



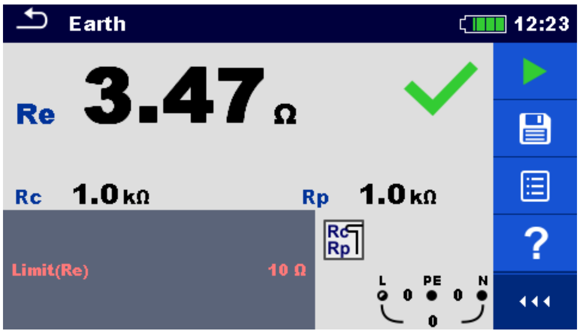


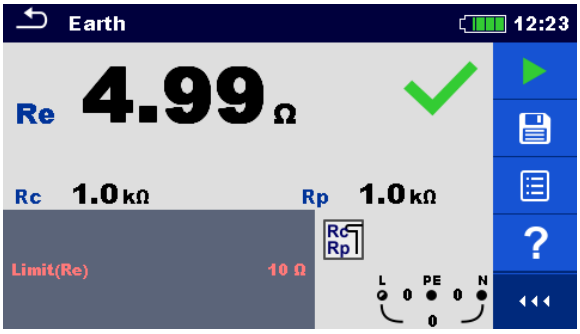
Expected results with a simulated error

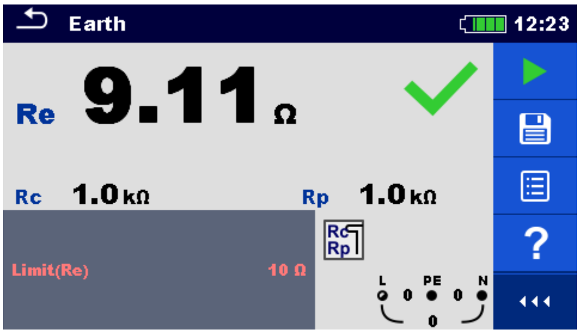
When measuring earth resistance in a TT system with a 3-wire method in the Application Trainer it is possible to simulate grounding errors **S23** and **S24**.

Exercises	Switch	Function	Site of error	ON	OFF
Earth Resistance R_E	**S23**	**R_E (classic method 3w)**	**Basic grounding in TT**	**approx. 3.3 Ω**	**approx. 2.6 Ω**
	S23 + S24	**R_E (classic method 3w)**	**Basic grounding in TT**	**approx. 9.8 Ω**	**approx. 2.6 Ω**
	S24	**R_E (classic method 3w)**	**Basic grounding in TT**	**approx. 4.8 Ω**	**approx. 2.6 Ω**
		R_E (2 - clamps method)	Basic grounding in TN (on Main PE wire) Lightning rod 1 Lightning rod 2	approx. 10 Ω approx. 22 Ω approx. 10 Ω	approx. 3.6 Ω approx. 5 Ω approx. 10 Ω

Figure 2-59: Simulated earth resistance errors







*Measured R_E with enabled error **S23** (upper left), **S24** (upper right) and combination of both – **S23 + S24** (bottom).*

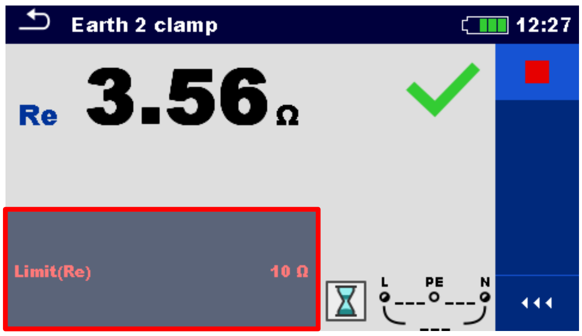
2.8.2.2 Exercise No. 2.8-2: Earth Resistance Measurement – two clamp method

This method is intended for measuring earth resistance in a TN earthing systems or when lightning systems and earth loops have to be checked.

Measuring procedure

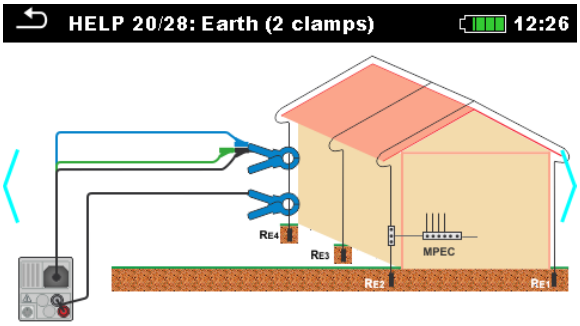
1 To measure the earth resistance in a TN system or lightning systems and earth loops select the **2-clamp** function in the **Earth** section.

2 Set the maximum allowed earth resistance by clicking in the bottom left dark grey corner.



When setting the limits the following thresholds should be considered:
- **2 Ω** above ground,
- **10 Ω** for the complete system,
- **20 Ω** for a single wire or
- **8%** of the specific earth resistance.

3 The measurement is done with two clamps:
- Current clamps (A1018). These clamps measure the current induced by the generator clamps. They can also be used when measuring leakage currents.
- Generator clamps (A1019). These clamps insert current into the circuit and measure the voltage drop.

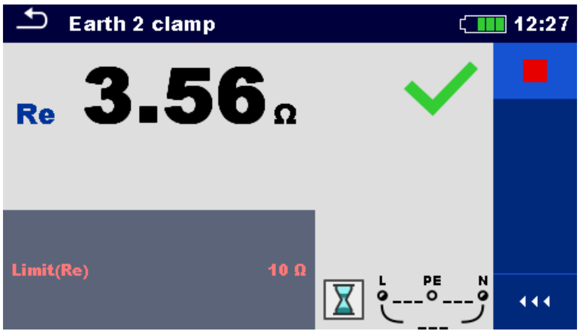


Both clamps are placed either on the earth electrode or on the PE (or even PEN) conductor. When checking lightning systems and earth loops both clamps are connected to the lightning rods around the building.

4 Press the **START** key.

Expected results

Allowed earth resistance is 10 Ω which is usually achieved in a TN system. When lightning systems are checked the measured earth resistance must be below this value to ensure proper safety.



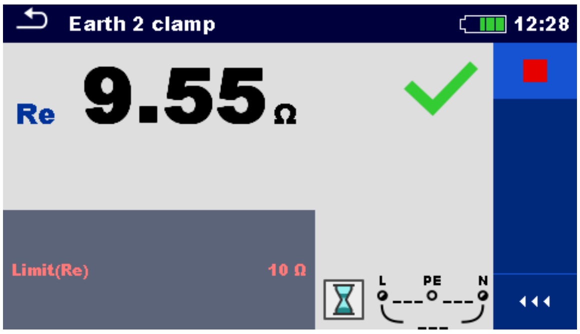
Expected results with a simulated error

When measuring earth resistance in a TN system with a 2-clamp method in the Application Trainer it is possible to simulate a basic grounding error on the main PE wire by enabling the switch **S24**.

Exercises	Switch	Function	Site of error	ON	OFF
Earth Resistance R_E	S23	R_E (classic method 3w)	Basic grounding in TT	approx. 3.3 Ω	approx. 2.6 Ω
	S23 + S24	R_E (classic method 3w)	Basic grounding in TT	approx. 9.8 Ω	approx. 2.6 Ω
	S24	R_E (classic method 3w)	Basic grounding in TT	approx. 4.8 Ω	approx. 2.6 Ω
		R_E (2 - clamps method)	**Basic grounding in TN (on Main PE wire)** **Lightning rod 1** **Lightning rod 2**	**approx. 10 Ω** **approx. 22 Ω** **approx. 10 Ω**	**approx. 3.6 Ω** **approx. 5 Ω** **approx. 10 Ω**

Figure 2-60: Simulated earth resistance error in a TN earthing system

As seen from the picture below even when the error in the Application Trainer was enabled the earth resistance did not exceed the 10 Ω limit. The measuring device correctly determined that the test passed. Such a measurement without any fault may be an actual real case since earth resistance is actually influenced by earth resistivity.



AD 2 - MI 3399
PQA Power and Voltage Quality Trainer

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1 Preface

In order to ease up the first steps in the world of electrical signal quality analysis using Metrel products, we have provided you with the next few exercises, to discover some of the basic and most common features of our Power Master MI 2892 and Power View software.

This document describes 12 exercises. They are organized from the easiest, describing most common measuring practice, to more complex and practical. Each exercise will lead you step-by-step, from instruments setup, observing data in real time, recording and simple data analysis using the PowerView software. After the completion of the exercises, the user will have a good insight into instrument features and basic knowledge of how to handle Power Quality issues. For additional details, please check instrument's user manuals and application notes.

2 Basic theory

There are quite a few reasons for measuring and analysing power quality nowadays. Potential interactions between end use equipment and electric distribution system, external electromagnetic interferences, resonant states between electrical circuits and some other factors call for a need to be analysed in order that harmful consequences can be omitted or prevented. Power quality analysing includes measurements of:

- Phase to ground voltages;
- Phase to neutral voltages;
- Neutral to ground voltages;
- Phase to phase voltages in three-phase systems;
- Phase currents;
- Current in a neutral conductor;
- Frequency;
- Power Factor, cos φ;
- Harmonic components of current and voltage and their direction;
- Waveform of current and voltage at specific circumstances (peak magnitude, primary frequency, time of occurrence, rising rate);
- Transients.

Power quality measurement is usually considered as a measurement of low frequency conducted disturbance with the addition of transient phenomena. The following parameters of supply voltage are influenced by disturbances:

- frequency
- voltage level
- waveshape
- symmetry of three phase system.

2.1 Power quality events

The ideal supply voltage of a single phase is a pure sinusoidal voltage with nominal frequency and voltage amplitude. **Any variation from this is considered as a power quality event or a disturbance.**

2.2 Rapid voltage changes

Rapid voltage change is a fast change in a voltage $U_{rms}(1/2)$ between two steady conditions. It is caused by switching on or off large loads. A typical cause of rapid voltage change is the start of a large motor. If a rapid voltage change exceeds the dip/swell threshold it is considered as a dip or swell.

2.3 Supply voltage dips

Supply voltage dip represents temporary reduction of a voltage below a threshold. Duration of phenomena is limited up to 1 minute. Decreased voltage for period longer than a minute is considered as a magnitude variation. A voltage dip is characterized by:

- dip threshold
- starting time of a dip

- dip duration
- retained voltage (u_{ret})

Dip threshold can be set by the user and represents part of nominal U_n or declared U_c voltage and can vary from 0.9 U_c for troubleshooting to 0.65 U_c for contractual purposes.

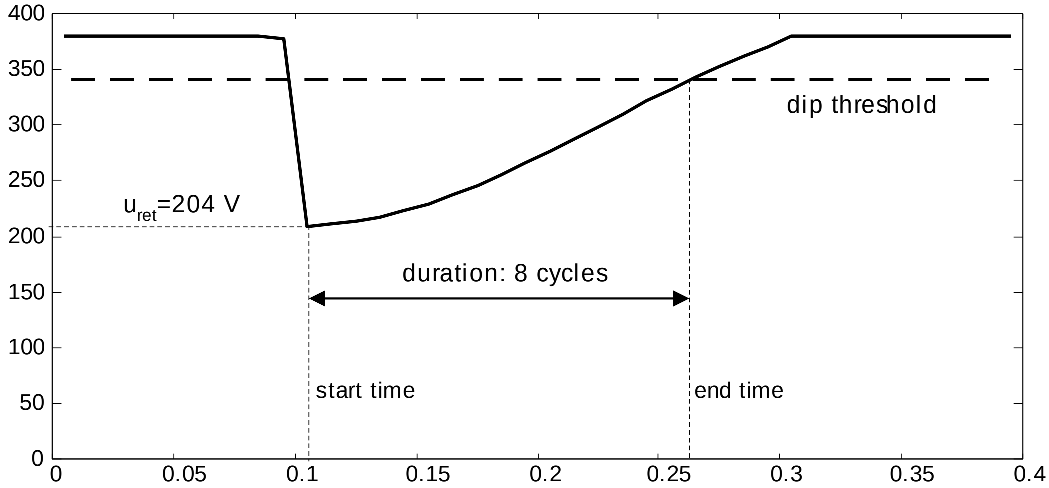


Figure 2-1: voltage dip attributes

The dip starts when $U_{rms(1/2)}$ drops below the dip threshold. The dip ends when $U_{rms(1/2)}$ rises above the dip threshold. The difference between end and start time is dip duration and is reported in seconds or in cycles. Retained (residual) voltage u_{ret} is the lowest $U_{rms(1/2)}$ value recorded during a dip.

Origin
Voltage dips are caused by failures in the network or by excessively large inrush currents.

Impact on customers' equipment
Studies conducted over recent years have confirmed that voltage dips cause the majority of malfunctions of equipment. Relays and contractors can drop out if a dip is 60% for longer that 1 cycle. Potential damage is dependent on the ability of the equipment to sustain lower voltage for short periods. Information technology is particular sensitive to a dip.
An asynchronous motor can draw a current higher than its starting current at dip recover.

2.4 Supply voltage swells

Swells are instantaneous voltage increases (opposite to dips). The same attributes are used for the classification of swells as are used for dips.

Origin
The origin of swells are single line ground failures (SLG), upstream failures, switching off a large load or switching on a large capacitor.

Impact on customers' equipment

Since swells usually last for a short period, there is no significant impact on equipment. However, light bulbs can burn out and safety problems may arise.

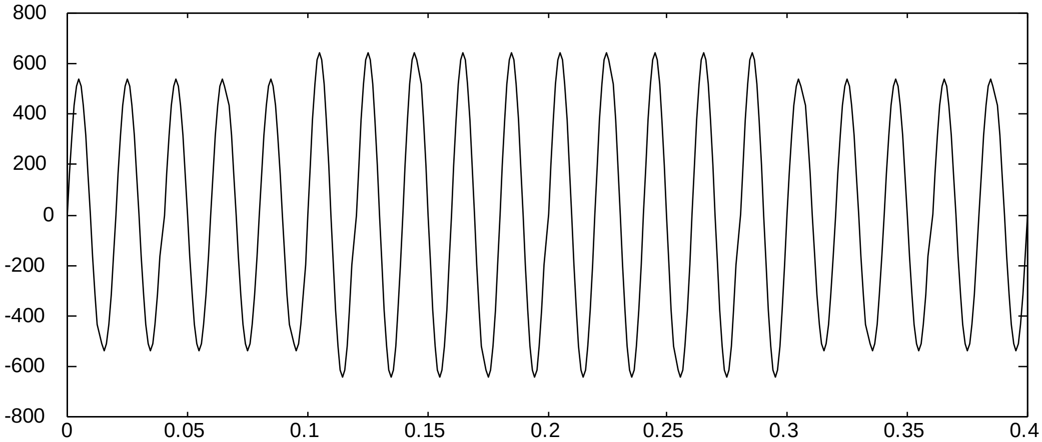


Figure 2-2: voltage swell

2.5 Voltage interruptions

An interruption is classified as a network's isolation from any source of supply. Because of energy stored in a network, a specific voltage above zero, exists for a short period after the interruption commences. For this reason an interruption is detected as a $U_{rms(1/2)}$ drop below an interruption threshold. The interruption threshold can vary but is usually set to 1%, 5% or 10% of the declared voltage. The duration of an interruption is measured in the same manner as a measurement of dip duration after setting an interruption threshold.

Because of the measurement technique a short circuit fault can appear as a short interruption in one section of the network and a dip in another. Interruptions are classified in two groups:

- short interruptions
- long interruptions.

Origin

Short interruptions are introduced by a fault condition in a network, which causes switchgear to operate. The duration of a short interruption is limited to 1 minute or 3 minutes.

Long interruptions are interruptions in excess of the short interruption duration limit. They arise when a fault condition cannot be terminated with a control sequence and the final tripping of a circuit breaker occurs.

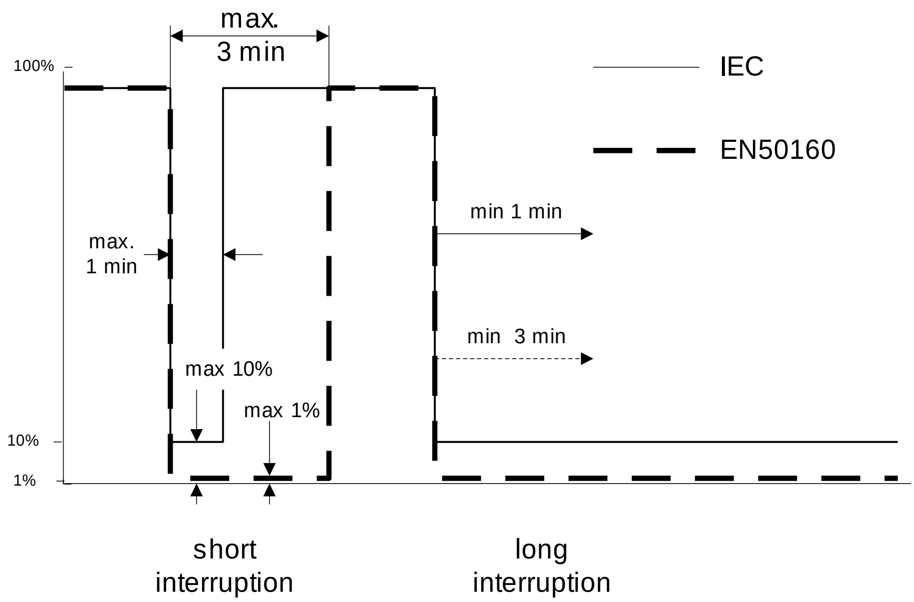


Figure 2-3: nterruption threshold and duration definitions

Impact on customers' equipment
In an industrial environment, interruptions can cause disruption in production by increasing the number of rejects or material wastage. In some areas, interruptions can increase the risk of equipment damage or even injury. Information technology is affected in two ways. First, current data can be lost and the system can be corrupted. Second, after interruption is over, the re-boot process, especially on a large and complex system, can last for several hours. Because of these reasons, critical computer systems and telecommunication equipment are supplied with UPS power.

2.6 Power measurement

Active Power (P)
Active power is the power generated if a voltage is placed over a purely resistive load and current is allowed to flow. Active power is usually measured in watts (W) or kilowatts (kW).

Reactive Power (Q)
Reactive power is the power that is generated by reactive components (e.g. inductors, capacitors) to create a magnetic field. This is usually measured in Volt-Ampers reactive (VAr).

Apparent Power (S)
Apparent power is the perceived power from a load that has both resistive and reactive components. Apparent power is the vector sum of both active and reactive power and is usually measured in Volt-Amperes (VA).

Power Factor
Power factor is a measure of a power system's efficiency and is the ratio of real power to apparent power.

2.7 Energy measurement

Energy is the generation or use of electric power over a period of time. This is usually expressed in kilowatt-hours (kWh).

2.8 Harmonics

Any periodic deviation of a pure sinusoidal voltage waveform can be presented with the sum of sinusoids of the power frequency and its integer multiples. Power frequency is called the fundamental frequency. A sinusoidal wave with a frequency k times higher than the fundamental (k is an integer) is called harmonic wave and is denoted with amplitude and a phase shift (phase angle) to a fundamental frequency signal. The ratio between harmonic frequency and a fundamental frequency (k) is called harmonic order.

Origin
Non-linear loads (rectifiers, variable speed drives, fluorescent lamps, PC, TV...) draw current with a high THDI (highly non-sinusoidal waveform). For analysis purposes, non-linear loads can be modelled with linear loads and the (current) source of harmonics. Current harmonics cause a non-sinusoidal voltage drop on the reference impedance and a distorted voltage at the power supply terminals. Non-linear loads disturb the supply voltage in such a way that only **odd harmonics** can be detected with a measurement instrument.
If the load is non-symmetrically controlled, positive and negative half periods of current differ in shape and rms value causing **even harmonics** and a DC component to arise. This situation causes saturation and overheating of transformer cores. A significant DC component can be caused by geomagnetic storms in some areas.
Another source of harmonics is the supply network itself. Magnetisation of the energy transformer core and its saturation cause non-sinusoidal currents that are manifested as a THDU on the supply terminals.

Origins of harmonics disturbances
- single phase rectifiers – high 3rd harmonic, THDI 80%
- three phase loads – 5th, 7th, 11th, 13th, 17th harmonic
- non-symmetrically controlled supply – even harmonics and DC
- higher pulse number – lower THDI
- serial inductance decreases THDI
- LV power supply network – THDU 1.5 ÷ 4.5%, mainly 5th harmonic

Impact on customers' equipment
- overall energy efficiency is decreased
- premature ageing of system components
- triple harmonics can produce high currents in a neutral line causing overheating and losses
- increased heating, noise and vibrations in transformers and motors
- current into capacitor bank increases with harmonic order causing failures
- presence of harmonic increase possibility of resonance
- problems with signalling frequencies
- tripping of protection devices

- electronic drives and switchers failure rate increases if THDU rises above 8%

2.8.1 Interharmonics

Interharmonics are harmonics that are not an integer multiplication of the fundamental frequency. The main sources of interharmonic waveform distortion are static frequency converters, induction motors and arcing devices.

2.8.2 Total Harmonic Distortion (THD)

THD is the ratio of a wave's harmonic content (for voltage or current) to its fundamental component.

2.9 Supply voltage unbalance

Supply voltage unbalance arises when rms values or phase angles between consecutive phases are not equal. Term *imbalance* is also used as an alternative. Supply voltage unbalance is defined as the ratio of the negative sequence component to the positive sequence.

$$u_u = \frac{|V_i|}{|V_d|}\cdot 100\ \% = \frac{negative\ sequence}{postive\ sequence}\cdot 100\ \%$$

Origin
Unbalance happens when current consumption is not balanced or during a faulty condition before tripping.

Impact on customers' equipment
Voltage unbalance affects three phase asynchronous motors causing overheating and a tripping of protective devices.

2.10 Flicker

Flicker is a visual sensation caused by unsteadiness of a light. The level of the sensation depends on the frequency and magnitude of a light change and on the observer.
Changing of a lighting flux can be correlated to a voltage envelope in the following figure.

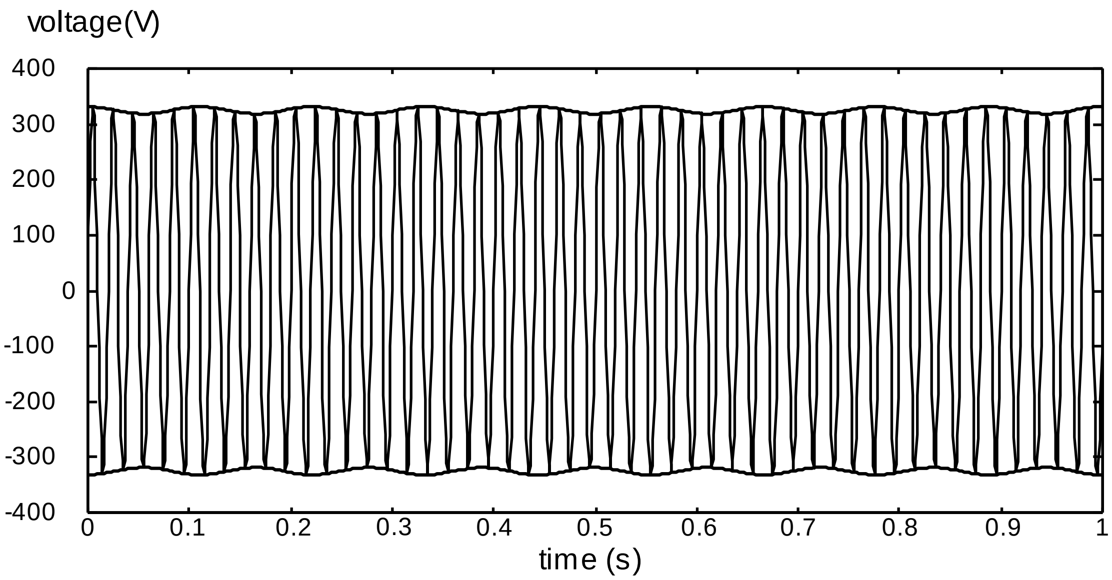


Figure 2-4: voltage fluctuation

Origin
Origins of voltage fluctuation are arc furnaces, welding machines and similar heavy loads that consume greatly varying currents. Flicker can arise in the presence of interharmonics with a frequency close to the base frequency or harmonic.

Impact to customers' equipment
Magnitude of voltage fluctuation is usually below 3% of supply voltage and does not have any noticeable influence to equipment. Flickering caused by voltage fluctuation of just 0.2% with frequency of 9 Hz is considered as annoying.

2.11 Inrush

Current needed to start a motor can be 10 to 15 times the normal operating current. This initial surge of current can cause dips in voltage and can be hard to analyse with normal test instruments, for this reason an analyser with a fast logging function is required.

2.12 Transient overvoltages

Transient is a term for **short, highly damped** momentary voltage or current disturbance.
There are two types of transient overvoltages:
- impulsive overvoltage
- oscillatory overvoltage

Origin
Impulsive transient overvoltages are *unidirectional* disturbances caused by lighting and have a high magnitude but low energy. Frequency range is above 5kHz with duration 30-200 microseconds.
Oscillatory transient overvoltages are caused by switching, Ferro resonance or can arise as a system response to an impulsive overvoltage. Switching overvoltages have

high energy and are classified as low (<5kHz), medium (5kHz<f<500kHz) and high frequency (>500kHz) transients.

Impact on customers' equipment
Transient overvoltages cause the immediate failure or degradation of a transformer, capacitor or semiconductor or causes cable isolation that can lead to faulty operation. Electronic drives may fall out.

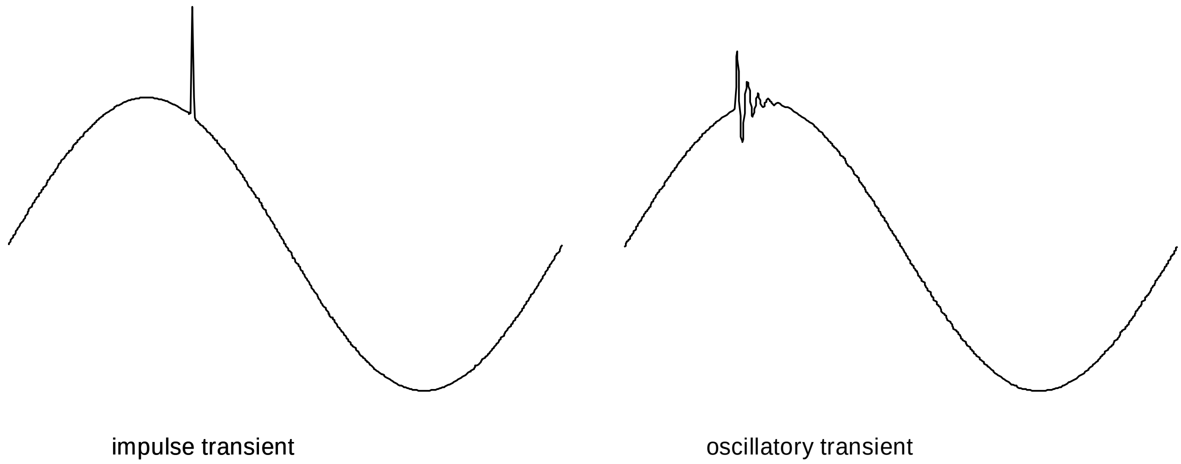


Figure 2-5: transients

3 Connection and setup

3.1 Electrical system configuration

Before we get on with measurements, the instrument and software should be set up properly.
For demonstration and exercise purposes, we will simulate a typical situation, where an instrument is connected to the 3-phase 4-wire system, somewhere between the transformer and the load.

U_{Nom} = 230 VL-N

I_{Nom} = 1000 A

f_{Nom} = 50/60 Hz

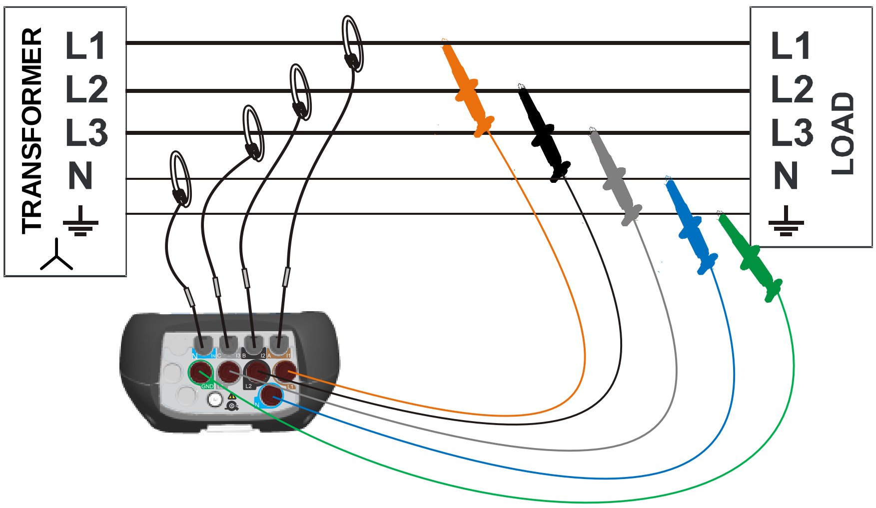


Figure 3-1: 3-phase 4-wire electrical system

In order to “simulate” this connection, in the Application Trainer, the instrument and current clamps should be connected to the Application Trainer as shown in the figure below.

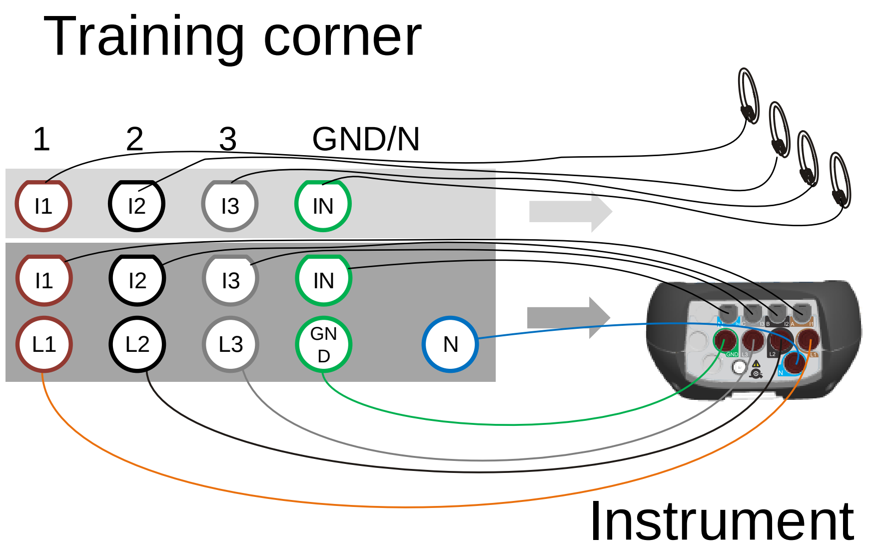


Figure 3-2: 3-phase 4-wire system connection to the Application Trainer

3.2 Instrument Setup

In order to measure power parameters correctly it is essential to properly setup the instrument.
Procedure how to do this is described in the next few figures. First, go to the MEASUREMENT SETUP menu and select the CONNECTION SETUP submenu. CONNECTION MENU is shown in the figure below.

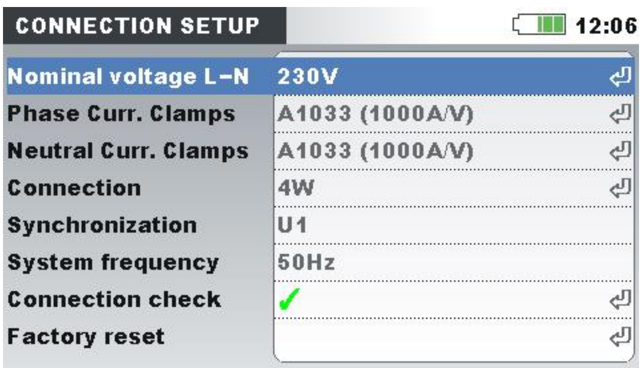


Figure 3-3: Connection setup menu

1. Select Nominal voltage L-N and press the  key
2. Set nominal voltage and ratio as shown in the figure below

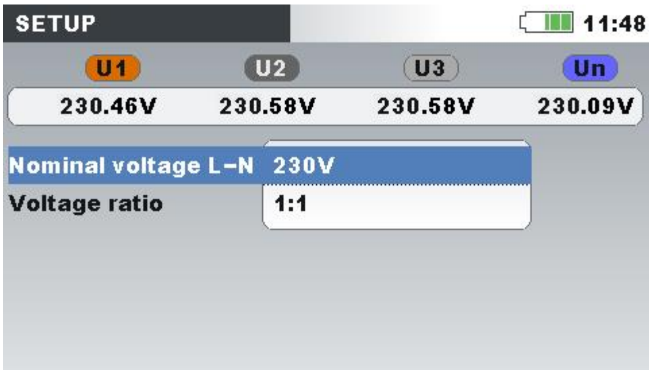


Figure 3-4: Setting Nominal voltage on the instrument

3. Exit the nominal voltage setup by pressing once the ESC key.
4. Select Phase Current Clamps menu and press the ENTER key
5. Select A1033 Clamps and press the ENTER key

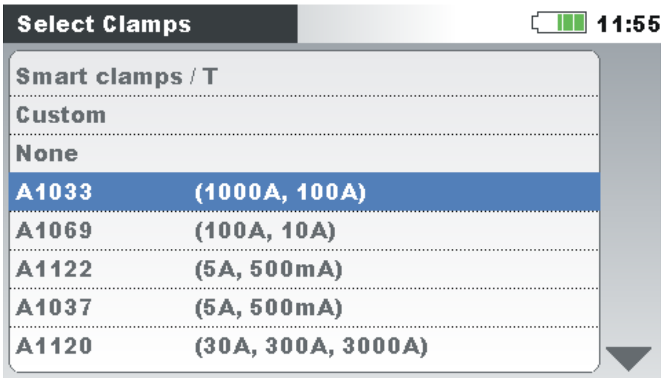


Figure 3-5: Current clamp selection

6. Select 100% measuring range and press the ESC key.

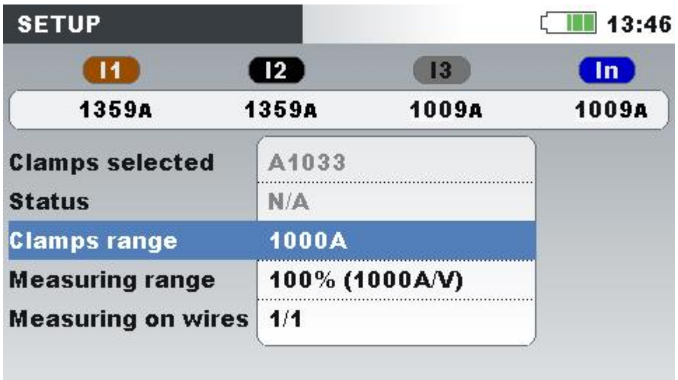


Figure 3-6: Setting Current clamps parameters on the instrument

7. Select Neutral Current Clamps and repeat procedure above (steps 5 and 6).
8. Select Connection menu and press the ENTER key

9. Select 3 phase / 4 wire connection (4W) by pressing the F3 key. After the appropriate mode is selected, press the ESC key.

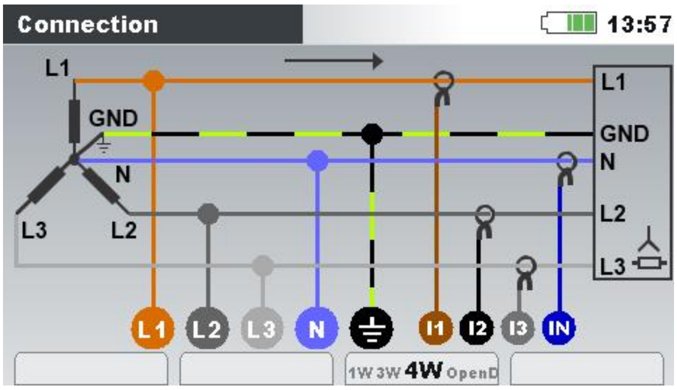


Figure 3-7: Choosing Connection configuration on the instrument

10. Select synchronisation channel: U1
11. Select System frequency: 50/60 Hz.
12. Check the Connection check status. If it's marked with a OK sign (✓), then you have set up the instrument correctly. If the status mark is fail (✗) then press ENTER and details will be shown. Check each parameter which is out of limit and try to troubleshoot the connection problem.

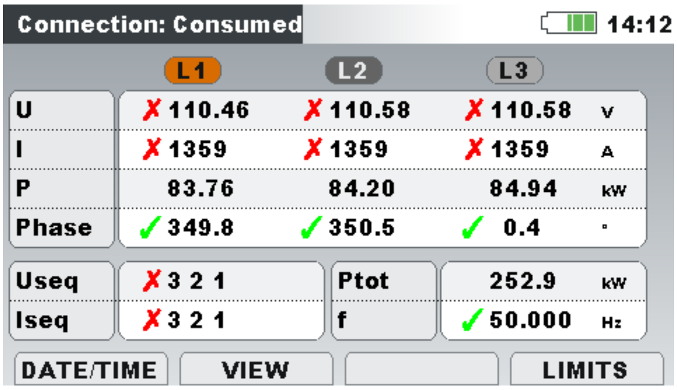


Figure 3-8: Connection check screen

13. Press F1 and check if Date/Time is set up correctly.

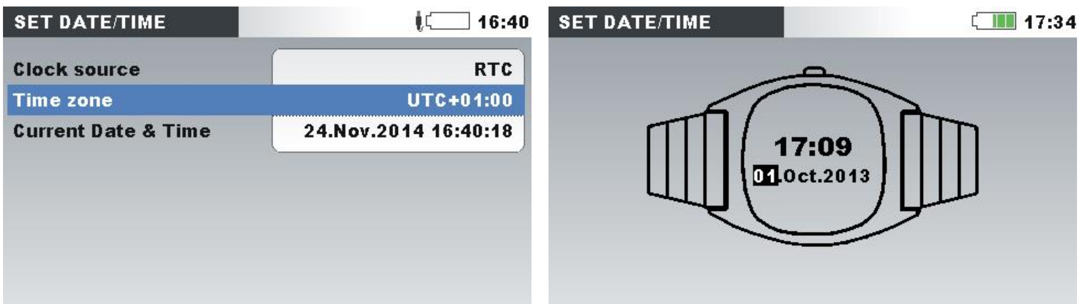
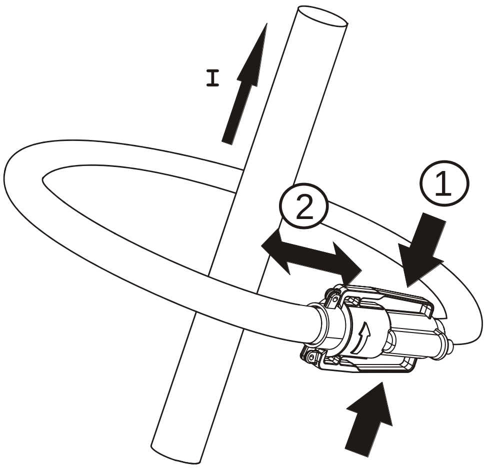


Figure 3-9: Setting time and date on the instrument

In practice, when connecting the instrument to the electrical system, it is essential that both current and voltage connections are correct. In particular the following rules have to be observed:

Clamp-on current clamp-on transformers

- The arrow marked on the clamp-on current transformer should point in the direction of current flow, from supply to load.



- If a clamp-on current transformer is connected in reverse the measured power in that phase would normally appear negative.

Phase relationships

- The clamp-on current transformer connected to the current input connector I_1 has to measure the current in the phase line to which the voltage probe from L_1 is connected.

3.3 Instrument's status bar

Instruments status bar is placed on the top of the screen. It indicates different instrument states. Icon descriptions are shown on table below.

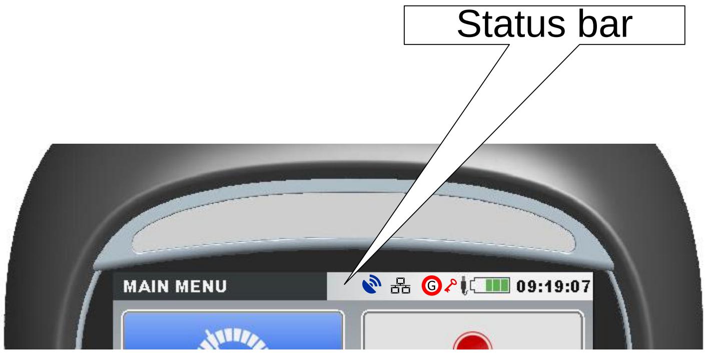


Figure 3-10: Instrument status bar

	Indicates battery charge level.
	Indicates that charger is connected to the instrument. Batteries will be charged automatically when charger is present.
	Instrument is locked.
	AD converter over range. Selected Nominal voltage or current clamps range is too small.
09:19	Current time.

GPS module status

?	GPS module detected but reporting invalid time and position data. (Searching for satellites or too weak satellite signal).
	GPS time valid – valid satellite GPS time signal.

Internet connection status

	Internet connection is not available.
	Instrument is connected to the internet and ready for communication.
	Instrument is connected to the PowerView.

Recorder status

G	General recorder is active, waiting for trigger.
G	General recorder is active, recording in progress.
W	Waveform recorder is active, waiting for trigger.
W	Waveform recorder is active, recording in progress.
T	Transient recorder is active, waiting for trigger.
T	Transient recorder is active, recording in progress.
R	Memory list recall. Shown screen is recalled from instrument memory.

Table 3-1: Instrument status bar description

3.4 Deleting the contents of the memory list

To delete the contents of the memory list (e.g. prior to start recording on a new location) , follow the procedure:

1. Go to the RECORDS menu
2. Select the MEMORY LIST submenu.
3. To delete only one file at a time select the CLEAR function by pressing the F3 key on the instrument.
4. To delete all files at once select the CLR ALL function by pressing the F4 key on the instrument.

3.5 PowerView installation and setup

Metrel PowerView is a powerful tool for downloading, analysing and reporting power quality data for the Metrel MI 2892 Power Master instrument. Through a simple but powerful interface, PowerView helps you find PQ issues quickly, while allowing you to easily make complex analysis and data comparisons. PowerView can be freely downloaded from Metrel's Download Center. You can download a 32-bit or a 64-bit version, according to your version of Microsoft Windows. Please use the following procedure in order to set up the PowerView for first time use:

1. Download PowerView ver.3 and start the installation. Follow the wizard through the installation.
2. After the installation is finished, turn on the instrument and connect it to the PC with a USB cable.
3. Windows will install all necessary drivers automatically. Note that the Windows user needs Administrator's privileges to complete this task.
4. In the Instrument, go to the GENERAL SETUP menu and choose the COMMUNICATION submenu.
5. Select USB connection as shown in the figure below.

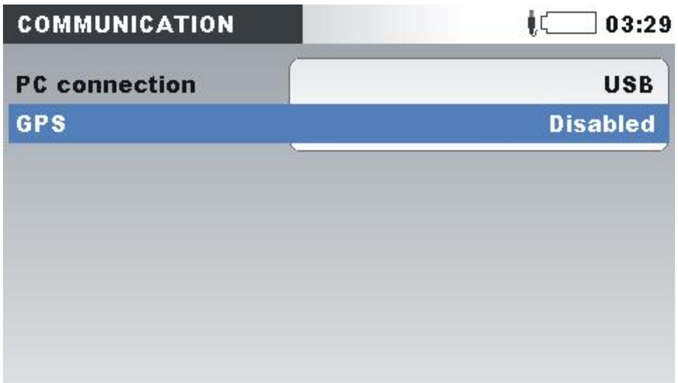


Figure 3-11: Connecting setup menu

6. Open Metrel PowerView software on your PC, select Tools → Options from the menu bar. A new pop-up window will appear. Set Connection type to USB, set port name (e.g. MI 2892 USB VCom Port (COM4[8])). Confirm settings. Communication has been set up successfully.

[8] Note that the actual COM port number may differ.

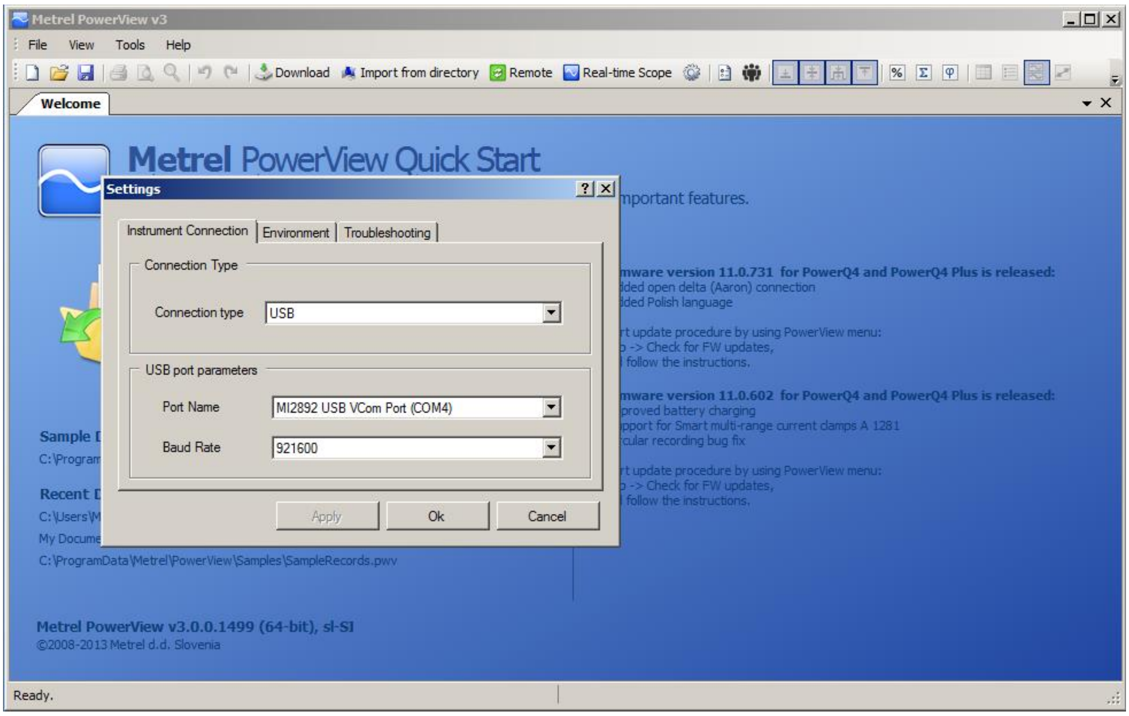


Figure 3-12: Setting USB communication in PowerView (PC Side)

7. For a quick check, it is advisable to click on the Real-time Scope icon and see if instantaneous measurements are downloaded from the instrument and presented on the screen.

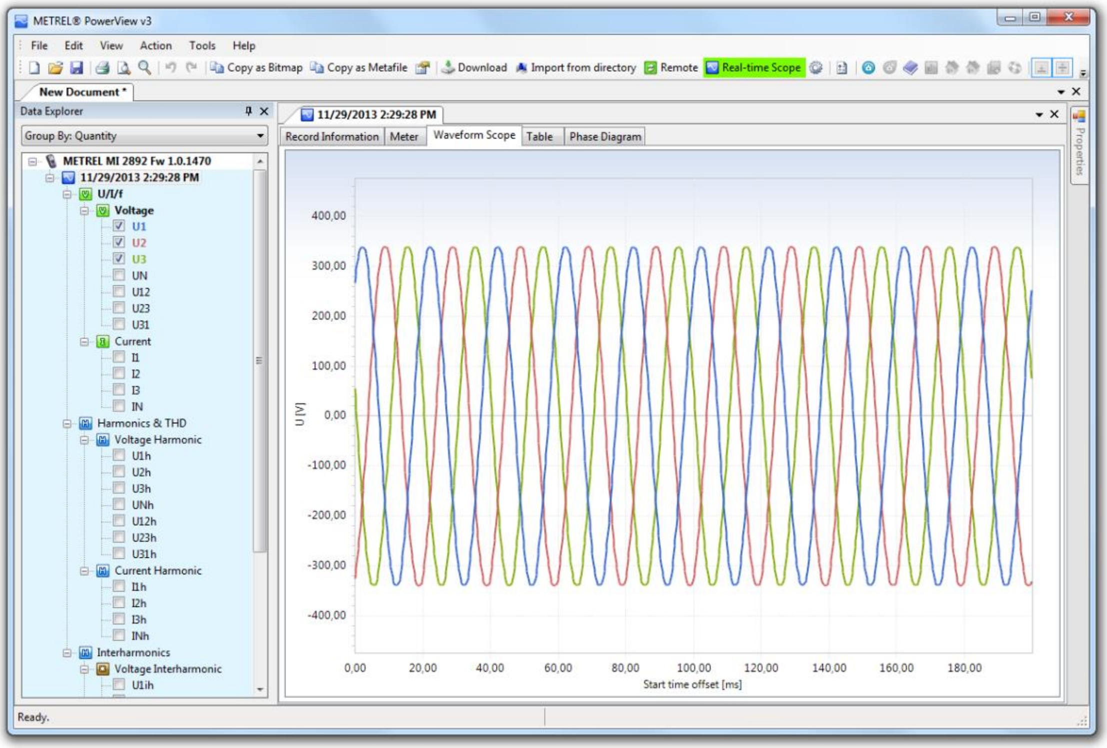


Figure 3-13: Observing waveform with PowerView

8. Click again on the Real-time Scope icon to stop continuous download.

4 Exercises

4.1 Exercise 1 – Basic general manipulation and recording:

In this exercise, we will show basic steps for Power Quality Analysis:

- Observing power quality measurements in real time
- Recording and observing recorded data on the instrument
- Downloading and observing downloaded data in PowerView

Before start, set switches S1 ÷ S11 of the Application Trainer to OFF as shown in the table below.

Attention! Please note that only one (1) error switch may be turned ON at any time when simulating power quality faults. If more than one (1) error switch is turned ON, an alarm buzzer will sound.

Switch	Description	State
S1	Dip	OFF
S2	Swell	OFF
S3	Interrupt	OFF
S4	Capacitive load & Energy	OFF
S5	Harmonics	OFF
S6	Unbalance	OFF
S7	Flicker	OFF
S8	Inrush	OFF
S9	Transient	OFF
S10	Phase (switch) failure	OFF
S11	Wrong instrument connection	OFF

The Application Trainer “simulates” an electrical system with the following parameters:

- Fundamental voltage: 230 V
- Fundamental current: 1000 A
- Load type: Inductive
- Load character: Load (Consumption of electrical power)
- Frequency: 50/60 Hz

Power Master MI 2892 should be connected to the Application Trainer and set up as described in previous section. It is good practice to observe Connection Check status in the MEASRUEMENT SETUP → CONNECTION SETUP menu. If it's marked with an OK sign (✓), you can start observing measurements.

4.1.1 Real time measurements

By entering the MEASUREMENTS MENU, the user can observe measured parameters in real time.

Figure 4-1: Measurement submenu

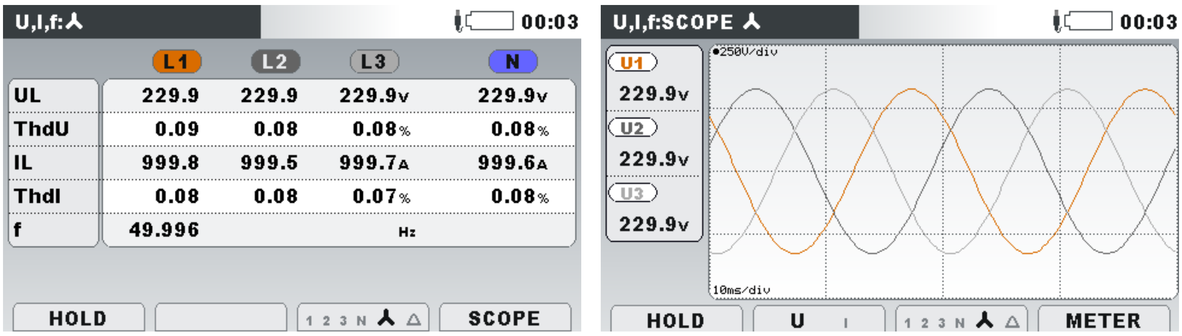


Figure 4-2: Real time measurements of voltage and current

4.1.2 Recording measurements

Basic tool for a Power Quality survey is recording parameters of an electrical system. In this step we will create a record and observe it on the instrument, as this is typical in case we are troubleshooting a problem in the field.

From the Main menu, enter RECORDERS window and then go to the GENERAL REC. menu. Here the user needs to set up all parameters as shown in the figure below. The user should set just basic recording parameters in order to get the sense for the data.

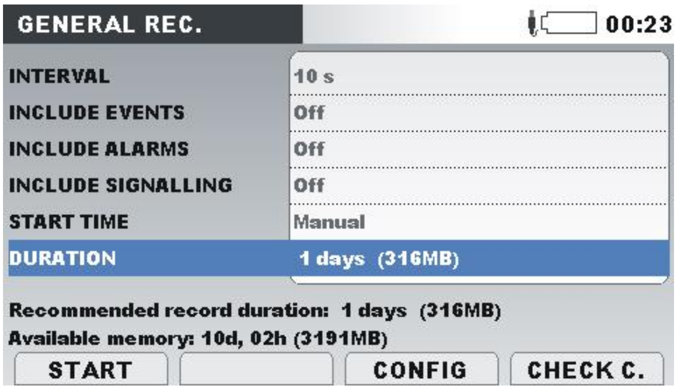


Figure 4-3: General record settings

The instrument is now prepared for recording electrical system parameters, generated by the Application Trainer. Please start the recorder by pressing the F1 (“START”) key. The recorder can be stopped anytime, by pressing the F1 (STOP) key.

After General recorder has been set, we are ready to run the recorder - by pressing F1 (START) key. Even though we have set it up to finish after 1 day, the recorder can be stopped anytime by pressing the F1 (STOP) key.

While recording is active , the user can evaluate recording parameters in the TREND screen, which appears in each MEASUREMENTS submenu. Figure below shows the voltage trend MEASUREMENT → U,I,f → TREND (press 2x key F4). Similar trends can be obtained for power parameters in POWER menu, harmonics in Harmonics menu, etc.

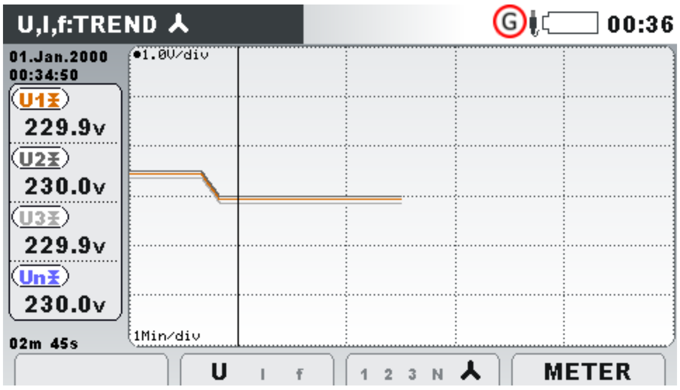


Figure 4-4: Showing voltage trend on the instrument

Finish recording after a few minutes, by entering the RECORDERS → GENERAL RECORDER menu, and pressing the F1 (STOP) key. Stored records can be observed on the instrument or transferred to PowerView. If we would like to analyse a record on the instrument (while we are in the field), enter the RECORDERS → MEMORY LIST menu. A list of available records will appear. Choose the record which you would like to observe by pressing the “VIEW” key, and then select the electrical system parameters.

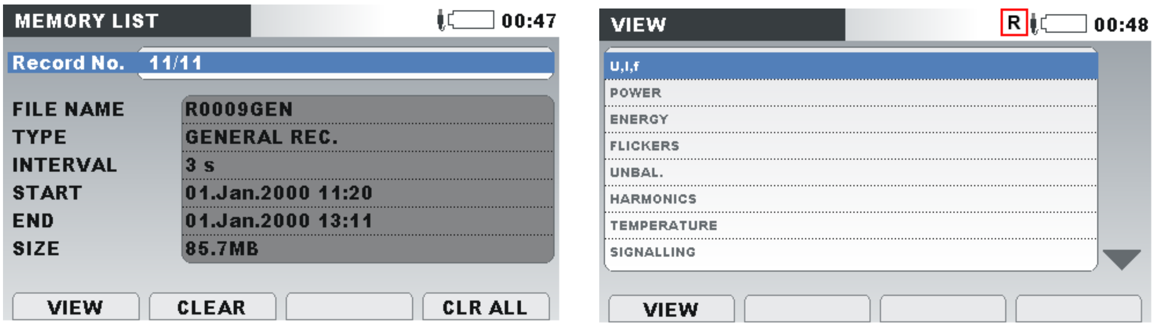


Figure 4-5: Observing records through Memory List submenu

4.1.3 Downloading and observing recorded data in PowerView

Recorded data can be imported into PowerView for further analysis. Please note that prior to this step PowerView should be installed and set up as described in section 3.5 PowerView installation and setup.

Open PowerView and click on the “Download” button from your toolbar. A new window will appear. Your instrument's information should be available on top of the window and a list of available records listed just below (see Figure 4-6: Download dialog). Select the desired records (current selections are coloured green), then click on the “Start importing” button.

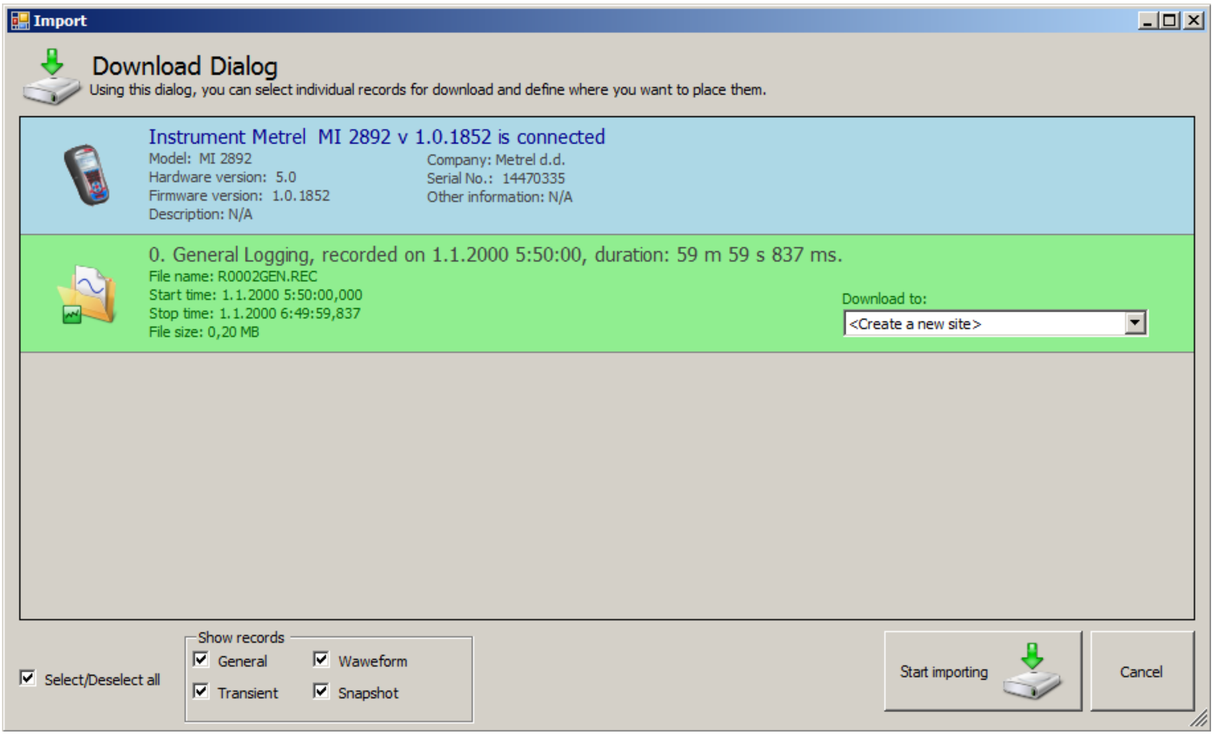


Figure 4-6: Download dialog

After the import, a “Record Information” tab will appear on the screen. This tab show basic information about record. Recorded data can now be accessed from the “Data explorer” tab.

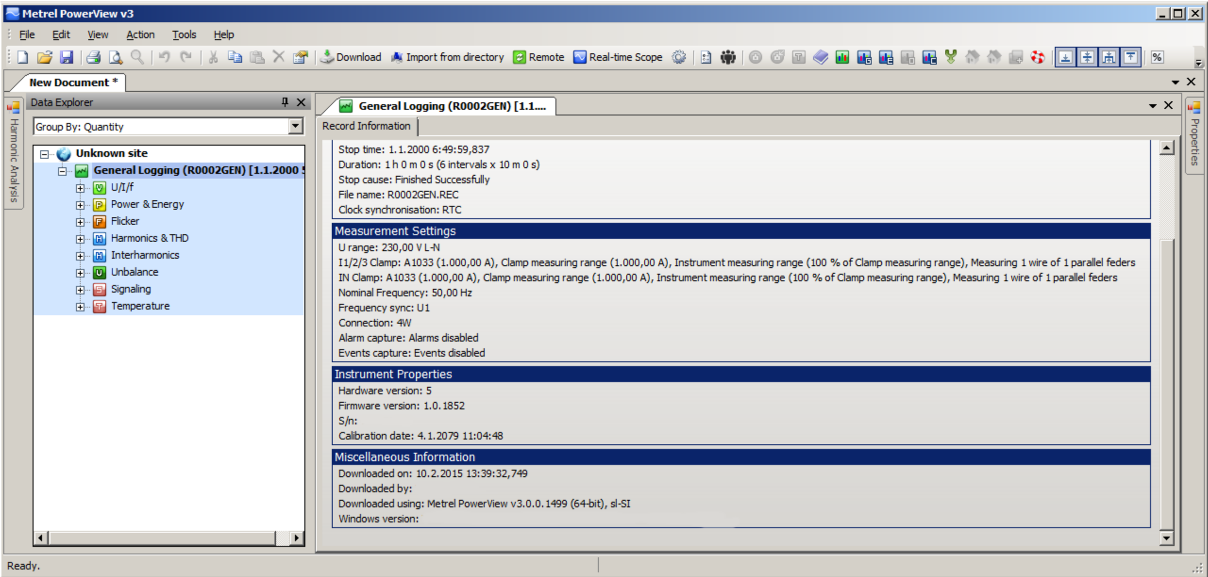


Figure 4-7: General logging information

Double click (or single click on ⊞ sign) on the "U/I/f" option, then double click "Current". Next, tick "I1" option. New tabs "Trend chart" (only when general recording option is used) and "Table" will appear on right side. "Trend chart" (see Figure 4-8: Chart view) graphically represents signal in time domain, whereas "Table" (see Figure 4-9: Table view) presents data in numerical form.

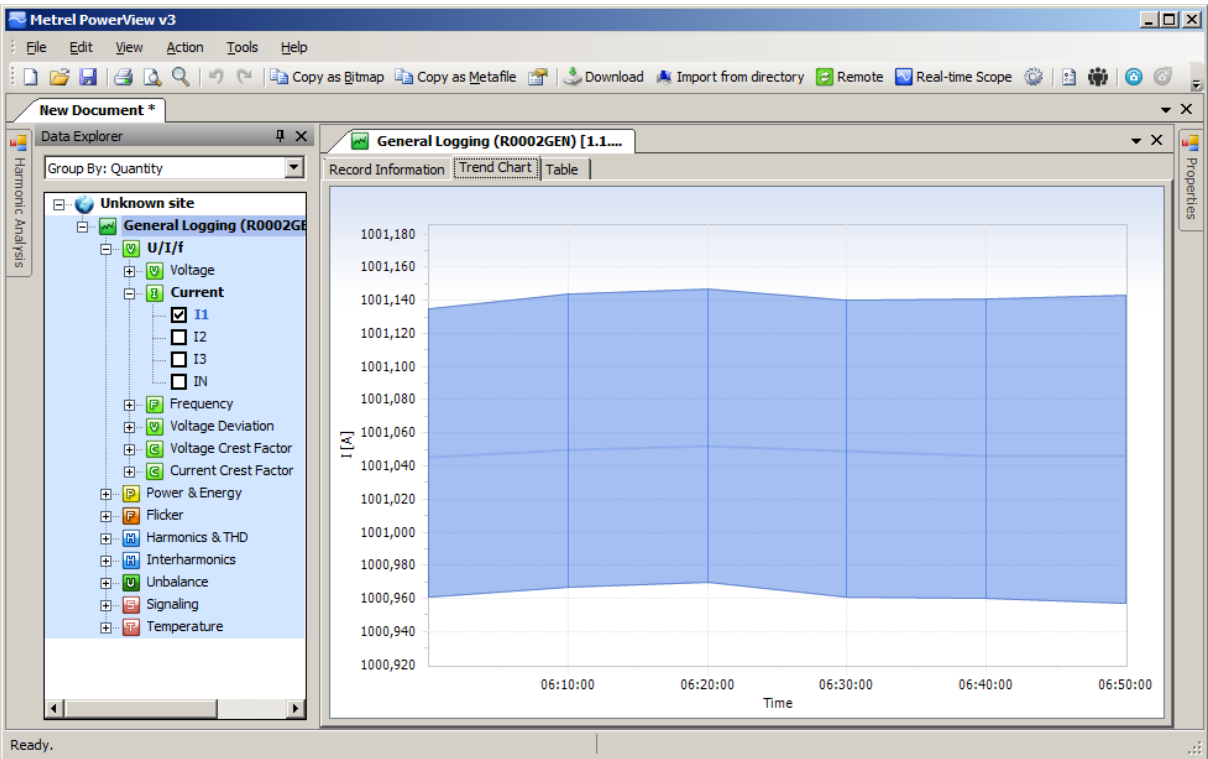


Figure 4-8: Chart view

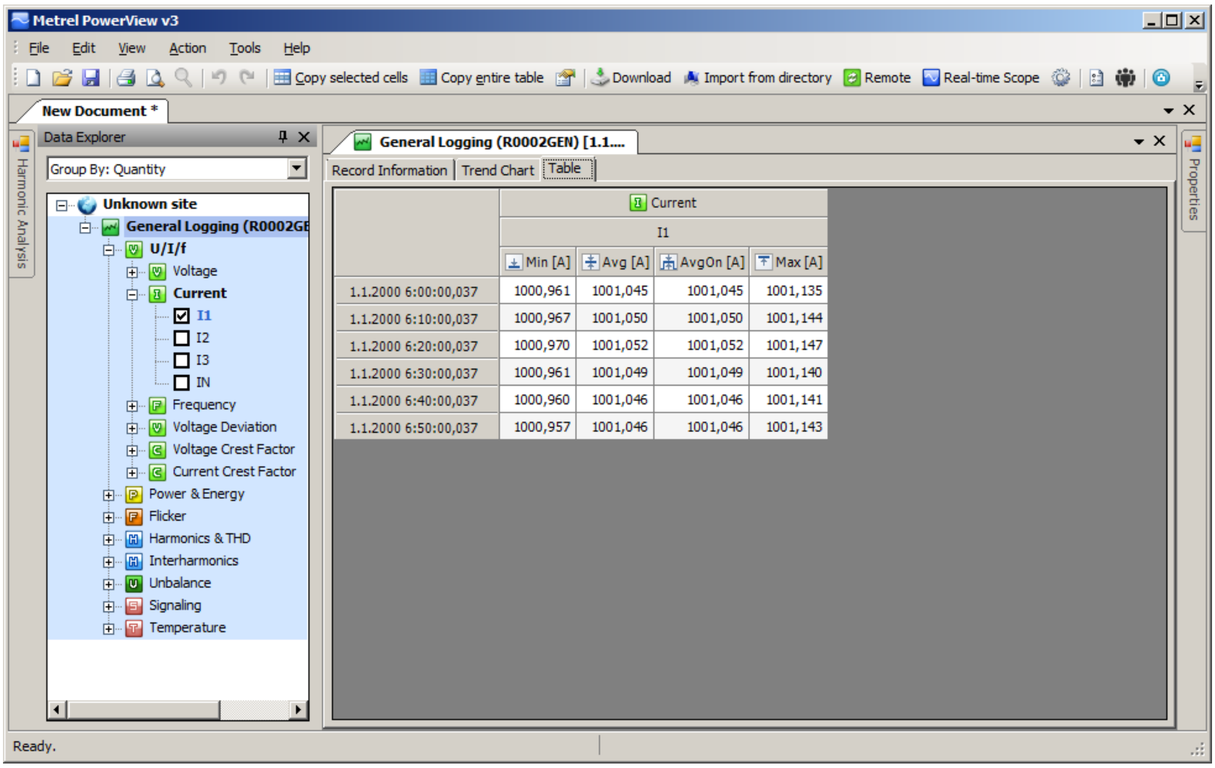


Figure 4-9: Table view

Depending on the parameter we're observing in “Table” view (in our case current), few options are shown:

- Min – presents minimal 10/12 cycle RMS value in given time interval,
- Avg – presents RMS average of 10/12 cycle RMS in given time interval,
- AvgOn – presents only non-zero RMS average of 10/12 cycle measurements in given time interval (same as Avg, but doesn’t take zero measured values into account). This measurement is useful for evaluating switch type of load
- Max – presents maximal 10/12 cycle RMS value in given time interval.

Other data (power, harmonics, etc.) can be accessed and analysed in similar fashion.

4.2 Exercise 2 – Voltage Dip

In this exercise, we will show how the instrument should be setup in order to capture and observe a voltage dip. Voltage dip is a temporary reduction of the voltage magnitude at a point in the electrical system below given limit. Before start, please set the switch S1 in the Application Trainer to ON as shown in the table below. The remaining switches should be set to OFF.

Switch	Description	State
S1	Dip	 ON

The Application Trainer will simulate an electrical system with the following parameters:

- Fundamental voltage: 230 V
- Fundamental current: 1000 A

- Load type: Inductive
- Load character: Load (Consumption of electrical power)
- Frequency: 50/60 Hz
- 138 V deep, 5 period's long voltage dip is present on phase L1. The dip is repeated every 10 seconds.

4.2.1 Instrument setup for Dip capturing

The Power Master MI 2892 should be connected to the Application Trainer and set up as described in section 3.2 Instrument Setup. It is good practice to verify the Connection Check status in the MEASRUEMENT SETUP → CONNECTION SETUP menu. If it is marked with an OK sign (✓), it means that the instrument is connected properly.
For observing voltage dips, it is necessary to set up a dip threshold voltage. If the voltage drops below the threshold, the voltage dip will be recorded. Limits are set up in the MEASRUEMENT SETUP → EVENT SETUP menu as shown in the figures below.

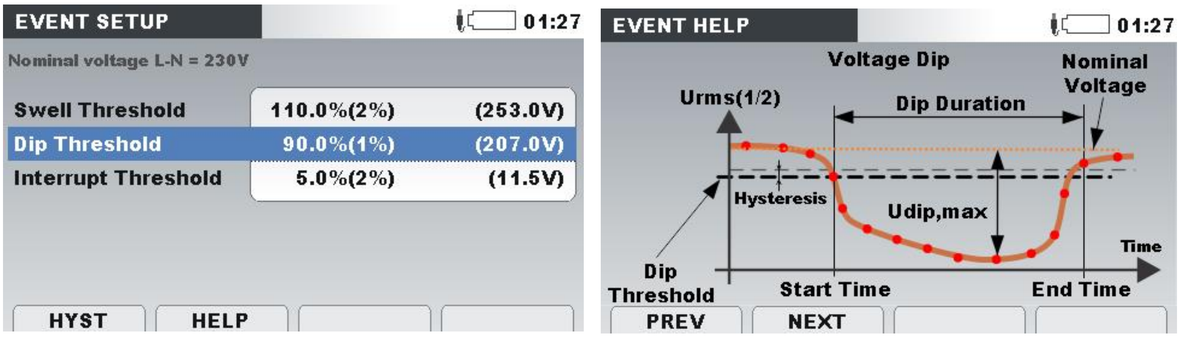


Figure 4-10: Dip threshold setup

Parameters need to be set:

- Swell: 110% - this event will be detected, if an increase of more than 10% of the nominal voltage occurs on the input channel,
- Dip: 90% - this event will be detected, if a drop of more than 10% of the nominal voltage occurs on the input channel,
- Interrupt: 5% - this event will be detected, if detected voltage on all phases is less than 5% of the nominal voltage.

For detailed explanation of these values, use the "Help" key on your instrument.

In order to get waveform and RMS voltages for each recorded dip, the waveform recorder should be set up. Enter the "WAVEFORM REC." submenu from the "RECORDERS" menu, and then set the following parameters:

- Trigger: **events** – waveform recording will be executed after an event happens, this way we're going to catch our generated event,
- Duration: **2s** - after an event is detected, the waveform recorder will run for the given Duration time minus Pretrigger time (in seconds),
- Pretrigger: **1s** – one second of signal history will be recorded before the trigger occurs,
- Store mode: **single** – value of this parameter is not important in this exercise.

A sample of such a screen is presented in the figure below.

Figure 4-11: Waveform record screen

Now go to RECORDERS → GENERAL REC and setup the general recorder with the following parameters:

- Interval: **10 sec** – recording interval is set to 10 seconds
- Include events: **On** (with waveforms) – this option allow us to record waveform shape for each event
- Include alarms: **Off** – no alarms will be triggered
- Start time: Manual
- Duration: **1 days** – recording will stop after 24 hours

Figure 4-12: General recorder setup

The instrument is now prepared for voltage event recording, which is generated by the Application Trainer. Please start the recorder by pressing the F1 (“START”) key. The recorder can be stopped anytime, by pressing the F1 (STOP) key.

4.2.2 Observing dips on the instrument

Enter the RECORDERS → EVENTS TABLE menu and check recorded events. The events table should be similar as shown in the figure below.

No	L	START	T	Level	Duration
1	1	14:08:06.708	D	91.92	0h00m0.110s
2	1	14:08:16.708	D	91.93	0h00m0.120s
3	1	14:08:26.719	D	91.94	0h00m0.110s
4	1	14:08:36.720	D	91.94	0h00m0.110s
5	1	14:08:46.720	D	91.96	0h00m0.110s
6	1	14:08:56.721	D	91.97	0h00m0.110s

Figure 4-13: Event table (dips)

Additionally, the waveform shape of a recorded event can be observed from the RECORDERS → MEMORY LIST, by selecting an appropriate recorded waveform and observing it, by pressing the F1 (VIEW) key. The recorded waveform should be similar to the one shown in the figure below.

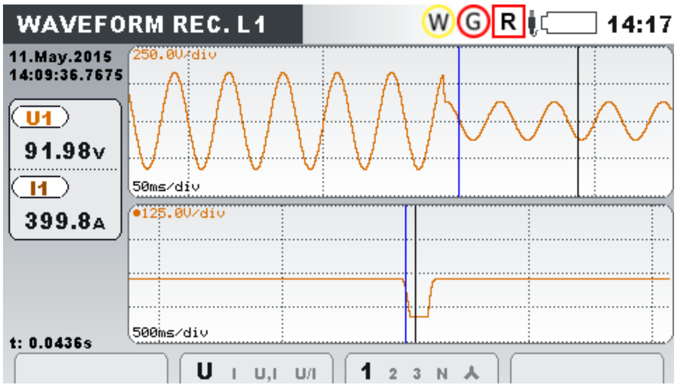


Figure 4-14: Voltage dip RMS measurements and waveform shape

4.2.3 Downloading and observing recorded data in PowerView

After capturing a few events, the recorder can be stopped, by pressing the F1 (STOP) key in the RECORDER → GENREAL REC. menu. To transfer the record into PowerView, we first need to be sure that PowerView is set up as described in section 3.3. First, click on the “Download” button in PowerView toolbar. A new window with connected instrument info opens. In this case we have several options available for download. Two types of records should be shown, as seen in the figure below:

- Triggered waveform – Event waveform is stored in this file type. Each event is stored in a separate record.
- General logging – Data trends and event tables are stored in this file type. All data recorded for a given period of time are stored in a single record.

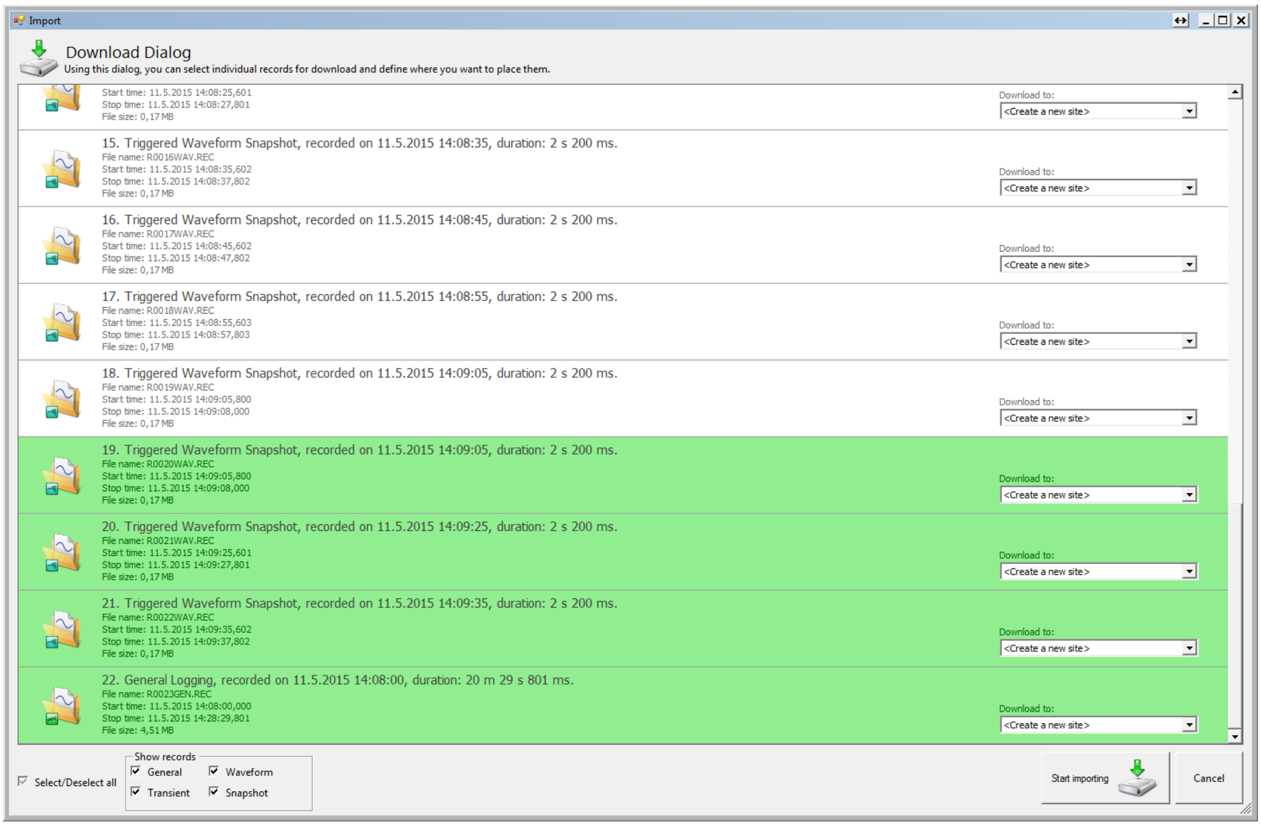


Figure 4-15: Download dialog with selected record

Select all records and click on »Start importing«. Three record types appear in the "Data explorer" tab:

- Triggered Waveform Snapshot – provides voltage and current samples for a captured voltage event, in our case a 5 periods long dip.
- Inrush Logging – provides voltage and current RMS measurements for each captured event.
- General Logging – basic record described in prior exercise.

Data explorer tree view is shown in the figure below.

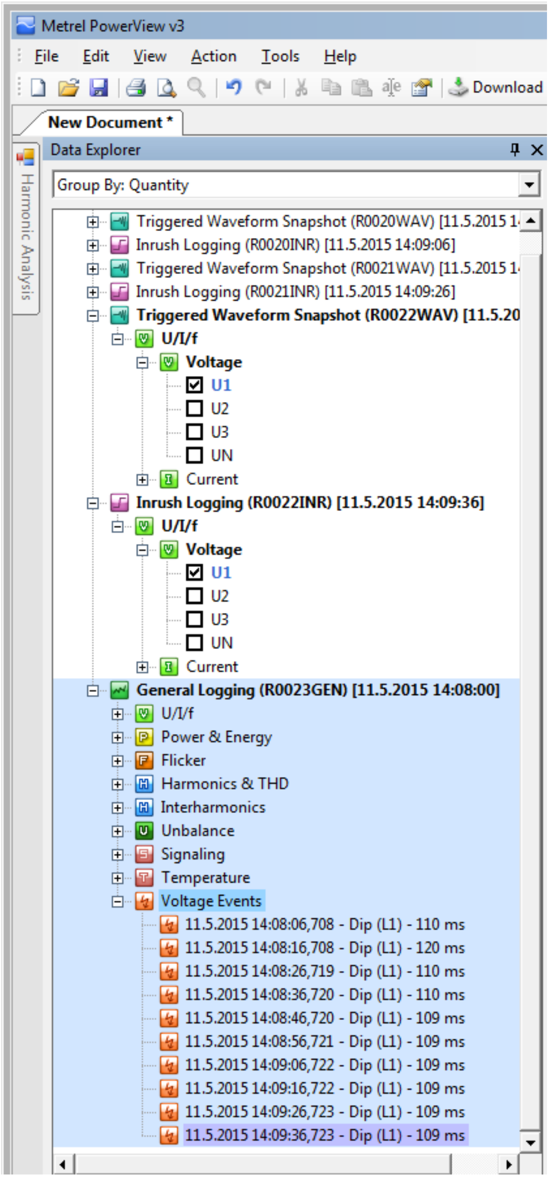


Figure 4-16: Records tree view (dips)

A voltage dip can be observed in table form within General Logging, where only dip signatures are shown. This kind of dip presentation is mainly used for statistic evaluation (for example: how many dips occurred during a given period). Tables and timeline graphs are shown in the next two figures.

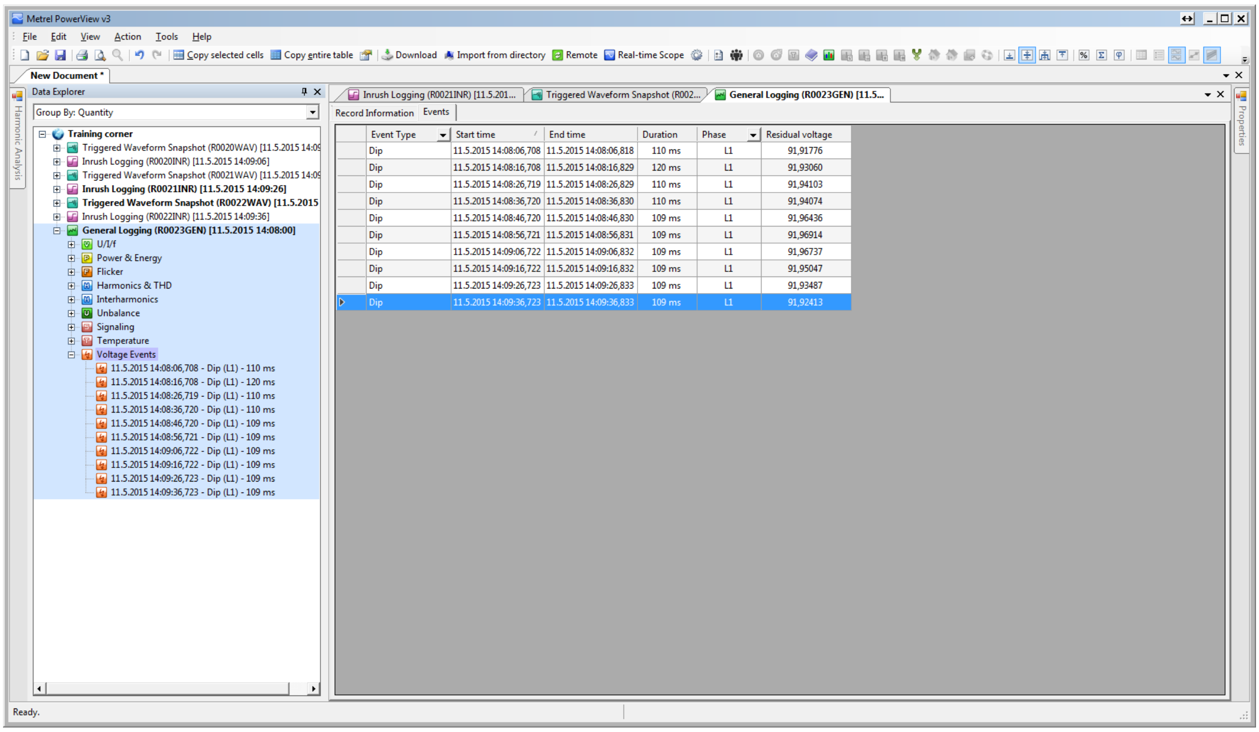


Figure 4-17: Voltage dips presented in table view in PowerView

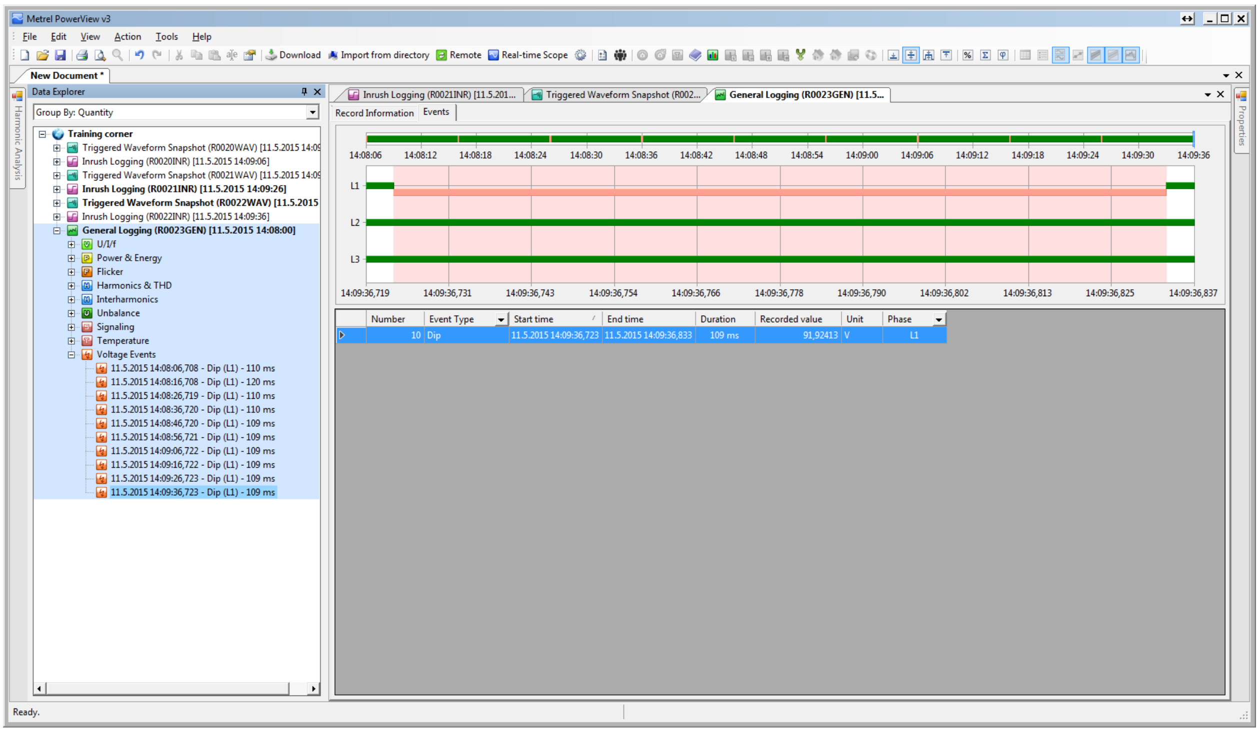


Figure 4-18: Voltage dip presented in timeline graph in PowerView

Each dip can be analysed in depth – through waveform records. PowerView can show two waveform record logs. Inrush log and waveform snapshot. Inrush log represents RMS values of voltage and current measured in one period and refreshed each half period (so-called RMS½). Captured voltage dip graph can be seen in the figure below.

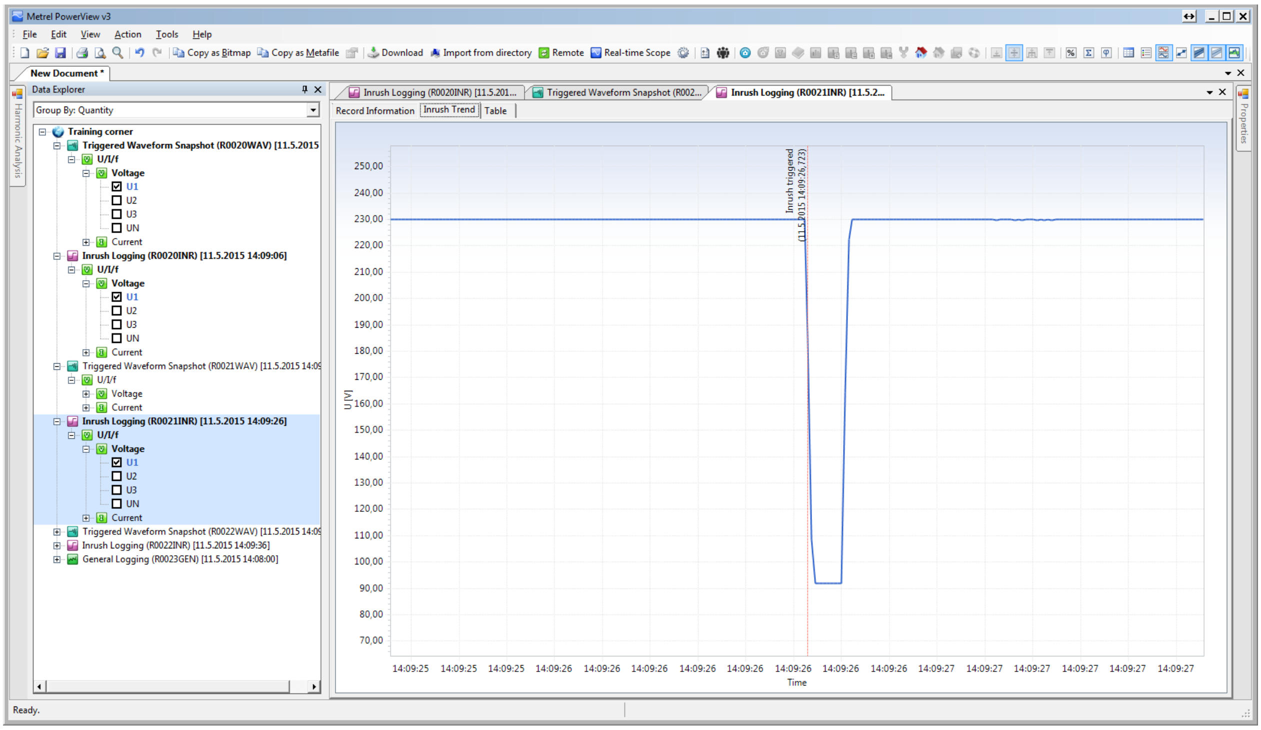


Figure 4-19: Captured voltage dip (RMS values)

For further analysis, the user can observe the waveform shape of the dip. From this graph, dip phase shift and dip starting point on the wave can be seen. Figure below represents such a view.

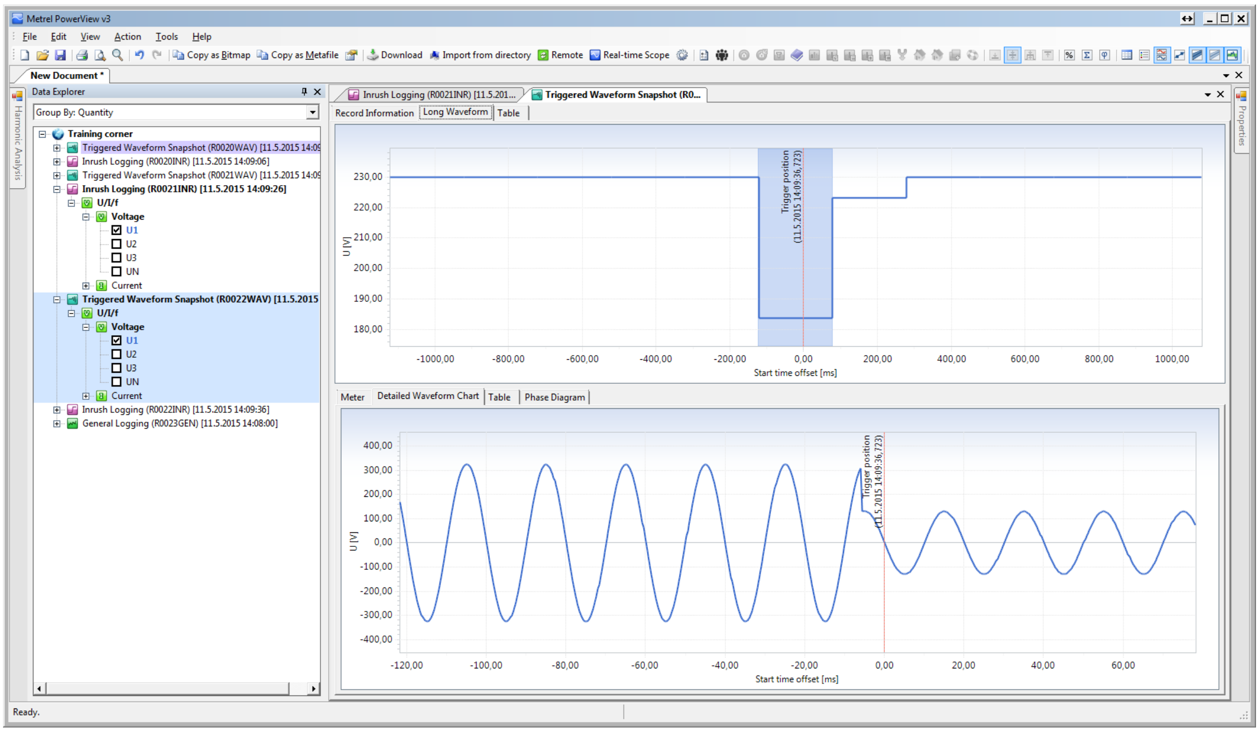


Figure 4-20: Captured waveform of voltage dip

4.3 Exercise 3 – Voltage Swell

In this exercise, we will show how the instrument should be setup in order to capture and observe a voltage swell. Voltage swell is temporary increase of the voltage magnitude at a point in the electrical system above given limit. Before start, please set the switch S2 in the Application Trainer to ON as shown in the table below. The remaining switches should be set to OFF.

Switch	Description	State
S2	Swell	ON

The Application Trainer will simulate an electrical system with the following parameters:

- Fundamental voltage: 230 V
- Fundamental current: 1000 A
- Load type: Inductive
- Load character: Load (Consumption of electrical power)
- Frequency: 50/60 Hz
- 276 V high, 5 periods long voltage swell is present on phase L1. The swell is repeated every 10 seconds.

4.3.1 Instrument setup for Swell capturing

The Power Master MI 2892 should be connected to the Application Trainer and set up as described in section 3.2 Instrument Setup. It is good practice to observe the Connection Check status in the MEASRUEMENT SETUP → CONNECTION SETUP menu. If it is marked with an OK sign (✓), you can start observing measurements.
For observing voltage swells, it is necessary to set up a swell threshold voltage. If the voltage raises above the threshold, the voltage swell will be recorded. Limits are set up in the MEASRUEMENT SETUP → EVENT SETUP menu as shown in the figures below.

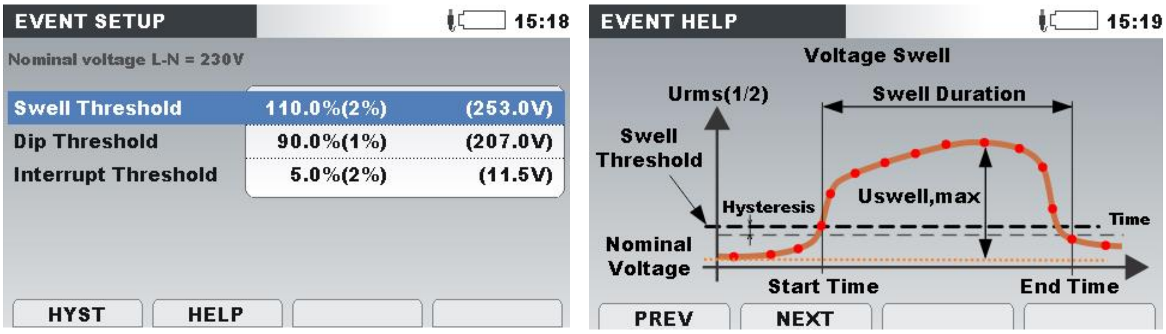


Figure 4-21: Swell threshold setup

Parameters need to be set:

- Swell: 110% - this event will be detected, if an increase of more than 10% of the nominal voltage occurs on the input channel,
- Dip: 90% - this event will be detected, if a drop of more than 10% of the nominal voltage occurs on the input channel,

- Interrupt: 5% - this event will be detected, if detected voltage on all phases is less than 5% of the nominal voltage.

For detailed explanation of these values, use the "Help" key on your instrument.

In order to get waveform shape and RMS voltages for each recorded swell, the waveform recorder should be set up. Enter the "WAVEFORM REC." submenu from the "RECORDERS" menu, and then set the the following parameters:

- Trigger: **events** – waveform recording will be executed after an event happens, this way we're going to catch our generated event,
- Duration: **2s** – after an event is detected, the waveform recorder will run for the given Duration minus Pretrigger time (in seconds),
- Pretrigger: **1s** – one second of signal history will be recorded before the trigger occurs,
- Store mode: **single** – value of this parameter is not important for this exercise.

A sample of such a screen is presented in the figure below.

Figure 4-22: Waveform record screen

Now go to RECORDERS → GENERAL REC and setup the general recorder with the following parameters:

- Interval: **10 sec**[9] – Averaging interval. Each 10 seconds an average value will be calculated for RMS voltage, current, power, harmonics, etc., and stored into memory.
- Include events: **On (with waveforms)** – this will run both general and waveform recorders.
- Include alarms: **Off** – no alarms will be triggered
- Start time: **manual**
- Duration: 1 days – recording will stop after 24 hours

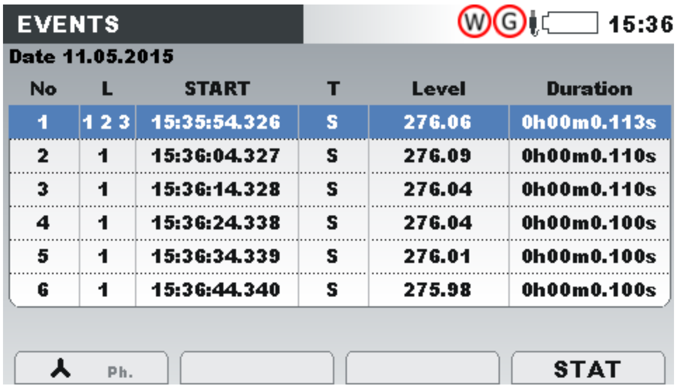
[9] Based on the standards IEC/EN 50160, the interaval should be set to 10 minutes and the waveform recorder is onshould be set to on. This is enough to capture all power quality problems. The general logging wil provide enough information if the quality is good. When an event does happen, the waveform will log any additional information needed for a complete analysis.

Figure 4-23: General recorder setup

The instrument is now prepared for voltage event recording, which is generated by the Application Trainer. Please start the recorder by pressing the F1 (“START”) key. The recorder can be stopped anytime, by pressing the F1 (STOP) key.

4.3.2 Observing swells on the instrument

Enter the RECORDERS → EVENTS TABLE menu and check recorded events. The events table should be similar as shown in the figure below.


EVENTS 15:36

Date 11.05.2015

No	L	START	T	Level	Duration
1	1 2 3	15:35:54.326	S	276.06	0h00m0.113s
2	1	15:36:04.327	S	276.09	0h00m0.110s
3	1	15:36:14.328	S	276.04	0h00m0.110s
4	1	15:36:24.338	S	276.04	0h00m0.100s
5	1	15:36:34.339	S	276.01	0h00m0.100s
6	1	15:36:44.340	S	275.98	0h00m0.100s

Ph. STAT

Figure 4-24: Event table (swells)

Additionally, the waveform shape of a recorded event can be observed from the RECORDERS → MEMORY LIST, by selecting an appropriate recorded waveform and observing it, by pressing the F1 (VIEW) key. The recorded waveform should be similar to the one shown in the figure below.

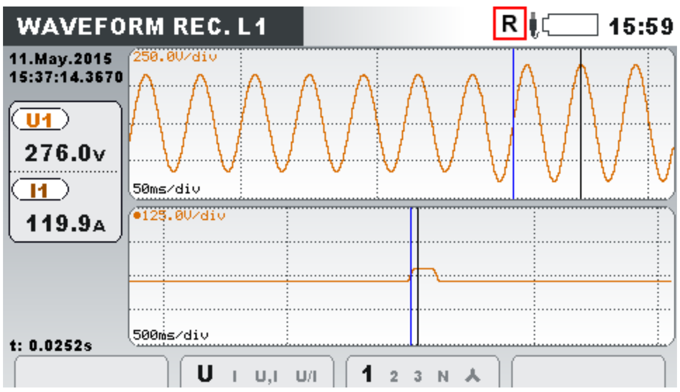


Figure 4-25: Voltage swell RMS measurements and waveform shape

4.3.3 Downloading and observing recorded data in PowerView

After capturing a few events, the recorder can be stopped, by pressing the F1 (STOP) key in the RECORDER → GENREAL REC. menu. To transfer the record into PowerView, we first need to be sure that PowerView is set up as described in section 3.3. First, click on the “Download” button in PowerView toolbar. A new window with connected instrument info opens. In this case we have several options available for download. Two types of records should be shown, as seen in the figure below:

- Triggered waveform – Event waveform is stored in this file type. Each event is stored in a separate record.
- General logging – Data trends and event tables are stored in this file type. All data recorded for a given period of time are stored in a single record.

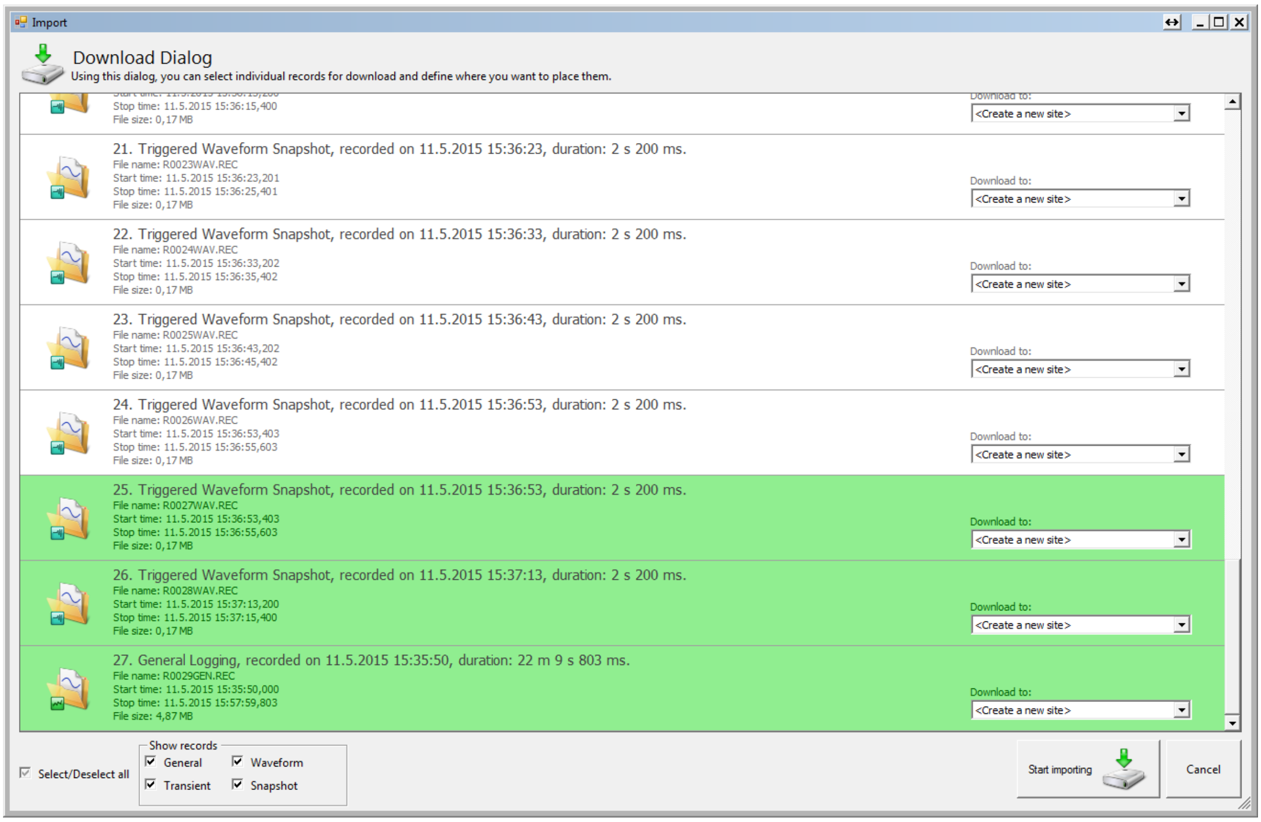


Figure 4-26: Download dialog with selected record

Select all records and click on »Start importing«. Three record types appear in the “Data explorer” tab:

- Triggered Waveform Snapshot – provides voltage and current samples for captured voltage event, in our case a 5 periods long swell.
- Inrush Logging – provides voltage and current RMS measurements for each captured event.
- General Logging – basic record described in prior exercise.

Data explorer tree view is shown in the figure below.

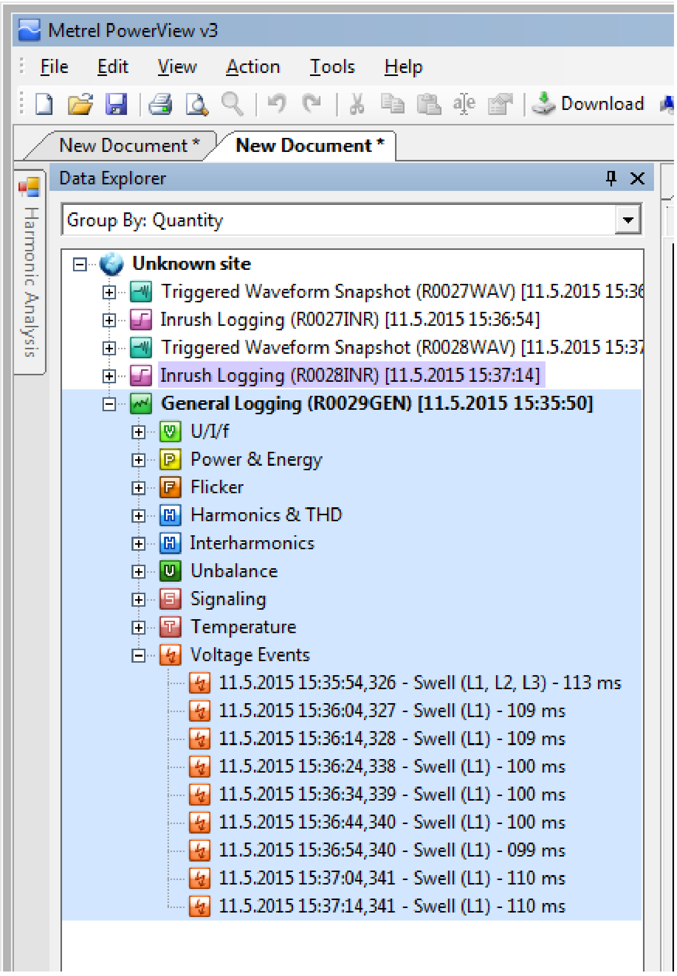


Figure 4-27: Records tree view (swells)

A voltage swell can be observed in table form within General Logging, where only swell signatures are shown. This kind of swell presentation is mainly used for statistic evaluation (for example: how many swells occurred during a given period). Tables and timeline graphs are shown in the next two figures.

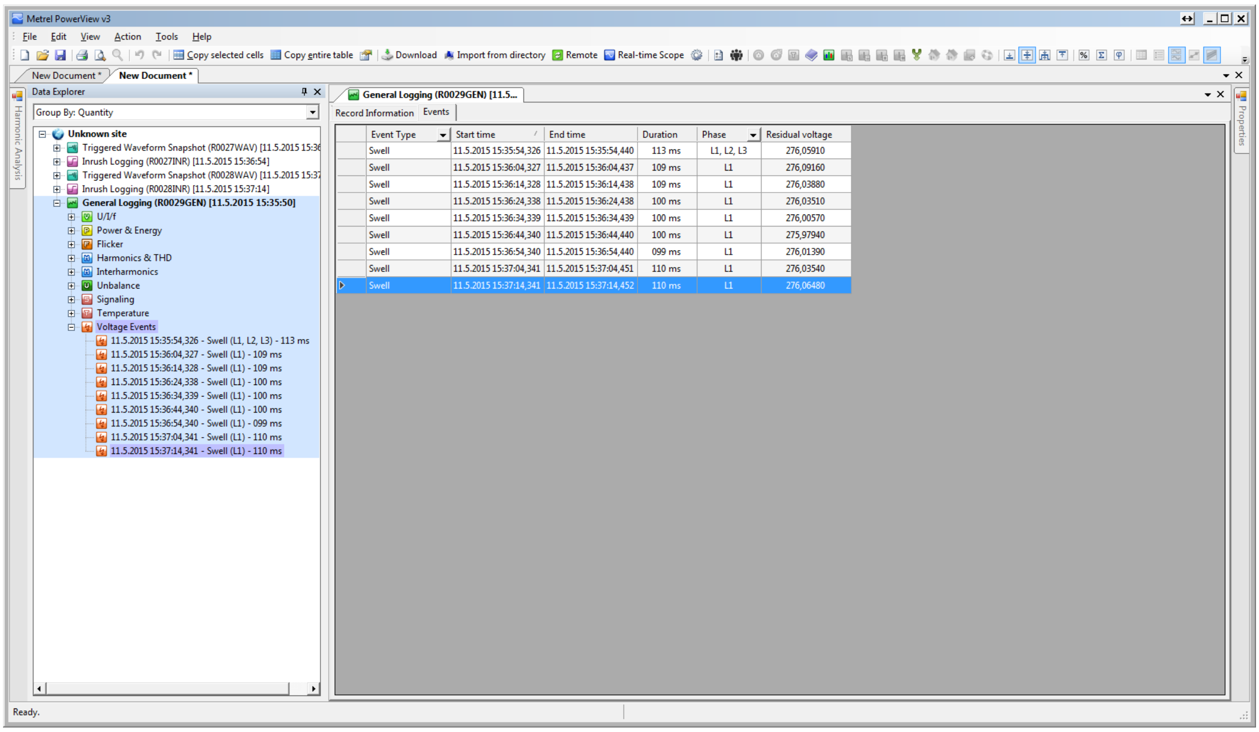


Figure 4-28: Voltage swells presented in table view in PowerView

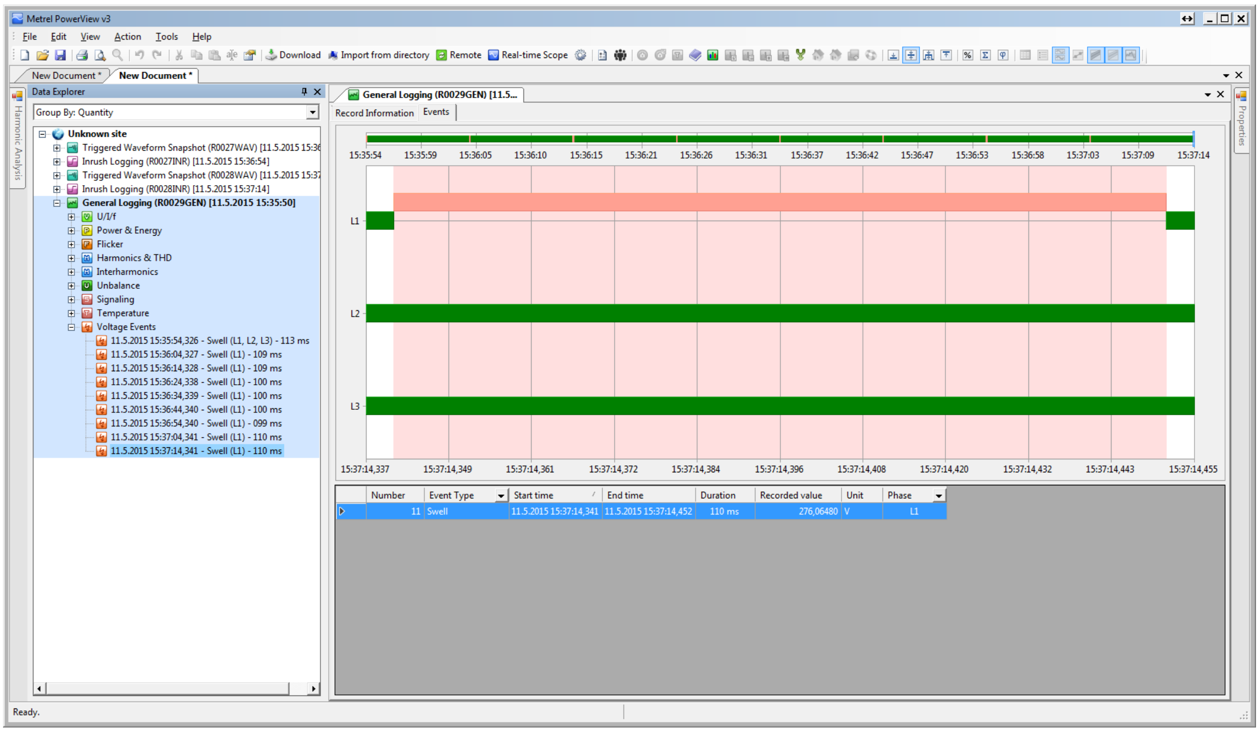


Figure 4-29: Voltage swell presented in timeline graph in PowerView

Each swell can be analysed in depth – through waveform records. PowerView can show two waveform record logs. Inrush log and waveform snapshot. Inrush log represents RMS values of voltage and current measured in one period and refreshed each half period (RMS1/2). Captured voltage swell graph can be seen in the figure below.

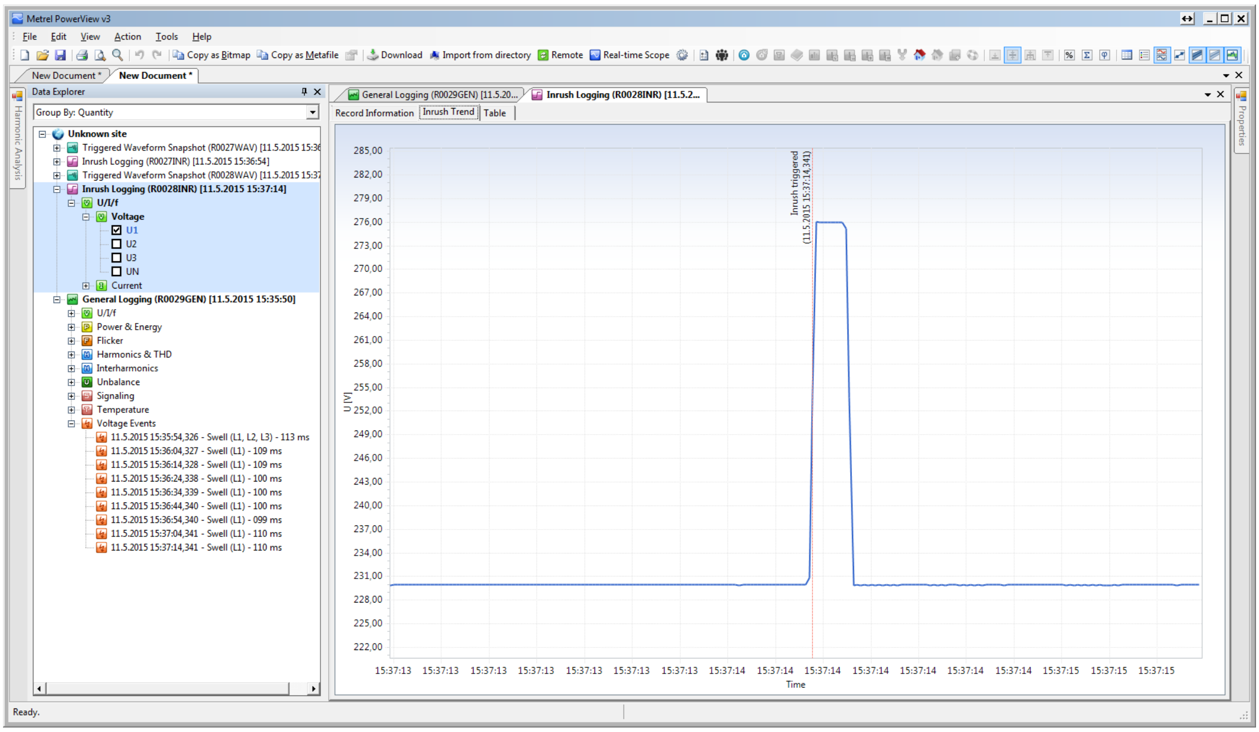


Figure 4-30: Captured voltage swell (RMS values)

For further analysis, the user can observe also the waveform shape of the swell. From this graph, swell phase shift or swell starting point on the wave can be seen. Figure below represents such a view.

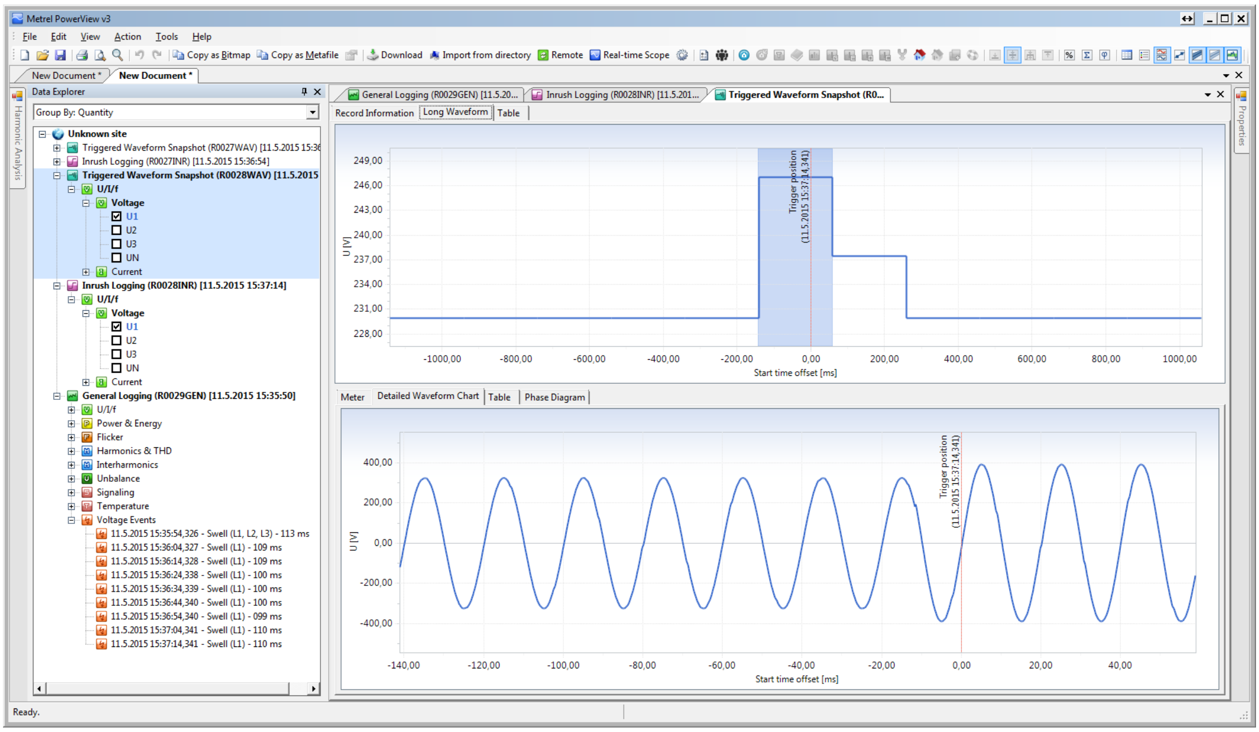


Figure 4-31: Captured waveform of voltage swell

4.4 Exercise 4 – Voltage Interrupts

In this exercise, we will show how the instrument should be setup in order to capture and observe a voltage interrupt. Voltage interrupt is a large reduction of the voltage magnitude on all phases, at a point in the electrical system below given limit. Actually, an interrupt is a special case of a voltage dip. Before start, please set the switch S3 in the Application Trainer to ON as shown in the table below. The remaining switches should be set to OFF.

Switch	Description	State
S3	Interrupt	ON

The Application Trainer will simulate an electrical system with the following parameters:

- Fundamental voltage: 230V
- Fundamental current: 1000A
- Load type: Inductive
- Load character: Load (Consumption of electrical power)
- Frequency: 50/60 Hz
- Voltage interrupt, 5 periods long voltage interrupt is present on all phases. The interrupt is repeated every 10 seconds.

4.4.1 Instrument setup for Interrupt capturing

The Power Master MI 2892 should be connected to the Application Trainer and set up as described in section 3.2 Instrument Setup. It is good practice to observe the Connection Check status in the MEASRUEMENT SETUP → CONNECTION SETUP menu. If it is marked with an OK sign (✓), you can start observing measurements.
For observing voltage interrupts, it is necessary to set up an interrupt threshold voltage. If the voltage on all phases falls below the threshold, the voltage interrupt will be recorded. Limits are set up in the MEASRUEMENT SETUP → EVENT SETUP menu as shown in the figures below.

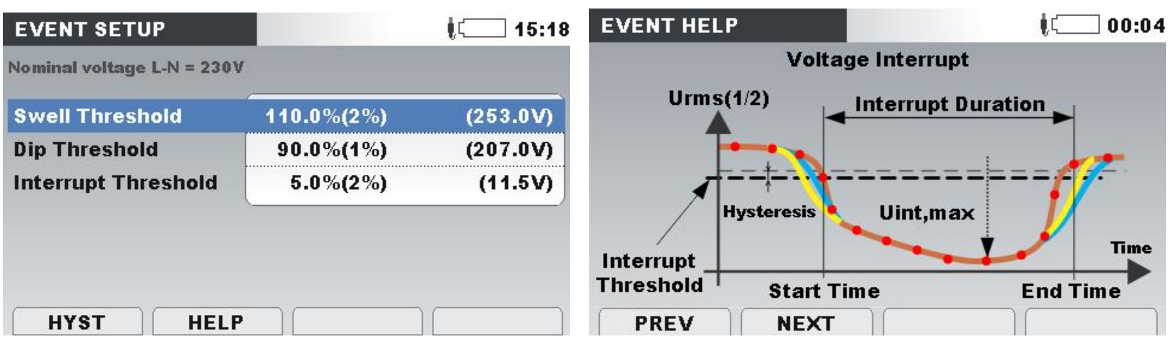


Figure 4-32: Interrupt threshold setup

Parameters need to be set:

- Swell: 110% - this event will be detected, if an increase of more than 10% of the nominal voltage occurs on the input channel,Dip: 90% - this event will be detected, if a drop of more than 10% of the nominal voltage occurs on the input channel,

- Interrupt: 5% - this event will be detected, if detected voltage on all phases is less than 5% of the nominal voltage.

For detailed explanation of these values, use the “Help” key on your instrument.

In order to get waveform shape and RMS voltages for each recorded interrupt, the waveform recorder should be set up. Enter the “WAVEFORM REC.” submenu from the “RECORDERS” menu, and then set the following parameters:

- Trigger: events – waveform recording will be executed after an event happens, this way we’re going to catch our generated event,
- Duration: 2s – after an event is detected, the waveform recorder will run for the given Duration minus Pretrigger time (in seconds),
- Pretrigger: 1s – one second of signal history will be recorded before the trigger occurs
- Store mode: single – value of this parameter is not important for this exercise.

A sample of such a screen is presented in the figure below.

Figure 4-33: Waveform record screen

Now go to RECORDERS → GENERAL REC and setup the general recorder with the following parameters:

- Interval: 10 sec – Averaging interval. Every 10 seconds an average value will be calculated for RMS voltage, current, power, harmonics, etc., and stored into memory.
- Include events: On (with waveforms) – this will run both general and waveform recorders.
- Include alarms: Off – no alarms will be triggered
- Start time: manual
- Duration: 1 days – recording will stop after 24 hours

Figure 4-34: General recorder setup

The instrument is now prepared for voltage event recording, which is generated by the Application Trainer. Please start the recorder by pressing the F1 (“START”) key. The recorder can be stopped anytime, by pressing the F1 (STOP) key.

4.4.2 Observing interrupts on the instrument

Enter the RECORDERS → EVENTS TABLE menu and check recorded events. The events table should be similar as shown in the figure below.

Figure 4-35: Event table (interrupts)

Additionally, the waveform shape of a recorded event can be observed from the RECORDERS → MEMORY LIST, by selecting an appropriate recorded waveform and observing it, by pressing the F1 (VIEW) key. The recorded waveform should be similar to the one shown in the figure below.

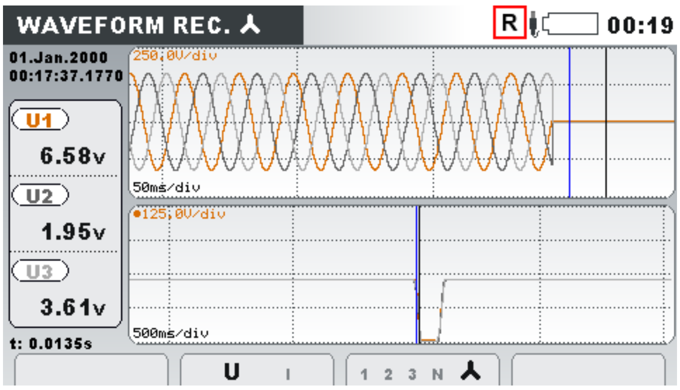


Figure 4-36: Voltage interrupt RMS measurements and waveform shape

4.4.3 Downloading and observing recorded data in PowerView

After capturing a few events, the recorder can be stopped, by pressing the F1 (STOP) key in the RECORDER → GENREAL REC. menu. To transfer the record into PowerView, we first need to be sure that PowerView is set up as described in section 3.3. First, click on the “Download” button in PowerView toolbar. A new window with connected instrument info opens. In this case we have several options available for download. Two types of records should be shown, as seen in the figure below:

- Triggered waveform – Event waveform is stored in this file type. Each event is stored in a separate record.
- General logging – Data trends and event tables are stored in this file type. All data recorded for a given period of time are stored in a single record.

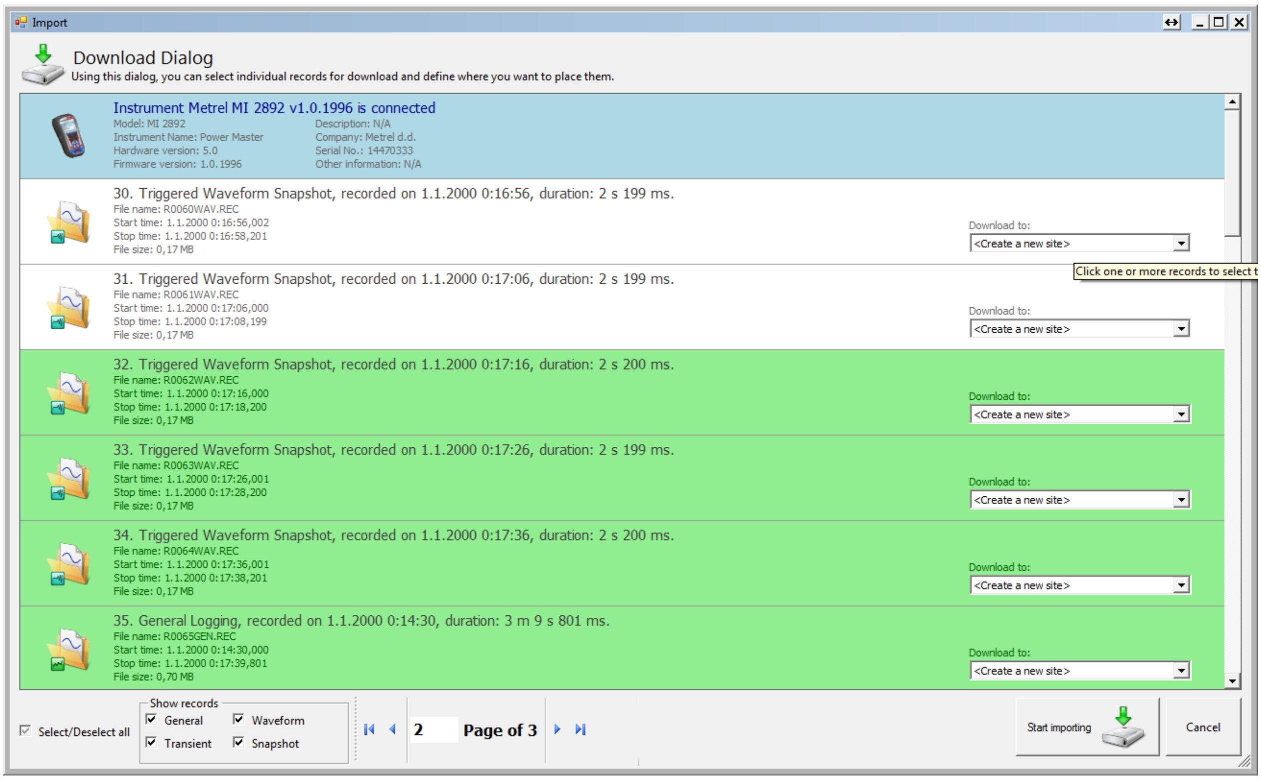


Figure 4-37: Generated logs

Select all records and click on »Start importing«. Three record types appear in the “Data explorer” tab:

- Triggered Waveform Snapshot – provides voltage and current samples for captured voltage event, in our case a 5 periods long interrupt.
- Inrush Logging – provides voltage and current RMS measurements for each captured event.
- General Logging – basic record described in prior exercise.

Data explorer tree view is shown in the figure below.

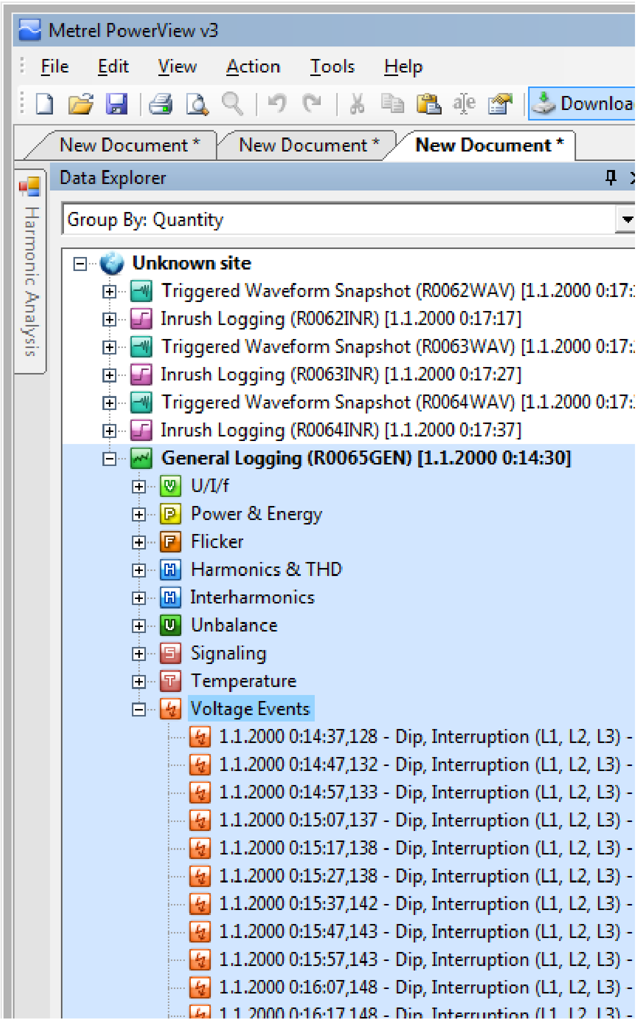


Figure 4-38: Records tree view (interrupts)

A voltage interrupt can be observed in table form within General Logging, where only interrupt signatures are shown. This kind of interrupt presentation is mainly used for statistic evaluation (for example: how many interrupts occurred during a given period). Tables and timeline graphs are shown in the next two figures.

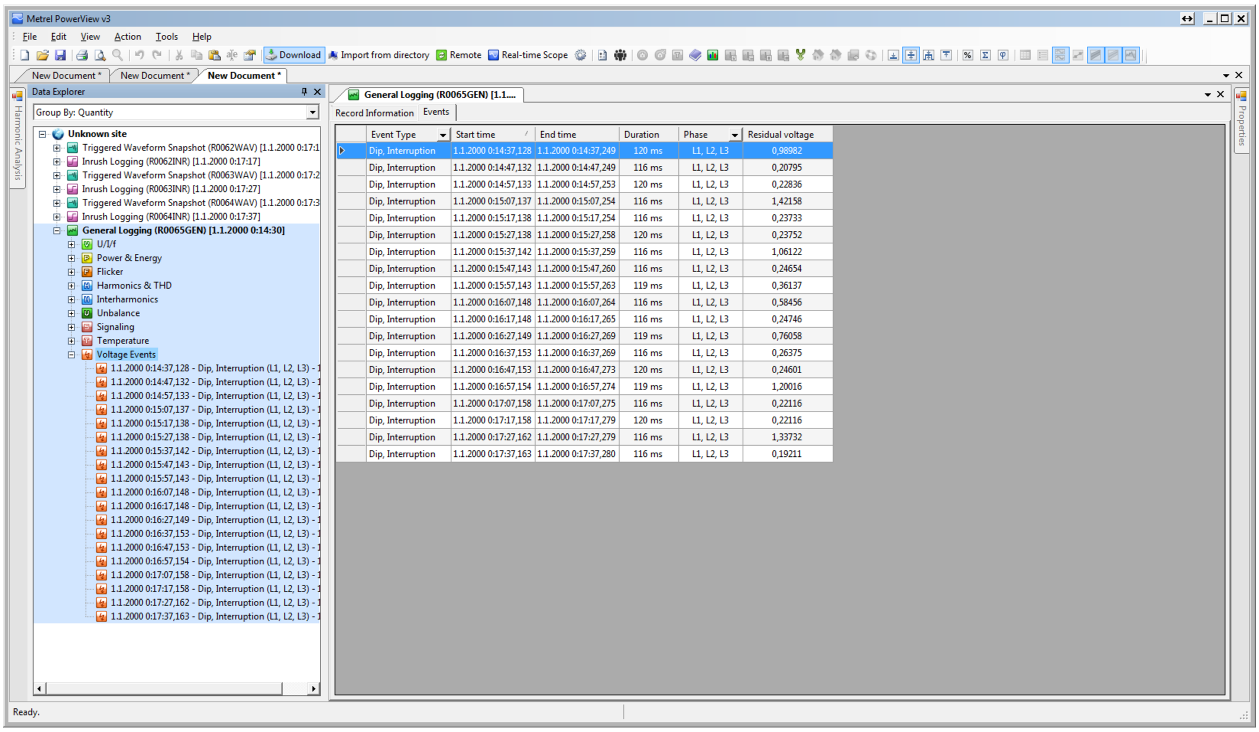


Figure 4-39: Voltage interrupts presented in table view in PowerView

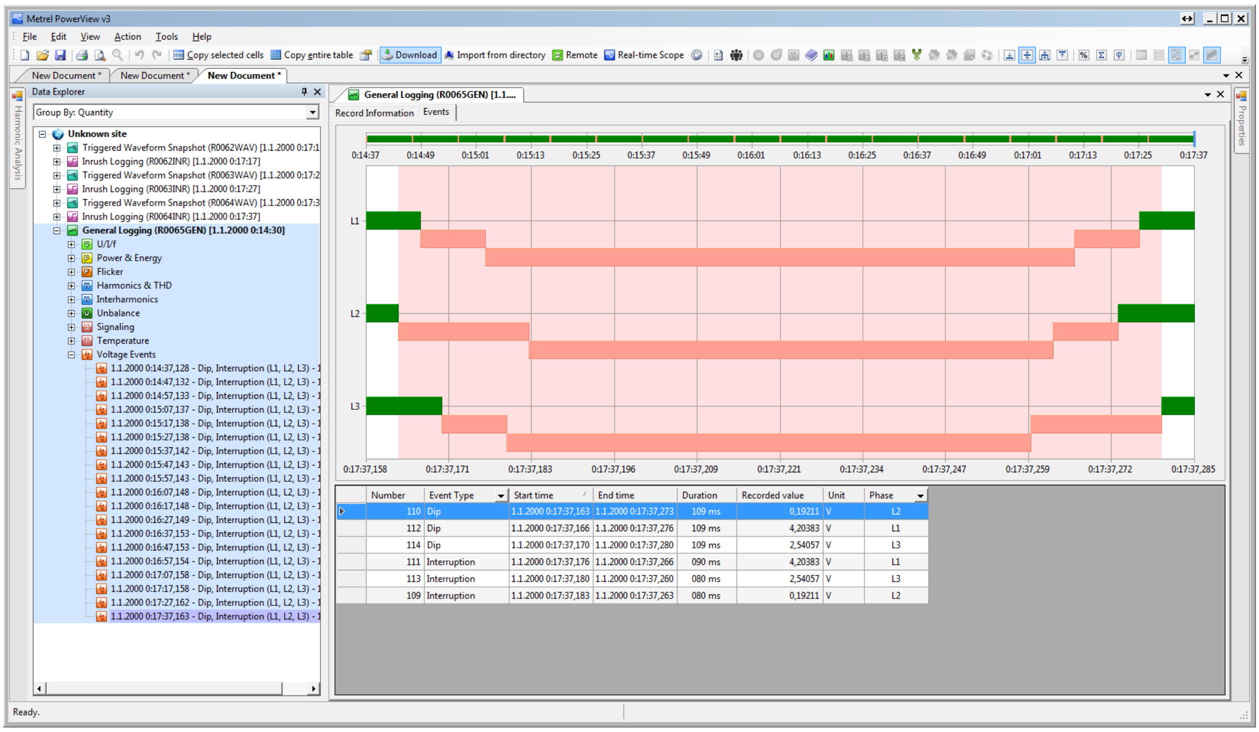


Figure 4-40: Voltage interrupt presented in timeline graph in PowerView

Each interrupt can be analysed in depth – through waveform records. PowerView can show two waveform record logs. Inrush log and waveform snapshot. Inrush log represents RMS values of voltage and current measured in one period and refreshed each half period (RMS1/2). Captured voltage interrupt graph can be seen in the figure below.

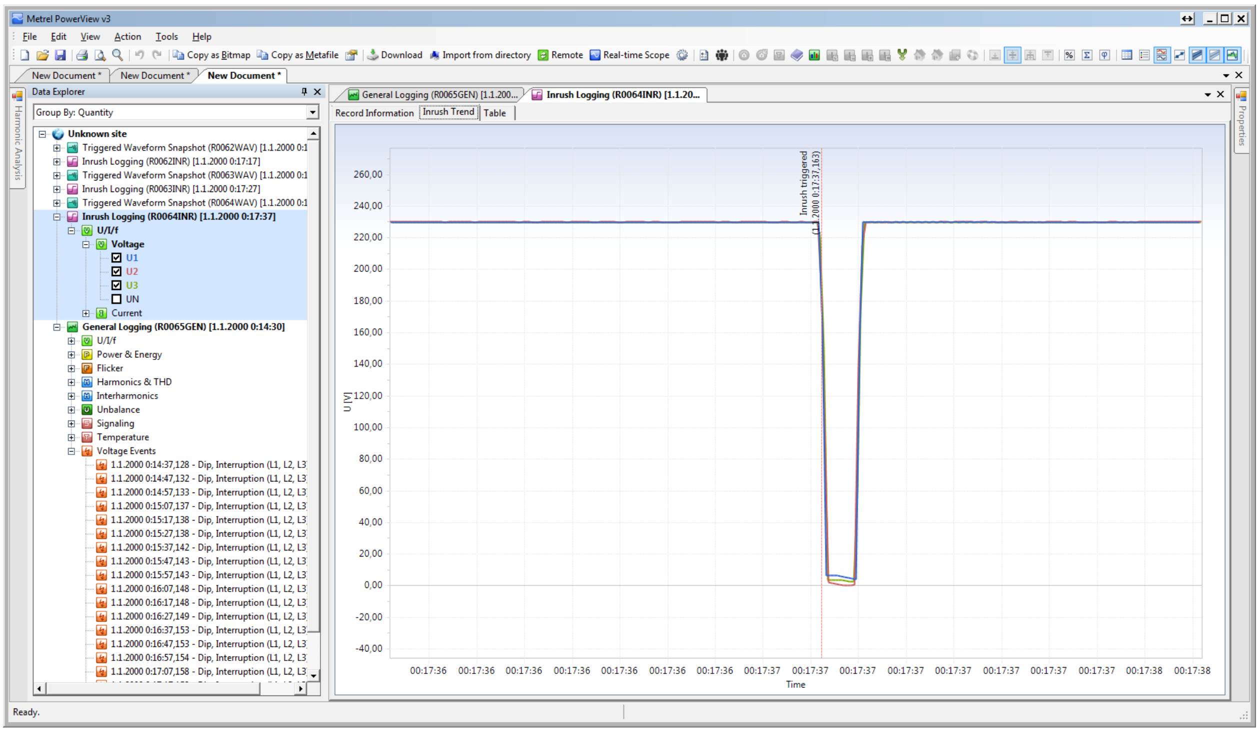


Figure 4-41: Captured voltage interrupt (RMS values)

For further analysis, the user can observe also the waveform shape of the interrupt. From this graph, interrupt phase shift or interrupt starting point on the wave can be seen. Figure below represents such a view.

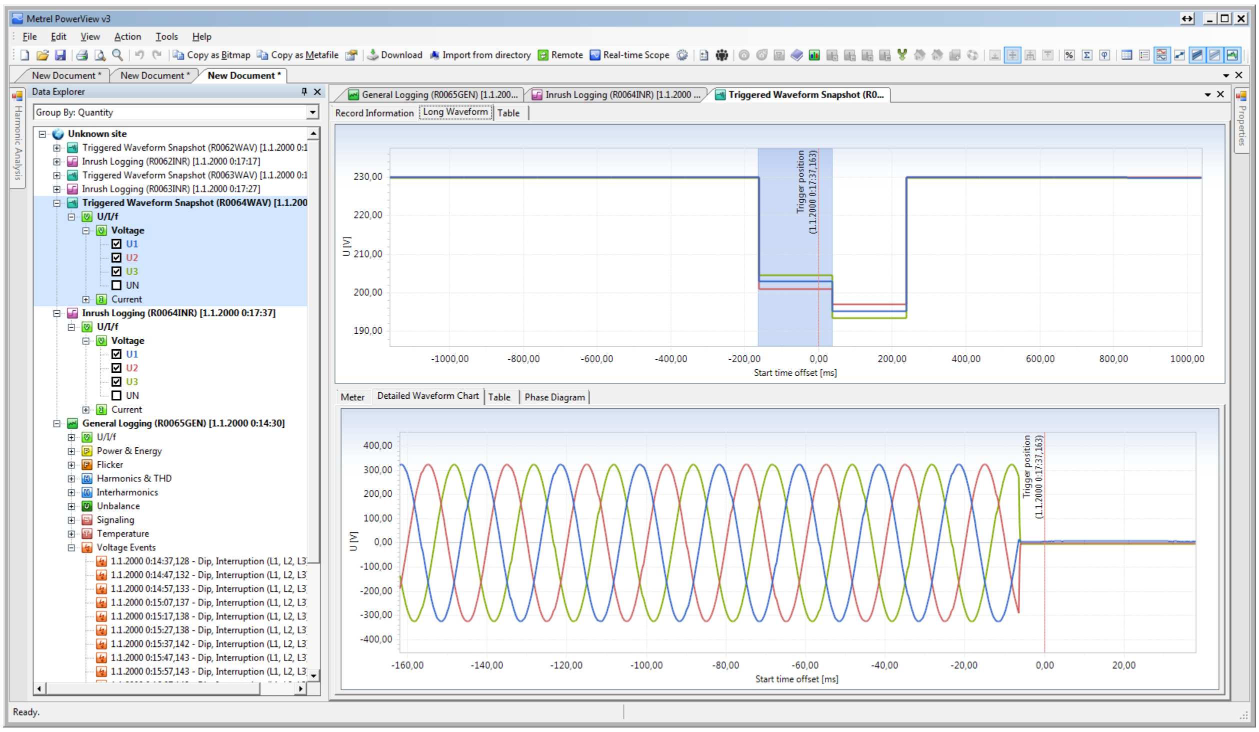


Figure 4-42: Captured waveform of voltage interrupt

4.5 Exercise 5 – Power and Energy measurement

In this exercise, we will show basic step of Energy and Power measurement.

- Recording active and reactive energy (linear load)
- Power measurements in real time
- Capacitive, switching and nonlinear load
- Recording and observing recorded data on the instrument
- Downloading and observing downloaded data in PowerView

Before start, please set the switches S1 ÷ S11 in the Application Trainer to OFF as shown in the table below.

Switch	Description	State
S1	Dip	OFF
S2	Swell	OFF
S3	Interrupt	OFF
S4	Capacitive load & Energy	OFF
S5	Harmonics	OFF
S6	Unbalance	OFF
S7	Flicker	OFF
S8	Inrush	OFF
S9	Transient	OFF
S10	Phase (switch) failure	OFF
S11	Wrong instrument connection	OFF

The Application Trainer will simulate an electrical system with the following parameters:

- Fundamental voltage: 230 V
- Fundamental current: 1000 A
- Load type: Inductive
- Load character: Load (Consumption of electrical power)
- Frequency: 50/60 Hz

The Power Master MI 2892 should be connected to the Application Trainer and set up as described in section 3.2 Instrument Setup. It is good practice to observe the Connection Check status in the MEASRUEMENT SETUP → CONNECTION SETUP menu. If it's marked with an OK sign (✓), you can start observing measurements.

4.5.1 Recording energy

If we would like to monitor energy consumption, then the General recorder should be started. From the MAIN MENU, enter the RECORDERS menu and then go to the GENRAL RECORDER menu. Set up all parameters as shown in the figure below:

Figure 4-43: General record settings

After these changes have been made, run the recorder by pressing the F1 key. The recorder can be stopped anytime by pressing the F1 (STOP) key. The instrument will record consumed active and reactive energy from the moment we started the recorder - for each phase separately and in total.

Energy measurement is divided in two sections: ACTIVE energy based on active power measurement (kWh) and REACTIVE energy, based on fundamental reactive power measurement (kVArh). Additionally energy and power is divided in two segments:

- Consumed energy (power) is energy consumed on consumer side. It is represented with a positive sign (see Figure 4-49).
- Generated active energy (power) is energy generated by generator. It is represented with a negative sign.

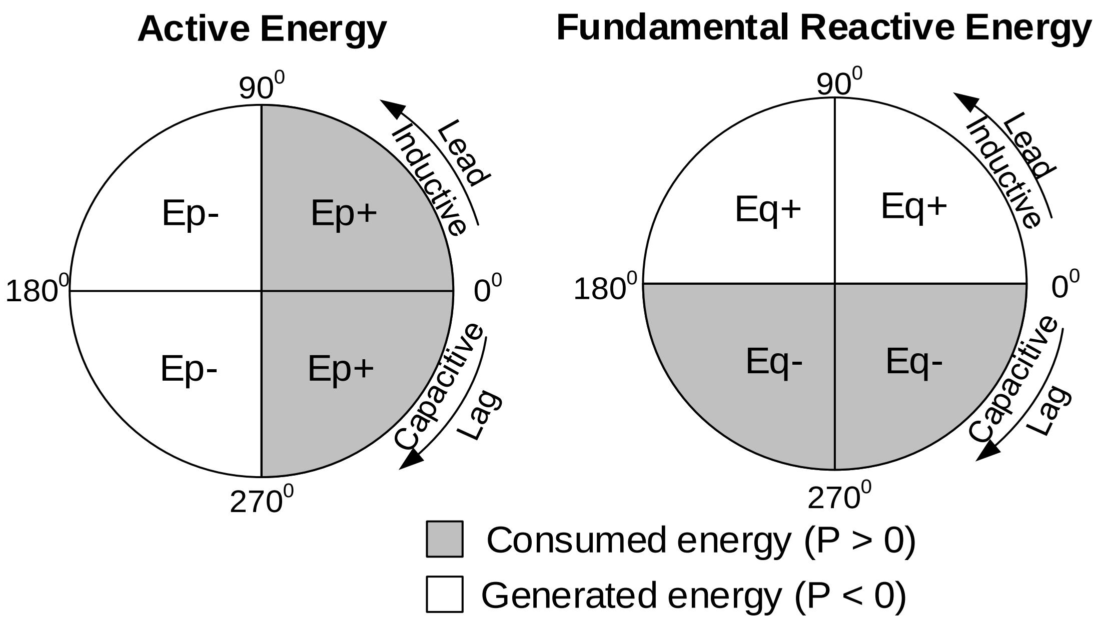


Figure 4-44: Energy counters and quadrant relationship

In the MEASUREMENTS → ENERGY menu, the instrument has 3 different energy modes:

1. Total energy TOT mode is used for measuring energy over a complete recording. When the recorder starts it sums the energy to the existent state of the counters.
2. Last integration period LAST mode measures energy during recording over the last completed interval. It is calculated at the end of each interval.
3. Current integration period CUR counter measures energy during recording over current time interval.

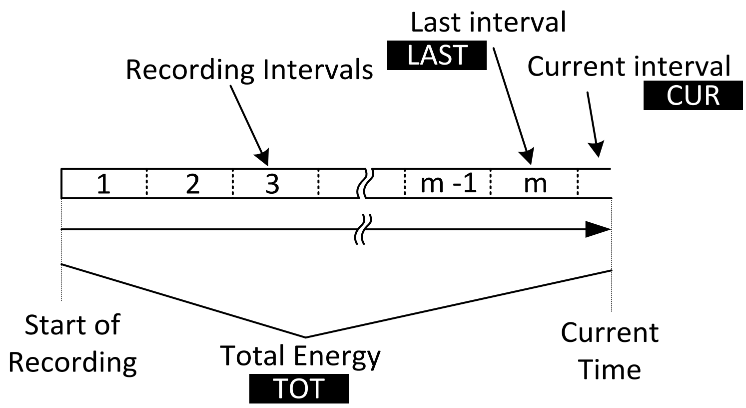


Figure 4-45: Instrument energy counters

During active recording, consumed energy is constantly accumulated, and we can observe it under the MEASUREMENT MENU → ENERGY menu. The recorded energy for each phase and total recorded energy is shown below.

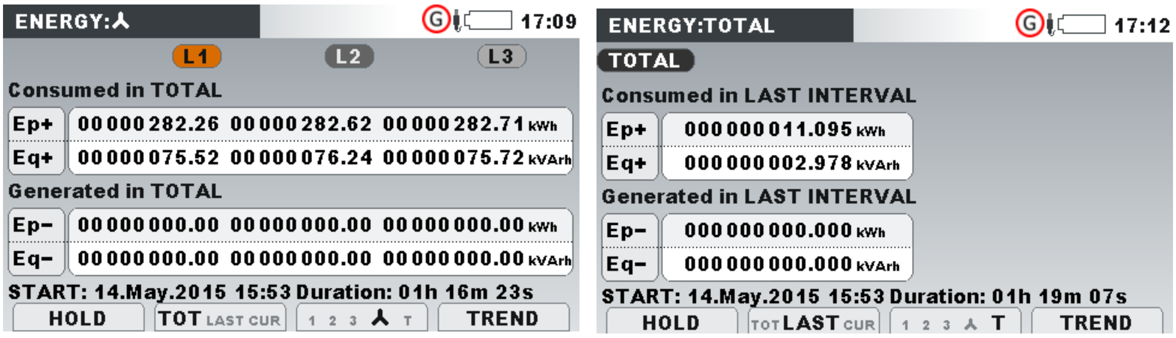


Figure 4-46: Energy counters

Stop the recorder from GENERAL RECORDER menu and download data into PowerView. Obtained results for active power P, fundamental reactive power Q_{fund} and effective apparent power S_{Eff} are shown below.

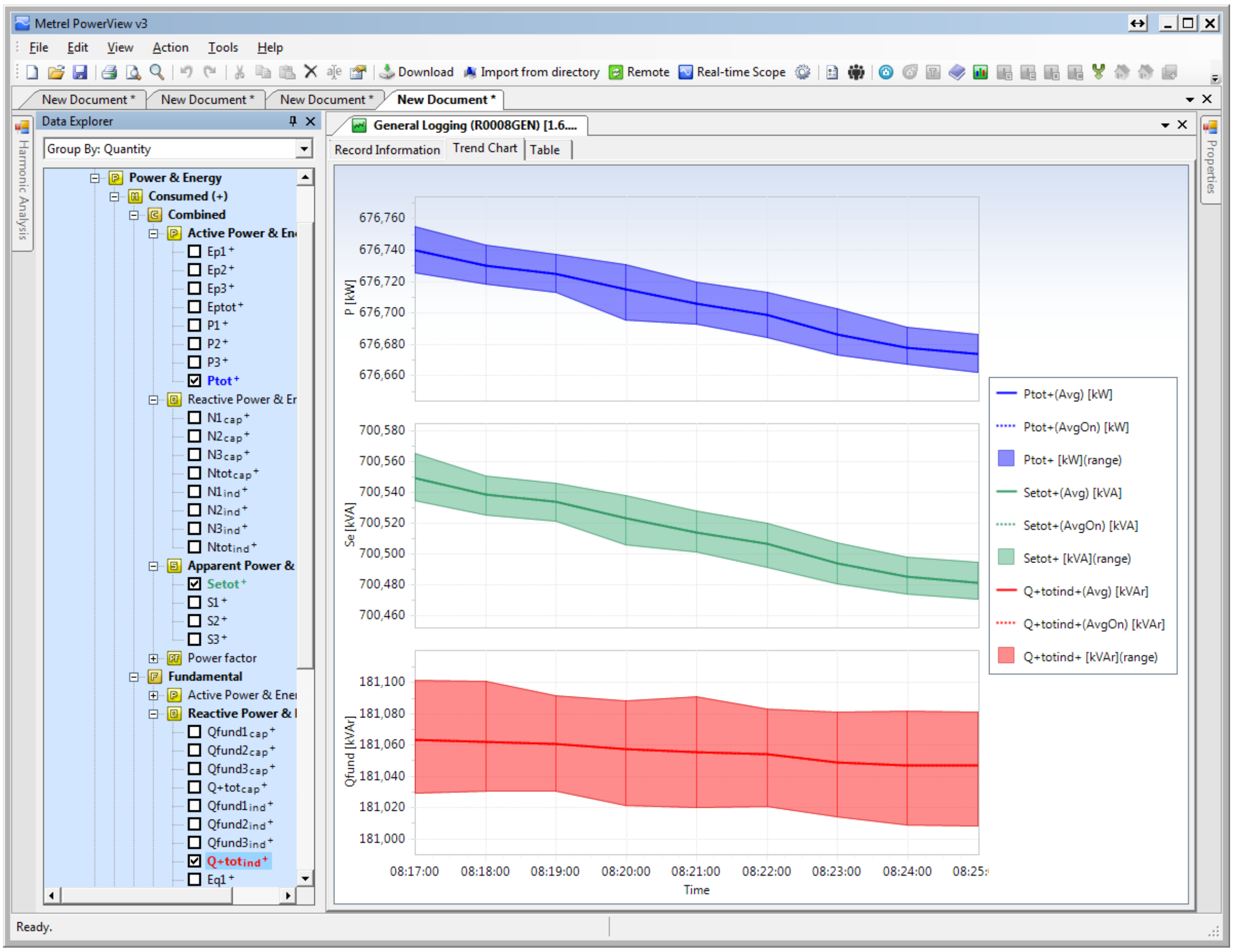


Figure 4-47: Recorded power parameters presented in time chart in PowerView

4.5.2 Real time Power measurements

By entering the MEASRUREMENTS MENU → POWER the user can observe power measured parameters in real time.

Figure 4-48: Measurement submenu

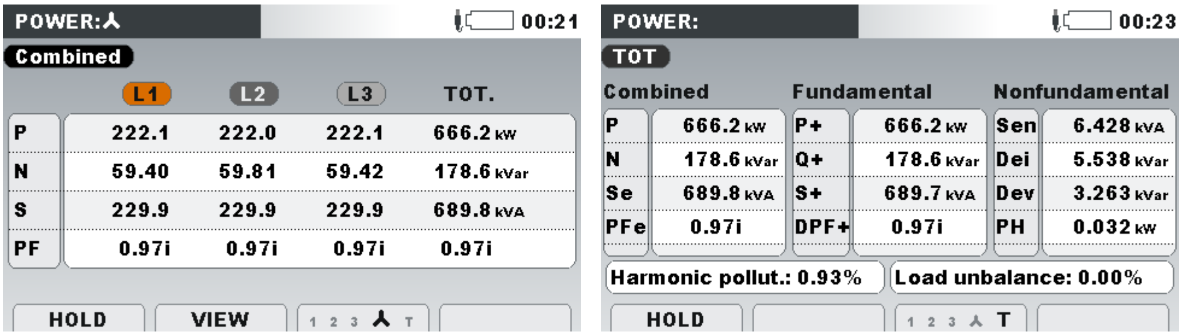


Figure 4-49: Real time measurements of powers

In this case, we have pure sinus symmetrical inductive load, without any harmonics. Therefore the instrument shows in TOT screen, that total consumed power is concentrated at the fundamental frequency, as non-fundamental (harmonic) power components are almost negligible. However 15º phase shift between voltage and current introduce 178 kVar of reactive power which in practice, can be compensated by adding a capacitor bank.

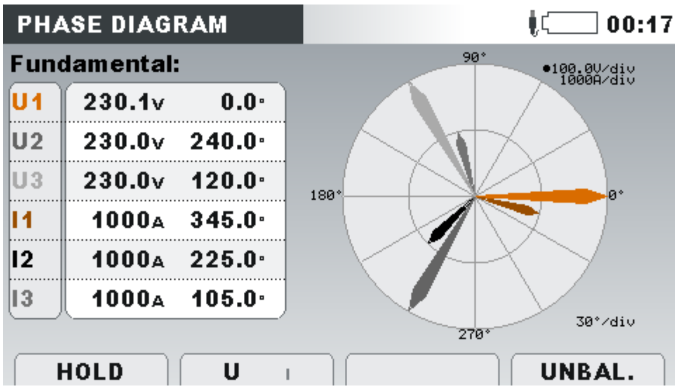


Figure 4-50: 15º phase shift between voltage and current

Real time measurements can be also presented in PowerView by using the Real-time Scope button in toolbar, as shown below.

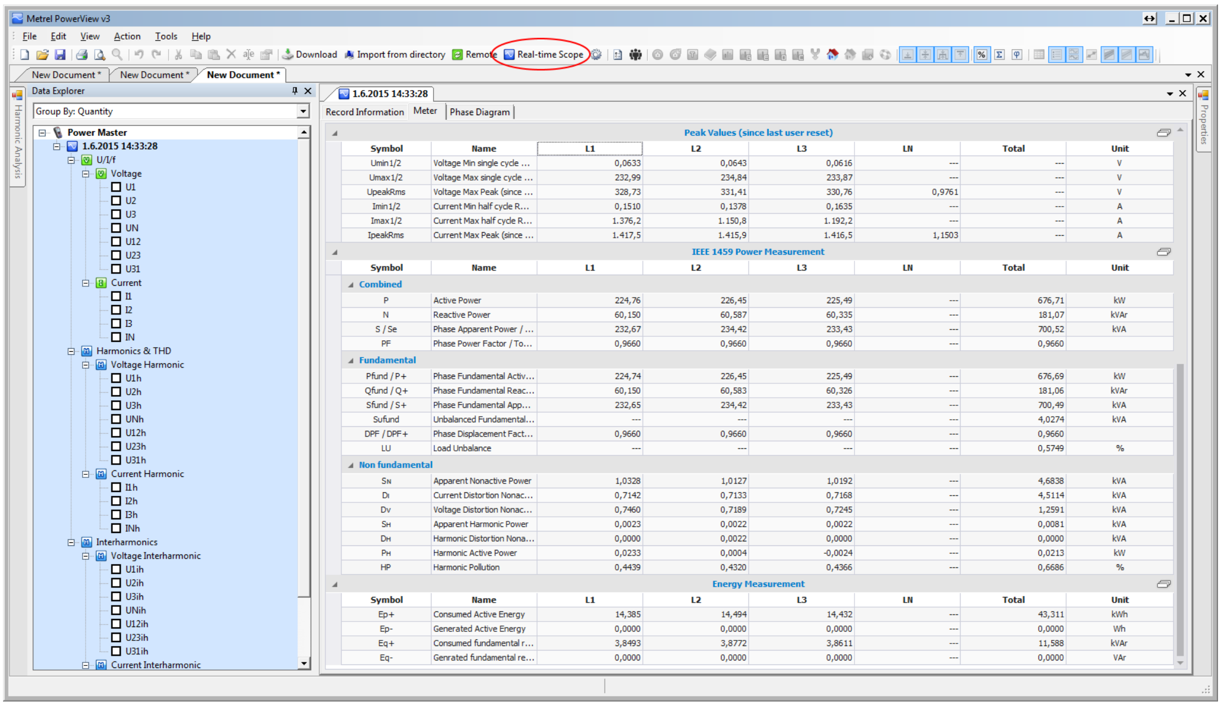


Figure 4-51: Real-time measurement presented in table view in PowerView

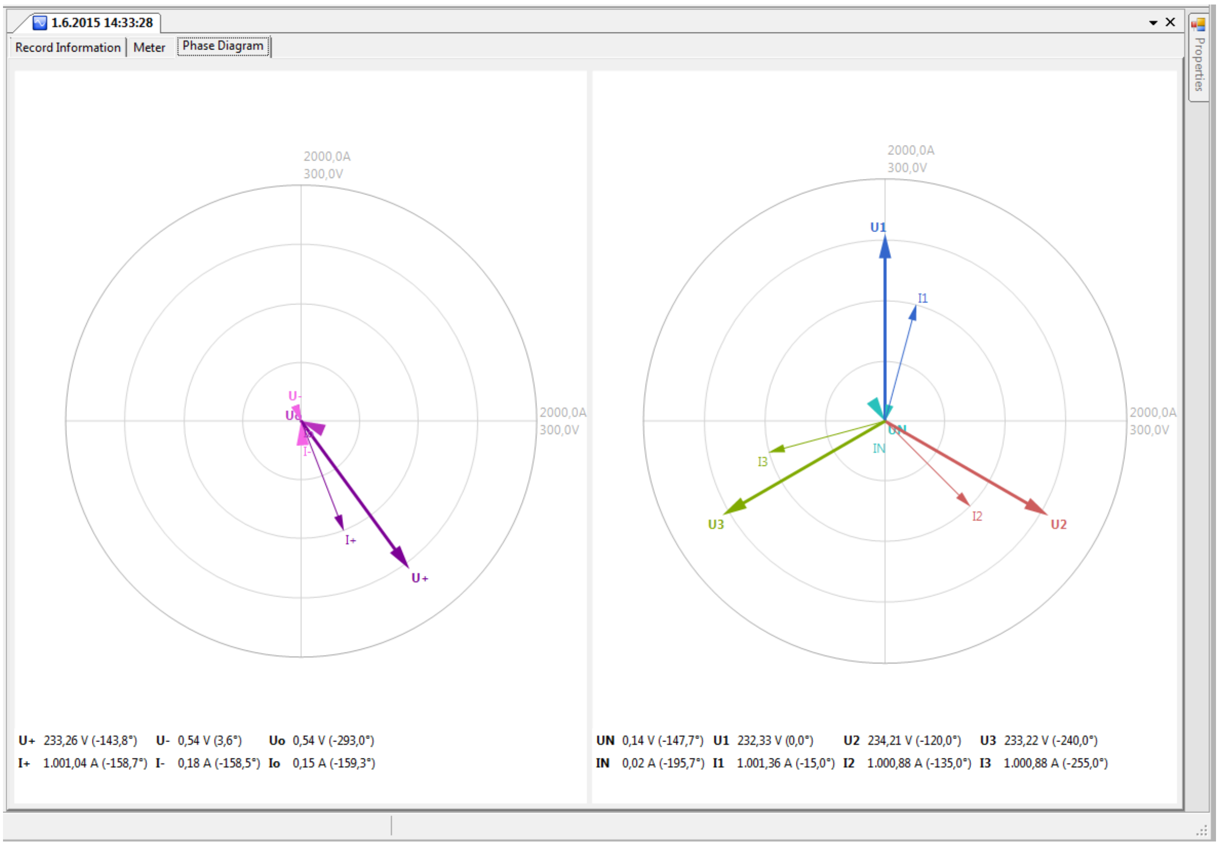


Figure 4-52: Phase diagram and unbalance presented in PowerView

4.5.3 Capacitive, switching and nonlinear load

In this step we will introduce capacitive load on phase L1, switching load on phase L2 and nonlinear (harmonic) load on phase L3. First, set switches S1 ÷ S11 on Application Trainer as shown in table below. This will introduce 15° phase lag on phase L1, switching current on phase L2 and harmonics on phase L3.

Switch	Description	State
S4	Capacitive load & Energy	ON

Figure 4-53: Power generated on second phase

Capacitive load can be seen on phase L1 (negative values for N and Q, and suffix "c" on Power Factor) as shown in the figure below.

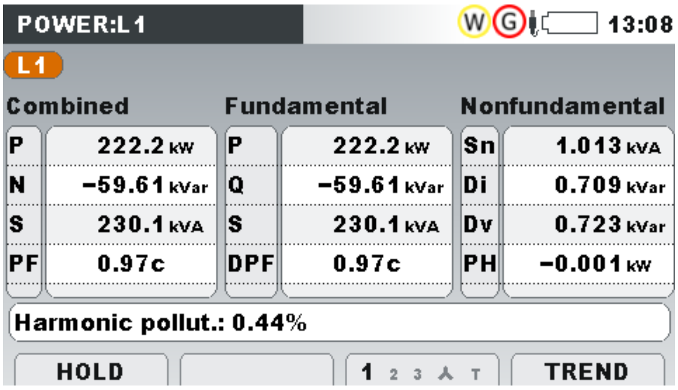


Figure 4-54: Capacitive load on phase L1

On phase L2 a switching load is present, which turns on and off every 10 seconds.

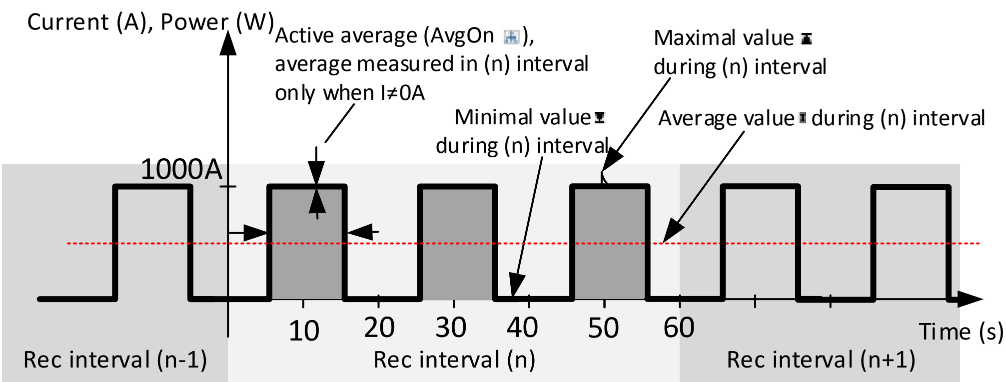


Figure 4-55: Switching load presented on phase L2

Current profile is shown in the graph above. Note that recording interval (1min) is longer than load switching frequency (10sec). What we see on the instrument is:

- METER screen: Real time power measurement (refreshed few times per second). Values are changed every 10 seconds, as load is turned on and off.
- TREND screen: power averaged over a 1 minute time interval.

By observing large differences between maximum (⊼), average (⧗) and minimum (⊻) recorded values within a single interval we can conclude that a switching load is present. See figure below.

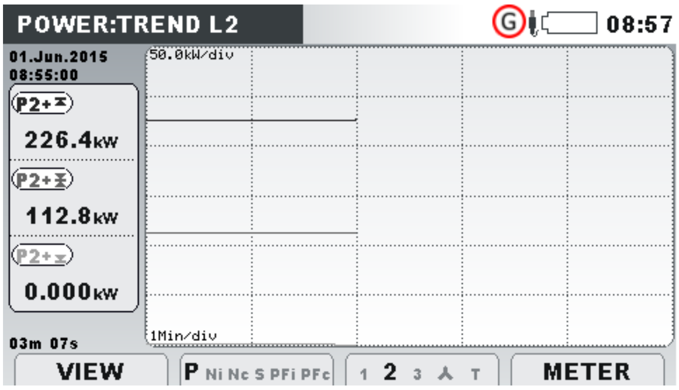


Figure 4-56: Observing power on switching load

On phase L3 we added a 3rd harmonic on current. As a consequence of current harmonics, nonfundamental apparent power (S_N) and phase current distortion power (Di) is introduced as shown in the figure below.

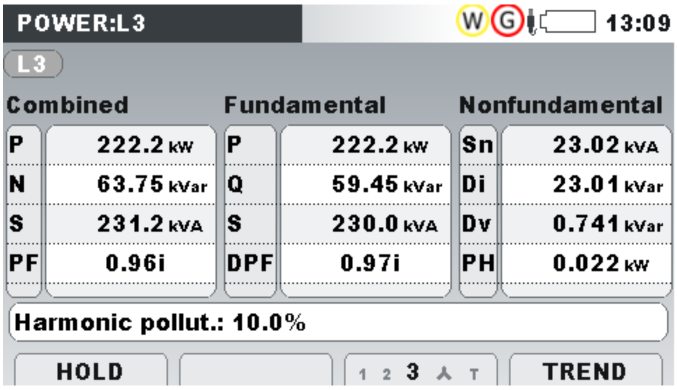


Figure 4-57: Observing power on inductive load with 10% of third harmonics on current channel I_3

Finish recording by entering the RECORDERS → GENERAL RECORDER menu, and pressing the F1 (STOP) key. The stored record can be observed on the instrument or transferred to PowerView. Import your recordings into Metrel PowerView software, as described in section 4.1.3. All Power and energy related measurements can be accessed using the “Power & Energy option” in the “Data explorer” tab. Current, active consumed power, reactive consumed power and Power Factor are shown below for example. Note that there is a large difference between Average and Active average (AvgOn) values in graphs, which clearly indicates that we are dealing with switch load.

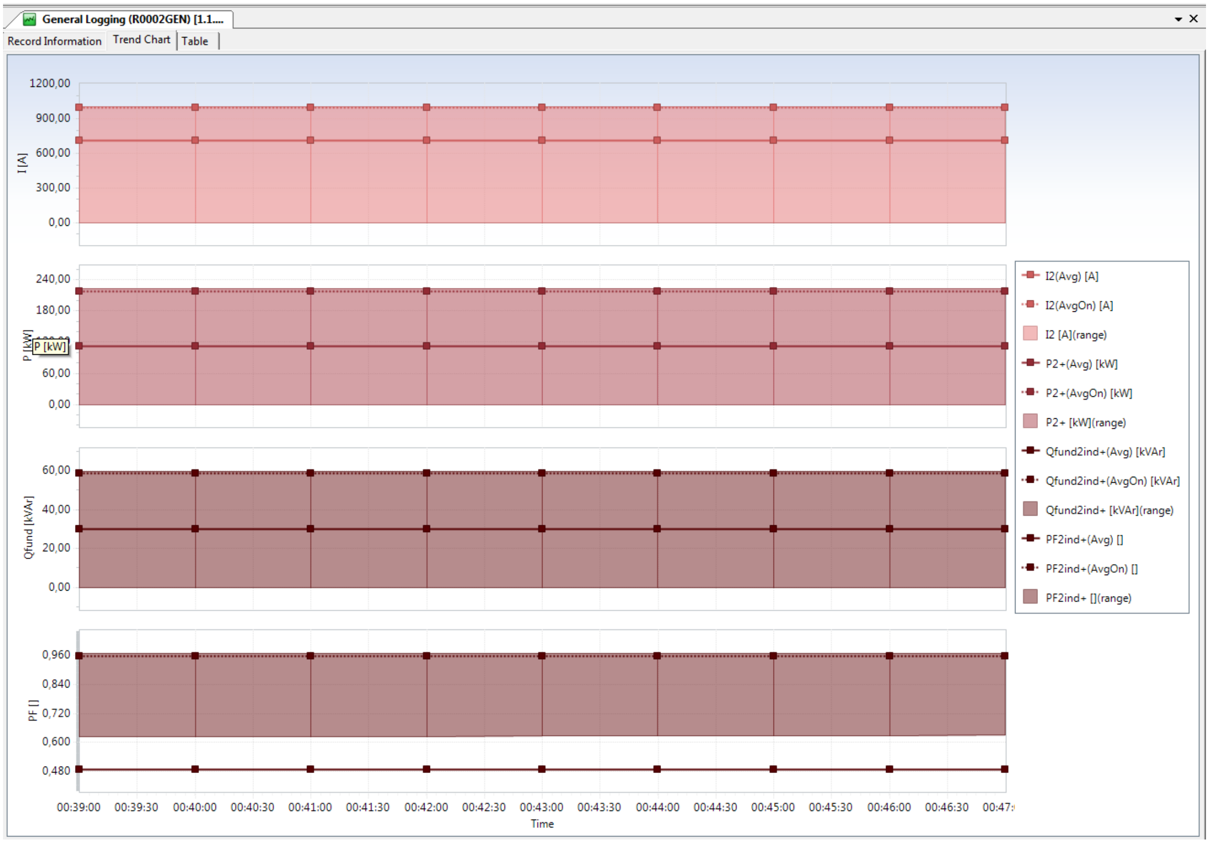


Figure 4-58: Expanded Power & Energy node

4.6 Exercise 6 – Harmonics measurement

In this exercise, we will show how instrument should be setup in order to measure and analyze harmonics. Before start, please set the switch S5 in the Application Trainer to ON as shown in the table below. The remaining switches should be set to OFF.

Switch	Description	State
S5	Harmonics	ON

The Application Trainer will simulate an electrical system with the following parameters:

- Fundamental voltage: 230 V
- Fundamental current: 1000 A
- Load type: Inductive
- Load character: Load (Consumption of electrical power)
- Frequency: 50/60 Hz
- Voltage harmonics:
    - 3rd harmonic:5%,
    - 5th harmonic: 5%,
    - 7th harmonic: 5%
- Current harmonics:
    - 3rd harmonic:15%,

- 5th harmonic: 15%,
- 7th harmonic: 15%

The Power Master MI 2892 should be connected to the Application Trainer and set up as described in section 3.2 Instrument Setup. It is good practice to observe the Connection Check status in the MEASRUEMENT SETUP → CONNECTION SETUP menu. If it's marked with an OK sign (✓), you can start observing measurements.

4.6.1 Real time measurements

By entering the MEASRUREMENTS MENU→HARMONICS menu, the user can observe the harmonics measurement in real time.

Figure 4-59: Measurement submenu

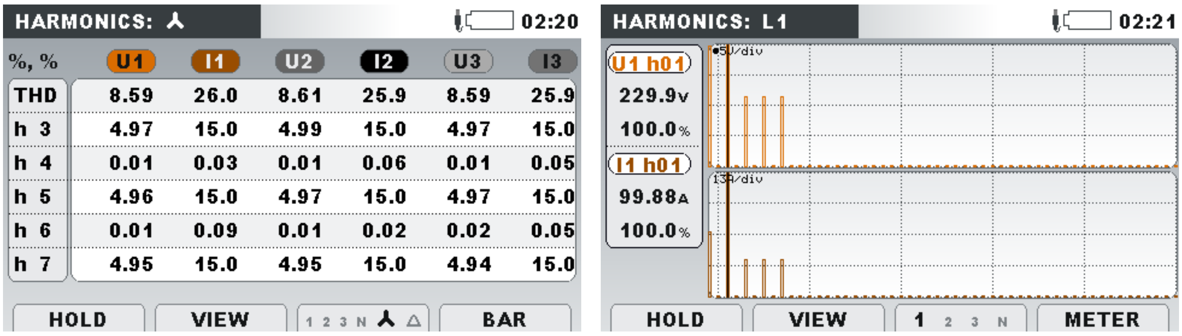


Figure 4-60: Real time measurements of voltage and current

4.6.2 Recording harmonics measurements

Basic tool for Power Quality analysis is recording parameters of an electrical system. In this step we will create a record and observe it on the instrument, as this is a typical case for troubleshooting.

From the MAIN MENU, enter the RECORDERS menu and then go to the GENRAL RECORDER menu. Set up all parameters as shown in the figure below:

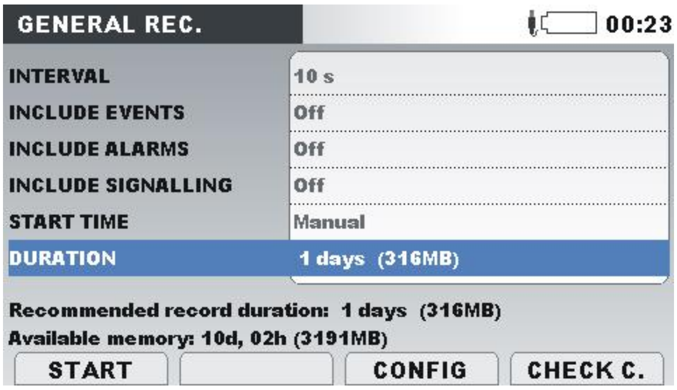


Figure 4-61: General record settings

After these changes have been made, run the recorder by pressing the F1 (START) key. The recorder can be stopped anytime by pressing the F1 (STOP) key.

While recording is active G, the user can evaluate all recording parameters in TREND screens, which appear in each MEASUREMENTS submenu. The figures below show voltage trends (MEASUREMENT → Harmonics → TREND (press 2x key F4). Harmonic selection and unit is choosen by the View menu (key F2).

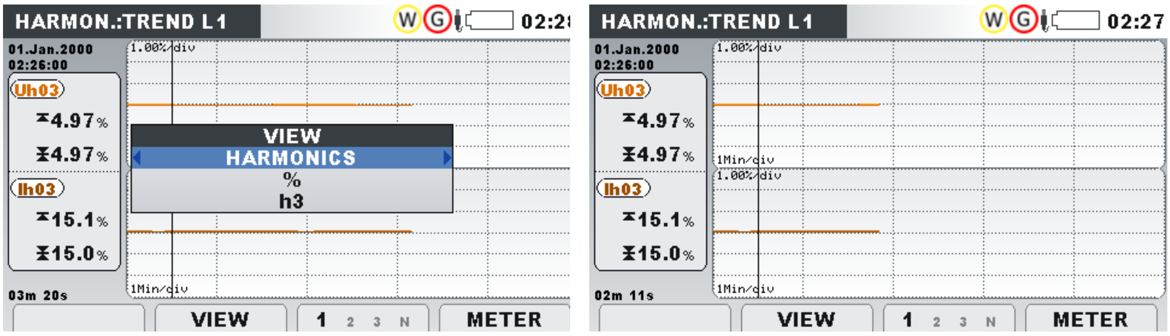


Figure 4-62: Showing 3rd harmonics trend on the instrument

Finish recording after a few minutes, by entering the RECORDERS → GENERAL RECORDER menu, and pressing the F1 (STOP) key. The stored record can be observed on the instrument by entering the RECORDERS → MEMORY LIST menu. A list of available records will appear. Choose the latest record and open it by pressing the “VIEW” key.

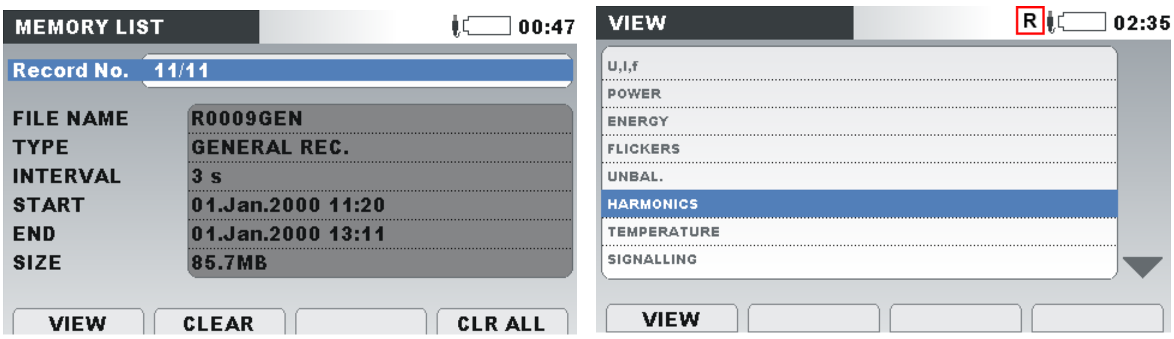


Figure 4-63: Observing records through Memory List submenu

Power View provides several options to observe harmonics and their corresponding THD. All measurements can be accessed through the “Harmonics & THD” node from the “Data Explorer”. Each measurement may be presented either by chart or table. As an example, the figure below shows THD and third harmonic in time chart.

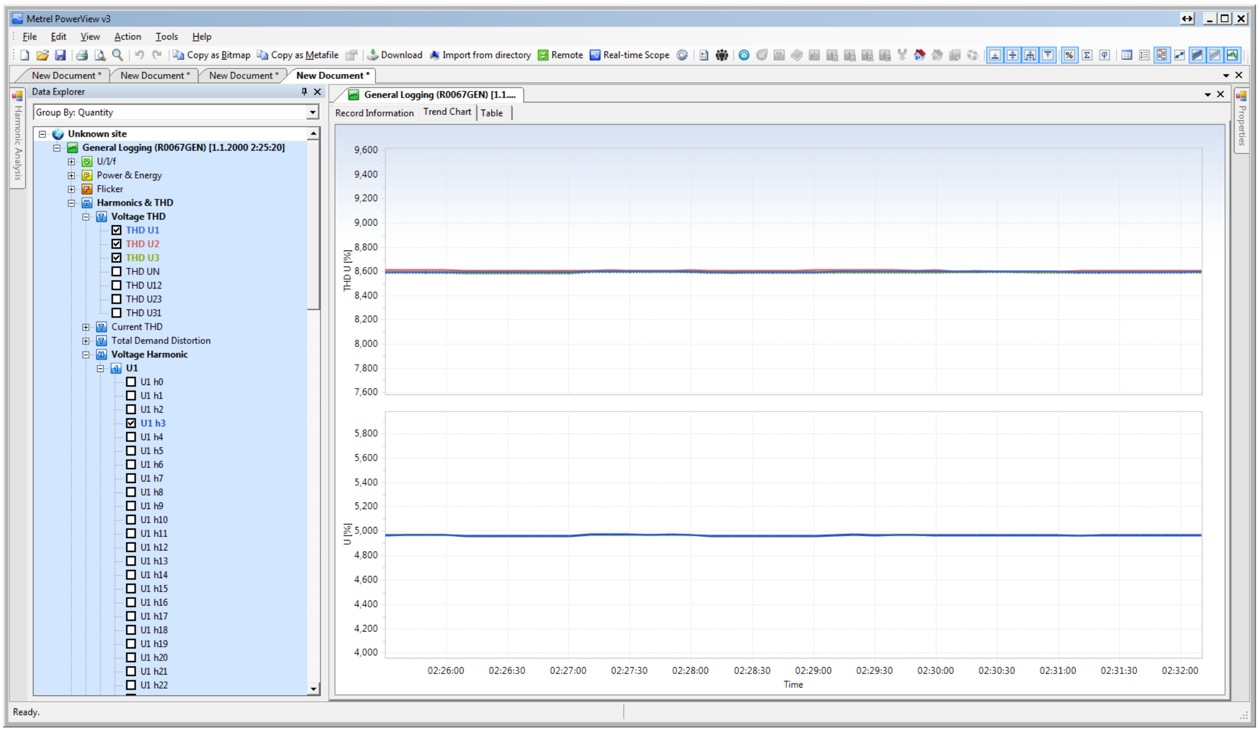


Figure 4-64: THD and 3rd harmonic frequency in time chart

4.7 Exercise 7 – Unbalance recording

In this exercise, we will show how instrument should be setup in order to monitor voltage and current unbalance. Before start, please set the switch S6 in the Application Trainer to ON as shown in the table below. The remaining switches should be set to OFF.

Switch	Description	State
S6	Unbalance	ON

The Application Trainer will simulate an electrical system with the following parameters:

- Fundamental voltage: U1=240, U2=230V, U3=220V
- Fundamental current: I1=900A, I2=1000A, I3=1100A
- Load type: Inductive
- Load character: Load (Consumption of electrical power)
- Frequency: 50/60 Hz

The Power Master MI 2892 should be connected to the Application Trainer and set up as described in previous section. It is good practice to observe the Connection Check status in the MEASRUEMENT SETUP → CONNECTION SETUP menu. If it's marked with an OK sign (✓), you can start observing measurements.

4.7.1 Real time measurements

By entering the MEASRUREMENTS MENU, the user can observe measured parameters in real time.

Figure 4-65: Measurement submenu

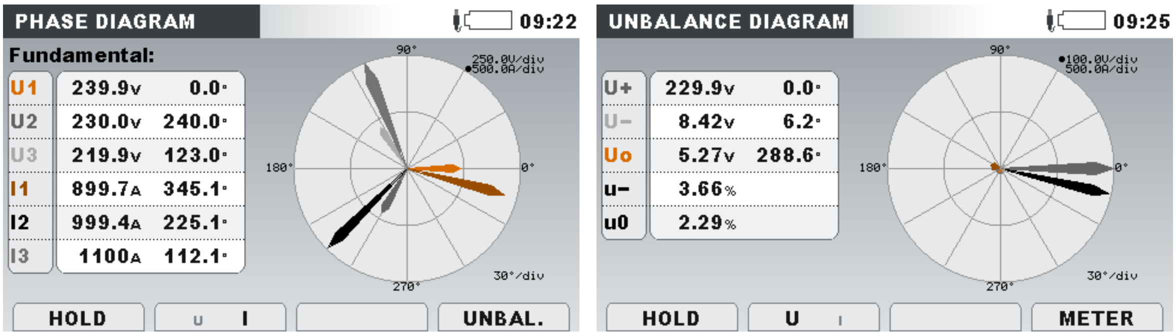


Figure 4-66: Real time measurements of phase diagram and unbalance

4.7.2 Recording unbalance measurements

Basic tool for Power Quality analysis is recording electrical system parameters. In this step, we will create a record and observe it on the instrument, as this is a typical case for troubleshooting.

From the Main menu, enter the Recorders window and then go to the General rec. menu. Here, the user needs to set up all parameters as shown in the figure below:

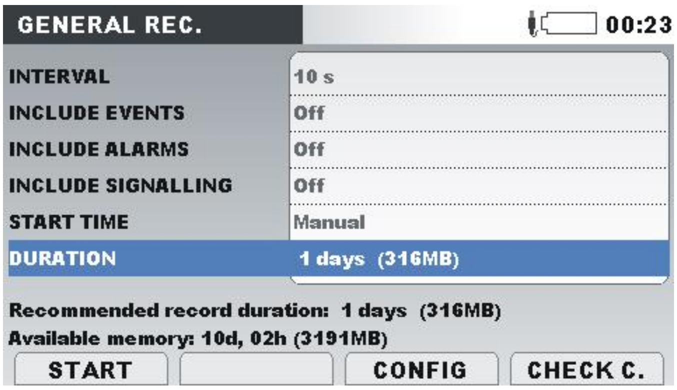


Figure 4-67: General record settings

The instrument is now prepared for recording electrical system parameters, generated by the Application Trainer. Please start the recorder by pressing the F1 (“START”) key. The recorder can be stopped anytime, by pressing the F1 (STOP) key.

While recording is active Ⓖ, the user can evaluate all recording parameters in TREND screens, which appear in each MEASUREMENTS submenu. Figure below show voltage trend (MEASUREMENT → Phase Diagram → TREND (press 2 x key F4).

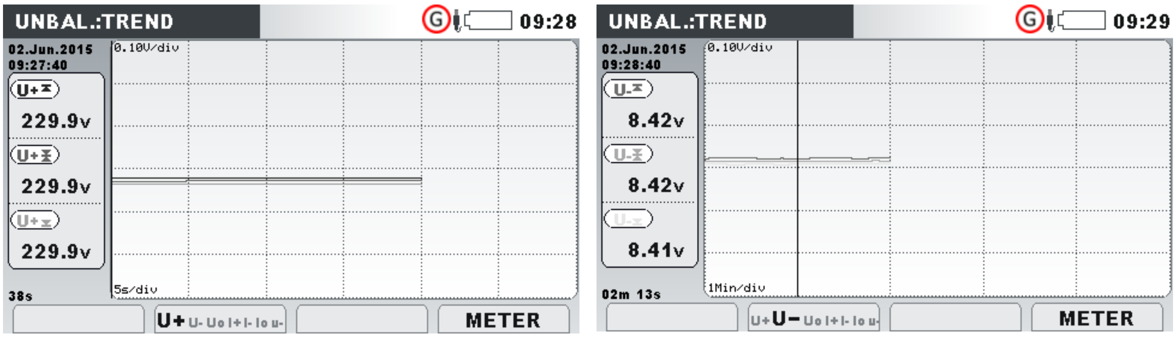


Figure 4-68: Showing 3rd harmonics trend on the instrument

After few minutes record can be finished. Enter into RECORDERS → MEMORY LIST menu. A list of available records will appear. Choose the latest record and open it by pressing the “VIEW” key. Select UNBAL to get unbalance data.

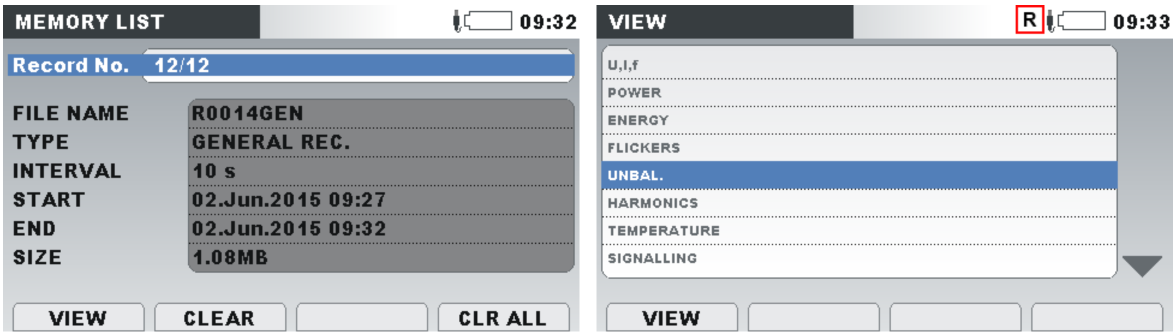


Figure 4-69: Observing records through Memory List submenu

Power View provides several options to observe unbalances. All measurements can be accessed through the “Unbalance” node from the “Data Explorer”. Each measurement may be presented in either chart or table presentation. Unbalance screen example is shown in the figure below.

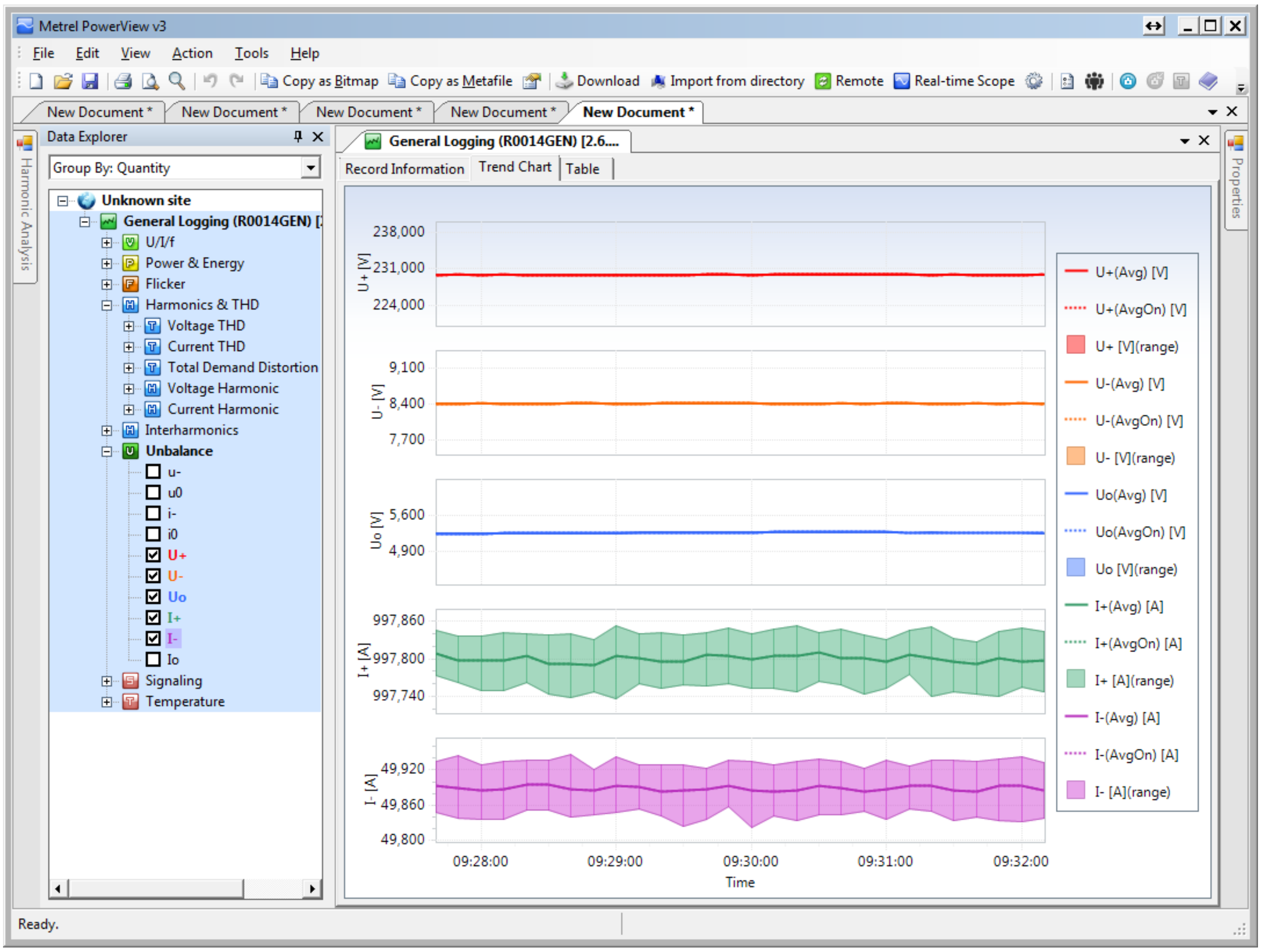


Figure 4-70: Unbalance in time chart

4.8 Exercise 8 – Flicker

In this exercise, we will show how the instrument should be setup in order to monitor voltage flicker. Before start, please set the switch S7 in the Application Trainer to ON as shown in the table below. The remaining switches should be set to OFF.

Switch	Description	State
S7	Flicker	ON

The Application Trainer will simulate an electrical system with the following parameters:

- Fundamental voltage: U1=230V
- Flicker Pst_{U1}=1, Pst_{U1}=1.5, Pst_{U1}=1.8
- Load type: Inductive
- Load character: Load (Consumption of electrical power)
- Frequency: 50/60 Hz

The Power Master MI 2892 should be connected to the Application Trainer and set up as described in previous section. It is good practice to observe the Connection Check status in the MEASRUEMENT SETUP → CONNECTION SETUP menu. If it's marked with an OK sign (✓), you can start observing measurements.

4.8.1 Real time measurements

By entering the MEASRUREMENTS MENU user can observe measured parameters in real time.
Please note that voltage dips and swells have great influence on the flickermeter filters, which can lead to faulty measurements. In order to get reliable values, it is therefore recommended to check if events are present, and then reset the previous flickermeter's history by pressing the F2 function key (Reset). This will guarantee that the obtained flicker measurement P_{st} will represent the first reliable value after approximately 20 minutes of measuring.

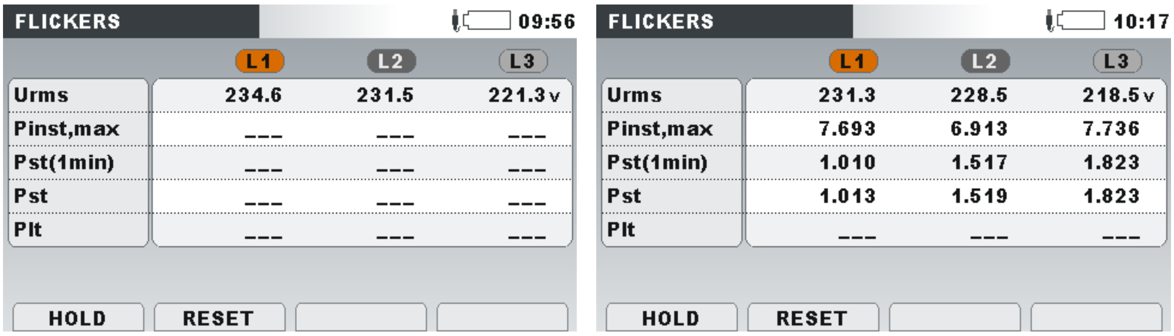


Figure 4-71: Real time measurements of flicker

4.8.2 Recording flicker measurements

The basic tool for Power Quality analysis is recording electrical system parameters. In this step we will create a record and observe it on the instrument, as this is a typical case for troubleshooting.

From the Main menu, enter the Recorders window and then go to the General rec. menu. Here the user needs to set up all the parameters as shown in the figure below:

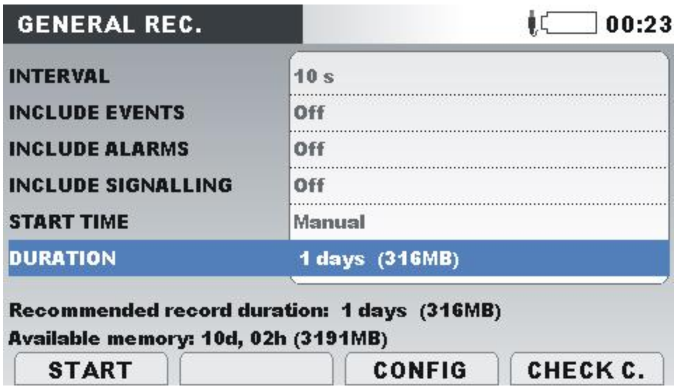


Figure 4-72: General record settings

After all these changes have been made, we are ready to run the recorder by pressing F1 key. Even though we've set it up to finish after 1 day, recorder can be stopped anytime by pressing F1 (STOP) key.

While recording is active (G), user can evaluate all recording parameters in TREND screens, which appears in each MEASUREMENTS submenu. The figure below shows voltage trend (MEASUREMENT → Flicker → TREND (press key F4).

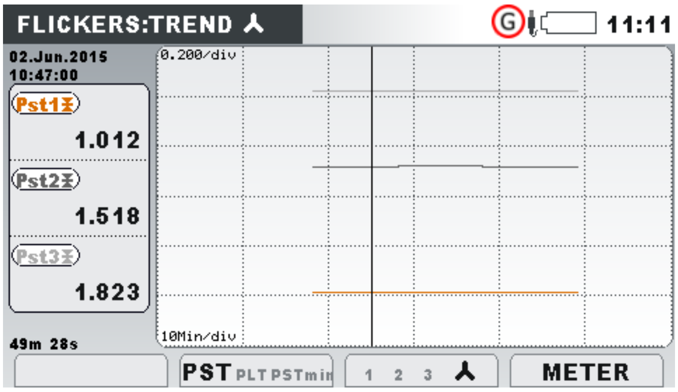


Figure 4-73: Showing flickers on the instrument

In order to get some values, the recorder should run at least 30 minutes. Finish the recording after you get some useful values, by entering the RECORDERS → GENERAL RECORDER menu, and pressing the F1 (STOP) key. If the user wants to observe recorded data on the instrument, enter the RECORDERS → MEMORY LIST menu. Choose the latest record and then open it by pressing the “VIEW” key.

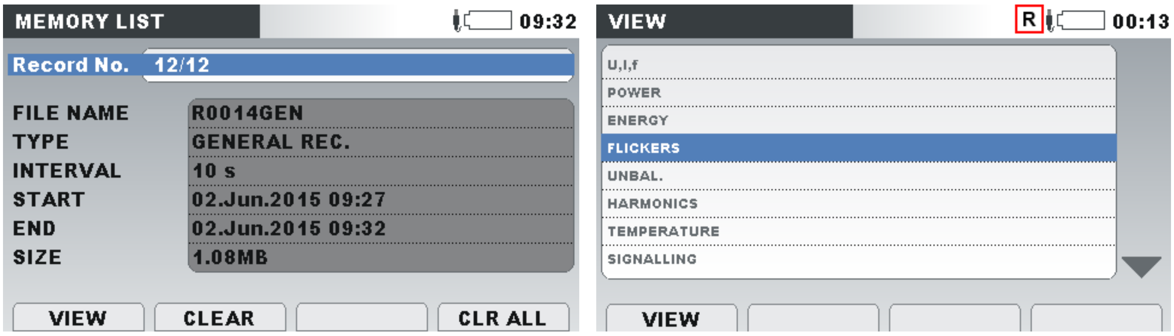


Figure 4-74: Observing records through Memory List submenu

Power View provides several options to observe flickers. All measurements can be accessed through the “Flicker” node from the “Data Explorer”. Each measurement may be presented in either chart or table presentation. An example is presented in the figure below.

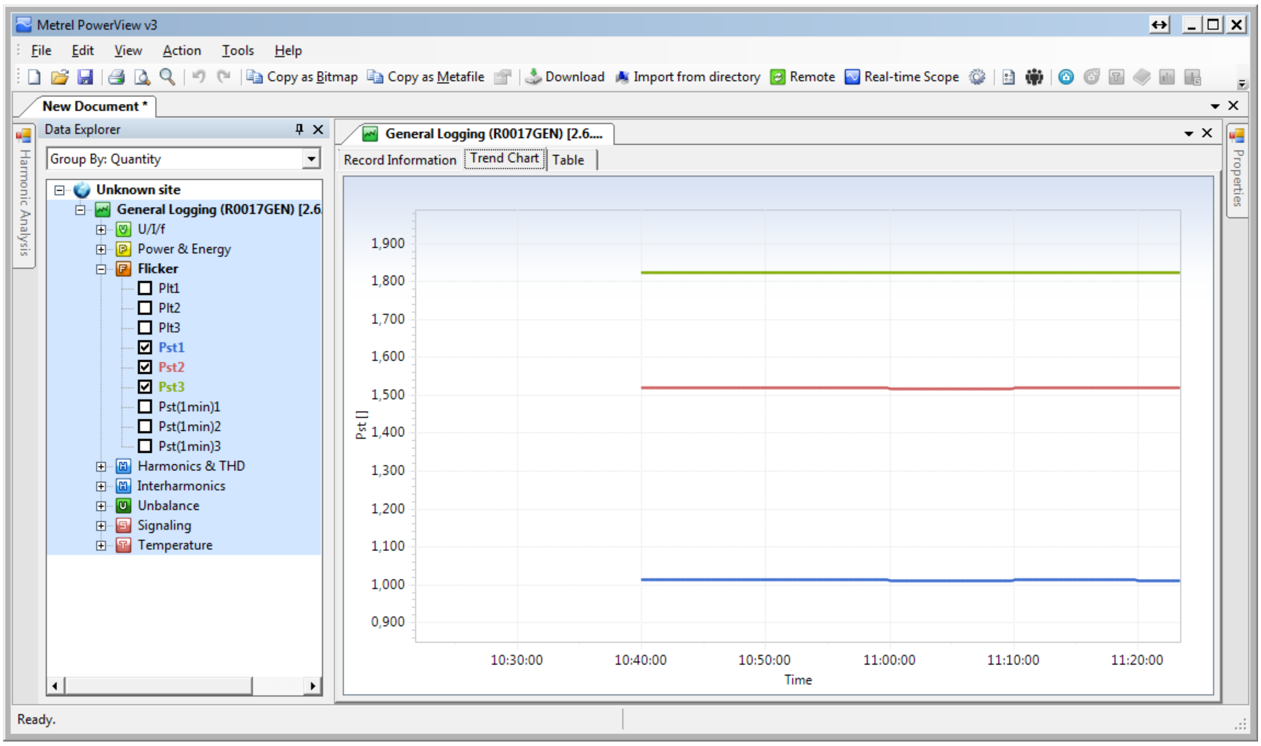


Figure 4-75: Flicker in time chart

4.9 Exercise 9 – Inrush recording

In this exercise, we will show how the instrument should be setup in order to capture current inrush events. Inrush current typically occurs during a motor start event. Before start, please set the switch S8 in the Application Trainer to ON as shown in the table below. The remaining switches should be set to OFF.

Switch	Description	State
S8	Inrush	ON

The Application Trainer will emulate an inrush event with the following parameters:

- Fundamental voltage: U1=U2=U3=230V
- Fundamental current: I1=I2=I3=1000A
- Inrush current on I1 with max. current 1700A and 200msec duration, repeated every 10 second
- Load type: Inductive
- Load character: Motor Load (Consumption of electrical power)
- Frequency: 50/60 Hz

4.9.1 Real time measurements

Usually inrush events can be triggered manually (by starting a motor). However inrush events are sometimes out of our control and occur randomly. It is recommended to start with observing maximum (MAX), minimum (MIN) and RMS current in the MEASRUREMENTS → U,I,f menu, as shown below. Before observing the RESET key (F2) should be pressed. In this exercise, maximum current generated by the

Application Trainer is raised to more than 1700 A (after pressing the RESET key). This clearly indicates a possible inrush event.

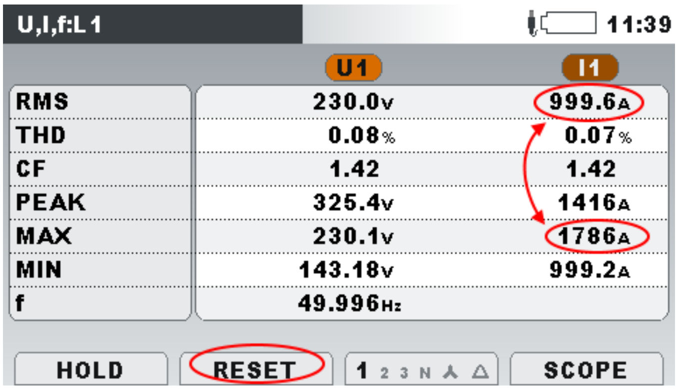


Figure 4-76: Measurement submenu

4.9.2 Inrush capturing

In order to capture inrush waveforms, it is necessary to choose the RECORDERS → WAVEFORM RECORDER. This recorder type is specifically designed to capture events, such as current inrush or voltage dips. In order to capture inrush, it is necessary to select "Level I" trigger. By observing RMS (996 A) and MAX (1786 A) values from the figure above, we can choose the current LEVEL which will trigger inrush capturing. In this case we chose 1100A trigger level with rising slope. The instrument starts waveform recorder when the measured current reaches the given current threshold, as shown in the figure below.

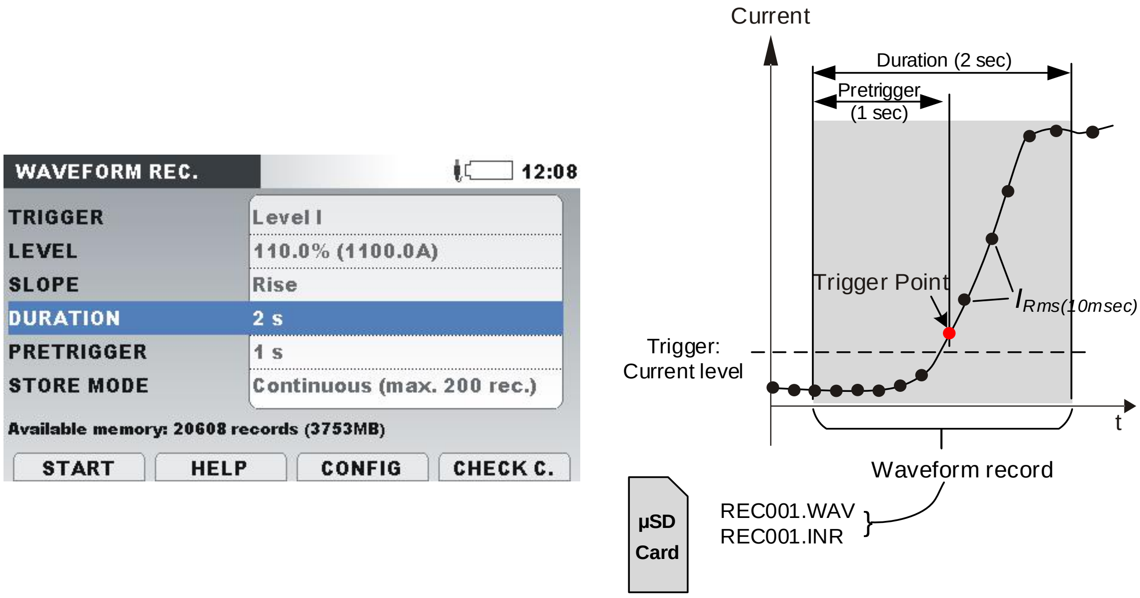


Figure 4-77: Current Level Triggering (Inrush)

After the WAVEFORM RECORDER is set up, we can proceed with recording. The recorder is started by pressing the START (F1) key. A yellow icon in the status bar W indicates that waveform recorder is active and is waiting for an inrush event to happen.

As soon as current on any cannel reaches the given LEVEL, it will start recording. Active recording will be indicated in the status bar, with a red icon W.

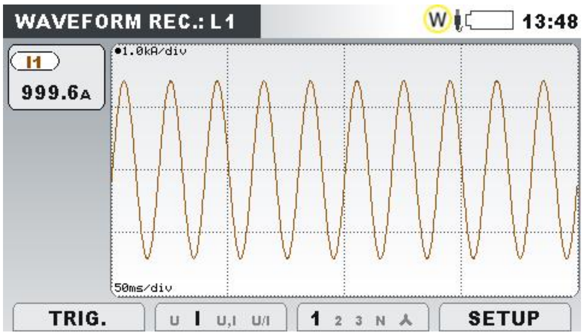


Figure 4-78: Observing current waveform during inrush capturing

After an inrush event is captured it can be observed in the RECORDERS → MEMORY LIST menu, as shown in the figures below.

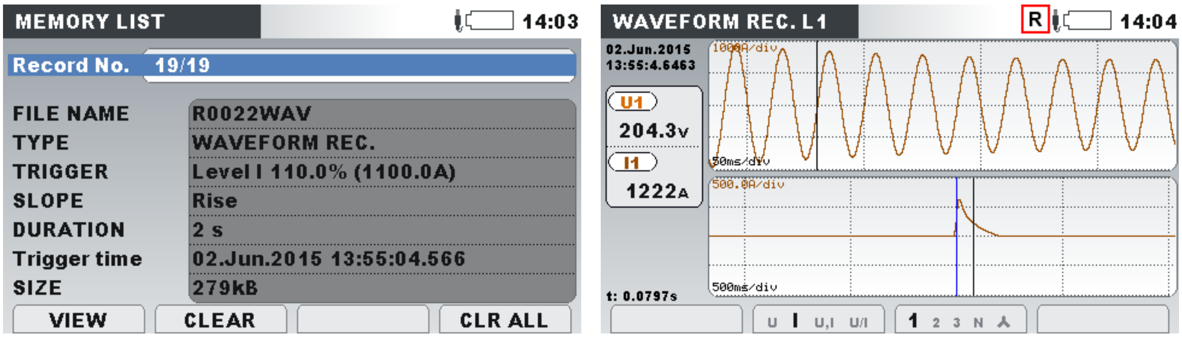


Figure 4-79: Real time measurements of current inrush

4.9.3 Downloading and observing recorded data in PowerView

The recorded data can be imported into PowerView for further analysis. Please note that prior this step PowerView should be installed and set up as described in section 1.2 PowerView installation and setup.

Open PowerView and click on the “Download” button on the toolbar. A new window will appear with the instrument's information and list of available records (see figure below). Select the desired records (current selections are coloured green), then click on the “Start importing” button.

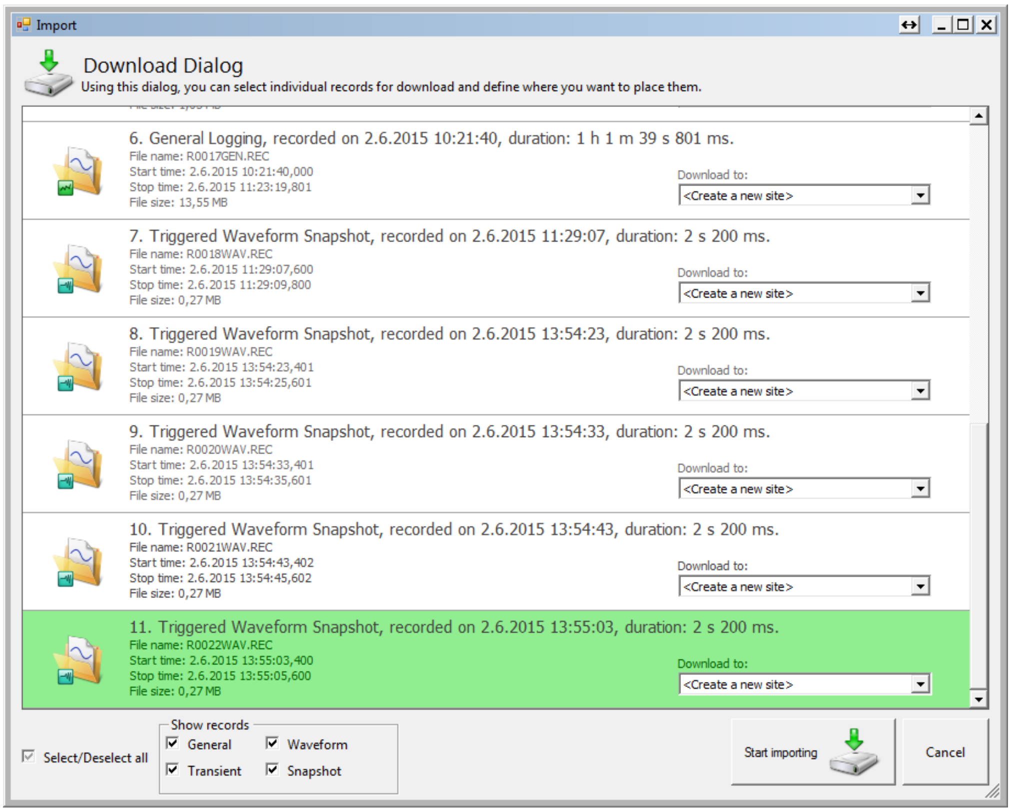


Figure 4-80: Download dialog

After the import “Record Information” tab is shown. This tab includes basic information about the imported record. Data sets from records, can be accessed from the “Data explorer” tab (on the left side).

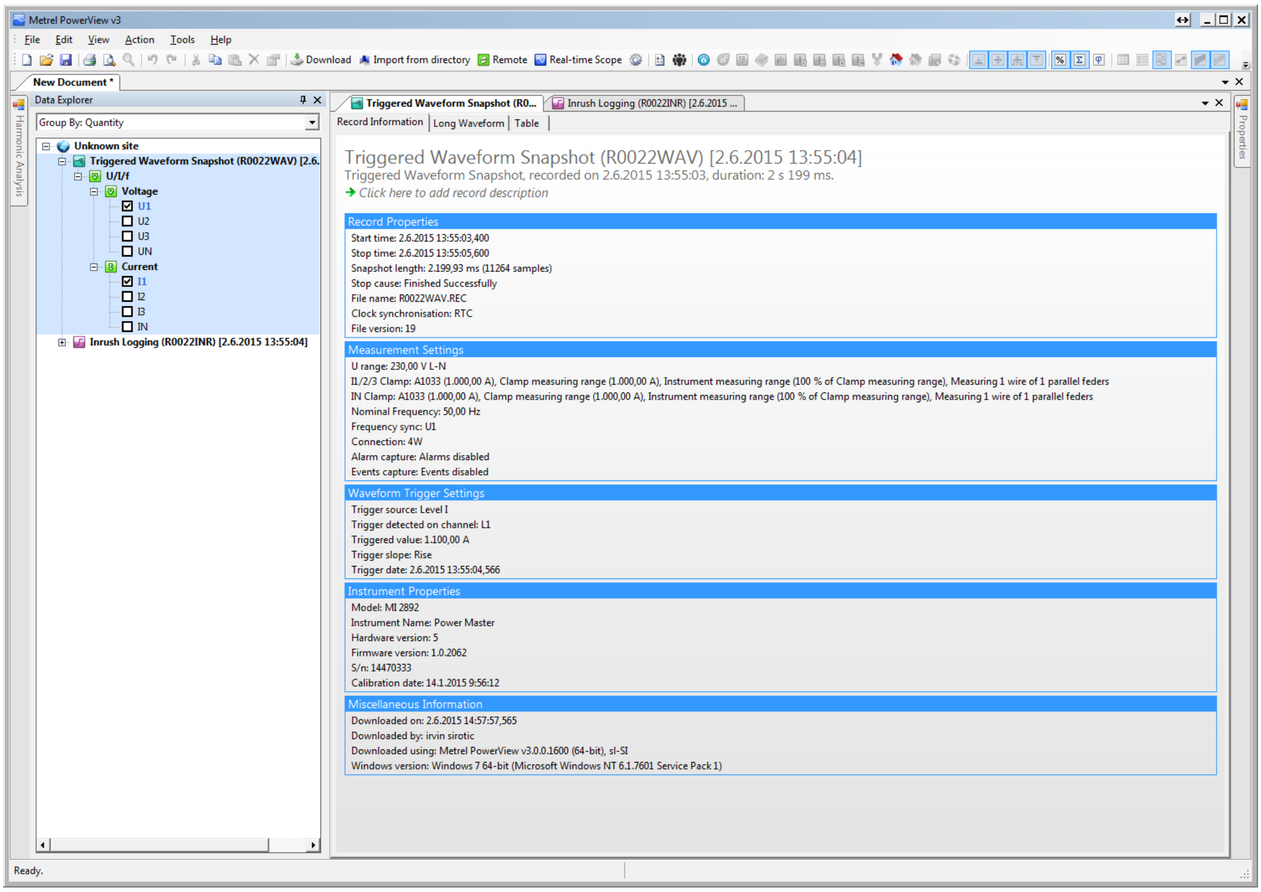


Figure 4-81: Inrush record information

For each waveform record, recorded by the instrument, PowerView will show two records type:

- Waveform record: record with waveform samples
- Inrush record: record with RMS½ (cycle RMS refreshed each half cycle) samples

For the most PQ cases inrush record will be the optimal choice for observing motor starts, dips and other events which last form 10ms ÷ 30sec. An inrush record is shown in the figure below. Inrush current, together with voltage surge, during motor start is clearly visible.

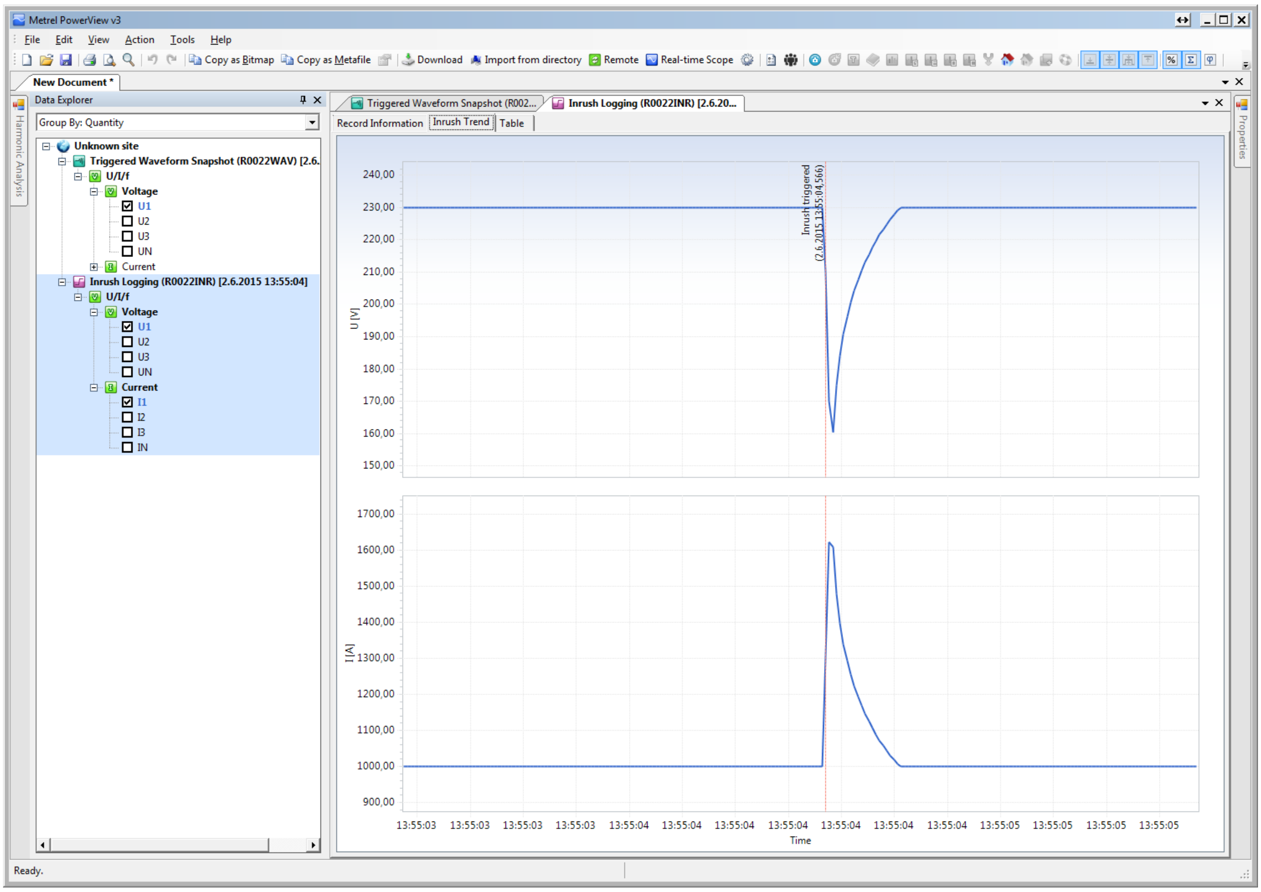


Figure 4-82: Inrush Chart view

If we want to observe voltage or current shape, or are interested in phase changes during such events, then waveform record should be used. Here we can see each sample of current and voltage. Additionally data is split on 10/12-cycle packets for which all relevant parameters (RMS U, RMS I, THD, Power) are calculated. Therefore, the user can check exactly what kind of stress was pushed to the observed object during such event.

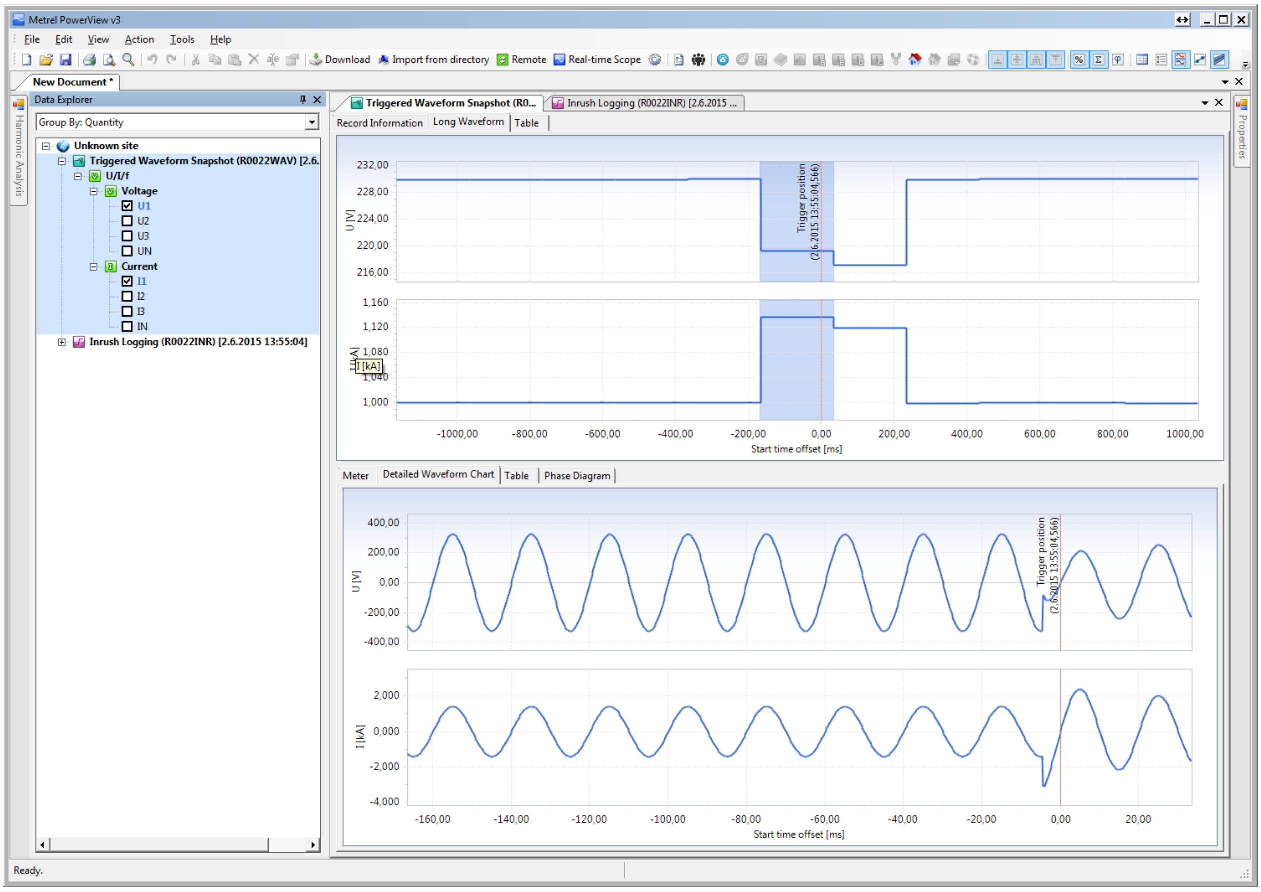


Figure 4-83: Inrush current waveform record

4.10 Exercise 10 – Transient recording

In this exercise, we will show how the instrument should be setup in order to capture voltage transient. Transients are mainly consequences of load or capacitor bank switching. Before start, please set the switch S9 in the Application Trainer to ON as shown in the table below. The remaining switches should be set to OFF.

Switch	Description	State
S9	Transient	ON

The Application Trainer will emulate a transient event with the following parameters:

- Fundamental voltage: U1=U2=U3=230 V
- Fundamental current: I1=I2=I3=1000 A
- Load type: Inductive
- Load character: Load (Consumption of electrical power)
- Frequency: 50/60 Hz
- Transient spike: 420Vpk, length <3 msec, repeat every 10 sec

4.10.1 Transient capturing

In order to capture transients, it is necessary to choose the RECORDERS → TRANSIENT RECORDER menu. This recorder is specifically designed to capture transients. Transient recorder is similar to waveform (inrush) recorder. It stores a selectable set of pre- and post-trigger samples on trigger activation, but with 10 times higher sampling rate (~ 50 k Samples/sec). The recorder can be triggered on envelope or level. The recommended envelope trigger is activated if the difference between same samples on two consecutive periods of input voltage signals, is greater than the given limit.

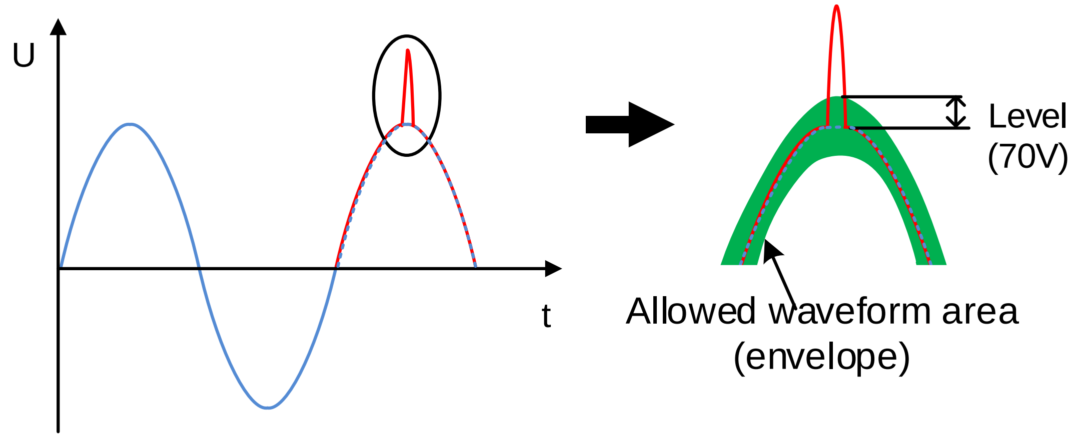
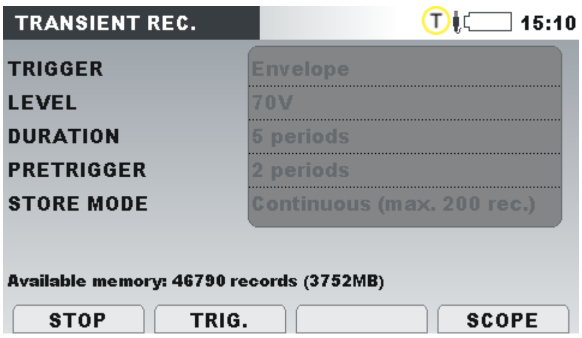


Figure 4-84: Transients trigger detection (envelope)

Figure 4-85: Transient recorder setup

After the WAVEFORM RECORDER is set up, we can proceed with recording. The recorder is started by pressing the START (F1) key. A yellow icon in the status bar indicates that transient recorder is active and it's waiting for a trigger. As soon as a trigger condition is met on any channel, the instrument will start recording it. Active recording will be indicated in the status bar, with a red icon .



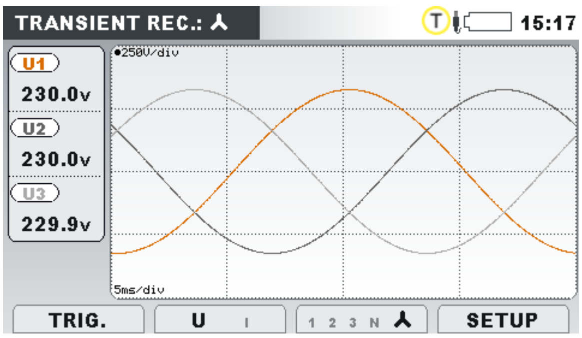


Figure 4-86: Transient record setup

After the transient is captured it can be observed in the RECORDERS → MEMORY LIST menu, as shown in the figures below.

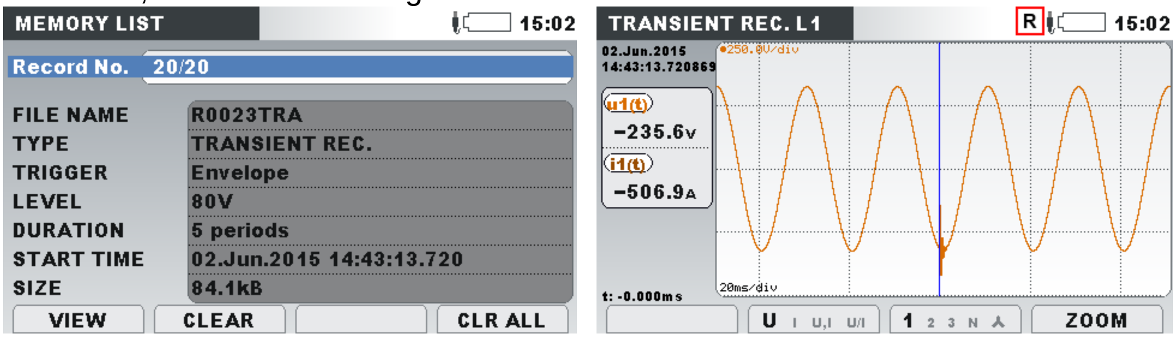


Figure 4-87: Observing transient record on instrument

4.10.2 Downloading and observing recorded data in the PowerView

The recorded data can be imported into PowerView for further analysis. Please note that prior to this step PowerView should be installed and set up as described in section 3.5 PowerView installation and setup.

Open PowerView and click on the "Download" button on the toolbar. A new window will appear with the instrument's information and a list of available records (see the figure below). Select the desired records (current selections are coloured green), then click on the "Start importing" button.

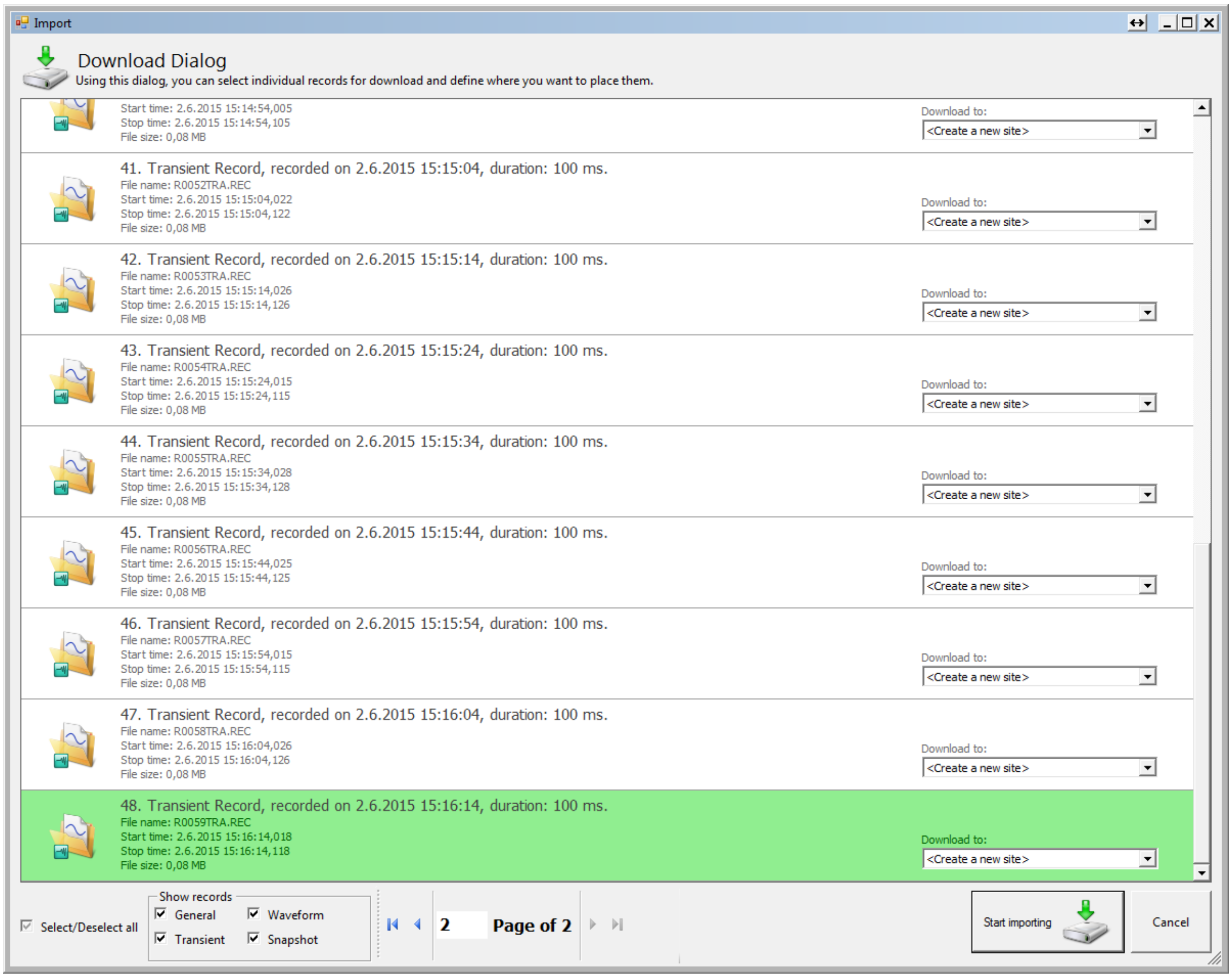


Figure 4-88: Download dialog

After the import “Record Information” tab is shown. This tab includes basic information about imported records. Data sets from records, can be accessed from the “Data explorer” tab (on the left side). As can be seen from the figure below, the capacitor bank switching is clearly visible. If necessary the user can evaluate sample values, RMS values and time stamps.

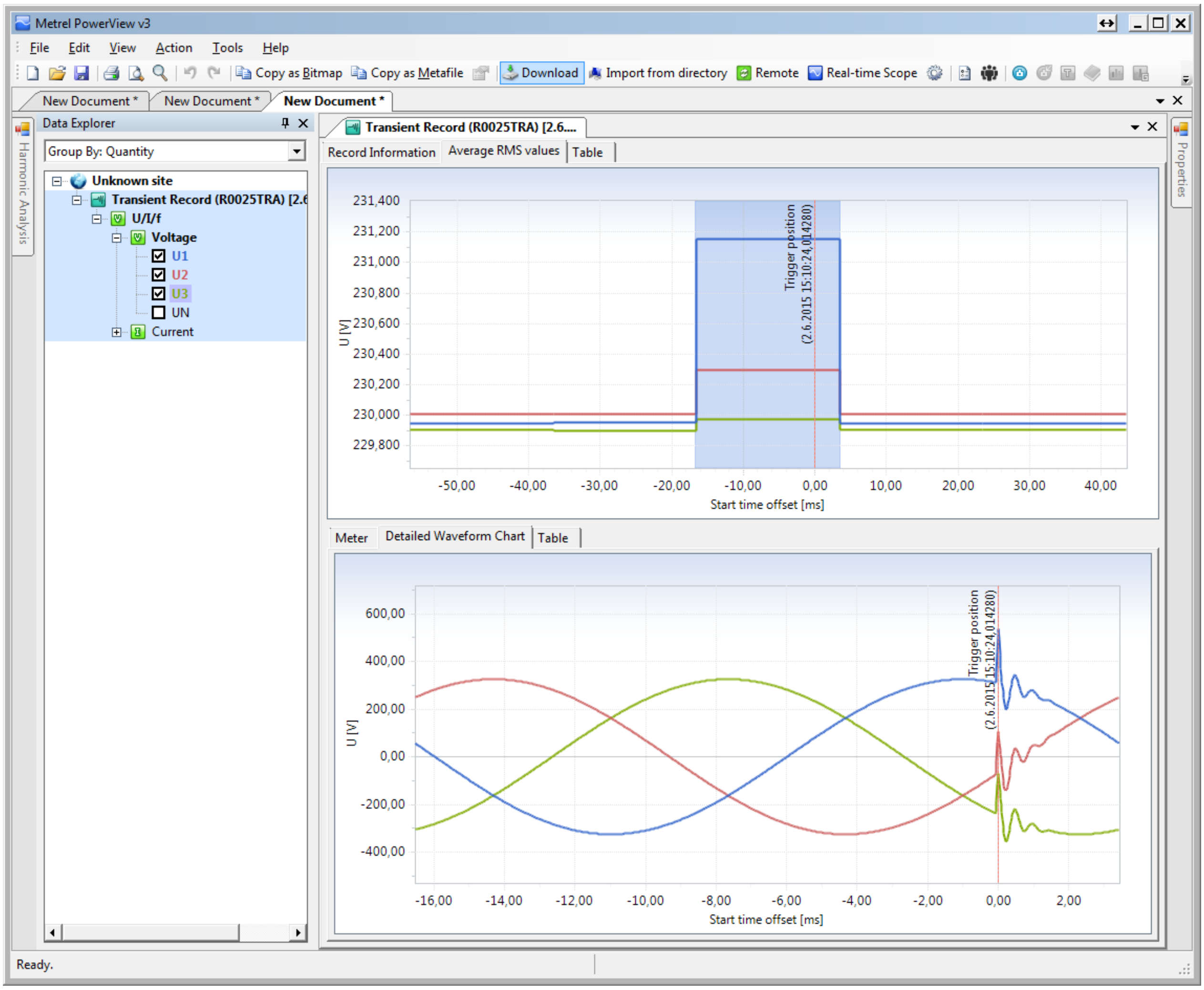


Figure 4-89: Transient Chart view

4.11 Exercise 11 – Phase (switch) failure

This practical example will reproduce an event where two phases are interchanged during switching power feeding form one transformer to another. During such an event excessive current inrush can occur, which could cause feeder tripping.

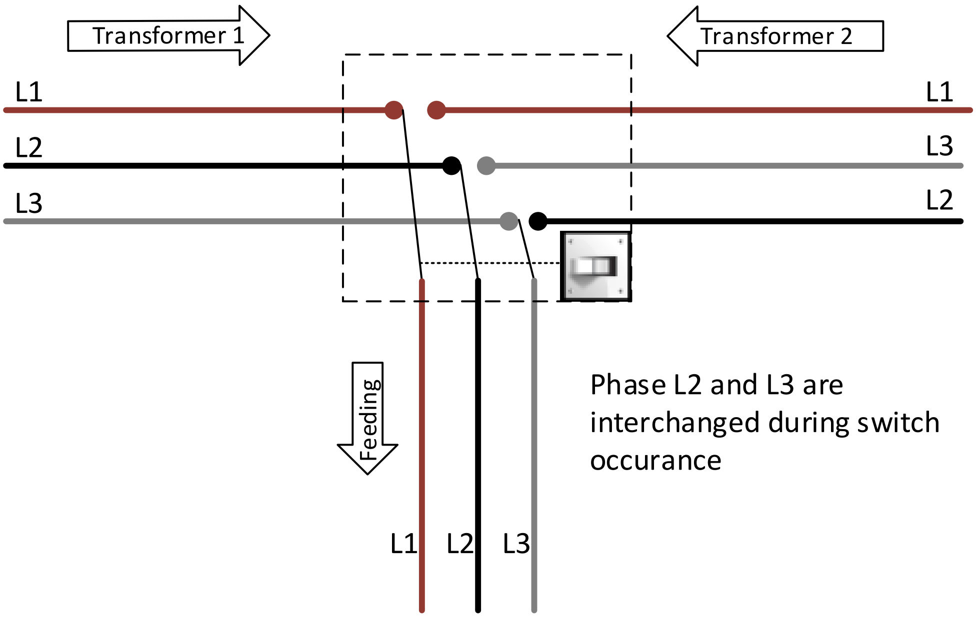


Figure 4-90: Phase switch

In order to simulate such an event, please set the switch S10 in the Application Trainer to ON as shown in the table below. The remaining switches should be set to OFF. The Application Trainer will switch between phases L2 and L3 every 10 seconds.

Switch	Description	State
S10	Phase (switch) failure	 ON

In practice we usually don't know where the problem is; therefore we recommend to start observing voltage, current and THD. This can be done by entering the U,I,f MENU in the MEASUREMENT MENU, as shown below.

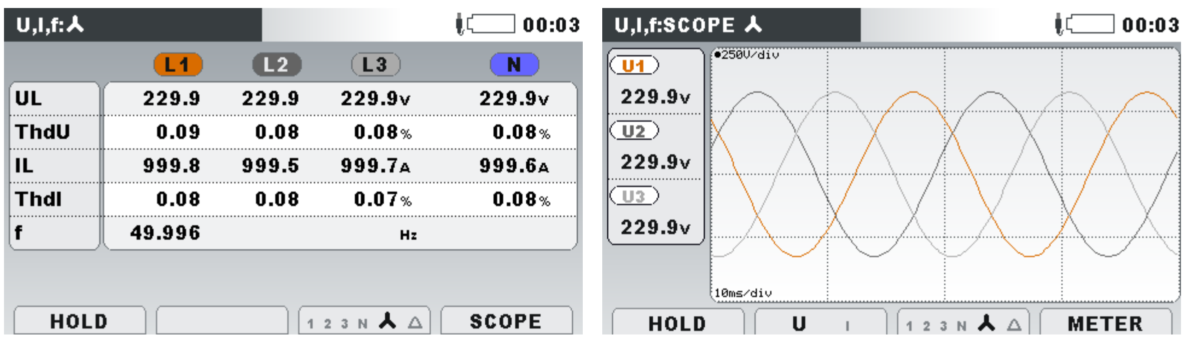


Figure 4-91: Real time measurements of voltage and current

As sudden changes (such we can observe) can't be seen on steady RMS measurements, the next step is to check minimum and maximum RMS values for each phase. Note that before observing, the RESET key (F2) should be pressed, in order to clear all previous values. As can be seen from the figure below, MAX and MIN values are significantly different from the average value, which clearly indicates that we are dealing with sudden changes on voltages (similar to dip/swell).

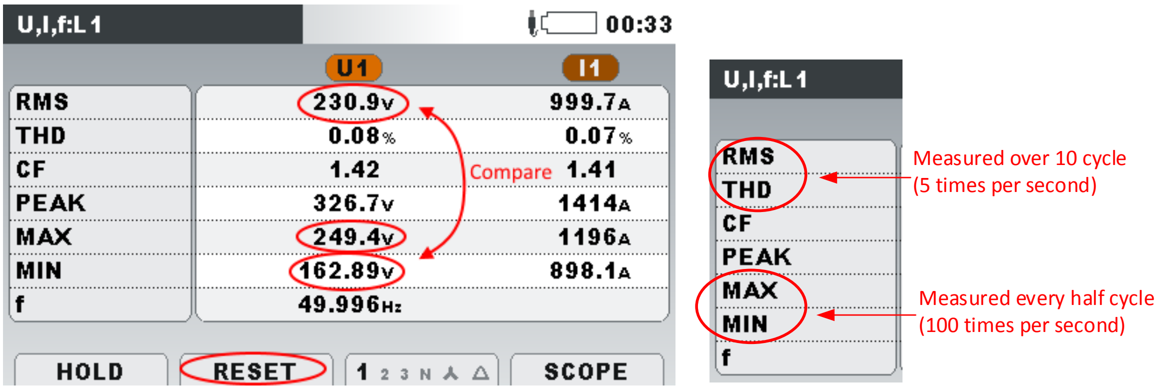


Figure 4-92: Half cycle minimal and maximal Voltage values

In such cases it is best to try to catch disturbance with a waveform recorder. Below is a WAVEFORM SETUP screen, which was setup according to the measured minimum voltage from the previous figure.

Figure 4-93: Waveform recorder setup parameters

After the WAFEFORM RECORDER is correctly setup, press the START button (Key F1). Phase shifting should occur within10 seconds. During the phase shift the RMS voltage will be changed, which triggers the waveform recorder. The captured waveform can be observed in the figure below, where disturbance can be seen. By carefully observing the waveform shape, we can
notice that the waveform shape before and after the disturbance is not the same. This indicates that we have a problematic switching event where the phase sequence is changed.

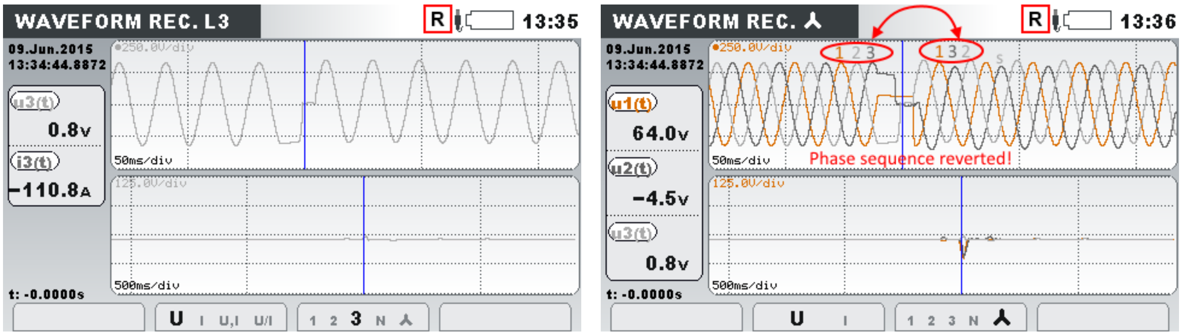


Figure 4-94: Observing phase switch event on the instrument

The captured waveform can be download to the PC and observed on the PC, as shown in the figure below.

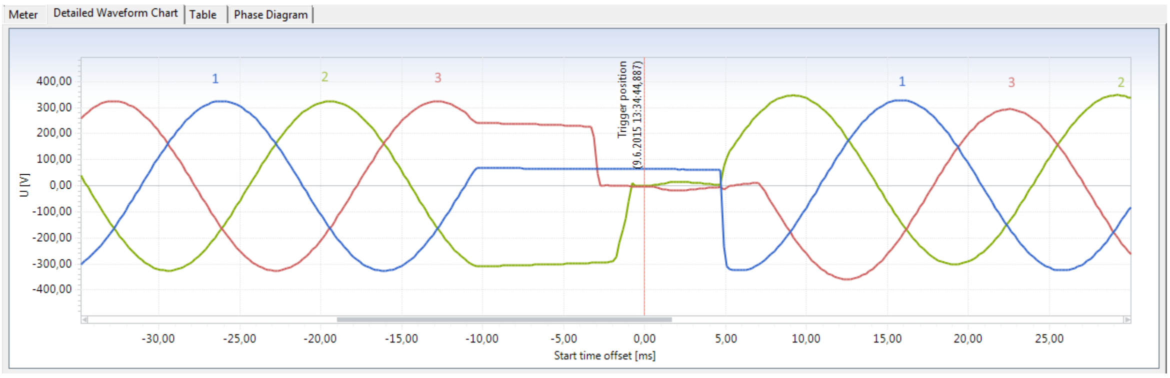


Figure 4-95: Observing phase switch event in the PowerView

4.12 Exercise 12 – Wrong instrument connection

This practical exercise will emphasize importance of right instrument connection. Sometimes it is not possible to identify which current belongs to which voltage, and this can lead to wrong instrument connection and faulty measurements. As there is no post fix solution to wrongly connected instrument – so it is very important to assure that instrument is connected properly.

In following exercise Application Trainer will interchange some current and voltage channel, and it to user have to find out which cables are mess up and how to connect instrument correctly. Set switches S1 ÷ S11 on Application Trainer as shown on table below.

Switch	Description	State
S11	Wrong instrument connection	ON

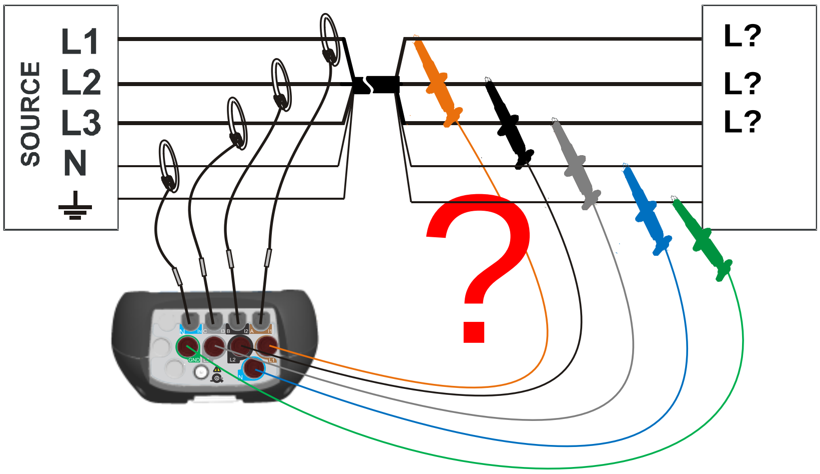


Figure 4-96: Wrong instrument connection

In order to resolve this problem press the button and select the Connection Check menu line. The following screen will appear:

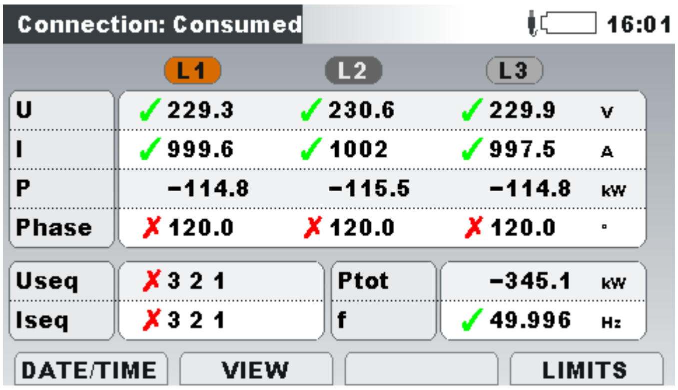


Figure 4-97: Connection check screen (wrong current and voltage sequence)

Here the user can check Voltage, Current, Power, frequency and other values, together with phase angle and sequence. All measurements are checked according to some logical limits and status is given as with an OK (✓) or Fail (✗) sign. For example: if we monitor a motor or any other kind of load (which consumes energy), then the phase angle between voltage and current should be less than 90 degrees. In our case, phase shift between voltage and adjacent current is more than 90 degree, which clearly indicates that the instrument is wrongly connected.

By interchanging L1 and L2 instrument voltage probes, we get a proper voltage connection, as shown in the figure below.

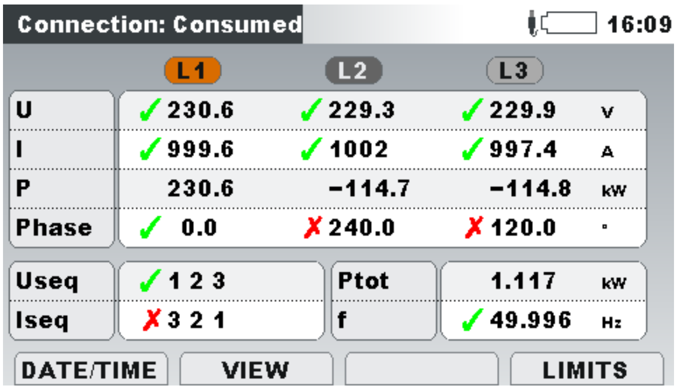


Figure 4-98: Connection check screen (correct voltage sequence)

From the figure above, we can see that the phase angles on channels L2 and L3 and current sequence is not correct. Particularly currents I2 and I3 have large phase shifts to adjacent voltages. By interchanging them, we get a correct connection as shown in the figure below.

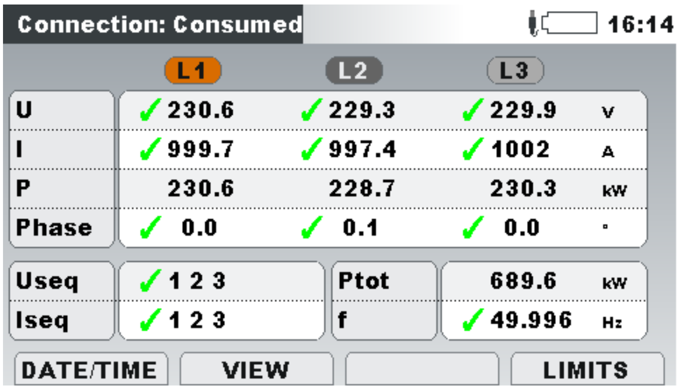


Figure 4-99: Connection check screen (correct voltage and current sequence)

5 Checklist

Before leaving the instrument at a site for recording, please go through the following checklist:

	INSTRUMENT SETUP	
1	**Batteries installed and charged**	
2	**microSD card installed**	
3	**Time and date correctly set (UTC GPS or RTC)**	
	CONNECTION	
1	**AC adapter connected**	
2	**Voltage leads connected**	
3	**Current clamp sensors connected**	
4	**Appropriate current sensors and optimal current range selected**	
5	**Appropriate connection type selected**	
6	**Appropriate synchronization type (U/I) selected**	
	RECORDER SETUP	
1	**Appropriate recorder (depending on the application) selected**	
	General recorder (enables periodic recording)	Can operate simultaneously
	Waveform recorder (enables waveforms recording) Single or Continuous	
	Transient recorder (enables high resolution waveforms recording) Single or Continuous	
	SETUP OF WAVEFORM TRIGGERS	
1	**Appropriate waveform recorder (depending on the application) selected**	
	Trigger set to Voltage events / Troubleshooting	
	Trigger set to Level on Voltage or Current / Inrush recorder	
	Trigger set to Interval	
	Trigger set to Alarm / Troubleshooting	
	START OF RECORDING SESION	
1	Check that appropriate symbols are displayed on the screen	
	General recorder	G
	Waveform recorder	W
	Transient recorder	T
	Ethernet Communication	

AD 3 - MI 3399
PAT Appliances & Machines Safety Trainer

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1 Introduction

PAT Demoboard is a part of the Application Trainer and is intended for demonstration of electrical equipment safety management. Typical applications are:

- Presentation of safety management of electrical equipment on seminars, courses.
- Presentation of typical safety problems on electrical equipment.
- Practical demonstration of measuring instruments (performing tests, making right connections, analysis of measured results).

Different values of electrical parameters that are usually checked during an electrical equipment safety test can be simulated. Error states can be switched On or Off.

Electrical parameters that can be simulated are:

- Continuity of equipotential bonding
- Insulation resistance
- Leakage current
- Touch leakage current
- Polarity of cables
- Functional operation

A practically unlimited number of different equipment (portable and handheld appliances, machines, switchgears) can be simulated by using different demonstration tables. Eight tables are included in the standard set.

On demand the PAT Demoboard can be simply upgraded with new demonstration tables (special applications, country design etc). For eventual upgrades contact METREL or your local distributor.

2 Safety warnings

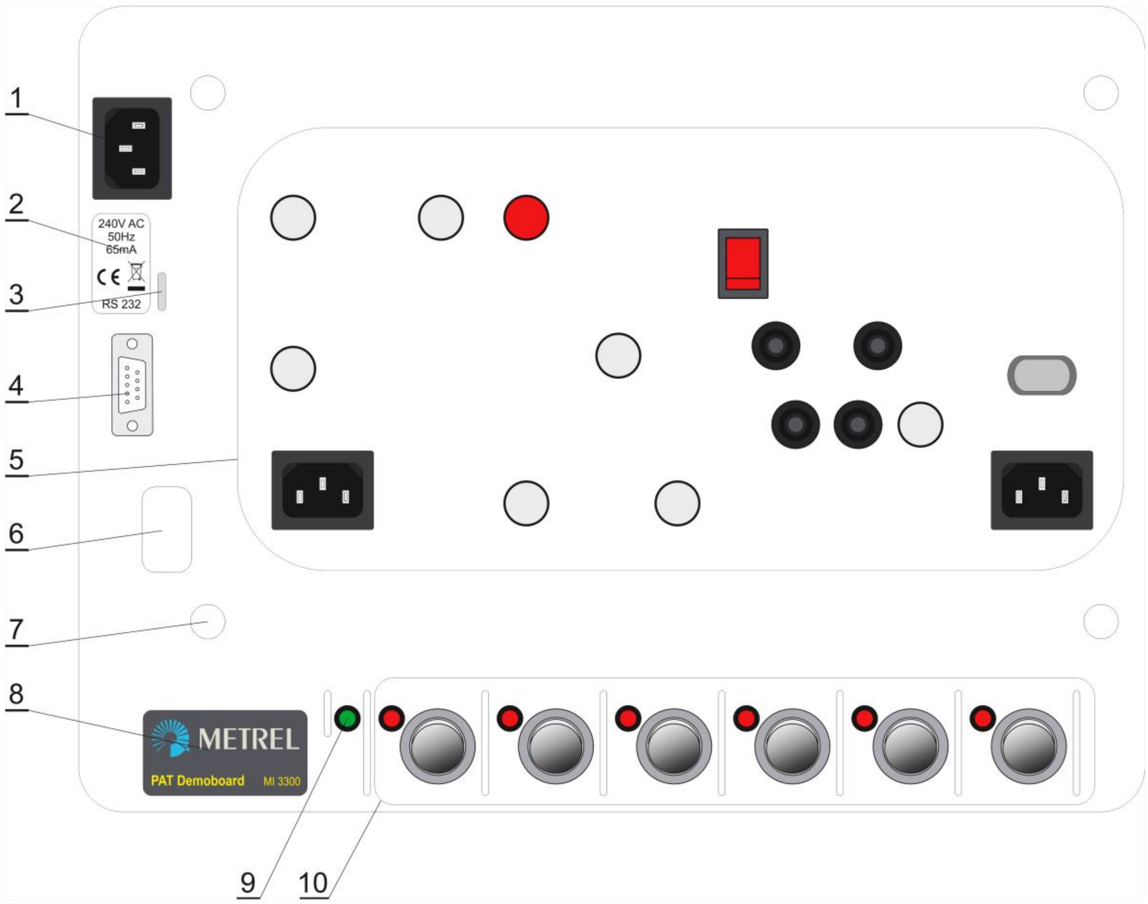
- Only qualified personnel who are familiar with the demoboard and measuring instruments may use PAT Demoboard!
- Use only original demonstration tables provided by the manufacturer!
- The PAT Demoboard must be considered as a real piece of electrical equipment. The simulated faults are real ones. Despite the fact that the simulated leakage currents are kept at relatively low levels it is strictly forbidden to touch any of the accessible metal parts inside the simulation area during the demonstration!
- The PAT Demoboard will work only if connected to a properly earthed TN or TT outlet. The Ready lamp must lit green for normal operation of the Demoboard.

If red light is blinking and buzzer sounds immediately disconnect the demoboard from the mains and check the supply connections!

- Special care must be taken if performing HV (withstanding) tests. All safety measures must be considered as if testing real electrical equipment.
- Always check that the current of HV test equipment is limited to a low level (<3.5mA) when performing withstanding tests on PAT Demoboard.
- If the equipment is not used in a manner specified by the manufacturer, the protection provided by the equipment may be impaired.
- Use of Demonstration board in a way not specified in this User Manual could damage the board.
- Do not use the Demonstration board in case of any damage noticed!
- Only an authorised person may carry out servicing of Demonstration boards!

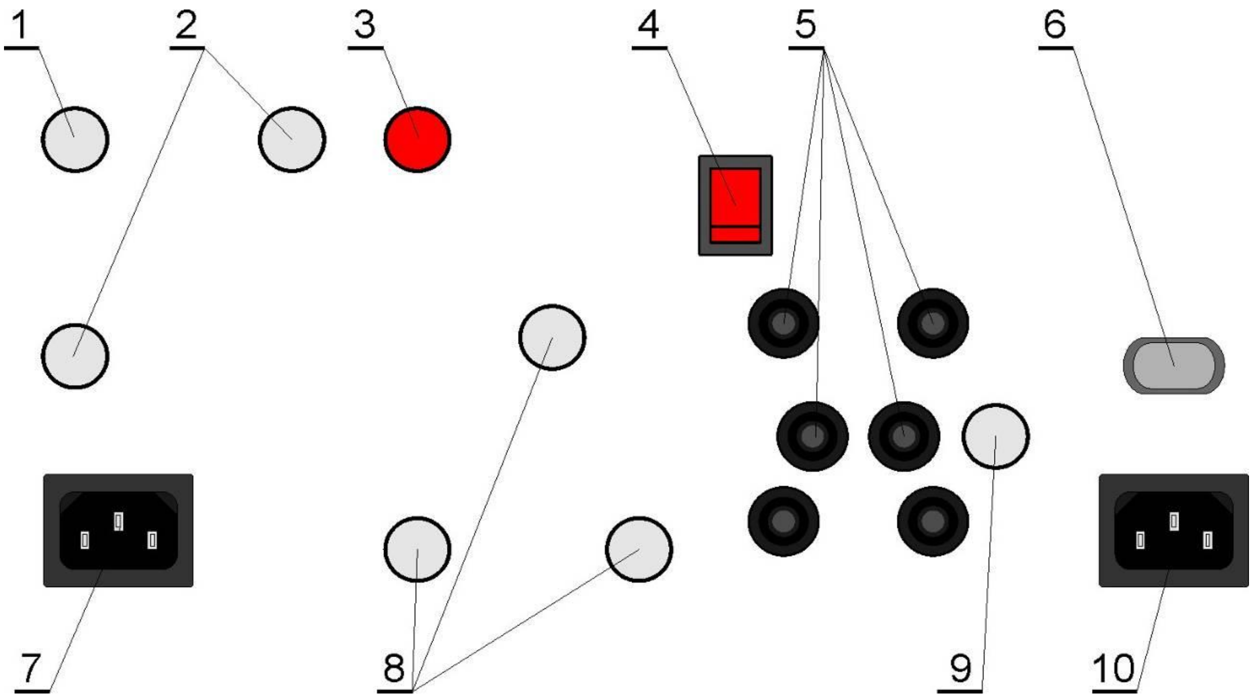
3 Description

3.1 Front panel



1. Mains supply socket for powering the demoboard (not used on the MI 3399 Application Trainer).
2. Demoboard data.
3. Cover holder.
4. RS232 socket (not used for PAT Demoboard normal operation).
5. Electrical equipment simulation area.
6. Groove for placing demonstration tables.
7. RFID reader.
8. Manufacturer label.
9. Ready indicator:
   Red light – demoboard is not ready.
   Blinking red light, buzzer sounds – improper mains connection.
   Green light – demoboard is ready for demonstration.
10. Error switches:
    Red light on – simulation of error is On.
    Red light off – simulation of error is Off.

3.2 Simulation area description



1. Accessible insulated metal part.
2. Grounded metal parts #1, #2.
3. Power ON signal light.
4. ON / OFF switch.
5. Sockets for simulation of various fixed connections.
6. Class II mains socket.
7. Socket for simulation of IEC cords.
8. Grounded metal part #3.
9. Grounded metal part #4.
10. Class I mains socket.

4 Basic theory

The primary goal of testing safety of electrical equipment is to use all electrical equipment without danger. Common accidents caused by electrical equipment are:

- Injuries through electric shock caused by malfunctioned equipment;
- Injuries through overheated equipment;
- Fire and explosions.

To prevent risk and possible danger caused by using electrical appliances and other equipment appropriate safety testing procedure should be performed.
Testing of electrical equipment is not regulated the same way in all countries.
Safety of electrical equipment depends on different factors which can improve or worsen the safety level.

According to the standards electrical equipment is divided in:

- Electrical appliances.
- Electrical equipment in medical use.
- Electrical machines.
- Electrical switchgears.

Types of safety tests of electrical equipment are:

- Type testing.
- End of line testing.
- Maintenance testing.
- Testing after modification and repair.
- Periodic testing.

4.1 Safety management

The term safety management summarizes all necessary steps that must be taken to assure the safety of electrical equipment through its complete lifetime.

This steps are:

- Quality type testing performed by the producer
- Obtaining an independent certification mark for the product (recommended)
- A strict quality end control at producer
- Quality maintenance of the product
- Correct handling with the product according to product manuals and working instructions
- Often visual checks by the user
- Regular safety check performed by a skilled person (visual check, testing of safety, “Logbook” of appliance, documentation of tests, etc.)
- Adequate corrective measures in case of a noticed safety problem. The figure below shows how individual factors can improve / worsen the safety level of electrical equipment

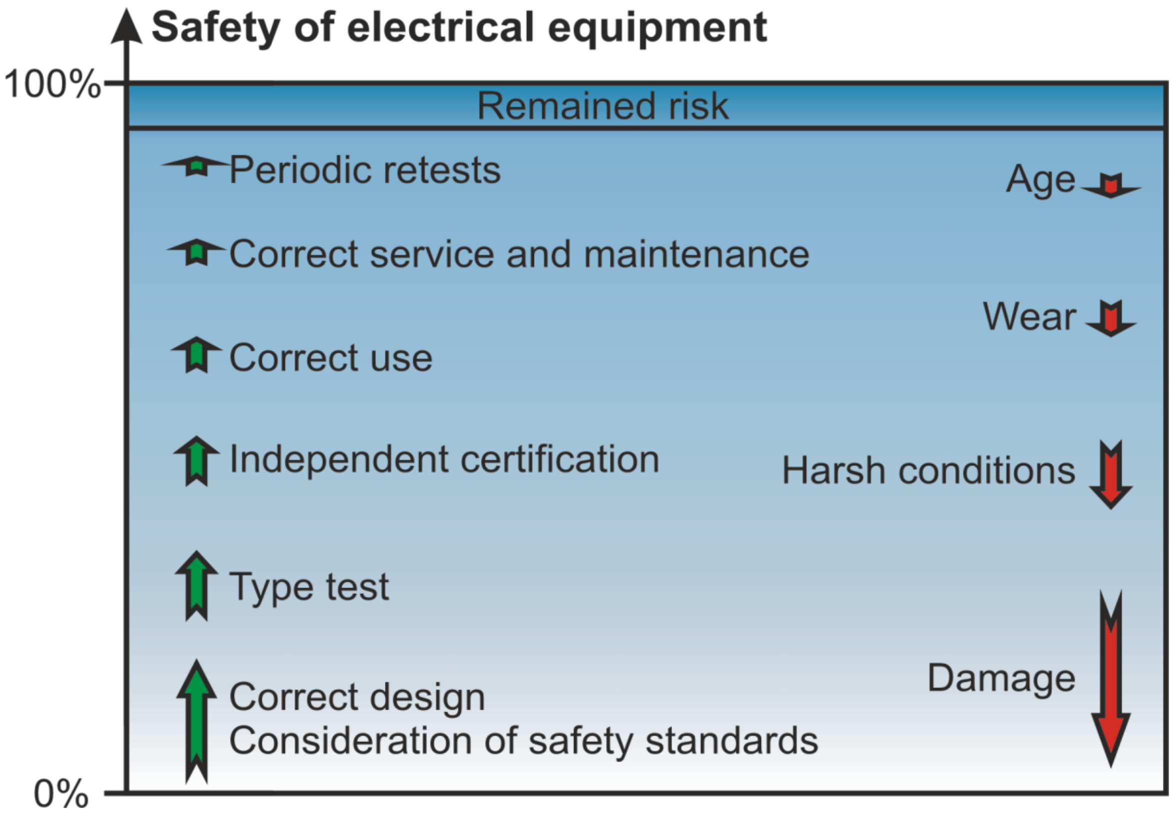


Figure 4-1: Safety management

4.2 Classification of appliances (by field of use)

Typical appliances are:

- Laboratory equipment.
- Measuring and regulating equipment.
- Power supplies.
- Heating appliances.
- Handheld tools.
- Luminaries.
- Consumer electronic.
- Information and communication technology (computers, fax machines, scanners etc.).
- Prolongation cords, IEC supply cords.
- Appliances for medical use.

Before testing the user must know the appliance construction e.g. protection class.

4.3 Classification of appliances (by protection classes)

According to the design electrical equipment can be divided in three classes. In the table below the differences between classes are described.

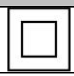
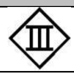
Class	I	II	III
Marking	No marking		
Connection to protection (PE) conductor of the installation.	Yes. All accessible conductive parts (case etc.) are connected to the PE connection.	No.	No connection to mains.
Basic insulation	Performed.	Performed.	Performed / looser limits.
Supplementary or reinforced insulation	Not needed in general. Needed if there are accessible unearthed conductive parts[10].	Performed.	Not needed.
Supply cord	Three pole (L,N, PE).	Can be two pole.	Two pole.
Notes	Installation must have adequate earth resistance.		Must be supplied from a SELV (safety low voltage) source, typically 12 V or 24 V.

Table 4-1: Classification of appliances

4.4 Portable electrical appliances – measurements

Basic test that need to be conducted while the portabe device is powered off:

1. Visual inspection
2. Earth bond/earth continuity
3. Insulation resistance (with or without Probe)
4. Sub-Leakage (optionaly)

If all conducted test above passed, the portable device should be turned on and the following tests performed:

1. Leakage (Differential or touch)
2. Polarity
3. PRCD
4. Functional

The probe test is conducted on Class II devices (flatiron, radio with an external antenna, …)

4.4.1 Visual inspection

Visual inspection of the equipment is intended to confirm that there are no visible signs of damage or defects. Electrical testing often does not disclose failures that become apparent on visual inspection. The visual inspection discloses most of faults! A thorough visual check must be carried out before each electrical safety test.

[10] Class I equipment can be combined with class II safety measures!

Scope of test:
Items that should be checked:
- Inspection of appliance for sign of damage.
- Inspection of flexible supply cable for damage.
- Any signs of pollution, moisture, dirt that can jeopardize safety. Especially openings, air filters, protection covers and barriers must be checked!
- Are there signs of corrosion?
- Are there signs of overheating?
- Inscriptions and marking related to safety must be clearly readable.
- Installation of the appliance must be performed according to the user manuals.
- During visual inspection the measuring points for the electrical testing have to be determined too.

Note: For Class II and Class III devices visual inspection is often the only applicable safety test!

4.4.2 Protective circuit continuity test (Earth bond)

Scope of test:
With the protective circuit continuity test (earth bond) test, the following is determined:
- That the contacts between accessible conductive parts and the PE conductor are firm.
- That the PE wire in the appliance supply cord is undamaged.
- That there are no signs of poor contacts, corrosion etc.

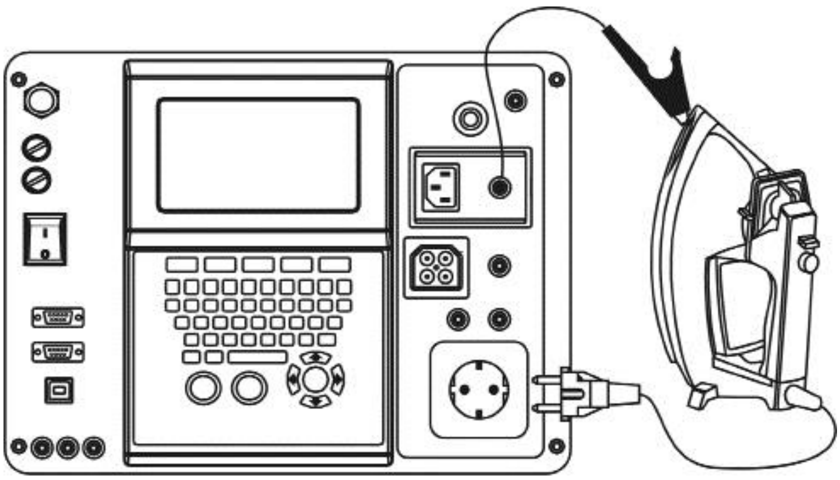


Figure 4-2: Earth bond test

Examples of faults, possible consequences
Fault: Accessible conductive part was not connected to PE conductor after repair.
Result: Dangerous contact voltage occurred on unconnected accessible conductive part. There is a possibility of electrical shock if this part would be touched. In this case the leakage would flow through the body instead through PE conductor to earth.

Fault: PE wire is broken in supply cord.
Result: There is no path to the earth for fault currents. Again the leakage would flow through the body instead through PE conductor to earth if enclosure would be touched.

This is extremely dangerous in case of a live to earth (e.g. insulation) fault in the appliance since live voltage can occur on the enclosure.

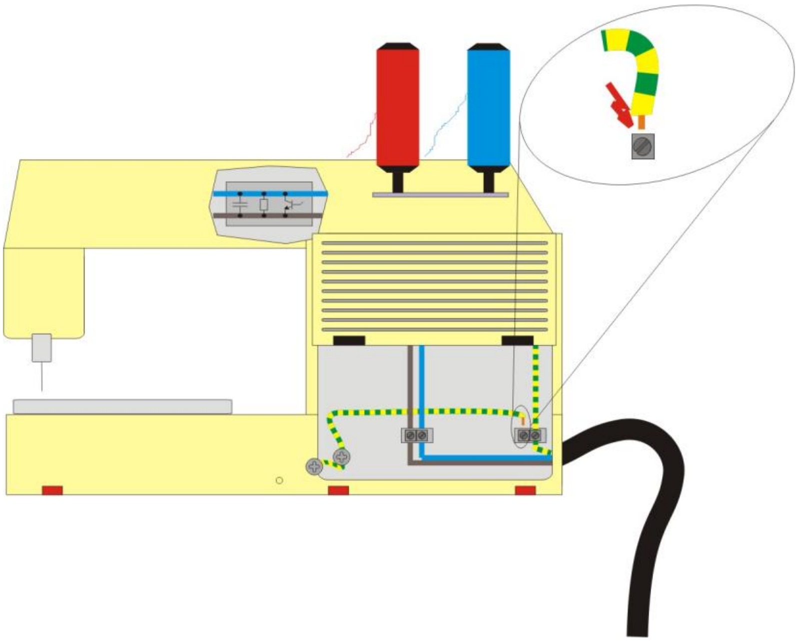


Figure 4-3: Examples of faults of PE connections

Measuring principle / limits

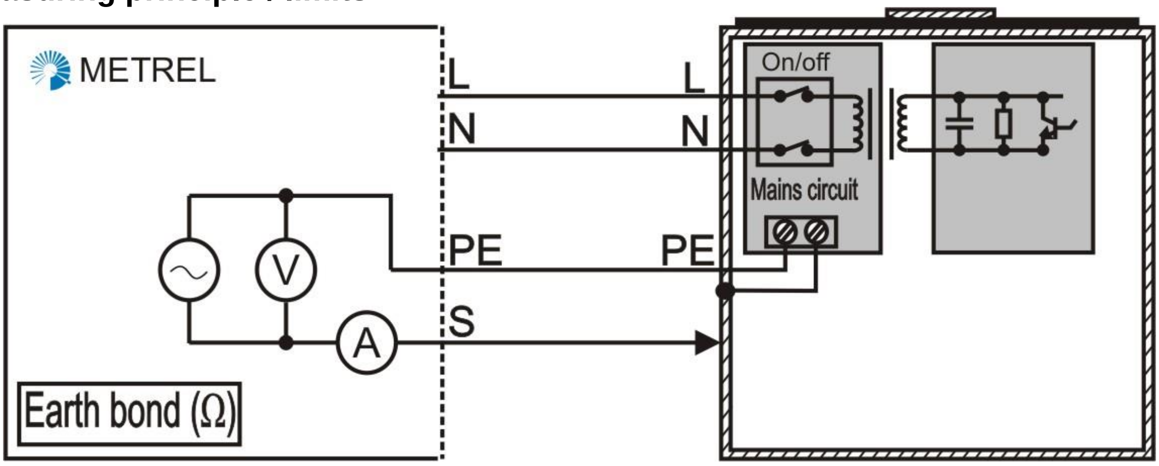


Figure 4-4: Earth bond test

Test signal is applied between PE pin of the supply cord and accessible conductive parts connected to the PE.

Notes:

- Flexible supply cords must be folded during test! If the result is changing during the measurement this means that the test failed.
- Care should be taken to assure a good contact between probe and conductive parts of tested appliance. Especially at expected results below 0.3 Ω the result could be affected by contact resistance.
- Some (IT) equipment may have accessible conductive parts that are earthed only for screening purposes. These non-safety parts are not subjected to the earth bond test. Such connections may be checked with low currents (100 mA, 200 mA).

- Galvanic separation of measuring circuit is preferred (obligatory for VDE tests). Otherwise additional current paths via ground can occur (through uninsulated floor, other connections with earth like EMC shields etc.). That can result in too low readings.

4.4.3 Insulation

Scope of test
Insulation resistance between live conductors and all accessible conductive parts (earthed and isolated) is checked. This test discloses faults caused by pollution, moisture, deterioration of insulation material etc.

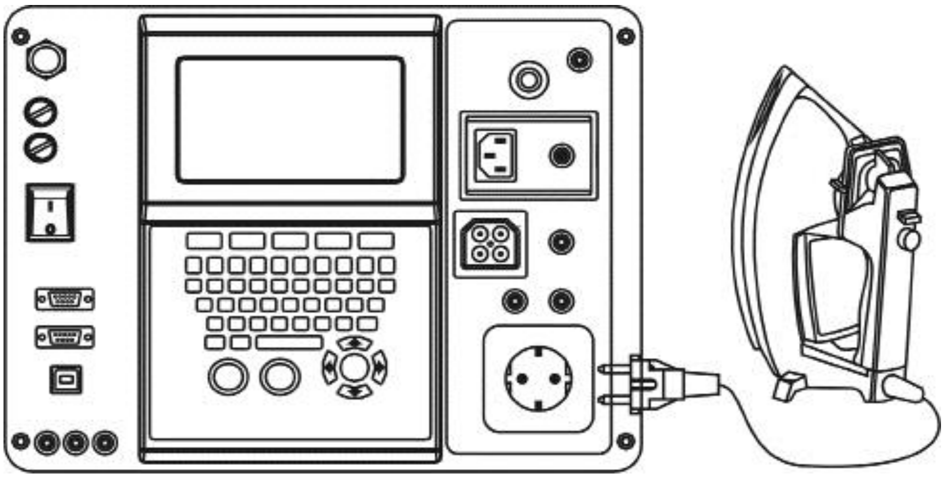


Figure 4-5: Insulation resistance test for Class I device

The capacitive part of leakage currents is not measured because of the DC test voltage.

High DC voltage test signal is applied between connected live pins and PE contact of supply cord. Unearthed accessible metal parts are NOT included in this test and are measured as Class II items.

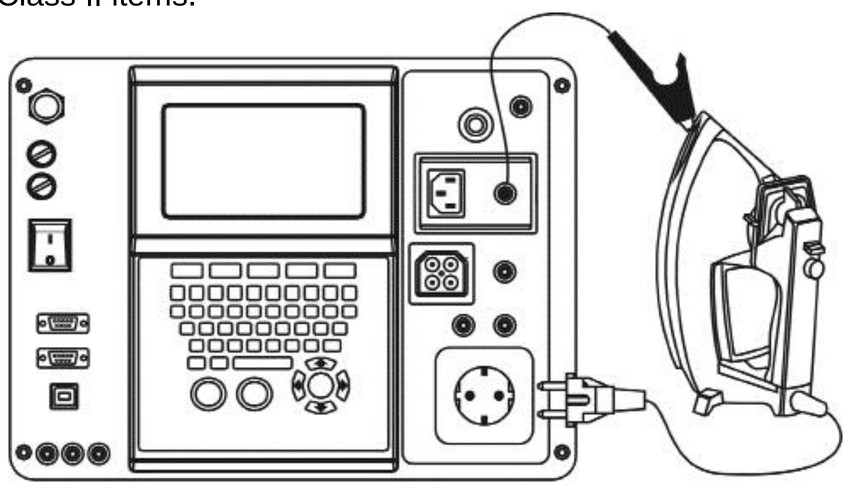


Figure 4-6: Insulation resistance test for Class II device

High DC voltage test signal is applied between connected live pins and accessible isolated metal part.

Examples of faults

Fault: Decreased insulation resistance between live parts and isolated accessible conductive part. Typical reasons are dirt, dust, moisture. Slots and openings in the enclosure are especially critical.

Result: Dangerous contact voltage on accessible conductive parts not connected to protective circuit. There is a risk of electrical shock if this part would be touched.

Fault: Deteriorated insulation between live parts and earthed conductive parts in the appliance.

Result: Too high leakage current, tripping of RCDs, sparking, overheating of appliance.

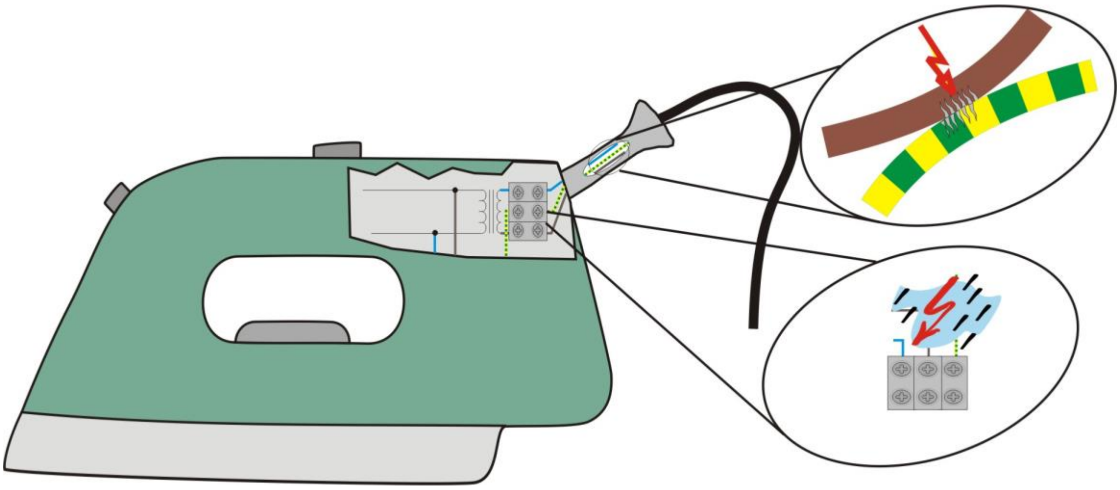


Figure 4-7: Examples of insulation faults

Measuring principle / limits:

Measurement on a class I appliance:

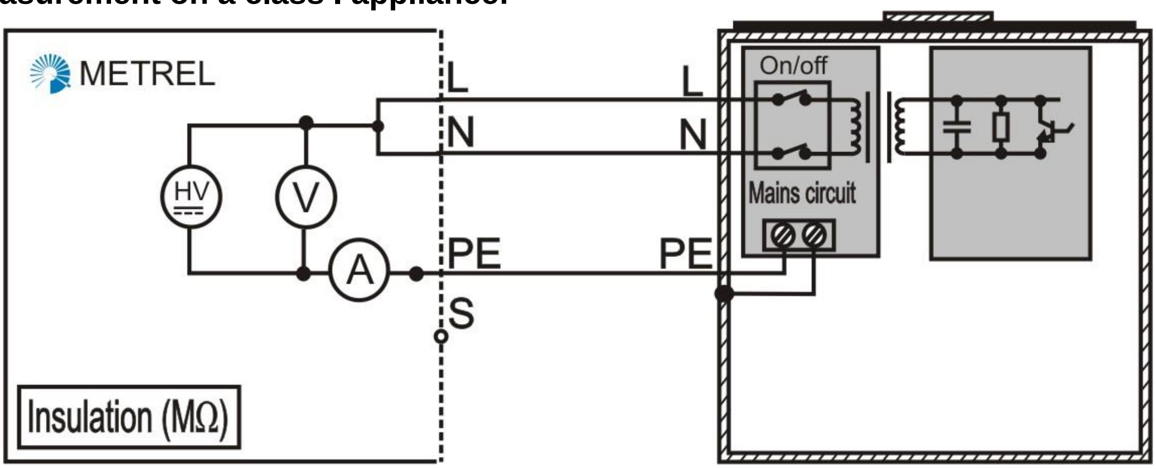


Figure 4-8: Example of the insulation test on a Class I appliance

High DC voltage test signal is applied between connected live pins and PE contact of supply cord. Unearthed accessible conductive parts are NOT included in this test and are measured as Class II items.

Measurement on a class II appliance:

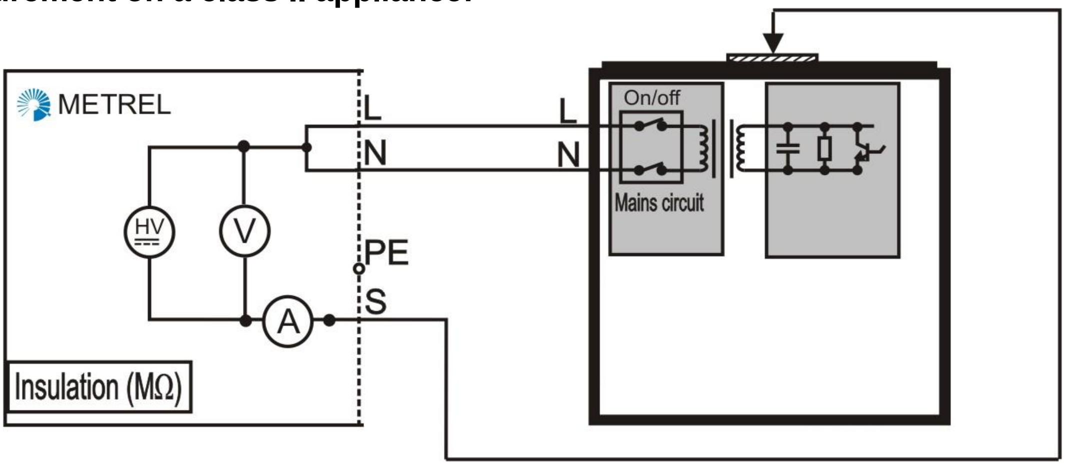


Figure 4-9: Example of the insulation test on a Class II appliance

High DC voltage test signal is applied between connected live pins and accessible conductive parts separated from protective circuit. Each accessible conductive part shall be tested separately.

Notes:

- On/Off switches must be closed. If after the switches were closed all safety relevant parts are not included the results will be impaired. This is often the case in electronic or relay driven On/Off circuits. In this case leakage current tests can be performed as an alternative.
- This test cannot be applied on Class II appliances without accessible conductive parts.
- The sub-leakage test is recommended to be performed after the insulation test too.
- Test voltage level is usually selected in the same level as maximum possible supply voltage.
- IT equipment not designed according to EN 60950 can be damaged by the 500 V test voltage.

4.4.4 Sub-leakage test

Scope of test

Overall impedance between live conductors and all accessible conductive parts (earthed and isolated) is checked with this test. Capacitive leakage paths (input filter capacitors, transformers, cables…) are included in the result, too.

In this test the live and neutral conductors of the appliance are shorted together and voltage of 30 - 50 V AC is applied between this point and either the earth conductor (class I) or the probe connected to any exposed conductive part (class I and class II). The test measures how much current passes from the live conductors into the test point.

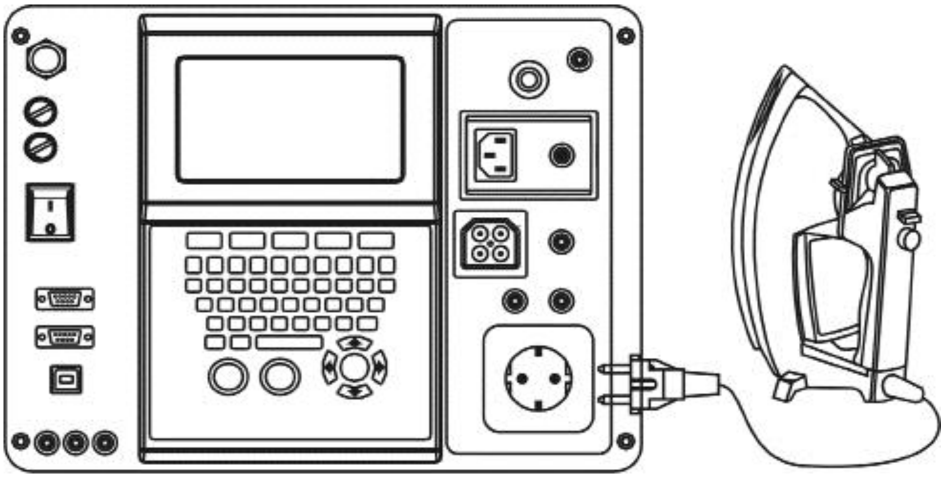


Figure 4-10: Substitute leakage test for Class I device

AC test signal is applied between connected live pins and PE contact of supply cord. Isolated accessible metal parts are NOT included in this test and are measured as Class II items.

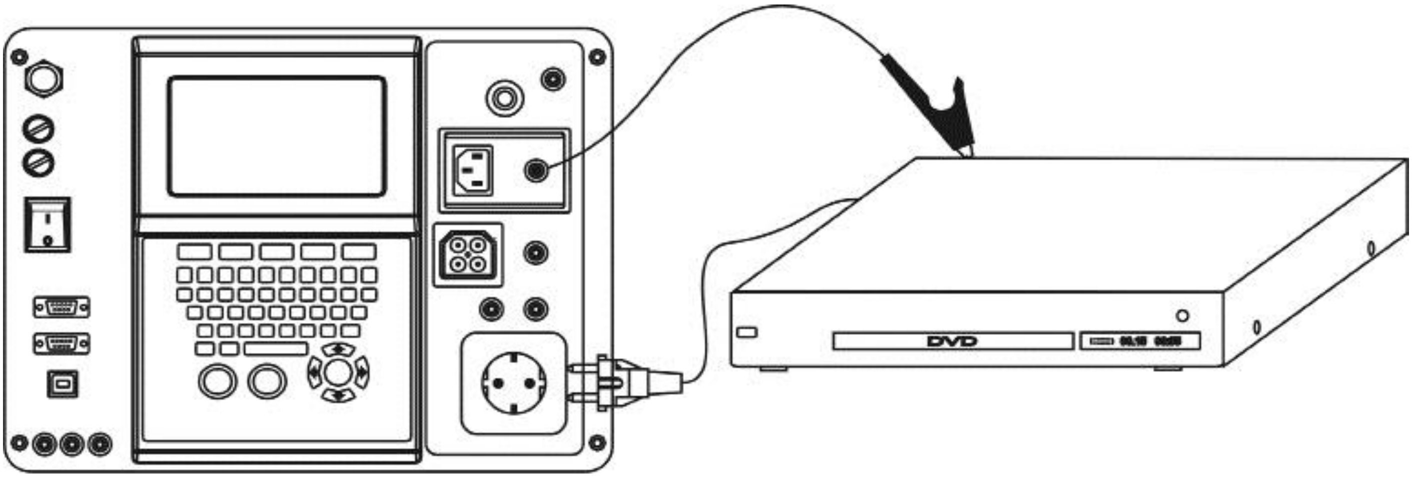


Figure 4-11: Substitute leakage test for Class II device

AC test signal is applied between connected live pins and accessible isolated metal part.

Examples of faults

Fault: Decreased insulation between live parts and isolated accessible conductive part caused by dirt, dust, moisture etc.

Result: Dangerous contact voltage on accessible conductive part. There is a risk of electrical shock if this part would be touched.

Fault: As the insulation in appliance between live and earthed parts deteriorates the overall leakage current can increase over the safety leakage limit level.

Result: Too high leakage currents result in tripping of RCDs. Bad insulation can result in sparking and local overheating of appliance. This is especially dangerous in case of bad earthing of the installation.

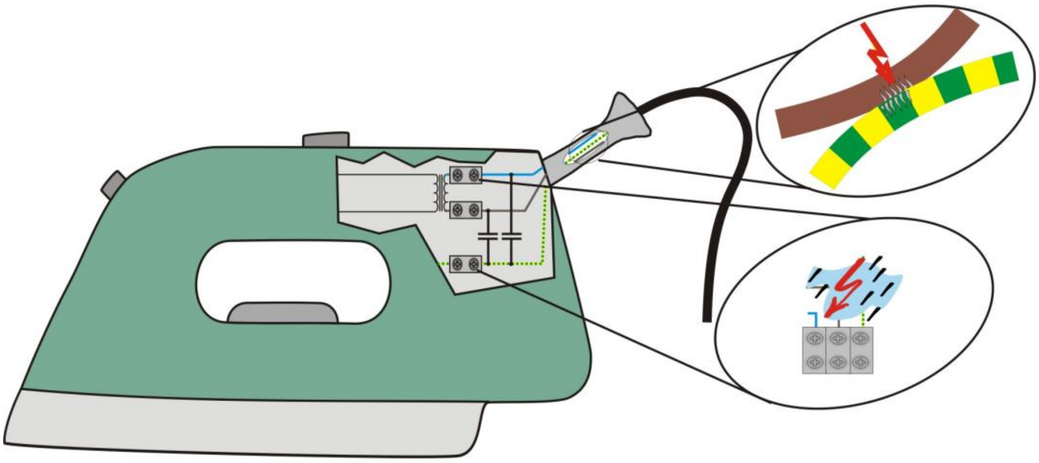


Figure 4-12: Examples of excessive leakage currents

Measuring principle / limits
Measurement on a class I appliance

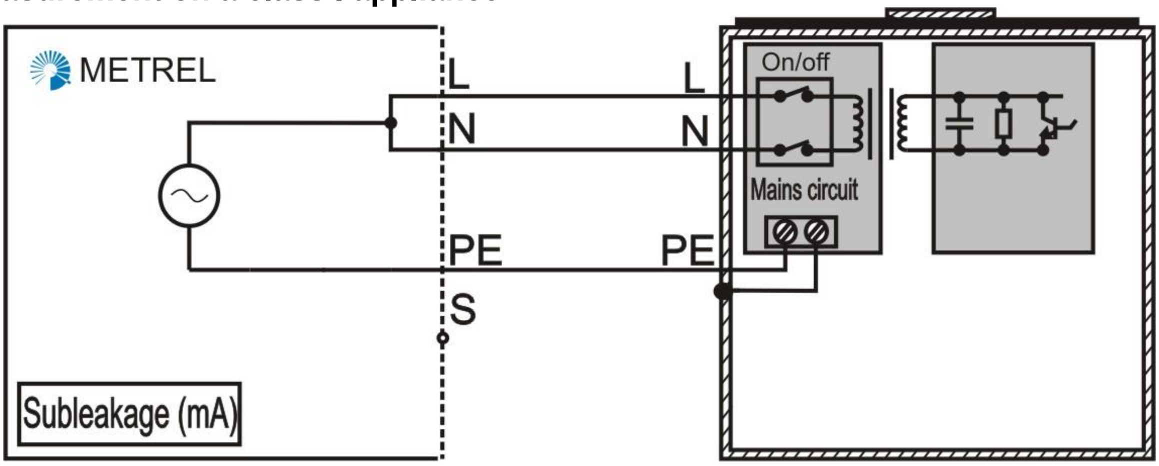


Figure 4-13: Example of sub-leakage test on a Class I appliance

AC test signal is applied between connected live pins and PE contact of supply cord. Accessible conductive parts not connected to protective circuit are NOT included in this test and are measured as Class II items.

Measurement on a class II appliance.

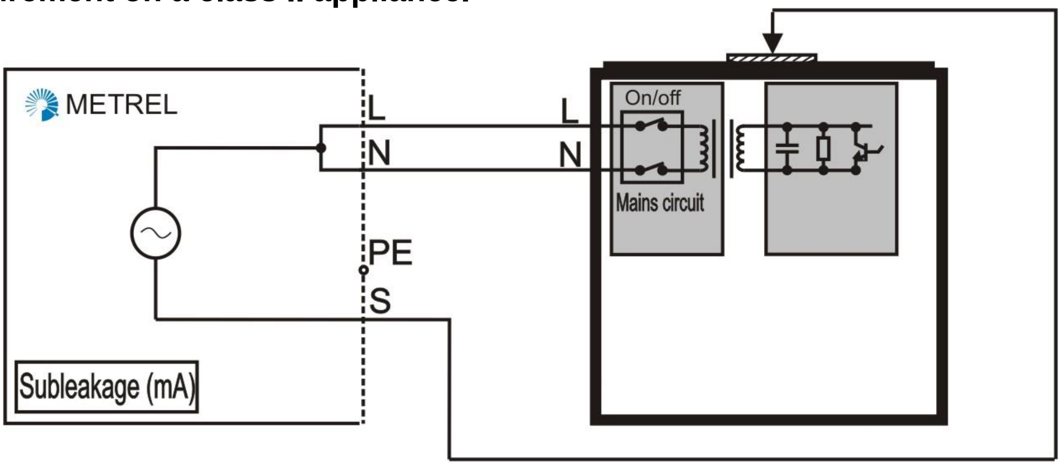


Figure 4-14: Example of sub-leakage test on a Class II appliance

AC test signal is applied between connected live pins and accessible conductive parts not connected to protective circuit. Each accessible part shall be tested alone.

Notes:

- On/Off switches must be closed. If after switches were closed all safety relevant parts are not included the results will be impaired. This is often the case in electronic or relay driven On/Off circuits. In this case or if in doubt leakage current tests can be performed as an alternative.
- This test cannot be applied on Class II appliances without accessible conductive parts.
- Appliances with leakage currents >3.5mA should be marked.
- This measurement returns similar results as leakage tests on powered appliances. The sub-leakage result is usually higher (up to 2 times) because of connected L and N conductors.
- The sub-leakage test is suitable for IT appliances (at connected mains voltage the test must last longer to allow booting up the equipment).

4.4.5 Leakage current tests – general

Scope of test

In this test the sum of leakage currents caused by appliance insulation resistances (resistive currents through the insulation material, fault currents through decreased insulation) and capacitances (capacitive leakage current) is checked. Even leakage currents in range of mA are dangerous. The danger increases if the installation is not properly earthed.
Excessive leakage currents are most often caused by deterioration of the appliance insulation (pollution, ageing, moisture) or faults in mains circuits of appliances.

In general three leakage currents are measured: the differential leakage current, the PE conductor (direct) leakage current and the touch leakage current.

4.4.6 PE conductor leakage current test

This test is sometimes called direct leakage test too.

Scope of test
See chapter 4.4.5 Leakage current tests – general for more details.

Examples of faults
See chapter 4.4.4 Sub-leakage test for more details.

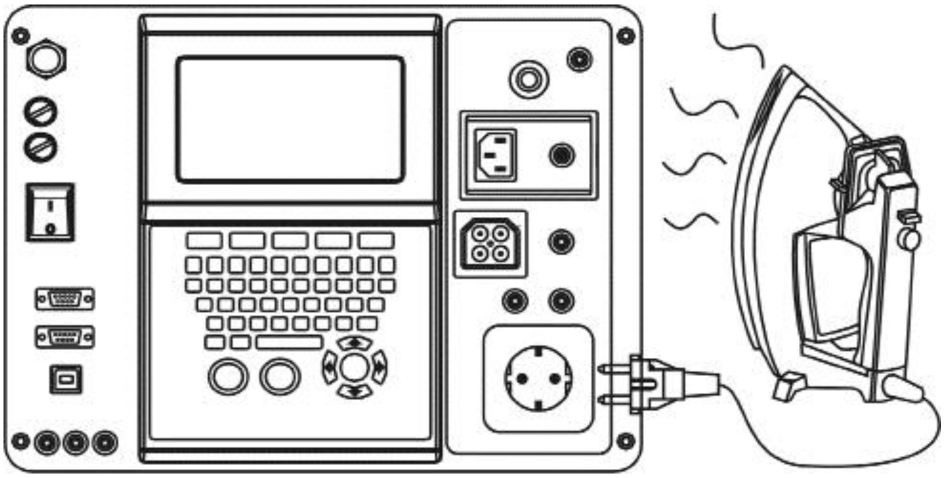


Figure 4-15: PE conductor leakage current test for Class I device

Measuring principle / limits
Measurement on Class I appliance:

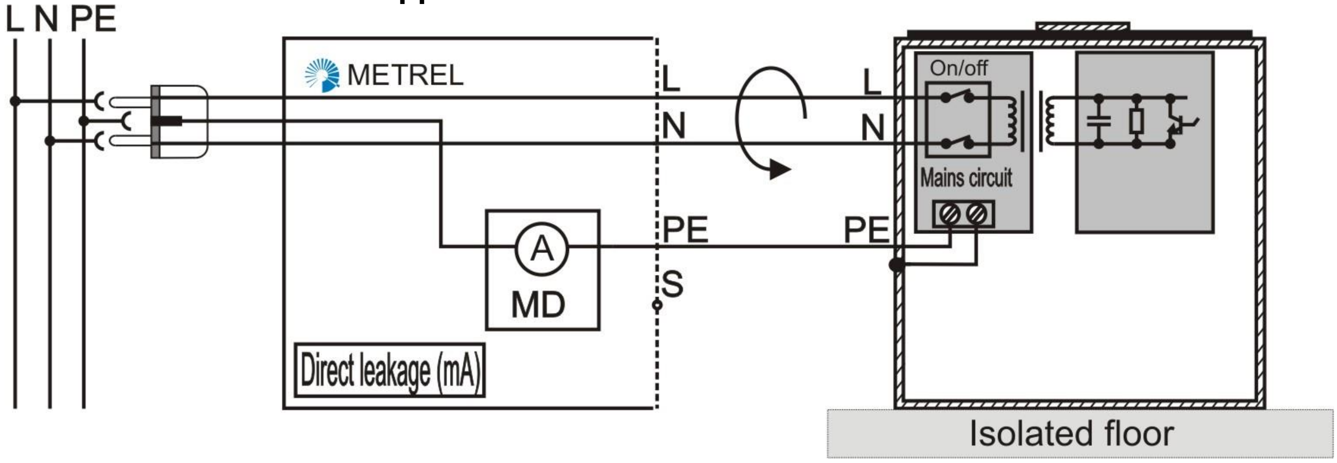


Figure 4-16: Example of the PE conductor current test

The appliance must be powered on. The current flowing through the appliance PE conductor is measured.
The appliance must be placed isolated against ground to prevent that a part of the leakage current would flow directly to ground instead through the PE conductor and ground. This is the main defectiveness compared to the differential leakage test.
Unearthed accessible conductive parts are not included in this test. They are considered as class II parts and are checked in the Touch Leakage test.

Notes:

- If leakage currents differ for different appliance operating modes all modes must be checked. The highest result (it is the worst) must be considered!

- If the position of line and neutral conductor in the installation or appliance plug is not predefined, the test must be performed in both directions with higher result considered.

4.4.7 Differential leakage current test

Differential leakage measures the difference in current between the live and neutral cable which provides a true value of how much current the appliance leaks to ground.

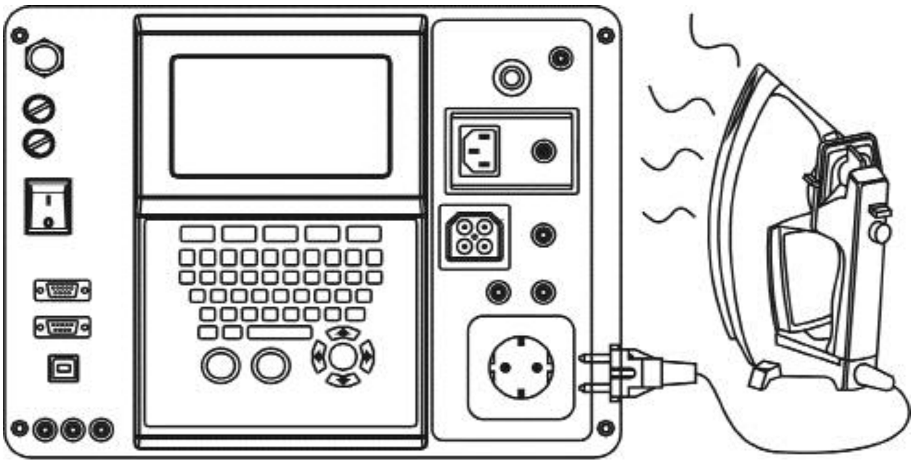


Figure 4-17: Differential leakage current test for Class I device

Scope of test
See chapter 4.4.5 Leakage current tests – general for more details.

Examples of faults
See chapter 4.4.4 Sub-leakage test for more details.

Measuring principle / limits
Measurement on Class I appliance:

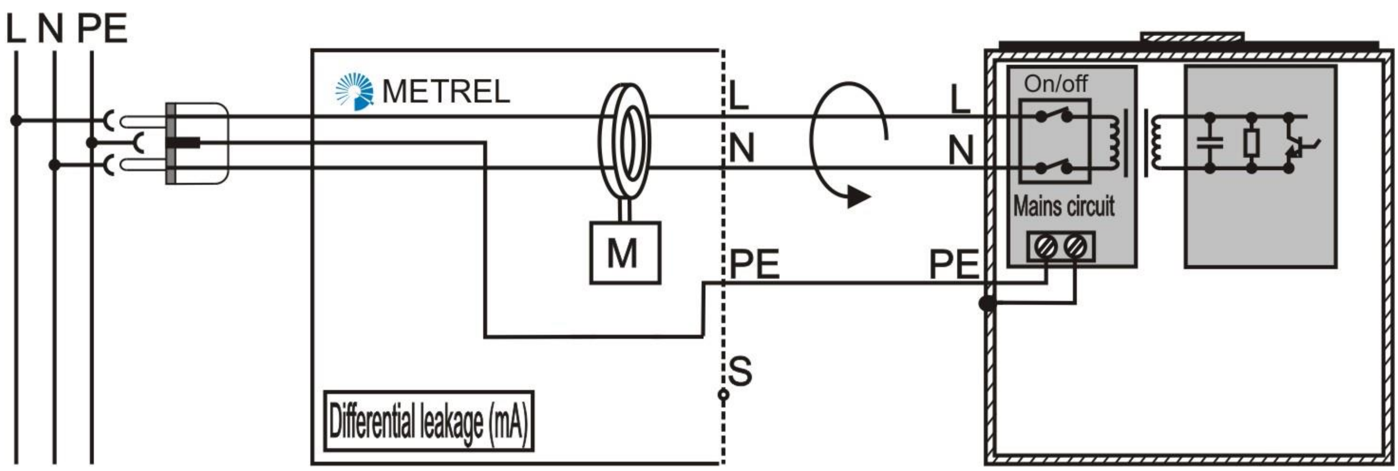


Figure 4-18: Example of differential leakage current test

The appliance must be powered on. The leakage current is measured as the difference of currents through L and N supply conductors. The result does not depend on what floor the appliance is placed.

Unearthed accessible metal parts are not included in this test. They are considered as class II parts and are checked in the Touch Leakage test.

Typical limits:
~~For limits and parameters see chapter *3.6 PE conductor leakage current test*.~~
~~Measuring equipment designed according to VDE404 must have specified frequency response from 40 Hz to 1 MHz (M characteristic).~~

Notes:

- If leakage currents differ for different appliance operating modes all modes must be checked. The highest result must be considered!
- If the position of line and neutral conductor in the installation or appliance plug is not predefined, the test must be performed in both directions with higher result considered.
- The differential leakage current test is preferred compared to the PE conductor test since placing the appliance on conductive floor does not disturb the measurement result.

4.4.8 Touch leakage test

Scope of test
The leakage (capacitive, resistive, fault) current is a current that would flow via the isolated accessible metal part (if touched) through body to ground are measured in this test.

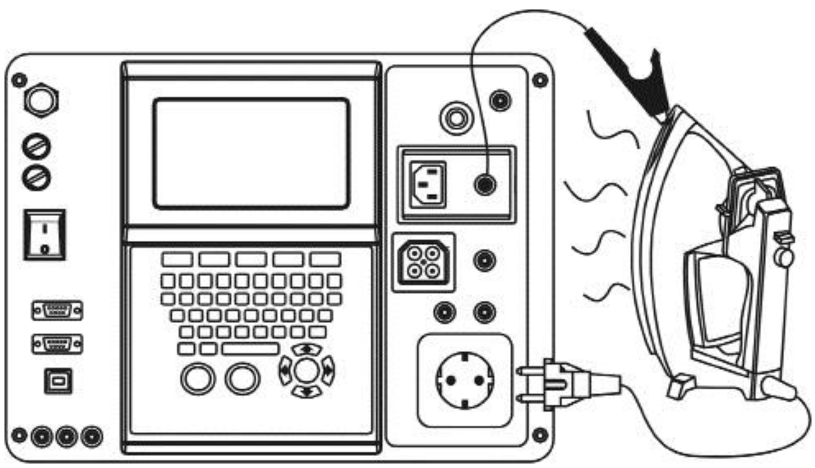


Figure 4-19: Touch leakage current test for Class II device

Appliance must be powered on. The current through the isolated accessible metal parts is measured (each part separately).
The measuring probe simulates the human body and is grounded inside the measuring instrument.

Examples of faults
Fault: Decreased insulation between live parts and isolated accessible conductive part because of dirt, dust and moisture.
Result: Dangerous contact voltage on accessible conductive part. There is a risk of electrical shock if this part would be touched.

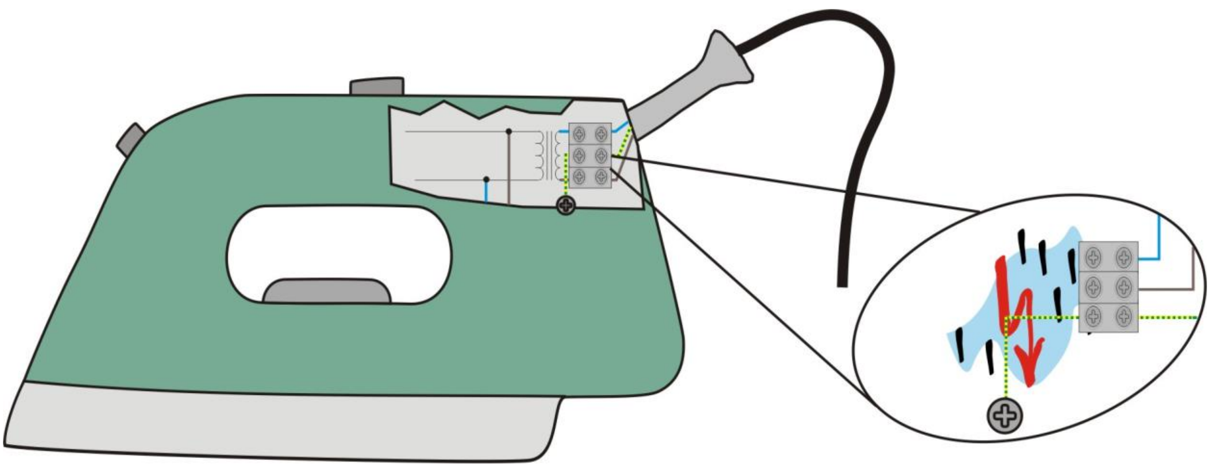


Figure 4-20: Example of excessive touch leakage

Measuring principle / limits:
Measurement on a class II appliance (same procedure is used for isolated accessible conductive parts on class I appliances).

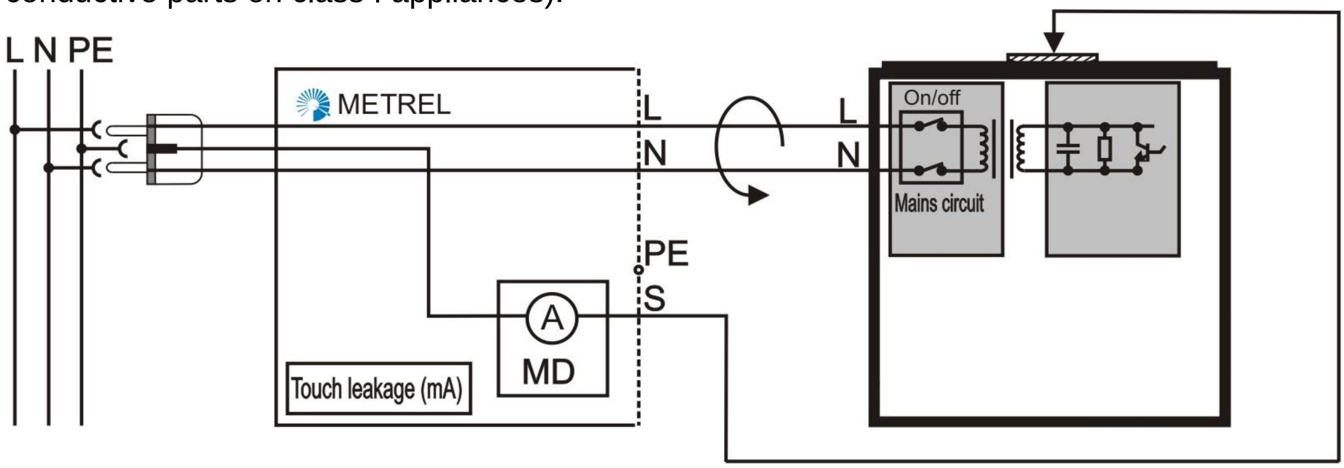


Figure 4-21: Example of excessive touch leakage

Notes:

- Each isolated accessible conductive part must be checked separately. The highest results must be considered.
- This is an alternative measurement if insulation and subleakage tests are questionable.
- This is often the only applicable leakage measurement if supply is not allowed to be interrupted.
- If touch leakage currents differ for different appliance operating modes all modes must be checked. The highest result must be considered!
- If the position of line and neutral conductor in the installation or appliance plug is not predefined, the test must be performed in both directions with higher result considered.
- The measuring instrument must be well grounded during the test.

4.4.9 Polarity test

Scope of test

The polarity test checks the correctness of polarity of IEC leads, prolongation cords etc. With this test shorts, crossed and opened wires in cords can be found. This test is obligatory in countries (e.g. UK, Australia) where the position of line and neutral conductors is predefined. With the polarity test shorts, crossed and opened wires in cords can be found.

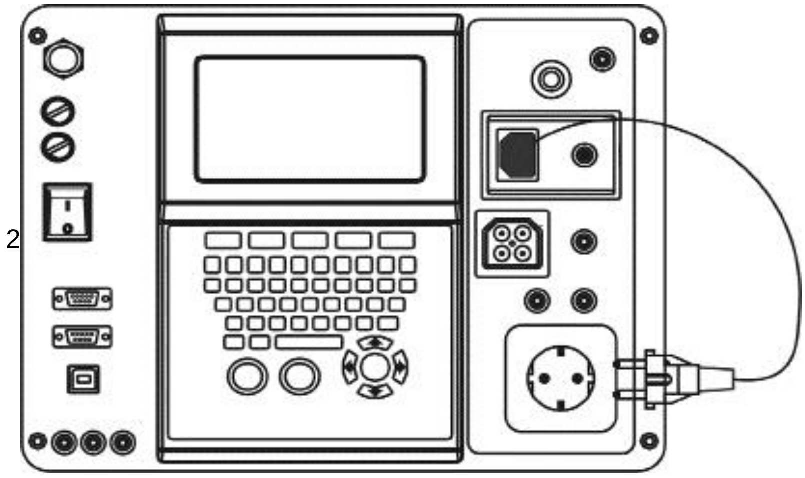


Figure 4-22: Polarity test

Examples of faults

Fault: L and N wires are crossed in the prolongation cord.
Result: the protection circuit installed in the L input of the appliance will not be functional.

Fault: L and N wires are crossed in the supply lead.
Result: the fuse installed in the appliance's L wire will blow only in a case of a short between L and N but not in a L to PE short.

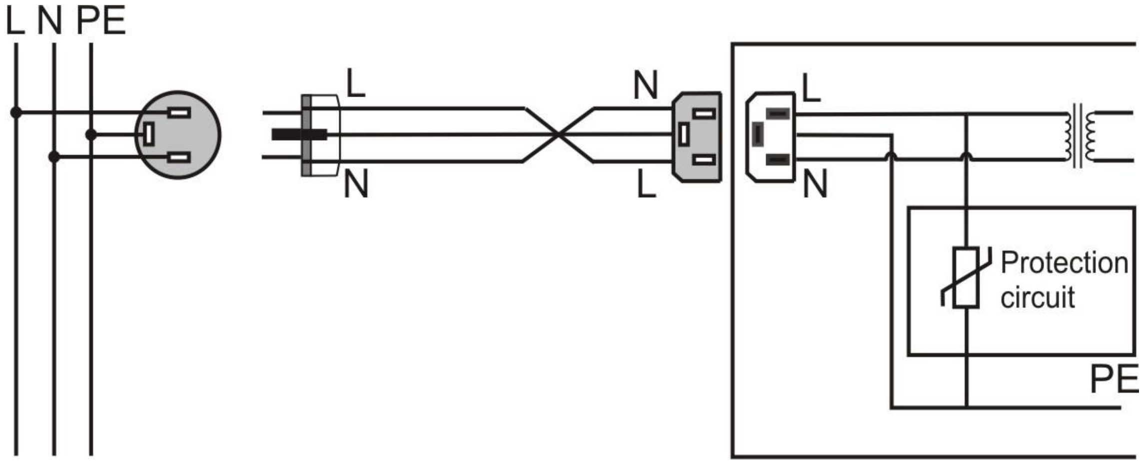


Figure 4-23: Failure of wires polarity

Measuring principle / limits

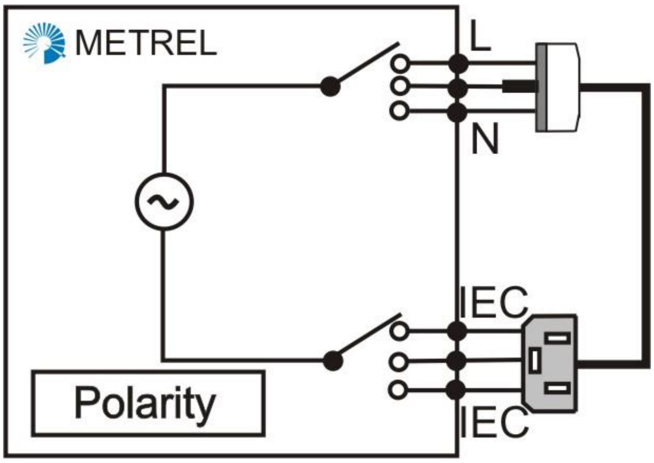


Figure 4-24: Example of the polarity test

4.4.10 Load and leakage currents (measurement with current clamps)

Advantages of clamp measurements are:

- Measured electrical equipment does not need to be disconnected from the mains.
- Selective current tests can be performed by embracing individual conductors.
- Individual currents can be measured without disconnections.

Scope of test – load currents

Current clamp is a standard measuring transducer for power and load measurements. For AC currents from 100mA up to several 1000AAC measuring with current clamps is simple and quite accurate. Current clamps are best suited:

- For functional testing of fixed installed appliances.
- For functional testing of appliances with nominal currents >16A.
- For troubleshooting of current paths in appliances.

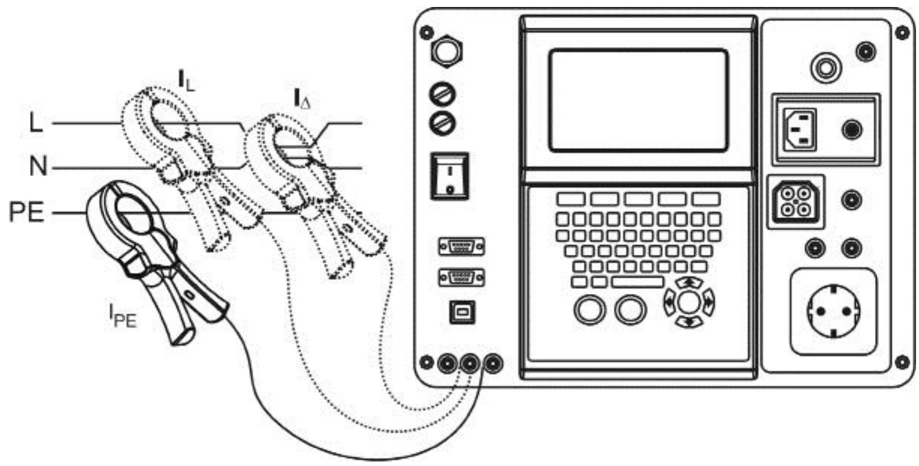


Figure 4-25: Current measurement with current clamps

Appliance must be powered on. By embracing separate conductors load or leakage currents can be measured.

Scope of test – leakage currents
With current clamps leakage currents can be measured too. However this measurement has many serious drawbacks:

- Results are not accurate. They are strongly influenced by external magnetic and electric fields (caused by load currents, big conductive surfaces close to voltage sources etc). At currents below 10mA the influences can likely make the results unusable.
- Embracing all live and neutral conductors in a single and three phase system would theoretically return the leakage current. This principle often does not work well in practice.

Therefore measuring of leakage currents range of several mA cannot be treated as accurate. A lot of presumptions and experience of the user are needed to obtain relevant results.
~~Local regulations must be checked whether the current clamp leakage test results can be considered as relevant.~~

Examples of faults for which troubleshooting with current clamp is recommended
Fault: A propeller of pump is sticked in the fixed installed appliance. High supply currents are flowing while the pump is supposed to work.
Result: High fault currents can result in dangerous overheating in the appliance. This can cause fire!

Fault: A powerful heater with high nominal leakage was fixed installed.
Result: Occasional tripping of the RCD. Dangerous contact voltages can occur on accessible conductive parts if the electrical installation is not designed properly.

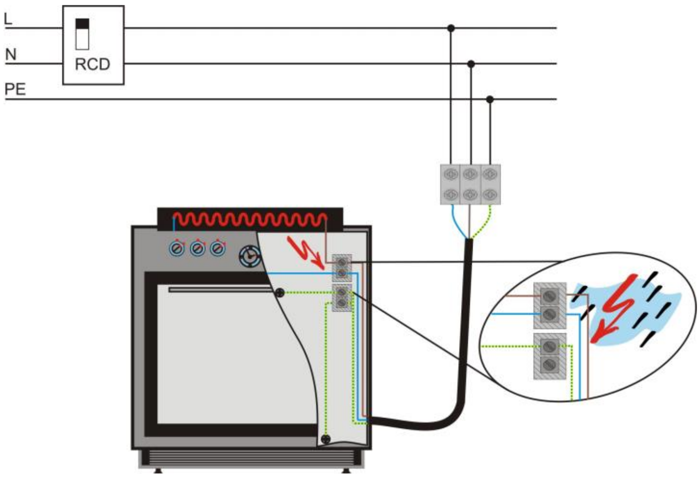


Figure 4-26: Functional and leakage problems

Measuring principle /limits

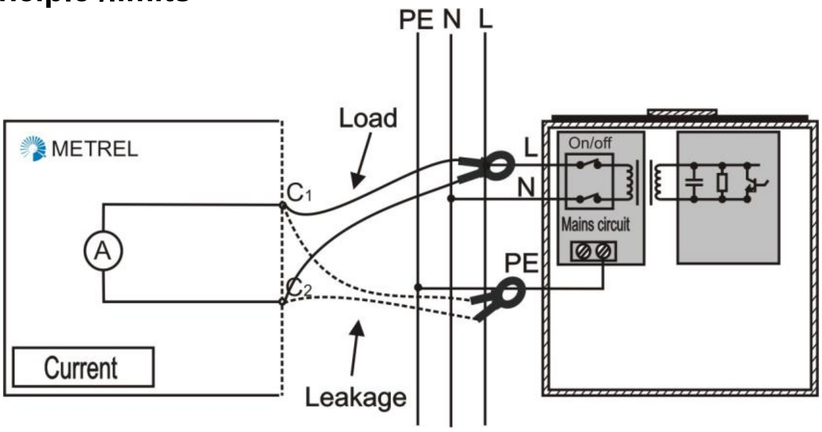


Figure 4-27: Examples of clamp current tests

Appliance is powered on. By embracing separate conductors load or leakage currents can be measured.

Notes:

- For leakage current measurements special current clamps must be used (eg METREL A1019)
- If large load currents (>1A) are present in the nearness they would almost certainly disturb the leakage current results (too high readings).
- It is advisable that the user learns to become familiar with the influence of external fields. If the source of disturbance is known the influence can be minimized by using different techniques (changing the position of the clamp, placing the clamp close to earth potential, searching for the minimal reading etc).
- If in doubt it is recommended to use other leakage measuring methods.
- If leakage currents differ for different appliance operating modes all modes must be checked. The highest result must be considered!
- If the position of line and neutral conductor in the installation or appliance plug is not predefined, the test must be performed in both directions with higher result considered.
- The current clamp measurement is well suited for fixed installed equipment.

4.4.11 Functional test

Scope of test

In its simplest form a functional check is simply a check to ensure that the appliance is working properly. The use of more sophisticated measuring instruments permits load testing, which is an effective way of determination if there are faults in the appliance.

Functional check explores if the appliance is working properly. The use of more sophisticated measuring instruments permits load testing, which is an effective way of determination if there are faults in the appliance.

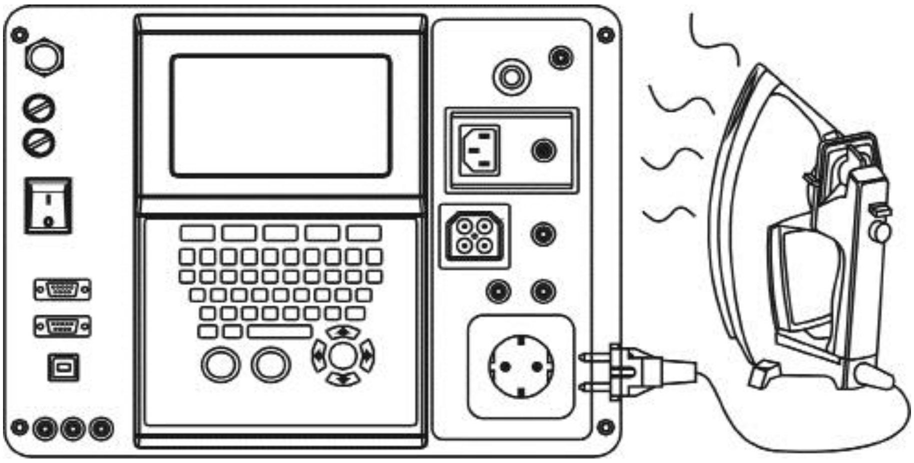


Figure 4-28: Functional test

Examples of faults

Fault: Improper assembling of appliances after repair is one of the common reasons for functional faults.
Fault: The possibility for failures is higher if appliances are working in dusty and moisturized environment, or if they used only occasionally.
Result: Improper operation of appliance, tripping of overcurrent disconnection devices.

Measuring principle / limits

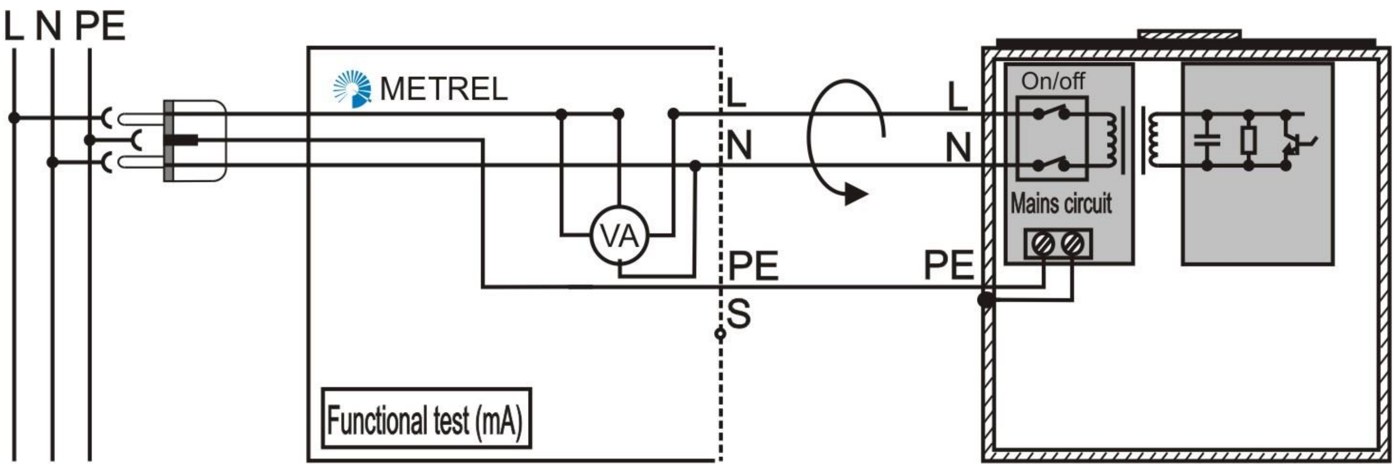


Figure 4-29: Example of functional tests

Appliance is powered on. The load current and supply voltage are measured in the measuring instrument. Load power or/and current are displayed on the measuring instrument.

Notes:

- All appliance operating modes should be considered.
- The functional test is performed as the last step of a safety test sequence. It should be run only if all previous safety tests passed successfully! The functional test would rarely disclose a safety problem!

- This test is recommended after maintenance or repairing works. On appliances that are used in harsh environment (dust, moisture, heat) it is wise to include the functional test as a part of a periodic test too.

4.4.12 PRCD test

This test checks how long it takes for a portable RCD to trip out in the case that a fault occurs.

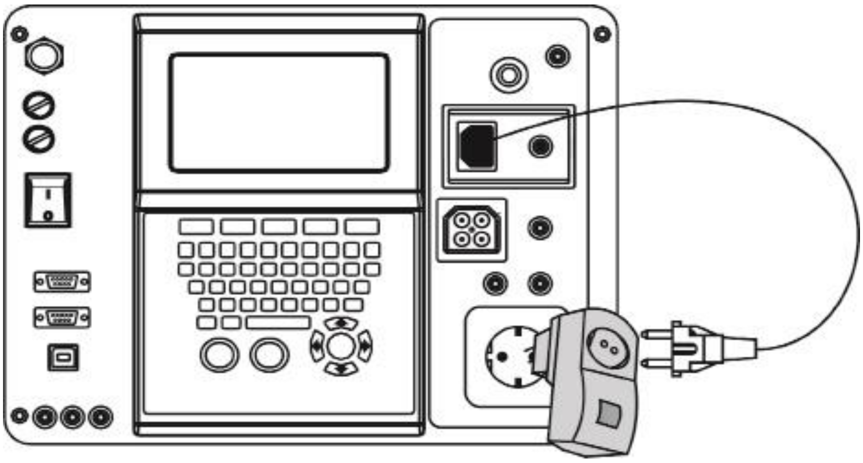


Figure 4-30: PRCD testing

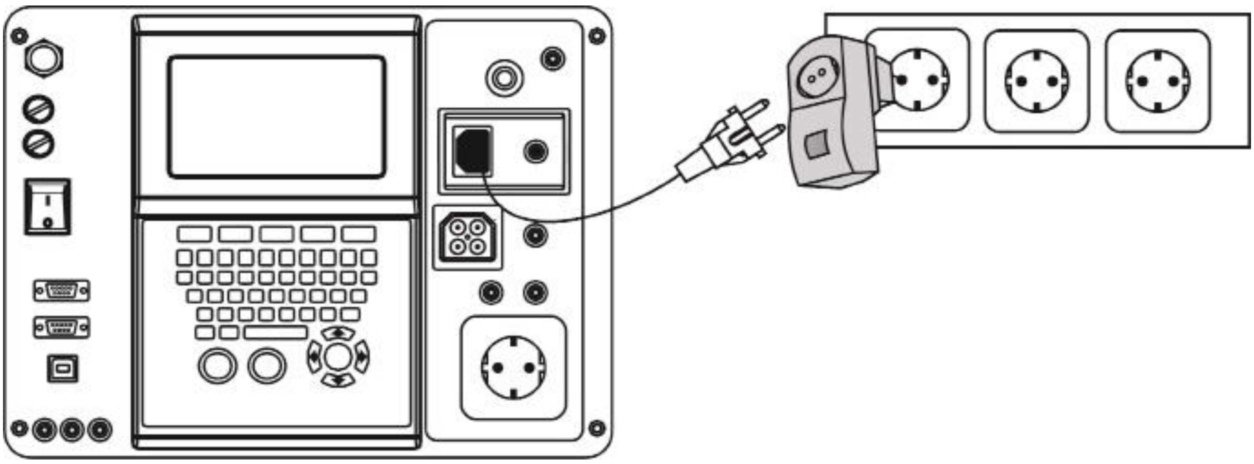


Figure 4-31: PRCD testing

4.4.13 Active polarity test

This test provides testing of PRCD protected cords while voltage is applied to tested object.

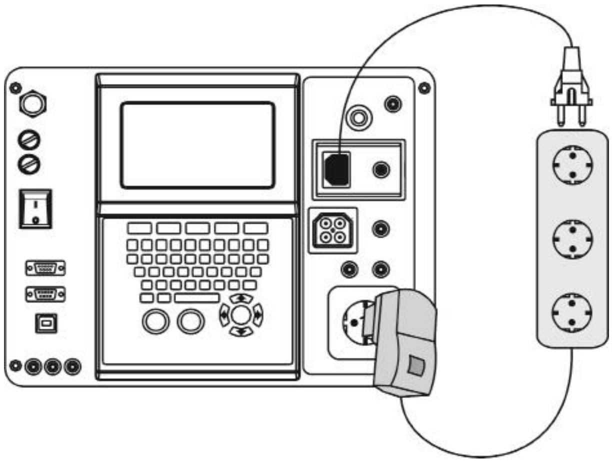


Figure 4-32: Active polarity test

4.5 Testing the safety of machines and switchboards

4.5.1 Find out more about testing safety of machines.

Typical hazardous situations related to electrical equipment are:

- Failures or faults in the electrical equipment resulting in the possibility of electric shock or electrical fire.
- Failures or faults in control circuits resulting in the malfunctioning of the machine.
- Disturbances or disruptions in power sources as well as failures or faults in the power circuits resulting in the malfunctioning of the ma-chine.
- Loss of continuity of circuits that depends on sliding or rolling contacts, resulting in failure of a safety function.
- Electrical disturbances either from outside the electrical equipment or internally generated, resulting in the malfunctioning of the machine.
- Release of stored energy (either electrical or mechanical) resulting in electric shock or unexpected movement that can cause injury.
- Audible noise at levels that cause health problems to persons.
- Surface temperatures that can cause injury.

To verify the electrical safety of machines the appropriate measurements should be performed:

- After erection of machine.
- After installation of machine.
- After upgrading or changing of machine.
- During periodic retests of machine.

4.5.2 Verification of safety of machines

According to IEC/EN 60204, Ed.5 verification of electrical safety of machines is performed by inspection and measurements:

- Inspection that the electrical equipment complies with its technical documentation.
- Verification of protection against indirect contact by automatic disconnection.
- Insulation resistance test.
- High voltage test.
- Protection against residual voltages.

- Functional tests.

4.5.3 Safety – measurements

Testing the safety of machines and switchboard uses the same testing techniques as when performing PAT tests. In addition to those five more tests have to be performed where the functional test an actual enhancement of the PAT test:

- High voltage withstanding test
- Loop impedance and prospective fault current
- RCD testing
- Discharge Time
- Functional test

4.5.3.1 High voltage withstanding test

The HV withstanding test is used to confirm integrity of the insulation materials. During the test the insulation materials in the machine are stressed with a higher voltage than during normal operation. A powerful AC high voltage source is applied between the live/ neutral input terminals and the metal housing of the machine. The instrument trips out if the leakage current exceeds the predefined limit.

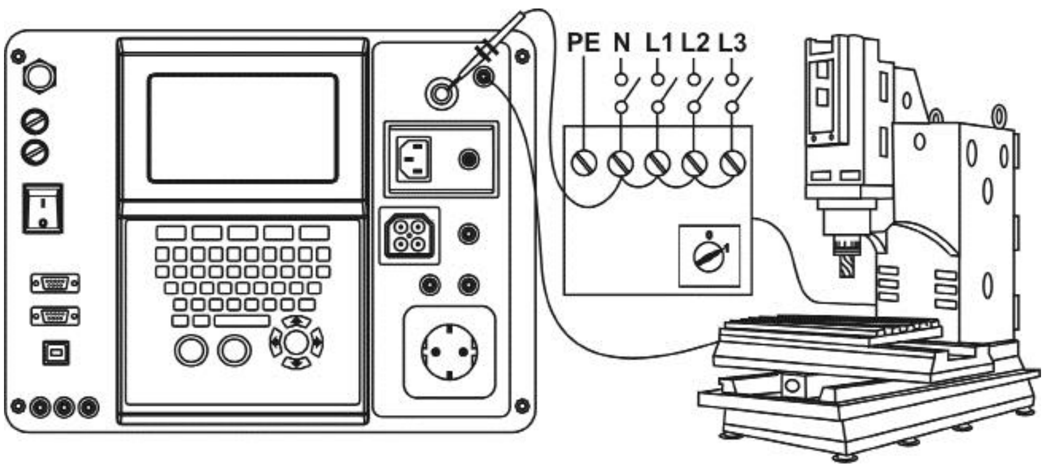


Figure 4-33: HV withstanding test

Components and devices that are not rated to withstand the test voltage shall be disconnected during the testing. Components and devices that have been voltage tested in accordance with their product standards may be disconnected during testing.

4.5.3.2 Loop impedance and prospective fault current

The instrument measures the impedance of the fault loop and calculates the prospective fault current. The results can be compared to limit values set on base of selected protective circuit breakers or RCDs. The measurement complies with requirements of the standard EN 61557-3.

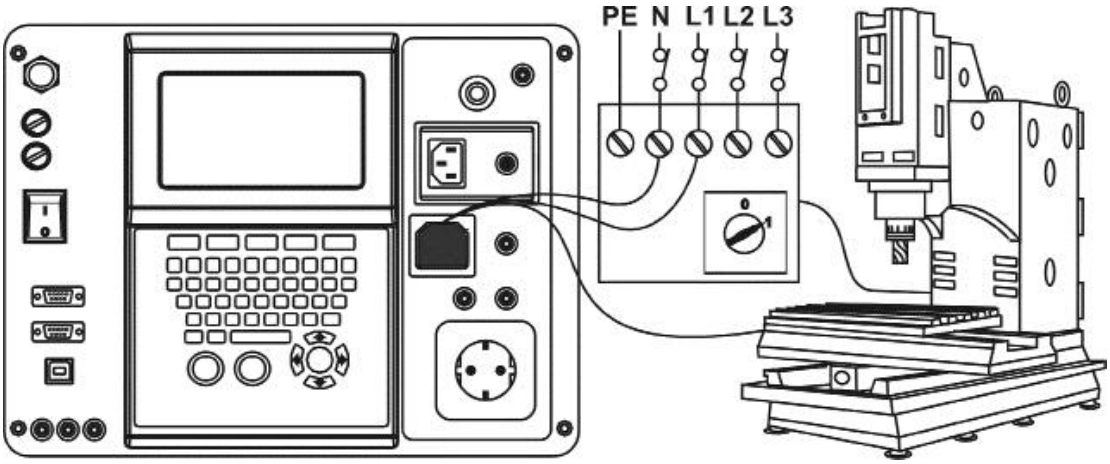


Figure 4-34: Loop impedance test

4.5.3.3 RCD testing

Various test and measurements are required for verification of RCDs in RCD protected machines. Measurements are complies to the EN 61557-6 standard. The following measurements and tests can be performed:

- Contact voltage.
- Trip-out time.
- Trip-out current.
- RCD autotest.

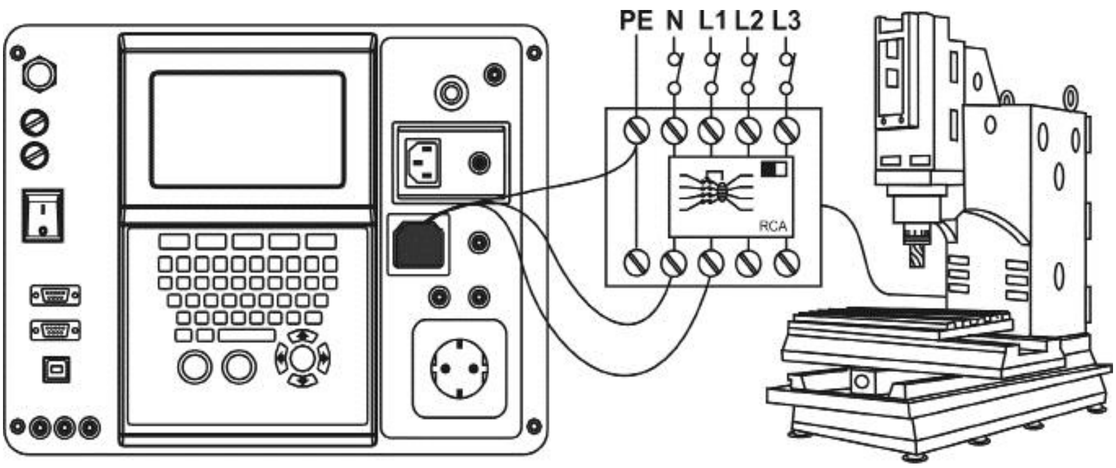


Figure 4-35: Testing of RCD in RCD protected machine

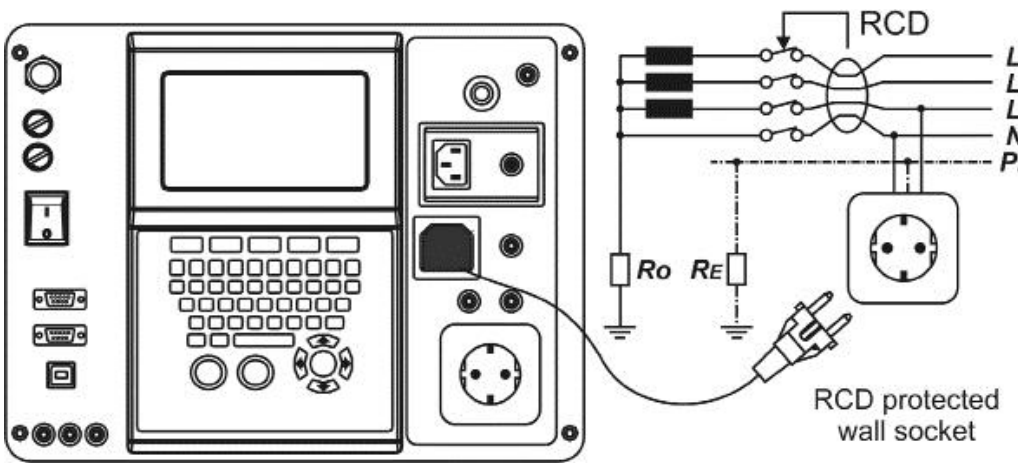


Figure 4-36: Testing of RCD in electrical installation

4.5.3.4 Discharge Time

If large capacitors in machines are disconnected from supply there is often a remaining (residual) charge on internal machine components. Live parts having a residual voltage greater than 60 V after the supply has been disconnected, shall be discharged to 60 V or less within a time period of 5 s after disconnection of the supply.
For plugs or similar devices with exposed conductors (for example pins) if plugged out it shall be discharged to 60 V or less within a time period of 1 s after disconnection of the supply.

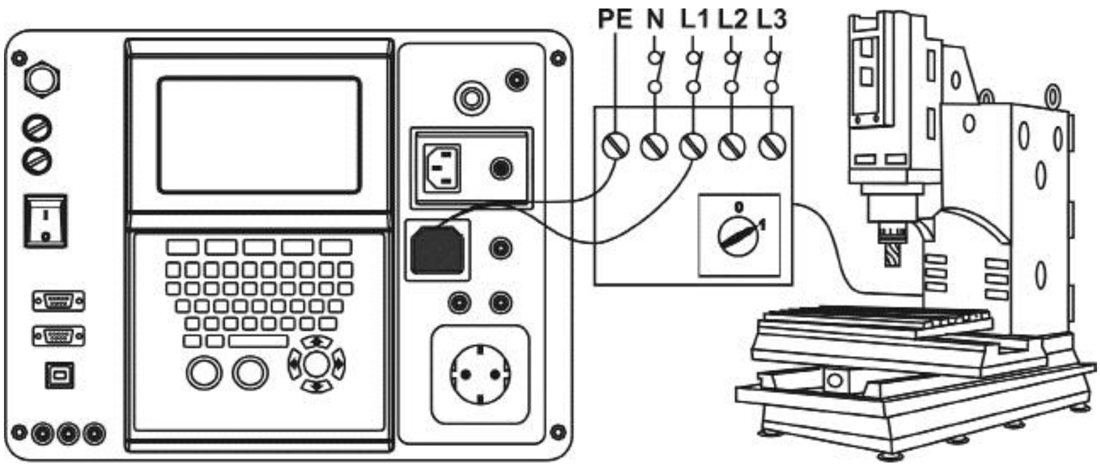


Figure 4-37: Discharge time test

4.5.3.5 Functional test

Functional check explores if the machine is working properly. Following items should be checked while the machine is operating:

- Temperature regulators, monitors.
- RCDs and other disconnection devices.
- Operation of functional disconnecting devices.
- Operation of switches, lamps, keys.
- Rotating parts, motors, pumps.

5 Demonstration tables information

5.1 General notes

- The description tables contain the following information:
  - Simulated values for normal and error conditions (“Error values”).
  - Indicative test results for typical measurements.
  - Position where simulated errors are applied in brackets under “Simulation between contacts”

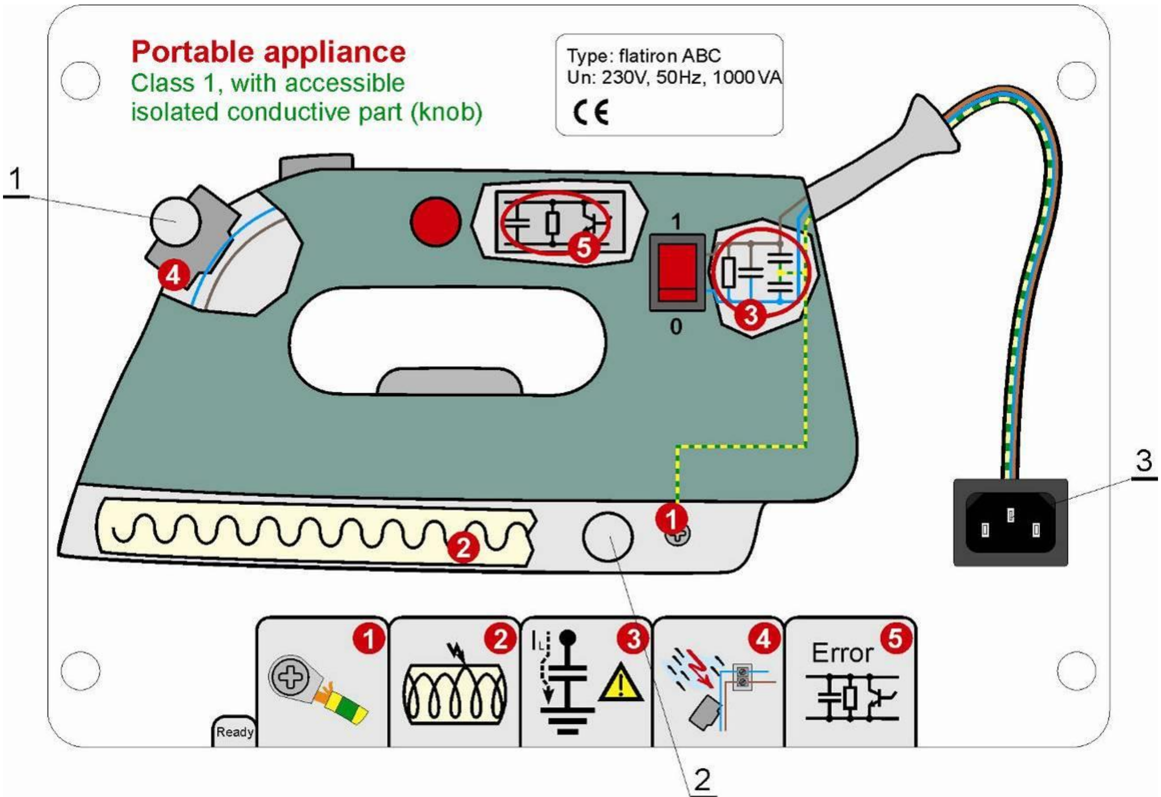
- The “Error values” (simulated values, shown in error fields of tables) in the description tables are valid only for one fault switched ON at the same time.
  If more than one fault is simultaneously ON the “Error values” are summarized.

- Individual demonstration tables are recognized on the basis of information stored in the RFID TAG (legend of errors, simulation values). The TAGs are placed in the lower left corner of each table. The TAG information is read by the PAT Demoboard if it is put correctly on the instrument.

- The values of errors (resistances and capacitances) in the description tables are informative only. The actual inaccuracy is up to ±10%.

- If the outputs of measuring instruments are not galvanically isolated, an additional error of up to 10% can occur on instrument’s reading.

5.2 Portable appliance of class 1 – Flatiron

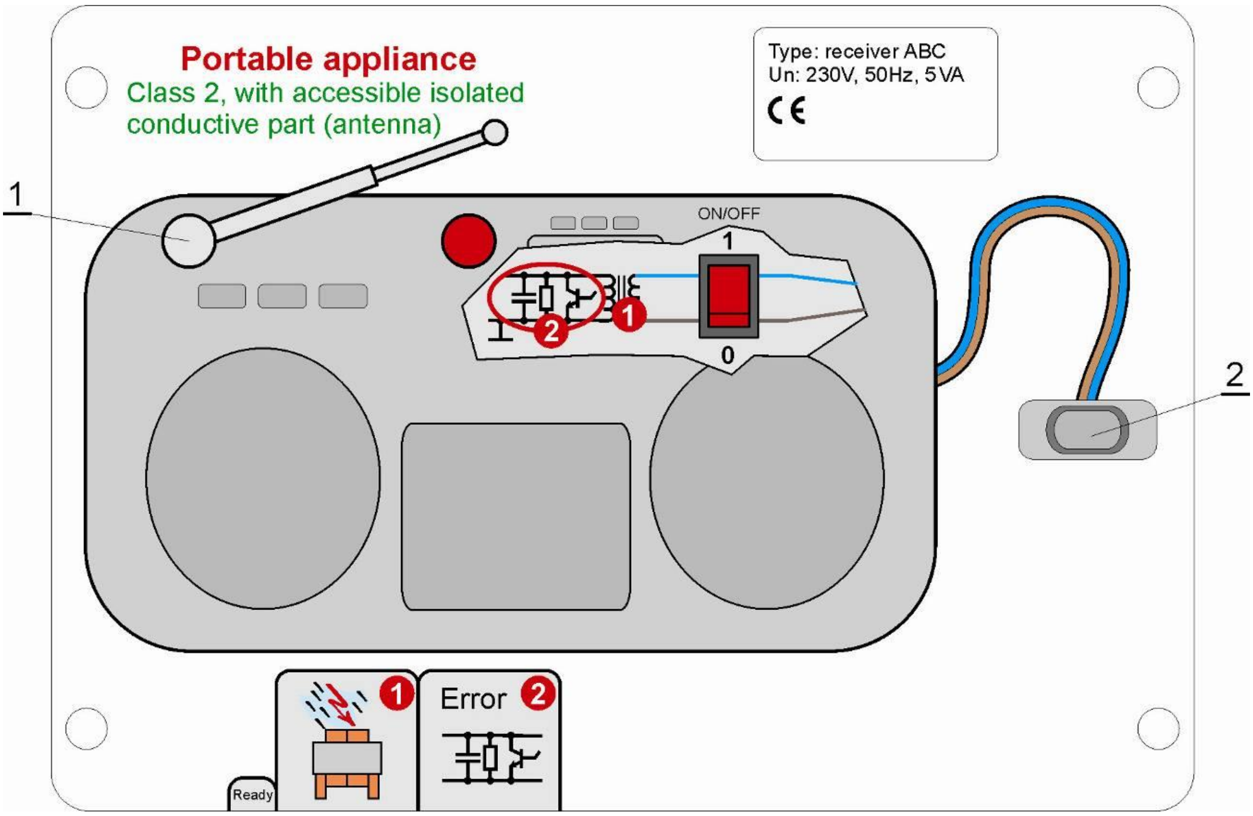


	Simulates	Error value	Error off	Error on
	Simulation between contacts	Measurement taken	Error off	Error on
Error 1	Loose contact of PE conductor	Error value	0,02 Ω	0,84 Ω
	Earthed metal part (2) and PE pin on socket (3)	Earth Bond	0,02 Ω	0,84 Ω
Error 2	*Insulation fault*	Error value	>20 MΩ	106 kΩ
	L and PE pins on socket (3)	Insulation 500 V DC	>20 MΩ	0,106 MΩ
		Leakage 230 V, 50/60 Hz	0,00 mA	2,17 mA
		Subleakage	0,00 mA	2,17 mA
Error 3	*Excessive capacitive current*	Error value	/	33 nF
	L and PE pins on socket (3)	Insulation 500 V DC	>20 MΩ	>20 MΩ
		Leakage 230V 50/60 Hz	0,00 mA	2,12 mA
		Subleakage	0,00 mA	2,12 mA
Error 4	Insulation fault	Error value	>20 MΩ	238 kΩ
	Accessible isolated metal part (1) and L pin on socket (3)	Insulation 500 V DC	>20 MΩ	0,238 MΩ
		Touch Leakage 230 V	0,00 mA	0,97 mA
		Subleakage	0,00 mA	0,97mA

Error 5	Functional fault	Functional	/	interruptions
	Functional	Functional	/	interruptions

Table 5-1: Description of simulated faults / relevant tests

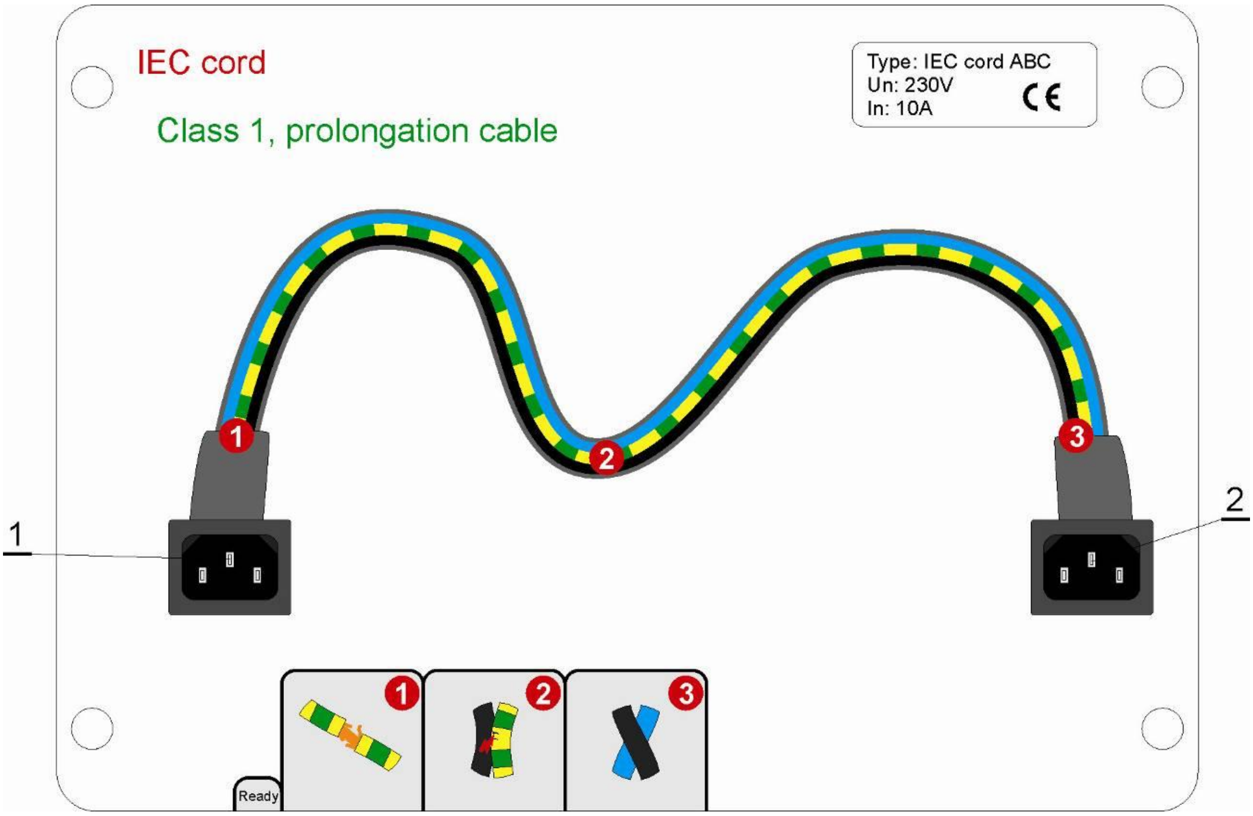
5.3 Portable appliance of class 2 – Receiver



	Simulates	Error value	Error off	Error on
	Simulation between contacts	Measurement taken	Error off	Error on
Error 1	Insulation fault	Error value	>20 MΩ	238 kΩ
	L pin on socket (2) and accessible isolated metal part (1)	Insulation 500V DC (probe)	>20 MΩ	0,238 MΩ
		Touch Leakage 230 V AC	0,00 mA	0,97 mA
		Subleakage (probe)	0,00 mA	0,97 mA
Error 2	Functional fault	Functional	/	interruptions
	Functional	Functional	/	interruptions

Table 5-2: Description of simulated faults / relevant tests

5.4 Portable appliance of class 1 – IEC cord

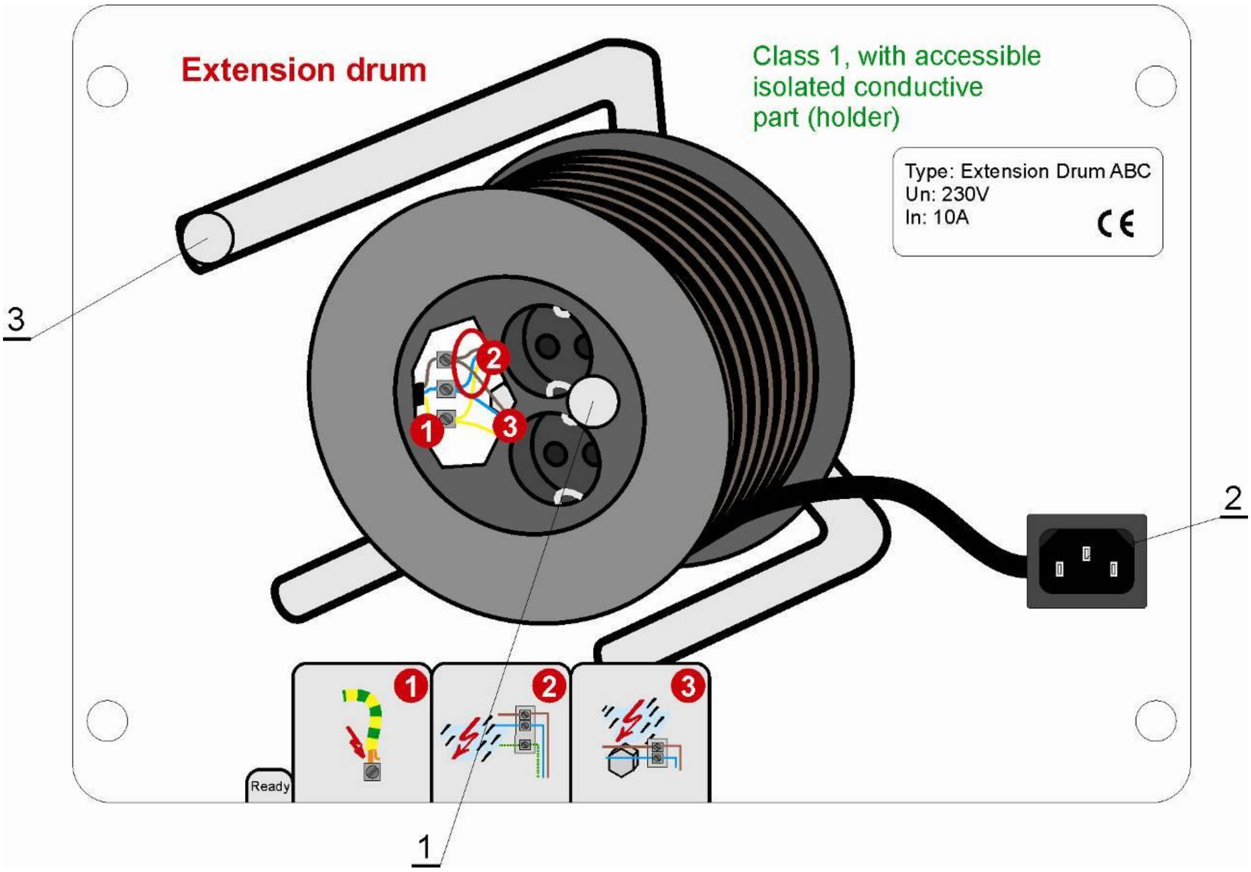


	Simulates	Error value	Error off	Error on
	Simulation between contacts	Measurement taken	Error off	Error on
Error 1	Loose contact of PE conductor	Error value	0,02 Ω	0,84 Ω
	PE pin on socket (1) and PE pin on socket (2)	Earth Bond	0,02 Ω	0,84 Ω
Error 2	Insulation fault	Error value	>20 MΩ	106 kΩ
	L and PE pins on socket (2)	Insulation 500 V DC	>20 MΩ	0,106 MΩ
Error 3	Crossed L and N wire	Polarity	/	L, N crossed
	Polarity	Polarity	/	“L, N crossed”

Table 5-3: Description of simulated faults / relevant tests

Note:
For safety reasons there is a serial resistance between L/N pins of socket 1 and socket 2. Some test instruments can therefore return a fail on the Polarity test!

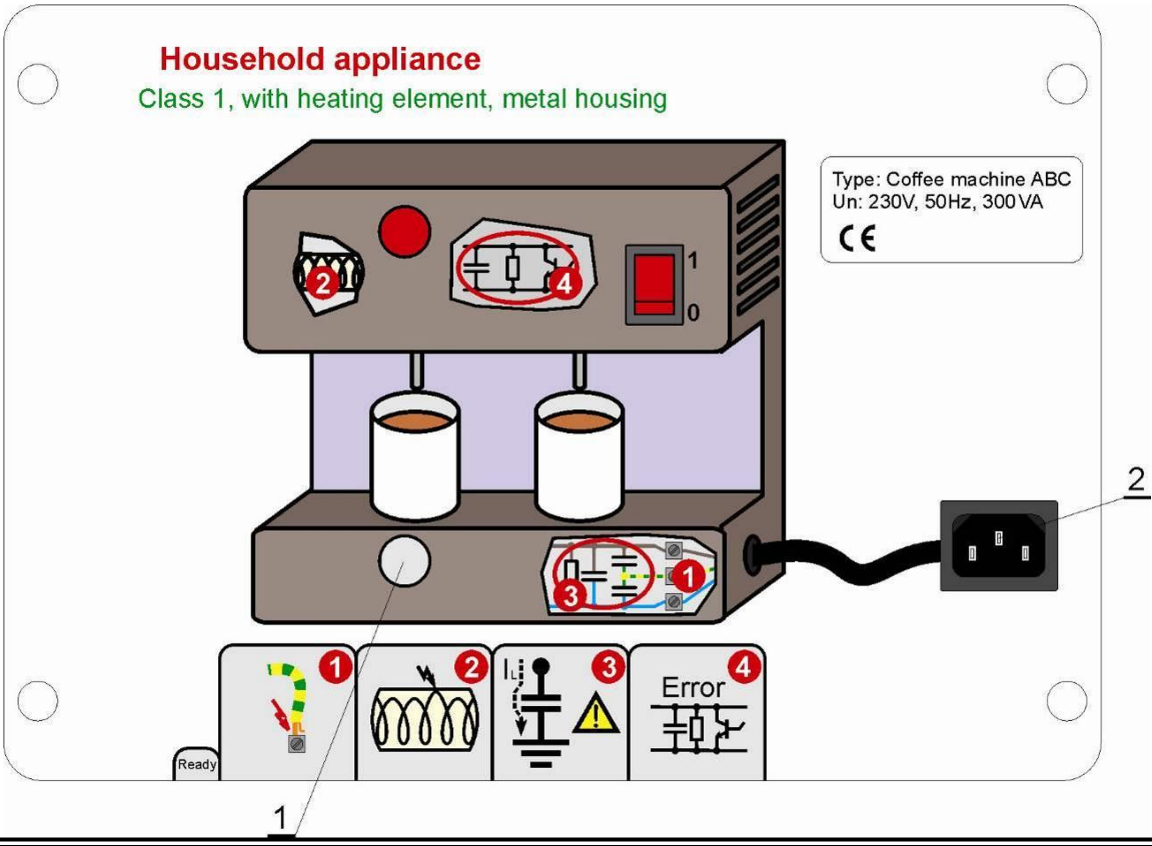
5.5 Portable appliance of class 1 – Extension drum



	Simulates / Simulation between contacts	Error value / Measurement taken	Error off	Error on
	Simulates	Error value	Error off	Error on
	Simulation between contacts	Measurement taken	Error off	Error on
Error 1	Loose contact of PE conductor	Error value	0,02 Ω	0,84 Ω
	PE connection on output socket (1) and PE connection on mains socket (2)	Earth Bond	0,02 Ω	0,84 Ω
Error 2	Insulation fault	Error value	>20 MΩ	106 kΩ
	L and PE pins on socket (1)	Insulation 500 V DC	>20 MΩ	0,106 MΩ
		Leakage 230 V, 50/60 Hz	0,00 mA	2,17 mA
		Subleakage	0,00 mA	2,17 mA
Error 3	Insulation fault	Error value	30 MΩ	238 kΩ
	Isolated accessible metal part (3) and L, pin on socket (2)	Insulation 500V DC (probe)	13 MΩ	0,237 MΩ
		Touch Leakage 230 V AC	0,00 mA	0,97 mA
		Subleakage (probe)	0,00 mA	0,97 mA

Table 5-4: Description of simulated faults / relevant tests

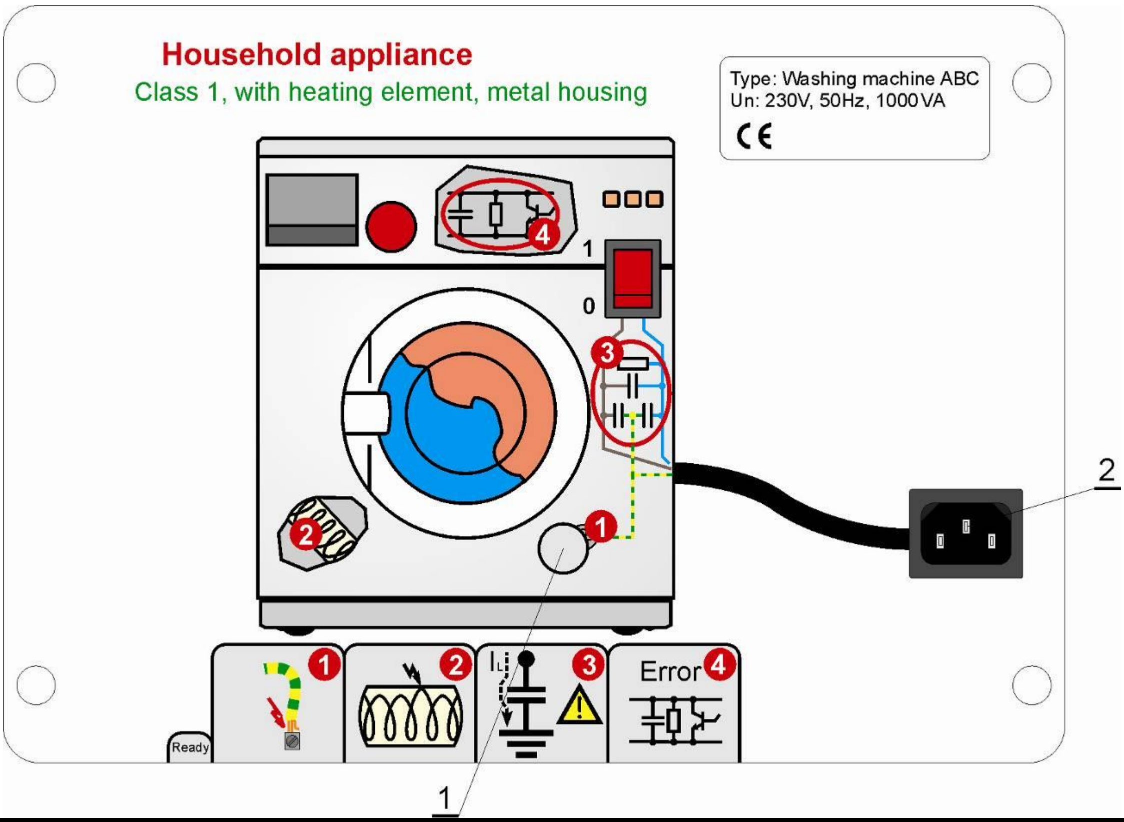
5.6 Household appliance of class 1 – Coffee machine



	Simulates	Error value	Error off	Error on
	Simulation between contacts	Measurement taken	Error off	Error on
Error 1	Loose contact of PE conductor	Error value	0,02 Ω	0,43 Ω
	Earthed metal part (1) and PE pin on socket (2)	Earth Bond	0,02 Ω	0,43 Ω
Error 2	Insulation fault	Error value	>20 MΩ	106 kΩ
	L and PE pins on socket (2)	Insulation 500 V DC	>20 MΩ	0,106 MΩ
		Leakage 230 V, 50/60 Hz	0,00 mA	2,17 mA
		Subleakage	0,00 mA	2,17 mA
Error 3	Excessive capacitive current	Error value	/	33 nF
	L and PE pins on socket (2)	Insulation 500 V DC	>100 MΩ	>100 MΩ
		Leakage 230V 50/60 Hz	0,00 mA	2,12 mA
		Subleakage	0’00 mA	2,12 mA
Error 4	Functional fault	Functional	/	interruptions
	Functional	Functional	/	interruptions

Table 5-5: Description of simulated faults / relevant tests

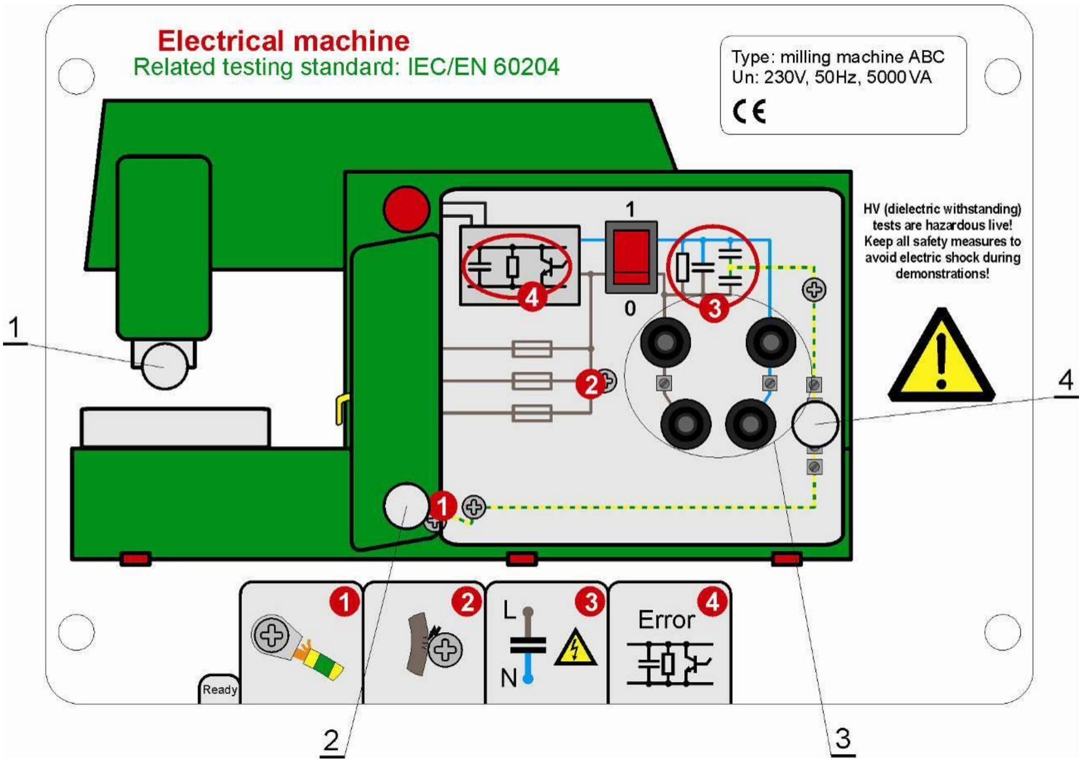
5.7 Household appliance of class 1 – Washing machine



	Simulates	Error value	Error off	Error on
	Simulation between contacts	Measurement taken	Error off	Error on
Error 1	Loose contact of PE conductor	Error value	0,02 Ω	0,84 Ω
	Earthed metal part (1) and PE pin on socket (2)	Earth Bond	0,02 Ω	0,84 Ω
Error 2	Insulation fault	Error value	>20 MΩ	106 kΩ
	L and PE pins on socket (2)	Insulation 500 V DC	>20 MΩ	0,106 MΩ
		Leakage 230 V, 50/60 Hz	0,00 mA	2,17 mA
		Subleakage	0,00 mA	2,17 mA
Error 3	Excessive capacitive current	Error value	/	33 nF
	L and PE pins on socket (2)	Insulation 500 V DC	>100 MΩ	>100 MΩ
		Leakage 230V 50/60 Hz	0,00 mA	2,12 mA
		Subleakage	0’00 mA	2,12 mA
Error 4	Functional fault	Functional	/	interruptions
	Functional	Functional	/	interruptions

Table 5-6: Description of simulated faults / relevant tests

5.8 Electrical machine

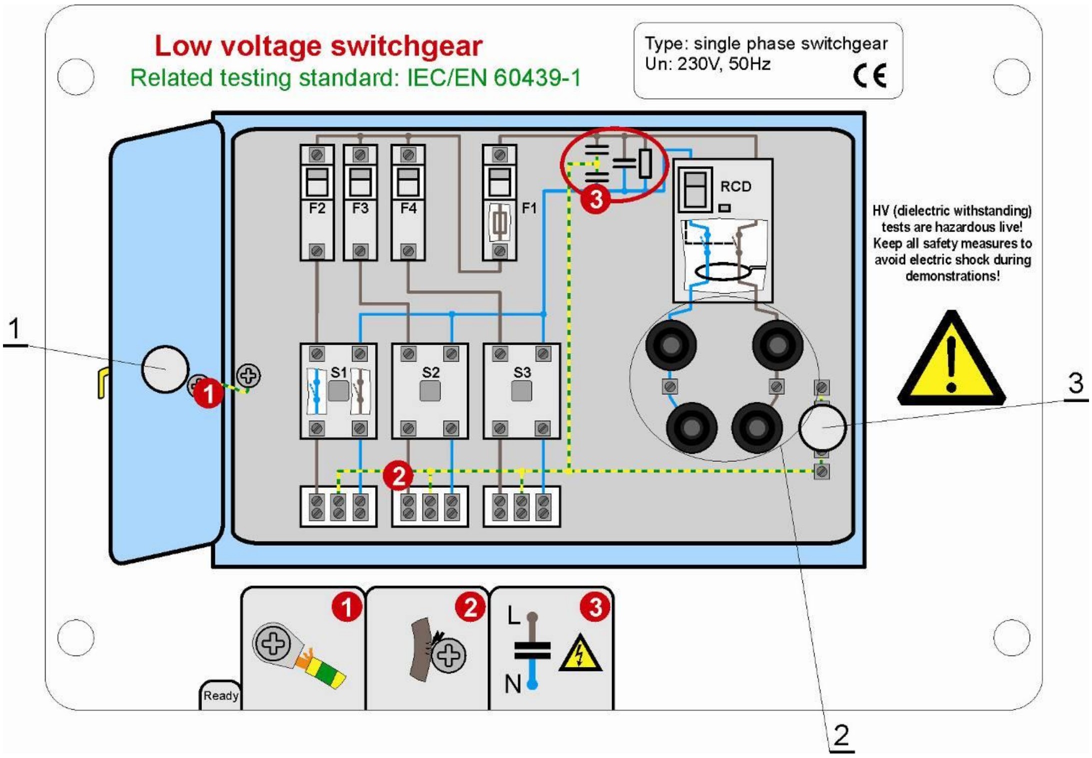


	Simulates	Error value	Error off	Error on
	Simulation between contacts	Measurement taken	Error off	Error on
Error 1	Loose contact of PE conductor	Error value	0,02 Ω	0,43 Ω
	PE input connection (4) and earthed metal part (2)	Earth Bond	0,02 Ω	0,43 Ω
	PE input connection (4) and earthed metal part (1)	Earth Bond	0,02 Ω	0,02 Ω
Error 2	Insulation fault	Error value	>20 MΩ	1.88 MΩ
	L (3) and PE (4) input connections	Insulation 1000 V DC	>20 MΩ	1.880 MΩ
		Withstanding 1000 V AC	0,1 mA	0,6 mA
Error 3	Excessive charge on filter capacitors	Error value	4.7 nF 100 MΩ	100 nF 100 MΩ
	L and N on input connection (3)	Discharging time*	cca 0,4 s	cca 9 s
Error 4	Functional fault	Functional	/	interruptions
	Functional	Functional	/	interruptions

Table 5-7: Description of simulated faults / relevant tests

* Measured with CE Multitester (resistance of measuring circuit 40 MΩ). Discharging times for other test instruments can vary, depending on their internal resistance.

5.9 Low voltage switchgear



	Simulates / Simulation between contacts	Error value / Measurement taken	Error off	Error on
Error 1	Loose contact of PE conductor	Error value	0,02 Ω	0,41 Ω
	PE input connection (1) and earthed metal part (2)	Earth Bond	0,02 Ω	0,41 Ω
Error 2	Insulation fault	Error value	>20 MΩ	1.88 MΩ
	L, (2) and PE connection (3)	Insulation 1000 V DC	>20 MΩ	1.880 MΩ
	L, (2) and PE connection (3)	Withstanding 2500 V AC	0,1 mA	1,4 mA
Error 3	Excessive charge on filter capacitors	Error value	4.7nF 100 MΩ	100 nF 100 MΩ
	L and N on input connections (2)	Discharging time*	cca 0,4 s	cca 9 s

Table 5-8: Description of simulated faults / relevant tests

* Measured with CE Multitester (resistance of measuring circuit 40MΩ). Discharging times for other test instruments can vary, depending on their internal resistance.

6 Specification

6.1 Technical specification

Protection classification (except simulation area)	Class I
Nominal input voltage:	230 V (+6 %, -10 %)
Optional on request:	115 V (+6 %, -10 %)
Power consumption:	15 VA max.
Over-voltage category:	CAT II 300 V
Frequency range:	45 Hz to 66 Hz
Pollution degree:	2
Dimensions (w × h × d):	350 mm x 335 mm x 160 mm
Mass (without accessories):	7 kg
Working temperature range:	10 °C ÷ 36 °C
Storage temperature range:	-20 °C ÷ +50 °C
Maximum humidity:	95 % RH (10 °C ÷ 36 °C) non-condensing

Given simulation resistance and capacitance values (description tables 5.1 to 5.8) are informative only. Actual inaccuracy is < ±10% of given “Error values”.

If the outputs of measuring instruments are not galvanically isolated an additional error of up to 10% can occur on instrument’s reading.

6.2 Standard set (Ordering code MI 3300)

- Instrument PAT Demoboard installed in the Application Trainer.
- 8 demonstration tables (iron, receiver, IEC cord, extension drum, coffee machine, washing machine, switchgear).
- CD with User Manual and Electrical equipment testing handbook.
- ~~Jumper for shorting L and N connections.~~
- Prolongation cord for demonstration of testing IEC prolongation cords.
- Mains supply cable.
- Class I mains cable for connecting PAT testers to PAT Demoboard.
- Class II mains cable for connecting PAT testers to PAT Demoboard.
- Measuring cable for testing discharging time.
- Carrying bag for demonstration tables.
- Production Verification Data.

AD 4 - MI 3399
PV Photovoltaic Systems Trainer

TABLE OF CONTENTS:

1 Introduction

1.1 General Description

PV demonstration board is a part of the Application Trainer and simulates photovoltaic electricity generation system. The PV demonstration board is preferably intended for sales persons to demonstrate operation and application of PV test equipment. However, it could also be applied as training and educational tool. Various tests supported by different PV test instruments can be presented. It is placed into a practical plastic carrying case.

Demonstration/simulation possibilities:
- PV array d.c. output,
- Measurement of d.c. current,
- Inverter operation with measurement of a.c. output current and voltage,
- Pyranometer simulation,
- Temperature simulation
- Insulation resistance of PV array,
- Continuity of protective earthing.

Demonstration board is designed according to European safety standard EN 61010-1.

1.2 General warnings

- If the equipment is not used in a manner specified by manufacturer, the protection provided by equipment may be impaired.
- Use the PV demonstration board on well-grounded supply systems only.
- Only qualified personnel, familiar with the board and the measuring instrument may use the PV demonstration board!
- Application of the PV demonstration board in a way not specified in this User Manual could damage the board.
- Do not use PV demonstration board in case of any damage noticed!
- Only an authorized person may carry out servicing of PV demonstration board!

1.3 Applied standards

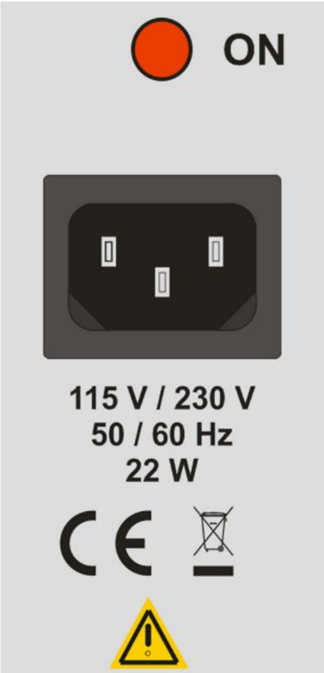
The PV demonstration board MI 3088 is manufactured and tested in accordance with the following regulations:

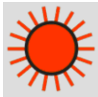
Electromagnetic compatibility (EMC)	
EN 61326	Electrical equipment for measurement, control and laboratory use – EMC requirements Class B (Hand-held equipment used in controlled EM environments)
Safety (LVD)	
EN 61010-1	Safety requirements for electrical equipment for measurement, control and laboratory use – Part 1: General requirements
Functionality	
Reference standard for photovoltaic systems	
EN 62446	Grid connected photovoltaic systems – Minimum requirements for system documentation, commissioning tests and inspection

Note about EN and IEC standards:

- Text of this manual contains references to European standards. All standards of EN 6XXXX (e.g. EN 61010) series are equivalent to IEC standards with the same number (e.g. IEC 61010) and differ only in amended parts required by European harmonization procedure.

1.4 Meaning of warning/information symbols on front panel





Indication of power supply.

Take care that demonstration board is connected only to mains voltage according to the description under the mains socket! In the opposite case the board can be damaged!

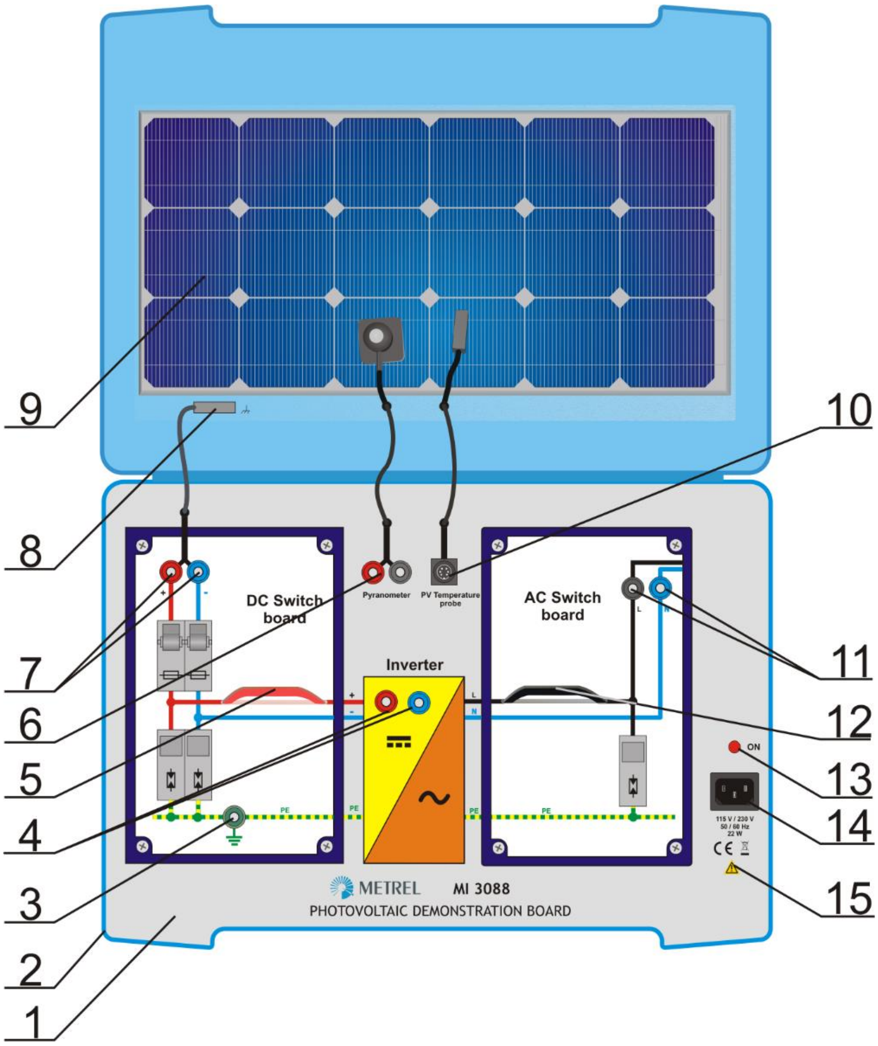
The product must undergo selective disposal for the recycling of the electric and electronic material in compliance with directive WEEE 2002/96/EC.

The CE marking guarantees conformity with European directives and with regulations covering EMC.

1.5 List of measurements that can be demonstrated

- PV string insulation resistance,
- Bonding resistance of PV panel metallic support to protective earthing,
- PV string U/I characteristics,
- PV string d.c. current,
- PV string d.c. power,
- Irradiance,
- Temperature on PV panels,
- Inverter output a.c. current,
- Inverter output a.c. voltage,
- Inverter output a.c. power,
- Inverter and PV system efficiency.

2 Front panel description



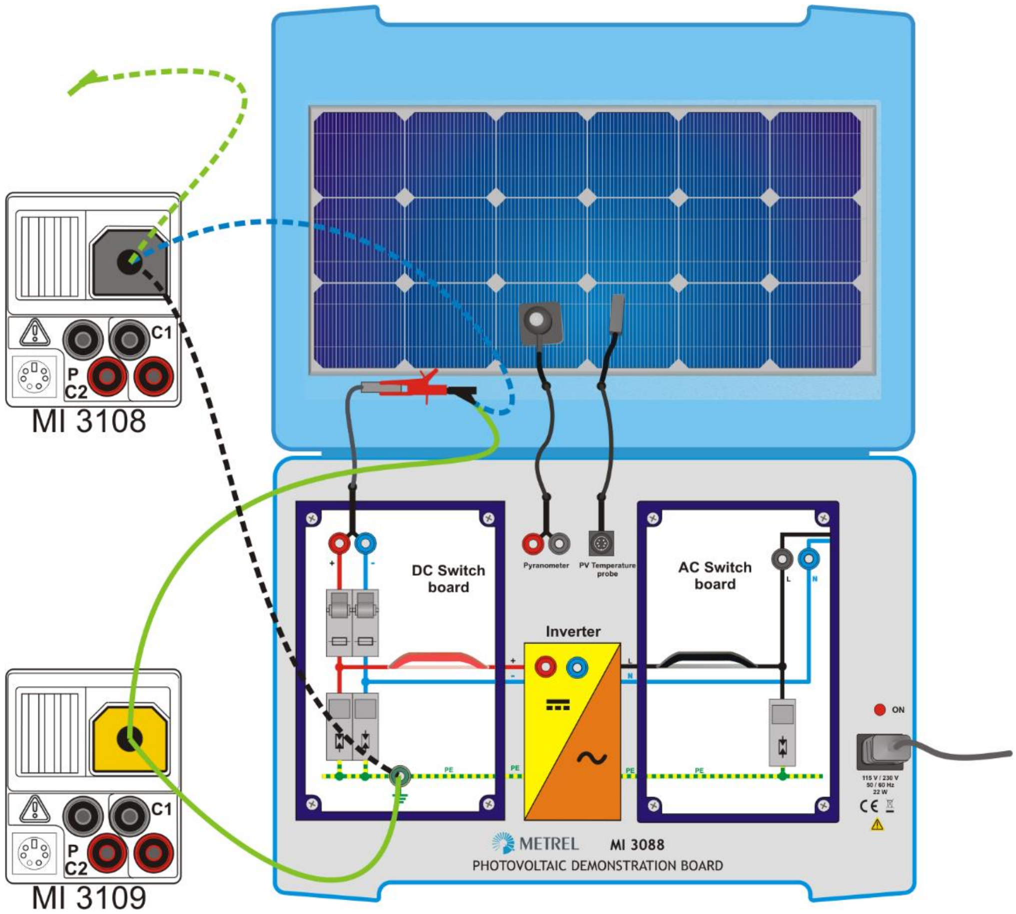
1	Front panel	Presents typical components required in PV power utility.
2	Case	Plastic case of PV demonstration board with handle.
3	PE connection	For testing purposes only!
4	Inverter d.c. input voltage	Sockets for measurement of inverter d.c. input voltage (from PV array).
5	Inverter d.c. input current	For applying d.c. current clamps.
6	Pyranometer output	Output for demonstration of irradiance measurement.
7	PV array output	Output representing PV array I/U characteristics.
8	Connection to metallic construction	Intended for continuity measurement of grounding system.
9	Case cover with label	Label representing PV panel.
10	Temperature probe output	Output representing PV array temperature.
11	Inverter a.c. output voltage	Sockets for measurement of inverter output a.c. voltage.
12	Inverter a.c. output current	For applying a.c. current clamps.
13	Supply indicator	Indicates proper supply of the PV demonstration board.

14	Supply entry	IEC appliance coupler for supplying the PV demonstration board, universal power supply input 115 V / 230 V
15	Warning symbol	To pay attention for right connection to proper mains power supply.

Warning: All outputs are intended for demonstration of possible PV testing only!

3 Measurements

3.1 Continuity of earthing system

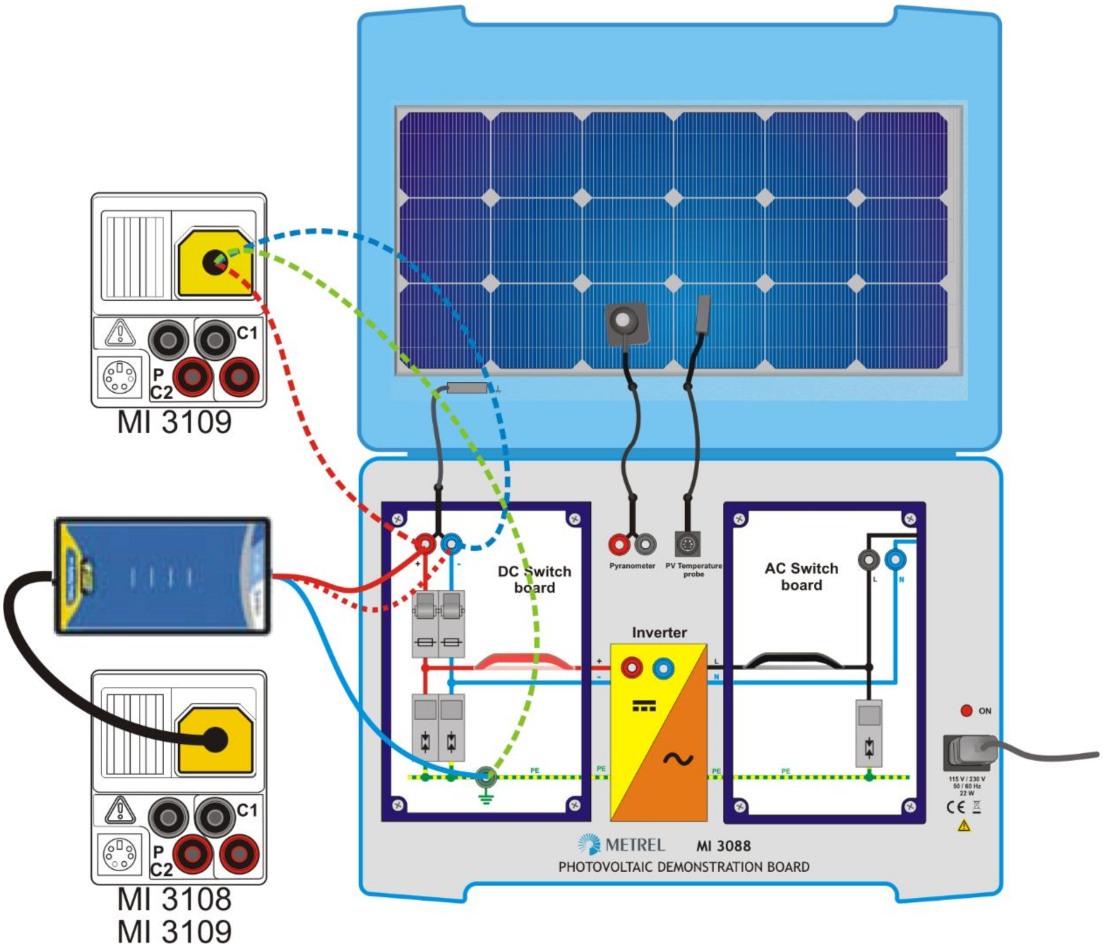


Measurement location	Nominal value
Connection to metallic construction – PE connection	0.1 Ω

Applied instruments and functions

Instruments	Functions
MI 3108	**R LOWΩ**; 200 mA resistance measurement (INSTALLATION menu)
MI 3109	**R LOWΩ**; 200 mA resistance measurement (SOLAR menu)

3.2 PV array insulation resistance

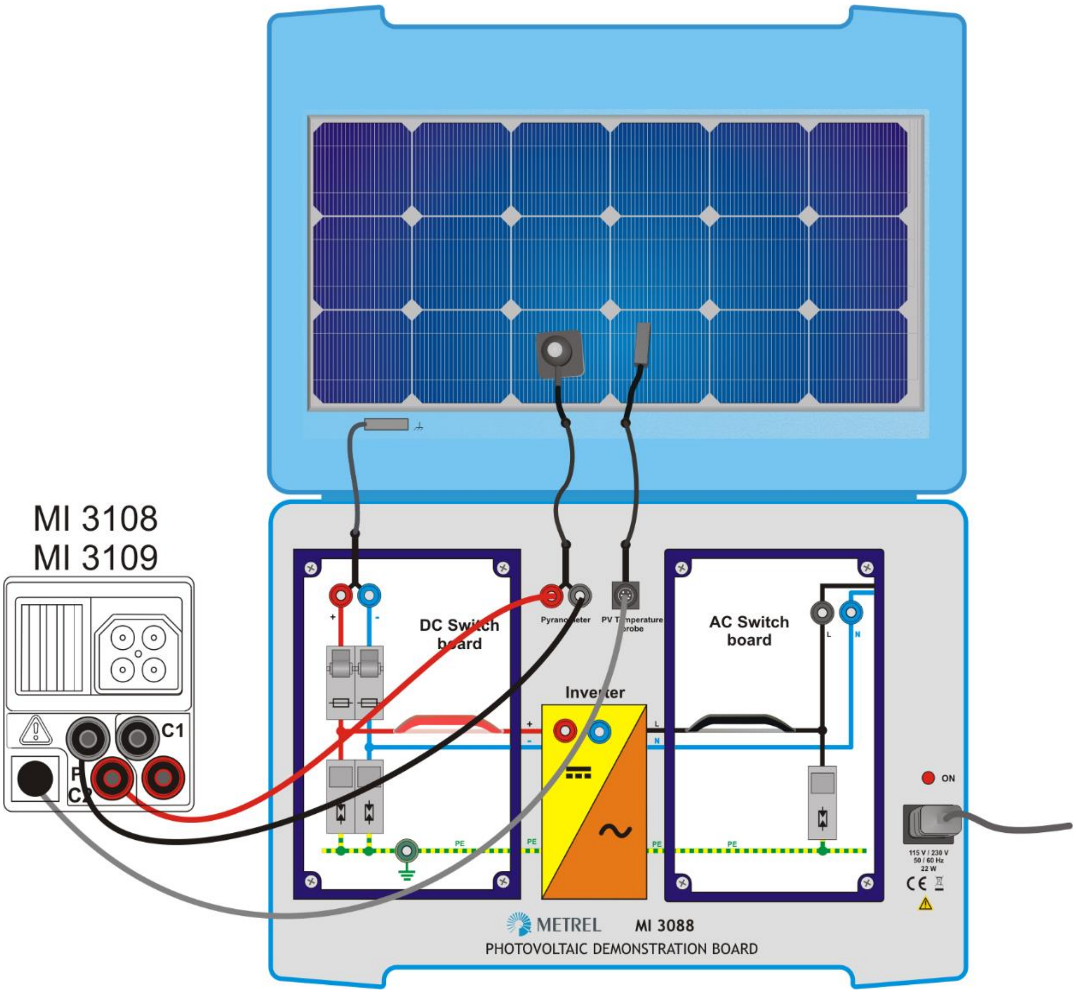


Measurement location	Nominal value
PE connection – DC switch board + socket	96 MΩ
PE connection – DC switch board - socket	92 MΩ

Applied instruments and functions

Instruments	Functions
MI 3108, MI 3109	**RISO +**; Insulation resistance measurement between panel / array / string positive and earth
	RISO -; Insulation resistance measurement between panel / array / string negative and earth

3.3 Measurement of irradiation and temperature



Pyranometer

Measurement location	Nominal value
Pyranometer sockets	780 W/m^2

Temperature

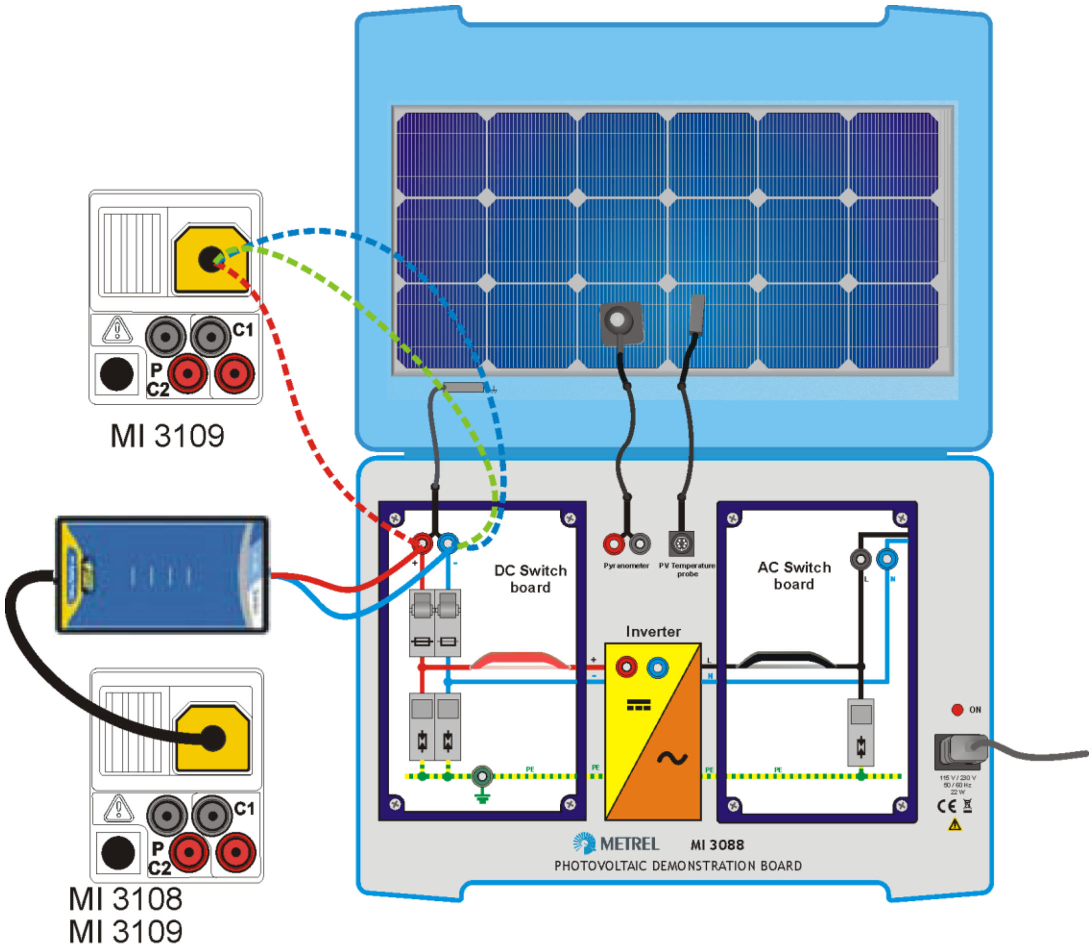
Measurement location	Nominal value
Temperature probe connector	25 °C *

* Depends on real ambient temperature and internal heating.

Applied instruments and functions

Instruments	Functions
MI 3108, MI 3109	**ENV.: MEAS**; Measurement of environmental parameters (Irradiance, temperature)

3.4 Uoc, Isc test and I/V characteristic measurement



Measurement location	Measured value		STC value	
DC switch board + socket – DC switch board - socket	Isc	48.2	Isc	49
	Uoc	3.1	Uoc	4.1
	Umpp	44.8V	Umpp	45.2 V
	Impp	2.4 A	Impp	3.1 A
	Pmpp	107 W	Pmpp	140 W

Applied instruments and functions

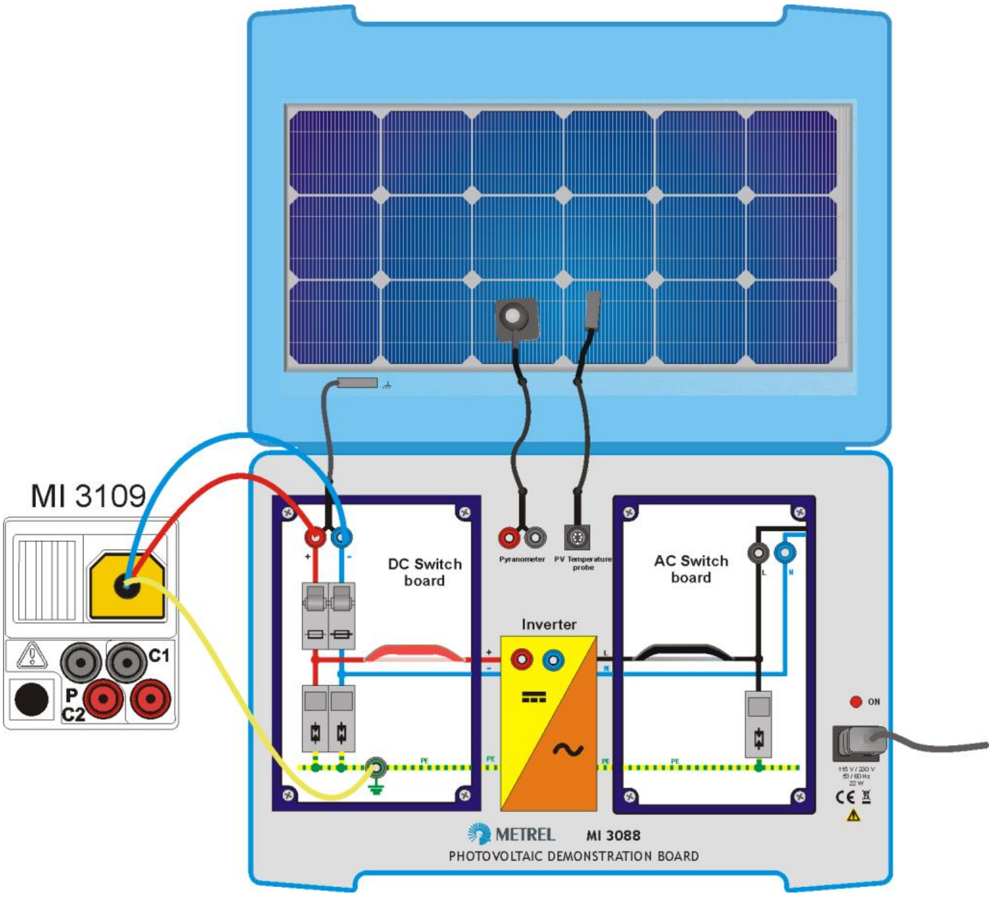
Instruments	Functions
MI 3108, MI 3109	**Uoc/Isc**; Open circuit voltage and short circuit current measurement, **I/V**; current/voltage and current/power characteristics measurement

Note:

- STC values are displayed if irradiance and temperature are measured before.

See chapter *3.3 Measurement of irradiation and temperature*.

3.5 Automatic test sequence



Measurement location	Measured value	STC value
PE connection – DC switch board + socket – DC switch board - socket	96 MΩ	
	92 MΩ	
	48.2	49 V
	3.1	4.1 A

Applied instruments and functions

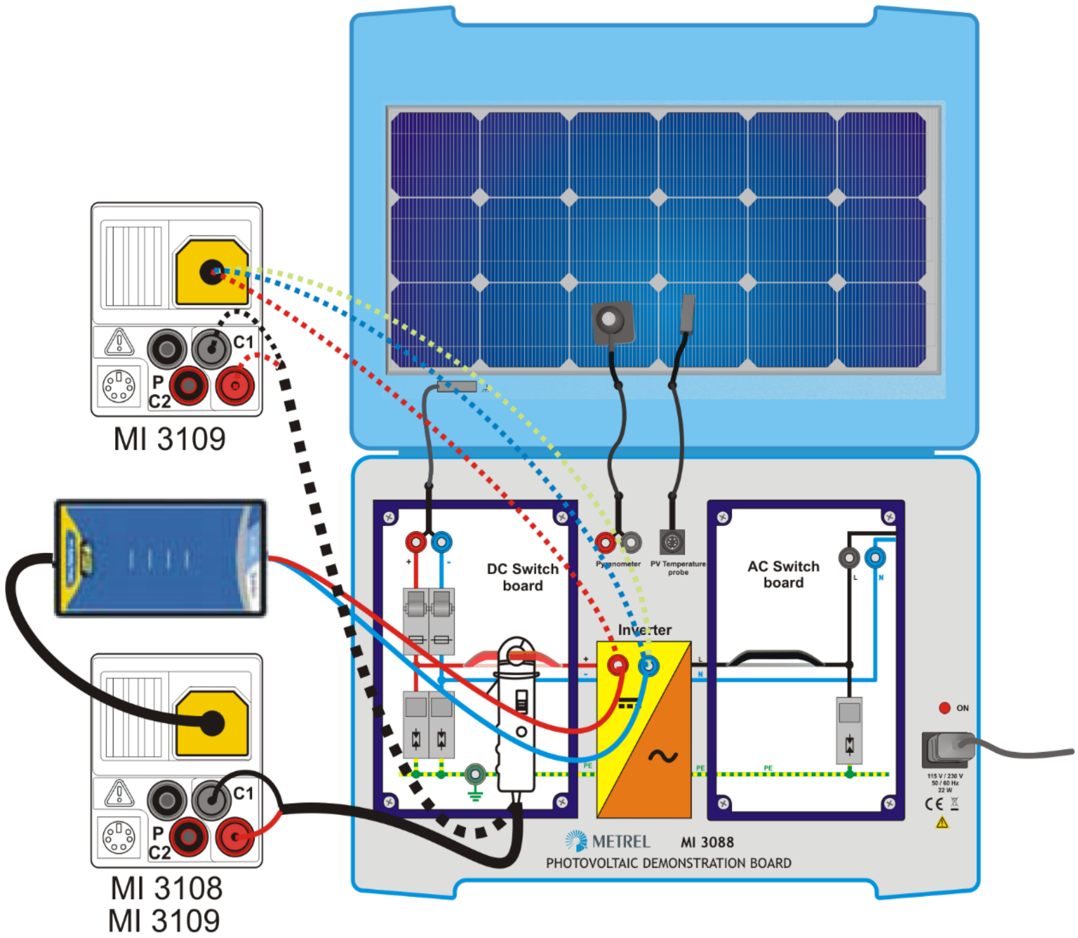
Instruments	Functions
MI 3109	**AUTOTEST**; Automatic measurement of insulation resistance and Uoc/Isc of PV panel / array / string.

Notes:

- Applicable only on MI 3109.
- STC values are displayed if irradiance and temperature are measured before.

See chapter *3.3 Measurement of irradiation and temperature*.

3.6 PV panel test



Measurement location	Measured value		STC value	
DC switch board + socket – DC switch board - socket	Umpp	48.2 V	Umpp	48.5 V
	Impp	3.1 A	Impp	4.1 A
	Pmpp	151 W	Pmpp	200 W

Applied instruments and functions

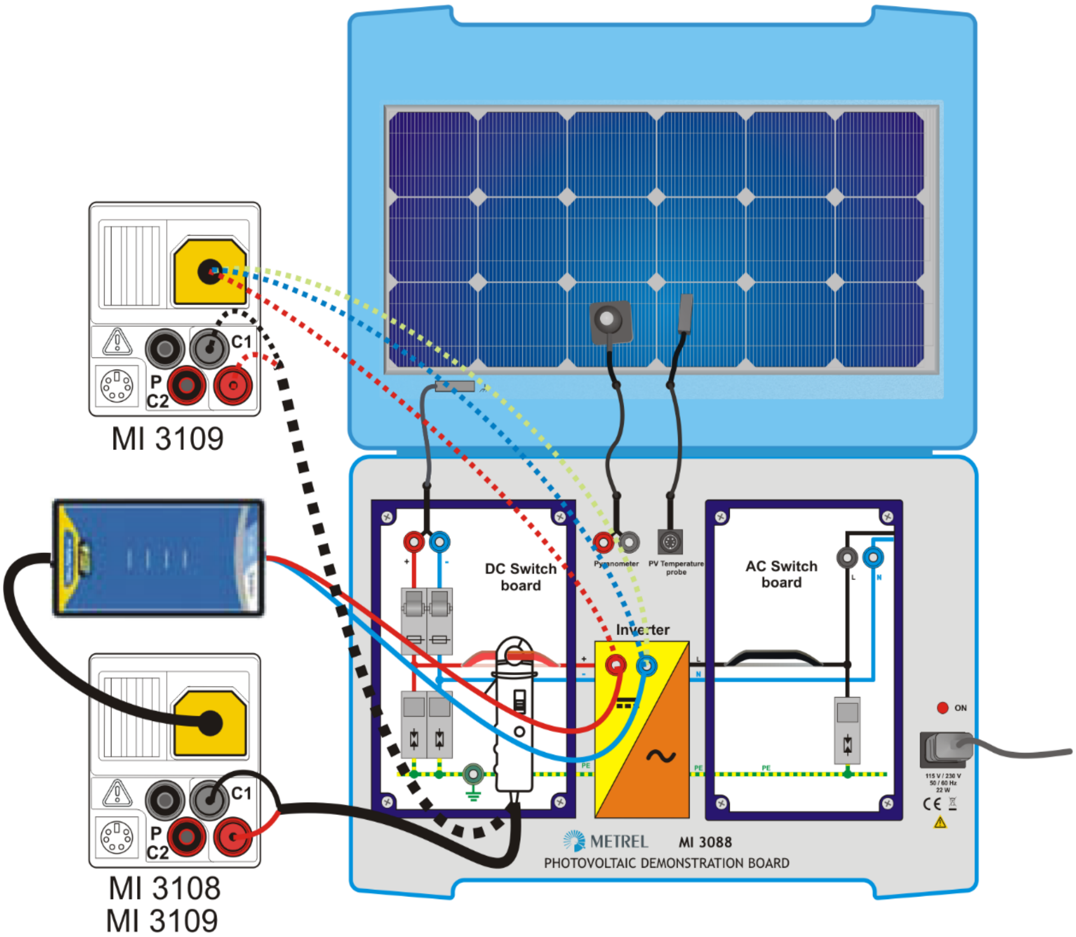
Instruments	Functions
MI 3108, MI 3109	**PANEL**; Current, voltage inverter working point

Note:

- STC values are displayed if irradiance and temperature are measured before.

See chapter *3.3 Measurement of irradiation and temperature*.

3.7 Measurement of inverter input – DC side

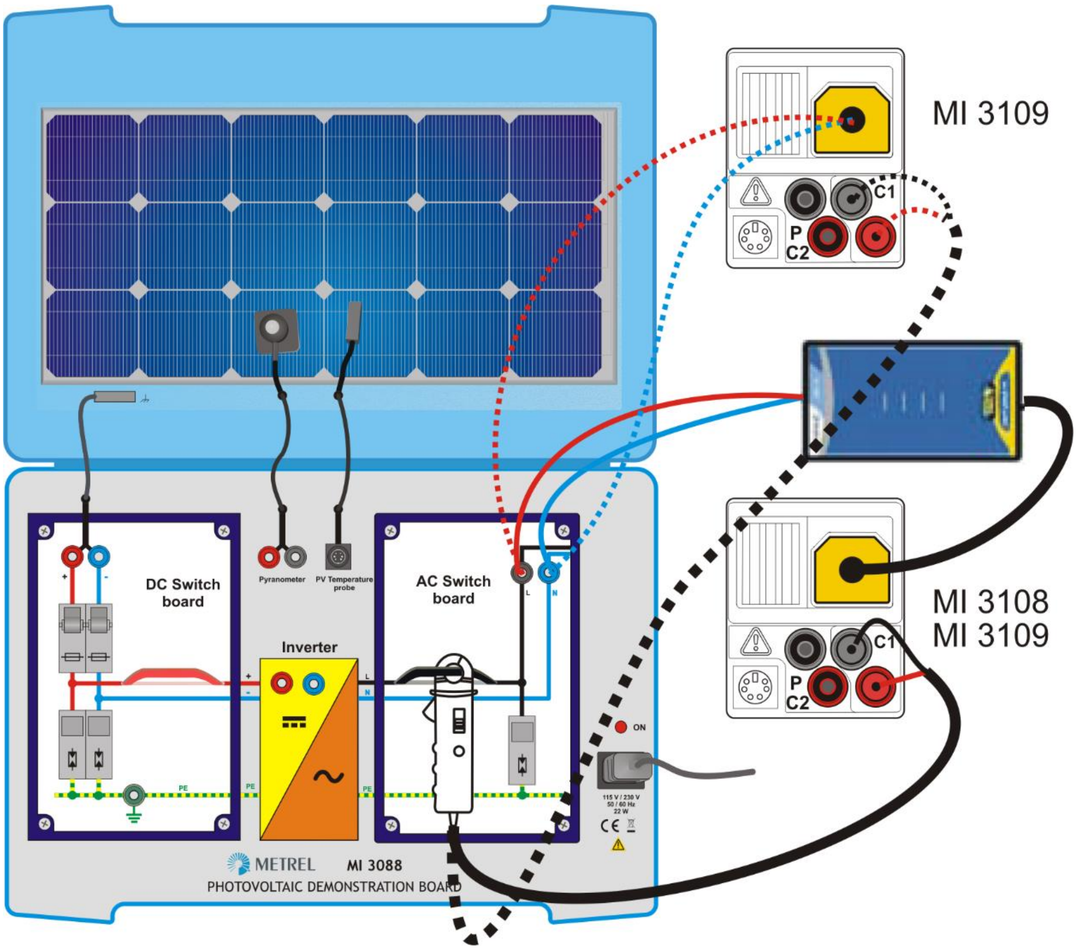


Measurement location	Measured value	
Inverter input + socket – Inverter input – socket Embraced red current loop using A 1391 current clamp	U_{DC}	48.2 V
	I_{DC}	3.1 A
	P_{DC}	151 W

Applied instruments and functions

Instruments	Functions
MI 3108, MI 3109	**INVERTER: DC**; Measurements at DC side of inverter

3.8 Measurement of inverter output – AC side

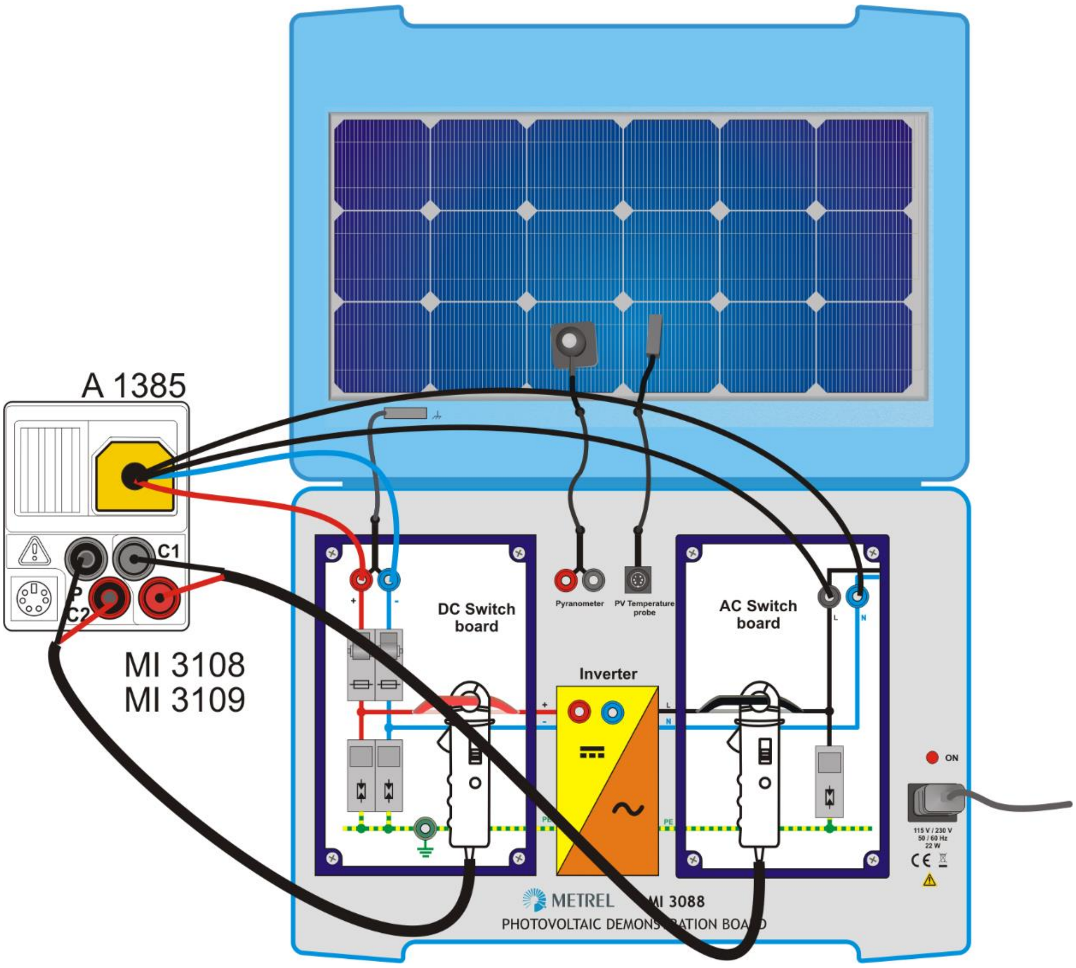


Measurement location	Nominal value	
AC switch board L – AC switch board N Embraced black current loop using A 1391 current clamp	U_{AC}	227 V
	I_{AC}	0.60 A
	P_{AC}	135 W

Applied instruments and functions

Instruments	Functions
MI 3108, MI 3109	**INVERTER: AC**; Measurements at AC side of inverter

3.9 Inverter efficiency



Measurement location	Nominal value	
Inverter + socket – Inverter - socket AC switch board L – AC switch board N Embraced red and black current loops using A 1391 current clamps	U_{DC}	48.2 V
	I_{DC}	3.1 A
	P_{DC}	151 W
	U_{AC}	227 V
	I_{AC}	0.60 A
	P_{AC}	135 W
	η	90 %

Applied instruments and functions

Instruments	Functions
MI 3108, MI 3109	**INVERTER: AC/DC**; Measurement of efficiency of inverter

4 Technical data

Nominal mains voltage	115 V/ 230 V, 50/60 Hz
Power consumption	200 W
Mains cord	single-phase
Dimensions (width × length × height)	450 × 330 × 110 mm
Weight	4.47 kg
Protection class	I (protective earth conductor)
Over voltage category	CAT II 300 V
Pollution degree	2

Reference conditions

Reference temperature range	10 °C ÷ 30 °C
Reference humidity range	40 %RH ÷ 70 %RH

Operation conditions

Working temperature range	0 °C ÷ 40 °C
Maximum relative humidity	95 %RH (0 °C ÷ 40 °C), non-condensing

Storage conditions

Temperature range	-10 °C ÷ 70 °C
Maximum relative humidity	90 %RH (-10 °C ÷ 40 °C), 80 %RH (40 °C ÷ 70 °C),

5 Maintenance

5.1 Cleaning

Use a soft cloth slightly moistened with soapy water or alcohol to clean the surface of the board and then leave the board to dry totally before use.

Do not use liquids based on petrol!
Do not spill liquids over the board!

5.2 Standard set

Upon receipt of Demonstration board it is advisable to check the content of the delivery. The following items have to be included:

- Demonstration board
- Mains cable
- PS2 male / male adapter
- Test lead 1.5 m, black
- Test lead 1.5 m, red
- User manual

APPENDIX

TABLE OF CONTENTS:

1 APPENDIX A – Abbreviations

@	Abbreviation of word 'at'
°C	Degrees Celsius
3W	3-wire method for measuring earth resistance (EIS)
4W	4-wire method (PQA testing with flex clamps)
A/AC/B	RCD types
AC; a.c.	Alternative Current
AUTOSEQUENCE®	A sequence of tests performed in 1 combined test - trademark of Metrel d.d.
Avg	Average (value)
CAT I	Overvoltage Category 1
CAT II	Overvoltage Category 2
CAT III	Overvoltage Category 3
CAT IV	Overvoltage Category 4
CATV	CAble TeleVision
CE	Conformité Européenne (eng.: European Conformity)
Class A/S/B	Class of accuracy of the voltage/power analyser
Cu	Copper
d2	Distance between probes S and H during a 3-wire earth measurement
DAR	Dielectric Absorption Ratio
DC; d.c.	Direct Current
EIS	Electrical Installation Safety
ELM	Electrical Leakage Monitor
EMC	Electro Magnetic Compatibility
FELV	Functional extra-low voltage
f_{Nom}	Nominal frequency
GAS	Gas pipe in an installation which is earthed and protected for overvoltages with a varistor.
GND	Ground
HV	High Voltage
I_a	Current for rated disconnection time
IEC	International Electrotechnical Commission
IMD	Insluation Monitoring Device
I_N; I_{Nom}	Rated current for selected fuse; nominal current
I_{PFC}	Prospective Fault Current
I_{PSC}	Prospective Short Circuit Current
I_{sc}	Short (S) Circuit (C) Current (I)
I_{SFL}	First Fault Leakage Current
ISO	InSulatiOn
IT	Earthing system that has supply part of the power source separated from earth.
I_Δ	Residual current
$I_{\Delta N}$; I_{dN}	Nominal trip-out current of RCD
$j\omega L_{L-PE}$	Inductive part of loop impedance

L	Line conductor in a 1-phase system
L1	Line1 conductor in a 3-phase system
L2	Line2 conductor in a 3-phase system
L3	Line3 conductor in a 3-phase system
LAN	Local Area Network
LV	Low Voltage
LVD	Low Voltage Directive
Max	Maximum (value)
Min	Minimum (value)
N	Neutral conductor
P	Active power
PAT	Portable Appliance Testing
PC	Personal Computer
PE	Protective Earth conductor
PELV	Protected extra-low voltage
PEN	Combined Protective Earth and supply conductor. Used in TN-C or TN-C-S earthing systems.
PI	Polarization Index
PowerView	Metrel's PC software for PQA support
PQA	Power Quality Analysis
PSC	Prospective Short Circuit
PV	Photo Voltaic
Q	Reactive power
R	Resistance
R_{PE}	Protective Equalization conductor Resistance
R_{200}	Continuity resistance with 200 mA
RCD	Residual Current Device
RCD Auto	Residual Current Device Automatic test
RCD AUTO SEQUENCE®	Residual Current Device Automatic test. A sequence of all RCD tests performed in 1 combined test - trademark of Metrel d.d.
RCD I	Residual Current Device trip-out current test
RCD t	Residual Current Device trip-out time test
RCD U_C	Residual Current Device contact voltage test
RCM	Residual Current Monitor
R_{CON}	Conductors resistance
R_E	Earth Resistance
R_{E_LOCAL}	Local Earth Resistance
RFID	Radio Frequency IDentitiy
RH	Relative Humidity
R_{ISO}	InSulatiOn Resistance
R_{LINE}	Line Resistance
R_{LOW}	Continuity Resistance
R_{L-PE}	Fault Loop resistance
RMS	Root Mean Square
R_{PEC_LOCAL}	PE conductor resistance of each individual or group earthing

R_T	Resistance of the transformer
RVC	Rapid Voltage Changes
S	Apparent power
SB	Switch board
SELV	Separated or safety extra-low voltage
STC	Standard Test Conditions
THD	Total Harmonic Distortion
TN	Earthing system earthed at the power source and/or distribution points.
TN-C	Earthing system earthed at the power source and/or distribution points. PE and N conductors are combined comprising a PEN conductor.
TN-C-S	Earthing system earthed at the power source and/or distribution points. Exposed conductive parts are partly connected to the PE conductor and partly to the PEN conductor.
TN-S	Earthing system earthed at the power source and/or distribution points. N and PE conductors are separated.
TRMS	True RMS
TT	All accessible metal parts are connected to basic grounding system.
t_Δ	Trip-out time of a RCD
U_C	Contact Voltage
U_{CL}	Contact Voltage Limit
U_{CSF}	Contact voltages at single fault on earthing
U_{LN}; U_{L-N}	Nominal mains voltage
U_{L-PE}	Rated fault loop voltage or nominal supply voltage
U_N; U_{Nom}	Nominal voltage
U_{OC}	Open (o) Circuit (c) Voltage (U)
USB	Universal Serial Bus
WEEE	Waste Electrical and Electronic Equipment (Directive)
Z_{LINE}; Z_{LN}; Z_{L-N}; $Z_{L-L,\ L-N}$	Line impedance
Z_{LOOP}; Z_{L-PE}	Fault loop impedance
Z_N	Impedance of the neutral conductor
Z_{REF}	Reference line impedance
Z_S; $Z_{S\ RCD}$	Loop impedance of a RCD protected system
Z_T	Transformer secondary impedance
ΔU; dU	Measured voltage drop
η	Efficiency
ρ	specific resistance of conductor's material

2 APPENDIX B

2.1 Changes

Title	Code No.	Version	Changes
MI 3399 ElectricalSafety and Quality Trainer	20752492	1.0	Preliminary version
MI 3399 ElectricalSafety and Quality Trainer	20752492	1.1	Added detailed description of MI 3399 with schematics into introduction part.
MI 3399 ElectricalSafety and Quality Trainer	20752492	1.1.2	Added user schematics of MI 3399 in the Introduction section. Enhanced the power quality section with theory from the PQA handbook and good to know. Enhanced the power quality section with theory from the PAT handbook and good to know. Added Appendix B.

2.2 Literature

[1] **MI 3399 Electrical Safety and Quality Application Trainer**; version 1.0; 20 752 499
[2] **General catalogue 2012: May Good to know**
[3] **Guide for testing and verification of low voltage installations**; version 1.1; 20 751 238
[4] **Guide for measurements on IT power installation**; version 1.1; 20 750 205
[5] **Guide for modern Power Quality Analysing Techniques**; version 1.0; 20 750 592
[6] **Guide for Electrical Equipment Testing**; version 1.1; 20 751 976
[7] **Verification of safety of machines**; version 1.1; 20 751 202
[8] **Guide for measurements on PV systems**; version 1.0; 20 752 069