OPERATING MANUAL

POWER SUPPLY QUALITY analyzer PQM-700

CE

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Version 1.00 09.04.2013

ON
ERROR
LOGG
BAT
MEM
START
STOP
Sonel®
PQM-700
BE0008
CAT IV 300 V

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1 General Information

1.1 Safety

PQM-700 instrument is designed to measure, record and analyse power supply parameters. In order to provide safe operation and correct measurement results, the following recommendations must be observed:

- Before you proceed to operate the analyzer, acquaint yourself thoroughly with the present manual and observe the safety regulations and specifications provided by the producer.
- Any application that differs from those specified in the present manual may result in a damage to the device and constitute a source of danger for the user.
- PQM-700 analyzers must be operated only by appropriately qualified personnel with relevant certificates authorising the personnel to perform works on electric systems. Operating the analyzer by unauthorised personnel may result in damage to the device and constitute a source of danger for the user.
- The device must not be used for networks and devices in areas with special conditions, e.g. fire-risk and explosive-risk areas.
- It is unacceptable to operate the device when:
  ⇒ it is damaged and completely or partially out of order,
  ⇒ its cords and cables have damaged insulation,
- Do not power the analyzer from sources other than those listed in this manual.
- If possible, connect the analyzer to the de-energized circuits.
- Opening the device socket plugs results in the loss of its tightness, leading to a possible damage in adverse weather conditions. It may also expose the user to the risk of electric shock.
- Repairs may be performed only by an authorised service point.

Measurement category of the whole system depends on the accessories used. Connecting analyzer with the accessories (e.g. current clamps) of a lower measurement category reduces the category of the whole system.

1.2 General characteristics

Power Quality Analyzer PQM -700 (Fig. 1) is a high-tech device providing its users with a comprehensive features for measuring, analysing and recording parameters of 50/60 Hz power networks and power quality in accordance with the European Standard EN 50160 and Regulation of the Ministry of Economy of 4 May 2007 on detailed conditions of power system functioning. The analyzer is fully compliant with the requirements of PN-EN 61000-4-30:2011, Class S.

The device is equipped with four cables terminated with banana plugs, marked as L1, L2, L3, N. The range of voltages measured by the four measurement channels is max. ± 1150 V. This range may be extended by using external voltage transducers.

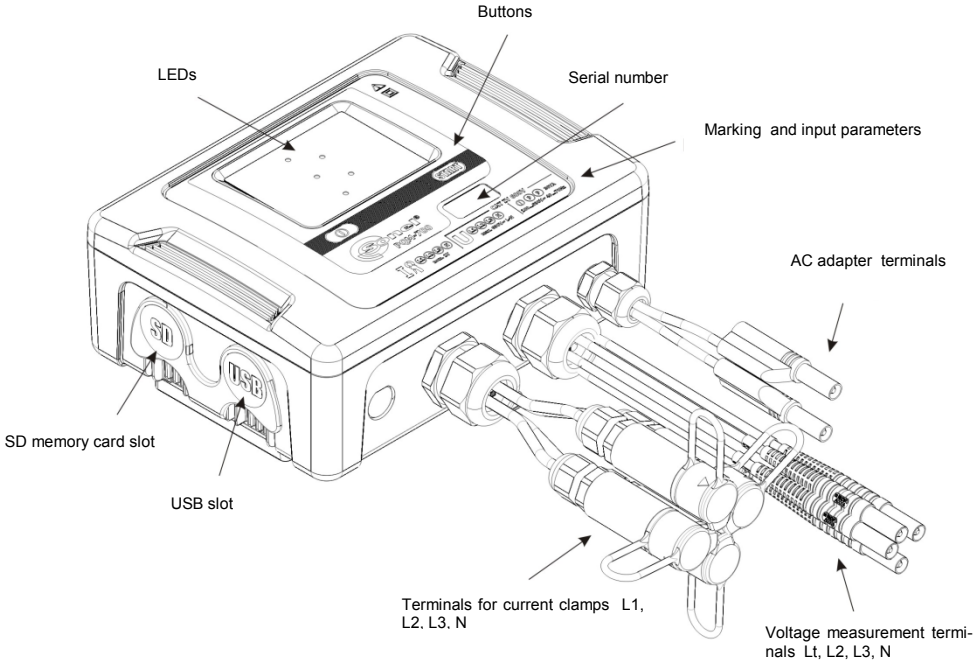


Fig. 1. Power Quality Analyser PQM-700. General view.

Measurements are carried out using four current inputs installed on short cables terminated with clamp terminals. The terminals may be connected to the following clamp types: flexible claps (marked as F-1, F-2, F-3) with nominal rating up to 3000A (differing from others only by coil diameter); and hard clamps marked as C-4 (range up to 1000A AC), C-5 (up to 1000A AC/DC), C-6 (up to 10A AC) and C-7 (up to 100A AC). The values of nominal measured currents may be changed by using additional transducers - for example, using a transducer of 100:1 ratio, the user may select C-4 clamps to measure currents up to 100kA.

The device has a built-in 2 GB memory card. Data from the memory card may be read via USB slot by an external reader.

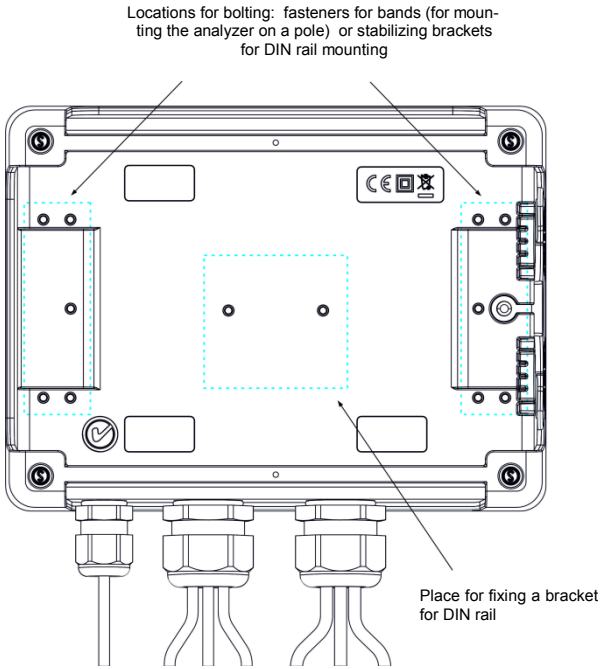


Fig. 2. The rear wall of PQM-700 analyzer.

Recorded parameters are divided into groups that may be independently turned on/off for recording purposes and this solution facilitates the rational management of the space on the memory card. Parameters that are not recorded, leave more memory space for further measurements.

PQM-700 has an internal power supply adapter operating in a wide input voltage range (100…460V AC/DC), which is provided with independent cables terminated with banana plugs.

An important feature of the device is its ability to operate in harsh weather conditions - the analyzer may be installed directly on electric poles. The ingress protection class of the analyzer is IP65, and operating temperature ranges from -20°C to +55°C.

Uninterrupted operation of the device (in case of power failure) is ensured by an internal rechargeable lithium-ion battery.

The user interface consists of five LEDs and 2 buttons.

The full potential of the device may be released by using dedicated PC software "Sonel Analysis 2.0."

Communication with a PC is possible via USB connection, which provides the bit rate up to 921.6 kbit/s

1.3 Power supply of the analyzer

The analyzer has a built-in power adapter with nominal voltage range of 90…460 V AC/DC. The power adapter has independent lines (red) marked with letter P (*power*) To prevent the power adapter from being damaged by undervoltage, it automatically switches off when powered with input voltages below approx. 80 V AC (110 V DC).

To maintain power supply to the device during power outages, the internal rechargeable battery is used. It is charged when the voltage is present at terminals of the AC adapter. The battery is able to maintain power supply up to 2 hours at temperatures of -20 °C...+55 °C. After the bat-

tery is discharged the meter stops its current operations (e.g. recording) and switches -off in the emergency mode. When the power supply from mains returns, the analyzer resumes interrupted recording.

> ***Note***
> *The battery may be replaced only by the manufacturer's service department.*

1.4 Tightness and outdoor operation

PQM-700 analyzer is designed to work in difficult weather conditions - it can be installed directly on electric poles. Two bands with buckles and two plastic fasteners are used for mounting the analyzer. The fasteners are screwed to the back wall of the housing, and bands should be passed through the resulting gaps.

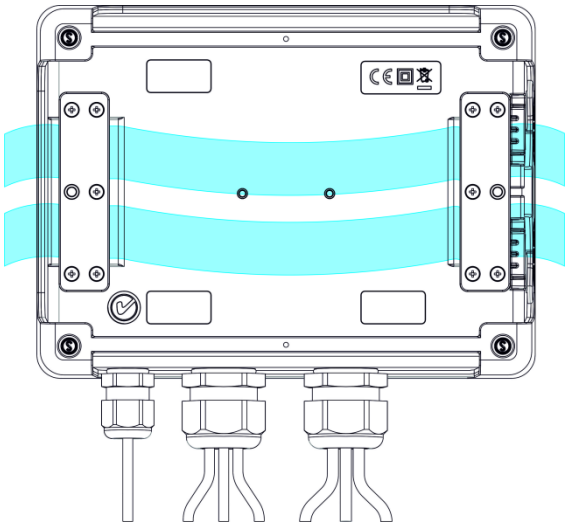


Fig. 3. Fasteners for bands (for mounting the analyzer on a pole)

The ingress protection class of the analyzer is IP65, and operating temperature ranges from -20°C to +55°C.

> ***Note***
> ***In order to ensure the declared ingress protection class IP65, the following rules must be observed:***
> - *Tightly insert the stoppers in the slots of USB and micro SD card,*
> - *Unused clamp terminals must be sealed with silicone stoppers.*

At ambient temperatures below 0°C or when the internal temperature drops below this point, the internal heater of the device is switched on - its task is to keep the internal temperature above zero, when ambient temperatures range from -20°C to 0°C.
The heater is equipped with a built-in AC adapter, and its power is limited to approx. 10 W.

Due to the characteristics of the built-in lithium-ion rechargeable battery, the process of charging is blocked when the battery temperature is outside the range of 0°C…45°C (in such case, "Sonel Analysis" software indicates charging status as "charging suspended").

1.5 Mounting on DIN rail

The device is supplied with a bracket for mounting the analyzer on a standard DIN rail. The bracket must be fixed to the back of the analyzer with the provided screws. The set includes also positioning catches (in addition to fasteners for mounting the analyzer on a pole), which should be installed to increase the stability of the mounting assembly. These catches have special hooks that are supported on the DIN rail.

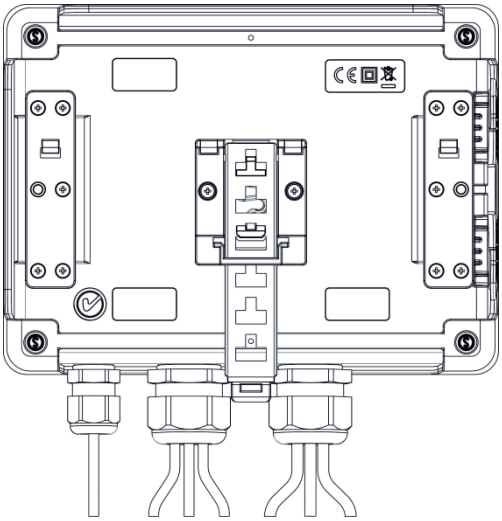


Fig. 4. The rear wall of the analyzer with fixtures for mounting on DIN rail.

1.6 Measured parameters

PQM-700 analyzer is designed to measure and record the following parameters:

- RMS phase and phase-to-phase voltages - up to 690V (peak voltages up to 1500V),
- RMS currents: up to 3000A (peak currents - up to 10kA) using flexible clamps (F-1, F-2, F-3); up to 1000A (peak values - up to 3600A) using hard clamps (C-4 or C-5); up to 10A (peak values - up to 36A) using C-6 clamps, or up to 100A (peak values - up to 720A) using C-7 clamps,
- crest factors for current and voltage,
- mains frequency within the range of 40...70Hz,
- active, reactive and apparent power and energy, distortion power,
- harmonics of voltages and currents (up to 40th),
- Total Harmonic Distortion THD_F and THD_R for current and voltage,
- power factor, cosφ, tgφ,
- unbalance factors for three-phase mains and symmetrical components,
- flicker factor P_{st} and P_{lt},
- inrush current up to 60 s.

Some of the parameters are aggregated (averaged) according to the time selected by the user and may be stored on a memory card. In addition to average value, it is also possible to record minimum and maximum values during the averaging period, and to record the current value occurring in the time of measurement.

The module for event detection is also expanded. According to EN 50160, typical events include voltage dip (reduction of RMS voltage to less than 90% of nominal voltage), swell (exceeding 110% of the nominal value) and interruption (reduction of the supplied voltage below 5% of the nominal voltage) The user does not have to enter the settings defined in EN 50160, as the software provides an automatic configuration of the device to obtain energy measurement mode compliant with EN 50160 The user may also perform manual configuration - the software is fully flexible in this area. Voltage is only one of many parameters for which the limits of event detection may be defined. For example, the analyzer may be configured to detect power factor drop below a defined value, THD exceeding another threshold, and the 9th voltage harmonic exceeding a user-defined percentage value. Each event is recorded along with the time of occurrence. For events that relate to exceeding the pre-defined limits for voltage dip, swell, interruption, and exceeding minimum and maximum current values, the recorded information may also include an waveform for voltage and current. It is possible to save two periods before the event, and four after the event.

A very wide range of configurations, including a multitude of measured parameters make PQM-700 analyzer an extremely useful and powerful tool for measuring and analysing all kinds of power supply systems and interferences occurring in them. Some of the unique features of this device make it distinguishable from other similar analyzers available in the market.

Table. 1 presents a summary of parameters measured by PQM-700, depending on the mains type.

Tab. 1. Measured parameters for different network configurations.

Parameter \ Network type, channel		1-phase		2-phase				3-phase wye with N,					3-phase triangle 3-phase wye without N,			
		L1	N	L1	L2	L3	Σ	L1	L2	L3	N	Σ	L12	L23	L31	Σ
U	Effective voltage	●	●	●	●	●		●	●	●	♣		●	●	●	
U_{DC}	Voltage constant component	●	●	●	●	●		●	●	●	♣		●	●	●	
I	Effective current	●	●	●	●	●		●	●	●	♣		●	●	●	
I_{DC}	Current constant component	●	●	●	●	●		●	●	●	♣		●	●	●	
F	Frequency	●		●				●					●			
CF U	Voltage crest factor	●	●	●	●	●		●	●	●	♣		●	●	●	
CF I	Current crest factor	●	●	●	●	●		●	●	●	♣		●	●	●	
P	Active power	●		●	●		●	●	●	●		●				●
Q_1, Q_B	Reactive power	●		●	●		●	●	●	●		●				●(1)
D, S_N	Distortion power	●		●	●		●	●	●	●		●				
S	Apparent power	●		●	●		●	●	●	●		●				●
PF	Power Factor	●		●	●		●	●	●	●		●				●
cosφ	Displacement power factor	●		●	●		●	●	●	●		●				
tgφ	Factor tangent φ	●		●	●		●	●	●	●		●				●(1)
THD U	Total harmonic distortion voltage	●	●	●	●	●		●	●	●	♣		●	●	●	
THD I	Total harmonic distortion current	●	●	●	●	●		●	●	●	♣		●	●	●	
E_{P+}, E_{P-}	Active energy (consumed and supplied)	●		●	●		●	●	●	●		●				●
E_{Q1+}, E_{Q1-} E_{QB+}, E_{QB-}	Reactive energy (consumed and supplied)	●		●	●		●	●	●	●		●				●(1)
E_S	Apparent energy	●		●	●		●	●	●	●		●				●
U_{h1}..U_{h40}	Voltage harmonic amplitudes	●	●	●	●	●		●	●	●	♣		●	●	●	
I_{h1}..I_{h40}	Current harmonic amplitudes	●	●	●	●	●		●	●	●	♣		●	●	●	
Unbalance U, I	Symmetrical components and unbalance factors											●				●
P_{st}, P_{lt}	Flicker factors	●		●	●			●	●	●			●	●	●	

Explanations: L1, L2, L3 (L12, L23, L31) indicate subsequent phases
N is a measurement for current channel I_N depending on the parameter type,
Σ is the total value for the system.
(1) $N = \sqrt{S_e^2 - P^2}$In 3-wire networks, the total reactive power is calculated as inactive power (see discussion on reactive power in section 10.7)

1.7 Compliance with standards

PQM-700 is designed to meet the requirements of the following standards.
Standards valid for measuring network parameters:

- PN-EN 61000-4-30:2011 – Electromagnetic compatibility (EMC) - Testing and measurement techniques - Power quality measurement methods,
- PN-EN 61000-4-7:2007 – Electromagnetic compatibility (EMC) – Testing and Measurement Techniques - General Guide on Harmonics and Interharmonics Measurements and Instrumentation for Power Supply Systems and Equipment Connected to them,
- PN-EN 61000-4-15:2011 – Electromagnetic compatibility (EMC) – Testing and Measurement Techniques - Flickermeter - Functional and Design Specifications,

- PN-EN 50160:2010 – Voltage characteristics of electricity supplied by public distribution networks.

Safety standards:
- PN-EN 61010-1 – Safety requirements for electrical equipment for measurement control and laboratory use. Part 1: General requirements

Standards for electromagnetic compatibility:
- PN-EN 61326 – Electrical equipment for measurement, control and laboratory use. Requirements for electromagnetic compatibility (EMC).

The device meets all the requirements of Class S as defined in PN-EN 61000-4-30. The summary of the requirements is presented in the table below.

Tab. 2. Summary of selected parameters in terms of their compliance with the standards

Aggregation of measurements at different intervals	PN-EN 61000-4-30 Class S: • Basic measurement time for parameters (voltage, current, harmonics, unbalance) is a 10-period interval for 50 Hz power supply system and 12-period interval for 60 Hz system, • Interval of 3 s (150 periods for the nominal frequency of 50 Hz and 180 periods for 60 Hz), • Interval of 10 minutes.
Real-time clock (RTC) uncertainty	PN-EN 61000-4-30 Class S: • Built-in real-time clock, set via "Sonel Analysis" software, no GPS/radio synchronization. • Clock accuracy better than ± 0.3 sec./day
Frequency	Compliant with PN-EN 61000-4-30 Class S of the measurement method and uncertainty
Power supply voltage	Compliant with PN-EN 61000-4-30 Class S of the measurement method and uncertainty
Voltage fluctuations (flicker)	The measurement method and uncertainty meets the requirements of PN-EN 61000-4-15 standard.
Dips, interruptions and surges of supply voltage	Compliant with PN-EN 61000-4-30 Class S of the measurement method and uncertainty
Supply voltage unbalance	Compliant with PN-EN 61000-4-30 Class S of the measurement method and uncertainty
Voltage and current harmonics	Measurement method and uncertainty is in accordance with PN-EN 61000-4-7 Class I

2 Operation of the analyzer

2.1 Buttons

The keyboard of the analyzer consists of two buttons: ON/OFF and START/STOP . To switch-on the analyzer, press ON/OFF button. START/STOP button is used to start and stop recording.

2.2 Switching the analyzer ON/OFF

- The analyzer may be switched-on by pressing button . Green LED is **ON**. Then, the analyzer performs a self-test and when an internal fault is detected, **ERROR** LED is lit and a long beep (3 seconds) is emitted - measurements are blocked. After the self-test, the meter begins to test its connections, when an error is detected **ERROR** LED flashes every 0.5 seconds, in this case the measurement may be triggered by pressing .
- If this test detects excessive voltage at the terminals or too-high current, **ERROR** LED flashes every 0.5 seconds and a two-tone beep is emitted.
- When the meter is switched on and detects full memory, **MEM** LED is lit - measurements are blocked, only read-out mode for current data remains active.
- When the meter is switched on and fails to detect the micro-SD card or detects its damage, **ERROR** and **MEM** LEDs are and measurements are blocked.
- If the connection test was successful, after pressing the meter enters the recording mode, as programmed in the PC.
- To switch the analyzer OFF, keep button pressed for 2 seconds, when no button or recording lock are active.

2.3 PC connection and data transmission

When the meter is switched-off by button, its USB port remains active.

- In the read-out mode for current data, PC software refreshes data with a frequency higher than once every 1 second
- During the recording process, the mater may transmit data already saved in memory. Data may be read until the data transmission starts.
- During the recording process the user may view mains parameters in PC:
  - instantaneous values of current, voltage, all power values, total values for three phases,
  - harmonics and THD
  - unbalance,
  - phasor diagrams for voltages and currents,
  - current and voltage waveforms drawn in real-time.
- When connected to a PC, button is locked, but when the analyzer operates with key lock mode (e.g. during recording), button is also locked.
- To connect to the analyzer, enter its PIN code. The default code is 000 (three zeros). The PIN code may be changed using "Sonel Analysis 2.0." software.
- When wrong PIN is entered three times in a row, data transmission is blocked for 10 minutes. Only after this time, it will be possible to re-entry PIN.
- When within 5 minutes of connecting a PC to the device no data exchange occurs between the analyzer and the computer, the analyzer exits data exchange mode and terminates the connection.

Notes

- *Holding down buttons START STOP and ⏻ for 5 seconds results in an emergency setting of PIN code (000).*
- *If you the keys are locked during the recording process, this lock has a higher priority (first the user would have to unlock buttons to reset the emergency PIN).*

USB is an interface that is continuously active and there is no way to disable it. To connect the analyzer, connect USB cable to your PC (USB slot in the device is located on the left side and is secured with a sealing cap). Before connecting the device, install "Sonel Analysis 2.0" software with the drivers on the computer

Bit rate is 921.6 kbit/s.

2.4 Taking measurements

2.4.1 Start / stop of recording

Recording may be triggered in three ways:

- immediate triggering - manually by pressing START STOP button after configuring the meter from a PC, **LOGG** LED is lit,
- scheduled triggering - according to time set in the PC, in this case pressing START STOP button does not trigger the recording process (the meter waits for the first pre-set time and starts automatically) – **LOGG** LED flashes every 1 second in stand-by mode and after triggering it is lit continuously,
- threshold triggering - after exceeding any threshold set in the settings, pressing of START STOP buttons triggers the normal measurement mode, but recording files (proper recording) starts only after detecting the first event. **LOGG** flashes every 1 second in stand-by mode and after triggering it is lit continuously.

The meter may be triggered by a current or voltage event, which is set in PC software. Thresholds for events triggering the recording process are the same as for event recording.

Stopping the recording process:

- recording ends automatically as scheduled (if the end time is set), in other cases the user stops the recording (using button START STOP or the software),
- Recording ends automatically when the memory card is full,
- after finishing the recording, when the meter is not in the sleep mode, **LOGG** LED turns off and the meter waits for operator commands,
- if the meter had LEDs turned-off during the recording process, then after finishing the recording no LED is lit; pressing any button activates **ON** LED.

2.4.2 Approximate recording times

The maximum recording time depends on many factors such as the size of the memory card, averaging time, the type of system, number of recorded parameters, waveforms recording, event detection, and event thresholds. A few selected configurations are given in Tab. 3. The last column presents approximate recording times for 2GB memory card. The typical configurations shown below are based on the measurement of I_N current.

Tab. 3. Approximate recording times for a few typical configurations.

Configuration type/ recorded parameters	Averaging time	System type (current measurement on)	Events	Event waveforms	Waveforms after averaging period	Approximate recording time with 2GB allocated space
according to EN 50160	10min	3-phase wye	• (1000 events)	• (1000 events)		60 years
according to the "voltages and currents" profile	1s	3-phase wye				270 days
according to the "Power and harmonics" profile	1s	3-phase wye				23 days
according to the "Power and harmonics" profile	1s	3-phase wye	• (1000 events)	• (1000 events)		22.5 day
all possible parameters	10min	3-phase wye				4 years
all possible parameters	10s	3-phase wye				25 days
all possible parameters	10s	1-phase				64 days
all possible parameters	10s	1-phase	• (1000 events / day)	• (1000 events / day)	•	22 days

2.5 Key Lock

Using the PC program, the user may select an option of locking the keypad after starting the process of recording. This solution is designed to protect the analyzer against unauthorized stopping of the recording process.
To unlock the keys, follow these steps:

- press three times in a row button in steps of 0.5 s and 1 s,
- then press

button within 0.5s to 1s,

When buttons are pressed, the user hears the sounds of inactive buttons - after completing the whole sequence the meter emits a double beep.

2.6 Sleep mode

PC software has the feature that activates the sleep mode. When the user starts recording, the meter turns off LEDs after 10 seconds. From this moment the following options are available:

- immediate triggering – after LEDs are turned off, **LOGG** LED blinks every 10 sec. signalling the recording process,
- triggering by event - after LEDs are turned off, **LOGG** LED blinks every 30 sec. in stand-by mode, and when the recording process starts **LOGG** LED starts to blink every 10 sec.,
- scheduled triggering - after LEDs are turned off, **LOGG** LED blinks every 30 sec. in stand-by mode, and when the recording process starts **LOGG** LED starts to blink every 10 sec.,

In addition to the above cases:

- if the user interrupts the recording process by pressing START STOP, then LEDs are lit, unless the next recording is triggered
- if the analyzer finishes the recording process due to the lack of space on the memory card or due to a completed schedule, the LEDs remain off.

Pressing any button (shortly) activates LED **ON** LED (and possibly other LEDs e.g. **MEM** depending on the state) and activates desired feature (if available).

2.7 Auto-off

When the analyzer operates for at least 30 minutes powered by the battery (no power supply from mains) and it is not in the recording mode and PC connection is inactive, the device automatically turns-off to prevent discharging the battery.

The analyzer turns off automatically also when the battery is fully discharged. Such an emergency stop is preceded by activating BATT LED for 5s and it is performed regardless of the current mode of the analyzer. In case of active recording, it will be interrupted. When the power supply returns, the recording process is resumed.

3 Measuring arrangements

The analyzer may be connected directly and indirectly to the following types of networks:

- 1-phase (Fig. 5)
- 2-phase (split-phase) with split-winding of the transformer (Fig. 6),
- 3-phase wye with a neutral conductor (Fig. 7),
- 3-phase wye without neutral conductor (Fig. 8),
- 3-phase delta (Fig. 9).

In three-wire systems, current may be measured by the Aron method, which uses only two clamps that measure linear currents I_{L1} and I_{L3}. I_{L2} jest current is then calculated using the following formula:

$$I_{L2} = -I_{L1} - I_{L3}$$

This method can be used in delta systems (Fig. 10) and wye systems without a neutral conductor (Fig. 11).

> ***Note***
> *As the voltage measuring channels in the analyzer are referenced to N input, then in systems where the neutral is not present, it is necessary to connect N input to L3 network terminal. In such systems, it is not required to connect L3 input of the analyzer to the tested network. It is shown in Fig. 7, Fig. 8, Fig. 9 and Fig. 10 (three-wire systems of wye and delta type).*

In systems with neutral conductor, the user may additionally activate current measurement in this conductor, after installing additional clamps in I_N channel. This measurement is performed after activating in settings the option of **Current in N conductor** (see section 5.2.1 and Fig. 27).

Note

In order to correctly calculate total apparent power S_e and total Power Factor (PF) in a 4-wire 3-phase system, it is necessary to measure the current in the neutral conductor. Then it is necessary to activate option ***Current in N conductor*** *and to install 4 clamps as shown in Fig. 6. More information may be found in sec. 10.7.5.*

Pay attention to the direction of current clamps (flexible and hard). The clamps should be installed with the indicating the load direction. It may be verified by conducting an active power measurement - in most types of passive receivers active power is positive. When clamps are incorrectly connected, it is possible to change their polarity using "Sonel Analysis" software (see section 5.3.2).

The following figures show schematically how to connect the analyzer to the tested network depending on its type.

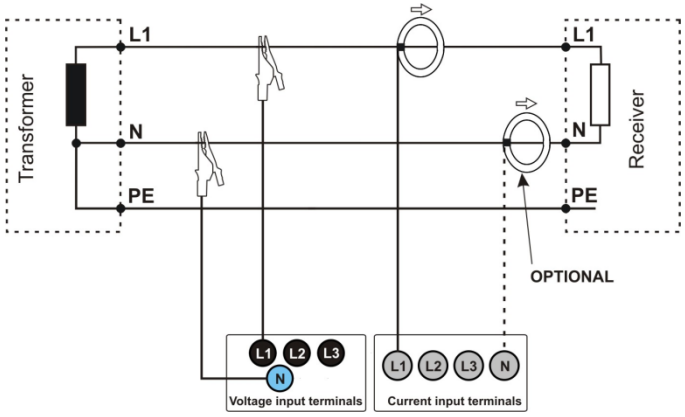


Fig. 5. Wiring diagram - single phase.

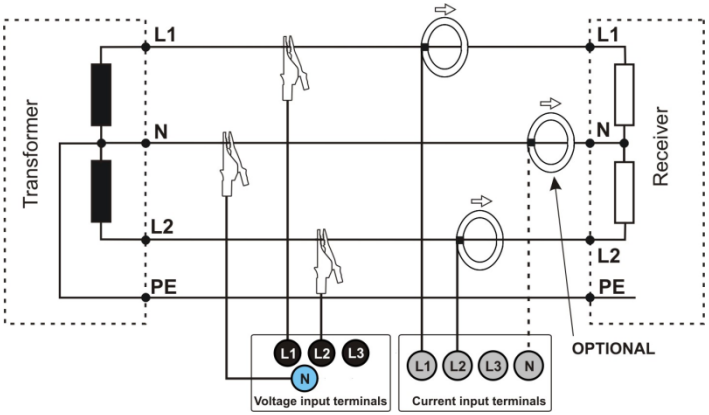


Fig. 6. Wiring diagram - 2-phase.

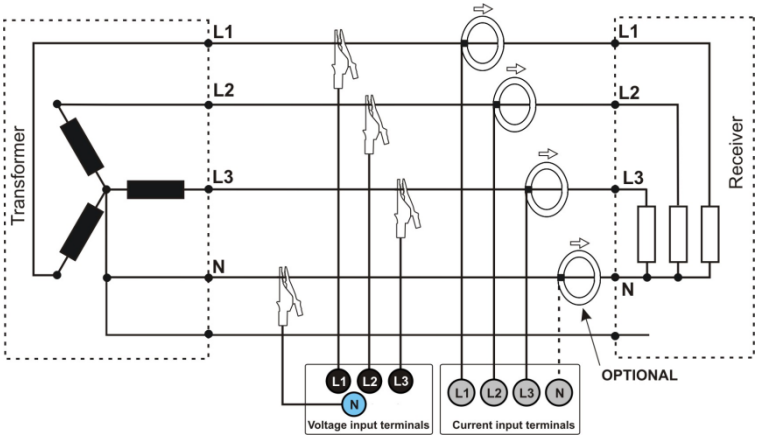


Fig. 7. Wiring diagram - 3-phase wye with a neutral conductor.

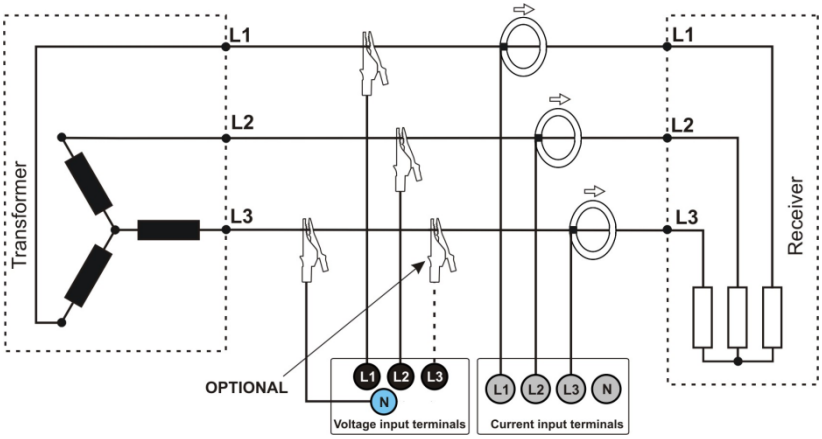


Fig. 8. Wiring diagram - 3-phase wye without neutral conductor.

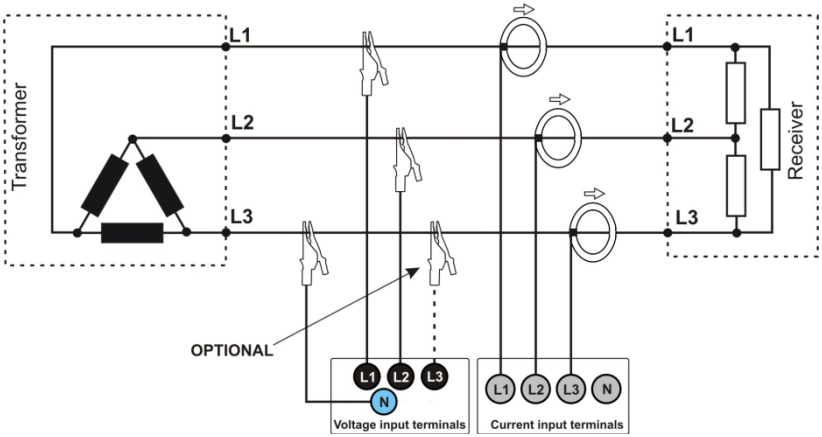


Fig. 9. Wiring diagram - 3-phase delta.

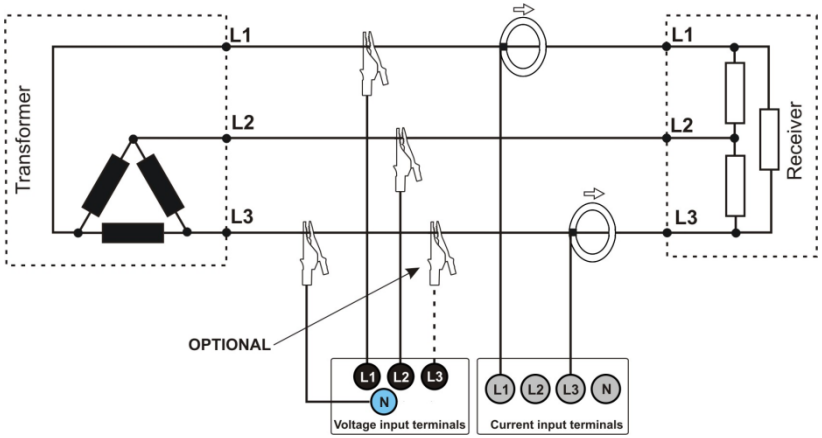


Fig. 10. Wiring diagram - 3-phase delta (current measurement using Aron method).

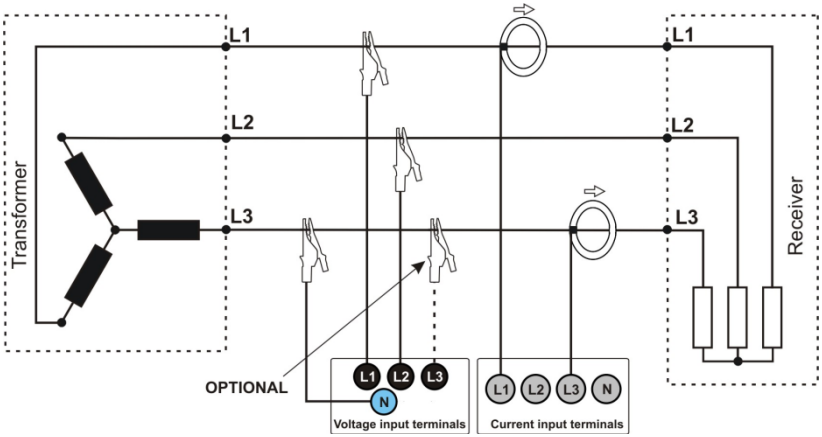


Fig. 11. Wiring diagram - 3-phase wye without neutral conductor (current measurement using Aron method).

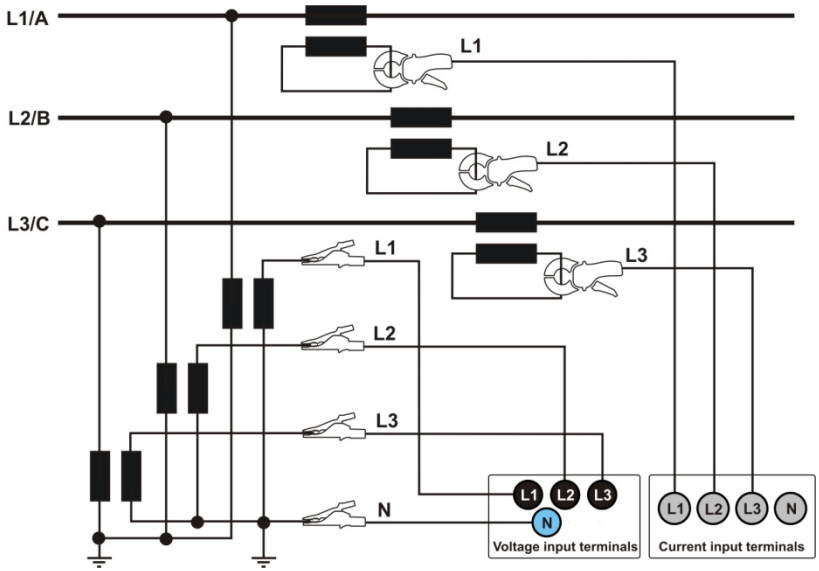


Fig. 12 Wiring diagram - a system with transformers

4 "Sonel Analysis 2.0" software

"Sonel Analysis 2.0" is an application required to work with PQM-700 analyzer. It enables the user to:

- configure the analyzer,
- read data from the device,
- real-time preview of the mains,
- delete data in the analyzer,
- present data in the tabular form,
- present data in the form of graphs,
- analysing data for compliance with EN 50160 standard (reports), system commands and other user-defined reference conditions,
- independent operation of multiple devices,
- upgrade to newer versions.

4.1 Minimum hardware requirements

Table. 4 presents the minimum and recommended configuration of a PC running the "Sonel Analysis 2.0" software.

Tab. 4. Minimum and recommended PC configuration.

Configuration	Minimum	Recommended
Processor	1.5 GHz	Pentium IV 2.4GHz
RAM	1GB	2GB
Free space on hard disk	200MB	8GB
Graphics Card	32MB, resolution 1024x768	With support for OpenGL 64MB, 1024x768
USB	•	•
Internet access (for automatic updates)		•
Operating system	Windows XP, Windows Vista, Windows 7	

4.2 Installation of the program

Note
In order to facilitate installing drivers for PQM-700, it is recommended to install "Sonel Analysis 2.0" software (including drivers as described in the following instructions) before connecting a USB cable.

To start the installation of "Sonel Analysis 2.0" software, run the installation file (e.g. "Setup Sonel Analysis 2.0.0.exe") included on the CD supplied with the analyzer.

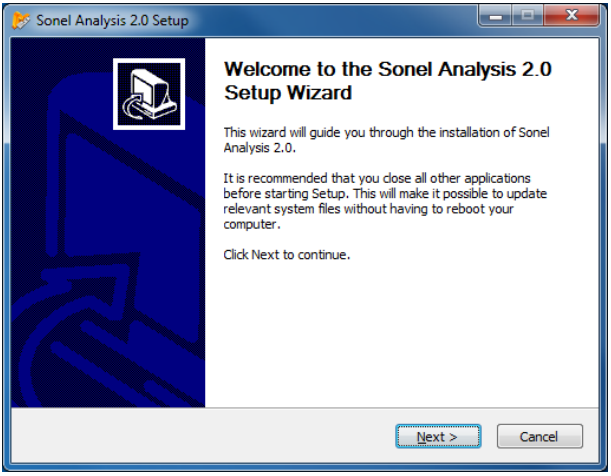


Fig. 13 Installer - the initial screen.

Click "Next>". Please read the software license agreement and click "I agree". On the next screen, specify location for the application to be installed and click "Next>".

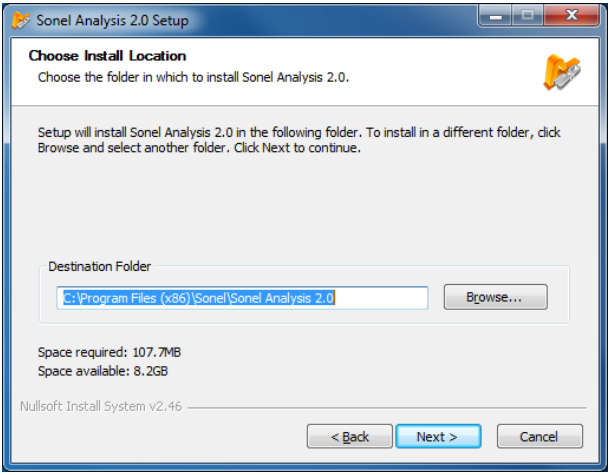


Fig. 14. Installer – program location settings.

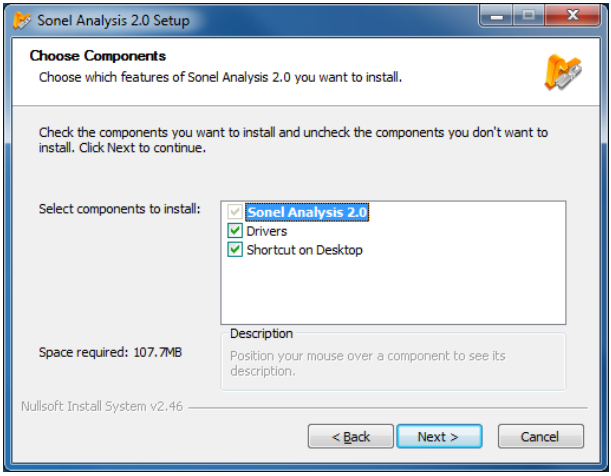


Fig. 15. Installer – choosing components.

Use component selection screen to select "Drivers" option and optionally tick "Create shortcut on the desktop". Then click "Next>"

The final step is to determine the location and name of the program, which will appear in the Start menu. The installer is ready to install the program. To begin the installation, press "Install".

In the final part, the program installs the drivers (if the user has chosen this option). Drivers for PQM-700 must be installed. Depending on the operating system, the installation wizard may look slightly different than the one shown in the presented screen-shots. After the installation wizard for drivers is displayed, follow the on-screen instructions. For Windows XP, select "Install the software automatically (recommended)". For Windows Vista and Windows 7, just select "Next>" and after installation is completed close the wizard, by clicking "Finish" button (Fig. 16, Fig. 17).

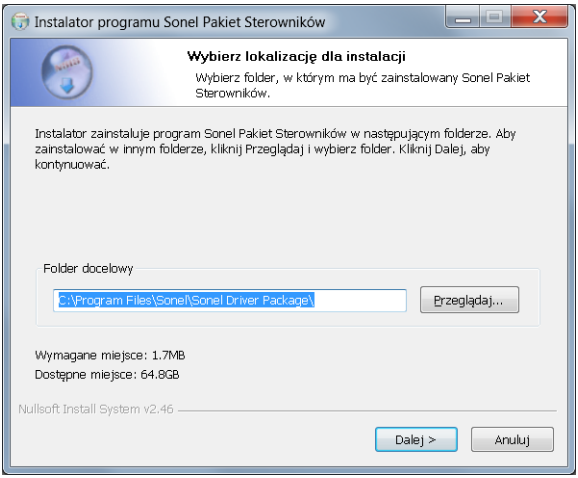


Fig. 16. Installer for the set of drivers.

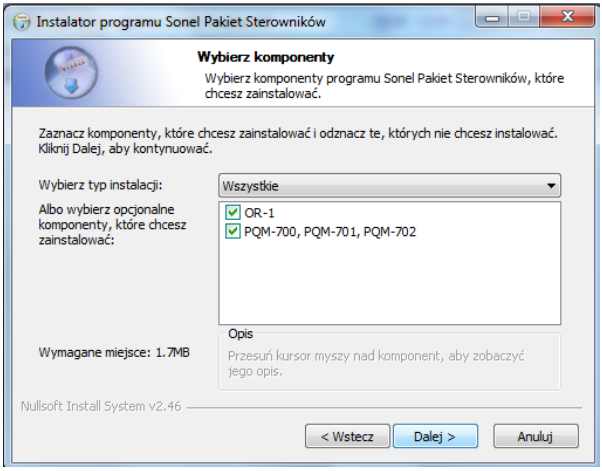


Fig. 17. Installer – selecting drivers to be installed.

At the end of the software installation, the window shown in Fig. 18 will be displayed When box "Launch Sonel Analysis 2.0" is ticked, then after pressing "Finish" button, the application will be launched.

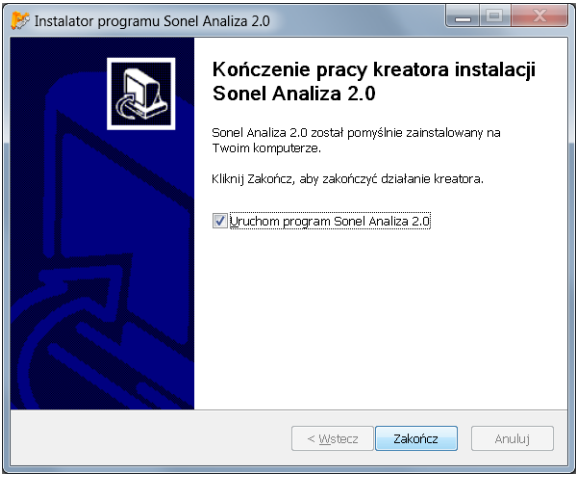


Fig. 18. Finishing the installation.

At this point, PQM-700 may be connected to a PC. The system should automatically recognize the connected device.

If the installation was successful, the computer is ready to cooperate with PQM-700.

4.3 Starting the program

When the program starts, the main window appears as shown in Fig. 19. The individual icons have the following meanings:

- **Open** – depending on the context, it enables the user to load the analyzer configuration, saved analysis, or saved recording from the disk
- **Save** – depending on the context, it enables the user to save the analyzer configuration on the disk (while editing the configuration), save raw data or present analysis files (during the analysis), ,
- **Settings** – configuration module of the analyzer,
- **Live mode** – the mode of reading current, real-time values,
- **Analysis** – the module for data analysis directly from the analyzer or from the memory card,
- **Disconnect** – ends the communication session with the analyzer.

Extensions of the files created by "Sonel Analysis" software are as follows:

- *.settings – analyzer configuration files (for the measurement point),
- *.config – "Sonel Analysis" configuration files,
- *.pqm700 – recording data files,
- *.analysis – analysis files.

The user may select commands from the top menu, by clicking icons with the mouse, or by using keyboard shortcuts (they are valid in the whole program):

- F5 – analyzer configuration
- F4 – current analyzer settings (including time and security)
- F6 – Live mode - reading current values,
- F8 - data analysis,
- Ctrl + Shift + N - deleting data
- F7 - control

There are many other keyboard shortcuts. Most of them are visible in the menu next to the name of an item.

> ***Tip***
> *The user may select commands using a mouse / keyboard (standard operation similar to Windows, ENTER - select option, ESC - Cancel, TAB - move to the next button, etc.).*

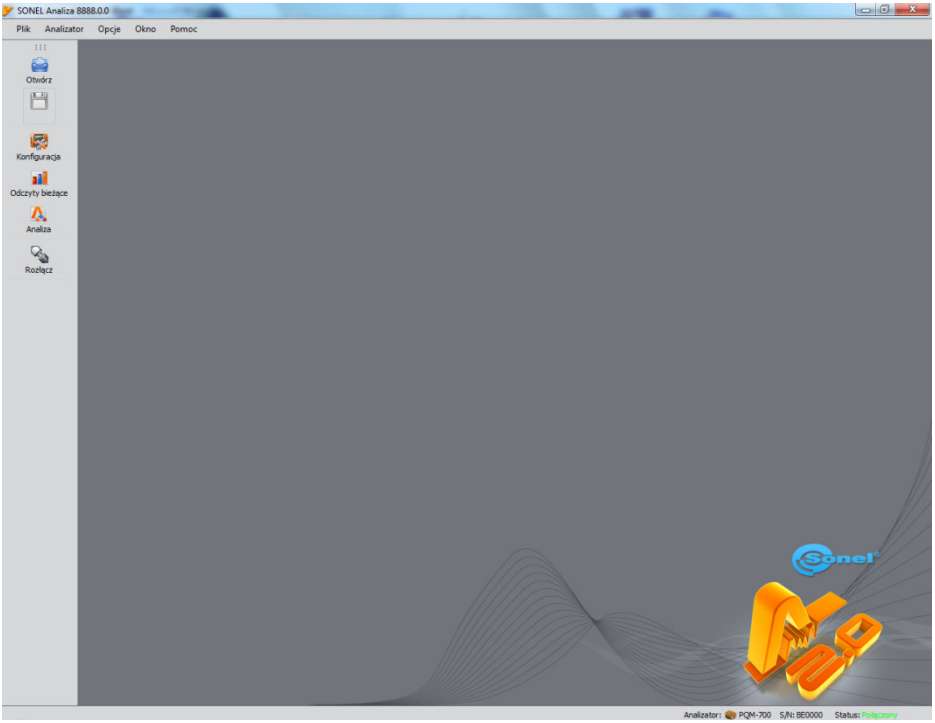


Fig. 19. The main screen.

4.4 Selecting the analyzer

Before sending any data from/ to the analyzer, it is necessary to select the analyzer to which "SONEL Analysis" software will connect. In order to establish the connection with the analyzer, select any option that requires an active connection e.g. **Settings**, **Live Mode** or **Analysis**.

After choosing one of the above options (when no previous connection was established), the program displays window "Connection" and starts scanning in the search for available analyzers (see Fig. 20). The analyzers are searched using wire connection (USB).

After a successful scan, the list of detected analyzers appears on the screen. Analyzers are displayed with their model, serial number and the type of communication link. Clicking on the selected analyzer and pressing **Select** icon approves the analyzer selected from the list. The analyzer may be also selected by double clicking on its field. Pressing **search again** restarts scanning in the search for the analyzers.

After selecting the analyzer, the program asks the user to enter PIN code, which protects it against unauthorized access. It consists of three digits (0 ... 9) By default PIN is set in the factory at 000.

Note
When wrong PIN is entered three times in a row, data transmission is blocked for 10 minutes.

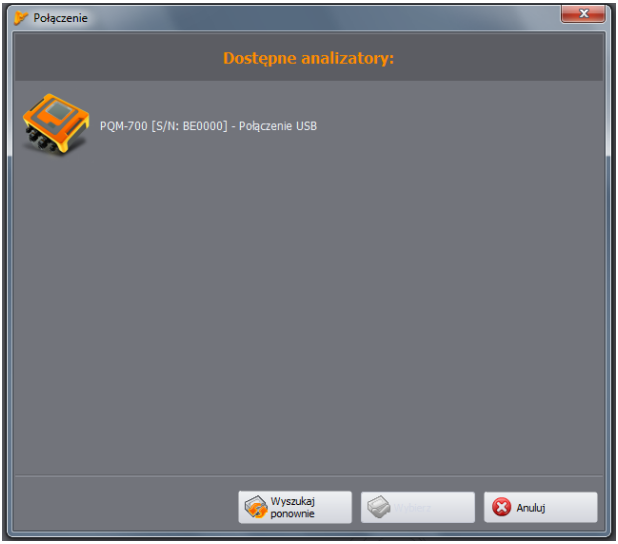


Fig. 20. Analyzer Selection Window.

After a successful connection, a window should appear to confirm the connection with the analyzer – see Fig. 21. This screen displays the analyzer information, such as its serial number, firmware and hardware versions.

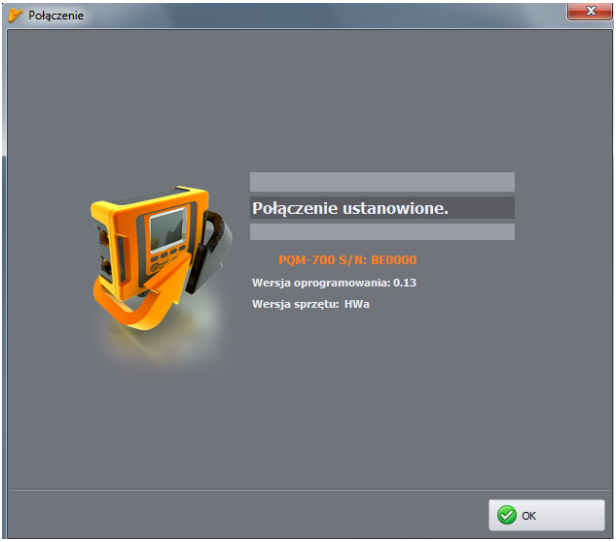


Fig. 21. The successful connection with the analyzer.

An unsuccessful attempt to connect the analyzer will trigger the error message. Press **Retry** button to repeat the attempt, or go to the analyzer selection window and select another analyzer, or rescan for available analyzers.

When during the communication the analyzer is switched off or the USB cable is plugged out, or other event would prevent receiving answer from the analyzer, the message shown in Fig. 22 will be displayed.

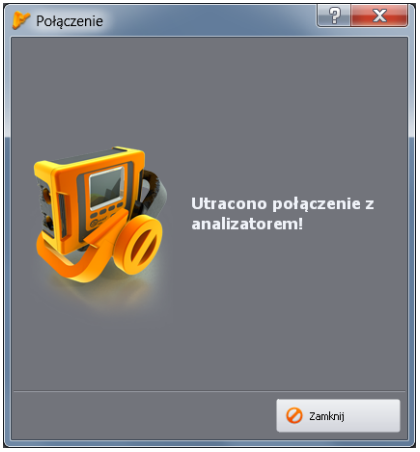


Fig. 22 Connection lost.

5 Analyzer Configuration

After selecting option **Analyzer→Settings** from the main menu (or clicking the icon) "Settings" window will be displayed as shown in Fig. 23. It is the most important part of the analyzer. Here the user determines which parameters will be recorded by the analyzer; the mains type and nominal values of the parameters.

The left part of the screen is divided into two parts (Fig. 23) **Local** and **Analyzer**. Top part (**Local**) is used by the user for parameters modification, whereas the bottom part (**Analyzer**) stores the current analyzer settings and is of read-only type. Each of the two parts includes **Analyzer settings** and one **measuring point.**

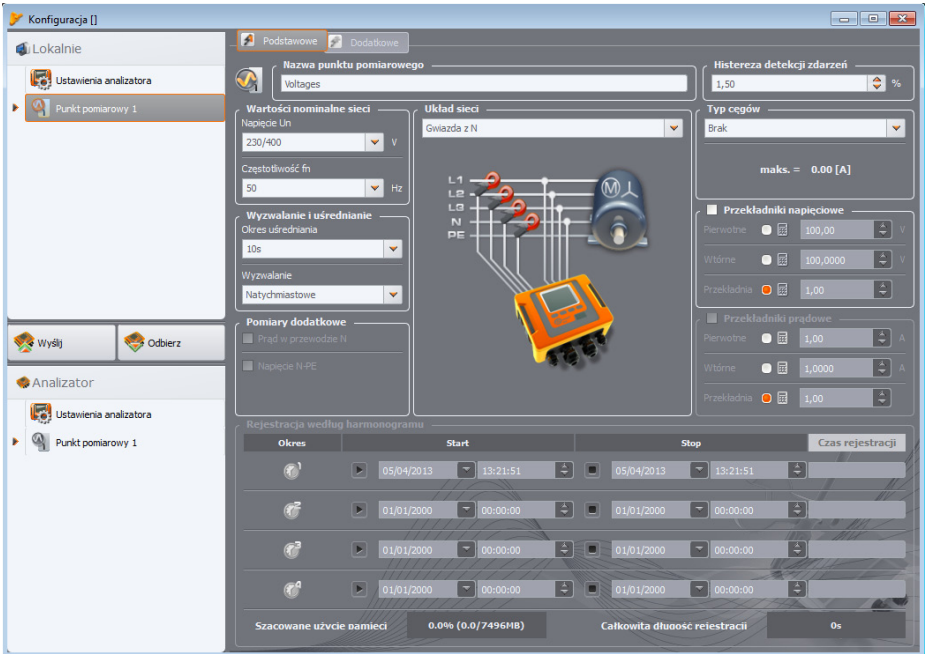


Fig. 23. Configuration of the measurement point - settings tree.

The measurement point represents an independent measurement configuration of the analyzer. This is the place where the user defines the mains system, nominal voltage, frequency, type of clamps and parameters for recording and detecting events.

The icons next to the measurement points may be displayed in various colours:

- grey - no connection with the analyzer,
- green - present configuration is synchronized with the analyzer configuration and with the configuration saved on the disk.
- blue - current configuration is compatible with the analyzer, but differs from the one saved to the disk,
- yellow - the configuration is not compatible with the analyzer, but is compatible with the one saved to disk,
- red - the current configuration is not compatible with the analyzer and not compatible with the one saved to disk.

Receive button is used to read the analyzer settings in order to edit them in the computer. If the settings have been previously modified by the user, a warning message will be displayed. The correct reading is also confirmed by a relevant message. Then the icon in the measurement point tree will change to blue, which means that the settings in the application and in the analyzer are identical.

Send button is used to send the settings to the analyzer. Before sending the settings, the user is asked to confirm the operation (Fig. 24).

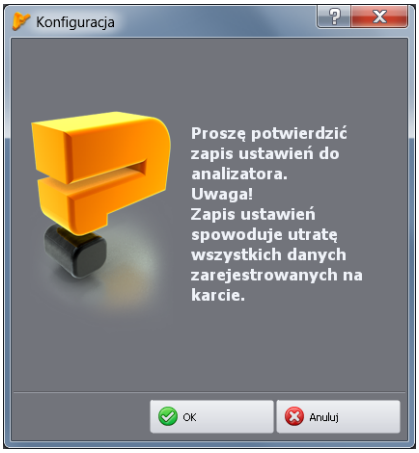


Fig. 24. Confirmation of entered settings.

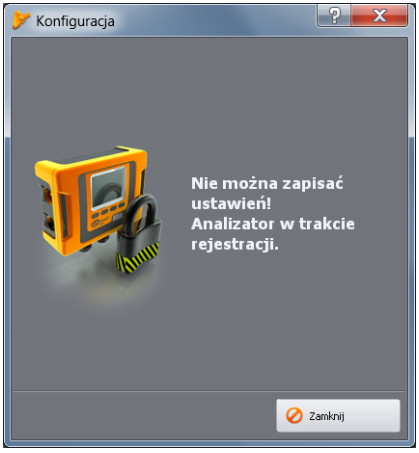


Fig. 25. Programming locked.

Note
Saving the new configuration will erase all data on the memory card. The user should read data previously collected from the analyzer and save it to local disk.

Note
Saving new settings in the analyzer is not possible when the device is in the recording mode (an appropriate message will be displayed to inform about this- Fig. 25).

5.1 Analyzer settings

The first element to be configured in the left-hand side of the window is **Analyzer Settings**. This part is divided into three tabs:

- **Analyzer type**: allows the user to choose the analyzer model for which the settings will be modified. As the software provides support for several models of analyzers with different capabilities, the user should pre-select the analyzer type from the list, to match the settings with analyzer performance. If the user is already connected to the analyzer, the analyzer type is selected automatically. In addition, the user may specify the type of the default analyzer in the settings (see section 9.3.1),
- **Memory Allocation**: this tab is not available for PQM-700.
- **UTC Synchronization**: this tab is not available for PQM-700.

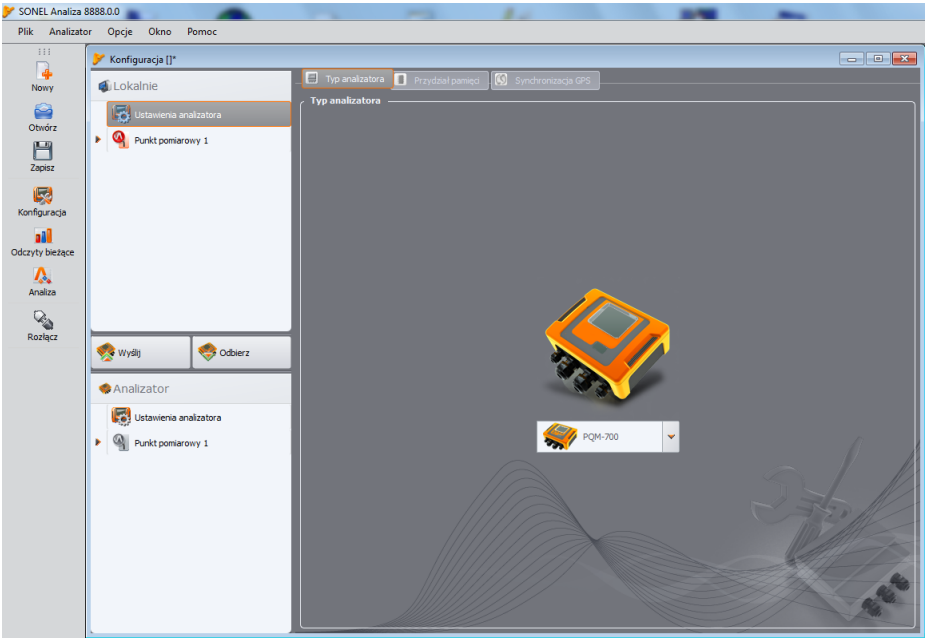


Fig. 26. Selection window for the analyzer type

5.2 Measurement point configuration

To drop down the "tree" of a measurement point, click once on the triangle at the measurement point, or double-click on a given measuring point.

Highlighting (by single-clicking) selected measurement point will result in displaying its **basic settings** on the right side of the screen. Main settings consist of two tabs: **Basic** and **Additional**.

After dropping down the measurement point, the following list is displayed:

- **EN 50160** – settings for EN 50160-compliant recording
- **Voltage** – settings of voltage-related parameters, divided into two tabs: **Basic** and **Additional**,
- **Current** – current parameters,
- **Power and energy** – power and energy parameters divided into three tabs: **Power**, **Additional** and **Energy**,
- **Harmonics** – harmonics parameters divided into three tabs: **Voltage**, **Current** and **Additional**,
- **Interharmonics** – these settings are not available for PQM-700.

Below we present the description of the main settings screen, and its individual cards.

5.2.1 Main Settings - <Basic> tab

Main settings screen of the measurement point and **Basic** tab is shown in Fig. 27. It is divided into a few sections: the mains-related settings are grouped in the top part, whereas the part located below relates to recording according to the schedule and time intervals. In addition, here the user may assign desired name to a measurement point and assign the hysteresis used during the event detection.

The following parameters are defined in the part related to the mains (Fig. 27):

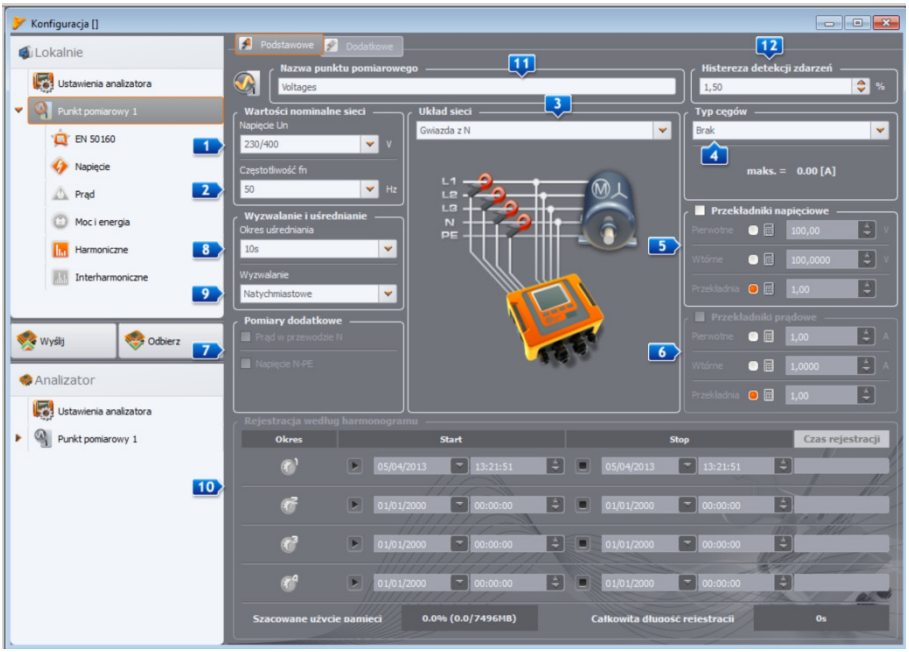


Fig. 27. Setting the mains parameters, nominal mains parameters and transducers.

- 1 **Voltage Un**: nominal voltage 64 V/110 V, 110 V/190 V, 115 V/200 V, 127 V/220 V, 220 V/380 V, 230 V/400 V, 240 V/415 V, 254 V/440V, 290 V/500 V, 400 V/690 V (phase /phase-to-phase, depending on the mains type),
- 2 **Frequency fn**: Mains nominal frequency – 50 or 60Hz,
- 3 **Mains system** – one-phase, split-phase, wye with N, delta, wye without N, and Aron's measuring systems; a connection drawing for selected system is shown in the field below the name. For mains of delta and wye with N type, the nominal voltage is the phase-to-phase value (the second value is specified in **Mains nominal values** field),
- 4 **Clamps type** – indicates the type of current clamps used for the measurements. The user may select C-4, C-5, C-6, C-7 clamps or F-1/F-2/F-3 flexible clamps. If the current measurement is not required, select **None**option.
- 5 **Current transducers –** – they define the current transducers ratio (when used). Please select one of the three possible parameters of the transducer that will be calculated using the other two:
  - Selecting "**Primary**" will grey out the primary voltage, which is calculated basing on two other parameters that may be changed by the user: the voltage of the secondary circuit - **Secondary** and **Ratio**. Primary voltage is calculated as the product of secondary voltage and ratio.
  - Selecting "**secondary**" will grey out the primary voltage, which is calculated by the software, basing Primary voltage and Ratio. Secondary output voltage is equal to the quotient of the primary voltage and ratio.
  - selecting "**Ratio**" will grey out "Ratio" field. The division is determined by defining the primary and secondary voltage. Ratio is calculated as the ratio of the primary and secondary voltage.

After turning the option of voltage transducers field **Voltage Un** is greyed out; a new nominal voltage is the primary voltage of the transformer.

- 6 **Current transducers** – define the current transducer ratio. The measuring range of selected clamps may be extended using external current transducers. The same method for determining the ratio is used as in the case of the voltage transducers. Select one of the three parameters, which will be calculated automatically based on the other two. The resulting measuring range (primary current which does not exceed the nominal range of used clamp) is displayed below the clamp selection list.
- 7 **Additional measurements** – use the additional option fields to define possible measurements of additional parameters, such as neutral conductor current (with the fourth clamp pair, if the system type is appropriate). Please note that the analyzer will not measure these parameters, if they are not checked in this place.
- 8 **Averaging Period** for measurements – use this field to define the basic results averaging period. Available times are as follows: ½ period (special mode with recording time limited to 60 s, recording only instantaneous values of voltage and current), 1 s, 3s, 10 s, 30 s, 1 min, 10 min, 15 min, 30 min,
- 9 **Triggering** of recording – enables the recording activation mode:
  - **Immediate** - immediate measurement after pressing START/STOP button or starting the recording process from the software,
  - **Scheduled** – after recording starts (by pressing the button or from the PC) the analyser compares the present time with intervals defined in the schedule and uses them to starts and stops the recording,
  - **Threshold** - the measurement after the limit for any active event is exceeded - after activating, the device analyses the mains and waits until a parameter is exceeded - this event triggers recording- at this moment data are recorded (loggged) on the memory Card.

> ***Note***
> *If the user turned on the option of standard-compliant recording in EN 50160 tab, it will result in setting the averaging time on 10 minutes and the selection list block averaging period selection list. To change these settings, the user must firstly disable the standard-compliant recording in EN 50160 tab.*

Other elements of the settings screen (Fig. 27):

- 10 **Scheduled logging** (recording) – 1 time period may be specified. After selecting a given period by clicking the green arrow, enter the start date and time (optionally you may specify the end date/time). If the user sets the recording start without defining its end, the device will operate until it is manually stopped or until the memory is filled-up. Time intervals must not overlap - the program does not allow you to configure overlapping ranges. The following time intervals must be set chronologically.
- 11 **Measurement point name** – the user may assign a name for selected measurement point; it may be consist of maximum 32 characters,
- 12 **Events detection hysteresis** – it determines the size of the hysteresis used in determining event detection thresholds. It may be set within the range of 0.0…10.0% in 0.5% steps. The typical size of the hysteresis is 2%. More information about this matter may be found in sections 10.10 and 10.11.

5.2.2 Analyzer settings according to EN 50160

After selecting "**EN 50160**" position from the selection tree, the user may quickly choose analyzer settings according to EN 50160 or local standards. This standard specifies the characteristics and quality criteria that should be met by the distribution networks of low and medium voltage. Settings shown in the list are defined in the program settings in the location: **Options→ Program settings→Analyzer settings→Default standard settings**. After choosing from the list a specific settings, the analyzer marks on the selection tree (of the measurement point) the parameters necessary to perform measurements according to EN 50160 and locks them to prevent inactivating them by the user. For example, if the averaging time was previously set to 3 seconds, after selecting "Record according to standard" and choosing specific settings from the list of, it will change into 10-minutes and it will be greyed out, preventing any further changes. At the same time, average voltage measurement is selected along with voltage THD, voltage harmonics, etc.

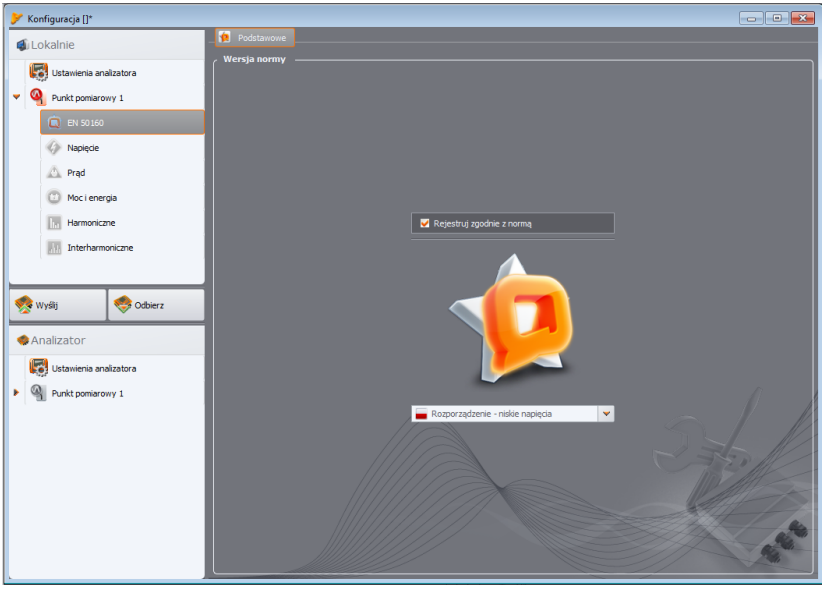


Fig. 28. EN 50160 tab for measurement point setting.

Basic mains measurement time, according to EN 50160, is one week. In this time, the following parameters are measured: RMS voltage, frequency, Total Harmonic Distortion, levels of individual voltage harmonics, unbalance (in three-phase mains), flicker . Because the week-long measurements are related to gathering a large amount of data, it was decided to use averaging algorithms. All the evaluated parameters, excluding the frequency and long-term flicker, are averaged over 10 minutes. Thus, within a week, the user obtains 1008 values for each of these parameters. These values are then evaluated by comparing them to the criteria defined in the standard.

If all parameters are within the specified thresholds, it can be concluded that the measured mains meets the quality requirements of EN 50160.

Tab. 5 contains the current criteria for measurements according to EN 50160 in mains with voltages up to 35kV. These settings are accepted by selecting the default settings for "**EN 50160**" or "**Regulation: low voltage**" and "**Regulation: medium voltage**".

Tab. 6 contains the criteria set out in the Regulation of the Minister of Economy of 4 May 2007 on detailed conditions of power system functioning, for connection of groups I and II. These criteria apply after selecting default settings "**Regulation: High Voltage**".

Tab. 5. Criteria for power quality according to standard EN 50160 for mains voltage up to 35kV.

<table>
<tr><th>Parameter</th><th>Basic measurement time</th><th>Criterion</th></tr>
<tr><td>Slow changes in voltage (RMS voltage)</td><td>10 minutes</td><td>for 95% of the measurements the deviation from the nominal voltage shall be within the range of ±10% U_{nom}
for 100% of the measurements: –15%...+10% U_{nom} (100% criterion applies only to LV mains)</td></tr>
<tr><td>Frequency</td><td>10 seconds</td><td>for 99.5% of the measurements the deviation should be within ±1% f_{nom} (i.e. for 50Hz it is 49.5…50.5Hz)
for 100% of measurements: –6%...+4% f_{nom} (47…52Hz)</td></tr>
<tr><td>Rapid voltage changes (flicker)</td><td>2 hours</td><td>for 95% of the measurements the long-term flicker factor is P_{lt} ≤ 1</td></tr>
<tr><td>Voltage unbalance</td><td>10 minutes</td><td>for 95% of the measurements of the negative-sequence unbalance factor should be ≤ 2%</td></tr>
<tr><td>Total Harmonic Distortion (THD-F)</td><td>10 minutes</td><td>for 95% of measurements, THD-F should be ≤ 8%</td></tr>
<tr><td>Voltage harmonics</td><td>10 minutes</td><td>For 95% of the measurements, the level of each voltage harmonic component related to the fundamental component should be less than:
<table>
<tr><th colspan="2">Odd order harmonics</th><th colspan="2">Even order harmonics</th></tr>
<tr><th>Order</th><th>Relative level</th><th>Order</th><th>Relative level</th></tr>
<tr><td>3</td><td>5.0%</td><td>2</td><td>2.0%</td></tr>
<tr><td>5</td><td>6.0%</td><td>4</td><td>1.0%</td></tr>
<tr><td>7</td><td>5.0%</td><td>6 … 24</td><td>0.5%</td></tr>
<tr><td>9</td><td>1.5%</td><td colspan="2" rowspan="9"></td></tr>
<tr><td>11</td><td>3.5%</td></tr>
<tr><td>13</td><td>3.0%</td></tr>
<tr><td>15</td><td>0.5%</td></tr>
<tr><td>17</td><td>2.0%</td></tr>
<tr><td>19</td><td>1.5%</td></tr>
<tr><td>21</td><td>0.5%</td></tr>
<tr><td>23</td><td>1.5%</td></tr>
<tr><td>25</td><td>1.5%</td></tr>
</table></td></tr>
</table>

Tab. 6. Quality criteria for the mains with a nominal voltage of at least 110 kV (based on the Regulation of the Minister of Economy of 4 May 2007 on detailed conditions of power system functioning).

<table>
<tr><th>Parameter</th><th>Basic measurement time</th><th>Criterion</th></tr>
<tr><td>Slow changes in voltage (RMS voltage)</td><td>10 minutes</td><td>Mains with nominal voltage of 110kV:
for 95% of the measurements the deviation from the nominal voltage shall be within the range of ±10% U_{nom}
Mains with nominal voltage of 220kV:
for 95% of the measurements the deviation from the nominal voltage shall be within the range of -10%...+5% U_{nom}</td></tr>
<tr><td>Frequency</td><td>10 seconds</td><td>for 99.5% of the measurements the deviation should be within ±1% f_{nom} (i.e. for 50Hz it is 49.5…50.5Hz)
for 100% of measurements: –6%...+4% f_{nom} (47…52Hz)</td></tr>
<tr><td>Rapid voltage changes (flicker)</td><td>2 hours</td><td>for 95% of the measurements the long-term flicker factor is P_{lt} ≤ 0.8</td></tr>
<tr><td>Voltage unbalance</td><td>10 minutes</td><td>for 95% of the measurements of the negative-sequence unbalance factor should be ≤ 1%</td></tr>
<tr><td>Total Harmonic Distortion (THD-F)</td><td>10 minutes</td><td>for 95% of measurements, THD-F should be ≤ 3%</td></tr>
<tr><td>Voltage harmonics</td><td>10 minutes</td><td>For 95% of the measurements, the level of each voltage harmonic component related to the fundamental component should be less than:
<table>
<tr><th colspan="2">Odd order harmonics</th><th colspan="2">Even order harmonics</th></tr>
<tr><th>Order</th><th>Relative level</th><th>Order</th><th>Relative level</th></tr>
<tr><td>3</td><td>2.0%</td><td>2</td><td>1.5%</td></tr>
<tr><td>5</td><td>2.0%</td><td>4</td><td>1.0%</td></tr>
<tr><td>7</td><td>2.0%</td><td>>4</td><td>0.5%</td></tr>
<tr><td>9</td><td>1.0%</td><td colspan="2" rowspan="13"></td></tr>
<tr><td>11</td><td>1.5%</td></tr>
<tr><td>13</td><td>1.5%</td></tr>
<tr><td>15</td><td>0.5%</td></tr>
<tr><td>17</td><td>1.0%</td></tr>
<tr><td>19</td><td>1.0%</td></tr>
<tr><td>21</td><td>0.5%</td></tr>
<tr><td>23</td><td>0,7 %</td></tr>
<tr><td>25</td><td>0,7 %</td></tr>
<tr><td>>25</td><td>0.2+0.5·25/h %</td></tr>
</table>
</td></tr>
</table>

Example

Nominal voltage 230V, 50Hz frequency, measurement time 1 week.
Out of 1008 values of the average RMS voltage, 95% i.e. 958, must be within the range of 207V…253V.
However, all measurements of RMS voltage must be within the range of 195.5 V ... 253V.
Within one week of, the number of 10-second frequency measurements is 60480 and 99.5% of this value (i.e. 60178), must be in within the range of 49.5 ... 50.5 Hz. All frequency measurements must be within the range of 47 ... 52Hz.

The procedure for setting the analyzer on the measurement compliant with the standard is as follows. On the main screen for the measurement point settings, the user should set the correct mains type, nominal voltage, frequency, type of clamps, or select the appropriate transducers.

Then select card **EN 50160** and enable "**Record according to the standard"**. This causes unlocking the standard version list. Then, from the list select the appropriate element.

After completing the settings, the user may trigger the recording process from the PC program or by using START STOP button.

The user has the ability to edit the standard default settings defined in the preferences. It may be useful in situations where the criteria defined in EN 50160 will change. The user will be able to adjust the settings yourself without the need to upgrade **Sonel Analysis** software.

Although the standard PN-EN 50160 does not provide for current measurement or testing the mains parameters associated with the current, because of the frequent need to test 15-minute power and tgφ average values (as per the aforementioned regulation of the Minister of Economy), the analyzer allows simultaneous measurement of the mains for conformity with PN-EN 50160 and 15-minute average values of active, reactive and apparent powers, as well as tgφ. To enable the recording of these parameters, select the Polish/English flag (depending on your preferences) from the presented list. Profiles dedicated to Polish conditions: "Regulation: Low Voltage", "Regulation: Medium Voltage" and "Regulation: High Voltage" have enabled the recording process (by default) for 15-minute average parameters: tangentφ, and active, reactive and apparent power. The user must on its own activate the current measurement in the measurement point settings (choose the correct type of clamps and optionally set transducers).

5.2.3 Configuring the Analyzer according to user settings

If the user did not chose recording in accordance with EN 50160, then all available parameters may be freely controlled by the user. All settings are included in the main card of the measurement point (**Basic** and **Additional** tabs) and four other cards (and their tabs): **Voltage**, **Current**, **Power and Energy**, **Harmonics**.

To switch into the user mode, close the options in card **EN 50160**: **Record according to the standard**.

In most cases, the settings for the selected parameter may be divided into a section of cyclical recording of parameter values according to the selected averaging time, and into the section related to event detection.

The user may select to record the value of average, minimum, maximum and instantaneous parameter. For voltage and current the user may define an additional averaging time that is used for detecting minimum and maximum values. To clarify these issues let us use an example.

Example

Global averaging time has been set to 1 minute, while min/max determination period for voltage has been set to 5 seconds. All four options have been checked: recording of average, minimum, maximum and instantaneous values.

Question: How these values are determined and what is recorded on the memory card?

$$U_{śr} = \sqrt{\frac{\sum_{i=1}^{k} U_i^2}{k}}$$

1. Average value is determined as the RMS (root mean square) from 10/12-period measurements (approx. 200ms). There will be approx. 300 of such measurements per 1 minute. Average voltage value is calculated as the square root of arithmetic mean of squared input values:

where:
U_{avg} – 1-minute RMS voltage,
k – number of gathered 10/12-period values,
U_i – RMS voltage of 10/12-period type.
2. Min/max averaging equal to 5 seconds means that firstly the analyzer averages 25 successive U_i values (using the method described above). Minimum and maximum values are selected from all 5-second average values gathered during 1 minute. Both, minimum and maximum values will be recorded.
3. Instantaneous value is the last 10/12-period voltage value measured during 1-minute averaging period. This value will also be saved on the card.

For most of parameters the user may enable detection of events. "Event" is the term, which describes the situation, when the measured value exceeds the threshold(s) set by the user. Depending on a parameter, the number of thresholds may be as follows: only one (e.g. for negative-sequence unbalance factor - exceeding the maximum value), two (e.g. for frequency - exceeding the upper and lower limits), three - for voltages (exceeding the threshold of swell dip and interruption).

Information about the event is recorded by the analyzer on the memory card at the time of its completion. Then the following information is recorded:

- start time of the event,
- end time of the event,
- threshold value,
- parameter limit value during the event,
- parameter average value during the event.

If the recording is interrupted during an event, information about this event is also saved, but only within the following scope:

- start time of the event,
- threshold value,
- limit value of the parameter recorded by the end of the recording process.

For two parameters: RMS voltage and current, the recording process of waveforms may be enabled along with $RMS_{1/2}$ values - at the beginning and end of the event.

5.2.4 Voltage

Voltage card is divided into two tabs: **Basic** and **Additional**.

5.2.4.1 <Basic> Tab

Fig. 29 presents basic settings for recording voltages. Depending on the mains type, the settings relate to phase-to-neutral voltages (one-phase, split-phase, three-phase 4-wire systems) or phase-to-phase voltages (three-phase 3-wire systems).
As a standard, the user may check the recording of the average value (**Avg**), minimum (**Min**), maximum (**Max**) and instantaneous (**Inst**) of the RMS voltage. Option **All** selects all four, or remove them all.

Measurement of minimum and maximum value is performed with the user-defined averaging time (option **Min/Max calculation period**). Available averaging times: ½ period, period, 200ms, 1s, 3 or 5s.

> ***Note***
> *Averaging times: 200ms, 1, 3 and 5 sec. are actually expressed as multiples of the mains basic period:*
> - *200ms – 10/12 periods (50/60Hz)*
> - *1 second – 50/60 periods*
> - *3 seconds – 150/180 periods*
> - *5 seconds – 250/300 periods*

For systems with phase-to-neutral voltages (split-phase and three-phase with a neutral conductor N), there is an additional option of recording RMS phase-to-phase voltages. In such case only the average value is recorded.

The part related to events is located on the right side of the screen.

Checking option **Log events** activate the fields for voltage threshold values. They may be entered as percentage or absolute values.
The setting ranges are as follows:

- **Swell**: 0.00…+20.00% with a resolution of 0.01% or in volts within the same range,
- **Dips**: 0.00…-99.90% with a resolution of 0.01% or in volts,
- **Interruptions**: 0.00...-100.00% with a resolution of 0.01% or in volts up to 0.00V (the dip level cannot be lower than the interruption level).

Switching between the threshold percentage values to absolute values results in automatic calculation to selected unit.

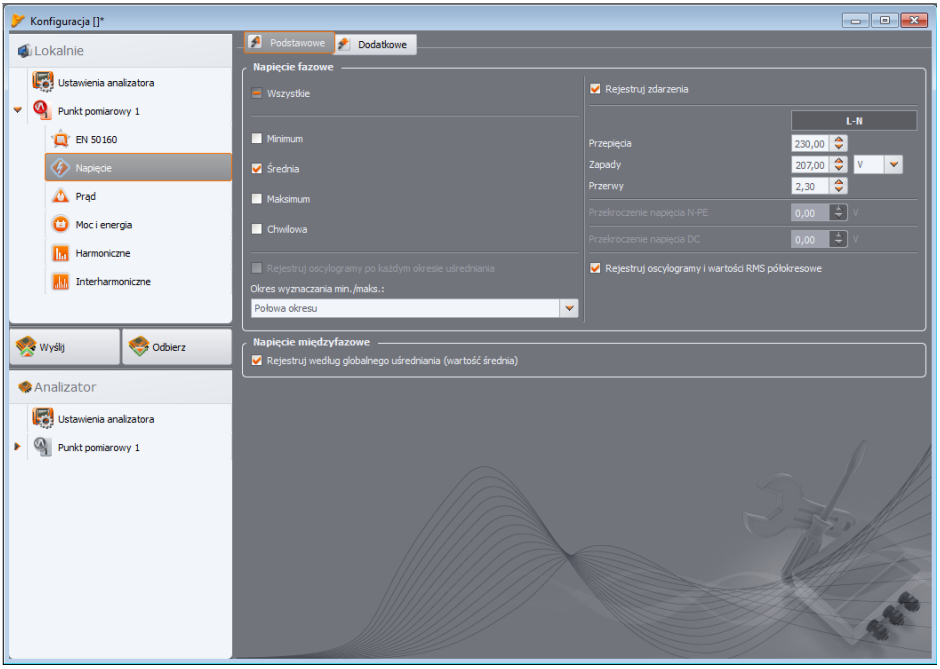


Fig. 29. Basic settings for voltage measurements.

> ***Note***
> *When the user changes mains nominal voltage after the event threshold have been set, the thresholds expressed in percentage values will remain on the same levels.*

After selecting **Log waveforms and RMS1/2** option, the analyzer will record 6 periods for voltage and current waveforms waveforms and RMS $_{1/2}$ values, at the beginning and the end of an event.

5.2.4.2 <Additional> tab

In this tab (see Fig. 30) the user defines recording parameters for the mains frequency, crest factor, voltage flicker rates and voltage unbalance. Similarly to other parameters, the user may select recording of average, minimum, maximum and instantaneous values. In the case of unbalance, the recorded parameters include: three symmetrical components in volts (zero positive and negative) and two unbalance factors (in %): zero and positive factor.

Additionally, the user may enable event recording. The setting ranges are as follows:

- frequency: 40 ... 70Hz with a resolution of 0.01 Hz or 0.01%, whereas the minimum value can not be higher than the defined mains reference frequency, and the maximum value can not be lower this reference value,
- crest factor: 1.00 ... 10.00, resolution 0.01,

- negative sequence unbalance : 0.00…20.00% every 0.01%,
- flicker (short-term and long-term): 0.00 ... 20.00 in 0.01 steps.

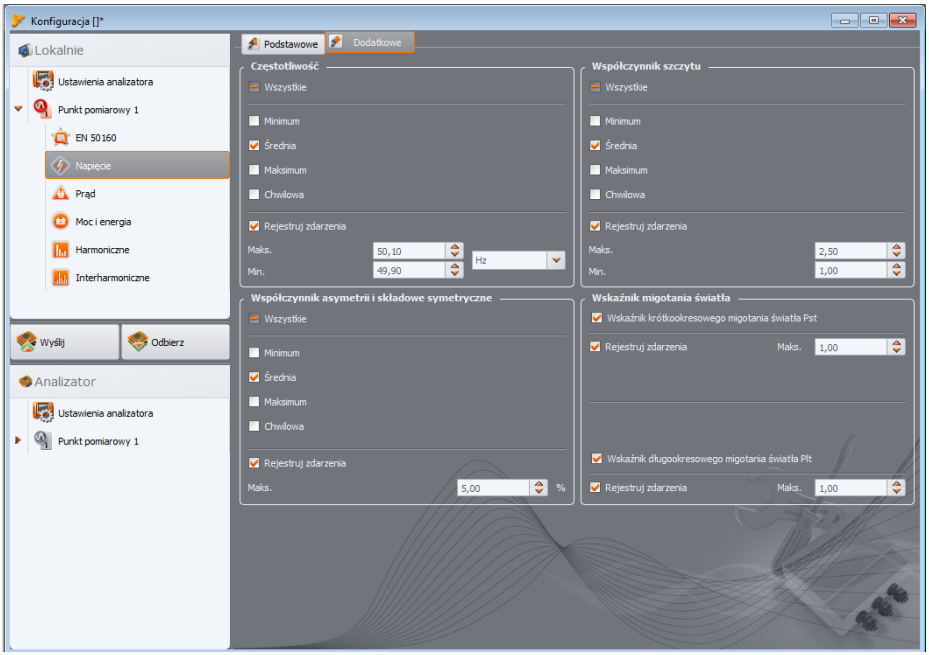


Fig. 30. Additional settings for voltage measurements.

5.2.5 Current

Screen of Actual settings is shown in Fig. 31.

> ***Note***
> *This tab is not available if the current measurement was disabled in the main measurement point configuration by selecting* ***None*** *option in* ***Clamps type*** *field*

The following elements are grouped here:

- recording RMS current,
- selection list of averaging times to determine minimum and maximum values (similarly to voltage, the available times include: ½ period, period, 1, 3 and 5 seconds),
- recording current crest factor,
- recording unbalance factors and current symmetrical components (as in the case of voltage unbalance).

For each parameter, the user may enable event logging:

- for RMS current two thresholds may be set : the maximum (upper limit) and minimum (lower limit) value. The settings range is from 0.00 A up to the rated current measuring range (clamps and possibly current transducers). The minimum value cannot be greater than the

maximum value. For mains with a neutral conductor, the user may set different thresholds for phase channels and for neutral channel (if current measurement in N conductor is enabled).

- current crest factor: two thresholds (minimum and maximum); adjustment range: 1.00…5.00; in 0.01 steps
- negative sequence unbalance: one threshold (maximum), range 0.0…20.0%; in 0.1% steps.

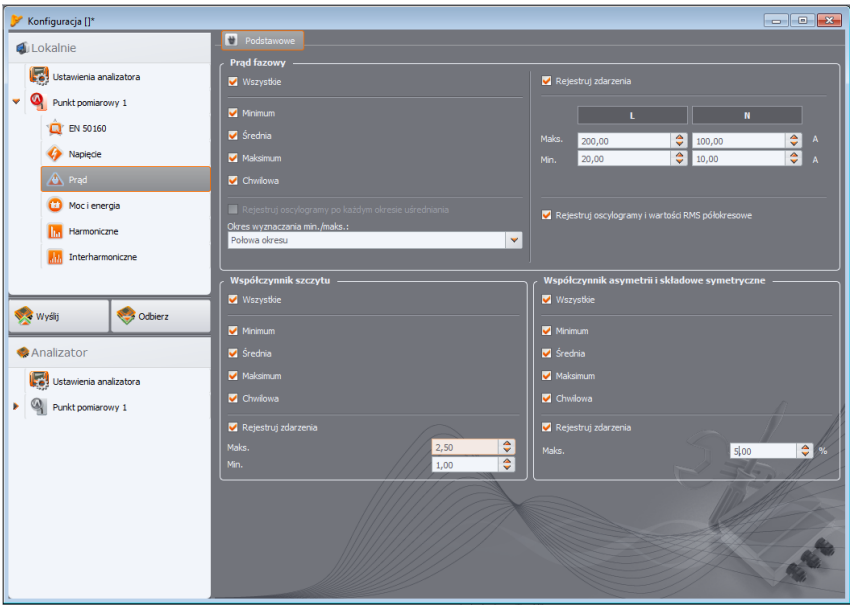


Fig. 31. Current measurement settings.

5.2.6 Power and energy

The configuration part relating to the power and energy settings has three tabs: **Power**, **Additional** and **Energy**.

> ***Note***
> *These tabs are not available if the current measurement was disabled in the main measurement point configuration by selecting **None** option in **Clamps type** field*

5.2.6.1 <Power> tab

Fig. 32 presents Power **tab**

Similarly to voltage and current, the user may set recording average, minimum, maximum and instantaneous values. The user may activate registering of the following parameters:

- active power,
- reactive power,
- apparent power,
- distortion power / apparent distortion power.

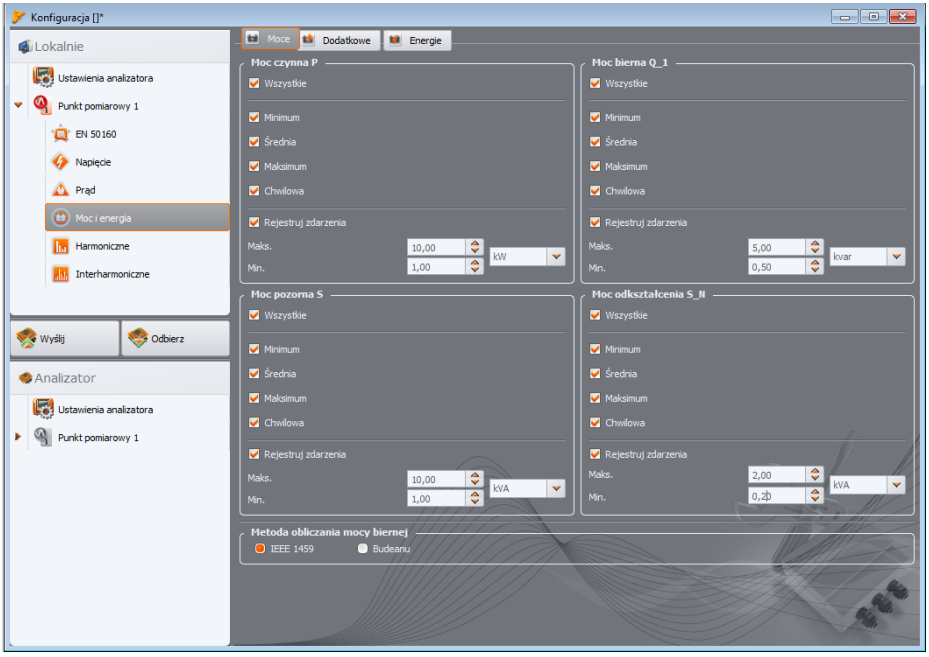


Fig. 32. Power and energy: Power tab.

For each of these power types, the user may enable event recording (logging). Two thresholds can be set for each power type (minimum and maximum) and the analyzer will detect every case of their exceeding.

The setting range is 0.00 W ... 999.9 MW (for active power), 0.00 var ... 999.9 Mvar (for reactive power), 0.00 VA ... 999.9 MVA (for apparent power), 0, 00 var / VA ... 999.9 Mvar / MVA (for distortion power/ apparent distortion power).

At the bottom of the screen, the user may see the method for calculating reactive power. Two alternative methods are available:

- as required by IEEE 1459-2000 standard,
- according to Budeanu's power theory (this method is not recommended).

This option has been added due to the doubts about the power measurement according to traditionally used Budeanu's method. IEEE 1459-2000 standard suggests slightly different calculation methods for this power, providing correct results also in unbalanced systems with distorted current and voltage waveforms. More about this issue - see section 10.7.

After selecting Budeanu option both reactive power Q and distortion power are calculated by the analyzer based on the Budeanu's theory.

After selecting IEEE-1459 option, the reactive power is the Q_1 reactive power of the fundamental component, and S_N non-fundamental apparent power (expressed in VA) is calculated instead of the distortion power.

5.2.6.2 <Additional> tab

Additional tab (Fig. 33) shows parameters related to the power measurements:

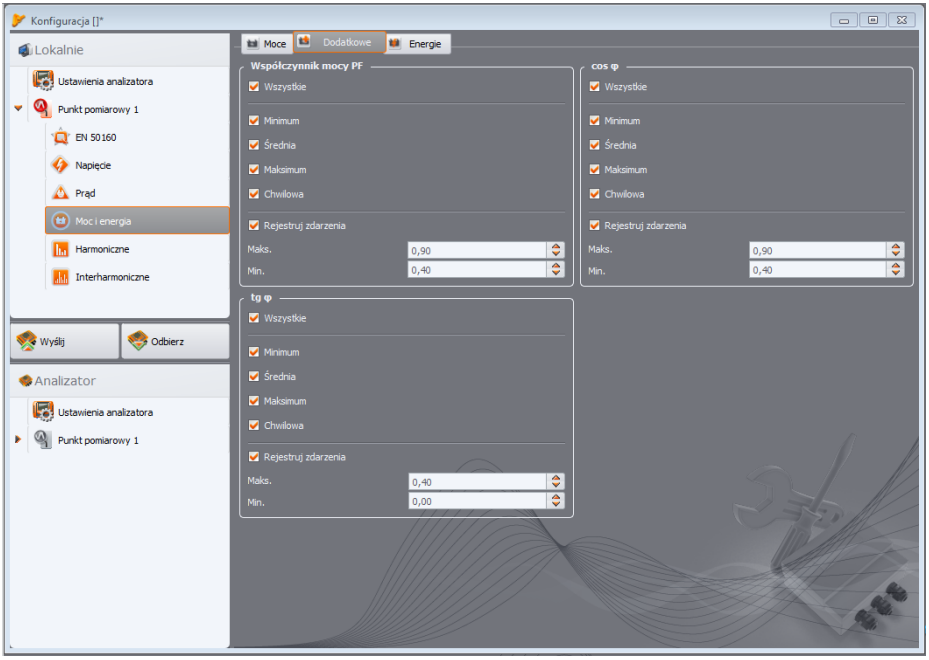


Fig. 33. Power and energy: Additional tab.

- Power factor (PF): event threshold setting range 0.00 ... 1.00 in 0.01 steps,
- Phase shift factor cosφ: event threshold setting range 0.00 ... 1.00 in 0.01 steps,
- tgφ, which is the ratio of reactive to active power: event threshold setting range 0.00…10.0 in 0.01 steps.

5.2.6.3 <Energy> tab

Energy tab is shown in Fig. 34. Apart from the option of enabling the recording process of energy values with a defined averaging period, the user may also define event detection when energy exceeds a given threshold. The setting ranges are as follows:

- Active energy E_P: 0.00 Wh…9.90 TWh, with resolution of 0.01Wh,
- Reactive energy E_Q: 0.00 varh…9.90 Tvarh, with resolution of 0.01varh,
- Apparent energy E_S: 0.00 VAh…9.90 TVAh with resolution of 0.01VAh.

For active and reactive energy, the analyzer separately measures two parameters: consumed (received) and supplied (delivered) energy. The indicated threshold refers to both values (i.e. the analyzer checks the exceeding threshold for both, consumed and supplied energy).

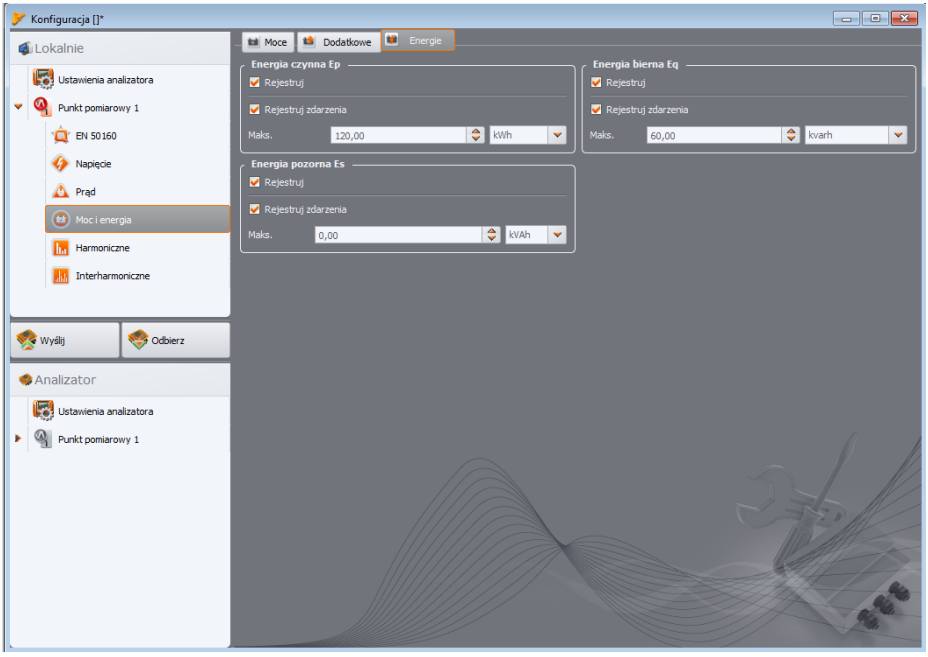


Fig. 34. Power and energy: Energy tab.

5.2.7 Harmonics

In **Harmonics** card the user may configure recording method and event detection for voltage and current harmonics and other parameters directly related to them. The card is divided into two tabs: **Voltage** and **Current**.

5.2.7.1 <Voltage> tab

Screen of this tab is shown in Fig. 35. The user may choose recording of minimum, average, maximum and instantaneous values for THD in voltage and voltage harmonic amplitudes.
The user may also activate the event recording for THD and harmonics amplitudes:

- for THD in voltage, an event will be recorded after THD exceeds the threshold set by the user. Event threshold setting range is 0.00 ... 100.00% in 0.01% steps
- Detection thresholds for events of voltage harmonics may be set independently for each of 39 harmonics (from 2 to 40). The user may select units: volts or percentage. The adjustment range for event thresholds: in volts 0.00 …U_{nom} in 0.01V steps, as percentage values 0.00 ... 100.00% in 0.01% steps. Setting the threshold to zero disables the event detection from the specified harmonic.

Setting limits for individual harmonics may be performed in two ways: completing the table below the graph or directly on the graph. When the table is filled, after values are approved, the graph located above presented the table visualization.

To change the limit on the graph, double-click on a selected harmonic and then holding down the left mouse button, set the desired level.
By clicking a harmonic in the table, the user may use the following keys:

- SPACEBAR- used to enter the editing selected harmonic (the user may also immediately start typing the threshold),

- ENTER - confirming values
- TAB – confirming values and moving to the next harmonics,
- UP and DOWN arrow - changing the value of the limit,
- LEFT and RIGHT arrow - used for moving to the previous or next harmonics
- HOME and END - used to toggle between the first and last harmonics.

> ***Note***
> *The level of THD and harmonics presented as a percentage value is referenced to the fundamental component.*

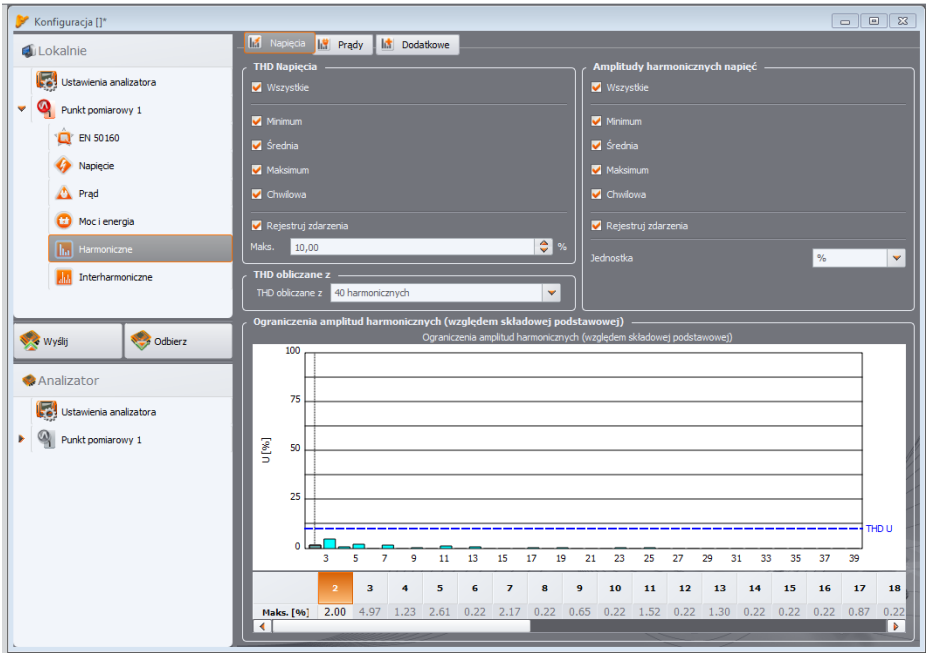


Fig. 35. Voltage harmonics settings.

5.2.7.2 <Current> tab

Screen of this tab is shown in Fig. 36. Available options are identical as those in **Voltage** tab: recording THD (with event detection option) and recording current harmonics (with setting of event thresholds from individual harmonics).

The event threshold setting ranges are as follows:

- for THD: 0.00…200.00% every 0.01%,
- for harmonics: in amperes 0.00…I_{nom} in 0.01A steps, as a percentage value 0.00…200.00% in 0.01% steps. Setting the threshold to zero disables the event detection from the specified harmonic.

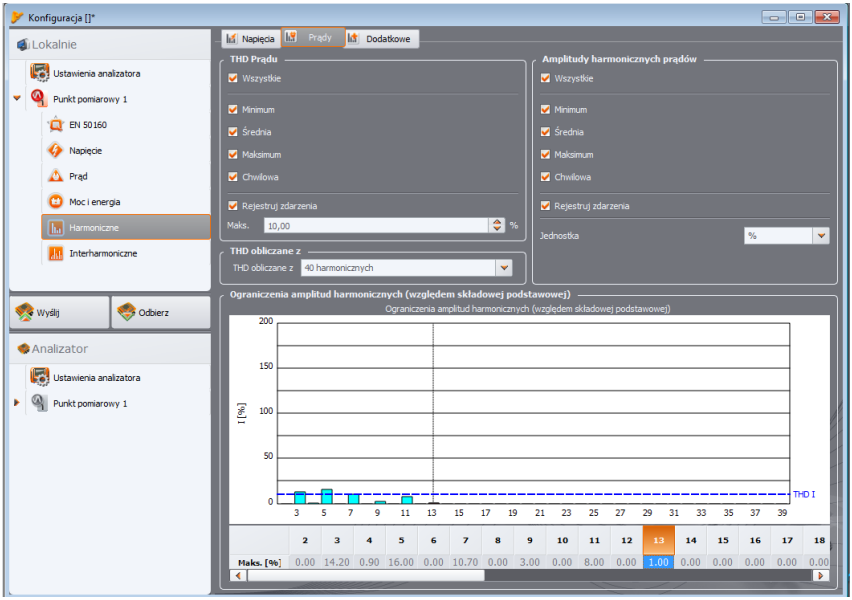


Fig. 36. Current harmonics settings.

5.2.8 Default configuration profile.

After installing, the application applies the default settings of the analyzer, where the measurement point profile is saved as: Voltages.

Recording in the default profile is done without saving the waveforms after the averaging period. Only average values of parameters are recorded and event detection is disabled. Network type is set as 3-phase wye system with a neutral conductor and the averaging time is 10 seconds.

5.3 Actual settings

After selecting from the main menu: **Analyzer→Actual settings** (or using a short-cut key) the window shown in Fig. 51 is displayed. The following cards are available:

- Time and security,
- Clamps phase,
- Additional settings.

5.3.1 <Time and security> card

Here the user may set the time and parameters important foe the analyzer security. Current date and time of the analyzer is shown on an on-going basis in **Analyzer time** field. In order to set desired date and time of the analyzer, use the drop down menu in **User time** field, enter desired values and confirm by pressing **Set** button on the right. PC system time may be also sent to the analyzer by simple pressing **Set** button next to **System time** button.

Checking **Keyboard lock** box, results in immediate key locking after the recording is activated. Unlocking method is described in 2.5. "Keyboard Lock" function prevents stopping an active recording process by unauthorized persons.

Sleep mode makes the LEDs blank 10 seconds after activating the recording process. Recording is indicated by blinking **LOGG** LED (see 2.6).

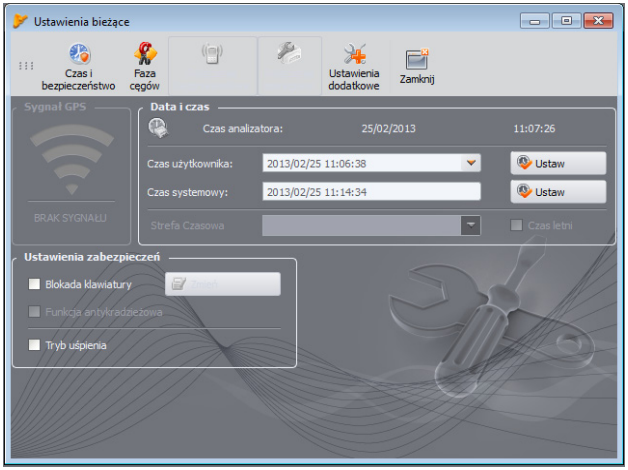


Fig. 37. Setting the time and security measures during recording

The following features are not available for PQM-700:

- GPS signal,
- Wireless connection,
- Anti-theft feature
- Time zone and daylight saving time.

5.3.2 <Clamps Phase> card

In case of a reverse clamp connection to the measured circuit (right direction is the one where the arrow on the clamp indicates the receiver), select the option from menu **Analyzer→Actual settings** and selecting **Clamps Phase**. Click a clamp icon in the selected channel to reverse the phase by 180°, which is equivalent to reverse placement on the clamp on the test lead. The change of direction applies to the measurement point and occurs immediately. The reversal effect can be verified on the phasor diagram screen, waveforms screen or by change of active power sign in the channel. The clamp phase cannot be reversed in the recording mode.

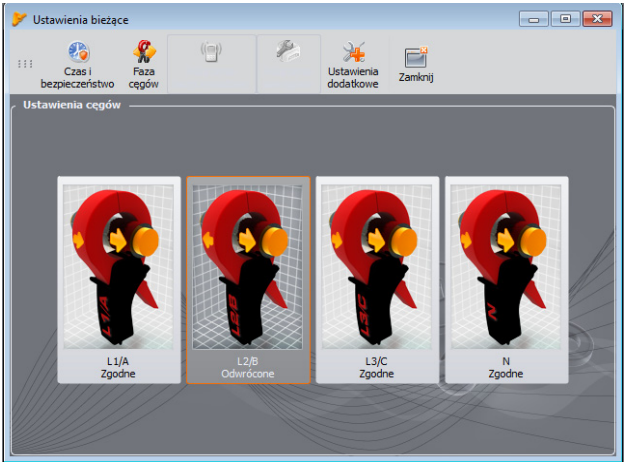


Fig. 38. Reversing the clamp phase

5.3.3 <Additional settings> card

Additional settings card includes two elements:

- **Language**, selection list , which is not available for PQM-700,
- **Heater enabled** button is used for switching on/off the heater that heats the interior of the analyzer when ambient temperatures are below 0°C. When the analyzer is activated in temperature below zero, it controls the temperature inside the analyzer by enabling the heater to maintain the temperature inside above 0°C. This results primarily from the need to provide positive temperature to built-in lithium-ion battery, as charging the battery in temperatures below zero Celsius is not allowed.

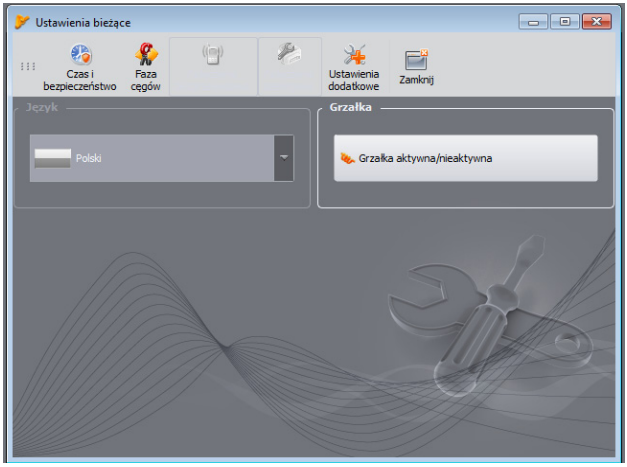


Fig. 39. Language and heater settings

Note: The heater should always be enabled. The heater may be turned off only when the analyzer is operated at a temperature above 0°C or when it is necessary to reduce the power consumed by the analyzer, e.g. during measurements with voltage transformers, from which the analyzer is to be supplied.

5.4 Analyzer database

Select from the main menu **Options→Analyzer database** - here you may add or edit existing analyzers (Fig. 40).

Column **Auto PIN** informs, whether the program requires PIN code before transmission. If the box is disabled, the user will be required to enter PIN.

In addition, the user may activate the option of reminding about the need for re-calibration. The manufacturer specifies the time after which the user should perform a calibration of the instrument, in order to maintain its declared accuracy. The accuracy degrades due to the ageing of components. To unlock this feature, select option **Certificate of Calibration**. If it is checked, then then the following lists are active **Validity period** and **Remind before**. They are used for:

- **Validity period** (may be set at 6, 12, 8 or 24 months) – it defines the frequency of instrument calibration,
- **Remind before** (may be set at week, two weeks, month) – it specifies the period for which the analyzer is required to generate the reminding message (during start-up).

The remaining columns in the table:

- **Calibration date** indicates the date of last calibration,
- **Description** - brief text description related to the analyzer,

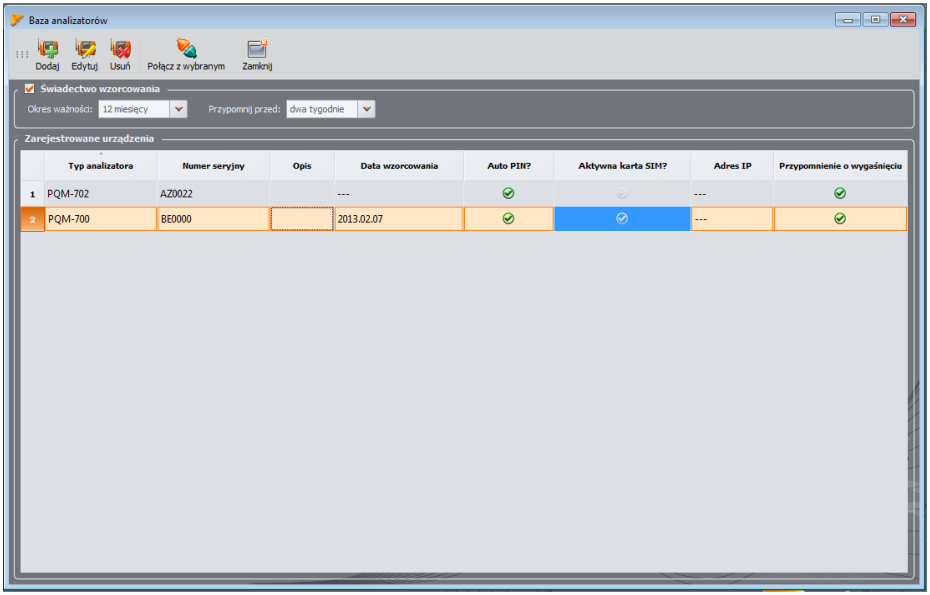


Fig. 40. Analyzer database

Clicking **Add** enables user to add an analyzer - as shown in Fig. 41. Please select a model analyzer, enter its serial number and optional description.

Remove icon allows the user to delete the selected analyzer from the database (after confirming it by the user).

Edit icon allows the user to change the parameters of the analyzer.

Click **Change PIN** button to change PIN. The new code must be entered twice and then accepted.

GSM feature is not available for PQM-700.

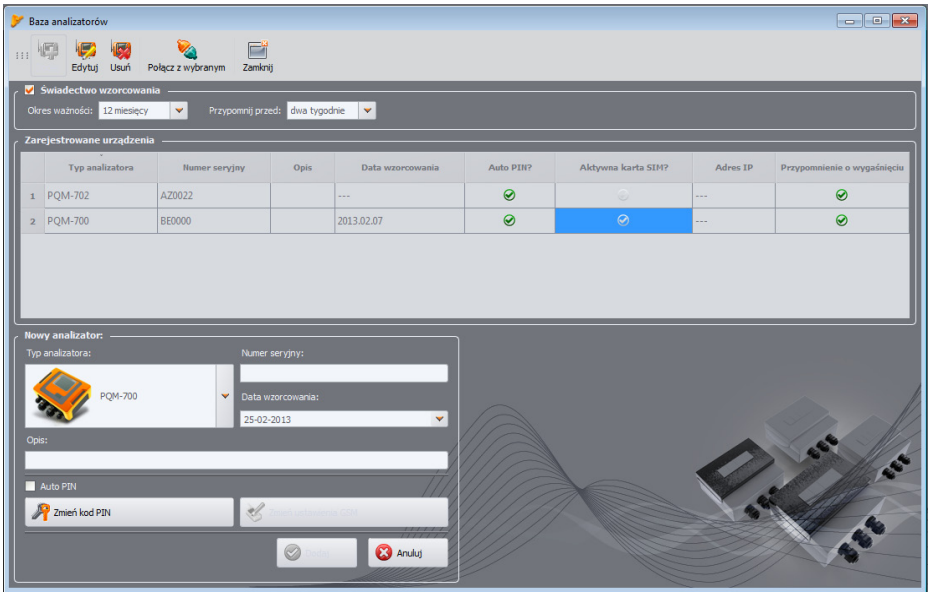


Fig. 41. Adding an analyzer to the database.

6 Live mode

To enter the live mode, click **Live mode** icon. If the connection to the analyzer has not been previously established, the program goes first to the connection screen (see chapter 4.4 Selecting the analyzer).
In this mode, the screen is divided into a few tabs:

- **Waveforms** – it presents transient waveforms of current and voltages
- **Timeplot** – presents RMS values of voltage and current as a timeline,
- **Measurements** – instantaneous values of measured parameters (phase and total values),
- **Phasor diagram** – graphical representation of phasors of fundamental voltage and current components
- **Harmonics** – view of harmonic components of individual phases for currents and voltages.
- **Interharmonics** – this card is not available for PQM-700.

The more detailed description of individual tabs is given below.

6.1 Waveforms

The voltage and current waveforms presents two instantaneous waveforms, as they would be seen on the oscilloscope screen. A sample screen is shown in Fig. 42. The graphs are refreshed instantaneously, allowing user to view the mains parameters in real time. All channels are presented in a single graph.

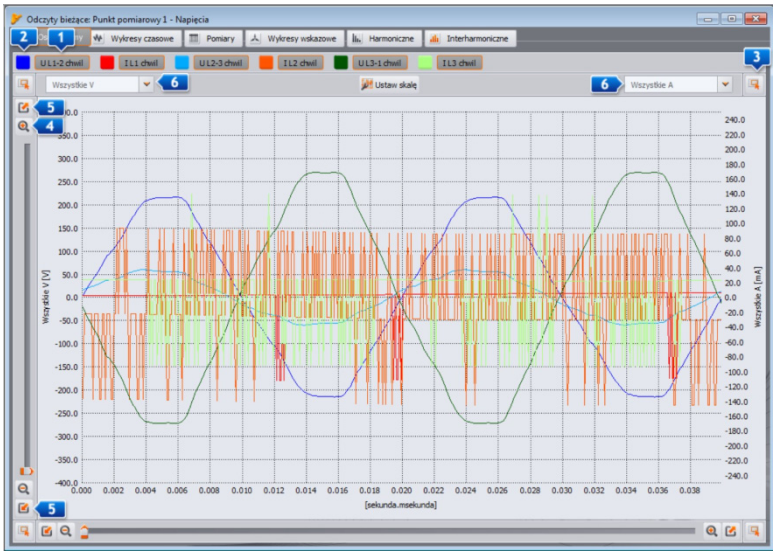


Fig. 42. Live mode screen – waveforms.

The checkboxes above the diagram are used to 1 enable/disable displaying of a chosen voltage/current channel. Buttons next to the boxes are used 2 to change the colour of presented waveforms.

The graph may be freely expanded in both axes. In the corners of the window there are four buttons 3, which activate displaying a window thumbnail with actually displayed area marked in orange. The thumbnail is displayed in one of the four corners of the window, depending on the button used. Four buttons marked by the magnifying glass icon are used for zooming-in and -out 4. 5 buttons are used to select the maximum or minimum zoom of a selected axis.

Mouse scrolling wheel may be also used for zooming-in and out. Using the scrolling wheel closer to the vertical edge of the window results in zooming-in of Y-axis, whereas using the scrolling wheel closer to horizontal edge - zooming-in of X-axis.

Zoom the selected area by holding down SHIFT button (the mouse pointer changes to a cross) and select the desired area with the mouse.

It is also possible to move the selected area within the graph. To do so, hold CTRL key (the cursor changes to a hand) and holding the left mouse button, move the display area.

The time scale (X-axis) is updated basing on the measured frequency value (e.g. from 0 to 40ms for 50Hz).

Two independent descriptions of Y-axis values are presented. For example, the user may display values in volts (for voltage channels) on the left axis, and in amperes (for current channels) on the right axis. Descriptions of axes are controlled by selection lists 6. These lists may include the following items:

- **All V** – when more than one voltage channel is measured. In this situation, one scale is selected for all the voltage waveforms, and the waveforms are scaled,
- **All A** – when more than one current channel is measured. In this situation, one scale is selected for all the current waveforms, and the waveforms are scaled,
- a separate entry for each measured channels. If the user selects this element from the list, then the screen displays a scale for the selected channel (it may be adjusted automatically or manually if the range was set by the user). **Note: If the graph presents other waveforms (voltage or current depending on the selected scale) then their actual amplitude does not correspond to the indicated scale. The scale applies only to the selected waveform.**

The scale is selected:

- statically - the upper scale range is set at the value close to the nominal voltage or maximum clamp range,
- dynamically - the graphs are automatically scaled to the highest instantaneous value of the waveform.
- manually – to do this use **Set scale** button, and then choose waveform(s) for which the scale is to be set manually, disabling the automatic mode and this activity will unlock the options of editing the minimum and maximum values of the axis. After clicking **Set** button, the scale of a given waveform is updated.

Switching between static and dynamic scaling mode is available after clicking the right mouse button on the graph: the context menu includes the following options: **Set scale to nominal value** and **Set scale automatically**, both for voltage and current values. After turning the program on, auto-scaling is turned off.

6.2 Timeplots

Fig. 43 presents the screen with current and voltage *timeplot*). The configuration elements are identical as those in the waveform screen: its upper part includes controls for switching on/off the display of current/voltage; changing the colour of waveforms; zooming-in and the vertical axis.

The time scale is shown in the graph from the moment to entering the Live mode. The time format is mm:ss. After reaching the end of the window, the entire graph shifts to the left by 30 seconds.

The graph is updated regardless of whether the tab is enabled or not, i.e. waveform are generated in the background, despite viewing for example harmonics.

As in case of waveforms, the user may apply the static scaling (according to the general settings of the measurement point) or dynamic scaling.

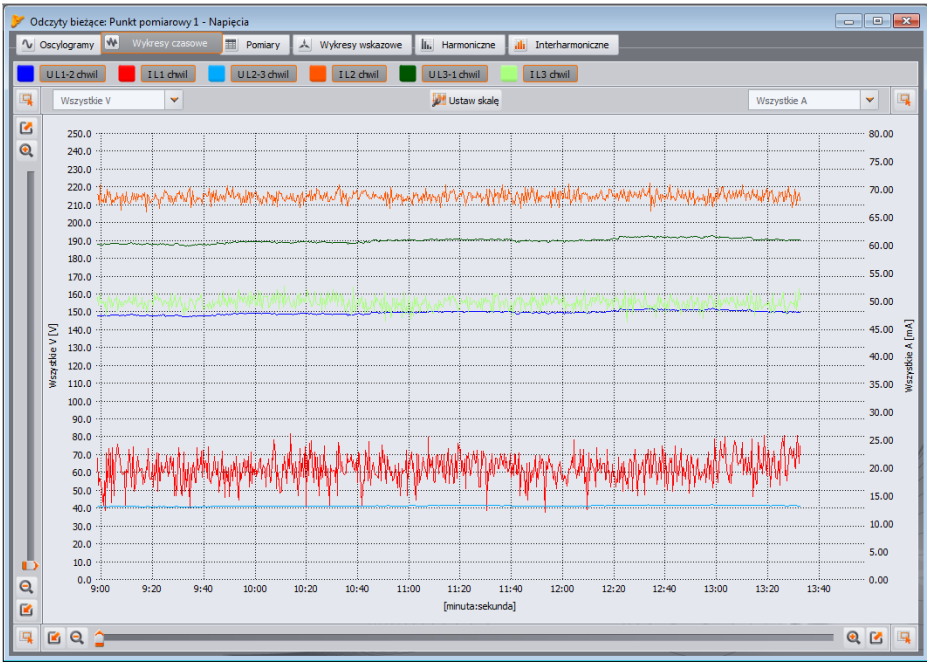


Fig. 43. Graph with values in real time.

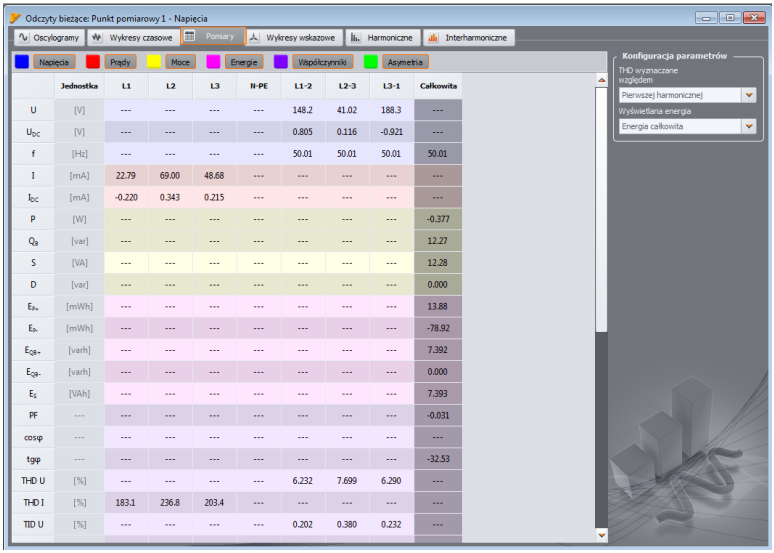
6.3 Measurements

Measurements tab provides a view of a range of parameters of the measured mains. Fig. 44 presents an example of a screen that shows a summary table of values read from the analyzer and displayed in real time.

In the following rows the individual parameters are grouped into several categories:

- **Voltage** – RMS voltage U, DC component U_{DC}, frequency f,
- **Current** – RMS current I, DC component I_{DC},
- **Power** – active power P, reactive power Q_B (according to the Budeanu theory) or non-fundamental apparent power Q_1 (acc. to IEEE 1459), apparent power S, distortion power D (acc. to Budeanu) or distortion apparent power S_N (acc. IEEE 1459),
- **Energy** – consumed active energy E_{P+} and supplied active energy E_{P-}, consumed reactive energy E_{Q+} and supplied reactive energy E_{Q-} (acc. to Budeanu or IEEE 1459), apparent energy E_S,
- **Factors** – Power Factor PF, Phase Shift Factor cosφ, tgφ, Total Harmonic Distortion THD for voltage and current, Crest Factors CF for voltage and current, flicker P_{ST} and P_{LT},

Unbalance – for voltage: zero component U_0, positive sequence component U_1 and negative sequence component U_2, negative sequence unbalance u_2, zero sequence unbalance u_0; for current: zero component I_0, positive sequence component I_1 and negative sequence component I_2, negative sequence unbalance i_2, zero component unbalance i_0.



	Jednostka	L1	L2	L3	N-PE	L1-2	L2-3	L3-1	Całkowita
U	[V]	---	---	---	---	148.2	41.02	188.3	---
U_{DC}	[V]	---	---	---	---	0.805	0.116	-0.921	---
f	[Hz]	---	---	---	---	50.01	50.01	50.01	50.01
I	[mA]	22.79	69.00	48.68	---	---	---	---	---
I_{DC}	[mA]	-0.220	0.343	0.215	---	---	---	---	---
P	[W]	---	---	---	---	---	---	---	-0.377
Q_B	[var]	---	---	---	---	---	---	---	12.27
S	[VA]	---	---	---	---	---	---	---	12.28
D	[var]	---	---	---	---	---	---	---	0.000
E_{P+}	[mWh]	---	---	---	---	---	---	---	13.88
E_{P-}	[mWh]	---	---	---	---	---	---	---	-78.92
E_{Q1+}	[varh]	---	---	---	---	---	---	---	7.392
E_{Q3-}	[varh]	---	---	---	---	---	---	---	0.000
E_S	[VAh]	---	---	---	---	---	---	---	7.393
PF	---	---	---	---	---	---	---	---	-0.031
cosφ	---	---	---	---	---	---	---	---	---
tgφ	---	---	---	---	---	---	---	---	-32.53
THD U	[%]	---	---	---	---	6.232	7.699	6.290	---
THD I	[%]	183.1	236.8	203.4	---	---	---	---	---
TID U	[%]	---	---	---	---	0.202	0.380	0.232	---

Fig. 44. Indications of phase and total values

Each group may be enabled/disabled independently of the other groups and column background colour may be changed using the buttons in the top of the screen.

When the program is started for the first time, the following parameters are shown: voltage, current, power and coefficients.

Using preferences the user may change the colours of groups and select groups to be displayed.

Parameter values are displayed in the consecutive columns, marked as follows:

- **L1** – L1 phase in circuits with a neutral conductor N,
- **L2** – L2 phase in circuits with a neutral conductor N,
- **L3** – L3 phase in circuits with a neutral conductor N,
- **L1-2** – L1 phase in circuits without neutral conductor (with phase-to-phase voltages),
- **L2-3** – L2 phase in circuits without neutral conductor (with phase-to-phase voltages),
- **L3-1** – L3 phase in circuits without neutral conductor (with phase-to-phase voltages),
- **Total value** – the total value of the entire system or the average value of the phase values.

For example, for a three-phase system with N conductor, the phase parameters values are displayed in columns **L1**, **L2**, **L3**. If the measurement of I_N current is enabled in the configuration, then in **N-PE** column the analyzer displays also parameter values calculated for this case. **Total** column displays the total values for the whole system.

In case of delta systems, the phase values are displayed in columns **L1-2**, **L2-3**, **L3-1** and **Total**.

Note

In some mains configurations it is not possible to calculate (measure) the values of some parameters. For example, in a delta three-phase system, it is impossible to calculate the cosφ displacement power factor between current and voltage, as the measured voltage is phase-to-phase voltage, and the measured current is line current which is a vector sum of two phase currents.

When in a given mains configuration a selected parameter is not calculated, the screen displays "---" instead of its value.

In the right part of the tab, the user may additionally define the calculation method for THD: in relation to fundamental component (THD_F) or RMS value (THD_R).
The displayed energy values depend on **Displayed energy** switch. The user may choose whether the energy meters are related to measuring session (metering started when **Live mode** window is opened) or to total energy metered by the analyzer.
Internal energy meters of the analyzer are reset:

- when recording starts,
- when the analyzer is switched on.

When the energy display mode is selected, the internal energy counters are not modified. The concept of this mode is based on the fact that at the moment of first read-out of values from energy counters (by the software) these values are remembered and the displayed values are the difference between the energy current read-out and the remembered value.

6.4 Phasor diagrams

Phasor diagram (Fig. 45) is used to present the vectors of fundamental voltage and current components. Angles between the vectors correspond to the angles of phase shift between individual phases. A table with numerical values is displayed on the right side of the graph. Individual rows of the table present:

- **U** – amplitudes of voltage fundamental components,
- **φ_U** – angles of voltage fundamental components in relation to L1 voltage fundamental component (in angle degrees),
- **I** – amplitudes of current fundamental components
- **φ_I** – angles of current fundamental components in relation to L1 voltage fundamental components (in angle degrees),
- **$\varphi_{U,I}$** – angles between voltage and current vectors ($\varphi_U - \varphi_I$) for a given phase (not available in 3-wire systems),
- **Type** – the type of a receiver, indicated by a coil symbol for inductive load or a capacitor symbol for capacitive load (unavailable in 3-wire systems).

Above the table are the on/off buttons for voltage (U, φ_U), current (I, φ_I), angle $\varphi_{U,I}$ and a receiver type. In addition, the user may change the default background colour of the table for these groups.

The vector angles are referenced to U_{L1}, vector angle which is always $\varphi = 0°$.

The vector amplitude scaling takes place automatically in relation to the highest value, independently for voltage and current.

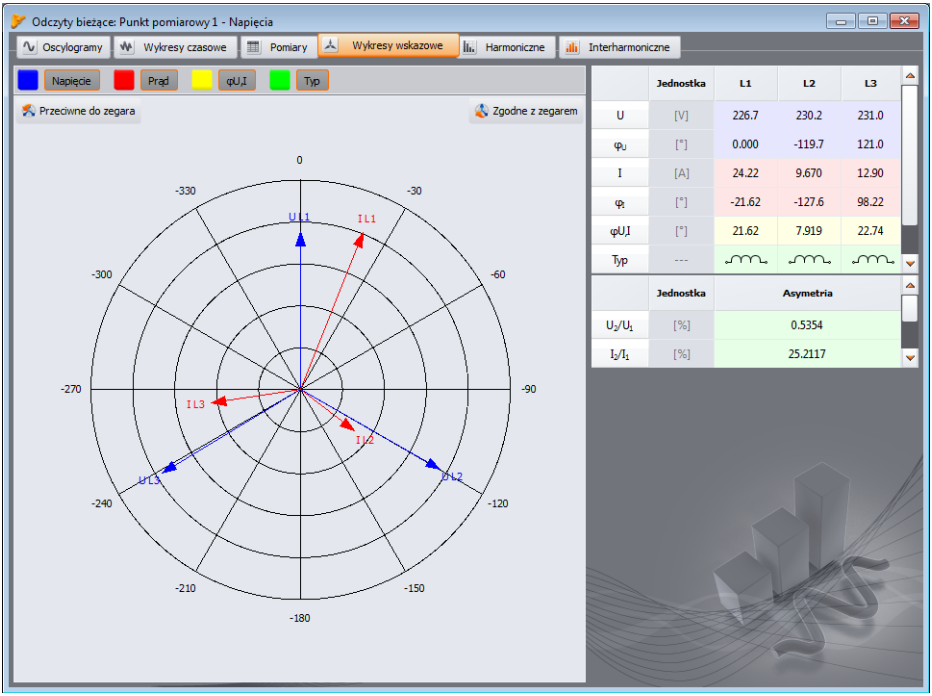


Fig. 45. Phasor diagram for wye connection.

On the diagram two buttons are present for turning the phasor diagram by 90° clockwise or counter-clockwise.

6.5 Harmonics

Harmonics tab enables user to view harmonic values in voltage and current and harmonic factors. A sample screen is shown in Fig. 46.Parameters are displayed for one phase, which is selected by buttons on the right.

A bar graph with harmonics is displayed in the central part of the screen: from DC component, through the first component up to the 40th.

Measurement 1 list on the right side of the window allows to select one option:

- **Voltage, Current**– displays the voltage and current harmonics,

On the left and right side of the graph, axes are displayed and marked with corresponding units: **Voltage, Current**- left side is assigned to voltage axis, while the right side is to current axis. This arrangement may be changed, using the lists above the axes 2.

The tables below the bar graph present (from the left):

- THD factors,
- a table with numerical values of voltage and current harmonics.

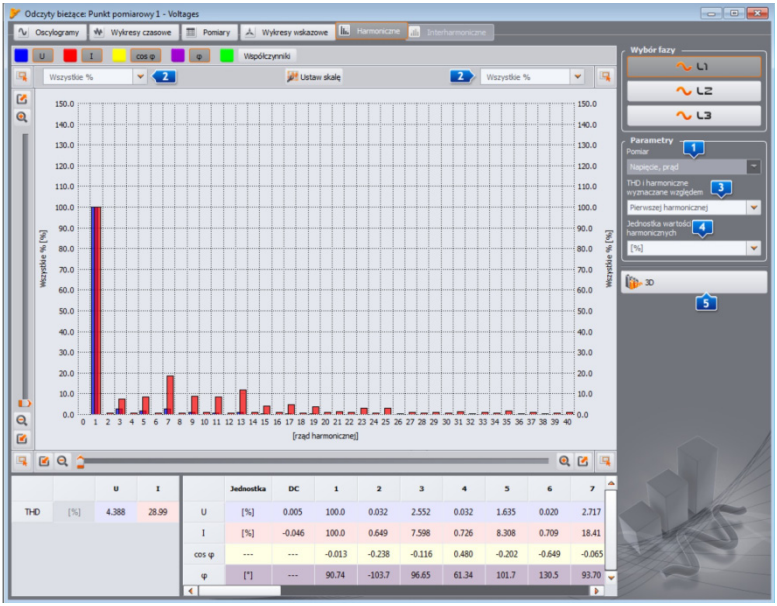


Fig. 46. Harmonics on 2D graph.

The user has the access to two settings:

- **3 THD and harmonics relative to** – two options are available: relative to RMS or to the first harmonics (this option is active only after selecting the percentage unit – see below),
- **4 Harmonics unit** – here also two options are available: in absolute units [V], [A], or as percentage values.

A right-click on the graph in **Voltage, Current** mode, displays a context menu with the following options:

- **Set the scale to the nominal value** (for power) or **Set the scale to the range of clamps** (for current). Use this option to re-scale the harmonics bars and adapts them to the graph window height, taking into account the nominal value,
- **Set the scale automatically**. This feature automatically adjusts the scale.
- **Voltage limits** (option available only for voltage harmonics and after selecting percentage display). This option results in imposing harmonics limits defined in the default profile of EN 50160 standard.

In the bottom right-hand corner, a button **5** is located for switching between 2D and 3D view. After clicking it, the harmonics are presented as a 3D view. After clicking **Any view** button, the graph may be freely positioned using a mouse. Hold the left mouse button on the diagram and set it in desired position. Hold the right mouse button to zoom in/out the graph. You can use also the sliders on the left side of the window or the mouse scrolling wheel.

7 Inrush current measurement

This function allows user to record half-period values of voltage and current within 60 sec. After this time, the function is automatically terminated. Before the measurement, set aggregation time at ½ period. Other settings and measurement arrangements are not limited.

8 Data Analysis

The analysis block allows the user to read data collected by the analyzer during the recording, view numerical data and graphical visualization. The user may generate reports that in a clear manner describe the tested system.

8.1 Reading data from the analyzer

after selecting analysis from the upper menu or clicking **Analysis** icon, when no analyzer-program connection is established, a standard connection procedure is launched to connect the analyzer and the program (sec. 4.4). In this way, the user may also read data from SD memory card, which is treated as the analyzer.

After correct connecting the analyzer to a PC, a window is displayed - as shown in Fig. 47 and data may be selected for downloading and further analysis. To do this, select the measurement point from which you want to download the data. On the right side of the bar representing the amount of stored data, the actual amount of data is displayed.

Select **Delete data after reading** option to delete data from the point of the read-out. Therefore, after pressing **Load data** button before the transmission, an appropriate warning message is displayed

During the data read-out, the status bar at the bottom of the window shows the download progress and **Cancel** button, which may be used for stooping the process.

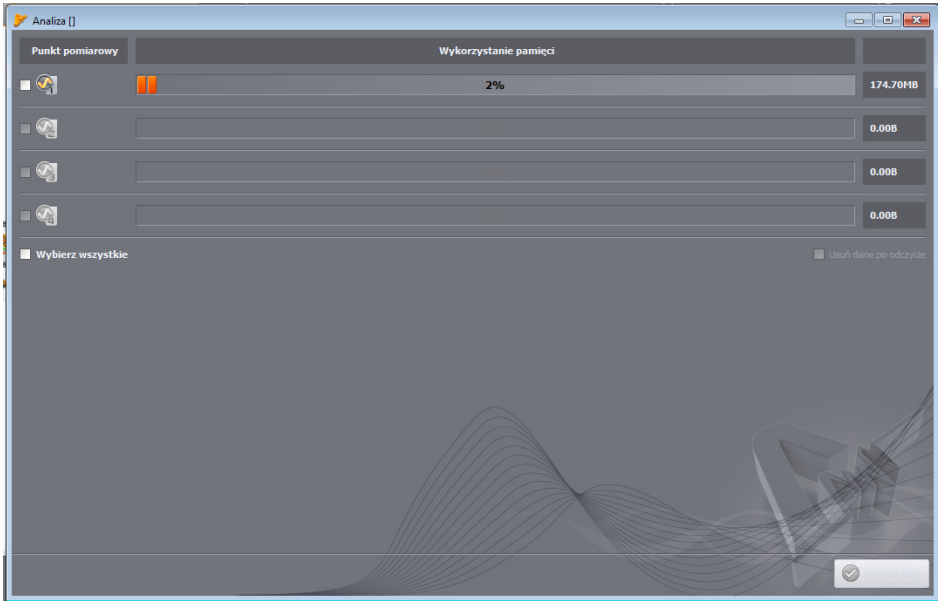


Fig. 47. Selecting data for read-out.

Data may be deleted from the card at any time by entering Analyzer menu and choosing the option of **Analyzer→Delete Data**. This action may be used to delete data (without changing their configuration) or to completely format the card.

After reading the data, a window with save option opens *.pqm700. In a file with this extension, the software saves identical copy of data read from the analyzer (not processed by the program). Saving this data is not required, but performing a next analysis, basing on recorded data will require to another data read-out from the analyzer.

Note

*When the user selected **Delete data after reading** option without saving data before proceeding to data analysis, the source data will be irreversible lost. It will be possible to perform analysis and save data to a file with *.analysis extension, but using the source data in full for further analysis will not be possible (e.g. for analysing different time period).*

8.2 Selecting the time interval for analysis

After correct data read-out, a window will be displayed, indicating data that will be taken for further analysis. The user must specify time interval for data. Only data from the specified range will be analysed. The dialogue box is shown in Fig. 48. The meaning of the window elements is as follows:

- On the left, a measurement point is located 1. Click on the point to display the following data: point name (if previously entered during the configuration) and all time intervals during which the analyzer was recording data.
- The middle and right part of the screen present graphically (bars) recording time intervals. After selecting the measurement point, the bars representing the periods from this point change colour to red, showing which data may be analyzed. At the same time **Data analysis** button is enabled.
- Next to the description -**Measurement point X** information is displayed, indicating whether data have been recorded according to the standard (text **EN 50160**) or according to user-defined settings (text **USER**),
- The following three fields define start 2, duration 3 and the end of the analysis interval 4, which is selected by two sliders 5 **S** (*start*) and **E** (*end*). The user may use these sliders, to select a shorter interval for analysis. If you select interval longer that a given period, the whole period will be selected for analysis.
- The central field, marked as **Range** 3 includes information about the period selected for the analysis. Its format is as follows: "week:day:hour:minute:second". The user may select standard time interval from the drop-down list: 6 10-min., hour, day, week. If a selected period is longer than recording, the whole recording is checked.
- A double-click on the time of starting the recording 7 sets slider **S** at the beginning of recording, whereas a double-click on the time of ending the recording sets slider **E** at the end of recording.
- Clicking **Data analysis** will display the screen for analysing data of the selected time period.

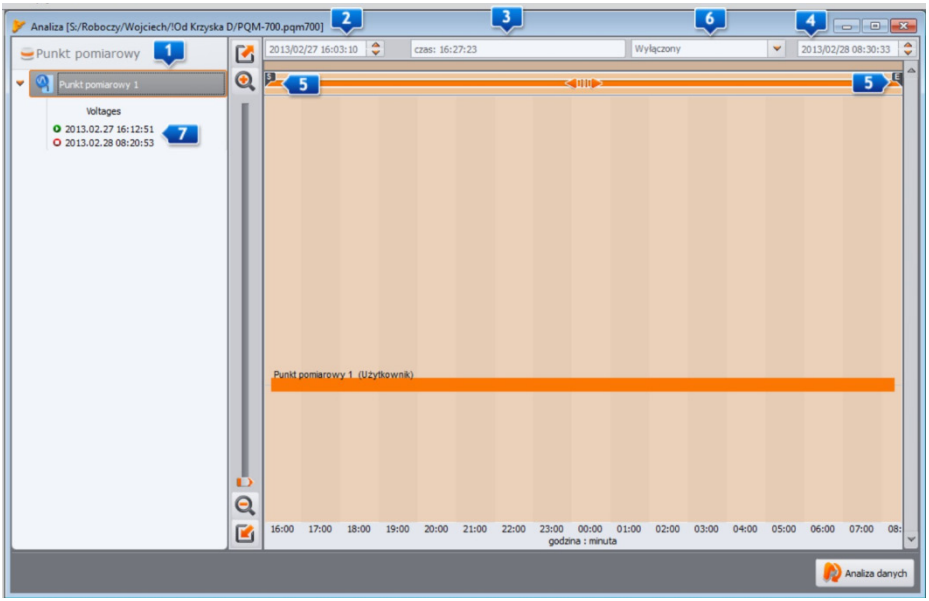


Fig. 48. Selection of time period for the analysis.

If the user wants to perform many analyses on the read data, after downloading, save such data on a local disk as a file with the extension *.pqm700. Such file will include an identical copy of the read data that may be used at any moment - then the user may return to the analysis time selection screen (Fig. 49). Please remember that if you send a new measurement point configuration, the SD card will be formatted and all recorded data will be irreversibly lost.

Starting the analysis **Data Analysis**), when the user did not save source data in *.pqm700, will require a next data read-out from the card, always when the user wants to perform another analysis based on the data stored on the card.

To save data on the disk click **Save** icon on the toolbar or select **Save** or **Save as** from **File** menu.

8.3 Analysing obtained data

8.3.1 General

After a correct data read-out, the main data analysis module window is displayed. The window is divided into several parts:

- On the left hand side, the user will find buttons that enable displaying of the following data:
  - **General** – all data of individual types are displayed as dots/points (Measurements, Events, and Waveforms),
  - **Measurements** – all types of measurements recorded according to the averaging time are displayed as dots/points (voltage, frequency, etc.),
  - **Events** – all types of detected events are shown as dots/points (voltage dips, swells, interruptions).
  - **Configuration** – displays the analyzer configuration that was active during the recording.
- Selecting a chosen button results also in displaying relevant data in the table below the graph.
- The fields that include start date, time period and end date are shown above the graph.

In **General** view, the user may access a quick preview of waveform and/or event. But the view of the measurements is not available. After pointing the cursor on an event point 1 and left-clicking the mouse, the screen displays information about this event 4 and the waveform (when recorded with the event - Fig. 49).

Sometimes the graph may be very dense and a single point may have few overlapping points; in such case placing the cursor over a point displays the event and waveform that were recorded with the earliest date/time. At the same time, above the selected point, information is displayed about the number of events or waveforms.

If there are more events in a point, tabs appear 2 above the graph. The descriptions of tabs correspond to the type of event or the waveform.

When an even is selected, the displayed waveform is from the beginning of this event.
Use the slider (or the mouse scrolling wheel) to zoom-in the selected area (reduce the time interval). If you select the dot of an event which has the beginning and end waveform, the corresponding waveforms will also be selected.

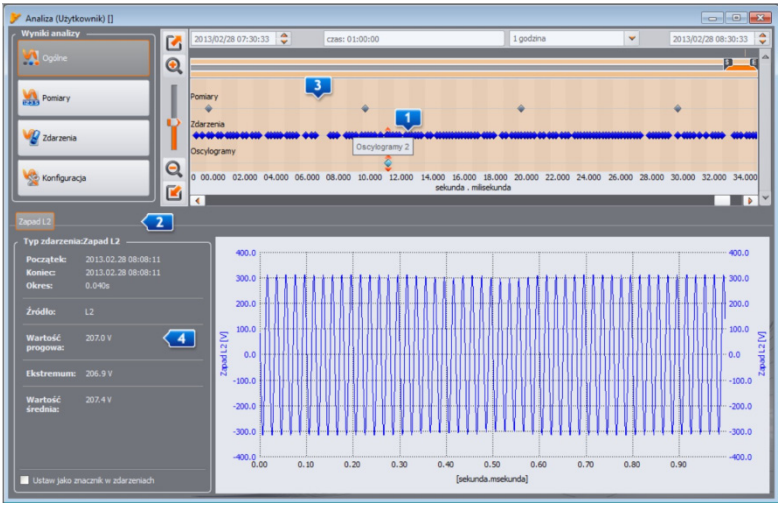


Fig. 49. "General " window with the waveform preview.

8.3.2 Measurements

Pressing **Measurements** button, changes the window image into the one shown in Fig. 50. In the bottom part, the program displays parameters that may be analysed.

The graph shows the dots representing measured parameters over time. In the case of large amount of data, dots may form a line.

Similar as in case of choosing the analysis time range, three fields are displayed to indicate the beginning, duration and the end of the selected time range (required time range may be manually entered). The range of data displayed in the table, may be also reduced using two sliders **S** (start) and **E** (end).

Below the graph, a summary table 1 is displayed with recorded values of the parameters. The table shows only the data for the selected time interval.

The checkboxes 2 on the left side are used to include/ exclude some parameters from the table.

If a parameter measured in a few phases is selected (such as voltage), all columns (U L1, U L2, U L3) will be displayed in the table. In order to limit the amount of data displayed in the table, use the buttons 3 (L1, L2, L3, N) on the right side.

A right-click within the table area results in displaying a context menu with 4 the following options: **Average**, **Instantaneous**, **Min.**, **Max.** (Fig. 51). The user may check/ uncheck these options to show/hide relevant values recorded earlier (as configured by the user). The selected data may also be copied to the clipboard.

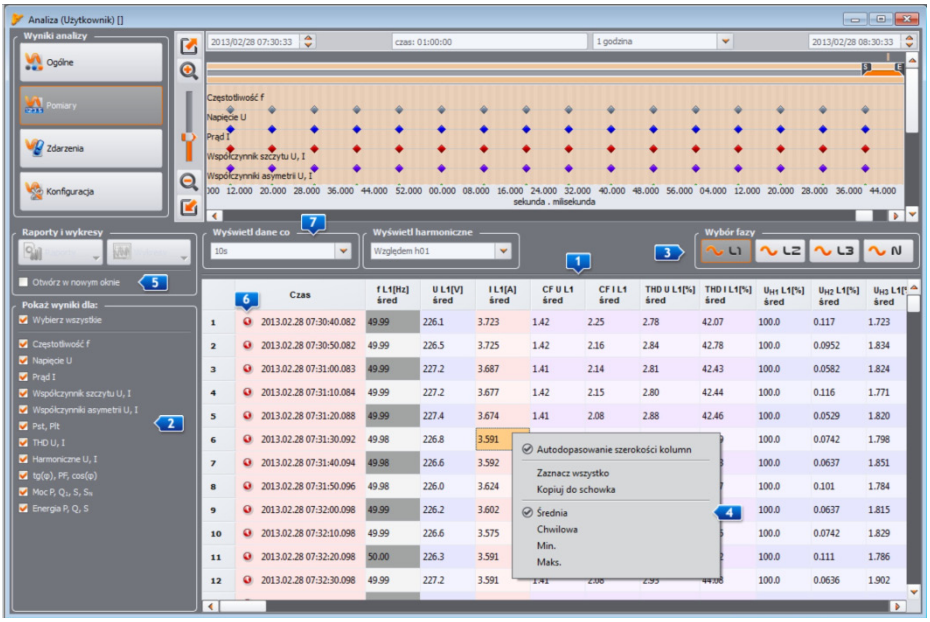


Fig. 50. Measurements window for user's recording.

Selecting 5 **Open in a new window** option, a new graph or table will always be opened in a new window. If this option is disabled, a separate window with a graph or table is refreshed.

Data in individual rows may be specially marked with an icon 6 next located next to the time field, indicating one of several possibilities:

- icon indicates that the parameters were measured without synchronization with UTC (such synchronization is required only for Class A analyzers, whereas PQM-700 analyzer is S-class - therefore the time synchronization is not required).
- icon indicates that during this averaging interval, a voltage event occurred e.g. dip, swell, or interruption. The listed types of events may be a cause of incorrect measurements for some mains parameters and PN-EN 61000-4-30 standard recommends that in such case the whole averaging period is flagged to inform the user that the measured values might be unreliable. The decision how to treat the flagged data is left to the user.
- icon indicates a momentary loss of PLL synchronization, detected during the averaging interval. This could occur e.g. during a voltage dip in L1 channel (reference channel for PLL circuit). Parameter values measured in such conditions may be uncertain.

The user may generate several types of graphs. This activity may be performed by using "Plot" button. The possibilities are as follows:

- **Time plot** – when **Time** column is selected along with any other column(s) (as in Fig. 51) and this option is chosen, a new window appears with a diagram showing the indicated parameters over time. To include only a part of total time interval in the diagram, in **Time** column select the period you are interested in, and then select relevant parameters. User may select any parameter columns, including individual harmonics e.g. U, I, f, H03, H05 etc. A typical time plot is shown in Fig. 52,
- **Waveform** – waveforms of voltage and current (if any), i.e. during the events (Fig. 56). The waveform may be displayed by highlighting the row with available waveform and selecting **Plots** option, and then **Waveform**option, or by double-clicking a given line
- **The graph showing semi-periodic rms values (RMS1/2)** for events for which the waveform diagram was recorded. This diagram is opened together with the waveform graph (e.g. by double clicking the waveform icon in the table).
- **Harmonics** – a bar chart showing the harmonics of 1..40 order. This option is active even when only one harmonic is selected (other harmonics are also plotted). All other selected values (which are not harmonics, such as U, f, I, etc.) are ignored. If a time interval has been selected (more than one row), the plotted chart represents the average harmonics values in this interval (Fig. 54).

In general, parameters are recorded according to the averaging time defined in the configuration. For example, if the user defined 10-minute averaging time, every 10 minutes a record is written on the memory card with the average values (and optionally minimum, maximum and instantaneous values) of the parameters. However, in some cases, there are exceptions to this rule. Examples may include the following:

- Long-term flicker P_{lt} – it is measured every 2 hours, hence at a 10-minute averaging time, a new P_{lt} value is displayed every 12 averaging periods,
- Frequency - the measurement time of this parameter is 10 seconds,
- 15-minute active and reactive power for the recording compliant with EN 50160 for which the basic averaging period is 10 minutes.

In order to facilitate search for parameters measured with different averaging times, an option has been added for displaying parameters in relation to the indicated averaging period. For example, if the user performed a measurement with 10-minute averaging time and wants to quickly display the records in which P_{lt} was measured, then option **Show data every** "2h" should be selected. Then, the table will include only the rows with times being the multiples of 2 hours, during which the next measured value of P_{lt} occurred.

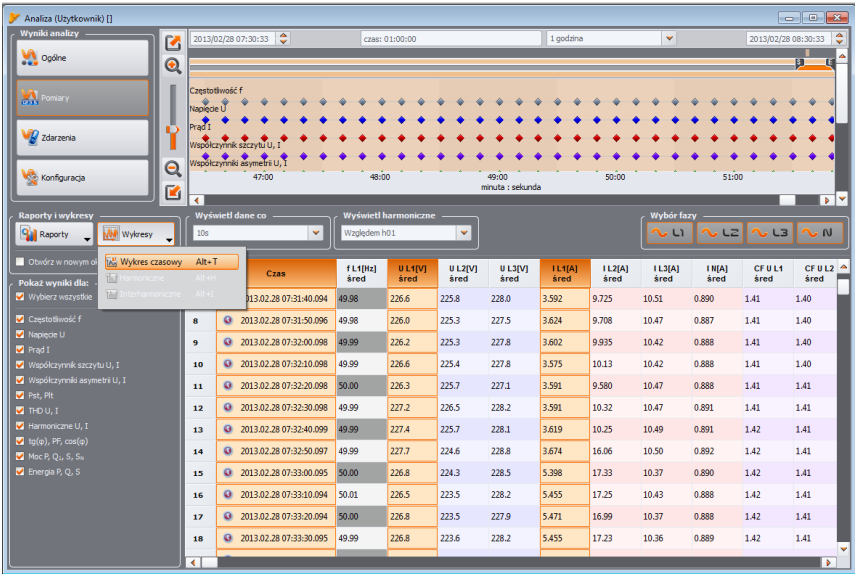


Fig. 51. Selecting data for the plot.

Description of the timeplot (Fig. 52):

- information 1 about the start, end and time difference of the plot time is presented on the left side at the top (horizontal axis),
- information 2 about the values of three independent markers 3 is displayed on the left side at the bottom (two circles on the plot),
- markers may be moved using the left mouse button (grab and move)
- use left/right arrows to move the markers along the time axis,
- use up/down arrows to move the active marker to the next waveform,
- in the default mode, the grabbed marker "sticks" to the nearest waveform. If after a right-click within the plot area, the user selects **Free mode enabled** option, the marker may be freely set. If there is no waveform near the marker, its color changes to grey and the coordinates in the X and Y axes refer to its current position.
- after right-clicking the mouse a **Comparative Mode** is also available. It sets the markers at the same time point and moving one of them moves the others. It enables users to easily compare up to the three chosen parameters for a given time.
- use the buttons 4 located above the plot to switch on/off individual waveforms and change their colour,
- use the sliders or the mouse scrolling wheel to zoom-in the plot vertically and horizontally (vertically, if the mouse pointer is close to side edges of the plot; horizontally, if it is close to the top or bottom edge)
- keeping SHIFT key pressed, use mouse to select a rectangular area to be zoomed-in,
- keeping CTRL key pressed, left-click within the plot area and still keeping it pressed, move the visible fragment (the cursor arrow turns into a hand)
- the plot has two vertical axes on the left and right side; from the drop-down lists 5, select the scale for the value to be displayed on the plot,

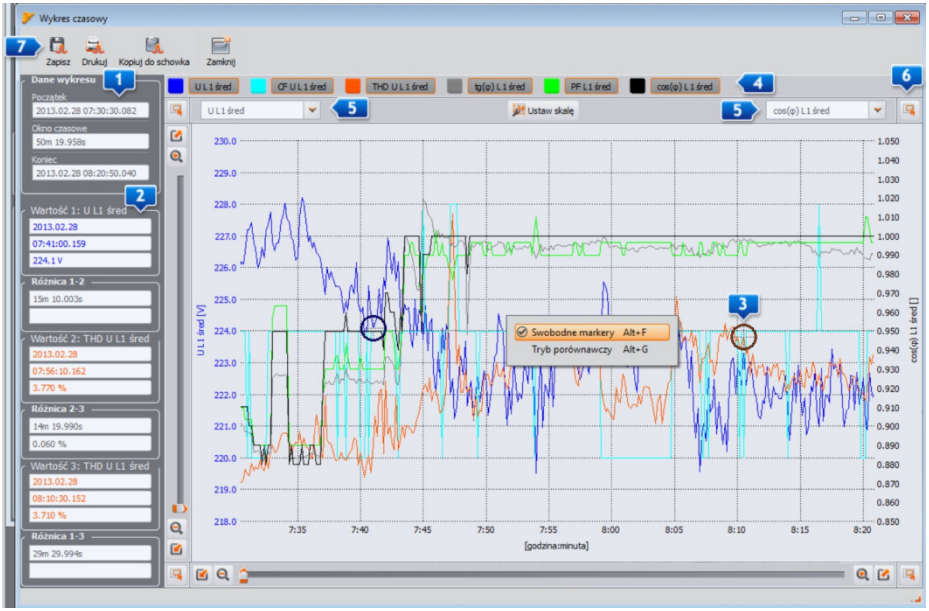


Fig. 52. Timeplot window.

- in addition to the parameters selected by the user (i.e. UL1, P etc.), the scales drop-down lists include also the group of parameters with the same units (V, A, W, var, VA, %, Hz, [---] - no unit). When a group is selected, one scale is adopted for the plot (e.g. in V) and all waveforms from this group are rescaled to fit the scale,
- selecting a given group for the left-side scale Y, will result in disabling this group and all its parameters on the right scale Y, and vice-versa
- clicking on icons 6 in the corners of the screen will result in displaying a miniature of the whole plot; the highlighted rectangle illustrates a part of the plot which is currently zoomed in; move it with a mouse on the plot miniature to move the plot in the main window,
- pressing any of the buttons 7 located in the top of the screen results in saving the plot on the disk in a user-selectable format (jpg, png or xpm), or copying it to the clipboard, or printing
- the plot may include maximum of 12 waveforms.

Highlight any column (e.g. f, U L1, THD U, etc.) or any range of cells and click **Reports** and **User Report** option, to display a new window that will provide options for: saving the selected data in a desired format (pdf, html, txt, csv); copying it to the clipboard, or printing. The data refer to the time specified in the selected column (columns or marked cells). Example of a report saved as a .pdf file is shown in Fig. 53. Maximum 12 columns of data may be generated.

RAPORT

Data rozpoczęcia rejestracji 2013.02.28 07:30:40.082
Data zakończenia rejestracji 2013.02.28 08:20:50.040

Flaga i czas	U L1[V] średnia	CF U L1 średnia	THD U L1[%] średnia	tg(φ) L1 średnia	PF L1 średnia	cos(φ) L1 średnia
X 2013.02.28 07:30:40.082	226.1	1.42	2.78	-0.45	0.84	0.91
X 2013.02.28 07:30:50.082	226.5	1.42	2.84	-0.46	0.83	0.91
X 2013.02.28 07:31:00.083	227.2	1.41	2.81	-0.46	0.83	0.91
X 2013.02.28 07:31:10.084	227.2	1.42	2.80	-0.47	0.83	0.90
X 2013.02.28 07:31:20.088	227.4	1.41	2.88	-0.47	0.83	0.90
X 2013.02.28 07:31:30.092	226.8	1.41	2.83	-0.52	0.81	0.89
X 2013.02.28 07:31:40.094	226.6	1.41	2.86	-0.52	0.81	0.89
X 2013.02.28 07:31:50.096	226.0	1.41	2.84	-0.52	0.81	0.89
X 2013.02.28 07:32:00.098	226.2	1.41	2.90	-0.52	0.81	0.89
X 2013.02.28 07:32:10.098	226.6	1.41	2.86	-0.53	0.81	0.88
X 2013.02.28 07:32:20.098	226.3	1.41	2.83	-0.52	0.81	0.89
X 2013.02.28 07:32:30.098	227.2	1.41	2.93	-0.52	0.81	0.88
X 2013.02.28 07:32:40.099	227.4	1.42	2.85	-0.52	0.81	0.89
X 2013.02.28 07:32:50.097	227.7	1.42	2.97	-0.52	0.81	0.89
X 2013.02.28 07:33:00.095	226.8	1.42	3.00	-0.52	0.81	0.89
X 2013.02.28 07:33:10.094	226.5	1.42	2.95	-0.52	0.82	0.89
X 2013.02.28 07:33:20.094	226.8	1.42	2.96	-0.51	0.82	0.89
X 2013.02.28 07:33:30.096	226.8	1.42	3.00	-0.52	0.82	0.89
X 2013.02.28 07:33:40.097	227.5	1.42	3.07	-0.52	0.82	0.89
X 2013.02.28 07:33:50.100	227.6	1.42	3.08	-0.52	0.82	0.89
X 2013.02.28 07:34:00.103	228.0	1.42	3.08	-0.52	0.82	0.89
X 2013.02.28 07:34:10.105	227.5	1.42	3.08	-0.52	0.82	0.89
X 2013.02.28 07:34:20.107	227.5	1.42	3.03	-0.53	0.81	0.88
X 2013.02.28 07:34:30.110	226.9	1.42	2.96	-0.52	0.81	0.89
X 2013.02.28 07:34:40.113	226.9	1.42	2.99	-0.54	0.81	0.88
X 2013.02.28 07:34:50.115	226.2	1.42	3.02	-0.53	0.81	0.88
X 2013.02.28 07:35:00.116	226.3	1.42	3.01	-0.53	0.81	0.88
X 2013.02.28 07:35:10.117	227.6	1.42	3.09	-0.53	0.81	0.88
X 2013.02.28 07:35:20.120	228.2	1.42	2.98	-0.52	0.81	0.89
X 2013.02.28 07:35:30.125	228.1	1.42	3.05	-0.53	0.81	0.88

Fig. 53. Example of a report saved as a .pdf file

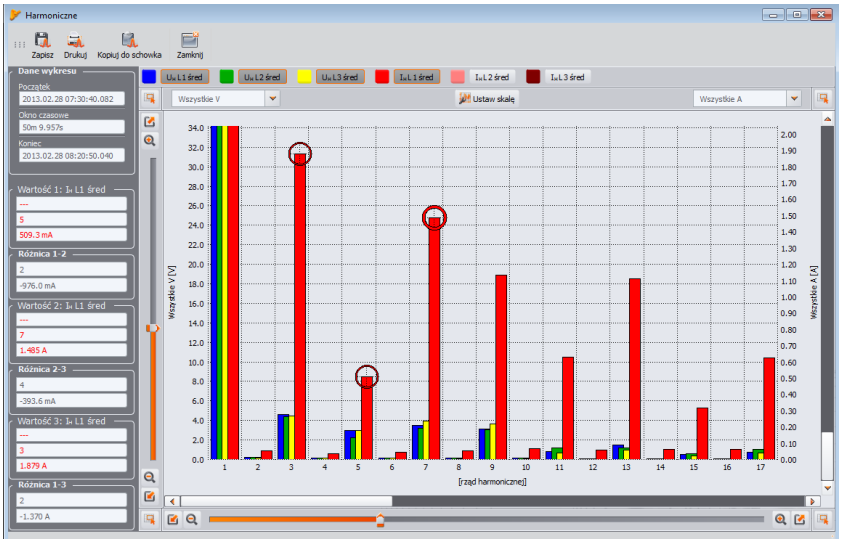


Fig. 54. Harmonics graph.

8.3.3 Events

Pressing **Events** button, changes the main window image into the one shown in Fig. 55. This mode may be used to analyze all events recorded by the analyzer The recorded events are presented as dots 1 in the graph.

In the bottom left part 2 the selectable parameters are displayed as listed in the table 3. The user may turn on/off the selected types by checking relevant boxes. The table displays only selected event types.

Description of individual columns:

- **Marker** – clicking this cell results in selecting an event with the waveform (if any) and adding the event to the list in **Marker**tab, double-clicking of a chosen event results in selecting it on dot graph in the top part of the window,
- **Type** – specifies the event type (voltage swell, dip, exceeding the minimum threshold, etc.),
- **Source** – defines the phase in which the event was detected,
- **Start**, **End** – the start and end of the event,
- **Duration** – event duration,
- **Extreme value** – the lowest or the highest value during the event,
- **Average**– average value during the event,
- **Threshold** – the threshold value exceeding of which has triggered the event detection (the same as the threshold set during the analyzer configuration),
- **Waveform** – waveform icon means that a waveform is available along with $RMS_{1/2}$ graph for the event.

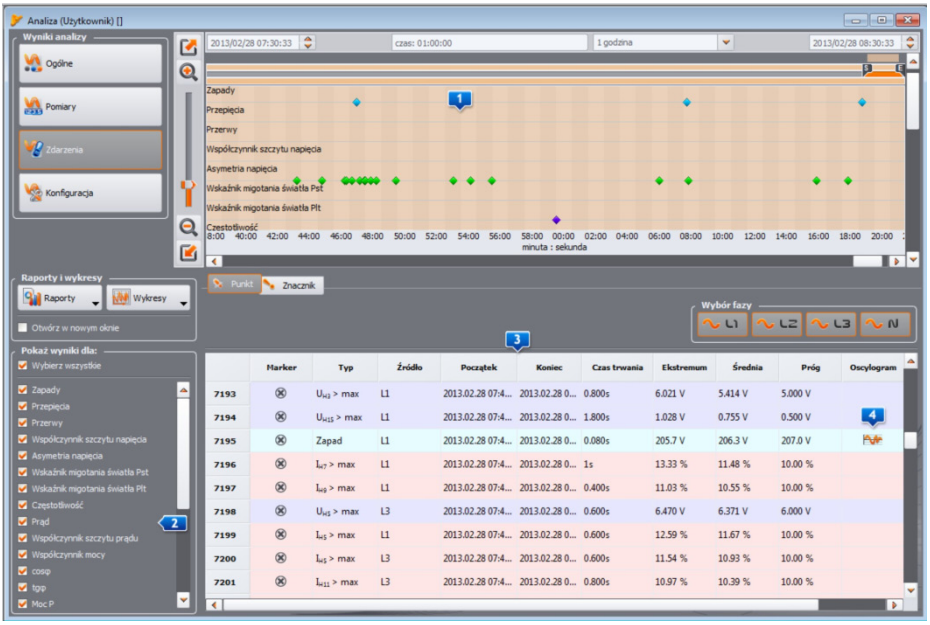


Fig. 55. Event window for User's recording

Clicking on Waveform icon 4 enables waveform graphs and an accompanying graph showing $RMS_{1/2}$ values (Fig. 57). **Open in a new window** option has the same functionality as in the data analysis. The waveform graph and $RMS_{1/2}$ values may be also displayed by highlighting the line with the chosen event - in place with waveform icon and selecting **Plots→Waveform** options.

Fig. 56 presents an example of a waveform. As two waveforms are assigned to this event (start and end of the event), the greyed-out boxes on the diagram mark the beginning (**Start**) and the end (**End**) of the event. In case of a short event, the waveform will be continuous. If the event

duration is longer, there will be two waveforms (one at the beginning of the event and the second at the end). The plot may be freely zoomed-in as shown in Fig. 57. Operations on the plot are the same as in case of the timeplot.

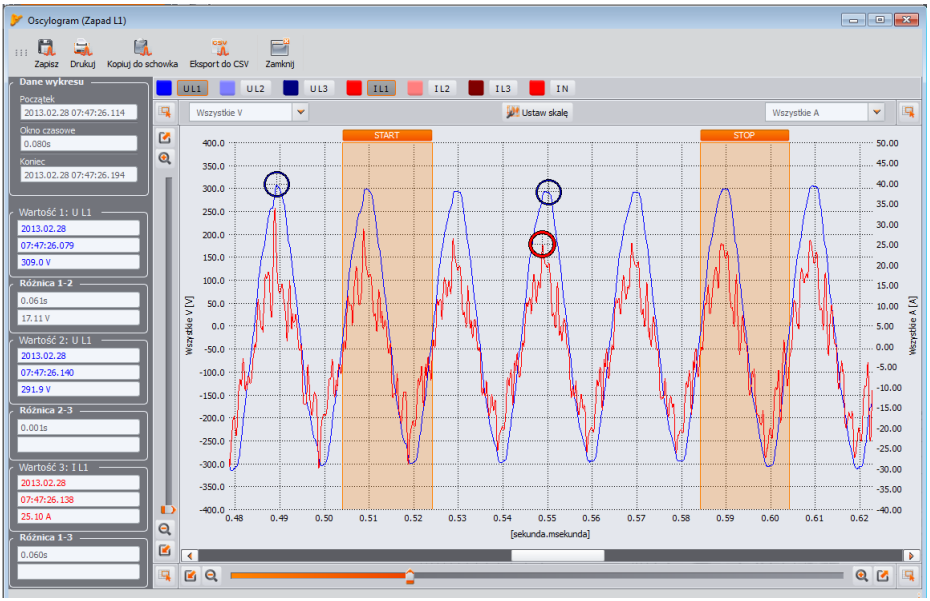


Fig. 56. Plot with a start and end waveform

Fig. 57. Zooming-in a part of the waveform.

Waveforms may be saved in CSV format, which allows user to analyse them in spreadsheets. All samples of enabled channels are saved. To save a waveform in this format, select **Export to CSV** icon and specify a file name and location where you want to save the file.

Typ	Źródło	Początek	Koniec	Czas trwania	Ekstremum	Średnia	Próg
I_{N} > max	L2	2013.02.28 07:22:36.159	2013.02.28 07:22:37.159	1.00 s	11.48 %	10.39 %	10.00 %
I_{L3} > max	L3	2013.02.28 07:22:36.159	2013.02.28 07:22:36.959	0.80 s	11.54 %	11.43 %	10.00 %
I_{L3} > max	L3	2013.02.28 07:22:36.159	2013.02.28 07:22:36.959	0.80 s	11.03 %	10.79 %	10.00 %
I_{N} > max	L1	2013.02.28 07:22:36.359	2013.02.28 07:22:37.359	1.00 s	11.68 %	10.62 %	10.00 %
U_{N} > max	L2	2013.02.28 07:22:36.959	2013.02.28 07:22:37.159	0.20 s	5.215 V	5.215 V	5.000 V
U_{L3} > max	L3	2013.02.28 07:22:36.959	2013.02.28 07:22:37.159	0.20 s	0.599 V	0.599 V	0.500 V
I_{L3} > max	L1	2013.02.28 07:22:36.959	2013.02.28 07:22:37.359	0.40 s	12.10 %	11.14 %	10.00 %
fO > maks.	L1	2013.02.28 07:22:37.159	2013.02.28 07:22:37.359	0.20 s	2.524	2.524	2.500
I_{N} > max	L3	2013.02.28 07:22:37.159	2013.02.28 07:22:38.360	1.20 s	16.44 %	13.19 %	10.00 %
U_{N} > max	L1	2013.02.28 07:22:37.359	2013.02.28 07:22:37.560	0.20 s	5.014 V	5.014 V	5.000 V
U_{L3} > max	L1	2013.02.28 07:22:37.560	2013.02.28 07:22:38.360	0.80 s	0.598 V	0.565 V	0.500 V
U_{L3} > max	L2	2013.02.28 07:22:37.560	2013.02.28 07:22:38.760	1.20 s	0.819 V	0.662 V	0.500 V
I_{N} > max	L1	2013.02.28 07:22:37.560	2013.02.28 07:22:37.760	0.20 s	10.22 %	10.22 %	10.00 %
I_{N} > max	L1	2013.02.28 07:22:37.560	2013.02.28 07:22:38.160	0.60 s	10.03 %	10.02 %	10.00 %
I_{L3} > max	L3	2013.02.28 07:22:37.760	2013.02.28 07:22:38.360	0.60 s	11.02 %	10.55 %	10.00 %
I_{L3} > max	L2	2013.02.28 07:22:38.160	2013.02.28 07:22:39.360	1.20 s	11.72 %	10.74 %	10.00 %
U_{N} > max	L3	2013.02.28 07:22:38.360	2013.02.28 07:22:38.960	0.20 s	0.604 V	0.604 V	0.500 V
I_{N} > max	L1	2013.02.28 07:22:38.360	2013.02.28 07:22:38.960	0.60 s	12.32 %	10.86 %	10.00 %
I_{N} > max	L1	2013.02.28 07:22:38.360	2013.02.28 07:22:38.760	0.40 s	10.18 %	10.04 %	10.00 %
I_{N} > max	L3	2013.02.28 07:22:38.560	2013.02.28 07:22:40.761	2.20 s	13.74 %	12.07 %	10.00 %
I_{L3} > max	L3	2013.02.28 07:22:38.560	2013.02.28 07:22:39.360	0.80 s	13.02 %	11.75 %	10.00 %
U_{N} > max	L1	2013.02.28 07:22:38.960	2013.02.28 07:22:39.360	0.40 s	0.668 V	0.637 V	0.500 V
U_{N} > max	L2	2013.02.28 07:22:38.960	2013.02.28 07:22:39.360	0.40 s	0.587 V	0.581 V	0.500 V
I_{N} > max	L1	2013.02.28 07:22:38.960	2013.02.28 07:22:39.360	0.40 s	10.65 %	10.55 %	10.00 %
I_{L3} > max	L1	2013.02.28 07:22:38.960	2013.02.28 07:22:39.160	0.20 s	10.63 %	10.63 %	10.00 %
I_{N} > max	L1	2013.02.28 07:22:39.360	2013.02.28 07:22:39.560	0.20 s	10.40 %	10.40 %	10.00 %
U_{N} > max	L2	2013.02.28 07:22:39.560	2013.02.28 07:22:39.761	0.20 s	5.059 V	5.059 V	5.000 V
U_{L3} > max	L1	2013.02.28 07:22:39.560	2013.02.28 07:22:40.361	0.80 s	0.564 V	0.537 V	0.500 V
U_{L3} > max	L2	2013.02.28 07:22:39.560	2013.02.28 07:22:40.161	0.60 s	0.767 V	0.662 V	0.500 V
fO > maks.	L1	2013.02.28 07:22:39.761	2013.02.28 07:22:39.961	0.20 s	2.791	2.791	2.500
I_{N} > max	L1	2013.02.28 07:22:39.761	2013.02.28 07:22:40.161	0.40 s	13.43 %	12.24 %	10.00 %
I_{L3} > max	L1	2013.02.28 07:22:39.761	2013.02.28 07:22:40.761	1.00 s	12.03 %	10.94 %	10.00 %
I_{L3} > max	L2	2013.02.28 07:22:39.761	2013.02.28 07:22:39.961	0.20 s	10.03 %	10.03 %	10.00 %
I_{L3} > max	L1	2013.02.28 07:22:39.761	2013.02.28 07:22:40.161	0.40 s	11.81 %	11.25 %	10.00 %
U_{N} > max	L2	2013.02.28 07:22:40.361	2013.02.28 07:22:41.361	1.00 s	0.830 V	0.662 V	0.500 V
U_{N} > max	L3	2013.02.28 07:22:40.361	2013.02.28 07:22:40.561	0.20 s	0.508 V	0.508 V	0.500 V
I_{N} > max	L1	2013.02.28 07:22:40.361	2013.02.28 07:22:40.761	0.40 s	10.41 %	10.18 %	10.00 %

Fig. 58. Event Report.

Events listed in the table may be stored in the form of a report, after selecting **Reports→User Report** option. A sample *pdf* report is shown in Fig. 58.

Fig. 59 shows a graph for **Value/duration**. In order to display it, select **Plots→Value/duration** option. This graph shows events in the form of dots/points and enables the program to display a number of events with their mutual relationship between the duration of the event (horizontal axis) and the extreme value of an event (vertical axis). The graph shows only the types of events that have been selected on the left side.

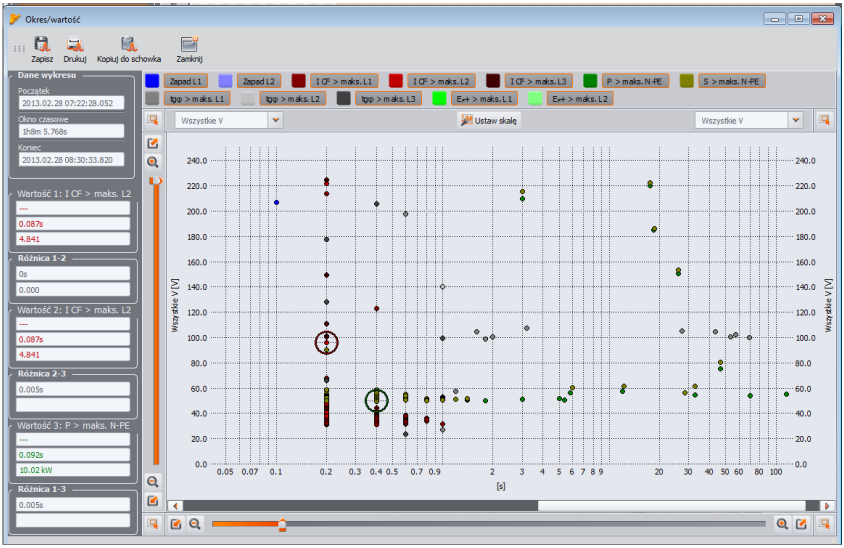


Fig. 59. Event Analysis - Value/duration graph.

When events of voltage dip, swell, or interruption were recorded option **Plots→ANSI/CBEMA** is enabled. When this option is selected, event graph is displayed similar to Value/duration graph, but with overlaid ANSI or CBEMA curves, which are standard in the evaluation of the device in terms of tolerance to fluctuations of the supply voltage. The graph type is selected from the pop-up menu displayed after right-clicking within the graph area and selecting **Curve type** option and choosing **ANSI** or **CBEMA**. Specific points of the curves may be modified manually in program preferences: **Options→Configuration→Data Analysis**. A sample screen is shown in Fig. 60.

More information on ANSI and CBEMA curves can be found in section 10.12.

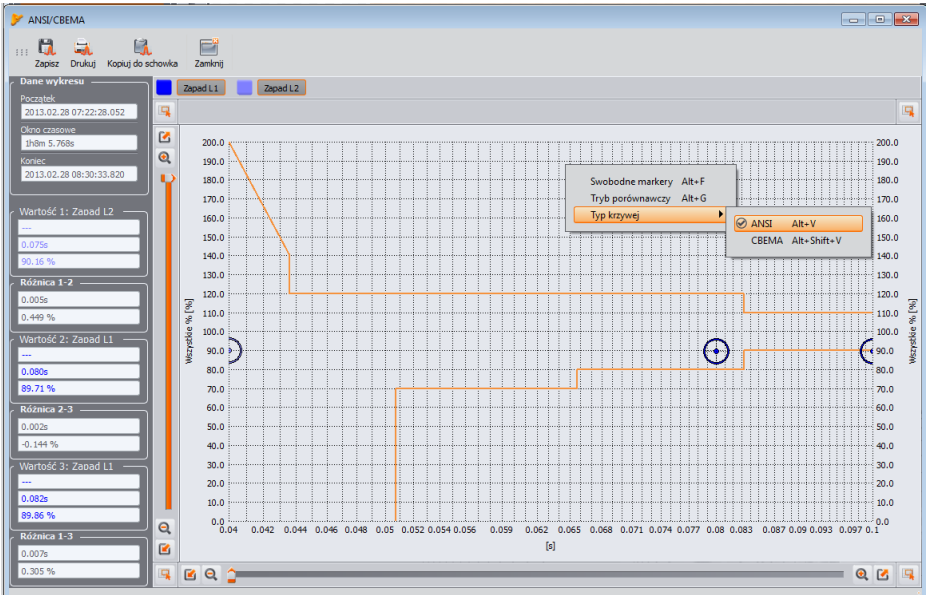


Fig. 60. ANSI/CBEMA graph

> ***Tip***
> *Actions for zooming-in/zooming-out, moving and others (including X activities) shown in Fig. 57, Fig. 56, Fig. 58 are similar to those shown in Fig. 52.*

Marker window includes events selected by the user. In this table the user may move rows (events), to arrange them according own choice. Rows are moved using "drag and drop" technique, or by clicking and keeping the left mouse button on any cell in the line you can move it up or down.

All buttons in **Markers** tab operate identical as in **Point** tab.

8.3.4 Analysing obtained data according to EN 50160

Data analysis according to EN 50160 standard is similar to the **User's** analysis. The main difference is that in this mode, the user may additionally generate a report on compliance with EN 50160 standard or other defined in the program. This report includes only those parameters and events that are important from the point of view of the standard. If the currents were measured, the measured parameters table will show also the 15-minute average values of active, reactive and apparent powers, as well as of tgφ. EN 50160 report takes into account the values of max. 15-minute power and tanφ.

After selecting **Reports** option, you may additionally have an access to **EN 50160 Report** button. After pressing the button, it is possible to save the final report for measurements of 50160 standard compliance. The report is saved as a PDF file (with a graph), a HTML file, or as a text file. Click **Report EN 50160** button to display a window where you can enter additional data to the report (Fig. 61).

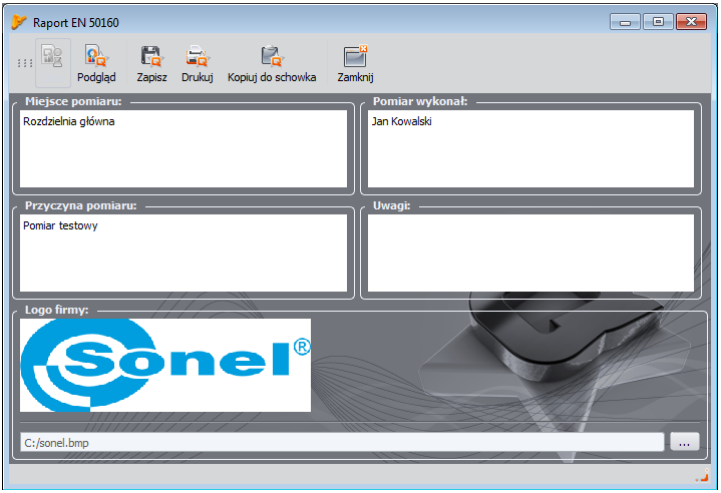


Fig. 61. Entering additional data to the report.

If the fields are left empty - then the corresponding fields in the report will also remain empty. If you want a company logo or another symbol to appear in the report header, indicate it in the **Company logo** field. These fields can also be defined in the configuration to serve as a template while generating reports. A fragment of a typical report is shown in Fig. 62.

Note

The time interval used in the measurement report depends on the interval selected by the user when the data for analysis were loaded. If this time is shorter or longer than 1 week (required by the standard), the report is still generated. The user is responsible for selecting the appropriate time.

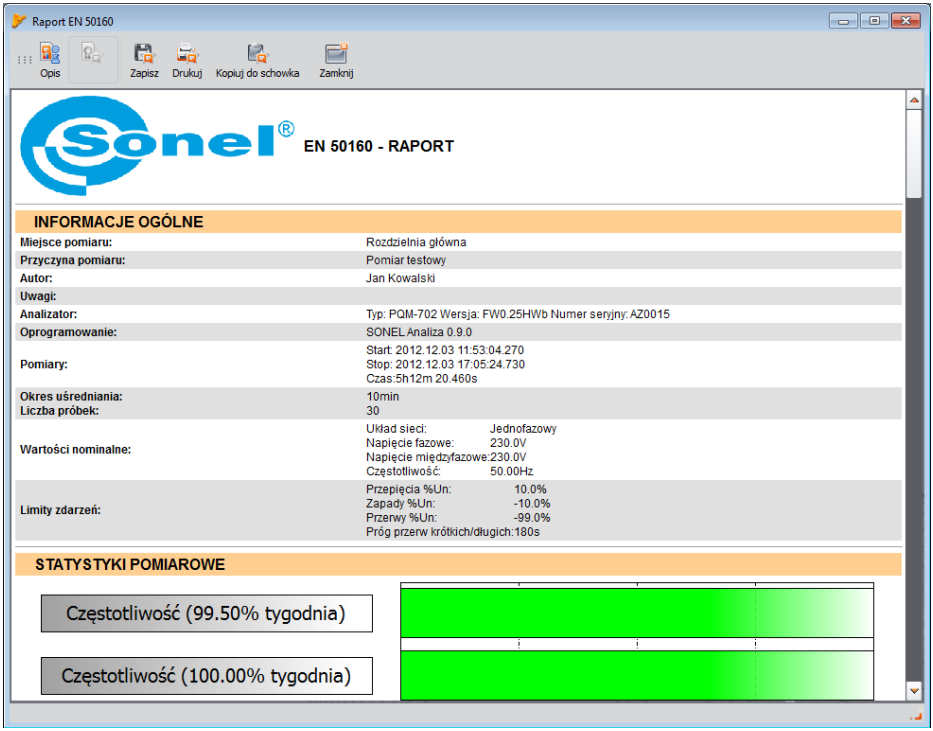


Fig. 62. Measurement report according to EN 50160.

8.3.5 Data export

Measurement data presented in a tabular form, may be selected and saved in a desired file format. This applies both to the data presented in part **Measurements** (section 8.3.2) and for Events (section 8.3.3):

- for 'measurements', click the time column and then select the parameters you want to export by selecting chosen columns with data. To instantly select all the data in the table, right-click in the table and choose **"Select All"** option. Time range may be reduced by selecting only some of the cells in the time column (holding down SHIFT or CTRL key). The second option of reducing the time range is using two sliders **S** (start) and **E** (end) in the part with the dotted graph. Then press **Reports→User report**. To save the data in a desired file format, select **Save**, and then indicate the location, name and format of your file. Available formats:
  - PDF (export to this format may contain maximum 12 data columns),
  - HTML (these files may be opened in a web browser)
  - TXT (standard text files)
  - CSV (*Comma Separated Values* - files of this type may be easily opened in spreadsheets e.g. in Microsoft Excel)
- for 'events', the data range (rows) may be reduced by using two sliders **S** (start) and **E** (end) in the part with the dotted graph. Then press **Reports→User report**. To save the data in a desired file format, select **Save**, and then indicate the location, name and format of your file. The data formats are the same as described above for the measurements.

It is possible to export only selected events - mark the icon in **Marker** column next to selected events and then, after choosing the **Marker** tab, press **Reports→User Report** and proceed as described above.

The standard way to export data to CSV files may be configured by selecting **Options→Program Configuration**, then clock **Report Settings** icon and **CSV Settings** tab.
The following features may be set here:

- an option for dividing data into files of smaller size. To do this, select **"Divide CSV file"** option and set the maximum desired number of lines in a single file. If the report contains more rows that defined in the settings, CSV Report will be divided into several files with names including respective numbers. The first file number is 000000.
- a character for separating the integer part from the decimal (dot or comma)
- a character for separating values (semicolon is used as default),
- a character for separating text fields (e.g. column headers).

9 Other program options

9.1 Analyzer status, starting and stopping recording

Selecting **Analyzer→ Control** option in the program menu displays a window as shown in Fig. 63. This window includes a lot of information about the current state of the analyzer - the user may also start/stop the recording process.

The following describes the elements of the status window:

- **Analyzer type** – model of the connected analyzer,
- **Serial Number** – the serial number of the analyzer, which is connected,
- **Temperature** – displays the current temperature inside the analyzer in Celsius and Fahrenheit degrees,
- **Charging status** – information about the status of charging when power is applied, or about the percentage of remaining battery power (including voltage) when device is supplied from the battery,
- **Power Source** – shows the current power source of the analyzer: battery or mains,
- **Firmware version** and **hardware version** – shows firmware and hardware versions,

Next information on recording:

- **Analyzer status**: indicates whether the analyzer is recording or not,
- **Number of the measurement point** – for PQM-700 it is always 1,
- **Memory available for the measurement point** – percentage value that specifies the amount of still available space assigned to the measurement point,

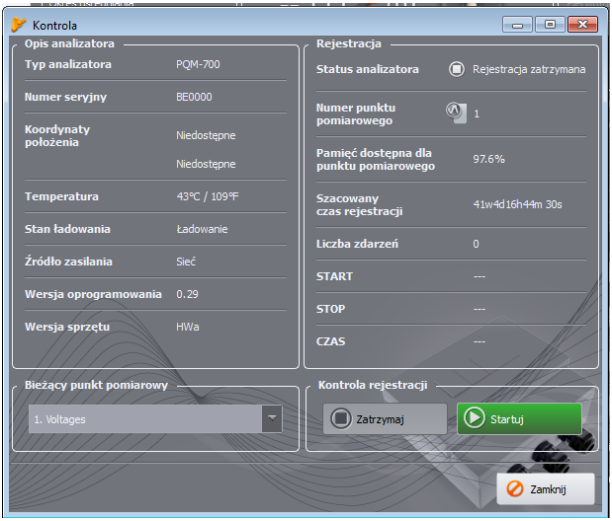


Fig. 63. Control window.

- **Estimated recording time** – shows the approximate recording time, according to the current configuration - shown in the following format: weeks(w) days(d) hours(h) minutes(m) second(s),
- **Number of events** – the number of recorded events - counted from the last recording start in the measurement point. Sending a new configuration or switching-off the analyzer results in resetting the counters.

This window also enables user to remotely start/stop the recording:

- **Recording Control** –two buttons are available: **Stop** and **Start**, which may be used to stop and start the recording process.

9.2 Deleting data

After selecting **Analyzer→Delete Data** from the menu, a window is displayed as shown in Fig. 64. In this window, you may select data of the measurement point to be deleted, without affecting its configuration. To do this, select the check box next to the measurement point and press **Delete data**. Pressing **Format Card** button results in deleting of all data and restoring the default file structure.

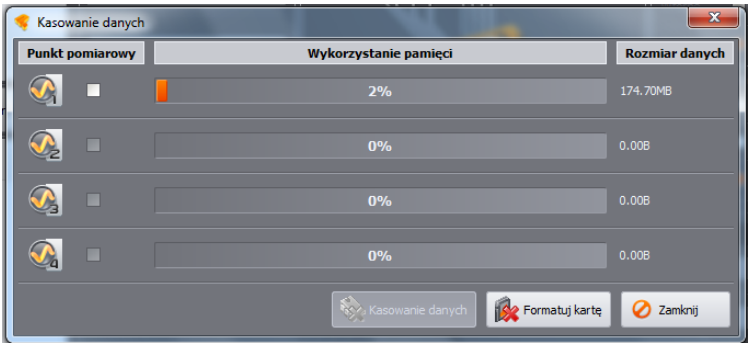


Fig. 64. Deleting data.

9.3 Configuration

The user may change the default application settings after choosing from the software menu **Options→ Software configuration**.

The whole settings section, is divided into a few parts, marked by icons located in the top part of the window

- Main Settings,
- Analyzer Configuration,
- Live mode
- Colour Settings
- Data Analysis,
- Report settings,
- Media settings.

After selecting any of them, detailed settings are presented in the middle part of the window - they also may be divided into tabs.

On the right side of the window, additional buttons are located:

- **Factory** – restores default (factory) settings of the program,
- **Load** – reads program settings from a file,
- **Save** / **Save As** – saves the program settings to a file,

9.3.1 Main Settings,

- **Default Language** – used to select the default language of the application.

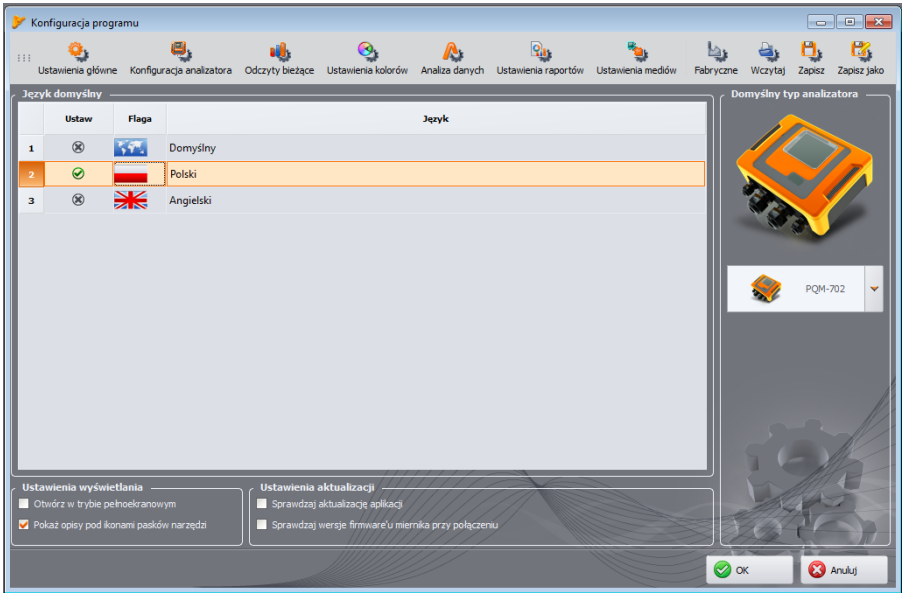


Fig. 65. Configuration - Main Settings.

- **Default analyzer type** – allows user to select a default type of the analyzer from a list - it affects e.g. opening of the analyzer configuration.
- **Display settings** – allows user to open the application in full screen mode.
- **Update Settings** - allows user to enable /disable the option to automatically check for new versions of "Sonel Analysis" program and for the analyzer firmware. When selected, each time the program is started - it will be connect to manufacturer's server and check for new program versions. The user will be informed about a new version and then may choose to download and install the update.

9.3.2 Analyzer settings

In the panel on the left side, the following options are available:

- **Default settings of the analyzer** - This option allows the user to specify the default configuration for a specific model of the analyzer after starting the application. Selecting **From file** option will result in loading the default configuration from a saved file with the *.settings extension. If the user does not indicated own configuration file in **Path**field, the application will use the standard file saved in the installation catalogue. When "From File" option is not selected, the program will use the built-in configuration (factory).
- **Standard default settings** – this option allows the user to configure individual profiles of EN 50160 standards and its variants. A drop-down tree are have all factory pre-defined profiles, which are available on the drop-down list when you set up the measurement according to EN 50160 (see sec. 5.2.2). Three Polish variants of the standard have been prepared - they are basically result directly from the Regulation of the Minister of Economy of 4 May 2007 on detailed conditions of power system functioning. Profile names:
    - **Low voltage** - criteria as in Tab. 5
    - **Medium voltage** - criteria as in Tab. 6
    - **High voltage** - criteria as in Tab. 6

Low voltage profile is dedicated to customers connected directly to the mains with a voltage lower than 1kV, **Medium voltage** profile is dedicated to customers connected to the mains with a voltage higher than 1kV but lower than 110kV, whereas **High voltage** is dedicated to customers connected to the mains with a voltage higher than 110kV. Default profiles **Low voltage** and **Medium voltage** have identical criteria.

Expanding the tree of a selected profile, you can view and change (if required) their default criteria:

- **Basic** card includes quality criteria for frequency, slow voltage changes, unbalance and flicker,
- **Harmonics** card includes THD criteria in voltage and voltage harmonics,
- **Events** card includes criteria for voltage events: interruptions, dips and swells

Basic

Use this card to set the measuring criteria for:

- Frequency – tolerance values that define allowable deviations as a percentage of nominal frequency value and the measurement time limit for the first tolerance (i.e. 99.5% of the week and ±1% f_n),
- Slow voltage changes – RMS voltage: two tolerance values that define allowable deviations as a percentage of nominal RMS voltage value and the measurement time limit for the first tolerance (i.e. 99.5% of the week and 10% U_n),
- Voltage unbalance factor – measurement time limit for a specified threshold,
- Long-term flicker P_{lt} – measurement time limit and the threshold.

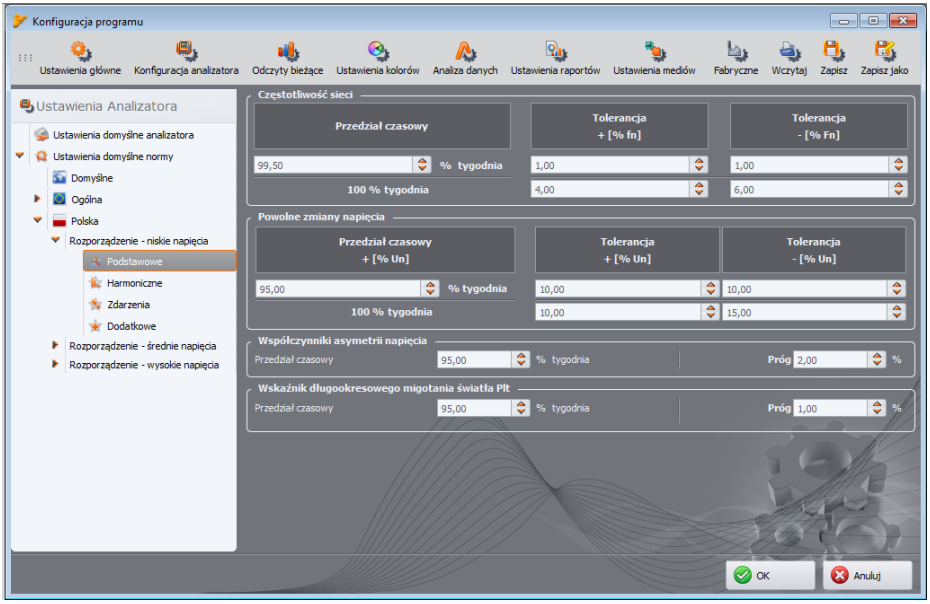


Fig. 66. Recording in accordance with EN 50160 - basic settings.

Harmonics

The screen is shown in Fig. 67. Here, the user may set the limits for THD factor, and limit levels for individual harmonics.

Setting limits for individual harmonics may be performed in two ways: completing the table below the graph or directly on the graph.
When the table is filled, after values are approved, the graph located above presented the table visualization.

To change the limit on the graph, double-click on a selected harmonic and then holding down the left mouse button, set the desired level. Additionally, after selecting a harmonic, the following keys may be also used:

- SPACEBAR- used to enter the editing selected harmonic
- ENTER - confirming values
- TAB – confirming values and moving to the next harmonics,
- UP and DOWN arrow - change the value of the limit,
- LEFT and RIGHT arrow - used for moving to the previous or next harmonics,
- HOME and END - jump between the first and the last harmonic.

> ***Note***
> *The level of THD and harmonics is referenced to the fundamental component.*
> *THD during recording in accordance with EN 50160 is always calculated basing on the first 40 harmonics.*

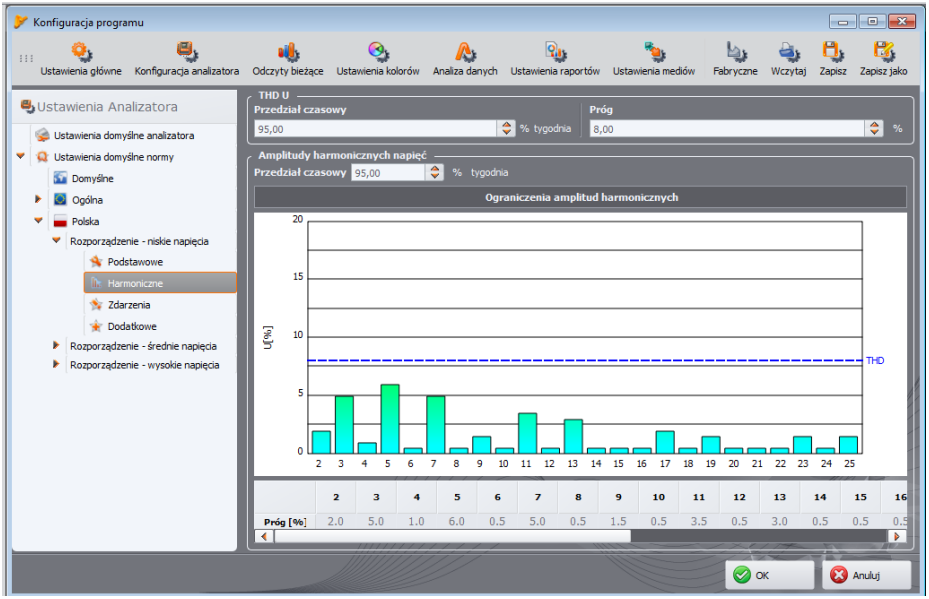


Fig. 67. Recording in accordance with EN 50160 - harmonics settings.

Events

Fig. 68 presents screen for recording events according to EN 50160.
The following features may be set here:

- thresholds for detecting voltage swells, dips and interruptions. These thresholds are expressed as a percentage of the nominal voltage value that to be added to the nominal value. For example, swell tolerance of +10% U_n means, that for voltage U_n=230V, the swell threshold is U_{swell}= 230 + 23 V = 253V.
  Interruption tolerance of -95% U_n, means, that event detection with a voltage equal to or less than $U_{interr.}$ = 230 – 227.7V = 2.3V.
- Threshold for short-term/ long-term interruption. This value is used for the classification of power-supply interruption events.

> ***Notes***
> *• Voltage dip cannot be set lower than interruption.*
> *• Nominal voltage value is taken from measurement point main settings (nominal values of mains system)*

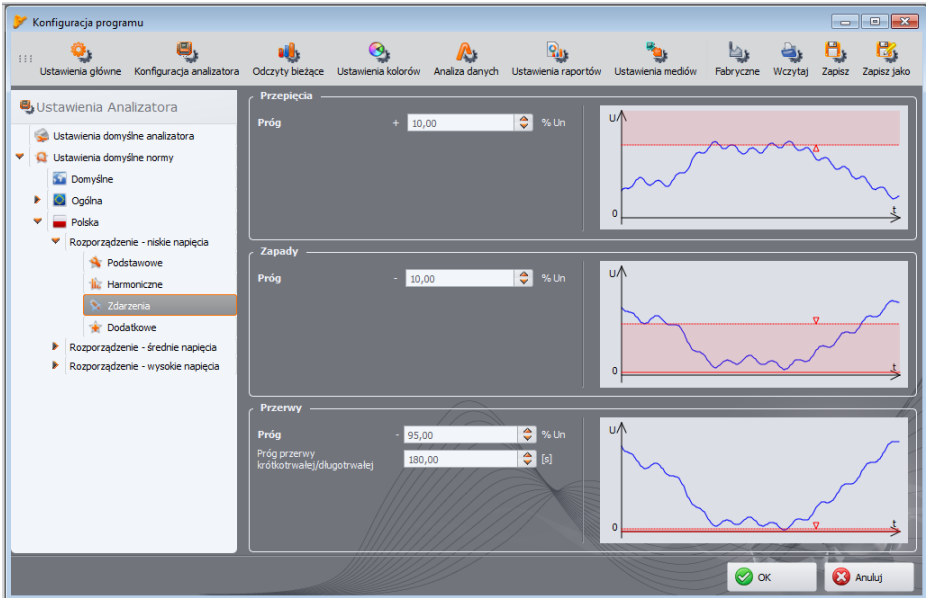


Fig. 68. Recording in accordance with EN 50160 - event settings.

Please note that the criteria set out in profiles of EN 50160 are used only for statistical analysis and generating EN 50160 report based on mains parameters previously measured by the analyzer. Threshold settings, week percentages etc., are not at any time sent to the analyzer (they are only stored in the program settings).

Selecting EN 50160 profile during the analyzer set-up is required, as the program must load quality criteria from the profile database. Some profiles have also some specific features, e.g. "Polish" profiles unlock 15-minute measurement of average values of power and tanφ, for which other profiles do not occur.

9.3.3 *Live mode*

This part of the settings (Fig. 69) allows defining the colours of elements and settings in the live mode. The part is divided into the following cards **Waveforms**, **Timeplot**, **Measurements**, **Phasor**, **Harmonics**.
The cards include the following groups:

- Activity - switching-off the preview of a given phase or selecting the active phase after turning on the screen, e.g. in displaying harmonics, the phase is selected by pressing button - this setting allows user to select the active phase after enabling harmonics screen.
- Visibility - allows the user to select which channels are visible by default,
- Colours - in this section you can set colours of individual phases / channels / parameters.

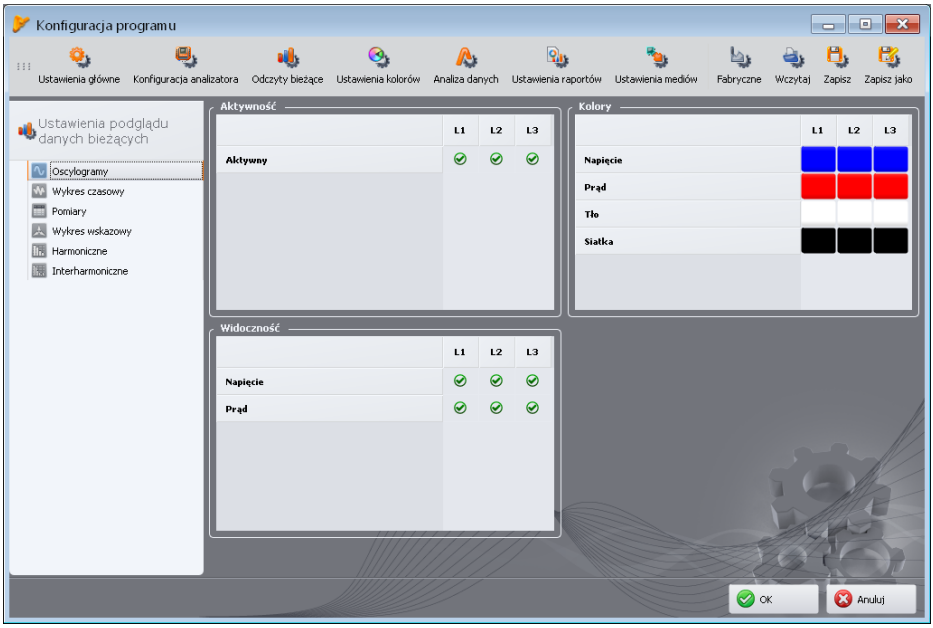


Fig. 69. Live mode settings.

9.3.4 *Colour Settings*

This section allows user to change the colours of individual application components. It is divided into the following cards (Fig. 70):

- Graph colours - divided into individual parameters and phases,
- General colours,
- Measurements colours,
- Event colours,

9.3.5 *Data Analysis*

This section contains the following cards:

- **Excluded devices** - allows user to display devices (disks) that are to be ignored during the search in connected devices with a SD card that include measurements (applies to PQM-700 analyzers),

- **Settings of CBEMA graphs** – enables user to change the default criteria for CBEMA graphs. Changes are introduced by changing the position of the nodes in the graph. Default settings may be restored by clicking **Reset graph**button.
- **Settings of ANSI graphs** – similarly as in case of CBEMA graphs - enables user to change the default criteria for ANSI graphs (Fig. 71). Changes are introduced by changing the position of the nodes in the graph. Default settings may be restored by clicking **Reset graph**button.

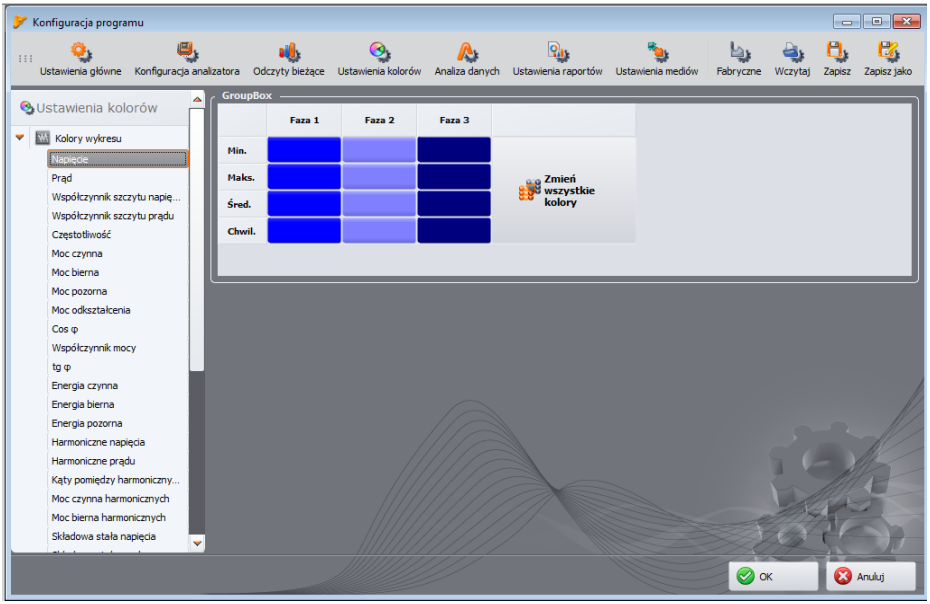


Fig. 70. Program configuration - Colour Settings.

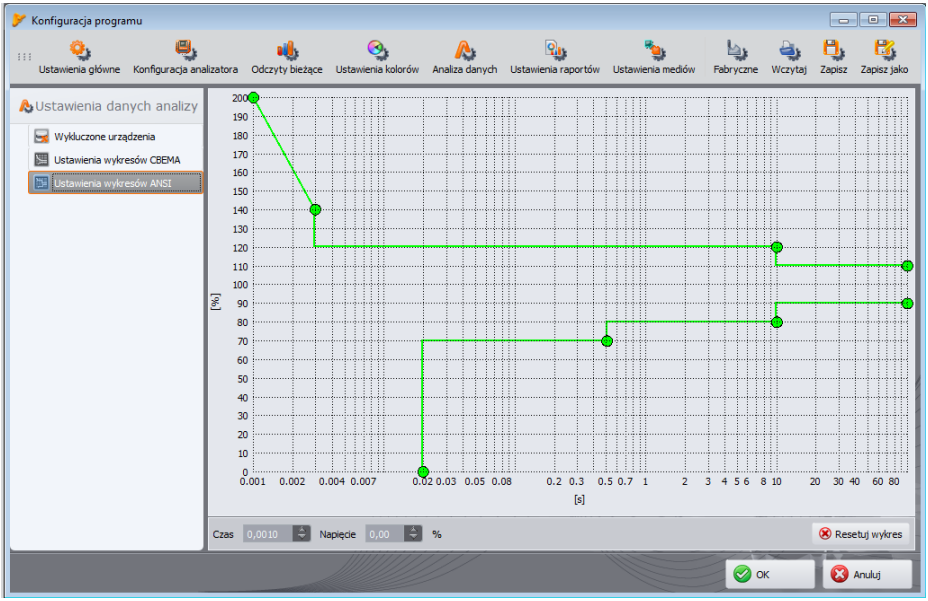


Fig. 71. Configuration - ANSI Graph Settings.

9.3.6 Report settings

The elements included in this part of the configuration:

- **Additional report data** - in this section you can fill in additional fields used for the generating measurement reports: "Measurement place", "Author", "Measurement cause", "Notes" and indicate the logo to be added to the reports.
- **CSV Settings** – enables the user to change the default way of generating CSV files: the number of rows for a single file, selecting the character that separates the integer part from the decimal (period or comma), the choice of separator individual values and selection of text delimiter.

9.3.7 Media Settings

This tab does not apply to PQM-700.

9.4 Upgrading software and firmware

Firmware of the analyzer and "Sonel Analysis" software must be regularly updated in order to correct discovered errors or introduce new functionalities. When the analyzer software is updated, check whether a new version of "Sonel Analysis" is available (and vice versa), if yes proceed with the upgrade.

9.4.1 Automatic software update

Every time the program is started, it checks for updates on the company server. This feature may be turned on/off in the preferences (see section 9.3.1). If this option is disabled, the update may be performed manually by selecting **Help→On-line update**. To perform the update, an operational Internet connection is required.

If the program detects that a new version of "Sonel Analysis" is available, the user may decide to upgrade the current version. After downloading necessary files the new version will be installed and the program will re-start.

The program may also check for a newer version of the analyzer firmware. Firmware update may be performed only after connecting the analyzer with a USB cable. When a new version is available, the user will see information concerning the software version and introduced changes. After confirmation by the user the update proceeds. Then, after it is completed, the analyzer automatically disconnects and re-starts.

10 Power Quality - a guide

10.1 Basic Information

The measurement methodology is mostly imposed by the energy quality standards, mainly IEC 61000-4-30. This standard, introducing precise measurement algorithms, ordered analyzers market, allowing customers to easily compare the devices and their results between the analyzers from different manufacturers. Previously, these devices used different algorithms, and often the results from measurements on the same object were completely different when tested with different devices.

The factors behind growing interest in these issues have included wide use of electronic power controllers, DC/DC converters and switched-mode power supplies, energy-saving fluorescent lamps, etc., that is widely understood electrical power conversion. All of these devices had a tendency to significantly deform the supply current waveform.

The design of switched-mode power supplies (widely used in household and industrial applications) is often based on the principle that the mains alternating voltage is first rectified and smoothed with the use of capacitors, meaning that it is converted to direct voltage (DC), and then with a high frequency and efficiency is converted to required output voltage. Such a solution, however, has an undesirable side effect. Smoothing capacitors are recharged by short current pulses at moments when the mains voltage is close to peak value. From power balance rule it is known that if the current is taken only at short intervals, its crest value must be much higher than in case it is taken in a continuous manner. High ratio of current crest value to RMS value (a so-called crest factor) and reduction of power factor (PF) will result in a situation in which in order to obtain a given active power in a receiver (in watts), the power supplier must supply power greater than the receiver active power (this is a so-called apparent power expressed in volt-amperes, VA). Low power factor causes higher load on the transmission cables and higher costs of electricity transfer. Harmonic current components accompanying such parameters cause additional problems. As a result, the electricity suppliers have started to impose financial penalties upon the customers who have not provided sufficiently high power factor.

Among entities that may be potentially interested in power quality analyzers are power utility companies on one hand, (they may use them to control their customers), and on the other hand the power consumers who may use the analyzers to detect and possibly improve the low power factor and solve other problems related to widely understood power quality issues.

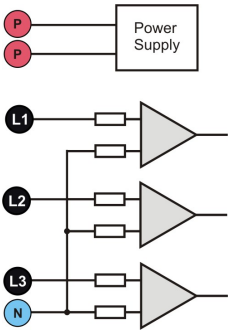
The power source quality parameters, as well as the properties of receivers, are described with many various magnitudes and indicators. This section can shed some light on this area.

As already mentioned, the lack of standardization of measurement methods has caused significant differences in values of individual mains parameters calculated with various devices. Efforts of many engineers resulted in IEC 61000-4-30 standard concerning power quality. For the first time, this standard (and related standards) provided very precise methods, mathematical relations and required measurement accuracy for power quality analyzers. Compliance with the standard (in particular, the class A) should be a guarantee of repeatable and almost identical measurement results of the same magnitudes measured with devices from different manufacturers.

10.2 Voltage Inputs

The voltage input block is shown in Fig. 72. Three phase inputs L1, L2, L3 and protective conductor PE have common reference line, which is the N (neutral) conductor. Such inputs configuration allows reducing the number of conductors necessary to connect the analyzer in the most expanded version from eight to five. Eight conductors are sometimes present in analyzers with four independent differential channels. In reality, however, a 5-input solution is not inferior to 8-input solutions and it may be connected to most operated mains and receiver systems. Five-input solution significantly simplifies connection to the tested facility and reduces the probability of mistake. presents that the power supply circuit of the analyzer is independent of the measuring circuit. The power adapter has a nominal input voltage range 90..460V AC and has a separate terminals.

The analyzer has one voltage range, with voltage range 1150V_{pp} (without clamping).



Rys. 72. Voltage Inputs and integrated AC power

10.3 Current inputs

The analyzer has four independent current inputs with identical parameters. Current transformer clamps with voltage output in a 1V standard, or flexible clamps (probes) F-1, F-2 and F-3 can be connected to each input.

A typical situation is using flexible clamps with built-in electronic integrator. However, the PQM-700 allows connecting the Rogowski coil alone to the input and a digital signal integration.

10.3.1 Current transformer clamps (CT) for AC measurements

CT Current Transformer Clamp is just a transformer converting a large current in primary winding to a smaller current in secondary winding. The jaws of typical current clamp are made of a ferromagnetic material (such as iron) with the secondary winding wound around. The primary winding is a conductor around which the clamp jaws are closed, hence most often it is one single coil. If the 1000-ampere current flows through the tested conductor, in the secondary winding with 1000 coils the current will be only 1A (if the circuit is closed). In case of clamps with voltage output, a shunt resistor is located in the clamps.

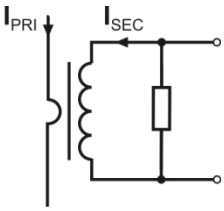


Fig. 1. Current transformer clamp with

Such current transformer has a few characteristic properties. It can be used to measure very large currents, and its power consumption is low. The magnetizing current causes some phase shift (tenth of a degree) which can result in some power measurement error (particularly when the power factor is low). Another disadvantage of this clamp type is also the core saturation phenomenon when very large currents are measured (above the rated range). Core saturation as a result of magnetizing hysteresis leads to significant measurement errors which can be eliminated only by the core demagnetization. The core becomes saturated also when the measured current has a significant DC component. An undeniable disadvantage of such clamp is also its considerable weight.

Despite such drawbacks, the CT clamps are presently the most widely used non-invasive alternating current (AC) measurement method.

The following CT clamps can be used with the PQM-700 analyzers to measure alternating currents:

- C-4, rated range 1000A AC,
- C-6, rated range 10A AC,
- C-7, rated range 100A AC.

10.3.2 AC/DC measurement clamps

There are situations when it is necessary to measure the current DC component. In such case, the clamps must be based on different principle of operation than a traditional current transformer. The clamps in this case use the physical phenomenon known as the Hall effect and include a Hall sensor. In brief: the effect is the production of voltage across an electrical conductor through which the current is flowing and which is placed in a magnetic field. The voltage is transverse to the field induction vector.

The clamps based on this phenomenon can measure the DC and AC current component. The

conductor with current located inside the clamps generates a magnetic field which concentrates in an iron core. In the core slot, where both clamp parts are joined, placed is a semiconductor Hall sensor, and its output voltage is amplified by an electronic circuit supplied from a battery.

This clamp type usually has the current zero adjustment knob. To adjust the current zero, close the jaws (no conductor inside) and turn the knob until the DC indication is zero.

In the area of AC/DC measurement clamps, Sonel S.A. offers the C-5 clamp with rated range of 1000A AC / 1400A DC. This clamp has a voltage output and for 1000A rated current it gives a 1V voltage signal (1mV/A).

10.3.3 Flexible current probes

Flexible Current Probes are based on a totally different physical principle than the current transformer. Their principal part is a so-called Rogowski coil, named after German physicist Walter Rogowski. It is an air-core coil wound around a conductor with current. Special design of the coil allows leading out its both ends on the same side, thus facilitating clamp placement around the conductor (the return end is placed inside the coil at its entire length). The current flowing through the measured conductor causes centric magnetic field lines which due to the self-induction phenomenon induce the electromotive force at the end of the coil. This voltage, however, is proportional to the rate of current change in the conductor, and not to the current itself.

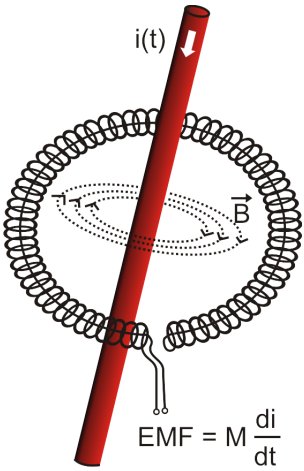


Fig. 2. Rogowski coil.

In comparison with current transformers, the Rogowski coil has a few indisputable advantages. As it does not have a core, the core saturation effect is eliminated; thus being a perfect instrument to measure large currents. Such coil has also an excellent linearity and a wide pass band, much wider than a current transformer, and its weight is much smaller.

However, until recently the wider expansion of flexible clamps in the current measurement area was difficult. There are some factors which hinder practical implementation of a measurement system with a Rogowski coil. One of them is a very low voltage level which is induced on the clamps (it depends on geometrical dimensions of the coil). For example, the output voltage for the 50 Hz frequency of the F-series flexible probes (to be used with PQM-700) is about 45µV/A. Such low voltages require the use of precise and low-noise amplifiers which of course increase the costs.

Because the output voltage is proportional to the current derivative, it is necessary to use an integrating circuit; generally, the flexible probes comprise a Rogowski coil and an analog integrator circuit (characteristic battery-powered module). On the integrator output available is the voltage signal proportional to measured current and suitably scaled (for example 1mV/A).

Another problem connected with the Rogowski coil is its sensitivity to external magnetic fields. A perfect coil should be sensitive only to the fields closed within its area and should totally suppress external magnetic fields. But this is a very difficult task. The only way to obtain such properties is very precise manufacture of the coil, with perfectly homogenous windings and impedance as low as possible. It is the high precision which causes a relatively high price of such probe.

The PQM-700 analyzer can be used with the following flexible probes from Sonel S.A.:

- F-1, with coil circumference 120cm,
- F-2, with coil circumference 80cm,
- F-3, with coil circumference 45cm.

All these probes have identical electrical parameters. The peak current which can be measured after connecting to PQM-700 is 10kA (the limitation is due to the properties of the input channels, and not the probe itself).

10.3.4 Digital integrator

The PQM-700 uses the solution with digital integration of signal coming directly from the Rogowski coil. Such approach has allowed the elimination of the analog integrator problems connected with the necessity to ensure declared long-term accuracy in difficult measuring environments. The analog integrators must also include the systems protecting the inputs from saturation in case DC voltage is present on the input.

A perfect integrator has an infinite amplification for DC signals which falls with the rate of 20dB/decade of frequency. The phase shift is fixed over the whole frequency range and equals -90°.

Theoretically infinite amplification for a DC signal, if present on the integrator input, causes the input saturation near the power supply voltage and makes further operation impossible. In practically implemented systems, a solution is applied which limits the amplification for DC to a specified value, and in addition periodically zeroes the output. There are also techniques of active cancellation of DC voltage which involve its measurement and re-applying to the input, but with an opposite sign, which effectively cancels such voltage. There is a term “leaky integrator” which describes an integrator with finite DC gain. An analog leaky integrator is just an integrator featuring a capacitor shunted with a high-value resistor. Such a system is then identical with a low-pass filter of a very low pass frequency.

Digital integrator implementation ensures excellent long-term parameters – the entire procedure is performed by means of calculations, and aging of components, drifts, etc. have been eliminated. However, just like in the analog version, also here we can find the saturation problem and without a suitable counteraction the digital integration may become useless. It should be remembered that both, input amplifiers and analog-to-digital converters, have a given finite and undesirable offset which must be removed prior to integration. The PQM-700 analyzer firmware includes a digital filter which is to remove totally the DC voltage component. The filtered signal is subjected to digital integration. The resultant phase response has excellent properties, and the phase shift for most critical frequencies 50 and 60Hz is minimal.

Ensuring the least possible phase shift between the voltage and current components is very important for obtaining small power measurement errors. It can be proven that approximate power measurement error can be described with the following relationship[1]:

Power measurement error ≈ phase error (in radians) × tan(φ) × 100 %

where *tan(φ)* is the tangent of the angle between the fundamental voltage and current components. From the formula, it can be concluded that the measurement errors are increasing as the displacement power factor is decreasing; for example, at the phase error of only 0.1° and cosφ = 0.5, the error is 0.3%. Anyway, for the power measurements to be accurate, the phase coincidence of voltage and current circuits must be the highest possible.

10.4 Signal sampling

The signal is sampled simultaneously in all eight channels at the frequency synchronized with the frequency of power supply voltage in the reference channel. This frequency equals 10.24kHz for the 50Hz and 60Hz mains systems.

Each period includes then about 205 samples for 50Hz systems, and about 170 samples for 60Hz systems. A 16-bit analog-to-digital converter has been used which ensures 64-fold oversampling.

[1] “Current sensing for energy metering”, William Koon, Analog Devices, Inc.

3-decibel channels attenuation has been specified for frequency of about 20kHz, and the amplitude error for the 3kHz maximum usable frequency (i.e. the frequency of 50th harmonics in the 60Hz system) is about 0.2dB. The phase shift for this frequency is below 15°. Attenuation in the stop band is above 75dB.

Please note that for correct measurements of phase shift between the voltage harmonics in relation to current harmonics and power of these harmonics, the important factor is not absolute phase shift in relation to the basic frequency, but the phase coincidence of voltage and current circuits. The highest phase difference error for f = 3kHz is maximum 10°. Such error is decreasing with the decreasing frequency. Also an additional error caused by used clamps are transducers must be considered when estimating the measurement errors for harmonics power measurements.

10.5 PLL synchronization

The sampling frequency synchronization has been implemented by hardware. After passing through the input circuits, the voltage signal is sent to a band-pass filter which is to reduce the harmonics level and pass only the voltage fundamental component. Then, the signal is sent to the phase locked loop circuits as a reference signal. The PLL system generates the frequency which is a multiple of the reference frequency necessary for clocking of the analog-to-digital converter.

The necessity to use the phase locked loop system results directly from the requirements of the IEC 61000-4-7 standard which describes the methodology and admissible errors during the measurements of harmonic components. The standard requires that the measuring window, being the basis for a single measurement and evaluation of harmonics content, is equal to the duration of 10 periods in the 50Hz mains systems and 12 periods in the 60Hz systems. In both cases, it corresponds to about 200ms. Because the mains frequency can be subject to periodical changes and fluctuations, the window duration might not equal exactly 200ms and for the 51Hz frequency will be about 196ms.

The standard also recommends that before the Fourier transform (to separate the spectral components), the data are not subject to windowing operation. Absence of frequency synchronization and allowing the situation in which the FFT is performed on the samples from not the integer number of periods can lead to spectral leakage. This phenomenon causes that the spectral line of a harmonic blurs also to a few neighboring interharmonic spectral lines which may lead to loss of data about actual level and power of the tested spectral line. The use of Hann weighting window, which reduces the undesirable spectral leakage, has been permitted, but is limited to the situations when the PLL has lost synchronization.

The IEC 61000-4-7 defines also the required accuracy of the synchronization block: the time between the sampling pulse rising edge and (M+1)-th pulse (where M is the number of samples in the measuring window) should equal the duration of indicated number of periods in the measuring window (10 or 12) with maximum allowed error of ±0,03%. To explain it in simpler terms, let's use the following example. For nominal frequencies the measuring window duration is exactly 200ms. If the first sampling pulse occurs exactly at time t = 0, the first sampling pulse of the next measuring window should occur at t = 200±0.06ms. ±60µs is allowed deviation of the sampling edge. The standard also defines the recommended minimum frequency range at which the above-mentioned synchronization system accuracy should be maintained and specifies it as ±5% of rated frequency, that is 47.5…52.5Hz and 57…63Hz for 50Hz and 60Hz mains, respectively.

The input voltage range for which the PLL system will work correctly is quite another matter. The 61000-4-7 standard does not give here any concrete indications or requirements. However, the 61000-4-30 standard defines the input voltage range within which the metrological parameters shall not deteriorate, and for the class A such range is 10%...150%U_{din}. The PQM-700 meets the above-mentioned requirements in terms of the PLL system operation also for the lowest supported nominal voltage U_{nom}=64 V, i.e. down to about 6 V.

10.6 Flicker

In terms of power quality, flicker means a periodical changes of the luminous intensity as a result of fluctuations of voltage supplied to light bulbs.

The flicker measurement function appeared in the power quality analyzers when it turned out that this phenomenon causes a deteriorated well-being, annoyance, sometimes headache, etc. The luminous intensity fluctuations must have a specified frequency, they may not be to slow as then human iris can adapt to changed lighting, and they may not be too fast because the filament inertia offsets these fluctuations almost totally.

The tests have proved that maximum arduousness occurs at the frequency of about 9 changes per second. The most sensitive light sources are traditional incandescent bulbs with tungsten filament. Halogen bulbs, which filaments have much higher temperature, have also much higher inertia which reduces the perceived brightness changes. Fluorescent lamps have the best flicker "resistance", as due to their some specific properties they stabilize the current flowing through the lamp during the voltage changes, and thus reduce the fluctuations.

Flicker is measured in so-called perceptibility units, and there are two types of flicker: short-term P_{st} which is determined once every 10 minutes, and long-term P_{lt} which is calculated on the basis of 12 consecutive P_{st} values, i.e. every 2 hours. Long measurement time results directly from slow-changing character of this phenomenon – in order to collect a reliable data sample, the measurement must be long. P_{st} equal to 1 is considered a value on the border of annoyance – certainly sensitivity to flicker is different in different people; this threshold has been adopted after tests carried out on a representative group of people.

What causes flicker? Most frequently, the reason is the voltage drop as a result of connecting and disconnecting large loads and some level of flicker is present in the majority of mains systems. Disregarding the unfavorable effect on humans described above, flicker does not need to be – and usually is not – a symptom of malfunctioning of our installation. However, if a rather abrupt and unexplainable flicker level increase is observed in the mains (increase of P_{st} and P_{lt}), this should not be ignored under any circumstances. It may turn out that the flicker is caused by unsure connections in the installation – increased voltage drops on connections in the distribution panel (for example) will result in higher voltage fluctuations on the receivers, such as light bulbs. The voltage drops on connections also cause their heating, and finally sparking and possibly a fire. Periodical mains tests and described symptoms can turn our attention and help find the source of hazard.

10.7 Power measurement

Power is one of the most important parameters defining the properties of electrical circuits. The basic magnitude used for financial settlements between the supplier and the consumer is electric energy which is the power multiplied by time.

A few different power types can be found in electrical engineering:

- active power, designated as P and measured in watts,
- reactive power, designated as Q, unit is var,
- apparent power, S, unit is VA.

These three types of power are the most known, but there are also other types.

At school we are taught that these three power types make up a so-called power triangle which properties are expressed by the following equation:

$$P^2 + Q^2 = S^2$$

This equation is however correct only for systems with sinusoidal voltage and current waveforms.

Before a more detailed discussion about the power measurement, individual types of power should be defined.

10.7.1 Active power

Active power P is a magnitude with precise physical meaning and it expresses the ability of a system to perform a given work. It is the power most desired by the energy consumers and it is for this supplied power that the consumer pays the supplier in a given settlement period (the problem of fees for additional reactive power is discussed separately – see below). It is the active power (and consequently, the active energy) which is measured by electric energy meters in each household.

Basic formula to calculate the active power is as follows:

$$P = \frac{1}{T}\int_{t}^{t+T} u(t)i(t)dt$$

where: u(t) – instantaneous voltage value, i(t) - instantaneous current value, T – period for which the power is calculated.

In sinusoidal systems, the active power can be calculated as:

$$P = UIcos\varphi$$

where: *U* is RMS voltage, *I* is RMS current, and φ is the phase shift angle between the voltage and the current.

The PQM-700 analyzer calculates the active power directly from the integral formula, using sampled voltage and current waveforms:

$$P = \frac{1}{M}\sum_{i=1}^{M} U_i I_i$$

where *M* is a number of samples in the 10/12-period measuring window (2048 for the 50Hz and 60Hz system), U_i and I_i are successive voltage and current samples.

10.7.2 Reactive power

The most popular formula for reactive power is also correct only for one-phase circuits with sinusoidal voltage and current waveforms:

$$Q = UIsin\varphi$$

Interpretation of this power in such systems is as follows: it is an amplitude of AC component of instantaneous power on the source terminals. Existence of a non-zero value of this power indicates a bidirectional and oscillating energy flow between the source and the receiver.

Let us imagine a one-phase system with sinusoidal voltage source which load is a RC circuit. As under such conditions, the elements' behavior is linear, the source current waveform will be sinusoidal, but due to the properties of capacitor it will be shifted in relation to source voltage. In such a system, reactive power Q will be non-zero and can be interpreted as an amplitude of energy oscillation which alternately is collected in the capacitor and returned to the source. Capacitor active power equals zero.

However, it turns out the energy oscillation seems only an effect, and that it appears in particular cases of circuits with sinusoidal current and voltage waveforms, and is not the cause of reactive power. Research in this area has shown that reactive power occurs also in circuits without any energy oscillation. This statement may surprise many engineers. In latest publications on power theory, the only physical phenomenon mentioned which always accompanies appearance of reactive power is phase shift between current and voltage.

The reactive power formula given above is correct only for one-phase sinusoidal circuits. The question thus arises: how do we calculate the reactive power in non-sinusoidal systems? This question opens a proverbial Pandora's box among electrical engineers. It turns out that the reactive power definition in real systems (and not only those idealized) has been subject to controversy and now (2009) we do not have one, generally accepted definition of reactive power in systems with non-sinusoidal voltage and current waveforms, not to mention even unbalanced three-phase systems. The IEEE (Institute of *Electrical* and Electronics Engineers) 1459-2000 standard (from 2000) does not give a formula for total reactive power for non-sinusoidal three-phase systems – as three basic types of power the standard mentions are active power, apparent power and – attention – nonactive power designated as N. Reactive power has been limited only to the fundamental component and designated Q_1.

This standard is the last document of this type issued by recognized organization which was to put the power definition issues in order. It was even more necessary as the voices had been appearing in scientific circles for many years that the power definitions used so far may give erroneous results. Most of all, the controversies related to the definition of reactive and apparent power (and also distortion power – see below) in one- and three-phase systems with non-sinusoidal current and voltage waveforms.

In 1987, professor L.S. Czarnecki proved that the widely used definition of reactive power by Budeanu was wrong. This definition is still taught in some technical schools and it was proposed by professor Budeanu in 1927. The formula is as follows:

$$Q_B = \sum_{n=0}^{\infty} U_n I_n \sin \varphi_n$$

where U_n and I_n are voltage and current harmonics of order n, and φ_n are angles between these components.

As, after this magnitude has been introduced, the known power triangle equation was not met for circuits with non-sinusoidal waveforms, Budeanu introduced a new magnitude called the *distortion power*:

$$D_B = \sqrt{S^2 - \left(P^2 + {Q_B}^2\right)}$$

Distortion power was to represent in the system the power appearing due to distorted voltage and current waveforms.

For years, reactive power had been associated with energy oscillations between the source and the load. The formula indicates that according to Budeanu's definition, the reactive power is a sum of reactive power of individual harmonics. Due to the $\sin\varphi$ factor, such components can be positive or negative, depending on the angle between the harmonics of voltage and current. Hence, a situation is possible when total reactive power Q_B will be zero at non-zero harmonic components. Observation that at non-zero components, total reactive power can – according to this definition – be zero is a key to a deeper analysis which finally allowed proving that in some situations Q_B can give quite surprising results. The research has questioned the general belief that there is a relation between energy oscillations and Budeanu reactive power Q_B. One can give examples of circuits in which despite oscillating character of instantaneous power waveform, reactive power according to Budeanu is zero. Over the years, the scientists have not been able to connect any physical phenomenon to the reactive power according to this definition.

Such doubts about the correctness of this definition of course also cast shadow on the related *distortion power* D_B. The scientists have started to look for answers to the question whether the distortion power D_B really is the measure of distorted waveforms in non-sinusoidal circuits. The distortion is a situation in which the voltage waveform cannot be "put" on the current waveform with two operations: change of amplitude and shift in time. In other words, if the following condition is met:

$$u(t) = Ai(t - \tau)$$

the voltage is not distorted in relation to the current. In case of sinusoidal voltage and load which is any combination of RLC elements, this condition is always met (for sinusoidal waveforms, these elements maintain linearity). However, when the voltage is distorted, the RLC load does not ensure absence of current distortion in relation to voltage any more, and the load is no longer linear – it is necessary to meet some additional conditions (module and phase of load impedance changing with frequency).

And then, is really D_B a measure of such distortion? Unfortunately, also in this case the Budeanu's power theory fails. It has been proven that the *distortion power* can be equal to zero in a situation when voltage is distorted in relation to current waveform, and vice versa, the *distortion power* can be non-zero at total absence of distortion.

Practical aspect of this power theory which relates to improvement of power factor in systems with reactive power was to be the feature to take the most advantage of correct definitions of reactive power. The compensation attempts based on the Budeanu reactive power and related distortion power fell through. These magnitudes did not allow even a correct calculation of correction capacitance which gives the maximum power factor. Sometimes, such attempts ended even with additional deterioration of power factor.

How come, then, that the Budeanu's power theory has become so popular? There may be several reasons. Firstly, engineers got accustomed to old definitions and the curricula in schools have not been changed for years. This factor is often underestimated, though as a form of justification it can be said that this theory had not been refuted for 60 years. Secondly, in the 1920s there were no measuring instruments which could give insight in individual voltage and current harmonic components and it was difficult to verify new theories. Thirdly, distorted voltage and current waveforms (i.e. with high harmonics contents) are a result of revolution in electrical power engineering which did not start before the second part of the last century. Thyristors, controlled rectifiers, converters, etc. began to be widely used. All these caused very large current distortion in the mains, and consequently increased harmonic distortion. Only then, were the deficiencies of the Budeanu's theory felt. Finally, fourthly, the scientific circles related to power utilities were aware of the fact that industrial plants had invested a fortune in the measuring infrastructure (energy meters). Each change is this respect could bring about huge financial consequences.

However, slow changes became visible in the views of electrical engineers. With time, as nonlinear loads were more and more frequent and the waveforms more and more distorted, the limitations of used formulas could no longer be tolerated.

A very significant event was the 2000 publication by IEEE of the standard 1459 called "Definitions for the Measurement of Electric Power Quantities Under Sinusoidal, Non-Sinusoidal, Balanced, or Unbalanced Conditions". For the first time, Budeanu's definition of reactive power has been listed as not recommended which should not be used in new reactive power and energy meters. Many magnitudes have been also divided into the part related to the current and voltage fundamental component (first harmonics) and the part related to remaining higher harmonics. In most cases, it is recognized that the usable part of energy is transmitted by the 50/60Hz components, with much smaller (and often harmful) participation of higher harmonics.

The standard also introduced a new magnitude – *nonactive power N* which represents all nonactive components of power:

$$N = \sqrt{S^2 - P^2}$$

Reactive power is one of the components of nonactive power N. In one-phase systems with sinusoidal voltage and current waveforms, N equals Q; hence the nonactive power does not have any other components. In three-phase systems, this is true only for symmetrical sinusoidal systems with a balanced purely resistive load.

Other nonactive power components are related to concrete physical phenomena. According to the professor Czarnecki's theory, which is one of the best in explaining the physical phenomena in

three-phase systems, the power equation in such systems is as follows:

$$S^2 = P^2 + {D_s}^2 + Q^2 + {D_u}^2$$

D_s is the scattered power which appears in the system as a result of changing load conductance with frequency. Hence, presence of reactive elements in the system may cause the scattered power.
In this equation, reactive power Q appears when there is a phase shift between the voltage and current harmonics.

D_u means the unbalanced power which is a measure of unbalance of a three-phase receiver. This component explains the situation in which an unbalanced three-phase load of a purely resistive character results in the power factor less than one. Such load does not have the reactive power Q, and still the results from the power triangle S, P, Q are totally different (the Budeanu's power theory with its distortion power could not explain this situation either – in a purely resistive load, the distortion power D_B equals zero).

An attempt to connect the IEEE 1459-2000 standard with the Czarnecki's power theory leads to the conclusion that nonactive power conceals at least three separate physical phenomena which influence the reduced effectiveness of energy transmission from the source to the receiver, i.e. reduction of the power factor.

$$PF = \frac{P}{S_e} = \frac{P}{\sqrt{P^2 + {D_s}^2 + Q^2 + {D_u}^2}}$$

In the IEEE 1459-2000 standard, reactive power known as Q has been limited to the fundamental component, for both one-phase and three-phase systems:

$$Q_1 = U_1 I_1 \sin \varphi_1$$

In three-phase systems, only the positive sequence component is taken into consideration:

$$Q_1^+ = 3U_1^+ I_1^+ \sin \varphi_1^+$$

Correct measurement of this power requires the same phase rotation sequence (i.e. phase L2 delayed by 120° in relation to L1, phase L3 delayed by 240° in relation to L1).

The term of positive sequence component will be discussed in more detail in the section devoted to unbalance.

The value of reactive power of the fundamental component is the main value which allows estimating the size of capacitor to improve the displacement power factor (DPF), that is the displacement of the voltage fundamental components in relation to the current fundamental component (i.e. compensator of the reactive power of the fundamental component).

10.7.3 Reactive power and three-wire systems

Correct reactive power measurement is impossible in unbalanced receivers connected according to the three-wire system (delta and wye systems without the N conductor). Such statement may come as a surprise for many people.

The receiver can be treated as a "black box" with only 3 terminals available. We cannot determine its internal structure. In order to calculate the reactive power, we need to know the phase shift angle between the voltage and the current at each leg of such receiver. Unfortunately, we do not know this angle. In the delta-type receiver we know the voltages on individual impedances, but we do not know the current; in such systems, the phase-to-phase voltages and line currents are measured. Each line current is a sum of two phase currents. In the wye without N-type receivers, we know the currents flowing through impedance, but we do not know the voltages (each phase-to-phase voltage is a sum of two phase-to-neutral voltages.

We need to take account of the fact that at given voltage values at terminals and currents flowing into such “black box”, there is an infinite number of variants of receiver internal structure which will give us identical measurement results of voltage and current values visible outside the black box.

Then, how is it possible that there are reactive power meters intended for measurements in three-wire systems and the mains analyzers which allow the reactive power measurement under such circumstances?

In both cases, the manufacturers use the trick which involves an artificial creation of a reference point (virtual neutral terminal N). Such point can be created very easily by connecting to the terminals of our black box a wye-connected system of three resistors of the same value.

In no case should a measuring instrument mislead the user, and such approximation can be allowed only after a clear reservation that the indicated value is not a result of actual measurement, but only an approximated value.

10.7.4 Reactive power and reactive energy meters

Reactive energy meters are devices unknown to the household users who for settlements with energy suppliers use the meters of active energy expressed in Wh or kWh. Household users are in a comfortable situation – they pay only for usable energy and do not have to think what the power factor is in their installations.

In contrast to the first group, the industrial consumers are obliged in their contracts and sometimes under pain of financial penalties to keep the power factor at an appropriate level.

The EN 50160 standard gives some guidelines for the power quality requirements, and defines the quality parameters which should be met by energy supplier. Among these parameters are, among others, mains frequency, RMS voltage, total harmonic distortion (THD) and allowed levels of individual voltage harmonics. Besides EN 50160 requirements there is often an additional condition: the supplier does not need to comply with those requirements if an energy consumer does not ensure the $tan\varphi$ factor below some threshold (agreed value which can be changed in the contract between the energy supplier and consumer, i.e. 0.4) and/or exceeds the agreed level of consumed active energy.

The $tan\varphi$ is defined as a ratio of measured reactive energy to the active energy in a settlement period. Going back for a while to the power triangle in sinusoidal systems, we can see that the tangent of the phase shift angle between the voltage and the current is equal to the ratio of reactive power Q to active power P. Consequently, the requirement to maintain the $tan\varphi$ below 0.4 means nothing else but only that maximum level of measured reactive energy may not exceed 0.4 of the measured active energy. Each consumption of reactive energy above this level is subject to additional fees.

Does the knowledge of $tan\varphi$ calculated in this manner give both interested parties an actual view of energy transmission effectiveness? Have we not mentioned before that the reactive power is only one of the nonactive power components which influence the power factor reduction?
Indeed, it seems that instead of $tan\varphi$ we should use the power factor PF which takes into account also other issues.

Unfortunately, if the present regulations leave no choice, than the correct reactive power measurement seems a key matter. Now, a question should be asked whether the reactive energy meters ensure correct readings in the light of the controversies described above. And what do such widely used meters really measure?

One can attempt to look for answers to these questions is the standard on such meters - IEC 62053-23. Unfortunately, to our disappointment, we will not find there any reference to measurements in non-sinusoidal conditions – the calculation formulas relate to sinusoidal conditions (we can read in the standard that due to “practical” reasons, non-sinusoidal waveforms have been excluded). The standard does not give any measurement criteria which would allow checking the meter properties at distorted voltage and current waveforms. As a surprise comes also the fact that the older standard IEC 61268 (already withdrawn) defined the test which involved checking the measurement accuracy at 10% of the third current harmonic.

The present situation leaves the choice of measuring method to the meters designers, which

unfortunately leads to significant differences in reactive energy indications in the presence of high harmonic distortion level.

Older, electromechanical meters have characteristics similar to that of a low-pass filter – higher harmonics are attenuated in such meters and the reactive power measurement in the presence of harmonics is very close to the value of reactive power of the fundamental component.

Electronic meters which are more and more popular can perform the measurement with various methods. For example, they can measure active and apparent power, and then calculate the reactive power from the power triangle (square root from the sum of both such powers squared). In reality, in the view of the IEEE 1459-2000 standard, they measure the nonactive power, not the reactive power. Another manufacturer may use the method with voltage waveform shift by 90°, which gives a result close to the reactive power of the fundamental component.

The higher the harmonics content, the higher difference in readings, and of course, as a consequence, other fees for measured energy.

As it has been signaled before, the reactive power measurement in unbalanced three-wire systems with traditional meters is subject to an additional error caused by creation of a virtual zero inside the meter which has little to do with actual zero of the receiver.

On top of that, the manufacturers usually do not give any information about the applied measuring method.

One can only wait impatiently for the next version of the standard, which – let's hope – will define the measuring and testing methods much more precisely, also for non-sinusoidal conditions.

10.7.5 Apparent power

Apparent power S is expressed as the product of RMS voltage and RMS current:

$$S = UI$$

As such, the apparent power does not have a physical interpretation; it is used during designing of transmission equipment. In terms of value, it is equal to maximum active power which can be supplied to a load at given RMS voltage and current. Thus, the apparent power defines the maximum capacity of the source to supply usable energy to the receiver.

The measure of effective use of supplied power by the receiver is the power factor, which is the ratio of apparent power to active power.

In sinusoidal systems:

$$PF = \frac{P}{S} = \frac{UIcos\varphi}{UI} = cos\varphi$$

In non-sinusoidal systems such simplification is however not allowed, and the power factor is calculated on the basis of actual ratio of active power and apparent power.

$$PF = \frac{P}{S}$$

In one-phase systems, the apparent power is calculated as shown in the formula above and there are no surprises. However, it turns out that in three-phase systems calculation of this power is equally difficult as calculation of reactive power. Of course, this is related to actual systems with non-sinusoidal waveforms which additionally can be unbalanced.

The tests have shown that the formulas used so far can give erroneous results if the system is unbalanced. As apparent power is a conventional magnitude and does not have a physical interpretation, determination which of proposed apparent power definitions is correct could be difficult. Yet, the attempts have been made based on the observation that the apparent power is closely related to the transmission losses and the power factor. Knowing the transmission losses and the

power factor, one can indirectly specify a correct definition of apparent power.

The definitions which have been used so far include arithmetic apparent power and vector apparent power. The test have shown however that neither the arithmetic definition nor the vector definition give correct value of the power factor. The only definition which did not fail in such a situation, was the definition proposed as early as in 1922 by German physicist F. Buchholz:

$$S_e = 3U_e I_e$$

It is based on RMS current and voltage, and the power is called an effective apparent power (hence, the index "e" in designations in three-phase systems). Those effective voltage and current values are such theoretical values which represent voltage and current in an energetically equivalent three-phase balanced system. Consequently, the key issue is to determine the U_e and I_e.

The IEEE 1459 standard gives the following formulas. In three-wire systems:

$$I_e = \sqrt{\frac{{I_a}^2 + {I_b}^2 + {I_c}^2}{3}}$$

$$U_e = \sqrt{\frac{{U_{ab}}^2 + {U_{bc}}^2 + {U_{ca}}^2}{9}}$$

In four-wire systems:

$$I_e = \sqrt{\frac{{I_a}^2 + {I_b}^2 + {I_c}^2 + {I_n}^2}{3}}$$

$$U_e = \sqrt{\frac{3\left({U_a}^2 + {U_b}^2 + {U_c}^2\right) + {U_{ab}}^2 + {U_{bc}}^2 + {U_{ca}}^2}{18}}$$

where I_a, I_b, I_c, are RMS currents for individual phases (line or phase), I_n is the RMS current in neutral conductor, U_a, U_b, U_c are RMS phase-to-neutral voltages, and U_{ab}, U_{bc}, U_{ca} are RMS phase-to-phase voltages.

S_e calculated in this manner includes both the power losses in the neutral conductor (in four-wire systems) and the effect of unbalance.

10.7.6 Distortion power D_B and effective nonfundamental apparent power S_{eN}

During the discussion on reactive power, it was proved that the distortion power according to Budeanu cannot be used at large voltage and current distortions and three-phase systems unbalance (a paradox of distortion power which is not a measure of actual distortion). Despite this fact, however, this power is often used by energy quality specialists and manufacturers of systems for reactive power compensation.

It must be clearly said that this parameter has given relatively good results only in conditions of slight distortion of voltage and current waveforms.

The IEEE 1459-2000 standard lists this definition of power, however just like in case of Budeanu reactive power, it has a non-removable defect and it is recommended to discard it entirely. Instead of D_B, another value has been proposed which is a much better characteristics of total distortion power in a system - nonfundamental apparent power S_{eN}. The S_{eN} power allows a quick estimation whether a load works in conditions of small or large harmonic distortion; it is also a basis for estimating the static values and active filters or compensators.

$$S_{eN} = \sqrt{S_e^2 - S_{e1}^2}$$

where:

$$S_{e1} = 3I_{e1}U_{e1}$$

Effective current and RMS voltage of the fundamental component (I_{ef} and U_{ef} respectively) are calculated similarly to I_e and U_e, but instead of RMS phase-to-neutral or phase-to-phase voltages, the effective voltages of fundamental components are substituted:

$$S_N = \sqrt{S^2 - (U_1 I_1)^2}$$

where U_1 and I_1 are effective values of fundamental components of phase-to-neutral voltage and current.

10.7.7 Power factor

True Power Factor or Power Factor (TPF or PF) is the value which takes into account also the presence of higher harmonics. For sinusoidal systems, it is equal to Displacement Power Factor (DPF), popular cosφ.

Hence, DPF is a measure of phase shift between the fundamental voltage and current components:

$$DPF = \frac{P_1}{S_1} = \frac{U_1 I_1 cos\varphi_{U1I1}}{U_1 I_1} = cos\varphi_{U1I1}$$

$$PF = \frac{P}{S}$$

In case of a purely resistive load (in a one-phase system), the apparent power is equal to active power (in terms of value), and reactive power equals zero, so such load fully uses the energy potential of the source and the power factor is 1. Appearance of reactive component inevitably leads to reduction of energy transmission effectiveness – the active power is then less than apparent power, and the reactive power is increasing.

In three-phase systems, the power factor reduction is also influenced by receiver unbalance (see discussion on reactive power). In such systems, correct power factor value is obtained using the effective apparent power S_e , that is the value defined, among others, in the IEEE 1459-2000 standard.

The PQM-702 analyzer calculates these factors in the manner described above.

10.8 Harmonics

Decomposition of periodic signal into harmonic components is a very popular mathematical operation based on Fourier's theorem which says that any periodic signal can be represented as a sum of sinusoidal components with frequencies equal to multiples of basic frequency of such signal. Time-domain signal can be subjected to Fast Fourier Transform (FTT) to receive amplitudes and phases of harmonic components in the frequency domain.

In a perfect situation, voltage is generated in a generator which at output gives a pure sinusoidal 50/60 Hz waveform (absence of any higher harmonics). If the receiver is a linear system, then also current in such situation is a pure sinusoidal waveform. In real systems, voltage and current waveforms can be distorted, hence in addition to the fundamental component there must be harmonics of higher orders.

Why is the presence of higher harmonics in the system not desirable?

One of the reasons is the skin effect which involves pushing out the electrons from the center of

conductor towards the surface as the current frequency is increasing. As a result, the higher the frequency, the smaller the effective conductor cross section which is available for the electrons, which means that the conductor resistance is increasing. Consequently, the higher the current harmonics, the higher effective cabling resistance for this harmonics, and this inevitably leads to more power losses and heating.

A classic example connected with this effect is related to neutral conductor in three-phase systems. In a system with little distortion, little unbalance and a balanced (or slightly unbalanced) receiver, the current in neutral conductor has the tendency of zeroing (it is much smaller that RMS phase currents). Such observation has tempted many designers to obtains savings by installing the cabling in such systems with neutral conductor of a smaller cross section than in phase conductors. And everything went well until the appearance of odd harmonic orders which are multiples of 3 (third, ninth, etc.). Suddenly, the neutral conductor began overheating and the measurement showed very high RMS current. Explanation of this phenomenon is however rather simple. In this example, the designer did not take into consideration two circumstances: in systems with distorted waveforms, the higher harmonics might not zero in the neutral conductor, and quite to the contrary, they may sum up, and secondly, the skin effect and high harmonic currents additionally contributed to the neutral conductor heating.

Let us try now to answer two basic questions:
What is the cause of harmonic components in voltage?
What is the cause of harmonic components in current?

Seemingly, these two questions are almost identical, but separation of current and voltage is extremely important to understand the essence of this issue.

The answer to the first question is as follows: harmonics in voltage are a result on a non-zero impedance of the distribution system, between the generator (assuming that it generates a pure sinusoid) and the receiver.

Harmonics in current, on the other hand, are a result of non-linear impedance of the receiver. Of course, it must be noted that a linear receiver to which distorted voltage is supplied will also have identically distorted current waveform.

For years, in the literature the following statement has been used “receiver generates harmonics”. It should be remembered that in such case, the receiver is not a physical source of energy (as suggested by the word “generates”). The only source of energy is the distribution system. If the receiver is a passive device, the energy sent from the receiver to the distribution system comes from the same distribution system. What we have here is a disadvantageous and useless bidirectional energy flow. As discussed earlier in the section on power factor, such phenomenon leads to unnecessary energy losses, and the current “generated” in the receiver causes an additional load on the distribution system.

Let us consider the following example. A typical non-linear receiver, such as widely used switched-mode power supplies (i.e. for computers) receives power from a perfect generator of sinusoidal voltage. For the time being, let us assume that the impedance of connections between the generator and the receiver is zero. The voltage measured on the receiver terminals will have sinusoidal waveform (absence of higher harmonics) – this is imply the generator voltage. The receiver current waveform will however include harmonic components – a non-linear receiver often takes current only in specified moments of the total sinusoid period (for example, maximum current can take place at the voltage sinusoid peaks).

However, the receiver does not generate these current harmonics, it simply takes current in a variable or discontinuous way. The whole energy is supplied only by the generator.

In the next step, we can modify the circuit by introducing some impedance between the generator and the receiver. Such impedance represents the resistance of cabling, transformer winding, etc.

Measurements of voltage and current harmonics will give slightly different results. What will change? Small voltage harmonics will appear, and in addition current frequency spectrum will slightly change.

When analyzing the voltage waveform on the receiver, one could notice that original sinuso-

idal waveform was slightly distorted. If the receiver took current mainly at voltage peaks, it would have visibly flattened tops. Large current taken at such moments results in larger voltage drops on the system impedance. A part of the ideal sinusoidal voltage is now dropped on this impedance. A change in the current spectrum is a result of slightly different waveform of voltage supplied to the receiver.

The example described above and “flattened tops” of the sinusoid are very frequent in typical systems to which switched-mode power supplies are connected.

10.8.1 Harmonics active power

Decomposition of receiver voltage and current to harmonic components allows a deeper analysis of detailed energy flow between the supplier and the consumer.

Let us assume that the power quality analyzer is connected between the voltage source and the receiver. Both, supply voltage and current are subjected to FFT, as a result of which we receive the harmonics amplitudes with phase shifts.

It turns out that the knowledge of voltage and current harmonics and of phase shift between these harmonics allows calculating the active power of each harmonics separately.

$$P_h = U_h I_h \cos \varphi_h$$

where:

P_h – active power of the hth order harmonics,

U_h – RMS voltage of the hth order harmonics,

I_h – RMS current of the hth order harmonics,

φ_h – phase shift angle between the voltage and current harmonics of the *h*th order.

If the power P_h has a plus sign, the dominating source of energy of this harmonics is on the energy supplier’s side. If it is a negative value, the dominating source is the receiver. It must be noted that on the basis of harmonics active powers measured in this way one cannot determine that only one party is the sole source of the harmonics, as the measured value is a resultant of the supplier and the consumer.

> ***Example***
> *If the supplier generates harmonics active power of P_{hD} = 1kW, and the consumer “generates” the power of this harmonics equal to P_{hO} = 100W, the resultant power measured at the terminals between the supplier and the consumer will be $P_h = P_{hD} – P_{hO}$ = 0.9kW.*

In the situation as in the example above, we have two separate energy flow sources. Unfortunately, the actual distribution cannot be indicated directly on the basis of such measurement.

In real systems, determination of the dominant source is often sufficient. By grouping the harmonic components with plus signs, we receive a set of power values which are responsible for the energy flow from the source to the receiver, that is the useful energy.

On the other hand, the set of harmonics active power values with negative sings makes up this part of energy which does not play any useful role and is “returned” back to the distribution system.

By adding all active harmonics power values we receive the receiver active power. Hence, we can notice that there are at least two alternative active power measurement methods.

The first method involves calculation of average active power instantaneous value, which is calculated on the basis of successive voltage and current samples:

$$P = \frac{1}{M} \sum_{i=1}^{M} U_i I_i$$

where U_i is a successive voltage sample, I_i is a successive current sample, and M is the number of samples in the measuring window.

The other method involves adding individual harmonics active power values which are obtained by the FFT decomposition.

$$P = \sum_h U_h I_h \cos \varphi_h$$

10.8.2 Harmonics reactive power

The harmonics reactive power values can be calculated in a similar manner as the active power values:

$$Q_h = U_h I_h \sin \varphi_h$$

Knowledge of harmonics reactive power values is a valuable information used during development of reactive parallel compensators of reactive power. Such compensators consist of LC branches tuned to concrete harmonics frequencies.

The sign of individual power components indicates the character of load for this component. If the sign is plus, the character is inductive, and if it is minus, the character is capacitive.

Source nonactive power can be reduced to zero when the following condition is met for each harmonics[2]:

$$B_h + B_{kh} = 0$$

where:

B_h – receiver susceptance for the h-th harmonics,

B_{kh} – parallel compensator susceptance for the h-th harmonics.

As the compensator complexity grows proportionally to the number of harmonics subjected to compensation, usually only the fundamental component is compensated and maximum a few higher harmonics with the largest values. However, even if only the fundamental component is compensated, the power factor can be improved considerably.

10.8.3 Harmonics characteristics in three-phase system

In three-phase systems, the harmonics of given orders have a particular feature which is shown in the table below:

Order	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Frequency [Hz]	50	100	150	200	250	300	350	400	450
Sequence (+ positive, – negative, 0 zero)	+	–	0	+	–	0	+	–	0

The row “Sequence” refers to the symmetrical components method which allows the resolution of any 3 vectors to three sets of vectors: positive sequence, negative sequence and zero sequence (more in the part related to unbalance).

Let us use an example. Assuming that a three-phase motor is supplied from a balanced, 4-wire mains (RMS phase-to-neutral voltage values are equal, and angles between the individual fundamental components are 120° each).

Sign “+” in the row specifying the sequence for the 1st harmonics means the normal direction of the motor shaft rotation. The voltage harmonics, for which the sign is also “+” cause the torque

[2] L.S. Czarnecki: „Power values in electrical circuits with non-sinusoidal voltage and current waveforms”, Warsaw 2005, page 109

corresponding with the direction of the fundamental component. The harmonics of the 2nd, 5th, 8th and 11th order are the opposite sequence harmonics, meaning that they generate the torque which counteracts normal motor direction of rotation, which can cause heating, unnecessary energy losses, and reduced efficiency. The last group are the zero sequence components, such as the 3rd, 6th and 9th, which do not generate torque but flowing through the motor winding cause additional heating.

Based on the data from the table, it is easy to note that the series +, –, 0 is repeated for all successive harmonic orders. The formula which links the sequence with order is very simple, and for k being any integer:

Sequence	Harmonic order
"+" positive	3k +1
"–" negative	3k – 1
"0" zero	3k

The even order harmonics do not appear when a given waveform is symmetrical in relation to its average value, and this is the case in majority of power supply systems. In a typical situation, the measured even order harmonics have minimum values. If we consider this property, it turns out that the group of harmonics with the most undesirable properties is the 3rd, 9th, 15th (zero sequence), and the 5th, 11th, and 17th (negative sequence).

The current harmonics which are multiples of 3 cause additional problems in some systems. In 4-wire systems, they have a very undesirable property of summing up in the neutral conductor. It turns out that, contrary to other order harmonics, in which the sum of instantaneous current values is zeroed, the waveforms of these harmonics are in phase with each other which causes adding of the phase currents in the neutral conductor. This can lead to overheating of such conductor (particularly in the distribution systems in which this conductor has a smaller cross section than the phase conductors, and this was widely practiced until recently). Therefore, in systems with non-linear loads and large current distortions, it is now recommended that the cross section of neutral conductor is larger than that of the phased conductors. In the delta systems, the harmonics of these orders are not present in the line currents (provided these are balanced systems), but they circulate in the load branches, also causing unnecessary power losses.

Character of individual harmonics as shown in the table is fully accurate only in three-phase balanced systems. Only in such systems, the fundamental component has the exclusively positive sequence character. In actual systems, with some degree of supply voltage unbalance and the load unbalance, there are non-zero positive and negative sequence components. The measure of such unbalance is so-called unbalance factors. And this is due to this unbalance of the fundamental component and additionally the differences in amplitudes and phases of the higher harmonics, that also these harmonics will have the positive, negative and zero sequence components. The larger the unbalance, the higher the content of remaining components.

10.8.4 Estimating the uncertainty of power and energy measurements

The total uncertainty of active and reactive power and energy measurements (for the fundamental component) and the harmonics power is based on the following relationship (additional uncertainty is omitted in case of energy measurements as much smaller than other uncertainty types):

$$\delta_{P,Q} \cong \sqrt{\delta_{Uh}^2 + \delta_{Ih}^2 + \delta_{ph}^2}$$

where: $\delta_{P,Q}$ – uncertainty of active or reactive power measurement,
δ_{Uh} – total uncertainty of voltage harmonic amplitude measurement (analyzer, transducers),
δ_{Ih} – total uncertainty of current amplitude measurement (analyzer, transducers, clamps),
δ_{ph} – additional uncertainty caused by the error of phase measurement between the voltage and current harmonics.

The δ_{ph} uncertainty can be determined if we know the phase shift angle for a given frequency ranges. Table 7 presents the phase difference error between the voltage and current harmonics for the PQM-700 analyzer (without clamps and transducers).

Table 7. Phase error in the PQM-700 analyzer depending on the frequency

	Phase difference error				
Frequency range	0..200Hz	200..500Hz	500Hz..1kHz	1..2kHz	2..3kHz
Error	≤1°	≤2,5°	≤5°	≤10°	≤15°

The phase error caused by used transducers and clamps can be usually found in their technical documentation. Such being the case, we need to estimate the resultant phase error between the voltage and the current for a given frequency caused by all elements of the measuring circuit: current and voltage transducers, clamps, and the analyzer.
The uncertainty of the harmonics active power measurements can be calculated according to the following formula:

$$\delta_{\mathrm{ph}} = 100\left(1 - \frac{\cos(\varphi+\Delta\varphi)}{\cos\varphi}\right)\ [\%],\ \cos\varphi \neq 0$$

On the other hand, the uncertainty of the harmonics reactive power measurements can be calculated according to the following formula:

$$\delta_{\mathrm{ph}} = 100\left(1 - \frac{\sin(\varphi-\Delta\varphi)}{\sin\varphi}\right)\ [\%],\ \sin\varphi \neq 0$$

In both formulas, φ means the actual phase shift angle between the current and voltage components, and $\Delta\varphi$ means the total phase error for a given frequency. The conclusion which can be drawn from these relationships is that power measurement uncertainty for the same phase error very clearly depends on the displacement power factor between current and voltage. It is shown in Fig. 75.

Example

Calculation of measurement uncertainty of active power fundamental component.

Conditions: φ = 60°, $U_{RMS} \cong U_{nom}$, I_{RMS} = 5% I_{nom}.

Fundamental uncertainty equals $\pm\sqrt{1.0^2 + \delta_{ph}^2}$ %.

For the 40..70Hz frequency range, the PQM-702 phase error is 0.5°. After substituting to the equation:

$$\delta_{ph} = 100\left(1 - \frac{cos(\varphi + \Delta\varphi)}{cos\varphi}\right) = 100\left(1 - \frac{cos(60.5°)}{cos(60°)}\right) = 1.52\%$$

then, the measurement uncertainty is:

$$\delta = \pm\sqrt{1.0^2 + 1.52^2} = \pm 1.82\%$$

Under the same conditions, but with the phase shift φ = 10°, we will obtain:

$$\delta_{ph} = 100\left(1 - \frac{cos(10.5°)}{cos(10°)}\right) = 0.16\%$$

and the measurement uncertainty is:

$$\delta = \pm\sqrt{1.0^2 + 0.16^2} = \pm 1.01\%$$

The above calculations do not take into account additional errors caused by used clamps and transducers.

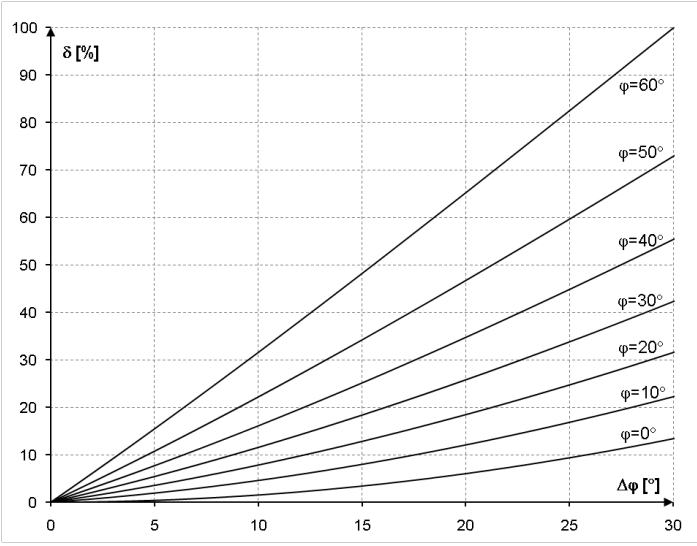


Fig. 75. Additional uncertainty from phase error depending on phase shift angle.

10.8.5 Harmonic components measuring method

The harmonics are measured according to the recommendations given in the IEC 61000-4-7 standard.

The standard specifies the measuring method for individual harmonic components.

The whole process comprises a few stages:

- synchronous sampling (10/12 periods),
- Fast Fourier Transform (FFT),
- grouping.

Fast Fourier Transform is performed on the 10/12-period measuring window (about 200ms). As a result of FFT, we receive a set of spectral lines from the 0Hz frequency (DC) to the 50^{th} harmonics (about 2.5kHz for 50Hz or 3kHz for 60Hz). The distance between successive spectral lines depends directly on the determined length of measuring window and is about 5Hz.

As the PQM-700 analyzer collects 2048 samples per measuring window (for 50Hz and 60Hz), this fulfills the requirement of Fast Fourier Transform that the number of samples subjected to transformation equals a power of 2.

A very important thing is to maintain a constant synchronization of sampling with the mains. FFT can be performed only on the data which include a multiple of the mains period. This condition must be met in order to minimize a so-called spectral leakage which leads to falsified information about actual spectral lines levels. The PQM-702 meets these requirements because the sampling frequency is stabilized by the phase locked loop (PLL).

Because the sampling frequency can fluctuate over time, the standard provides for grouping together with the harmonics main spectral lines also of the spectral lines in their direct vicinity. The reason is that the components energy can pass partially to neighboring interharmonic components.

There are two grouping methods:

- harmonic group (includes the main spectral line and five or six neighboring interharmonic components on each side),
- harmonic subgroup (includes the main spectral line and one neighboring line on each side).

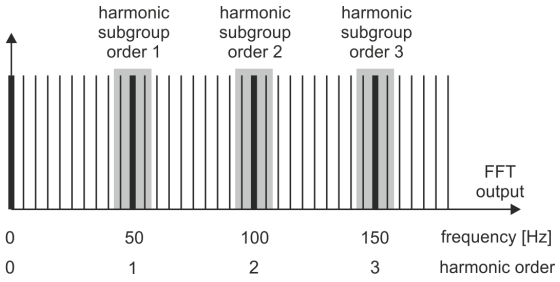


Fig. 76. Determination of harmonic subgroups (50Hz system).

The IEC 61000-4-30 standard recommends that the harmonic subgroup method is used in power quality analyzers.

Example

In order to calculate the 3rd harmonic component in the 50Hz system, use the 150Hz main spectral line and neighboring 145Hz and 155Hz lines. The resultant amplitude is calculated with the RMS method.

10.8.6 THD

Total Harmonic Distortion (THD) is the most widely used measure of waveform distortion. Two versions of this factor are applied in practical use:

- THD_F (THD-F or simply THD) – total harmonic distortion referred to the fundamental component,
- THD_R (THD-R) – total harmonic distortion referred to the RMS value.

In both cases, THD is expressed in percent. The definitions are given below:

$$THD_F = \frac{\sqrt{\sum_{h=2}^{n} A_h^2}}{A_1} \times 100\%$$

$$THD_R = \frac{\sqrt{\sum_{h=2}^{n} A_h^2}}{A_{RMS}} \times 100\%$$

where: A_h – RMS of the *h*th order harmonics,
A_1 – RMS of the fundamental component,
A_{RMS} – RMS waveform.

Limitation of the number of harmonics used to calculate THD is conventional and is caused mainly by measuring limitations of the device. Because the PQM-700 is capable of measuring the harmonic components up to the 50th order, the harmonics up to the 50th order are used to calculate THD.

Please note that when the waveforms are very distorted, the two definitions presented above will give significantly different results. THD_R may not exceed 100%, but there is no such limit for THD_F and it may go up to 200% or higher. Such case can be seen when measuring very distorted current. The voltage harmonic distortion usually does not exceed a few percent (both THD_F and THD_R); for example, the limit according to EN 50160 is 8% (THD_F).

10.9 Unbalance

Unbalance is term related to three-phase systems and can refer to:

- supply voltage unbalance,
- load current unbalance,
- receiver unbalance.

In three-phase systems, the voltage (current) unbalance occurs when values of three component voltages (currents) are different and/or the angles between individual phases are not equal to 120°.

The receiver unbalance occurs when impedance values of individual receiver branches are not equal.

These phenomena are particularly dangerous for three-phase motors, in which even a slight voltage unbalance can cause current unbalance that is many times larger. In such situation, the motor torque is reduced, heat losses in windings increase, and mechanical wear is faster. The unbalance also has an unfavorable effect on power supply transformers.

The most frequent reason of unbalance is uneven load on individual phases. A good example is connecting to three-phase systems of large one-phase loads, such as railway traction motors.

The PQM-700 is capable of measuring the voltage and current unbalance with a symmetrical components method. This method is based on the assumption that each set of three unbalanced vectors can be resolved to three groups of vectors: positive sequence, negative sequence and zero sequence.

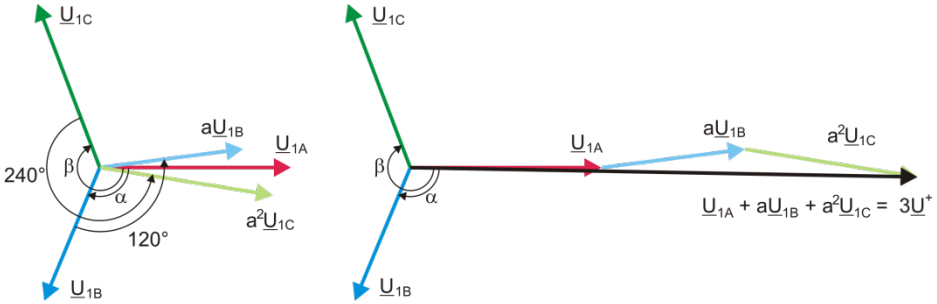


Fig. 77. Example of determination of positive sequence component.

As an example, let us use the calculation of voltage positive sequence component.

$$\underline{U}^{+} = \frac{1}{3}\left(\underline{U}_{1A} + a\underline{U}_{1B} + a^2\underline{U}_{1C}\right)$$

where: $\underline{U}^{+}$ is the vector of positive sequence component ,

$\underline{U}_{1A}$, $\underline{U}_{1B}$, $\underline{U}_{1C}$ are vectors of positive sequence components of phase-to-neutral voltages U_A, U_B, U_C

$$a = 1e^{j120^\circ} = -\frac{1}{2} + \frac{\sqrt{3}}{2}j$$

$$a^2 = 1e^{j240^\circ} = -\frac{1}{2} - \frac{\sqrt{3}}{2}j$$

Fig. 77 shows a graphical representation of determination of this component. As we can see from the definition, the vector of positive-sequence component equals one third of the sum of the summands $\underline{U}_{1A}$, $a\underline{U}_{1B}$, $a^2\underline{U}_{1C}$. Operators *a* and a^2 are unit vectors with angles 120° and 240°. The procedure is as follows: turn the voltage vector $\underline{U}_{1B}$ by 120° counterclockwise (multiply by a) and add to the vector $\underline{U}_{1A}$. Then, turn the vector $\underline{U}_{1C}$ by 240° and add to the previous sum of vectors. As a result, you get the vector $3\underline{U}^{+}$. The vector $\underline{U}^{+}$ is the symmetrical positive sequence component. Let us note that in case of a perfect symmetry (equal voltages and angles), the positive sequence component is equal in terms of value to the phase-to-neutral voltages.

The positive sequence component is a measure of similarity of the tested set of three-phase vectors to the symmetrical set of positive sequence vectors.

Analogously, the negative sequence component is a measure of similarity to the symmetrical set of negative sequence vectors.

The zero sequence component exists in the systems in which the sum of three voltages (or currents) is not equal to zero.

A measure of the system unbalance which is widely used in the power generation is the negative sequence and zero sequence unbalance (formulas are for the voltage).

$$u_0 = \frac{U_0}{U_1} \cdot 100\%$$
$$u_2 = \frac{U_2}{U_1} \cdot 100\%$$

where: u_0 – zero sequence unbalance,
u_2 – negative sequence unbalance,
U_0 – zero sequence symmetrical component,
U_1 – positive sequence symmetrical component,
U_2 – negative sequence symmetrical component.

The most convenient method to calculate the symmetrical components and unbalance is using the complex number calculus. The vectors parameters are amplitude of the voltage (current) fundamental component and its absolute phase shift angle. Both these values are received from FFT.

10.10 Event detection

The PQM-700 analyzer gives a lot of event detection options in the tested mains system. An event is the situation when the parameter value exceeds the user-defined threshold.
The fact of event occurrence is recorded on the memory card as an entry which includes:

- parameter type,
- channel in which the event occurred,
- times of event beginning and end,
- user-defined threshold value,
- parameter extreme value measure during the event,
- parameter average value measure during the event.

Depending on the parameter type, you can set one, two or three thresholds which will be checked by the analyzer. The table below lists all parameters for which the events can be detected, including specification of threshold types.

Table 8. Even threshold types for individual parameters

Parameter		Interruption	Dip	Swell	Minimum	Maximum
U	RMS voltage	•	•	•		
f	Frequency				•	•
CF U	Voltage crest factor				•	•
u_2	Voltage negative sequence unbalance					•
P_{st}	Short-term flicker P_{st}					•
P_{lt}	Long-term flicker P_{lt}					•
I	RMS current				•	•
CF I	Current crest factor					
i_2	Current negative sequence unbalance					•
P	Active power				•	•
Q_1, Q_B	Reactive power				•	•
S	Apparent power				•	•
D, S_N	Distortion power				•	•
PF	Power factor				•	•
cosφ	Displacement power factor				•	•
tanφ	tanφ				•	•
E_{P+}, E_{P-}	Active energy (consumed and supplied)					•
E_{Q+}, E_{Q-}	Reactive energy (consumed and supplied)					•
E_S	Apparent energy					•

THD_F U	Voltage THD_F					•
$U_{h2}..U_{h50}$	Voltage harmonic amplitudes (order n = 2…50)					•
THD_F I	Current THD_F					•
$I_{h2}..I_{h50}$	Current harmonic amplitudes (order n = 2…50)					•
TID_F U	Voltage TID_F					•
$U_{ih0}..U_{ih50}$	Voltage interharmonic amplitudes (order n = 0…50)					•
TID_F I	Current TID_F					•
$I_{ih0}..I_{ih50}$	Current interharmonic amplitudes (order n = 0…50)					•
K	K-Factor					•

Some parameters can take positive and negative values. Examples are active power, reactive power and power factor. As the event detection threshold can only be positive, in order to ensure correct detection for above-mentioned parameters, the analyzer compares with the threshold their absolute values.

Example

Event threshold for active power has been set at 10kW. If the load has a generator character, the active power with correct connection of clamps will be a negative value. If the measured absolute value exceeds the threshold, i.e. 10kW (for example -11kW) an event will be recorded – exceeding of the maximum active power.

Two parameter types: RMS voltage and RMS current can generate events for which the user can also have the waveforms record.

The analyzer records the waveforms of active channels (voltage and current) at the event start and end. In both cases, six periods are recorded: two before the start (end) of the event and four after start (end) of the event. The waveforms are recorded in an 8-bit format with 10.24kHz sampling frequency.

The event information is recorded at its end. In some cases it may happen that event is active when the recording is stopped (i.e. the voltage dip continues). Information about such event is also recorded, but with the following changes:

- no event end time,
- extreme value is only for the period until the stop of recording,
- average value is not given,
- only the beginning waveform is available for RMS voltage or current related events.

In order to eliminate repeated event detection when the parameter value oscillates around the threshold value, the analyzer has a functionality of user-defined event detection hysteresis. It is defined in percent in the following manner:

- for RMS voltage events, it is the percent of the nominal voltage range (for example 2% of 230V, that is 4.6V),
- for RMS current events, it is the percent of the nominal current range (for example for C-4 clamps and absence of transducers, the 2% hysteresis equals 0.02×1000A = 20A,

for remaining parameters, the hysteresis is specified as a percent of maximum threshold (for example, if the maximum threshold for current crest factor has been set to 4.0, the hysteresis will be 0.02×4.0 = 0.08.

10.11 Detection of voltage dip, swell and interruption

Voltage dips, swells and interruptions are the mains system disturbances during which the RMS voltage significantly differs from the nominal value. Each of the three states can be detected by the analyzer when the event detection is activated and when the user defines the threshold values.

Voltage dip is a state during which the RMS voltage is lower than the user-defined voltage dip threshold. The basis for the dip measurement is $U_{RMS(1/2)}$, that is the one period RMS value refreshed every half period.

Voltage dip definition (according to the IEC 61000-4-30 standard):

The voltage dip starts at the moment when the $U_{RMS(1/2)}$ voltage decreases below the dip threshold value, and ends at the moment when the $U_{RMS(1/2)}$ voltage is equal to or greater than the dip threshold value plus the voltage hysteresis.

The dip threshold is specified at 90% of U_{nom}. During the voltage dip, the analyzer remembers the minimum recorded voltage (this is called the residual voltage U_{res} and is one of the parameters characterizing the dip) and the average voltage value.

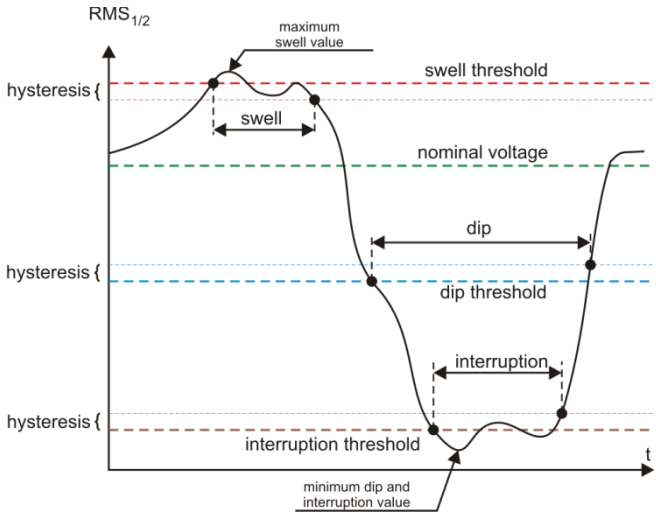


Fig. 78. Voltage swells, dips and interruptions.

Interruption is a state during which the $U_{RMS(1/2)}$ voltage is lower than the specified interruption level. The interruption threshold is usually set much below the voltage dip level, at about 1..10% of U_{nom}.

The interruption starts at the moment when the $U_{RMS(1/2)}$ voltage decreases below the interruption threshold value, and ends at the moment when the $U_{RMS(1/2)}$ voltage is equal to or greater than the interruption threshold value plus the voltage hysteresis.

During the interruption, the analyzer remembers the minimum recorded voltage and the average voltage value.

Swell is a state of increased voltage. The swell threshold is usually set at the level close to 110% of U_{nom}.

The swell starts at the moment when the $U_{RMS(1/2)}$ voltage increases above the swell threshold value, and ends at the moment when the $U_{RMS(1/2)}$ voltage is equal or less than the swell threshold value minus the voltage hysteresis. During the interruption, the analyzer remembers the maximum recorded voltage and the average voltage value.

The hysteresis for all three states is the same, and it is a user-defined percent of nominal voltage U_{nom} (**Events detection hysteresis** parameter).

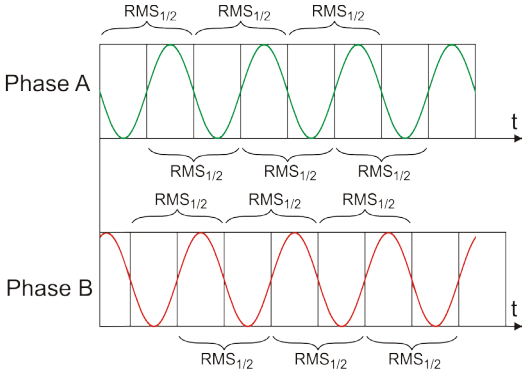


Fig. 79. Determination of the $U_{rms(1/2)}$ value.

The analyzer remembers the event start and end time (with a half a period accuracy).

The minimum voltage dip, interruption and swell duration is half a period.

The $U_{RMS(1/2)}$ values are determined during 1 period when the fundamental voltage component passes the zero and they are refreshed every half-period, independently for each voltage channel. This means that these values will be obtained at different times for different channels. Fig. 79 shows the method of the $RMS_{1/2}$ determination with two voltage phases. Information about the fundamental component's passing the zero is obtained by FFT.

10.12 CBEMA and ANSI curves

CBEMA curve was first proposed in the 70's of the last century by the organization that gave the curve its name - *Computer and Business Equipment Manufacturers Association* (now *Information Technology Industry*), which associated manufacturers of computer and office equipment. The curve was developed as a guide in the construction of power supply adapters and at the beginning it was a graph showing the tolerance of equipment to the size and duration of the disturbances in the power grid. Later, the curve was used to design equipment sensitive to voltage fluctuations as the reference range in which the equipment must operate properly. Finally the curve began to be widely used in the analyses of power-supply quality in terms of disturbances such as swell, dip, interruptions.

The vertical axis of the graph presents voltage in percent of the nominal value, whereas the horizontal axis presents time (in logarithmic scale). The middle part of the graph (between curves) represents the area of the correct operation of the device. The area above represents high voltage conditions that may damage the device or trigger over-voltage protection, while the area under the curves represents a situation of low voltage in mains, which may disconnect the power supply or temporary power shortage resulting in incorrect operation of the equipment.

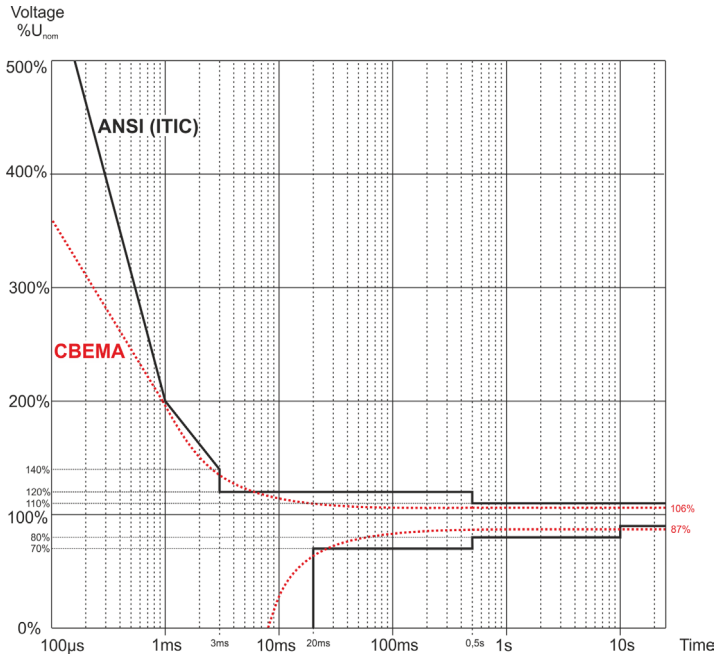


Fig. 80. Voltage tolerance curves ANSI (ITIC) and CBEMA.

As shown in the graph on Fig. 80, there is a relationship between the voltage value and the duration of the disturbance. For example, voltage swell of 200% U_{nom} and with duration of 1 ms, in typical cases, does not result in failure or malfunctioning (point between curves), but an interference of such amplitude, which lasts for half-period of the mains may be have very adverse effects (the point above two curves). Generally it is accepted that in a typical situation, events occurring in the power grid when it comes to the value of the mains voltage, should fit in the middle area of the graph (between curves) and then they should not lead to malfunction or damage to the connected equipment. Equipment manufacturers (especially power adaptors) often use this pattern while designing their products, in order to ensure their reliable operation and maintaining proper output voltage. Note, however, that the curve represents typical cases and cannot be a guarantee of correct operation for each device, as tolerance for interferences is very different.

ITIC curve is the successor of the CBEMA curve developed by ITI in 1994, and later modified to its present form in 2000. This curve has the form of two broken lines and is also known as ANSI curve, as it was adapted by ANSI (*American National Standards Institute*). Both curves are presented In Fig. 80.

"Sonel Analysis" software provides the ability to modify the characteristic points of the curves allowing user to adjust them to individual requirements (see sec. 9.3.5).

10.13 Averaging the measurement results

Mains monitoring over a longer period means that a significant amount of data needs to be collected. To ensure that such data analysis is possible at all, it is necessary to introduce the mechanisms for reducing data size to the values acceptable by both, people and machines.

Let us take the example of EN 50160 compliant power quality measurements The basic mains test period is one week. If all 200-millisecond RMS values were to be remembered, we would get 3.024 million measurements. Processing this amount of data may be time-consuming and difficult.

Therefore, the averaging concept has been introduced which involves recording one value per a specified time interval for the analysis purposes. For the EN-50160 standard, such time interval is 10 minutes. In such case, the analyzer calculates an average 10-minute value basing on about 3000 of 200-millisecond values (approximately, as in reality the conventional 200-millisecond value is 10/12-period value synchronized with the mains frequency). Each average voltage value is recorded every 10 minutes which gives "only" 1008 measurement results.

Fig. 81 presents the method according to which the PQM-700 analyzer determines the average values at averaging intervals equal to or greater than 10 seconds with the 10-minute averaging time. This method meets the requirements for a Class A of IEC 61000-4-30:2008 standard.

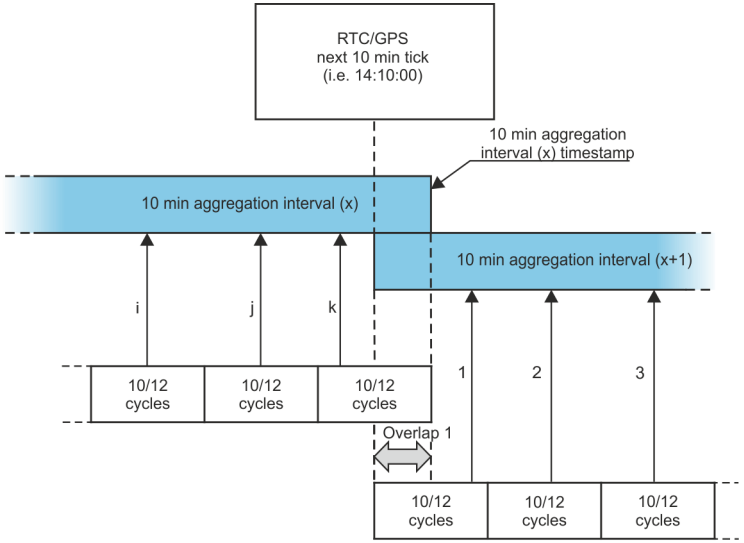


Fig. 81. Determining the averaging intervals longer than 10 seconds (with the 10-minute averaging).

Average values are synchronized with a real time clock as follows. When the clock counts another integer multiple of the averaging period, two processes occur:

- current 10/12-period interval (*k*-th measurement in Fig. 81) is assigned as the last in the aggregation interval (x),
- simultaneously the first 10/12-period interval is started for the next averaging period (x +1).

Such a resynchronization method generates *Overlap 1* (see Fig. 104). The data from this area are processed twice, as each of the 10/12-period interval is analyzed independently. The aim of this kind of resynchronization is to ensure that the two analyzers of Class A, connected to the same system, and synchronized with UTC, will give the same results. In PQM-700 analyzer, the resynchronization of intervals according to the method described above is performed for averaging times: 10s, 15s, 30s, 1min, 3min, 5min, 10min, 15min, 30min, 60min, 120min.

Averaging with times less than 10 seconds is somewhat different. Although, they are all expressed in time units (200ms, 1s, 3s, 5s), in reality they are measured in multiples of the mains period. For example, selecting 3-second averaging period means averaging in the time equal to 150/180 mains periods (fifteen 10/12-period measurements)

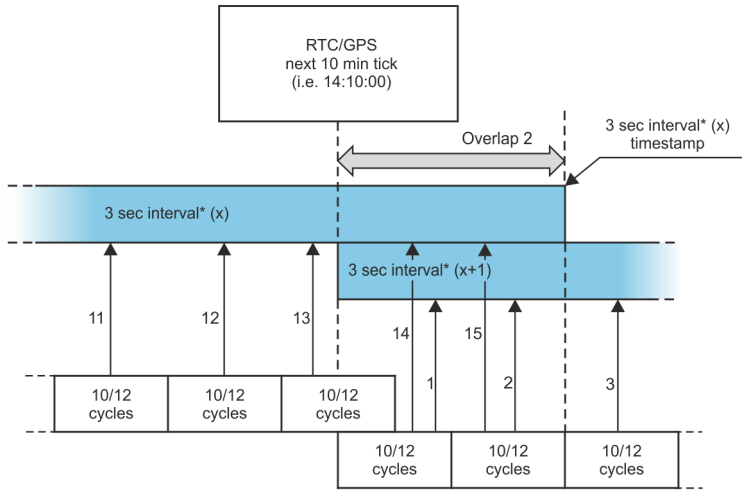


Fig. 82. Determining the averaging intervals shorter than 10 seconds (with the 3-second averaging).

The method of determining average values for such periods is shown in Fig. 82. Also in this case the resynchronization of 10/12-period intervals, but it is always done using clock time of 10 minutes. When the clock counts another integer multiple of the 10-min. period, another aggregation interval is resynchronized and the next interval is started; the aggregation interval (x) is terminated normally, until the specified number of 10/12-period windows are gathered (e.g. for 3-second averaging, always 15 intervals are gathered). The re-synchronization results in generating *Overlap 2* (see Fig. 82), where data from two aggregation intervals are simultaneously processed ((x)-interval ends, (x+1)-interval starts). The size of the overlay depends on fluctuations in the mains frequency.

The time stamp corresponds to the end of the aggregation interval.

Averaging of measurement results leads to the loss of extreme values (smoothing of results). In cases when the information about limit values of the measured parameter is important, the user may use the option of measuring the minimum, maximum and instantaneous values in the averaging period. If a given parameter is measured in the 10/12-period time, the minimum and maximum value is respectively the smallest and the largest 10/12-period value measured in a given

averaging interval. On the other hand, the instantaneous value is the last 10/12-period value in this averaging interval.

In case of RMS current and voltage, the method of searching for minimum and maximum values is more flexible and it is controlled by **Min/Max calculation period** parameter. The user may choose from the following options: half period, 200ms, 1s, 3s and 5s. If the half-period option is selected, the minimum and maximum values will be searched for with the highest sensitivity – up to $U_{RMS(1/2)}$. As this time is increasing, additional smoothing is being introduced; for example, with 5 seconds, first a 5-second average value is calculated which is then used to search for the minimum and maximum values. This gives a lower sensitivity to instantaneous changes of the measured value.

Note: similarly to the averaging times shorter than 10 seconds, the 200ms, 1s, 3s and 5s times are actually the multiples of the mains period - 10/12, 50/60, 150/180 and 250/300 mains periods, respectively.

Selecting the right averaging time is not easy. To a large extent it depends on the type of disturbance in the system and the user's expectations for the final data analysis. A frequent situation is that we know only that there is a problem in the mains, and the measurements with the analyzer will only help us identify the cause. In this situation it is better to use shorter averaging times (e.g. 10 seconds), and activate the recording of minimum and maximum values (for the voltages and currents it is advisable in such situation to set the shortest possible time for determining the maximum and minimum value, i.e. half the period). Short time averaging will give more precise diagrams of changes of parameters over time, and minimums and maximums will be detected and recorded. Recording with short averaging times is performed mostly during a, limited time, primarily due to rapid growth of data; the air of such recording is identifying the possible cause of a problem, and not a long-term analysis.

Recording with a short averaging time may be sufficient to evaluate the performance of the mains and disturbances in it. However, equally detailed information can probably also be obtained with longer times (in minutes) but with activated recording of minimum and maximum values and event detection. An important advantage in this situation that the volume of recorded data is much smaller which means faster data retrieval and analysis.

On the other hand, the power quality tests are usually made according to the EN 50160. In this case, the analysis is carried out over a longer period of time (e.g. 7 days), and therefore the chosen averaging time is also long - 10 minutes.

Please note that there is no single best setting for both, the averaging time and other parameters or event thresholds. Each mains system is different and so are the goals of the mains tests. Therefore, the optimal configuration of the analyzer may require several approaches and will also depend on the experience of the operator.

10.14 Frequency measurement

The signal for measurement of 10-second frequency values is taken from the L1 voltage channel. It is the same signal which is used for synchronization of the PLL. The L1 signal is sent to the 2nd order band pass filter which passband has been set to 40..70Hz. This filter is to reduce the level of harmonic components. Then, a square signal is formed from such filtered waveform. The signal periods number and their duration is counted during the 10-second measuring cycle. 10-second time intervals are determined by the real time clock (every full multiple of 10-second time). The frequency is calculated as a ratio of counted periods to their duration.

11 Calculation formulas

11.1 One-phase network

One-phase network			
Parameter			Method of calculation
Name	Designation	Unit	
Effective voltage (True RMS)	U_A	V	$U_A = \sqrt{\frac{1}{M}\sum_{i=1}^{M} U_i^2}$ where U_i is a subsequent sample of voltage $U_{A\text{-}N}$ M = 2560 for 50Hz networks M = 3072 for 60Hz networks
Voltage constant component	U_{ADC}	V	$U_{ADC} = \frac{1}{M}\sum_{i=1}^{M} U_i$ where U_i is a subsequent sample of voltage $U_{A\text{-}N}$ M = 2560 for 50Hz networks M = 3072 for 60Hz
Frequency	F	Hz	number of all voltage periods $U_{A\text{-}N}$ counted during 10-sec period (clock time) divided by the total duration of full periods
Effective current (True RMS)	I_A	A	$I_A = \sqrt{\frac{1}{M}\sum_{i=1}^{M} I_i^2}$ where I_i is subsequent sample of current I_A M = 2560 for 50Hz networks M = 3072 for 60Hz
Current constant component	I_{ADC}	A	$I_{ADC} = \frac{1}{M}\sum_{i=1}^{M} I_i$ where I_i is a subsequent sample of current I_A M = 2560 for 50Hz networks M = 3072 for 60Hz
Active power	P	W	$P = \frac{1}{M}\sum_{i=1}^{M} U_i I_i$ where U_i is a subsequent sample of voltage $U_{A\text{-}N}$ I_i is a subsequent sample of current I_A M = 2560 for 50Hz networks M = 3072 for 60Hz
Budeanu reactive power	Q_B	var	$Q_B = \sum_{h=1}^{50} U_h I_h \sin\varphi_h$ where U_h is h-th harmonic of voltage $U_{A\text{-}N}$ I_h jest h-th harmonic of current I_A φ_h is h-th angle between harmonic U_h and I_h
Reactive power of fundamental component	Q_1	var	$Q_1 = U_1 I_1 \sin\varphi_1$ where U_1 is fundamental component of voltage $U_{A\text{-}N}$ I_1 is fundamental component of current I_A φ_1 is angle between fundamental components U_1 and I_1
Apparent power	S	VA	$S = U_{ARMS} I_{ARMS}$
Apparent distortion power	S_N	VA	$S_N = \sqrt{S^2 - (U_1 I_1)^2}$

Budeanu distortion power	D_B	var	$D_B = \sqrt{S^2 - P^2 - Q_B^2}$
Power Factor	*PF*	-	$PF = \frac{P}{S}$ If PF < 0, then the load is of a generator type If PF > 0, then the load is of a receiver type
Displacement power factor	*cosφ* *DPF*	-	$\cos\varphi = DPF = \cos(\varphi_{U_1} - \varphi_{I_1})$ where φ_{U1} is an absolute angle of the fundamental component of voltage U_{A-N} φ_{I1} is an absolute angle of the fundamental component of current I_A
Tangent φ	*tgφ*	-	$tg\varphi = \frac{Q}{P}$ where: Q = Q_B when Budeanu method was chosen, Q = Q_1 when IEEE 1459 method was chosen,
Harmonic components of voltage and current	U_{hx} I_{hx}	V A	method of harmonic subgroups according to PN-EN 61000-4-7 x (harmonic) = 1..50
Total Harmonic Distortion for voltage, referred to the fundamental component	$THDU_F$	-	$THDU_F = \frac{\sqrt{\sum_{h=2}^{40} U_h^2}}{U_1} \times 100\%$ where U_h is *h*-th harmonic of voltage U_{A-N} U_1 is fundamental component of voltage U_{A-N}
Total Harmonic Distortion for voltage, referred to RMS	$THDU_R$	-	$THDU_R = \frac{\sqrt{\sum_{h=2}^{40} U_h^2}}{U_{ARMS}} \times 100\%$ where U_h is *h*-th harmonic of voltage U_{A-N}
Total Harmonic Distortion for current, referred to the fundamental component	$THDI_F$	-	$THDI_F = \frac{\sqrt{\sum_{h=2}^{40} I_h^2}}{I_1} \times 100\%$ where I_h is *h*-th harmonic of current I_A I_1 is fundamental component of current I_A
Total Harmonic Distortion for current, referred to RMS	$THDI_R$	-	$THDI_R = \frac{\sqrt{\sum_{h=2}^{40} I_h^2}}{I_{ARMS}} \times 100\%$ where I_h is *h*-th harmonic of current I_A
Voltage crest factor	*CFU*	-	$CFU = \frac{max\|U_i\|}{U_{ARMS}}$ $max\|U_i\|$Where the operator expresses the highest absolute value of voltage U_{A-N} samples *i* = 2560 for 50Hz networks *i* = 3072 for 60Hz networks
Current crest factor	*CFI*	-	$CFI = \frac{max\|I_i\|}{I_{ARMS}}$ $max\|I_i\|$Where the operator expresses the highest absolute value of current I_A samples *i* = 2560 for 50Hz networks *i* = 3072 for 60Hz networks
Short-term flicker	P_{st}	-	calculated according to PN-EN 61000-4-15
Long-term flicker	P_{lt}	-	$P_{LT} = \frac{1}{3}\sqrt{\sum_{i=1}^{12}(P_{STi})^3}$ where P_{STi} is subsequent i-th indicator of short-term flicker

Active energy (consumed and supplied)	E_{P+} E_{P-}	Wh	$$E_{P+} = \sum_{i=1}^{m} P_+(i)T(i)$$ $$P_+(i) = \begin{cases} P(i) \ \ dla\ P(i) > 0 \\ 0\ dla\ P(i) \le 0 \end{cases}$$ $$E_{P-} = \sum_{i=1}^{m} P_-(i)T(i)$$ $$P_-(i) = \begin{cases} \lvert P(i) \rvert \ \ dla\ P(i) < 0 \\ 0\ dla\ P(i) \ge 0 \end{cases}$$ where: *i* is subsequent number of the 10/12-period measurement window *P(i)* represents active power*P* calculated in *i*-th measuring window *T(i)* represents duration of *i*-th measuring window (in hours)
Budeanu reactive energy (consumed and supplied)	E_{QB+} E_{QB-}	varh	$$E_{QB+} = \sum_{i=1}^{m} Q_{B+}(i)T(i)$$ $$Q_{B+}(i) = \begin{cases} Q_B(i) \ \ dla\ Q_B(i) > 0 \\ 0\ dla\ Q_B(i) \le 0 \end{cases}$$ $$E_{QB-} = \sum_{i=1}^{m} Q_{B-}(i)T(i)$$ $$Q_{B-}(i) = \begin{cases} \lvert Q_B(i) \rvert\ dla\ Q_B(i) < 0 \\ 0\ dla\ Q_B(i) \ge 0 \end{cases}$$ where: *i*is subsequent number of the 10/12-period measurement window $Q_B(i)$ represents Budeanu active power Q_B calculated in *i*-th measuring window *T(i)* represents duration of *i*-th measuring window (in hours)
Reactive energy of fundamental component (consumed and supplied)	E_{Q1+} E_{Q1-}	varh	$$E_{Q1+} = \sum_{i=1}^{m} Q_{1+}(i)T(i)$$ $$Q_{1+}(i) = \begin{cases} Q_1(i) \ \ dla\ Q_1(i) > 0 \\ 0\ dla\ Q_1(i) \le 0 \end{cases}$$ $$E_{Q1-} = \sum_{i=1}^{m} Q_{1-}(i)T(i)$$ $$Q_{1-}(i) = \begin{cases} \lvert Q_1(i) \rvert\ dla\ Q_1(i) < 0 \\ 0\ dla\ Q_1(i) \ge 0 \end{cases}$$ where: *i*is subsequent number of the 10/12-period measurement window $Q_1(i)$ represents reactive power of fundamental component Q_1 calculated in *i*-th measuring window *T(i)* represents duration of *i*-th measuring window (in hours)

Apparent energy	E_S	VAh	$E_S = \sum_{i=1}^{m} S(i)T(i)$ where: *i*is subsequent number of the 10/12-period measurement window *S(i)* represents apparent power *S* calculated in *i*-th measuring window *T(i)* represents duration of *i*-th measuring window (in hours)

11.2 2-phase network

2-phase network (parameters not mentioned are calculated as for single-phase)			
Parameter			**Method of calculation**
Name	**Designation**	**Unit**	
Total active power	P_{tot}	W	$P_{tot} = P_A + P_B$
Total Budeanu reactive power	Q_{Btot}	var	$Q_{Btot} = Q_{BA} + Q_{BB}$
Total reactive power of fundamental component	Q_{1tot}	var	$Q_{1tot} = Q_{1A} + Q_{1B}$
Total apparent power	S_{tot}	VA	$S_{tot} = S_A + S_B$
Total apparent distortion power	S_{Ntot}	VA	$S_{Ntot} = S_{NA} + S_{NB}$
Total Budeanu distortion power	D_{Btot}	var	$D_{Btot} = D_{BA} + D_{BB}$
Total Power Factor	PF_{tot}	-	$PF_{tot} = \frac{P_{tot}}{S_{tot}}$
Total displacement power factor	$\cos\varphi_{tot}$ DPF_{tot}	-	$\cos\varphi_{tot} = DPF_{tot} = \frac{1}{2}(\cos\varphi_A + \cos\varphi_B)$
Total tangent φ	$tg\varphi_{tot}$	-	$tg\varphi_{tot} = \frac{Q_{tot}}{P_{tot}}$ where: $Q_{tot} = Q_{Btot}$, when Budeanu method was chosen, $Q_{tot} = Q_{1tot}$, when IEEE 1459 method was chosen,
Total active energy (consumed and supplied)	E_{P+tot} E_{P-tot}	Wh	$E_{P+tot} = E_{P+A} + E_{P+B}$ $E_{P-tot} = E_{P-A} + E_{P-B}$
Total Budeanu reactive energy (consumed and supplied)	E_{QB+tot} E_{QB-tot}	varh	$E_{QB+tot} = E_{QB+A} + E_{QB+B}$ $E_{QB-tot} = E_{QB-A} + E_{QB-B}$
Total reactive energy of fundamental component (consumed and supplied)	E_{Q1+tot} E_{Q1-tot}	varh	$E_{Q1+tot} = E_{Q1+A} + E_{Q1+B}$ $E_{Q1-tot} = E_{Q1-A} + E_{Q1-B}$
Total apparent energy	E_{Stot}	VAh	$E_{Stot} = E_{SA} + E_{SB}$

11.3 3-phase wye network with N conductor

3-phase wye network with N conductor (parameters not mentioned are calculated as for single-phase)			
Parameter			**Method of calculation**
Name	**Designation**	**Unit**	
Total active power	P_{tot}	W	$P_{tot} = P_A + P_B + P_C$
Total Budeanu reactive power	Q_{Btot}	var	$Q_{Btot} = Q_{BA} + Q_{BB} + Q_{BC}$
Total reactive power acc. to IEEE 1459	Q_1^+	var	$Q_1^+ = 3U_1^+ I_1^+ \sin\varphi_1^+$ where: U1+ is the voltage positive sequence component (of the fundamental component I1+ his the current positive sequence component (of the fundamental component) φ_1+ is the angle between components U_1^+ and I_1^+
Effective apparent power	S_e	VA	$S_e = 3U_e I_e$ where: $U_e = \sqrt{\frac{3\left(U_A{}^2 + U_B{}^2 + U_C{}^2\right) + U_{AB}{}^2 + U_{BC}{}^2 + U_{CA}{}^2}{18}}$ $I_e = \sqrt{\frac{I_A{}^2 + I_B{}^2 + I_C{}^2 + I_N{}^2}{3}}$
Effective apparent distortion power	S_{eN}	VA	$S_{eN} = \sqrt{S_e{}^2 + S_{e1}{}^2}$ where: $S_{e1} = 3U_{e1} I_{e1}$ $U_{e1} = \sqrt{\frac{3\left(U_{A1}{}^2 + U_{B1}{}^2 + U_{C1}{}^2\right) + U_{AB1}{}^2 + U_{BC1}{}^2 + U_{CA1}{}^2}{18}}$ $I_{e1} = \sqrt{\frac{I_{A1}{}^2 + I_{B1}{}^2 + I_{C1}{}^2 + I_{N1}{}^2}{3}}$
Total Budeanu distortion power	D_{Btot}	var	$D_{Btot} = D_{BA} + D_{BB} + D_{BC}$
Total Power Factor	PF_{tot}	-	$PF_{tot} = \frac{P_{tot}}{S_e}$
Total displacement power factor	$\cos\varphi_{tot}$ DPF_{tot}	-	$\cos\varphi_{tot} = DPF_{tot} = \frac{1}{3}(\cos\varphi_A + \cos\varphi_B + \cos\varphi_C)$
Total tangent φ	$tg\varphi_{tot}$	-	$tg\varphi_{tot} = \frac{Q_{tot}}{P_{tot}}$ where: $Q_{tot} = Q_{Btot}$, when Budeanu method was chosen, $Q_{tot} = Q_{1tot}$, when IEEE 1459 method was chosen,
Total active energy (consumed and supplied)	E_{P+tot} E_{P-tot}	Wh	$E_{P+tot} = E_{P+A} + E_{P+B} + E_{P+C}$ $E_{P-tot} = E_{P-A} + E_{P-B} + E_{P-C}$
Total Budeanu reactive energy (consumed and supplied)	E_{QB+tot} E_{QB-tot}	varh	$E_{QB+tot} = E_{QB+A} + E_{QB+B} + E_{QB+C}$ $E_{QB-tot} = E_{QB-A} + E_{QB-B} + E_{QB-C}$

Total reactive energy of fundamental component (consumed and supplied)	E_{Q1+tot} E_{Q1-tot}	varh	$E_{Q1+tot} = E_{Q1+A} + E_{Q1+B} + E_{Q1+C}$ $E_{Q1-tot} = E_{Q1-A} + E_{Q1-B} + E_{Q1-C}$
Total apparent energy	E_{Stot}	VAh	$E_{Stot} = \sum_{i=1}^{m} S_e(i)T(i)$ where: *i*is subsequent number of the 10/12-period measurement window $S_e(i)$ represents the effective apparent power S_e, calculated in *i*-th measuring window $T(i)$ represents duration of *i*-th measuring window (in hours)
RMS value of zero voltage sequence	U_0	V	$\underline{U_0} = \frac{1}{3}(\underline{U_{A1}} + \underline{U_{B1}} + \underline{U_{C1}})$ $U_0 = mag(\underline{U_0})$ where $\underline{U_{A1}}$, $\underline{U_{B1}}$, $\underline{U_{C1}}$ are vectors of fundamental components of phase voltages U_A, U_B, U_C Operator *mag()* indicates vector module
RMS value of positive voltage sequence	U_1	V	$\underline{U_1} = \frac{1}{3}(\underline{U_{A1}} + a\underline{U_{B1}} + a^2\underline{U_{C1}})$ $U_1 = mag(\underline{U_1})$ where $\underline{U_{A1}}$, $\underline{U_{B1}}$, $\underline{U_{C1}}$ are vectors of fundamental components of phase voltages U_A, U_B, U_C Operator *mag()* indicates vector module $a = 1e^{j120^\circ} = -\frac{1}{2} + \frac{\sqrt{3}}{2}j$ $a^2 = 1e^{j240^\circ} = -\frac{1}{2} - \frac{\sqrt{3}}{2}j$
RMS value of negative voltage sequence	U_2	V	$\underline{U_2} = \frac{1}{3}(\underline{U_{A1}} + a^2\underline{U_{B1}} + a\underline{U_{C1}})$ $U_2 = mag(\underline{U_2})$ where $\underline{U_{A1}}$, $\underline{U_{B1}}$, $\underline{U_{C1}}$ are vectors of fundamental components of phase voltages U_A, U_B, U_C Operator *mag()* indicates vector module $a = 1e^{j120^\circ} = -\frac{1}{2} + \frac{\sqrt{3}}{2}j$ $a^2 = 1e^{j240^\circ} = -\frac{1}{2} - \frac{\sqrt{3}}{2}j$
Voltage unbalance factor for zero component	u_0	%	$u_0 = \frac{U_0}{U_1} \cdot 100\%$
Voltage unbalance factor for negative sequence	u_2	%	$u_2 = \frac{U_2}{U_1} \cdot 100\%$
Current zero sequence	I_0	A	$\underline{I_0} = \frac{1}{3}(\underline{I_{A1}} + \underline{I_{B1}} + \underline{I_{C1}})$ $I_0 = mag(\underline{I_0})$ where $\underline{I_{A1}}$, $\underline{I_{B1}}$, $\underline{I_{C1}}$ are vectors of fundamental components for phase currents I_A, I_B, I_C Operator *mag()* indicates vector module

RMS value of positive current sequence	I_1	A	$\underline{I}_1 = \frac{1}{3}\left(\underline{I}_{A1} + a\underline{I}_{B1} + a^2\underline{I}_{C1}\right)$ $I_1 = mag(\underline{I}_1)$ where $\underline{I}_{A1}$, $\underline{I}_{B1}$, $\underline{I}_{C1}$ are vectors of fundamental current components I_A, I_B, I_C Operator *mag()* indicates vector module
RMS value of negative current sequence	I_2	A	$\underline{I}_2 = \frac{1}{3}\left(\underline{I}_{A1} + a^2\underline{I}_{B1} + a\underline{I}_{C1}\right)$ $I_2 = mag(\underline{I}_2)$ where $\underline{I}_{A1}$, $\underline{I}_{B1}$, $\underline{I}_{C1}$ are vectors of fundamental components for phase voltages I_A, I_B, I_C Operator *mag()* indicates vector module
Current unbalance factor for zero sequence	i_0	%	$i_0 = \frac{I_0}{I_1} \cdot 100\%$
Current unbalance factor for negative sequence	i_2	%	$i_2 = \frac{I_2}{I_1} \cdot 100\%$

11.4 3-phase wye and delta network without N conductor

3-phase wye and delta network without N conductor (parameters: effective voltage and current, constant components of voltage and current, THD and K factors, symmetrical components and unbalance factors, flicker are calculated as for 1-phase circuits; instead of the phase voltages, phase-to-phase voltages are used)			
Parameter			**Method of calculation**
Name	**Designation**	**Unit**	
Phase-to-phase voltage U_{CA}	U_{CA}	V	$U_{CA} = -(U_{AB} + U_{BC})$
Current I_2 (Aron measuring circuits)	I_2	A	$I_2 = -(I_1 + I_3)$
Total active power	P_{tot}	W	$P_{tot} = \frac{1}{M}\left(\sum_{i=1}^{M} U_{iAC} I_{iA} + \sum_{i=1}^{M} U_{iBC} I_{iB}\right)$ where: U_{iAC} is a subsequent sample of voltage $U_{A\text{-}C}$ U_{iBC} is a subsequent sample of voltage $U_{B\text{-}C}$ I_{iA} is a subsequent sample of current I_A I_{iB} is a subsequent sample of current I_B M = 2048 for 50Hz and 60Hz
Total apparent power	S_e	VA	$S_e = 3U_e I_e$ where: $U_e = \sqrt{\frac{{U_{AB}}^2 + {U_{BC}}^2 + {U_{CA}}^2}{9}}$ $I_e = \sqrt{\frac{{I_A}^2 + {I_B}^2 + {I_C}^2}{3}}$
Total reactive power (Budeanu and IEEE 1459)	Q_{Btot}	var	$Q = N = \sqrt{S_e^2 - P^2}$

Total Budeanu distortion power	D_{Btot}	var	$D_{Btot} = 0$
Effective apparent distortion power	S_{eN}	VA	$S_{eN} = \sqrt{{S_e}^2 + {S_{e1}}^2}$ where: $S_{e1} = 3U_{e1}I_{e1}$ $U_{e1} = \sqrt{\frac{{U_{AB1}}^2 + {U_{BC1}}^2 + {U_{CA1}}^2}{9}}$ $I_{e1} = \sqrt{\frac{{I_{A1}}^2 + {I_{B1}}^2 + {I_{C1}}^2}{3}}$
Total Power Factor	PF_{tot}	-	$PF_{tot} = \frac{P_{tot}}{S_e}$
Active energy (consumed and supplied)	E_{P+tot} E_{P-tot}	Wh	$E_{P+tot} = \sum_{i=1}^{m} P_{+tot}(i)T(i)$ $P_{+tot}(i) = \begin{cases} P_{tot}(i) \ \ dla\ P_{tot}(i) > 0 \\ 0\ dla\ P_{tot}(i) \le 0 \end{cases}$ $E_{P-tot} = \sum_{i=1}^{m} P_{-tot}(i)T(i)$ $P_{-tot}(i) = \begin{cases} \lvert P_{tot}(i) \rvert \ \ dla\ P_{tot}(i) < 0 \\ 0\ dla\ P_{tot}(i) \ge 0 \end{cases}$ where: *i* is subsequent number of the 10/12-period measurement window $P_{tot}(i)$ represents total active power P_{tot} calculated in *i*-th measuring window $T(i)$ represents duration of *i*-th measuring window (in hours)
Total apparent energy	E_{Stot}	VAh	$E_{Stot} = \sum_{i=1}^{m} S_e(i)T(i)$ where: *i*is subsequent number of the 10/12-period measurement window $S_e(i)$ represents the total apparent power S_e calculated in *i*-th measuring window $T(i)$ represents duration of *i*-th measuring window (in hours)

11.5 Method of averaging parameter

Method of averaging parameter	
Parameter	**Averaging method**
Effective voltage	RMS
DC voltage	arithmetic average
Frequency	arithmetic average
Crest factor U, I	arithmetic average
Symmetrical components U, I	RMS

Unbalance factor U, I	calculated from average values of symmetrical components
Effective current	RMS
Active, Reactive, Apparent and Distortion Power	arithmetic average
Power factor PF	calculated from the averaged power values
cosφ	arithmetic average
tgφ	calculated from the averaged power values
THD U, I	calculated as the ratio of the average RMS value of the harmonics to the average RMS value of the fundamental component (for THD-F), or the ratio of the average of RMS value of higher harmonics to the average value of effective voltage (for THD-R)
Harmonic amplitudes U, I	RMS
The angles between voltage and current harmonics	arithmetic average
Active and reactive power of harmonics	arithmetic average

12 Technical specifications

- Specifications are subject to change without prior notice. Recent revisions of technical documentation are available at www.sonel.pl.
- Basic uncertainty is the uncertainty of a measurement instrument at reference conditions specified in Tab. 9.
- Provided uncertainties apply to PQM-700 without additional transformers and clamps.
- Abbreviations:
  - m.v. - reference measured value,
  - U_{nom} – nominal voltage,
  - I_{nom} – nominal current (clamps),
  - RMS – RMS current,
  - n - harmonic,
  - δ_{ph} – additional uncertainty of error in the measurement of the phase between voltage and current harmonics.

12.1 Inputs

Voltage input terminals	
Number of inputs	5 (L1, L2, L3, N - 3 measuring channels) not galvanically insulated
Maximum input voltage	$760V_{RMS}$
Peak input voltage (without cutting)	1150V
Range of measured direct current voltages	±1150V
Analogue transmission band (-3dB)	>12kHz
Transformers	defined by user
Impedance of measurement inputs	14MΩ
CMRR	>70dB (50Hz)

Current input terminals	
Number of inputs	4 (3 phases + neutral) not insulated galvanically
Nominal input voltage	$1V_{RMS}$
Peak input voltage	3.6V
Analogue transmission band (-3dB)	>12kHz
Input Impedance	Path for hard clamps: 100kΩ Path for flexible clamps: 12.4kΩ
Measurement range (without transformers)	Flexible clamps F-1/F-2/F-3: 1 ...3000 A (10000A peak) Hard clamps C-4, C-5: 1 ...1000 A (3600A peak) Hard clamps C-6: 0.01..10A (36A peak) Hard clamps C-7: 0..100A (360A peak)
Transformers	defined by user
CMRR	60dB (50Hz)

12.2 Sampling and RTC

Sampling and RTC	
A/C converter	16-bit
Sampling rate	12.8 kHz for 50 Hz 15.36 kHz for 60 Hz Simultaneous sampling in all channels
Samples per period	256
PLL synchronization	40..70Hz
Reference channel for PLL	L1
Real-time clock	±3.5 ppm max (approx. ± 9 sec./month) in the temperature range of -20°C…+55°C

12.3 Measured parameters - accuracy, resolution and ranges

12.3.1 Reference conditions

Tab. 7. Reference conditions.

Reference conditions	
Ambient temperature	23°C ±2°C
Relative Humidity	40…60%
Voltage unbalance	≤ 0.1% for unbalance factor of negative sequence (applies only to 3-phase systems)
Continuous, external magnetic field	≤ 40A / m (fixed) ≤ 3A / m (variable) for 50/60Hz frequency
Constant component of voltage and current	zero
Waveforms	- sinusoidal
Frequency	50Hz ±0,2% or 60Hz ±0,2%

12.3.2 Voltage

Voltage	Ranges and conditions	Resolution	Basic uncertainty
U_{RMS} (AC+DC)	20% U_{nom} ≤ U_{RMS} ≤ 120% U_{nom} for U_{nom} ≥ 100V	0.01% U_{nom}	±0.5% U_{nom}
Crest Factor	1..10 (1..1,65 for 690V voltage) for U_{RMS} ≥ 10% U_{nom}	0.01	±5%

12.3.3 Current

Current	Ranges and conditions	Resolution	Basic uncertainty
I_{RMS} (AC+DC)	**Input path without clamps**		
	0..1V (0..3.6V_{p-p})	0.01% I_{nom}	±1% I_{nom}
	Flexible clamps F-1/F-2/F-3		
	0..3000A (10kA_{p-p})	0.01% I_{nom}	**Additional uncertainty** ±1% (±2% taking into account additional error due to the position)
	Hard clamps C-4		
	0..1000A (3600A_{p-p})	0.01% I_{nom}	**Additional uncertainty** 0.1..10A: ± (3% + 0.1A) 10A: ±3% 50A: ±1,5% 200A: ±0.75% 1000..1200A: ±0.5%
	Hard clamps C-5		
	0..1000A (3600A_{p-p})	0.01% I_{nom}	**Additional uncertainty** 0,5..100A: ≤ (1,5% + 1A) 100..800A: ≤ 2,5% 800..1000A AC: ≤ 4% 800..1400A DC: ≤ 4%
	Hard clamps C-6		
	0..10A (36A_{p-p})	0.01% I_{nom}	**Additional uncertainty** 0,01..0.1A: ± (3% + 1mA) 0.1..1A: ±2.5% 1..12A: ±1%
	Hard clamps C-7		
	0..100A (360A_{p-p})	0.01% I_{nom}	**Additional uncertainty** 0..100A: ± (0,5% + 0,02A)

			(45..65Hz) 0..100A: ± (1,0% + 0,04A) (40..1000Hz)
Crest Factor	1..10 (1..3,6 for I_{nom}) for $I_{RMS} \geq 1\%\ I_{nom}$	0.01	±5%

12.3.4 Frequency

Frequency	Ranges and conditions	Resolution	Basic uncertainty
F	40..70Hz $10\%\ U_{nom} \leq U_{RMS} \leq 120\%\ U_{nom}$	0.01Hz	±0,05Hz

12.3.5 Harmonics

Harmonics	Ranges and conditions	Resolution	Basic uncertainty
Harmonic (n)	DC, 1..40, grouping: harmonics sub-groups acc. to PN-EN 61000-4-7		
U_{RMS} amplitude	0..200% U_{nom}	0.01% U_{nom}	±0.15% U_{nom} if m.v. <3% U_{nom} ±5% m.v. if m.v. ≥ 3% U_{nom} (acc. to PN-EN 61000-4-7 Class I)
I_{RMS} amplitude	Depending clamps used (see specifications for I_{RMS})	0.01% I_{nom}	±0.5% I_{nom} if m.v. <10% I_{nom} ±5% of m.v. if m.v. ≥ 10% I_{nom} (acc. to PN-EN 61000-4-7 Class I)
Voltage THD-R (n = 2..50)	0.0…100.0% for $U_{RMS} \geq 1\%\ U_{nom}$	0.1%	±5%
Current THD-R (n = 2..50)	0.0…100.0% for $I_{RMS} \geq 1\%\ I_{nom}$	0.1%	±5%
Phase angle (voltage)	-180°…+180°	0.1 °	±(n × 1°)
Phase angle (current)	-180°…+180°	0.1 °	±(n × 1°)

12.3.6 Power and energy

Power and energy	Conditions (for power and energy $80\%\ U_{nom} \leq U_{RMS} < 120\%\ U_{nom}$)	Resolution	Basic uncertainty (1)
Active power Active Energy	$2\%\ I_{nom} \leq I_{RMS} < 5\%\ I_{nom}$ cosφ = 1	depending on U_{nom} and I_{nom}	$\sqrt{2{,}5^2 + \delta_{ph}^2}$ ± %
	$5\%\ I_{nom} \leq I_{RMS} \leq I_{nom}$ cosφ = 1		$\sqrt{2{,}0^2 + \delta_{ph}^2}$ ± %
	$5\%\ I_{nom} \leq I_{RMS} < 10\%\ I_{nom}$ cosφ = 0.5		$\sqrt{2{,}5^2 + \delta_{ph}^2}$ ± %
	$10\%\ I_{nom} \leq I_{RMS} \leq I_{nom}$ cosφ = 0.5		$\sqrt{2{,}0^2 + \delta_{ph}^2}$ ± %
Reactive power Reactive energy	$2\%\ I_{nom} \leq I_{RMS} < 5\%\ I_{nom}$ sinφ = 1	depending on U_{nom} and I_{nom}	$\sqrt{3{,}99^2 + \delta_{ph}^2}$ ± %
	$5\%\ I_{nom} \leq I_{RMS} < I_{nom}$ sinφ = 1		$\sqrt{3{,}0^2 + \delta_{ph}^2}$ ± %
	$5\%\ I_{nom} \leq I_{RMS} < 10\%\ I_{nom}$ sinφ = 0.5		$\sqrt{3{,}99^2 + \delta_{ph}^2}$ ± %
	$10\%\ I_{nom} \leq I_{RMS} < I_{nom}$ sinφ = 0.5		$\sqrt{3{,}0^2 + \delta_{ph}^2}$ ± %
	$10\%\ I_{nom} \leq I_{RMS} < I_{nom}$ sinφ = 0.25		$\sqrt{3{,}99^2 + \delta_{ph}^2}$ ± %
Apparent power Apparent energy	$2\%\ I_{nom} \leq I_{RMS} < 5\%\ I_{nom}$	depending on U_{nom} and I_{nom}	±2.5%
	$5\%\ I_{nom} \leq I_{RMS} \leq I_{nom}$		±2.0%
Power factor (PF)	0…1 $50\%\ U_{nom} \leq U_{RMS} < 150\%\ U_{nom}$ $10\%\ I_{nom} \leq I_{RMS} < I_{nom}$	0.01	±0.03
Displacement power	0…1	0.01	±0.03

factor (cosφ/ DPF)	50% U_{nom} ≤ U_{RMS} < 150% U_{nom} 10% I_{nom} ≤ I_{RMS} < I_{nom}		

(1) See sec. 10.8.4.

12.3.7 Flicker

Flicker **-**	Ranges and conditions	Resolution	Basic uncertainty
P_{st} (10min.), P_{lt} (2h)	0.4 ... 10 for U_{RMS} ≥ 80% U_{nom}	0.01	±10% within the values presented in tables of PN-EN 61000-4-15 standard

12.3.8 Asymmetry

Asymmetry (voltage and current)	Ranges and conditions	Resolution	Basic uncertainty
Unbalance factor for positive, negative and zero sequence	0.0% ... 10.0% for 80% U_{nom} ≤ U_{RMS} < 150% U_{nom}	0.1%	±0.3% (absolute uncertainty)

12.4 Event detection - voltage and current RMS

U_{RMS} voltage (dips, interruptions and surges)	Range	Resolution	Basic uncertainty
$U_{RMS(1/2)}$	0.0%...120.0% U_{nom}	0.01% U_{nom}	±1% U_{nom}
Detection thresholds	Set by the user in percentage or absolute values. Event detection based on the measurement of $U_{RMS(1/2)}$ (1-period RMS refreshed every ½ period).		
Duration	hh:mm:ss.ms	½ period	One period
Waveform record	Two periods before event + 4 periods after the event (total of 6 cycles) 256 samples per period		

I_{RMS} current (min, max)	Range	Resolution	Basic uncertainty
$I_{RMS(1/2)}$	0.0%...100.0% I_{nom}	0.01% I_{nom}	±1% I_{nom}
Detection thresholds	Set by the user in percentage or absolute values. Event detection based on the measurement of $I_{RMS(1/2)}$ (1-period RMS refreshed every ½ period).		
Duration	hh:mm:ss.ms	½ period	One period
Waveform record	Two periods before event + 4 periods after the event (total of 6 cycles) 256 samples per period		

12.5 Event detection - other parameters

Parameter	Range	Detection method
Frequency (min, max)	40 ... 70Hz (percentage or absolute value)	Detection based on 10-sec. measurement (acc. to PN-EN 61000-4-30)
Voltage crest factor (min, max)	1.0 ... 10.0	Basing on 10/12-period value
Current crest factor (min, max)	1.0 ... 10.0	Basing on 10/12-period value
Voltage unbalance factor for negative sequence (max)	0.0 ... 20.0%	Basing on 10/12-period value
Current unbalance factor for negative sequence (max)	0.0 ... 20.0%	Basing on 10/12-period value
Short-term flicker P_{st} (max)	0..20	Basing on 10-minute value

Long-term flicker P_{lt} (max)	0..20	Basing on 2-hour value
Active power P (min, max)	Depending on the configuration	Basing on 10/12-period value (for consumed and supplied power)
Reactive power Q (min, max)	Depending on the configuration	Basing on 10/12-period value (for consumed and supplied power)
Apparent power S (min, max)	Depending on the configuration	Basing on 10/12-period value
Distortion power D / Apparent distortion power S_N (min, max)	Depending on the configuration	Basing on 10/12-period value
Power Factor PF (min, max)	0…1	Basing on 10/12-period value
Displacement power factor cosφ/ DPF (min, max)	0…1	Basing on 10/12-period value
tgφ (min, max)	0…10	Basing on 10/12-period value
Active energy E_P (max)	Depending on the configuration	Exceedance checked every 10/12 periods (for consumed and supplied energy)
Reactive energy E_Q (max)	Depending on the configuration	Exceedance checked every 10/12 periods (for consumed and supplied energy)
Apparent energy E_S (max)	Depending on the configuration	Exceedance checked every 10/12 periods
Total harmonic distortion voltage THD-F (max)	0…100%	Basing on 10/12-period value
Total harmonic distortion current THD-F (max)	0…200%	Basing on 10/12-period value
Voltage harmonic amplitudes (max)	0 ... 100% or absolute values	Basing on 10/12-period value; Independent thresholds for all harmonics in the range of 2 ... 50
Current harmonic amplitudes (max)	0…200% or absolute values \	Basing on 10/12-period value; Independent thresholds for all harmonics in the range of 2 ... 50

12.5.1 Event detection hysteresis

Event detection hysteresis	Range	Calculation method
Hysteresis	0..10% in 0.1% steps	For each of the parameters calculated as a percentage of maximum threshold value.

12.6 Inrush current measurement

Range [A,%]	Resolution [A, %]	Basic error
0…100% In	0.1%	±1% In

- voltage and current measurement is carrie out every ½ period in all channels (averaging every ½period)
- measurement time up to 60 seconds.

12.7 Recording

Recorder	
Averaging time [(1)]	1s, 3s, 10s, 30s, 1min, 10min, 15min, 30min. Special Mode: ½ period (for recording waveforms with a limited recording time up to 60 sec, e.g. inrush current) [(2)]
Averaging min / max for U_{RMS}	½ period, period, 200ms, 1s, 3s, 5s [(3)]
Averaging min / max for I_{RMS}	½ period, period, 200ms, 1s, 3s, 5s [(3)]
Waveforms	Option to record three periods of waveforms for active channels, after each averaging period
Recording activation mode	manual starting at the first detected event scheduled (four defined time periods)
Measurement Points	1, independent of user configuration
Recording time	Depending on the configuration

Memory	Built-in 2GB memory card
Memory Model	Linear
Security	Key lock to prevent unauthorized access

(1) Averaging times shorter than 10 seconds. are in fact equal to a multiple of the mains period: 1s = 50/60 periods; 3s = 150/180 periods.
(2) $U_{RMS(1/2)}$ and $I_{RMS(1/2)}$ are effective values for one period, refreshed every half period.
(3) Averaging periods min./max. 1s, 3s are in fact equal to a multiple of the mains period: 1s = 50/60 periods; 3s = 150/180 periods.

Recorded parameters	Mean value	Minimum Value	Maximum Value	Instantaneous value
Effective phase/phase-to-phase voltage (depending on the type of system) U_{RMS}	•	•	•	•
Effective phase-to-phase voltage (only 3-phase wye system with N and 2-phase system) U_{RMS}	•			
Effective current I_{RMS}	•	•	•	•
Frequency f	•	•	•	•
Voltage crest factor CF U	•	•	•	•
Current crest factor CF I	•	•	•	•
Unbalance factors for negative and positive sequence, symmetrical components: negative, positive, zero (voltage) U_0, U_1, U_2, u_0, u_2	•	•	•	•
Unbalance factors for negative and positive sequence, symmetrical components: negative, positive, zero (current) I_0, I_1, I_2, i_0, i_2	•	•	•	•
Flicker factor P_{st} and P_{lt},	•	•	•	•
Active power (consumed and supplied) P_{+}, P_{-}	•	•	•	•
Reactive power (consumed and supplied) Q_{1+}, Q_{1-} / Q_{B+}, Q_{B-}	•	•	•	•
Apparent power S	•	•	•	•
Distortion power D / Apparent distortion power S_N	•	•	•	•
Power factor PF	•	•	•	•
Displacement power factor cosφ/DPF	•	•	•	•
Tgφ factor	•	•	•	•
Active energy (consumed and supplied) E_{P+}, E_{P-}				•
Reactive energy (consumed and supplied) E_{Q+}, E_{Q-}				•
Apparent energy E_S				•
Total harmonic distortion (THD) Voltage THD-F	•	•	•	•
Total harmonic distortion (THD) current THD-F	•	•	•	•
Voltage harmonic amplitudes U_{h1}…U_{h40}	•	•	•	•
Current harmonic amplitudes I_{h1}…I_{h40}	•	•	•	•

12.8 Power supply and heater

Power supply	
Input voltage range	90…460V AC, 127…460V DC
Overvoltage category	CAT IV/300V
Power Consumption	max. 30VA
Battery	Li-Ion 4.5Ah
Operating time on battery	> 6h
Battery charging time (fully discharged battery)	8h
Current consumption from battery in analyzer off mode (mains power failure, does not apply to anti-theft mode)	< 1mA

Heater	
Heater temperature threshold (activation)	+5°C
Heater power supply	from AC adapter
Heater power	max. 10W

12.9 Supported networks

Types of supported networks (directly and indirectly)	
1-phase	1-phase with a neutral conductor (terminals: L1, N)
2-phase (split-phase)	Split phase with a neutral conductor (terminals: L1, L2, N)
3-phase wye with N,	3-phase wye with a neutral conductor (terminals: L1, L2, L3, N)
3-phase delta	Three-phase delta (terminals: L1, L2, L3, N shorted with L3)
3-phase Araon delta	Three-phase delta (terminals: L1, L2, L3, N shorted with L3) with two current clamps
3-phase wye without N,	3-phase wye without neutral conductor (terminals: L1, L2, L3, N shorted with L3)
3-phase wye without Aron N,	3-phase wye without neutral conductor (terminals: L1, L2, L3, N shorted with L3) with two current clamps

12.10 Supported current clamps

Types of supported current clamps	
F-1	Flexible clamps (Rogowski coil), perimeter: 120cm, measuring range 3000A $_{RMS}$
F-2	Flexible clamps (Rogowski coil), perimeter: 80cm, measuring range 3000A $_{RMS}$
F-3	Flexible clamps (Rogowski coil), perimeter: 45cm, measuring range 3000A $_{RMS}$
C-4	CT, AC clamps, measuring range 1000A$_{RMS}$, 1mV/A
C-5	CT, AC clamps with Hall sensor, measuring range 1000A$_{RMS}$, 1mV/A
C-6	CT, AC clamps for low currents, measuring range 10A$_{RMS}$, 1mV/10mA
C-7	CT, AC clamps, measuring range 100A$_{RMS}$, 5mV/A

12.11 Communication

Communication	
USB	Optically isolated Max. bitrate: 921.6 kbit/s, Compatible with USB 2.0

12.12 Environmental conditions and other technical data

Environmental conditions	
Operating temperature range:	-20°C…+55°C
Storage temperature range	-30°C…+60°C
Humidity	10…90% with posible condensation
Ingress protection (according to EN 60529)	IP 65
Reference conditions	Ambient temperature: 23°C ±2°C Humidity: 40…60%
Dimensions	200 x 180 x 77mm (without cables)
Weight	approx. 1.6 kg
Display	5 LEDs indicating operational status
Data Memory	removable memory card (2GB as standard) option of extending up to 8GB (optional).

12.13 Safety and electromagnetic compatibility

Safety and EMC	
Compliance with	PN-EN 61010-1
Measurement Category	IV 600V - measuring inputs, IV 300V - power supply, pollution

	class 2 according to PN-EN 61010-1
Insulation	Double acc. to PN-EN 61010-1
Electromagnetic compatibility	PN-EN 61326
Immunity to radio frequency interferences	PN-EN 61000-4-3 sinusoidal modulation 80% AM, 1kHz 80…1000MHz, 10V/m 1.4…2.0 GHz, 3 V/m 2.0 ... 2.7 GHz, 1 V/m
Resistance to electrostatic discharge	PN-EN 61000-4-2 Air discharge: 8 kV Contact discharge: 4kV
Immunity to conducted disturbances, induced by radio-frequency fields	PN-EN 61000-4-6 sinusoidal modulation 80% AM, 1kHz 0.15…80MHz, 10V
Resistance to a series of electrical fast transients	PN-EN 61000-4-4 Amplitude of 2kV, 5kHz
Surge immunity	PN-EN 61000-4-5 Amplitude 2kV (L-L)
Emissions of interferences with radio frequency	PN-EN 61000-6-3 30…230MHz, 30dB(μV/m) at 10m 230…1000MHz, 37dB(μV/m) at 10m
Emissions of conducted interferences	PN-EN 61000-6-3 Levels for a quasi-peak detector: 0.15kHz…0.5MHz: 66dBμV…56dBμV 0.5MHz…5MHz: 56dBμV 5MHz…30MHz: 60dBμV

12.14 Standards

Standards	
Measurement Methods	PN-EN 61000-4-30 Class S
Measurement Accuracy	PN-EN 61000-4-30 Class S
Power Quality	PN-EN 50160
Flicker	PN-EN 61000-4-15
Harmonics	PN-EN 61000-4-7
Quality standard	design, construction and manufacturing are ISO 9001 compliant

13 Equipment

13.1 Standard equipment

The standard set of equipment supplied by the manufacturer includes:

- Permanently fixed cables (2.2 m) with banana plugs (6 pcs)
- K01 crocodile clip, black (3 pcs) – **WAKROBL20K01**,
- K02 crocodile clip, blue – **WAKROBU20K02**,
- red crocodile clip (2 pcs.) – **WAKRORE20K02**,
- mains plug with banana inputs (L1 and N) for connecting the analyzer to a socket in order to charge the battery and/or carry out data transmission from a PC - **WAADAAZ1**,
- software for data reading and analysing "Sonel Analysis 2.0"
- USB cable – **WAPRZUSB**,
- 2GB microSD card,
- meter case L-5 – **WAFUTL5**,
- band for mounting the device on a pole (2 pcs) – **WAPOZOPAKPL**,
- bracket for mounting the analyzer on DIN (ISO) rail with stabilizing connectors – **WAPOZUCH3**,
- connectors for bands used for mounting the device on a pole (2 pcs) – **WAPOZUCH4**
- built-in battery

- operating manual,
- guarantee card,
- calibration certificate.

13.2 Optional accessories

Additionally, the following items that are not included in the scope of standard equipment can be purchased from the manufacturer or the distributors:

- hard clamps C-4 1000A AC – **WACEGC4OKR**,
- hard clamps C-5 1000A AC/CD – **WACEGC5OKR**,
- clamps C-6 for low currents in 10A AC transformers – **WACEGC6OKR**,
- clamps C-7 100A AC – **WACEGC7OKR**,
- flexible clamps F-1 for current up to 3kA AC (length: 120cm) – **WACEGF1OKR**,
- flexible clamps F-2 for current up to 3kA AC (length: 80cm) – **WACEGF2OKR**,
- flexible clamps F-3 for current up to 3kA AC (length:45cm) – **WACEGF3OKR**,
- battery (replaceable by SONEL after-sale services) – **WAAKU11**,
- phase splitter AC-16 – **WAADAAC16**,
- a set of magnetic voltage adapters – 3 pcs black and 1 pc blue - **WAADAUMAGKPL**,
- a set of voltage adapters (threaded) – 3 pcs black, 1 pc blue and 1 pc yellow - **WAADAM4M6**,
- a case for the analyzer and standard accessories - **WAWALXL4**,
- hard case for clamps– **WAWALL2**.

13.2.1 Clamps C-4

Clamps C-4 are used to measure AC in electrical systems of low and medium power. The output voltage is proportional to the measured current. The output signal is conducted by a cable (1.5 m) ended with a pin adapted to the socket on the meter.

The arrow marked on one of the clamps indicates the direction of current flow. It is assumed that the current flows in the positive direction if it flows from the source to the receiver. This orientation of clamps is required for the correct power measurement.

Fig. 83. Clamps C-4.

Note

Do not measure currents exceeding 1200A. Limit the measurement time for currents higher than 1000A, according to the following data:

Current Range	I ≤ 1000A	1000A < I ≤ 1200A
Operating mode	continuous [1]	15 minutes of measurement, followed by 30-minute break

[1)] For frequencies f ≤ 1kHz. Limiting the maximum current in continuous operation for frequencies above 1kHz according to the ratio $I_{cont.}$ = 1000A / f [kHz]

Warning

Do not use non-insulated clamps for conductors with a potential exceeding 600V with respect to the ground and in systems with the measurement category higher than III.

- **Reference conditions**

  - Temperature +20…+26°C
  - Relative Humidity 20…75%
  - conductor position conductor centred in the jaws
  - frequency of sinusoidal current 48…65Hz
  - Total harmonic distortion <1%
  - current constant component none
  - constant magnetic field <40A/m (Earth's magnetic field)
  - variable, external magnetic field none
  - conductors in the immediate vicinity no current flow

- **Specifications**

  - accuracy:

Current Range	Basic uncertainty [1)]	Phase error
0.1 ... 10A	≤ 3% + 0.1 A	unspecified
10…50A	≤ 3%	≤ 3°
50…200A	≤ 1.5%	≤ 1.5°
200…1000A	≤ 0.75%	≤ 0.75°
1000…1200A	≤ 0.5%	≤ 0.5°

[1)] as % of the measured value

  - output for maximum power 1V AC
  - ratio 1mV AC/1A AC
  - frequency range 30Hz...10kHz
  - type of insulation double, according to PN-EN 61010-1
  - measurement category according to EN 61010-1 III 600V,
  - protection class acc. to EN 60529 IP40, with open jaws: IP30
  - dimensions 216 × 111 × 45mm
  - weight approx. 640g
  - jaws opening distance 53mm
  - height of open jaws 139mm
  - maximum diameter of tested cable ∅52mm
  - length of clamp cables 1.5 m
  - working temperature –10°C…+55°C
  - Relative Humidity <85%
  - height ≤ 2000m
  - Electromagnetic compatibility EN 61000-6-3:2008
    EN 61000-6-2:2008

13.2.2 Clamps C-5

Fig. 84. Clamps C-5

Clamps C-5 are used to measure AC and DC currents and without breaking the circuit with flowing current. The measuring range is 1400A for DC and 1000A for DC. The output voltage is proportional to the measured current. The clamps have the range of 1000A, with a sensitivity of 1 mV/A, zero adjustment knob and a LED indicating power supply.
The output signal is conducted by a cable (1.5 m) ended with a pin adapted to the socket on the meter.

The arrow marked on one of the clamps indicates the direction of current flow. It is assumed that the current flows in the positive direction if it flows from the source to the receiver. This orientation of clamps is required for the correct measurement of power and constant components.

- **Overloads:**
  - direct current (DC): up to 3000A (continuous mode),
  - alternating current (AC): up to 1000 in the continuous mode, with frequency up to 1 kHz
  - limiting the maximum current in continuous operation for frequencies above 1kHz according to the ratio: $I_{cont.} = 1000A/f\ [kHz]$

- **Turning on**
  In order to activate the clamps, slide the switch to 1 mV/A. Green LED will indicate proper operation. If after the switching operation, the LED is not lit or goes off during the measurements, replace the battery supplying the meter.

- **Correcting zero DC indication**
  After making sure that the jaws are closed and there is no conductor between them, connect them to PQM analyzer and run "Sonel Analysis" software in the current preview mode (pay attention to correctly configure the measuring point for the measurement with clamps C-5). Press the knob and turn it around until zero is reached in constant current component.

- **Reference conditions**
  - temperature: +18…+28°C
  - relative humidity: 20…75%
  - battery voltage: 9 V ± 0.1 V
  - conductor position: conductor centred in the jaws
  - current: DC or sinusoidal (AC) f ≤ 65Hz
  - constant magnetic field: <40A/m (Earth's magnetic field)
  - variable, external magnetic field: none
  - conductors in the immediate vicinity: no current flow

- **Technical specifications**
  - accuracy:

Current range	0.5…100A	100…800A	800…1000A (AC) 800…1400A (DC)
Basic uncertainty [1)]	≤ 1.5% + 1A	≤ 2.5%	≤ 4%

[1)] as % of the measured value

- phase error (45...65Hz):

Range	10…200A	200…1000A
Phase error	≤ 2.5°	≤ 2°

- ratio: 1mV/1A
- frequency range: DC...5kHz
- output impedance: 100Ω
- DC zero adjustment range: ±10A
- noise: DC up to 1kHz: ≤1mVp-p (or 1Ap-p)
  DC up to 5kHz: ≤1.5mVp-p (or 1.5Ap-p)
  1Hz up to 5kHz: ≤0.5mVp-p (or 0.5Ap-p)
- additional errors:
  - due to current frequency: 65...440Hz: -2%
    440..1000Hz: -5%
    1..5kHz: -4dB
  - due to the battery voltage: ≤1A/V
  - due to temperature: ≤ 300ppm/°C or 0.3%/10°C
  - due to relative humidity in the range of 10 ... 85%:
    ≤ 0.5%
  - due to the position of the conductor ∅20mm:
    DC up to 440Hz: <0.5%
    DC up to 1kHz: <1%
    DC up to 2kHz: <3%
    DC up to 5kHz: <10%
  - due to a parallel conductor with 50…60Hz AC, located within 23mm of the clamps:
    <10mA/A
  - due to an external magnetic field of 400A / m (50 Hz), influencing the centred conductor
    <1.3 A
  - in-phase rejection factor >65dB A/V (50…400Hz)

- **Other data**
  - type of insulation: double, according to EN 61010-1
  - measurement category according to EN 61010-1: III 600V,
  - protection class acc. to EN 60529:
    IP30
  - power supply: 9V battery (6LR61, 6LF22, NEDA 1604)
  - operating time powered by alkaline battery: approx. 120h
  - dimensions 237 × 97 × 44mm
  - weight: approx. 520g
  - maximum diameter of tested cable:
    ∅39mm
  - length of clamp cables: 1.5 m
  - operating temperature –10°C…+55°C
  - relative humidity: <85%
  - height: ≤ 2000m
  - Electromagnetic compatibility: EN 61000-6-3:2008
    EN 61000-6-2:2008

13.2.3 Clamps C-6

Clamps C-6 are designed to measure AC currents with frequencies up to 10kHz for range 10mA ... 10A.
The output signal is a voltage proportional to the measured current at the sensitivity of 100mV/A. It is introduced via a cable (length: 1.5 m) ended with a plug suitable for a socket in the meter.

The arrow marked on one of the clamps indicates the direction of current flow. It is assumed that the current flows in the positive direction if it flows from the source to the receiver. This orientation of clamps is required for the correct power measurement.

Fig. 85. Clamps C-6.

Note!
Do not use non-insulated clamps for conductors with a potential exceeding 600V with respect to the ground and in systems with the measurement category higher than III.

- **Reference conditions**
  - temperature: +20…+26°C
  - relative humidity: 20…75%
  - conductor position: Conductor centred in the jaws
  - frequency of sinusoidal current: 48 ... 65Hz
  - Total harmonic distortion: <1%
  - current constant component: none
  - constant magnetic field: <40A/m (Earth's magnetic field)
  - variable, external magnetic field: none
  - conductors in the immediate vicinity: no current flow

- **Technical data**
  - accuracy

Current Range	Basic uncertainty [1)]	Phase error
0.01 ... 0.1 A	≤ 3% + 1mA	unspecified
0.1 ... 1A	≤ 2.5%	≤ 5°
1…12A	≤ 1%	≤ 3°

[1)] as % of the measured value

  - ratio: 100mV AC/1A AC
  - frequency range: 40Hz...10kHz
  - type of insulation: double, according to EN 61010-1
  - measurement category according to EN 61010-1: III 600V,
  - protection class acc. to EN 60529: IP40, with open jaws: IP30
  - dimensions 135 × 50 × 30mm
  - weight: approx. 240g
  - jaws opening distance: 21mm
  - height of open jaws: 69mm
  - maximum diameter of tested cable: ∅20mm

- length of clamp cables: 1.5 m
- operating temperature –10°C…+55°C
- relative humidity: <85%
- height: ≤ 2000m
- Electromagnetic compatibility: EN 61000-6-3:2008
  EN 61000-6-2:2008

13.2.4 C-7 Clamps

C-7 Clamps are used to measure alternating currents in networks of low and medium power within the range up to 100A.
The output signal is a voltage proportional to the measured current at the sensitivity of 5 mV/A. It is introduced via a cable (length: 1.5 m) ended with a plug suitable for a socket in the meter.

The arrow marked on one of the clamps indicates the direction of current flow. It is assumed that the current flows in the positive direction if it flows from the source to the receiver. This orientation of clamps is required for the correct power measurement.

Fig. 86. C-7 Clamps.

Note!
Do not use non-insulated clamps for conductors with a potential exceeding 300V with respect to the ground and in systems with the measurement category higher than III.

- **Reference conditions**
  - temperature: +18…+28°C
  - relative humidity: <85% (non-condensing)

- **Technical data**
  - test range 0…100A AC
  - frequency range 40Hz..3kHz
  - maximum allowable continuous current 100A AC (50/60Hz)
  - accuracy (sine wave)

Frequency	Basic uncertainty	Phase error
45…65 Hz	± 0.5% ± 0.1 mV	≤ 2°
40Hz…1kHz	±1.0% ±0.2mV	unspecified

  - ratio: 5mV AC/1A AC
  - output impedance 11Ω
  - type of insulation: double, according to EN 61010-1
  - measurement category according to EN 61010-1: III 300V,
  - dimensions 100 × 60 × 26mm
  - weight: approx. 160g
  - maximum diameter of tested cable: ∅24mm
  - length of clamp cables: 1.5 m
  - operating temperature 0°C…+50°C
  - relative humidity: <85% (non-condensing)

- Electromagnetic compatibility: EN 61326

13.2.5 Clamps F-1, F-2, F-3

Flexible clamps (Rogowski coil) F-1, F-2 i F-3 are designed to measure AC currents with frequencies up to 10kHz for range 1A…3000A.

Flexible clamps F-1, F-2 and F-3 are different only in terms of the coil perimeter. Electrical parameters are the same.

The output signal is voltage proportional to the measured current derivative at the sensitivity of 38.83 mV/1000A for 50Hz and 46.6 mV/1000A for 60Hz.

Fig. 87. Clamps F-1.

Fig. 88. Clamps F-2

Fig. 89. Clamps F-3

The output signal is conducted by a cable (2 m) ended with a pin adapted to the socket on the meter.

The arrow marked on one of the clamps indicates the direction of current flow. It is assumed that the current flows in the positive direction if it flows from the source to the receiver. This orientation of clamps is required for the correct power measurement.

Note

Do not use non-insulated clamps for conductors with a potential exceeding 1000V with respect to the ground and in systems with the measurement category higher than III.

- **Reference conditions**
  - Temperature: +18…+22°C
  - Conductor position: conductor centred in the clamp loop
  - Constant magnetic field: <40A/m (Earth's magnetic field)
  - Variable, external magnetic field: none
  - External electric field: none

- **Technical data**
  - Nominal measuring range: 1A ... 3000A (10000A peak at 50Hz)
  - Input / output ratio: 38.83mV/1000A (50Hz)
    46.6mV/1000A (60Hz)
  - Basic uncertainty: ±1% within the range of 1A…3000A
  - Linearity: ± 0.2%
  - Additional error due to the position of the conductor: ±2% max.
  - Additional error due to external magnetic field:
    ±0,5% max.

- Additional error due to temperature: ± 0.07%
- Output impedance: 30Ω/400mm

- **Other data:**
  - type of insulation: double, according to EN 61010-1
  - measurement category according to EN 61010-1: III 1000V
  - protection class acc. to EN 60529: IP65
  - coil diameter: 15.5 mm
  - diameter of the clamps (maximum): 30mm
  - coil perimeter: F-1: 120cm
F-2: 80cm
F-3: 45cm
  - inner diameter of clamps after closing: F-1: 360mm
F-2: 235mm
F-3: 120mm
  - weight: F-1: approx. 410g
F-2: approx. 310g
F-3: approx. 220g
  - length of clamp cables: 2m
  - operating temperature –20°C…+80°C
  - Electromagnetic compatibility: EN 61000-6-3:2008
EN 61000-6-2:2008

14 Other information

14.1 Cleaning and maintenance

> ***Note***
> *Use only the maintenance methods presented by the manufacturer in this manual.*

Clean the analyzer casing with a wet cloth, using generally available detergents. Do not use any solvents and cleaning media which could scratch the casing (powder, paste, etc.).

Clean the leads can with water and detergents, then wipe dry.

The analyzer electronic system is maintenance free.

14.2 Storage

When storing the device, observe the following recommendations:

- disconnect all leads from the analyzer,
- thoroughly clean the analyzer and all accessories,
- recharge the battery from time to time to prevent total discharging.

14.3 Dismantling and disposal

Used electric and electronic equipment should be collected selectively, i.e. not placed with other types of waste.

Used electronic equipment shall be sent to the collection point according to the Used Electric and Electronic Equipment Act.

Before sending the instrument to the collection point, do not dismantle any parts by yourself. Observe local regulations on disposal of packages and used batteries.

14.4 Manufacturer

The manufacturer of the equipment and provider of service during and past the warranty period:

SONEL S.A.
ul. Wokulskiego 11
58-100 Świdnica
Poland
tel. +48 74 858 38 60
fax +48 74 858 38 09
E-mail: export@sonel.pl
Web page: www.sonel.pl

> ***Note***
> *Service repairs must be performed solely by the manufacturer.*

MPI-525
Multifunction Electrical Installations Meter

MPI-505
Multifunction Electrical Installations Meter

MPI-502
Multifunction Electrical Installations Meter

MRU-200
Earth Resistance and Resistivity Meter

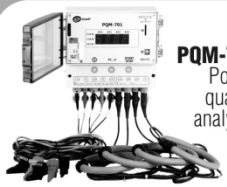
MRU-20
Earth Resistance and Resistivity Meter

MIC-2510
Insulation Resistance Meter

MIC-2
Insulation Resistance Meter

KT-384
Thermal imager

MIC-30
Insulation Resistance Meter



PQM-701
Power quality analyzer

LXP-1
Datalogging Light Meter

PAT-805
Portable appliance tester

CMM-40
Industrial multimeter

CMP-1006
Digital Clamp-on multimeter

MMR-630
Microohmeters

CMP-200
Digital Clamp-on AC

DIT-500
IR thermometer

LKZ-700
Wire tracer