OPERATING MANUAL

POWER QUALITY ANALYZER
PQM-701
PQM-701Z
PQM-701Zr

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PQM-701
P1
P2
P3
P4
L1/A
L2/B
L3/C
CAT IV
600V
P1...4
START
STOP
960120

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1 General information

1.1 Safety

PQM-701 Power Quality Analyzer is designed to measure, record and analyze power parameters. In order to ensure safe operation, observe the following recommendations:

- Before you proceed to operate the meter, acquaint yourself thoroughly with the present manual and observe the safety regulations and recommendations of the manufacturer.
- Any application that differs from those specified in the present manual may cause damage of the instrument and a serious hazard to its user.
- The PQM-701 analyzers must be operated solely by appropriately qualified personnel with relevant certificates to perform measurements of electric installation. Operation of the instrument by unauthorized personnel may result in damage to the device and constitute a hazard to the user.
- The instrument must not be used for the mains and equipment in rooms with special conditions, such as fire or explosion hazard.
- It is unacceptable to operate the following:
  ⇒ A damaged instrument which is completely or partially out of order,
  ⇒ Leads with damaged insulation,
- Use only the power supplies specified in this manual.
- If possible, connect the analyzer to the de-energized circuits.
- Before placing the analyzer in the electrical panel it is recommended to remove the metal bracket on the back panel to avoid accidental short circuit.
- Opening the instrument cover causes loss of tightness which, during an unfavorable weather, can result in a damage to the instrument as well as a hazard for its user.
- Repairs may be performed solely by an authorized service point.

The PQM-701 analyzer meets the requirements of IEC 61010-1 for the measurement category IV 600V and of double insulation with closed casing cover. With open cover, it conforms to the class IV 600V and basic insulation.

The measurement category of the whole system depends on used accessories. If a lower category accessories (such as clamps) are connected to the analyzer, the category for the whole system will be reduced.

1.2 General features

Power quality analyzer PQM-701 (Fig. 1) is an advanced product for comprehensive measurements, analysis and recording of the parameters of the 50/60 Hz mains systems and of the power quality according to the EN 50160.

The analyzer has five voltage input terminals, marked L1/A, L2/B, L3/C, N and PE, and the N terminal (neutral conductor) is shared. The range of voltages measured by four measuring channels is ±1150V maximum. This range may be changed by using external voltage transducers.

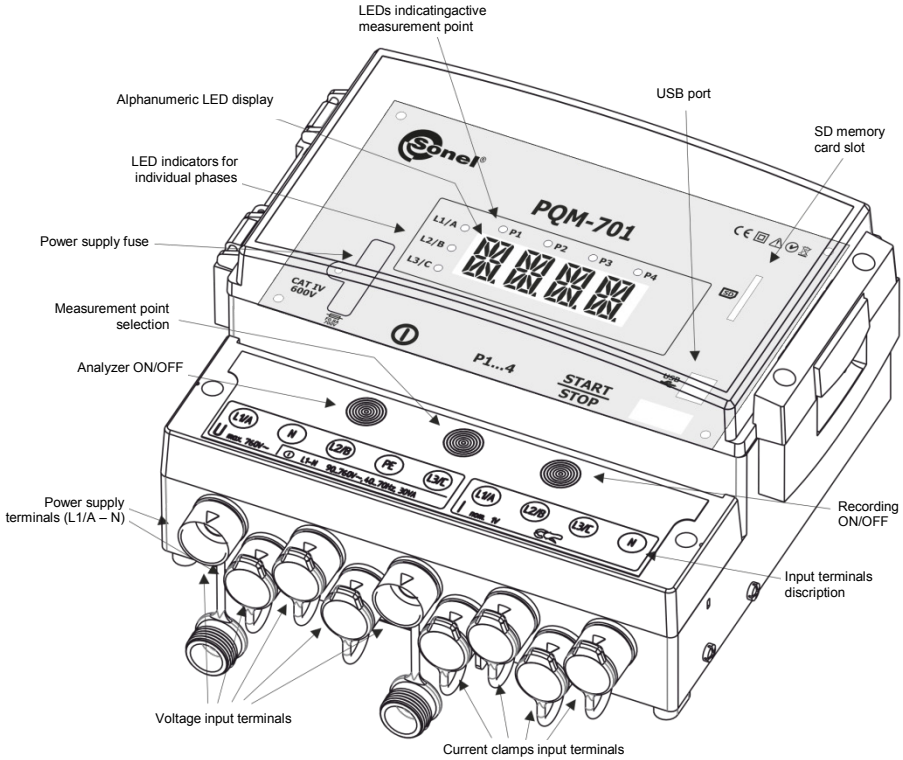


Fig. 1. Power Quality Analyser PQM-701. General view.

Current is measured by means of four current inputs to which several types of current clamps can be connected, such as flexible clamps F-1, F-2, F-3 with the 3000A nominal range (the only difference between them is the coil size) and the C-4 clamp (range 1000A AC), C-5 clamp (range 1000A AC/DC) C-6 clamp (range 10A AC) and C-7 (range 100A AC). Also in case of currents, the nominal range can be changed by using additional transducers. For example, by using a 100:1 transducer with C-4 clamp, currents up to 100kA can be measured.

A lot of attention has been given to functionality in the recording mode. The instrument is equipped with a high-capacity removable SD memory card (*Secure Digital*). When the recording is completed, the card can be removed from the analyzer and the data can be transferred quickly to the computer by means of an external card reader and the software which is included in the package. The data can also be read by two communication links: USB or wireless transmission.

The recorded parameters are divided into groups, which can be independently included or excluded from the recording, which allows a rational use of the memory card space. Parameters which are not recorded do not take up space, hence there is more time to record other parameters.

In the PQM-701 the power is supplied to the analyzer from the tested mains; internal power supply with wide input voltage range (90…760V AC) is permanently connected to the L1/A and N inputs. In the PQM-701Z the internal power supply has separate terminals on the right side of the enclosure and is not internally connected to the L1/A and N voltage measurement terminals.

The PQM-701 is adapted to operation under difficult weather conditions – it can be used directly on electric poles. The ingress protection rating is IP65, and the operating temperature range is from -20°C to +55°C.

In case of a power outage, an uninterrupted operation is ensured by an internal lithium-ion battery.

A simplified user interface includes a 4-character LED alphanumeric display which ensures perfect visibility with external lighting, and a 3-button touch-type keyboard.

Dedicated PC software “SONEL Analysis” allows using the full potential of the instrument.
There are two types of communication with a computer:

- Optoisolated USB interface which ensures the transmission speed of up to 921.6kbit/s (to connect, it is necessary to open the instrument top cover),
- Wireless transmission with the 57,6kbit/s speed.

In order to use the wireless communication, connect the OR-1 receiver to the USB port in the computer. Wireless communication is slower, and thus it is recommended for viewing the current data of the mains measured by the analyzer and for analyzer configuration and control. Due to lower speed, it is however not recommended to use wireless communication for transmission of large amounts of data stored on the SD card.

1.3 Analyser PQM-701Z

Analyser PQM-701Z differs from PQM-701 by the following features:

- PQM-701Z has separate terminals for a power adapter, installed on the right side of the analyser housing. The internal power adapter is connected only to these terminals (there is no connection to voltage test terminals L1/A and N).
- External dimensions of the two analysers are slightly different; see technical specifications in section 12.10.

Other features of the analyser remain the same as in PQM-701 model.

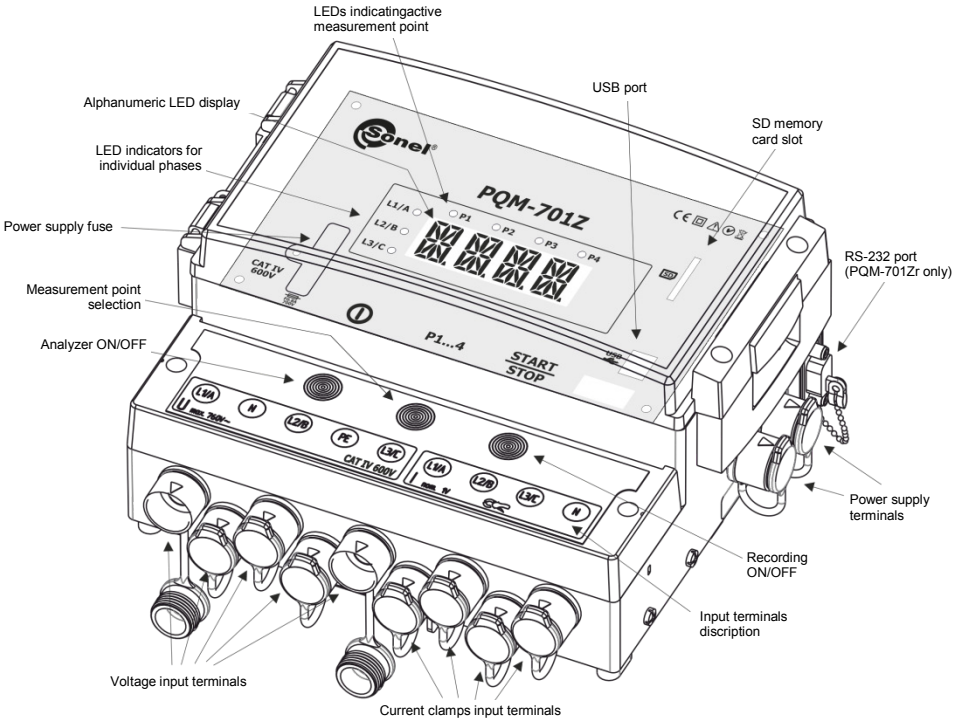


Fig. 2. Power Quality Analyser PQM-701Z and PQM-701Zr. General view. NOTE: RS-232 slot is installed only in PQM-701Zr analyser.

1.4 Analyser PQM-701Zr

Analyser PQM-701Zr differs from PQM-701 by the following features:

- PQM-701Zr has separate terminals of a power adapter, installed on the right side of the analyser housing (as in case of PQM-701Z). The internal power adapter is connected to these terminals only (no connection to the voltage measurement terminals L1 / A and N).
- PQM-701Zr has additional galvanically isolated serial port (RS-232), which is installed in a slot on the side of the unit casing.
- External dimensions of the two analysers are slightly different; see technical specifications in section 12.10.

Serial port RS-232 allows for communication with an external PC or an external communication module (e.g. GSM modem). The hardware flow control (using CTS and RTS lines) is supported.

RS-232 is active only when the USB cable is not connected do the socket on the analyser's front panel. If a PC is connected to the analyser using the USB cable the active RS-232 connection shall be disconnected.

RS-232 bitrate is maximum 921600 bit/s and may be adjusted by the user.

Serial port RS-232 has an ingress protection rating of IP65 when not connected. The supplied protective plug protects the connectors against weather conditions.

An additional standard accessory of the PQM-701Zr analyser is the non-interlaced, female-male RS-232 data transmission cable.

Other features of the analyser remain the same as in PQM-701 model.

Information
In this manual "PQM-701" shall be used to name all the analyser models (including PQM and PQM-701Z-701Zr), unless otherwise stated.

1.5 Analyzer power supply

The analyzer has built-in mains power supply that can operate in the rated voltage range from 90…760V AC. In PQM-701 the power supply is internally connected to the L1/A and N voltage measurement terminals so the power to the analyzer can be supplied from the tested mains. In the PQM-701Z and PQM-701Zr the power supply has been separated from voltage measurement terminals and has separate terminals on the right side of the analyzer.

Internal rechargeable battery is used to maintain power supply in case of an outage. The battery is charged during the operation of the analyzer when voltage is supplied to the power supply terminals. The battery can ensure up to 5h of operation at -20...+55°C. When the battery is discharged, the meter discontinues current operation (such as recording) and turns off in emergency mode showing the "**BATT**" message. If the previous operation was the recording, when the power supply is restored, the analyzer resumes recording.

After a long period of not using the analyzer with disconnected power supply (more than 3 months), the battery pack can become totally discharged and some settings will be lost (current time, last measurement point used), PIN, keys lock password, etc.) When resuming work, it is recommended to restore the settings using the "SONEL Analysis" software.

Note
The battery can be replaced only at the manufacturer's service department.

1.6 Protection rating and outdoor operation

The PQM-701 analyzer is adapted to operation under difficult weather conditions – it can be used directly on electric poles. Installation is performed by means of two bands with clasps, which should be passed through a metal frame bolted to the analyzer rear wall. The ingress protection rating is IP65, and the operating temperature range is from -20°C to +55°C.

Note
In order to ensure declared IP65 protection rating, the following rules must be observed:
- *The analyzer shall be installed with connecting terminals facing down;*
- *Fasten the transparent cover with two screws near the cover catch (closing the cover with the catch only is not sufficient);*
- *Unused measuring terminals shall be made tight with silicon plugs.*

Because the capacitive keyboard keys can be triggered by a strong stream of water (rain), it is recommended to activate the keyboard protection option with a 3-digit code in order to minimize the risk of unintentional stopping of the recording.

The internal heater is activated at ambient temperatures below 0°C in order to maintain above-freezing temperature inside for the -20°C…0°C ambient temperature range.
The power supply to the heater is from the internal mains power supply, and its power rating is limited to about 10W.

The Li-ion battery will not be charged when temperature inside the analyzer is below freezing. Such situation may occur when analyzer does not have the power supply energized and the ambient temperature drops below 0°C. The battery can be recharged when the temperature inside the analyzer rises to above 0°C.

1.7 Measured parameters

PQM-701 analyzer measures and records the following parameters:

- RMS phase-to-neutral and phase-to-phase voltages up to 690V (1150V peak),
- RMS current up to 3000A (10kA peak) with flexible clamps (F-1, F-2, F-3), up to 1000A (3600A peak) with C-4 or C-5 clamps, up to 10A (36A peak) with C-6 clamp, or up to 100A (141A peak) with C-7 clamps,
- Voltage and current crest factors,
- Power frequency in the 40 – 70Hz range,
- Active, reactive and apparent power and energy values, distortion power,
- Voltage and current harmonic components (up to the 50^{th}),
- Total harmonic distortion THD_F and THD_R for current and voltage,
- K-Factor (factor for losses caused by higher harmonics),
- Active and reactive power values of harmonic components,
- Angles between voltage and current harmonics,
- Power factor, cosφ, tanφ,
- Unbalance factors and symmetrical components for three-phase systems,
- Short-term and long-term flicker P_{st} and P_{lt}

Selected parameters are aggregated (averaged) according to the time set by the user and can be written on the memory card. In addition to average value, it is also possible to record minimum and maximum values during the averaging period, as well as the actual value at the instant the record is being written.

The event detection module is also expanded. According to EN 50160, typical events include voltage dip (reduction of RMS voltage to less than 90% of nominal voltage), swell (increase to more than 110% of nominal value), and interruption (reduction of the supply voltage to less than 1 % of the nominal voltage). The user does not need to enter the settings defined in EN 50160, as the software allows an automatic configuration of the instrument to the energy measurement mode according to EN 50160. The user can take advantage of the manual configuration option, and the software offers a full flexibility in this area. Voltage is only one of many parameters according to which event detection thresholds can be defined. For instance, the analyzer can be configured to detect power factor reduction to below a set threshold, THD increase to above another threshold, and similarly the event of exceeding by the 9^{th} voltage harmonic of the user-defined value in percent. An event is recorded along with the time at which it happened. In case of events which involve exceeding of the set thresholds for voltage dip, swell and interruption, and exceeding of the current minimum and maximum values, the information can also include the voltage and current waveforms. It is possible to record 2 periods before the event and 4 after.

Very extensive configuration options along with a long list of measured parameters make the PQM-701 analyzer an exceptionally useful and powerful tool for measuring and analyzing of all types of mains systems and faults which occur in them. With some unique features, the PQM-701 stands out from other similar analyzers available in the market.

The list of parameters measured by the PQM-701 analyzer depending on the mains type is presented in Table 1.

Table 1. Measured parameters for various mains configurations

Parameter \ Mains type, channel		1-ph		2-ph				3-ph wye with N					3-ph delta 3-ph wye without N			
		A	N	A	B	N	Σ	A	B	C	N	Σ	A	B	C	Σ
U	RMS voltage	●	●	●	●	●		●	●	●	●		●	●	●	
U_{DC}	Voltage DC component	●	●	●	●	●		●	●	●	●		●	●	●	
I	RMS current	●	●	●	●	●		●	●	●	●		●	●	●	
I_{DC}	Current DC 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	●		●	●		●	●	●	●		●				
tanφ	Tangent φ	●		●	●		●	●	●	●		●				●(1)
THD U	Total Harmonic Distortion – voltage	●	●	●	●	●		●	●	●	●		●	●	●	
THD I	Total Harmonic Distortion – current	●	●	●	●	●		●	●	●	●		●	●	●	
K	K-Factor	●	●	●	●	●		●	●	●	●		●	●	●	
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_{h50}	Voltage harmonics amplitudes	●	●	●	●	●		●	●	●	●		●	●	●	
I_{h1}..I_{h50}	Current harmonics amplitudes	●	●	●	●	●		●	●	●	●		●	●	●	
φ_{UI1}.. φ_{UI50}	Angles between voltage and current harmonics	●		●	●			●	●	●						
P_{h1}..P_{h50}	Harmonics active power	●		●	●			●	●	●						
Q_{h1}..Q_{h50}	Harmonics reactive power	●		●	●			●	●	●						
Unbalance U, I	Symmetrical components and unbalance factors											●				●
P_{st}, P_{lt}	Flicker	●		●	●			●	●	●			●	●	●	

Note: A, B, C: successive phases (L1/A, L2/B, L3/C),
N: measurement for the N-PE voltage channel or I_N current channel depending on the parameter type,
Σ: total value of the system.
(1) In three-phase 3-wire mains systems, the total reactive power is calculated as the nonactive power $N = \sqrt{S_e^2 - P^2}$ (see discussion on reactive power in section 9.7)

1.8 Conformity to standards

The PQM-701 analyzer has been designed to meet the requirements of the following standards.
Standards relating to measurement of mains parameters:

- IEC 61000-4-30:2009 – Electromagnetic compatibility (EMC). Testing and measurement techniques. Power quality measurement methods,
- IEC 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 Thereto,
- IEC 61000-4-15:1999 – Electromagnetic compatibility (EMC) – Testing and Measurement Techniques - Flickermeter. Functional and Design Specifications,
- EN 50160:2008 – Voltage characteristics of electricity supplied by public distribution networks.

Standards relating to safety:

- IEC 61010-1 - Safety requirements for electrical equipment for measurement, control and laboratory use. Part 1: General requirements

The instrument meets fully the requirements of class S according to IEC 61000-4-30, however in many aspects it meets also the requirements of more restrictive class A. This is summarized in the table below.

Table 2. Summary of conformity to standards for selected parameters

Aggregation of measurements in time intervals	IEC 61000-4-30 class S: • Basic measurement time for parameters (voltage, current, harmonics, unbalance) is a 10-period interval for 50 Hz system and 12-period interval for 60 Hz system, • 3-s interval (150 periods for 50 Hz rated frequency and 180 periods for 60 Hz), • 10-min interval, • 2-h interval (based on twelve 10-min intervals)
Real time clock (RTC) uncertainty	IEC 61000-4-30 Class S: • In-built real time clock set from the “SONEL Analysis” software, no GPS or radio synchronization, • Clock accuracy better than ±0,3s/day
Frequency	Meets the requirements of IEC 61000-4-30 class A for measurement method and uncertainty
Supply voltage	Meets the requirements of IEC 61000-4-30 class A for measurement method and uncertainty
Voltage fluctuations (flicker)	Measurement method and uncertainty meet the requirements of IEC 61000-4-15
Supply voltage dip, interruption and swell	Meets the requirements of IEC 61000-4-30 class A for measurement method and uncertainty
Supply voltage unbalance	Meets the requirements of IEC 61000-4-30 class A for measurement method and uncertainty
Voltage and current harmonics	Measurement method and uncertainty conforms to IEC 61000-4-7 class I

1.9 Mounting on DIN rail

The kit includes two catches for mounting the analyzer on a standard DIN rail. To do this, first remove the metal bracket bolted to the back of the analyzer. Then, install two catches on the casing, hand the analyzer on the DIN rail and finally turn and lock the catches. Mounting is shown in Fig. 2.

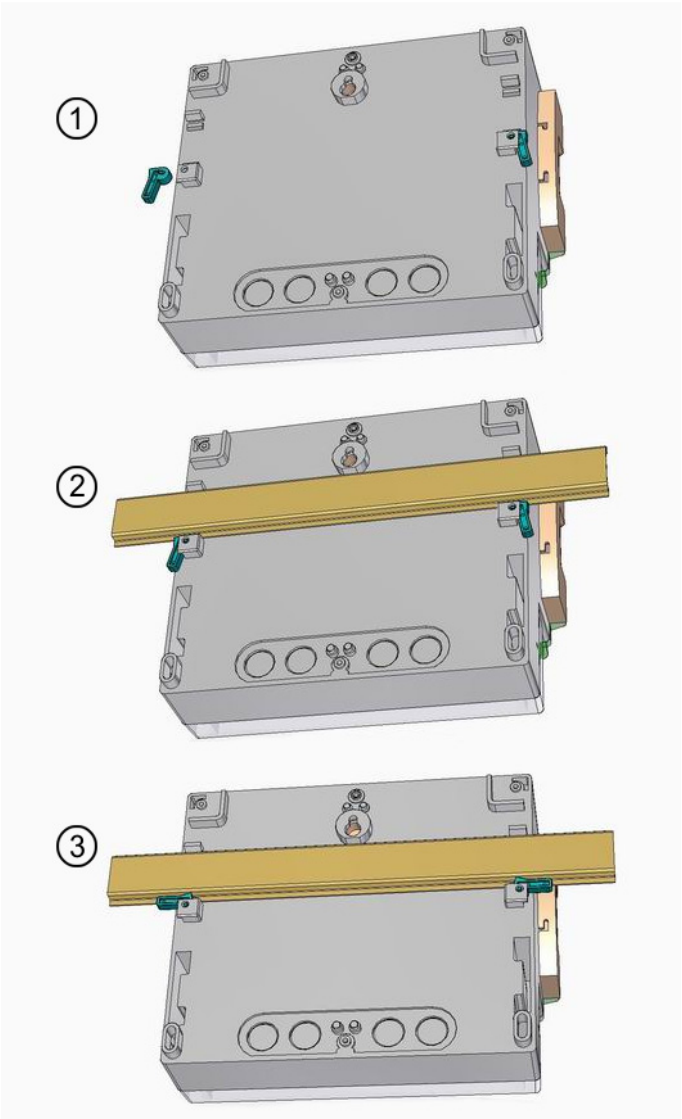


Fig. 3. Mounting the analyzer on DIN rail

2 Operation of the analyzer

2.1 Switching on and off

- To switch on the analyzer, briefly press the ⏻ button. Self-test is launched when the instrument is switched on and relevant **Exxx** message is displayed accompanied by a long audio signal (3 seconds) when internal error is detected – the measurements are blocked.
- Current time of the analyzer is displayed after the self-test (2 seconds).
- The **WAIT** message informs about initialization of the SD card - it may take a few seconds.
- If the memory card is from another analyzer, the user is asked to enter the analyzer's – card owner's PIN code to get access to the card. During the first logging with such card, it is assigned to the analyzer and its PIN is updated.
- **CARD** message appears in case of an initialization error. If the file system on the card is damaged (or if the user has formatted the card manually), the analyzer will suggest card formatting (message **FORM**); press **START/STOP** to start the formatting process (3 short audio signals). When the formatting is completed, the analyzer repeats the SD card initialization.
- During the formatting of the card, the analyzer performs speed test of the card. The **CARD** message is displayed if the card is too slow. It is recommended to use only the cards supplied by the analyzer manufacturer.
- If, during the card initialization, the analyzer detects the FIRMWARE.PQF file in the root directory which includes the analyzer firmware, and its version is newer than present analyzer firmware version, a firmware update process will be suggested – **UPDT** message. Press **START/STOP** to start the process (3 short audio signals), and observe progress in percent on the display. **DONE** informs about successful update; if the update has been unsuccessful, the message is **FAIL.** Then, the analyzer will automatically switch off. This process brings the risk of the analyzer damage, so it is performed without the manufacturer's warranty. A safer method is to perform this process at the manufacturer's service department.
- The analyzer sets on the last active measurement point and starts the test of connection correctness depending on the set mains configuration.
  A typical test procedure for three-phase wye or delta configuration:
  - L1 LED is on (or L1 and L2 for delta configuration) and the display shows the voltage in this phase for 2 seconds, and then the current for 2 seconds (if the current measurement is activated),
  - L2 LED is on (or L2 and L3 for delta configuration) and the display shows the voltage in this phase for 2 seconds, and then the current for 2 seconds,
  - L3 LED is on (or L1 and L2 for delta configuration) and the display shows the voltage in this phase for 2 seconds, and then the current for 2 seconds,
  - If a configuration error has been detected (such as incorrect RMS voltage or switched phases), the **ERR** message will be displayed for 2 seconds. This does not block the analyzer operation, and only warns the user about a potential configuration or connection error,
  - The displays shows the **STOP** message which indicates absence of recording. Press **START/STOP** to activate recording (**MEM** message is displayed if the space on the card for this measurement point is full; if the space allocated to this point is set to zero, the message is **LIVE**).
- Before the measurement or during the recording (if not in the sleep mode), the LED's show the following mains statuses:
  - LED is off – correct voltage and phase angle
  - LED is flashing – emergency state (i.e. switched phases L2 and L3 - both LED's are flashing).
  - LED (LEDs) is flashing faster – measured mains frequency differs from the rated frequency of present measurement point.

This depends on the mains type selected in the configuration. For a one-phase system, only the L1 LED is active. For a split-phase system, active are L1 and L2, and all three LEDs are active in case of a three-phase system.

- Table 3 lists the messages displayed during the test and during the operation of the instrument.

Table 3. Messages shown on the analyzer display.

Displayed message	Description
BATT	Analyzer switches off due to discharged battery. Connect external power supply.
CARD	Absence of SD card or card damaged. Measurements are blocked.
CODE	Enter the key lock code to unlock.
ERR + long audio signal	Installation error (i.e. switched two phases, wrong polarization of current clamp, etc.) which can cause incorrect measurements (incorrect phasor diagram). The LED's corresponding to phases with potential error are on. This error does not block the measurements, it only warns about possible incorrect recording.
EVNT	Waiting for automatic triggering of recording by the first detected event.
Exxx	Internal analyzer error. If the error persists after rebooting, contact the Sonel S.A. service department.
E150	Open fuse detected (PQM-701 only). Replace with the same rated fuse.
F1.00	Displaying the firmware after switching the analyzer on (here: version 1.00)
FORM	SD card formatting (user to confirm the formatting by pressing the **START/STOP** button)
LIVE	No space on the SD card has been allocated to a given measurement point – it is only possible to measure the instantaneous data and view them in the PC application, according to the saved configuration.
LOGG	Recording in progress. Inactive connection with PC.
MEM	After switch-on, the instrument has detected full memory in the active measurement point. Measurements are blocked. To change the measurement point, press **P1…4**.
PC	Active connection with the PC's "SONEL Analysis" software
PIN	Enter the PIN code to get access to the SD card from another analyzer
REP	Attempt to restore the data after the SD card has been removed during the recording
STOP	Standby mode. No recording. Inactive connection with PC.
TIME	Waiting for automatic triggering of recording in case of scheduled recording
UPDT	The user to confirm the firmware update by pressing **START/STOP** button. Press **P1…4** to skip the update.
WAIT	SD card scanning in progress.
DONE/OK/FAIL	Operation successful/ failed.

- When the measurement point is changed, the connections testing sequence is repeated.
- To switch off the analyzer, press the ⏻ button and hold for 2 seconds, unless the key lock or recording are activated.
- Pressing an active key causes a short, high-pitched audio signal; for an inactive key, the signal will be longer and lower pitched.

Notes

*• Before removing the SD card, it is recommended to switch off the analyzer with the **ON/OFF** button. This will prevent possible data loss on the memory card.*

*• The **CARD** message indicates that the SD card has been removed during the analyzer operation. This may cause the loss of unsaved data or total damage of the SD card file system, particularly if recording was in progress.*

• Do not interfere with the SD card file system (i.e. create and save your own files or delete the files saved by the analyzer).

*• Removing the card from the slot when recording is in progress brings the risk of data loss or file system damage. To minimize such risk, reinsert the card to the slot (without switching the analyzer off), and an attempt will be made to save the buffered data. The display will show the **REP** message. If the procedure has been successful, the display will show **OK**, and the analyzer will resume recording; otherwise, the display will show **FAIL**, which may mean an irreversible damage to the file system.*

• It is recommended to discharge any accumulated electrostatic charges before touching the card by touching a conductive and earthed object.

2.2 Connection with PC and data transmission

- When the analyzer is switched on with the ⏻ button, the radio module and USB port are permanently active to send the measurement data at any moment in real time and to remotely trigger or stop the recording.

Note

Before connecting to the analyser through a wireless connection, the user must add the analyser to the base of analysers (Options -> Base of analysers). When searching for analysers in the base, the list of displayed analysers includes only those entered in the base. See more information in Chapter 8.4.

- **PC** message appears when the analyzer is connected to a PC; if the instrument is in the recording mode, the message is **P.C.** (the dots are flashing with the 0.5s period).
- Connection to a computer (PC mode) allows:
  - Transmission of data saved in the recorder memory:
    - During the recording, it is possible to read some of the data saved for an active measurement point; successive data blocks are successively saved on the card;
    - All saved data can be read for other measurement points.
  - Viewing the mains parameters on the computer:
    - instantaneous values of current, power and energy; total values for the whole system;
    - harmonic components, harmonics power and THD,
    - unbalance,
    - voltage phasor diagrams,
    - current and voltage waveforms drawn in the real time.
- All buttons are locked during the connection with a PC except for the ⏻ button unless the analyzer is working in the key lock mode (i.e. during the recording) – then all buttons are locked.

- In order to connect with the analyzer, enter its PIN code which is saved on the memory card. The default code is 000 (three zeros). The PIN code can be changed with the "SONEL Analysis" application. It is not possible to connect to the analyzer without a correct memory card inserted.
- If an incorrect PIN code is entered three times in a row, the data transmission will be impossible for 10 minutes. You can re-enter the PIN code only after this 10-minute period.
- If after the analyzer has been connected to the PC and no data exchange has occurred within 30 seconds, the analyzer exits the data transmission mode and terminates the connection.

Notes

- *Keeping the **P1…4** and ⏻ buttons depressed for 5 seconds causes an emergency reset to the default PIN code (000).*
- *If the key lock mode is activated during recording, it has a higher priority (you need to unlock the keys in an emergency mode to reset the PIN). Emergency unlocking of the keyboard is performed by keeping the buttons **START/STOP** and ⏻ depressed for 5 seconds.*

2.2.1 Serial port RS-232 (only PQM-701Zr)

Serial port (RS-232) of PQM-701Zr may be used for:

- direct communication with a computer using a null-modem type cable (male-female interlaced cable),
- to connect an external GSM modem for remote communication with the analyser via an Internet connection. In this a female-male non-interlaced cable shall be used (this kind of cable is supplied as a standard accessory for the PQM-701Zr analyser).

Depending on a selected method for communication the Sonel Analiza software must be configured appropriately.
See more information in Chapter 9.

2.3 Performing the measurements

2.3.1 Measurement points

The analyzer allows storing 4 totally independent measurement configurations which are called "measurement points". The number of an activated point is indicated by a relevant LED above the display.

- The point can be changed in the 1…4 sequence by pressing the **P1…4** button.
- After the next measurement point is selected, the correctness test sequence of connection to the mains is performed.
- The user can define any share of memory (in percent) of each point (i.e. 100% for 1, no other points; or 25% for each point). If the whole memory is allocated to a given measurement point, when the remaining points are selected, the display shows the **LIVE** message to signal that only viewing of the mains parameters is available in the Live mode.

2.3.2 Triggering and stopping the recording

The recording according to the measurement point configuration can be activated by three methods:

- in the immediate mode, by pressing the **START/STOP** button; or from the application, if the connection with PC is active;
- according to the schedule preset in the application (up to four time intervals): in this case when the **START/STOP** button is pressed, the analyzer checks if current time is included in

one of the preset time intervals. If yes, the analyzer starts the recording. If the analyzer is in the waiting mode for the next recording period, the **TIME** message is displayed;
- in the threshold mode, after an event threshold set in the configuration is exceeded; pressing of the **START/STOP** button switches the meter into the normal measurement mode, but the saving of the files (proper recording) starts only when the first event is detected. In the event waiting mode, the display shows the **EVNT** message.

In the recording mode (if there is no active connection with PC), the display shows **LOGG**, including the flashing dots (recording in the PC mode is indicated with dots only). Pressing the **P1…4** button will display voltages and currents values in the same fashion as in the test procedure described earlier.

Termination of the recording:
- The recording is terminated automatically in the schedule mode; in remaining cases the recoding continues until stopped by the user (by means of the **START/STOP** or from the application). Absence of recording is indicated by the **STOP** message on the display.
- The recording is terminated automatically if the whole space on the memory card allocated to given measurement point is used up. Such being the case, the display shows the **MEM** message.
- The display remains off after the recording is completed, if the sleep mode is activated in the configuration. By pressing any button, you can cause the **STOP** message to be displayed (if no key lock has been activated) or the **CODE** message (if the lock has been activated).

2.3.3 Approximate recording times

The maximum recording time depends on many factors such as the size of the allocated space on a 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 Table 4. The last column gives the approximate recording times when 2GB of memory card space is allocated to a measurement point. The typical configurations shown below includes the measurement of the N-PE voltage and I_N current.

Table 4. 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 EN 50160	10min	3-phase wye	• (1000 events)	• (1000 events)	•	6 years
according to the "voltages and currents" profile	1s	3-phase wye				270 days
according to the "voltages and currents" profile	1s	3-phase wye			•	4 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 days
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)	•	14.5 days

2.4 Key lock

The PC application allows the key lock function to be activated after the start of the recording. This is to protect the analyzer from stopping the recording by unauthorized personnel. To unlock the keys (buttons), enter a three-digit code:

- press any button to display the **CODE** message, and then three dashes "**- - -**";
- use the keyboard buttons to enter the correct unlocking code: with the ⏻ button change the digits sequentially 0, 1, 2…9, 0 on position one, with the **P1…4** button on position two, and with the **START/STOP** on position three.
- a three-second inactivity of the keyboard buttons causes the entered code to be checked;
- correctly entered code is indicated by the **OK** message and the keys are unlocked; if an incorrect code has been entered, the display shows the **NO** message for 2 seconds and returns to the previous state (i.e. it switches off if previously in the off mode),

After unlocking, the keyboard automatically locks again, if the user has not pressed any button for 30 seconds.

> ***Note***
> *Emergency unlocking of the keyboard is performed by keeping the buttons START/STOP and ⏻ depressed for 5 seconds.*

2.5 Sleep mode

You can activate the sleep mode in the PC software. In this mode, after 10 seconds following the recording, the analyzer switches off the display and all LED's. Since then, only the dots which signal the recording flash every 10 seconds.

2.6 Indication of connection error

Three yellow LEDs, marked as L1/A, L2/B, L3/C, are used to signal a possible error in connecting the analyzer to the mains, or possibly the discrepancies of the measured parameters with the configuration of active measurement point.

The LEDs have dual function: they are used during the self-test procedure when the analyzer displays the voltage and current values, and in the real time during the analyzer operation.

The self-test is performed when the analyzer is switched on and each time after the measurement point is changed with the **P1…4** button. During this procedure, the LEDs are

permanently on, indicating the tested phase. For more detailed description of the self-test, refer to section 2.1.

During the analyzer operation (in the **STOP** and recording modes), these LEDs perform the control function and indicate the following states:

- deviation from the RMS voltage by more than ±15% of the rated value – slow flashing - every 300ms),
- deviation from the phase angle of voltage fundamental component by more than ±30° of the theoretical value at the resistive load and the symmetrical system (slow flashing),
- deviation from the phase angle of current fundamental component by more than ±30° of the theoretical value at the resistive load and the symmetrical system (slow flashing),
- deviation from the mains frequency by more than ±10% of the rated value (fast flashing – every 150ms).

> ***Note***
> *The phase error detection requires that the fundamental is greater or equal 5% of the nominal voltage, or 5% of the nominal current range. If this condition is not met, the angles correctness is not checked.*

Activated are only the LEDs of the phases in which a parameter has been exceeded. In case of a frequency error, LEDs of all active phases are flashing.

For the wye or delta systems without a neutral conductor, two LEDs are activated for each phase, i.e. a phase-to-phase voltage error results in the L1/A and L2/B LEDs flashing.

This functionality allows a quick visual assessment if the mains parameters are compatible with the analyzer configuration.

2.7 Automatic switch-off function

If the analyzer operates for at least 30 minutes on the battery supply (absence of mains supply), and is not in the recording mode, and the connection with the PC is not active, the instrument will switch off automatically to prevent the battery discharge. The display shows the **OFF** message for one second.

The analyzer will also switch off automatically in case of total battery discharge. Such emergency switch-off is performed independently of the present analyzer mode. Any active recording will be stopped. The recording will resume when the power supply is restored. Emergency switch-off is indicated by the **BATT** message.

3 Measuring circuits

The analyzer can be connected to the following mains types:

- Single-phase with neutral (Fig. 3)
- Split-phase (Fig. 4),
- Three-phase 4-wire wye (Fig. 5),
- Three-phase 3-wire wye (Fig. 6),
- Three-phase 3-wire delta (Fig. 7).

In three-phase systems, it is possible to measure the currents with Aron's method, using only two clamps measuring the line currents I_{L1} and I_{L3}. The I_{L2} is then calculated according to the formula:

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

This method can be used in the delta systems (Fig. 8) and the wye systems without neutral conductor (Fig. 9).

> ***Note***
> *Because the voltage measuring channels are referenced to terminal N, in the systems without neutral conductor, it is necessary to connect (short) the N and L3 analyzer terminals, as shown in Fig. 7, Fig. 8, Fig. 9 and Fig. 10 (three-phase 3-wire wye and delta systems).*

In systems with neutral conductor, the current can be measured in such conductor after an additional clamp is connected in the I_N channel. To perform this measurement, activate the **N-conductor current** option in the configuration (see section 5.2.1 and Fig. 30).

> ***Note***
> *For correct calculation of total apparent power S_e and total power factor PF in a 4-wire, three-phase system, it is necessary to measure the current in the neutral conductor. In such case always activate the **N-conductor current** option and connect 4 clamps as shown in Fig. 6. For more information, refer to section 10.7.5.*

In case of systems with PE and N conductors (protective earth and neutral), it is also possible to measure the N-PE voltage. To do this, connect the PE conductor to the PE voltage analyzer terminal and additionally select the option **N-PE voltage** in the measurement point configuration (see section 5.2.1 and Fig. 30).

Note the direction of current clamps (also flexible clamps). The clamp should be placed so that the arrow on it is directed towards the load. To verify, you can measure the active power – in majority of passive receivers, active power has the plus (positive) sign.

Connection of the analyzer to different mains types is shown in the figures below.

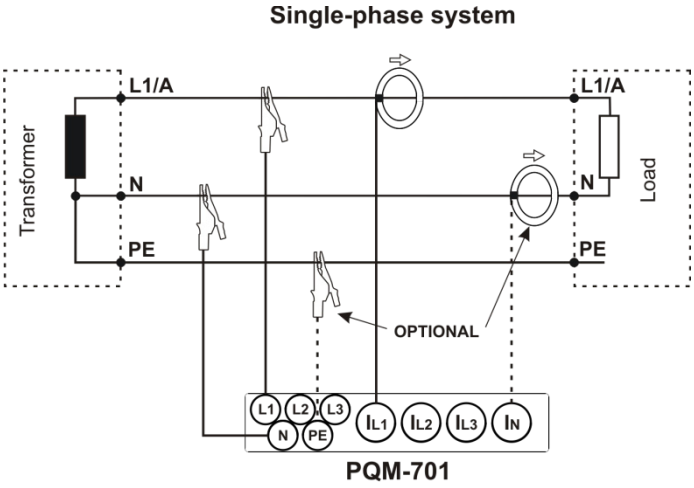


Fig. 4. Connection diagram – single-phase system.

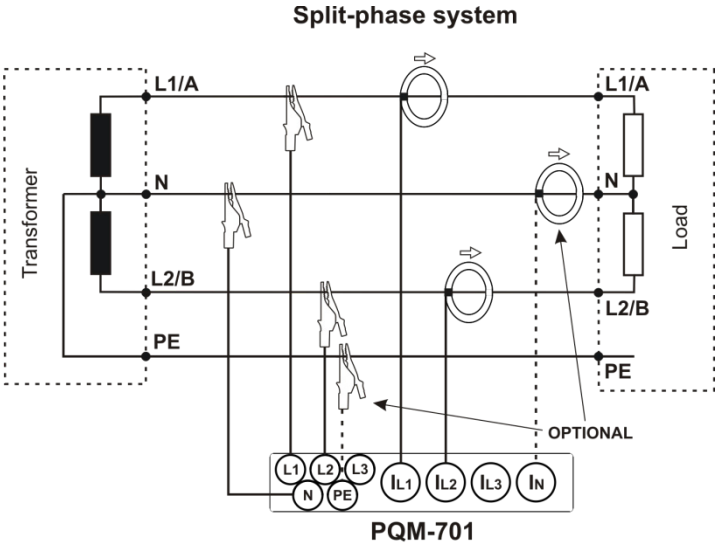


Fig. 5. Connection diagram – split-phase system.

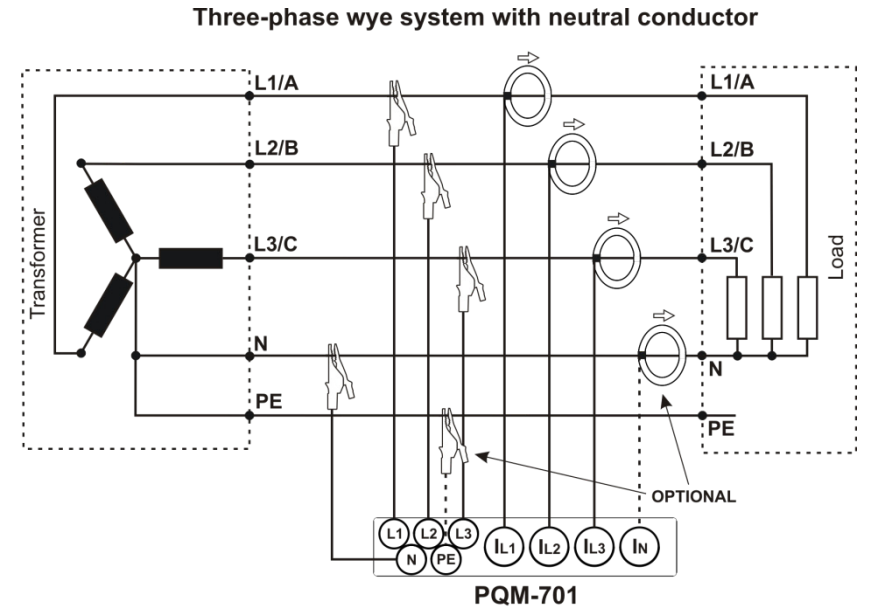


Fig. 6. Connection diagram – three-phase wye system with neutral conductor.

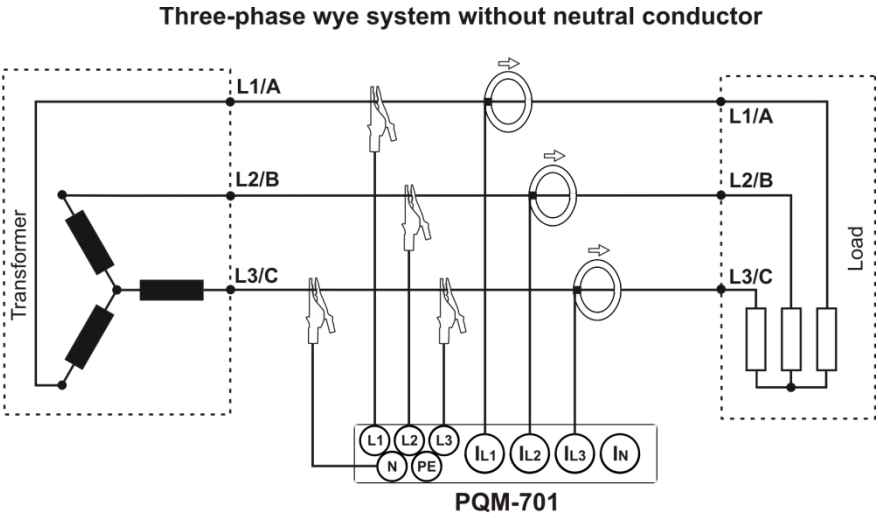


Fig. 7. Connection diagram – three-phase wye system without neutral conductor.

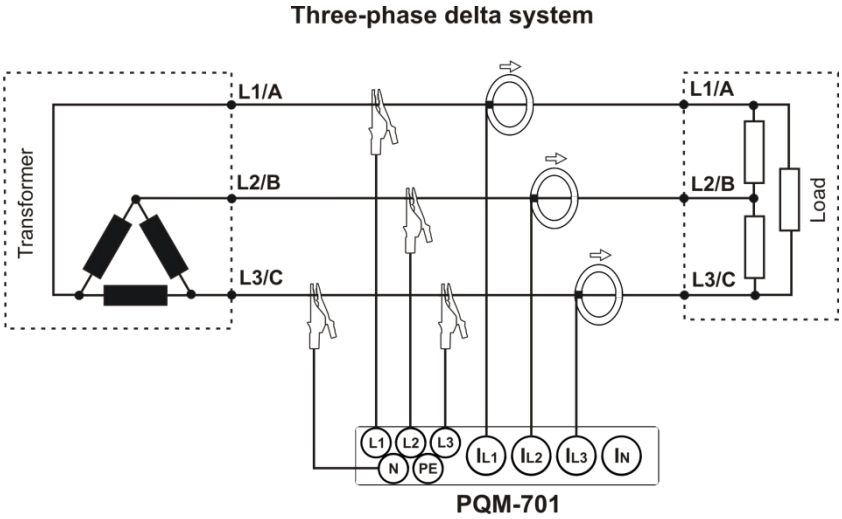


Fig. 8. Connection diagram – three-phase delta system.

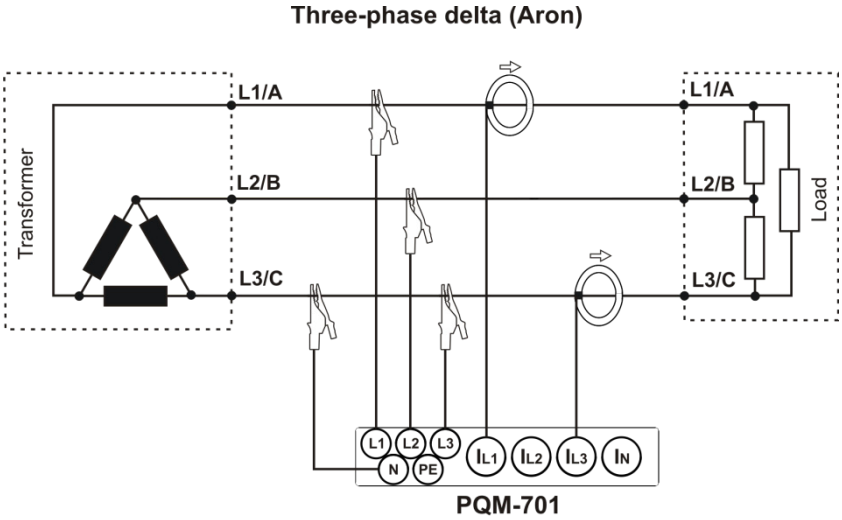


Fig. 9. Connection diagram – three-phase delta system (current measurement with Aron's method).

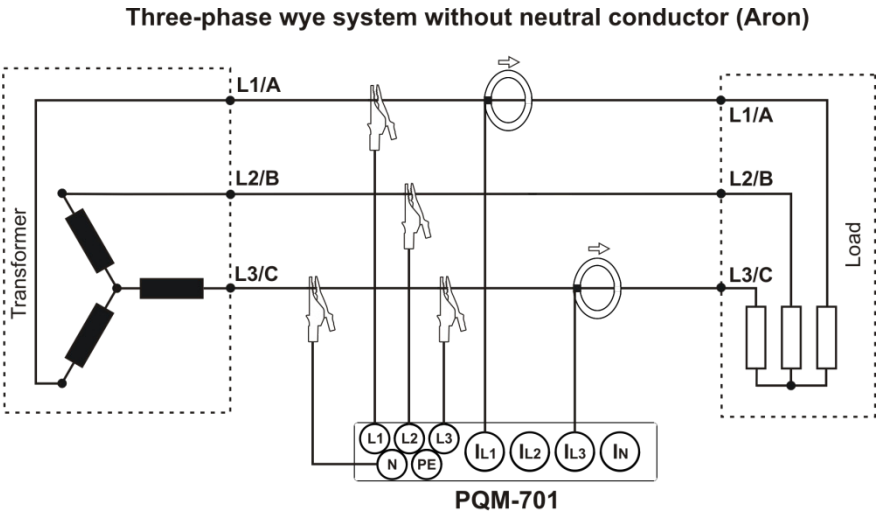


Fig. 10. Connection diagram – three-phase wye system without neutral conductor (current measurement with Aron's method).

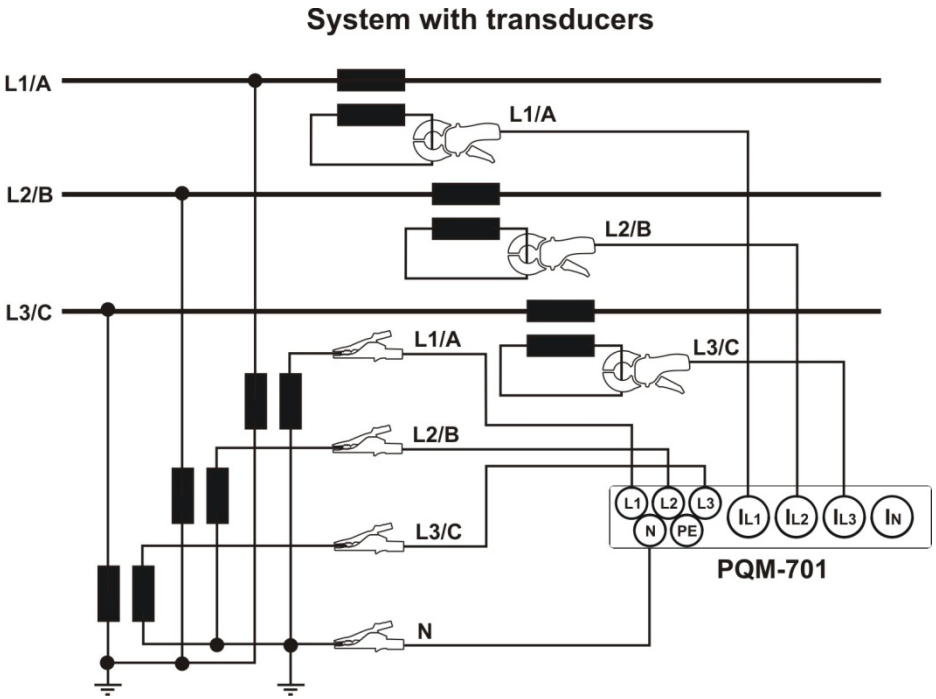


Fig. 11. Connection diagram – system with transducers

4 “SONEL Analysis” software

“SONEL Analysis” is an application necessary for using the PQM-701 analyzer. It allows:

- analyzer configuration,
- reading data from the recorder,
- viewing the mains parameters in real time,
- deleting data in the analyzer,
- showing the data in table format,
- showing the data in the graph format,
- analyzing the data in terms of EN 50160 (reports) and other user defined reference conditions,
- independent operation of many devices,
- web-based upgrade to newer versions.

4.1 Minimum hardware requirements

Table 5 gives the minimum and recommended configuration of a PC running the "Sonel Analysis" software.

Table 5. Minimum and recommended PC configuration

Configuration	Minimum	Recommended
Processor	1GHz	Pentium IV 2.4GHz
RAM	512MB	2GB
Free space on hard disk	150MB	2GB
Graphics Card	32MB, resolution 1024x768	64MB, with OpenGL support, 1024x768
USB	•	•
Internet access (for automatic updates)		•
Operating system	Windows XP, Windows Vista, Windows 7	

4.2 Software installation

Note
In order to facilitate installation of the PQM-701 drivers, it is recommended to install the “ SONEL Analysis” software and the drivers before connecting the USB cable.

To start the installation of “SONEL Analysis”, open the installation file (such as “Setup Sonel Analysis 1.0.57.exe”) from the CD delivered with the analyzer.

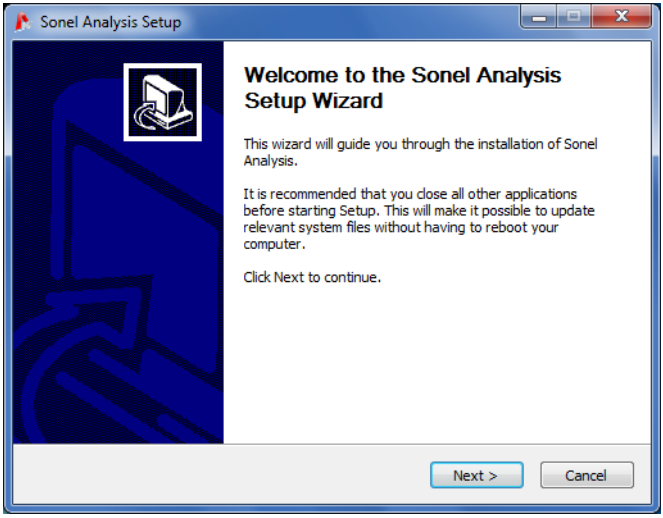


Fig. 12. Installer – starting screen.

Click “Next>”.

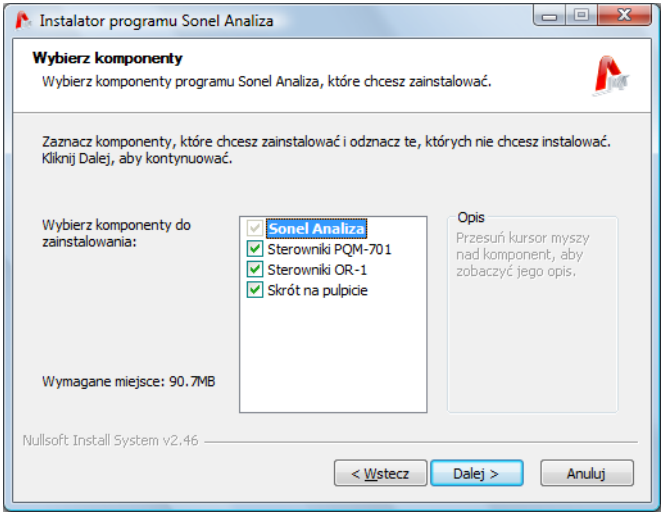


Fig. 13. Installer – choosing components.

Select option; "PQM-701 drivers", "OR-1 drivers" (when using wireless module OR-1), and optionaly "Desktop shortcut". Then click „"Next>”.

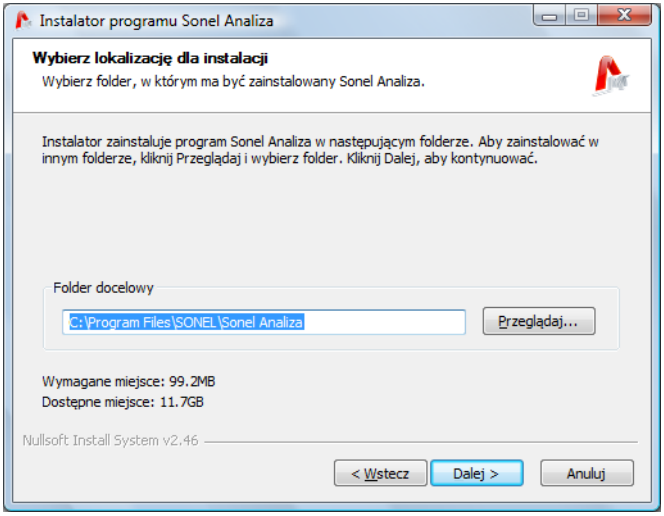


Fig. 14. Installer – program location settings.

Select the installation location by clicking "Browse...", or leave default settings of the installation. Click "Next>".

The last step is to choose the software name which will be displayed in the Start menu. The installer is ready to install the software.

To begin the installation, press "Install".

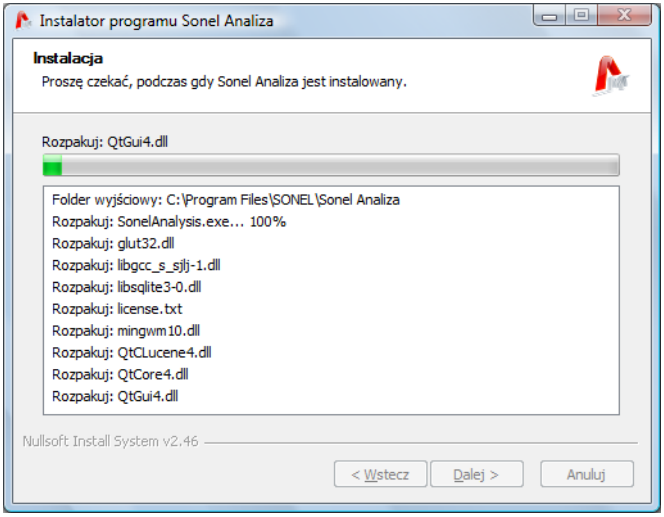


Fig. 15. Installation of the program.

In the final part, the program installs the drivers (if the user has chosen this option). 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).

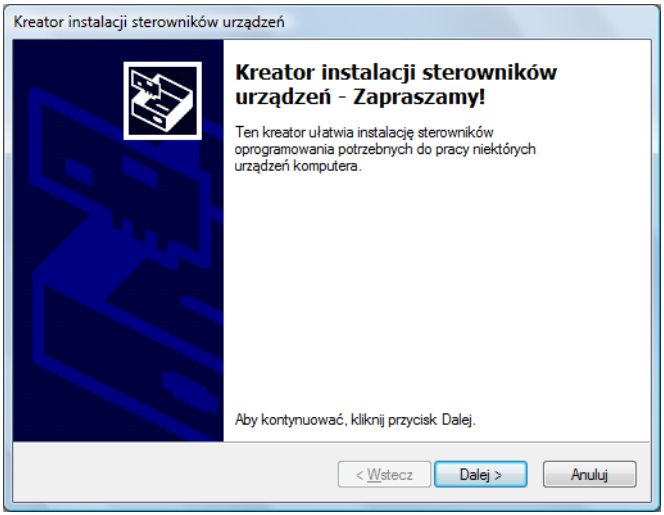


Fig. 16. Installer – installation wizard for drivers.

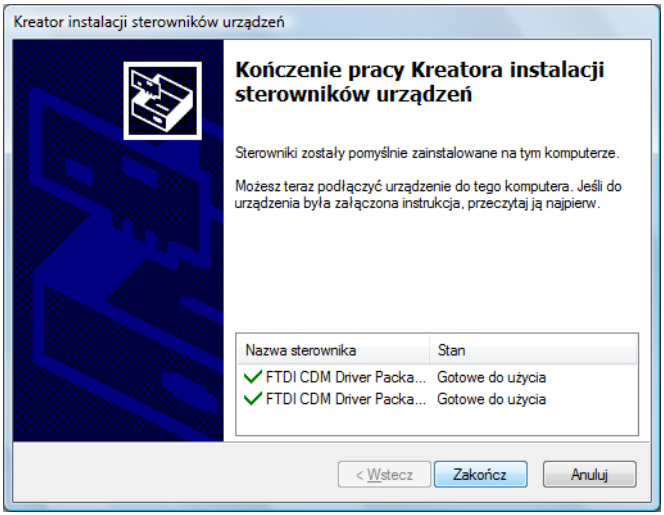


Fig. 17. Installer – installation of drivers completed PQM-701.

At the end of software installation, the window will appear as shown in Fig. 18. If the option “Run Sonel Analysis” has been checked, then after clicking the “Finish” button, the application will be launched.

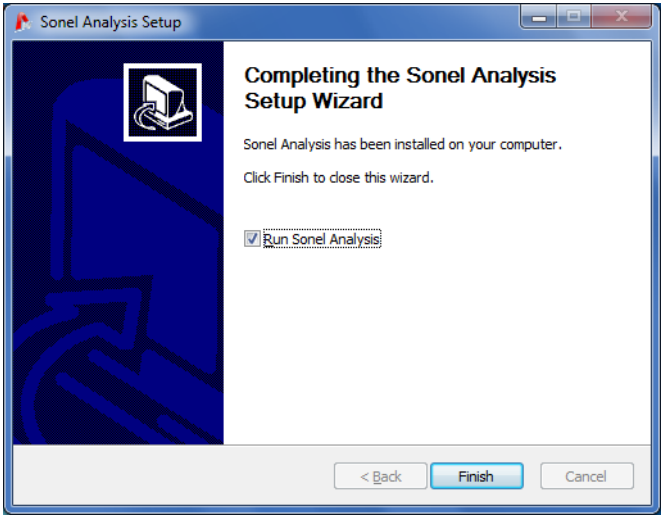


Fig. 1. Finishing the installation.

Now you can connect the PQM-701 to the computer. The system should automatically recognize the connected device.
If the installation has been successful, the computer is ready to work with the PQM-701 analyzer.

4.3 Launching the program

When the program is launched, the main window appears as shown in Fig. 19. Individual icons have the following meaning (from left to right):

- **Open** – depending on the context, load the analyzer configuration, the saved analysis, or the saved recording from the disk,
- **Save** – depending on the context, save the analyzer configuration on the disk (during configuration editing), save raw data or present analysis files (during the analysis),
- **Settings** – analyzer configuration module,
- **Live mode** – view the instantaneous values in real time,
- **Analysis** – module for data reading directly from the analyzer and data analysis,
- **SD card analysis** – module for data reading from the SD card (with the reader) and data analysis,
- **Disconnect** – terminate the communication session with the analyzer.

Extensions of the files created by SONEL Analysis software:

- *.settings – analyzer configuration files,
- *.config – SONEL Analysis configuration files,
- *.pqm701 – recording data files,
- *.analysis – analysis files.

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

- CTRL + T – analyzer configuration
- CTRL + I – time and security settings
- CTRL + F – program configuration,
- CTRL + L – live mode,
- CTRL + A – data analysis from the analyzer,
- CTRL + D – data analysis from the SD card,
- CTRL + S – save the analysis on the disk or screenshot in the instantaneous values reading mode.

After clicking on relevant icons, selecting items from top menu, or using hotkeys, the user can go to individual modules (described below) or to the software parameters configuration.

> ***Advice***
> *The commands can be selected with the mouse and with the keyboard (standard for Windows: ENTER – select option, ESC – cancel, TAB – go to the next button, etc.).*

Fig. 2. Main screen.

4.4 Selecting the analyzer

Before sending any data from/ to the analyzer, it is necessary to select the analyzer with which the “SONEL Analysis” software will connect. In order to connect to the analyzer, select any option which requires an active connection, such as **Settings**, **Live mode** or **Analysis.**

When one of the above-mentioned options has been selected and if no active connection with the analyzer has happened before, the software will display the “Connection” window (see Fig. 20). The analyzers are searched for in the wire mode (USB ports) and the wireless mode (if the OR-1 radio receiver is connected to the computer).

When the scanning is successful, a list appears with detected analyzers: analyzer model, serial number and type of communication line. Click on the selected analyzer and press the **Select** icon to accept a given analyzer from the list. Press the **Search again** icon to scan again for the analyzers.

When the analyzer is selected, the system will request the PIN code protecting against an unauthorized access. The PIN code has three digits: 0…9. Default PIN code is 000.

> ***Note***
> *If the PIN code is entered incorrectly three times, the data transmission will be blocked for 10 minutes.*

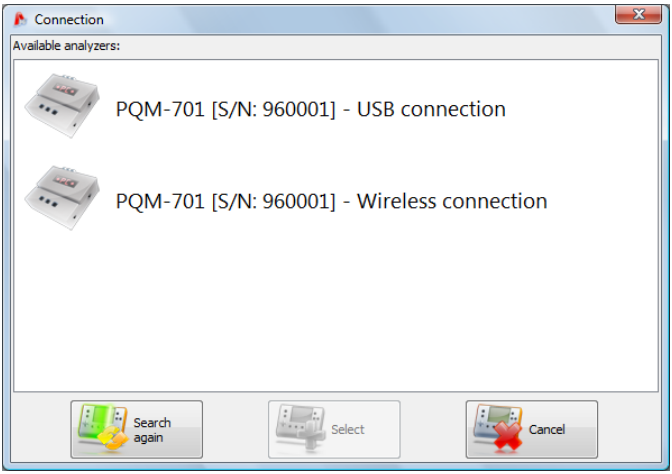


Fig. 3. Analyzer selection window.

Note

• Wireless analyzer detection is possible only after previous connection of the analyzer by means of the USB link, entering the correct PIN code and selecting the "Remember PIN" option (see Fig. 21). Then, the analyzer is added to the analyzer database. During the wireless search, only analyzers from the database can be detected.

• Registration involves entering the unique serial number. Based on this number, the software filters other analyzers (for instance within the radio interface range) which do not belong to the owner of a given software copy.

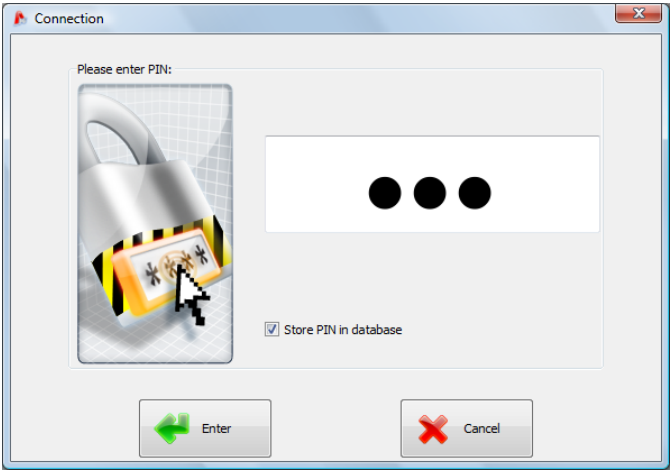


Fig. 4. PIN code verification.

If the "Remember PIN" option is checked in the authorization window, the serial number and the entered PIN will be associated, so that the user does not have to enter it again during the next connection (serial number and analyzer model are automatically added to the analyzer database). After a successful connection, a window appears which confirms connection with the analyzer – see Fig. 22. This screen also shows the analyzer information, such as its serial number, firmware and hardware version.

If automatic log-in is unsuccessful, the window shown in Fig. 21 is displayed again.

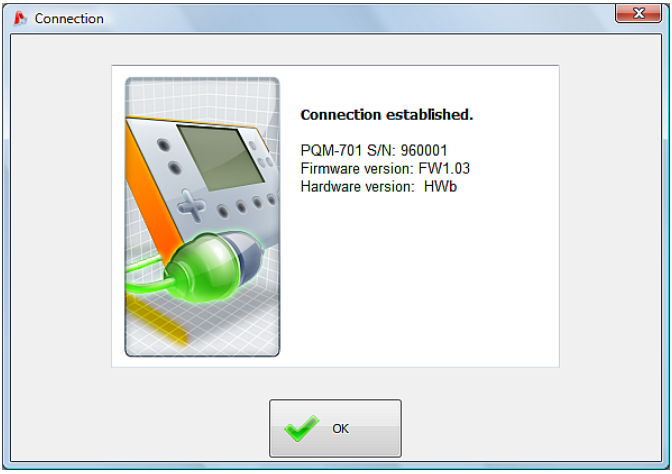


Fig. 5. Successful connection to the analyzer.

When incorrect PIN is entered, the window shown in Fig. 23 appears.

> ***Note***
> *When the transmission is blocked after three unsuccessful attempts to enter the PIN, during the next attempt to connect to the analyzer, the window will appear with the following message “Transmission blocked due to incorrect PIN!”*

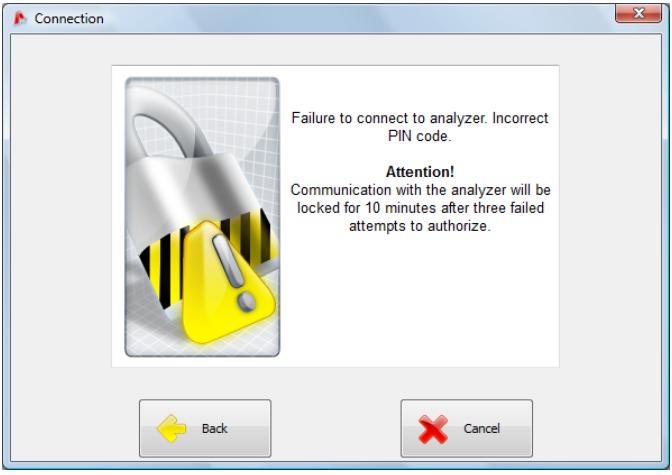


Fig. 6. Incorrect PIN.

An unsuccessful attempt to connect the analyzer for reasons not attributable to PIN will trigger the error message. Press the **Retry** button to repeat the attempt, or go to the analyzer selection window and select another analyzer, or rescan for available analyzers.

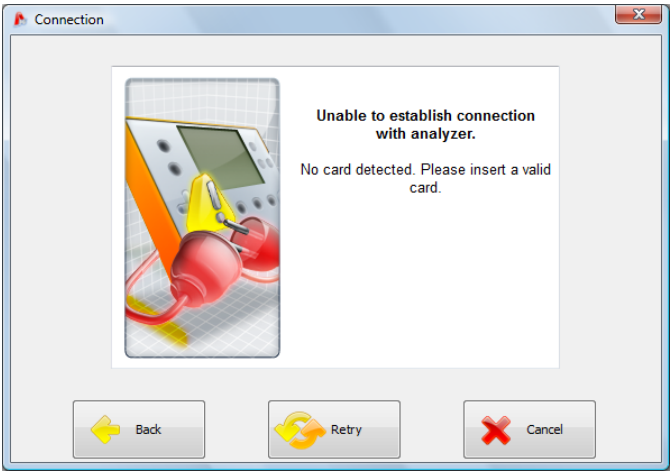


Fig. 7. Unsuccessful connection to the analyzer.

If the analyzer is switched off during the communication, the USB cable is plugged out, or the application cannot receive answer from the analyzer for any other reasons, the message shown in Fig. 25 will appear.

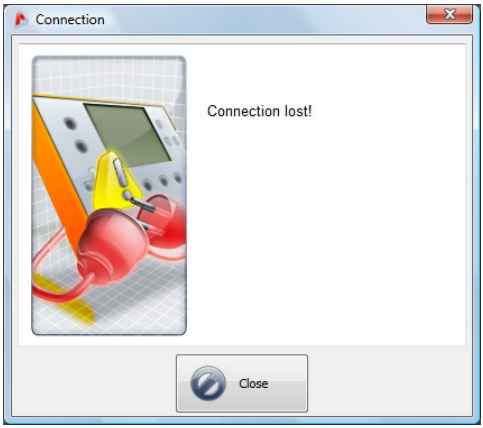


Fig. 8. Lost connection.

5 Analyzer configuration

In the main menu select **Analyzer → Settings** (or click the icon) to open the measurements configuration window as shown in Fig. 26. This is the most important part of the analyzer configuration, as 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. 26)) **Local** and **Analyzer**. The top part (**Local**) is used for parameters modification by the user, and the bottom part (**Analyzer**) stores the present analyzer settings and is read-only. Each part has a drop-down tree divided into four ***measurement points*** and **Analyzer settings**.

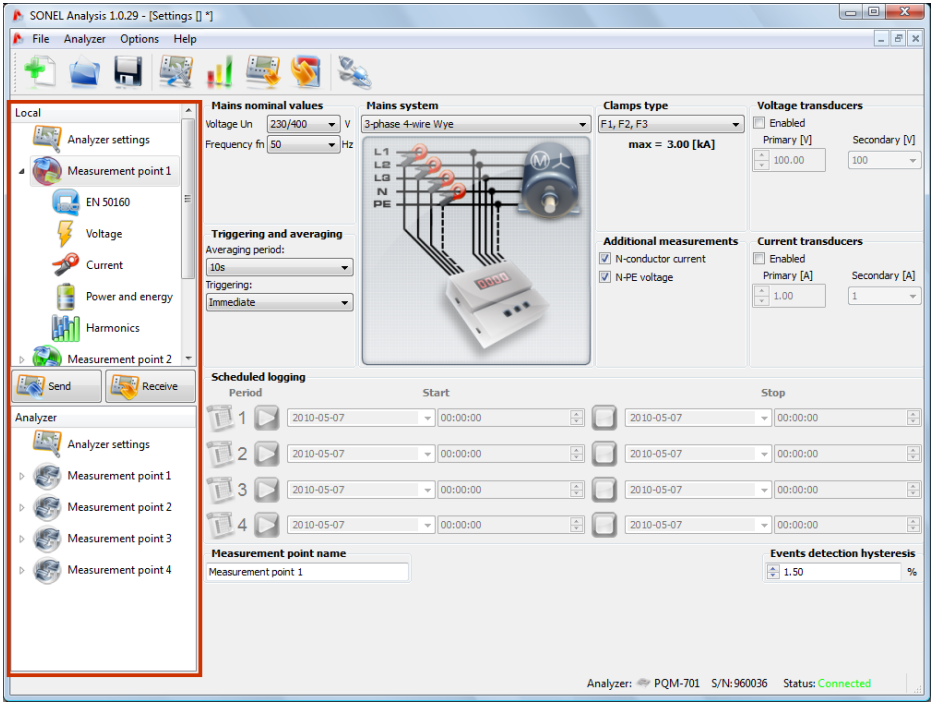


Fig. 9. Configuration of measurement points – settings tree.

Each of the four measurement points represents an independent measurement configuration of the analyzer. It is the measurement point configuration where the user defines the mains type, rated voltage and frequency, clamp type, recording parameters, and event detection parameters.

Active measurement point is indicated by one of the four green LED's located above the alphanumeric display.

The icons near the measurement points can appear in various colors:

- grey color means absence of connection with the analyzer.
- green means that the present configuration is synchronized with the analyzer configuration and with the configuration saved on the disk.

- blue means that the present configuration is compatible with the analyzer but differs from the configuration saved on the disk,
- yellow - configuration is incompatible with the analyzer but compatible with the configuration saved on the disk,
- red - present configuration differs from the analyzer configuration and from the configuration saved on the disk.

The **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 appear. The correct reading is also confirmed by a relevant message. Then all icons in the measurement points tree will change to blue, which means that the settings in the application and in the analyzer are identical.

The **Send** button is used to send the configuration to the analyzer. Before sending, the user is asked to confirm the operation (Fig. 27).

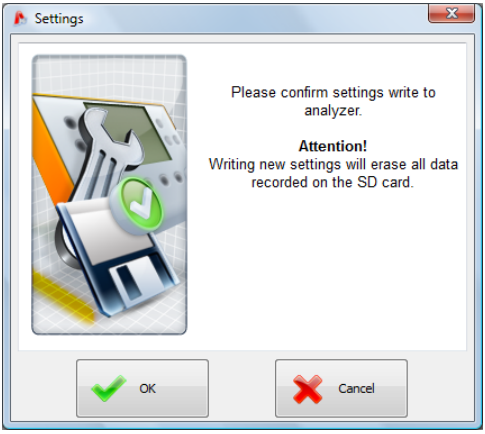


Fig. 10. Confirm configuration saving.

Note
Saving a new configuration will cause the loss of all data on the memory card. Such data should be previously downloaded from the analyzer and saved on a local disk.

Note
It is not possible to save a new configuration in the analyzer if the instrument is in the recording mode (the user will be warned by a relevant message – Fig. 28).

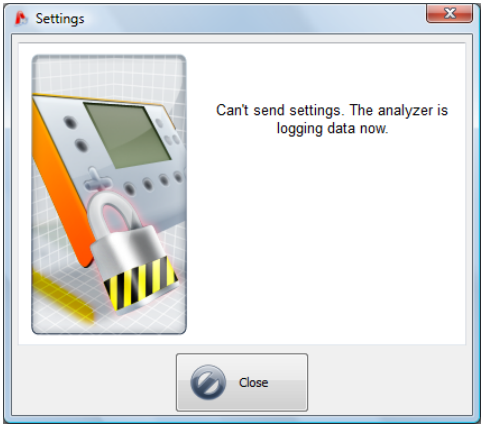


Fig. 11. Programming locked.

5.1 Analyzer settings

The first element to be configured in the left-hand side of the window is **Analyzer settings**. The **Memory allocation** tab is used to allocate the SD card memory to individual measurement points. Use the four sliders to determine the amount of memory for a given point (in MB and %). The allocation visualization is shown in the centre. All available card space (100%) can be freely divided among the four measurement points.

You can allocate card space to one measurement point; then the recording for other points will not be possible, the instantaneous mains data can only be viewed.

All measurement points have linear recording in the memory, when the memory allocated to a given point is used up, the recording stops.

Please remember that modification of memory allocation can require deletion of all data from the memory card. Thus, it is advisable to download such data and save it on a local disk.

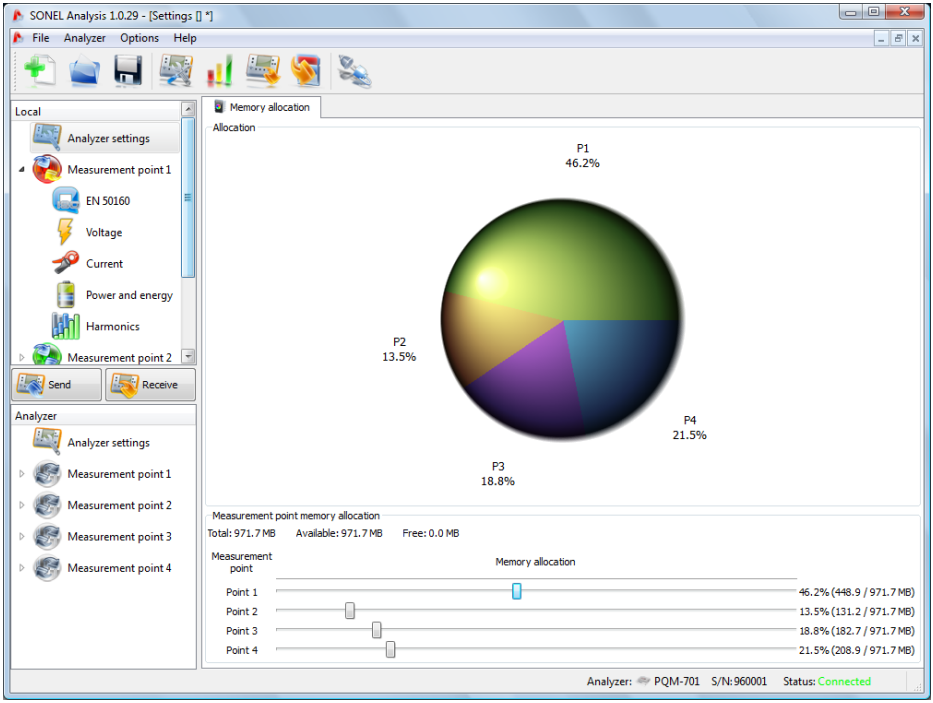


Fig. 12. Memory allocation window.

5.2 Measurement point configuration

To drop down the measurement point tree, click once on the square with the "+" or ">" sign or double-click on a given measurement point.
When a given memory point is highlighted (by single clicking), the main data settings related to such point appear in the right-hand part of the screen.

After dropping down of a given measurement point, the following list will be displayed:

- **EN 50160** – settings for the EN 50160-compliant recording,
- **Voltage** – setting the voltage-related parameters,
- **Current** – setting the current-related parameters,
- **Power and energy** – power and energy parameters,
- **Harmonics** – harmonics parameters.

Below please find the description of the main settings screen, and then of given fields.

5.2.1 General settings

The measurement point main settings screen is shown in Fig. 30. It has a few sections: the mains-related settings are grouped in the top part, below is the part related to recording by the schedule and time intervals. In addition, here you can give your own name to a measurement point and determine the hysteresis used during the event detection.

The following can be defined in the top part (Fig. 30):

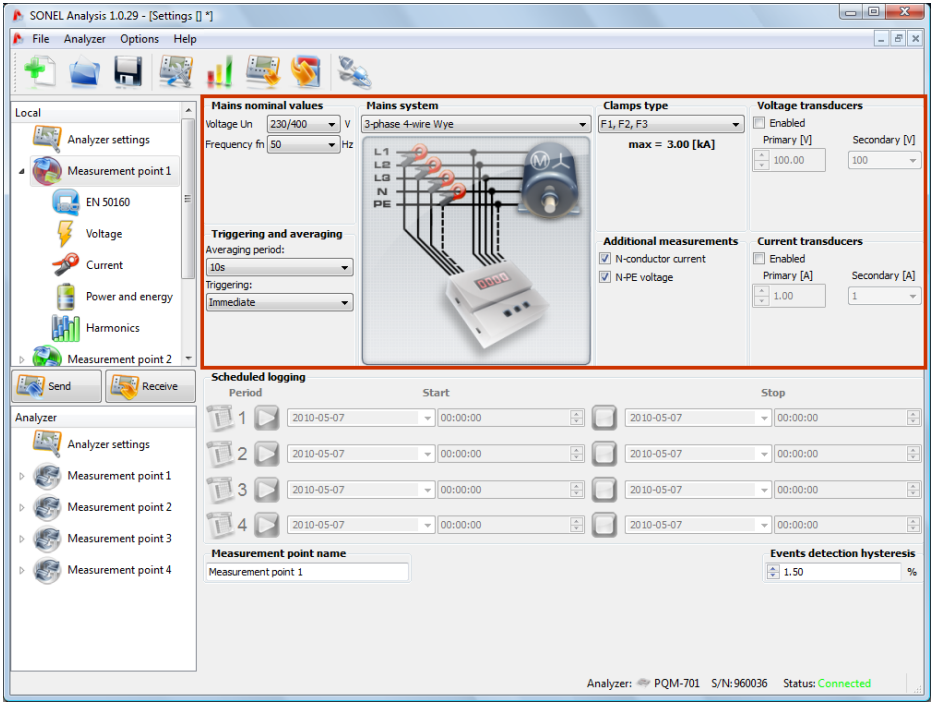


Fig. 13. Setting the mains type, rated parameters of the mains and transducers.

- **Mains nominal values**: voltage 110/190V, 115/200V, 127/220, 220/380V, 230/400V, 240/415V, 254/440, 400/690V (phase-to-neutral/phase-to-phase, depending on the mains type),
- Frequency – 50 or 60Hz,
- **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,
- **Clamps type** – indicates the type of current clamps used in the measurements. You can choose the C-4, C-5, C-6, C-7 clamps, and F-1/F-2/F-3 flexible clamps. If the current measurement is not required, you can select the **None** option.
- **Voltage transducers** – define the voltage transducer ratio if the transducers are used. Set the primary voltage (range 1..999999V) and the secondary voltage from among the 100V, 100V/√3, 110V, 110V/√3, 115V, 115V/√3, 120V, 120V/√3 standard values. When the voltage transducers option is activated, the field **Voltage Un** becomes grey; the value entered for the transducer primary side becomes a new nominal voltage.
- **Current transducers** – define the current transducer ratio. The measuring range of selected clamps can be extended by using external current transducers. Set the primary current in the 1…99999A range, and the secondary current: 1A or 5A. The resulting measuring range (primary current which does not exceed the nominal range of used clamp) is displayed below the clamp selection list.
- **Additional measurements** – use the additional option fields to define possible measurements of additional parameters, such as neutral conductor current (with the fourth

clamp, if the system type is appropriate) and the N-PE voltage (for systems with separate N and PE conductors). Remember that the analyzer will not measure such parameters unless you check relevant options.

- **Averaging period** for measurements – use this field to define the basic results averaging period. Available times are as follows: half period (special mode, only voltage and current instantaneous values are recorded), 200ms, 1s, 3s, 5s, 10s, 15s, 30s, 1min, 3min, 5min, 10min, 15min, 30min, 60min, 120min,
- **Triggering** of recording – select the recording activation mode:
  - Immediate measurement after pressing the **START/STOP** button.
  - Measurement by the schedule – after pressing the **START/STOP** button the meter compares the present time with intervals defined in the schedule and starts and stops the recording according to such defined intervals,
  - Measurement after the limit for any active event is exceeded - after pressing the **START/STOP** button the meter analyzes the mains and waits until a parameter is exceeded which triggers the recording.

> ***Note***
> *If in the EN 50160 tab the user has activated the standard-compliant recording, the averaging will be set to 10 minutes and the averaging period selection list will be blocked. To change these settings, first deactivate the standard compliant recording in the above-mentioned tab.*

The following can be defined in the bottom part of the screen (Fig. 31):

- **Schedule** recording – you can define 4 periods. When a given period is selected by clicking the green arrow, enter the start date and time and optionally the stop date and time. If you set the start and not the stop, the recorder will operate until the **START/STOP** button is pressed or until the memory is used up. The time intervals must be disjoint – the software does not allow to configure overlapping intervals. Successive times must be set chronologically.
- **Measurement point name** – give your own name to a given point; maximum 32 characters,
- **Events detection hysteresis** – define the hysteresis used during evaluation of event detection thresholds. You can use the 0.0…10.0% range with the 0.5% increment. Typical hysteresis value is 2%. To find out more on the topic, go to the event detection part, sections 10.10 i 10.11.

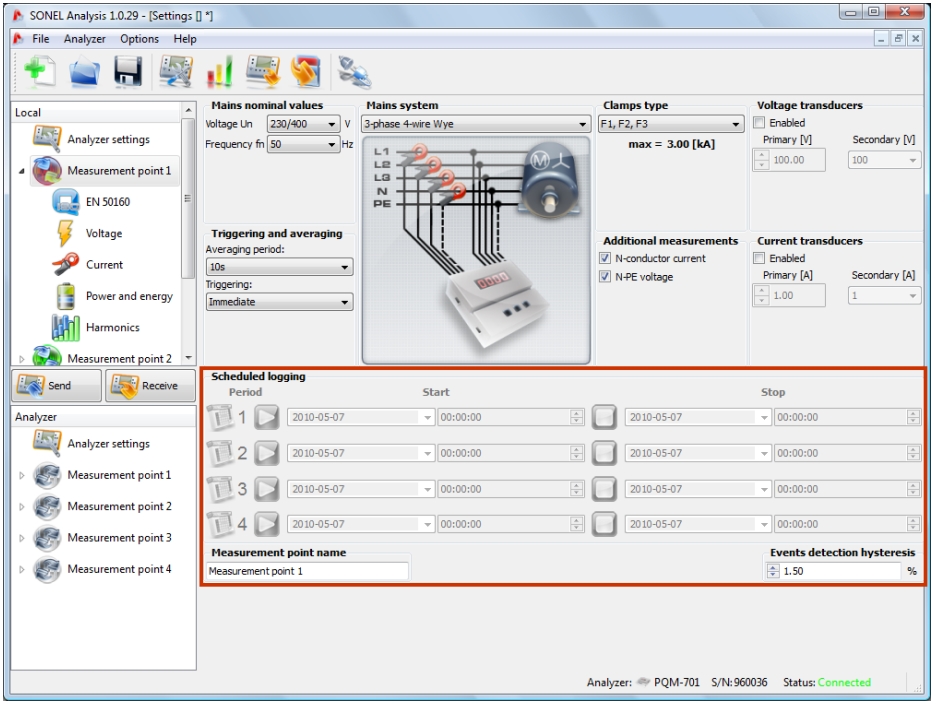


Fig. 14. Additional settings.

5.2.2 Settings according to EN 50160

When the item "**EN 50160**" is selected from the tree, the user can quickly configure a selected measurement point for recording of power quality parameters according to the requirements defined in the EN 50160 European standard. This standard specifies the parameters and quality criteria for LV and MV distribution networks.

According to this standard, the basic mains measurement period is one week. The checked values include RMS voltage, frequency, total harmonic distortion (THD), levels of individual harmonics, unbalance (in three-phase system) and flicker. As a test of the mains which lasts one week entails collecting of a huge amount of data, it has been decided to use averaging algorithms. All parameters to be evaluated, except for the frequency and long term flicker, are averaged in 10 minutes. Therefore, the user gets 1008 values for each parameter. These values are then evaluated by comparing them with the criteria specified in the standard.

If all parameters are within specified limits, one can say that the distribution network meets the EN 50160 quality requirements.

Table 6 shows the present measurement requirements according to EN 50160 in the network with voltage up to 35kV. These settings are activated after selecting the default settings "**Low and medium voltage systems**".

Table 6. Power quality requirements according to EN 50160 for networks with voltage up to 35kV.

<table>
<tr><th>Parameter</th><th>Basic measurement time</th><th>Criterion</th></tr>
<tr><td>Slow voltage changes (RMS voltage)</td><td>10 minutes</td><td>for 95% of measurements, deviation from the nominal voltage shall be within the ±10% U_{nom} range
for 100% of measurements: –15%...+10% U_{nom} (100% criterion is binding only for LV networks)</td></tr>
<tr><td>Frequency</td><td>10 seconds</td><td>for 99.5% of measurements, deviation shall be within the ±1% f_{nom} range (for 50Hz corresponds to 49.5…50.5Hz)
for 100% of measurements: –6%...+4% f_{nom} (47…52Hz)</td></tr>
<tr><td>Fast voltage changes (flicker)</td><td>2 hours</td><td>for 95% of measurements, the long-term flicker $P_{lt} \leq 1$</td></tr>
<tr><td>Voltage unbalance</td><td>10 minutes</td><td>for 95% of measurements, the negative sequence unbalance shall be ≤ 2%</td></tr>
<tr><td>Total harmonic distortion (THD-F)</td><td>10 minutes</td><td>for 95% of measurements, THD-F shall be ≤ 8%</td></tr>
<tr><td>Voltage harmonics</td><td>10 minutes</td><td>For 95% of measurements, level of each voltage harmonics referenced to the basic component shall be less than:
<table>
<tr><th colspan="2">Odd harmonic order</th><th colspan="2">Even harmonic order</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="11"></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>

Table 7 presents the criteria specified activated after loading "**High voltage systems**" default settings.

Table 7. High voltage systems default criteria.

<table>
<tr><th>Parameter</th><th>Basic measurement time</th><th>Criterion</th></tr>
<tr><td>Slow voltage changes (RMS voltage)</td><td>10 minutes</td><td>for 95% of measurements, deviation from the nominal voltage shall be within the -10%...+5% U_{nom} range</td></tr>
<tr><td>Frequency</td><td>10 seconds</td><td>for 99.5% of measurements, deviation shall be within the ±1% f_{nom} range (for 50Hz corresponds to 49.5…50.5Hz)
for 100% of measurements: –6%...+4% f_{nom} (47…52Hz)</td></tr>
<tr><td>Fast voltage changes (flicker)</td><td>2 hours</td><td>for 95% of measurements, the long-term flicker $P_{lt} \leq 0,8$</td></tr>
<tr><td>Voltage unbalance</td><td>10 minutes</td><td>for 95% of measurements, the negative sequence unbalance shall be ≤ 1%</td></tr>
<tr><td>Total harmonic distortion (THD-F)</td><td>10 minutes</td><td>for 95% of measurements, THD-F shall be ≤ 3%</td></tr>
<tr><td>Voltage harmonics</td><td>10 minutes</td><td>For 95% of measurements, level of each voltage harmonics referenced to the basic component shall be less than:
<table>
<tr><th colspan="2">Odd harmonic order</th><th colspan="2">Even harmonic order</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="9"></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>
</table>
</td></tr>
</table>

Example

Nominal voltage 230V, frequency 50Hz, measuring time: one week.
From among 1008 average values for RMS voltage, 95%, that is 958, must be in the 207V…253V range.
All RMS voltage measurements must be in the 195.5V…253V range.
In one week we have 60480 ten-second frequency measurements. 99.5% (60178) must be in the 49.5…50.5Hz range. All frequency measurements must be in the 47…52Hz range.

The analyzer configuration procedure for standard compliant measurement is as follows. In the main configuration screen, set the correct mains system type, nominal voltage, frequency, clamp type, and select appropriate transducers if necessary.

Then go to the **EN 50160** section. In the **Basic** tab, check the option "**Enable logging according to standard**". Then, the averaging time will be set to 10 minutes, and the recording parameters are only taken from **EN 50160**. The remaining options in the tree: **Voltage, Current, Power and energy**, **Harmonics**, are blocked and disregarded by the analyzer.

Then, click one of buttons for default settings for the standard (for LV and MV networks up to 35 kV, or HV networks). Now the application loads the default parameters within the **EN 50160** tab. You can now see the recording parameters in all three tabs (**Basic, Harmonics, Events**).

When the configuration is completed, trigger the recording from the application level or by pressing the **START/STOP** button.

You can edit the settings in the **Basic, Harmonics, Events** tabs even after the default values are loaded. It can be helpful in the situation when the criteria defined in EN 50160 change. Then you can adjust the settings by yourself, without the need to update the **SONEL Analysis** software.

Although the standard 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 tanφ average values, the analyzer allows simultaneous measurement of the mains for conformity with EN 50160 and 15-minute average values of active, reactive and apparent powers, as well as tanφ. To enable recording of these parameters activate the option **"Record according to the standard"**, enable the current measurement by selecting an appropriate clamp from the list, and possibly set the parameters of the transducers.

Basic

Use this screen to set the measuring criteria for:

- Frequency – tolerance values which define admissible deviations as a percent 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 which define admissible deviations as a percent 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.

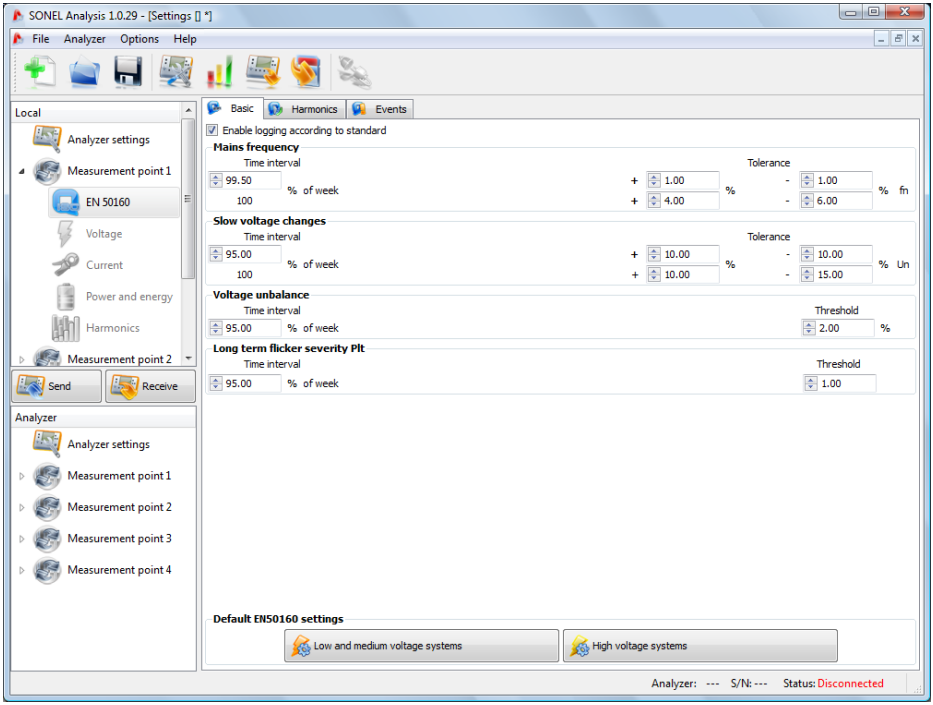


Fig. 15. Recording according to EN 50160 – basic settings.

In the bottom part, you will find the default settings buttons for LV and MV networks, as well as the HV networks.

A very important element in this screen is the option **Enable logging according to standard**. It is necessary to check this option to set the analyzer in the recording mode compliant with the parameters set in the tabs of the **EN 50160** screen. Otherwise, the analyzer will record according to the measurement point settings in the **Voltage, Current, Power and energy, Harmonics** trees.

Harmonics

The screen is shown in Fig. 33. Use this screen to set the total harmonic distortion (THD) limits and the threshold limits for individual harmonic components.

You can use two methods to set the limits of individual harmonic components: filling in the table below the diagram, or directly on the diagram.

When filling in the table, the entered value is shown on the diagram after it is confirmed with the ENTER or TAB key.

To change the limit on the diagram, double-click the selected harmonics, and then holding the left mouse button set the required level. In addition, after selecting the harmonics, you can also use the following keys:

- UP and DOWN arrows to change the limit value,
- LEFT and RIGHT arrows to select the previous or next harmonics,
- SPACE BAR – to select limit value for editing,
- PAGE UP and PAGE DOWN to toggle between the min and max values,
- HOME and END to toggle between the first and last harmonics.

> ***Note***
> *The THD and harmonics values are referenced to the fundamental component.*
> *The THD calculation in EN 50160 mode includes harmonics up to the 40th order*

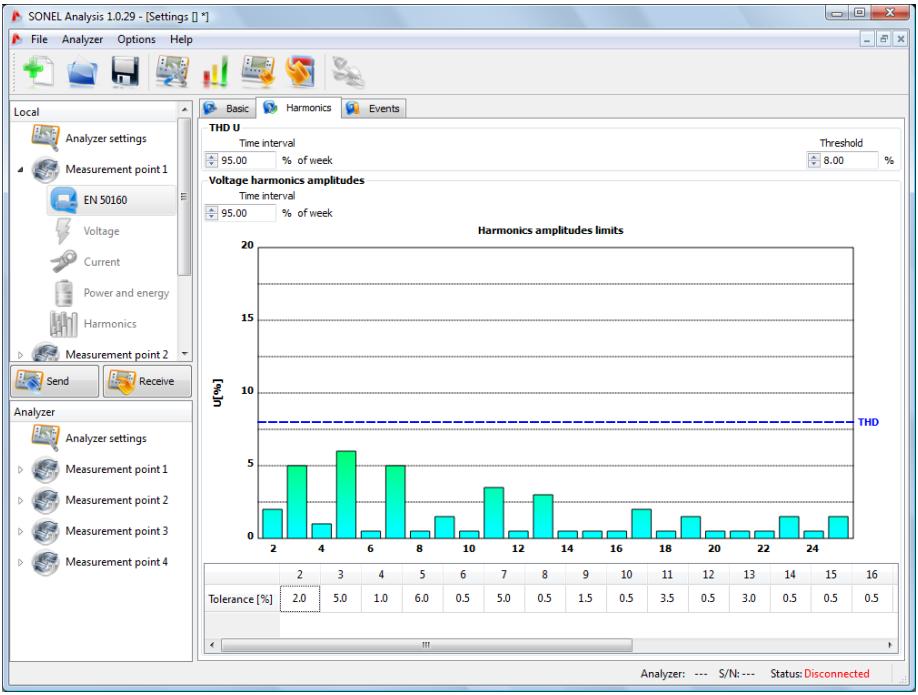


Fig. 16. Recording acc. to EN 50160 – harmonics settings.

Events

The events setting screen for recording acc. to EN 50160 is shown in Fig. 34.
Use this screen to set:

- Swell, dip and interruption detection thresholds. These thresholds are set as a percent of the nominal voltage which should be added to the nominal value.
  For example: the swell tolerance of +10% U_n means that for the voltage U_n=230 V, the swell threshold U_{swell} = 230 + 23 V = 253V.
  The interruption tolerance set at -99% U_n means that the detection of the interruption event takes place at the voltage equal to or greater than U_{swell} = 230 – 227.7V = 2.3V.
- Recording of the waveforms at the beginning and the end of detected events. It can be set independently for each of 3 event types.
- Short-term/ long-term interruption threshold. This value is used for the classification of the interruption events.

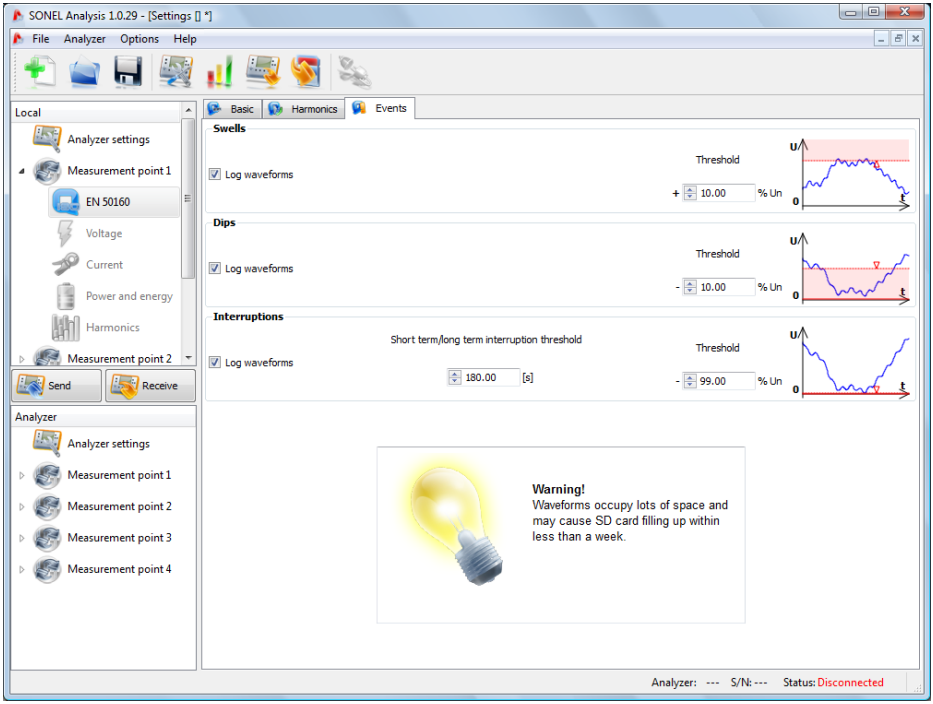


Fig. 17. Recording acc. to EN 50160 – event settings.

Notes

- *Voltage dip cannot be set lower than interruption.*
- *Nominal voltage value is taken from measurement point main settings (mains system nominal values)*
- *Waveforms take up relatively a lot of space on memory card which may cause that the space allocated to a measurement point is used up prematurely.*

User's configuration

In addition to the EN 50160 compliant recording, the analyzer has also a much more flexible user's recording option. In this mode it is possible to define precisely which parameters are to be recorded, what must trigger event detection, what the averaging time should be, etc. In contrast to EN 50160 compliant recording, where only a few mains parameters have been defined, the user mode gives much more flexibility. It has four branches of measurement point configuration: **Voltage, Current, Power and energy, Harmonics**.

To switch into the user mode, close the options in the branch **EN 50160** – **Basic: Enable logging according to standard**.

Note

*The settings from the **EN 50160** branch are ignored in the user mode.*

In most cases, the settings of a selected parameter can be divided into the part relating to cyclical recording of the parameter values according to selected averaging time, and to the part relating to event detection.
You can choose between recording of average, minimum, maximum, and instantaneous parameter value. You can set an additional averaging time for voltage and current to be used during detection of maximum and minimum values. We will use an example to explain these issues.

Example

Global averaging time has been set to 1 minute, 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?
1. Average value is the RMS (root mean square) from 10/12-period measurements (about 200ms). There will be about 300 such measurements. Average voltage value is the square root of arithmetic mean of squared input values:

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

where:
U_{ave} – 1-minute RMS voltage,
k – number of collected 10/12-period values,
U_i –10/12-period RMS voltage.
2. Min/max averaging equal to 5 seconds means that first the analyzer averages 25 successive U_i values (using the method described above). Minimum and maximum values are selected from among all 5-second average values collected 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 recorded on the card.

Event detection can be configured for majority of parameters. An event is the situation when the measured parameter value exceeds the user-defined threshold or thresholds. Depending on the parameter, there can be only one threshold (i.e. for the unbalance factor of negative sequence component – exceeding of the maximum value), there can be two (i.e. for frequency – exceeding of the upper and lower limit), and in case of voltage there can be even three (exceeding of the swell, dip and interruption thresholds).

The analyzer saves the event information on the memory card when event ends. The following information is saved:

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

If recording has been discontinued during an event, the event information is also saved, but only the following data is recorded:

- event start time,
- threshold value,
- parameter limit value recorded until the recording was stopped.

Recording of waveforms at the event beginning and the end can be activated for two parameters: RMS voltage and RMS current. Six waveform periods are recorded: two periods before the event and four after.

5.2.3 Voltage

Voltage branch has two tabs: **Basic** and **Additional**.

Basic

Fig. 35 shows basic voltage recording settings. 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, you can check recording of the average value (**Avg**) minimum value (**Min**), maximum (**Max**) or instantaneous (**Inst**.) of the RMS voltage. Use the **All** option to select all four or remove all four.

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

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

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

Check the **Log waveforms after each averaging period** option to record three voltage waveform periods after each successive averaging periods (for example every 10 minutes).

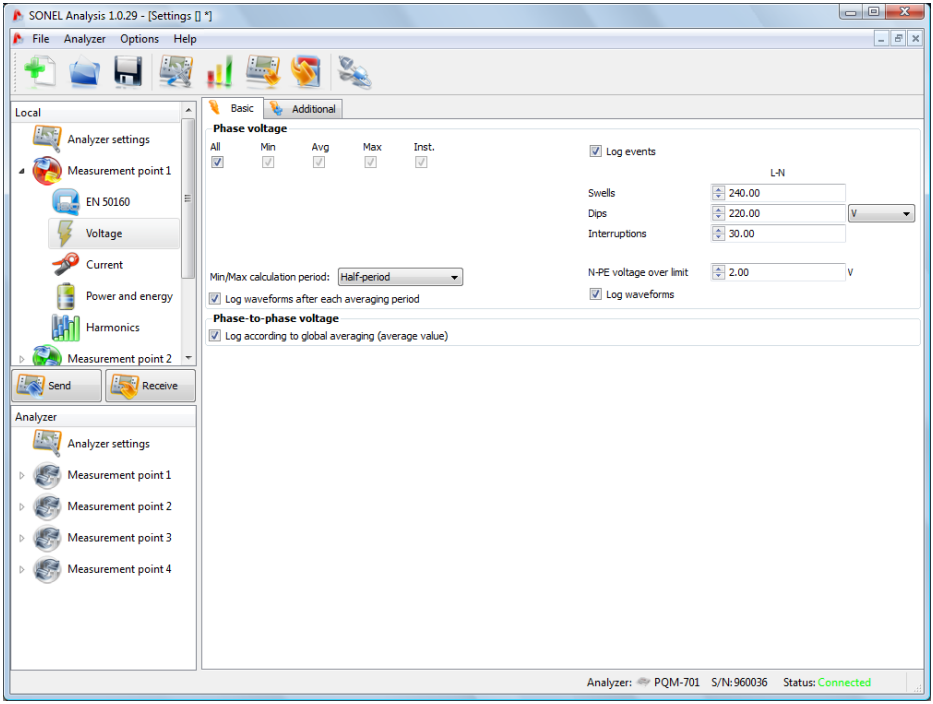


Fig. 18. Basic voltage measurement settings.

The parts related to events is to the right.

Check the **Log events** option to activate the fields for voltage threshold values. You can enter them in absolute values or in percent.

- swell: 0,0…+20.0% with the 0.1% resolution, or in volts in the same range,
- dips: 0.0…-99.9% with the 0.1% resolution, or in volts,
- interruptions: 0.0...-100.0% with the 0.1% resolution, or in volts down to 0.0V (the dip level cannot be lower than the interruption level).

For mains with neutral conductor, it is possible to set also the maximum N-PE voltage level. When this level is exceeded, an event will be triggered.

Switching from the threshold percent values to absolute values causes automatic calculation to selected unit.

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

Check the **Log waveforms** option to enable recording of 6 voltage and current waveform periods at the beginning and the end of event.

Additional

This tab (see Fig. 36. Additional voltage measurement settings.) is used to set the recording parameters for mains frequency, voltage crest factor, flicker and voltage unbalance. Just like in case of other parameters, you can select recording of average, minimum, maximum and instantaneous values.

The event settings are to the left. The settings ranges are as follows:

- frequency: 40…70Hz with the 0.01Hz or 0.1% resolution, but the minimum value must not be above the set nominal power frequency, and the maximum value must not be below the set nominal power frequency
- crest factor: 1.00…2.50; 0.01 resolution
- negative sequence unbalance: 0.0…20.0%; 0.1% increment
- flicker (short-term and long-term): 0.0…20.0; 0.1 increment

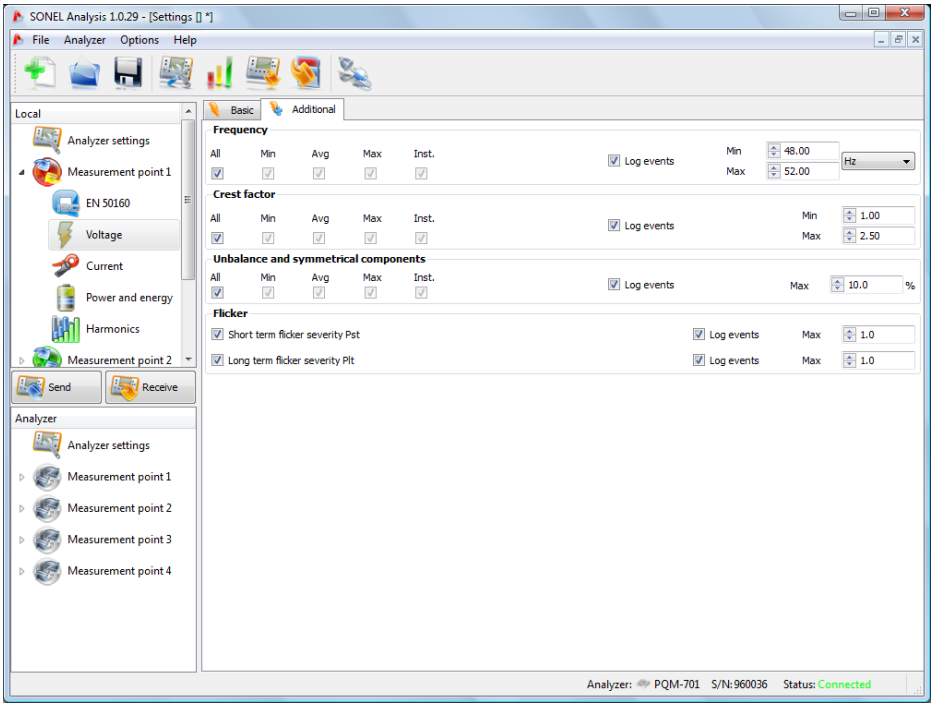


Fig. 19. Additional voltage measurement settings.

5.2.4 Current

Current recording setting screen is shown in Fig. 37.

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

The following elements are grouped here:

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

The event recording can be activated on the right-hand side:

- two thresholds can be set for RMS current: maximum (upper limit) and minimum (lower limit). The settings range is from 0.0A up to the rated current measuring range (clamps and possibly current transducers). The minimum value cannot be greater than the maximum value. In case of mains with neutral conductor, different thresholds can be set for phase channels and neutral channel.
- current crest factor: two thresholds (minimum and maximum); adjustment range: 1.00…5.00; 0.01 increment
- negative sequence unbalance: one threshold (maximum), range 0.0…20.0%; 0.1% increment.

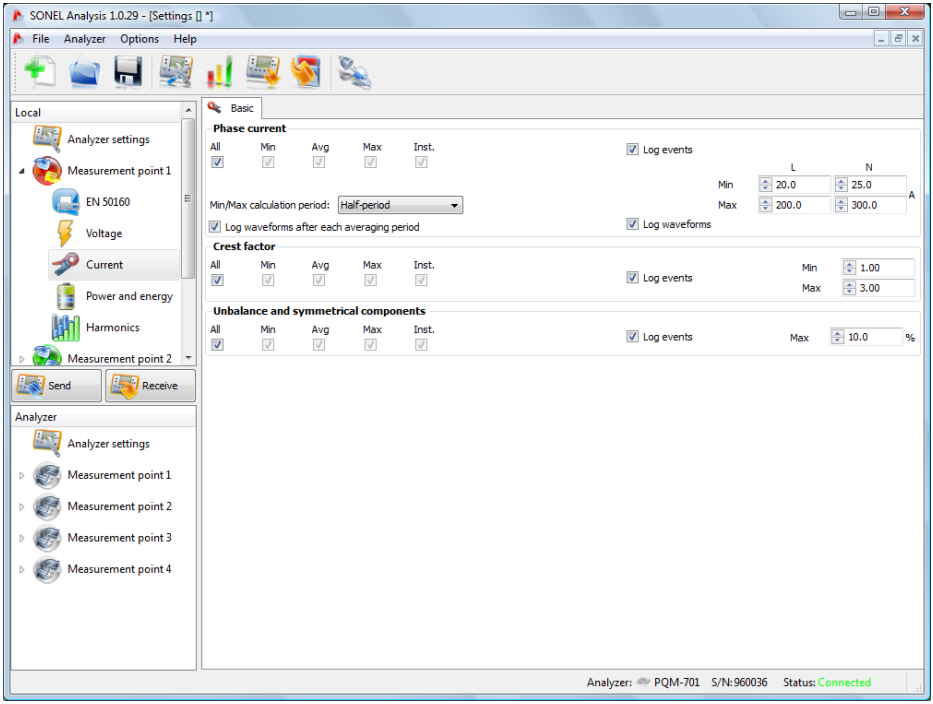


Fig. 20. Current measurement settings.

5.2.5 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 the **None** option in the **Clamps type** list.*

Power

The **Power** tab is shown in Fig. 38.

Similarly to voltage and current, the user can set recoding of average, minimum, maximum and instantaneous values. The parameters which can be recorded include:

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

Event recording can be set for each power type. Two thresholds can be set for each power type (minimum and maximum), exceeding of which will be detected by the analyzer.
The settings range is 0.0…999.9 W/kW/MW (for active power), 0.0…999.9 var/kvar/Mvar (for reactive power), 0.0…999.9 VA/kVA/MVA (for apparent power), 0.0…999.9 var/kvar/Mvar (for distortion power).

Reactive power calculation methods are given in the bottom of the screen. The User can choose from between two options:

- according to recommendations of IEEE 1459-2000 standard,
- according to Budeanu's power theory.

This option has been added due to the doubts about the power measurement according to traditionally used Budeanu's method. The IEEE 1459-2000 standard suggests somewhat different calculation methods of this power which give correct results also in unbalanced systems with distorted current and voltage waveforms. For more information about this issue, see section 9.7.
When the Budeanu option is selected, both the reactive power Q and the distortion power are calculated according to Budeanu's power theory.
If the IEEE-1459 option is checked, the reactive power is the Q_1 reactive power of the fundamental component, and S_N nonfundamental apparent power (expressed in VA) is calculated instead of the distortion power.

The units for entering the limit values for events are user-definable. The setting range are as follows:

- P, Q_B, S, D according to Budeanu's power theory: 0.0…999.9W, var, VA (or kW, kvar, kVA or MW, Mvar, MVA), 0.1W resolution; var, VA (or kW, kvar, kVA or MW, Mvar, MVA),
- P, Q_1, S, S_N acc. to IEEE 1459: 0.0…999.9W, var, VA (or kW, kvar, kVA or MW, Mvar, MVA), 0.1W resolution; var, VA (or kW, kvar, kVA or MW, Mvar, MVA)

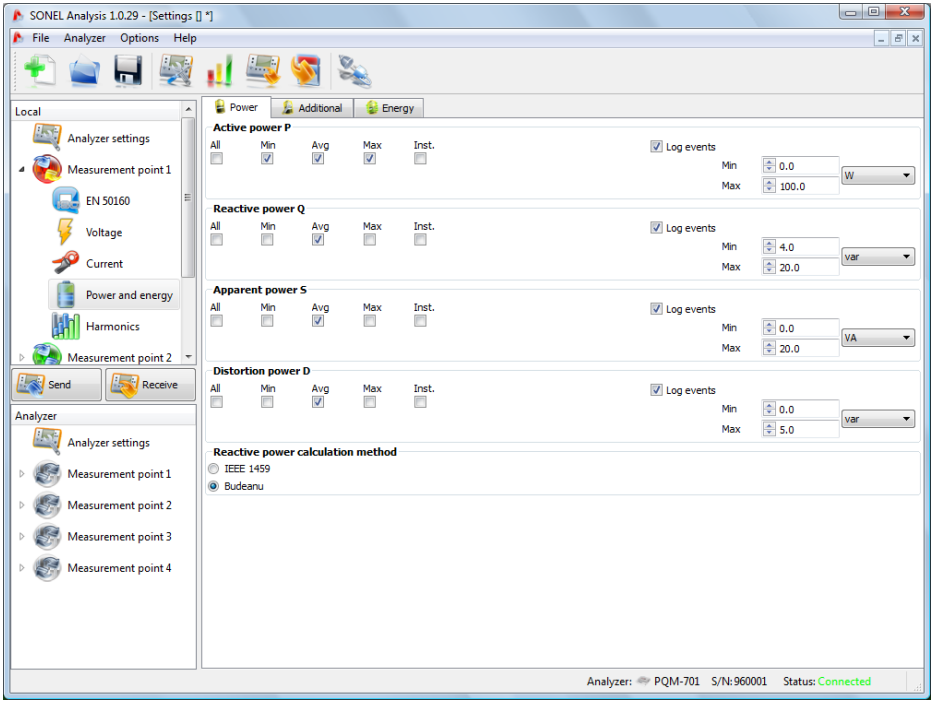


Fig. 21. Power and energy: Power tab.

Additional

The **Additional** tab (Fig. 39) includes the following power calculation parameters:

- Power factor: event threshold setting range: 0.00…1.00; 0.01 increment
- Displacement power factor cos(φ): event threshold setting range: 0.00…1.00; 0.01 increment
- tan(φ), factor of reactive power to active power: event threshold setting range: 0.00…10.00; 0.01 increment.

Energy

The **Energy** tab is shown in Fig. 40. In addition to energy values recording option with settable averaging period, the user can also define event detection when energy exceeds a given threshold. The setting ranges are as follows:

- Active energy E_P: 0.0…999.9Wh (kWh, MWh, GWh) or 9,9TWh; 0.1Wh resolution (kWh, MWh, GWh, TWh),
- Reactive energy E_Q: 0.0…999.9varh (kvarh, Mvarh, Gvarh) or 9,9Tvarh; 0.1varh resolution (kvarh, Mvarh, Gvarh, Tvarh),
- Apparent energy E_S: 0.0…999.9VAh (kVAh, MVAh, GVAh) or 9.9TVAh; 0.1VAh resolution (kVAh, MVAh, GVAh, TVAh).

For active and reactive energy, the analyzer separately measures two magnitudes: 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).

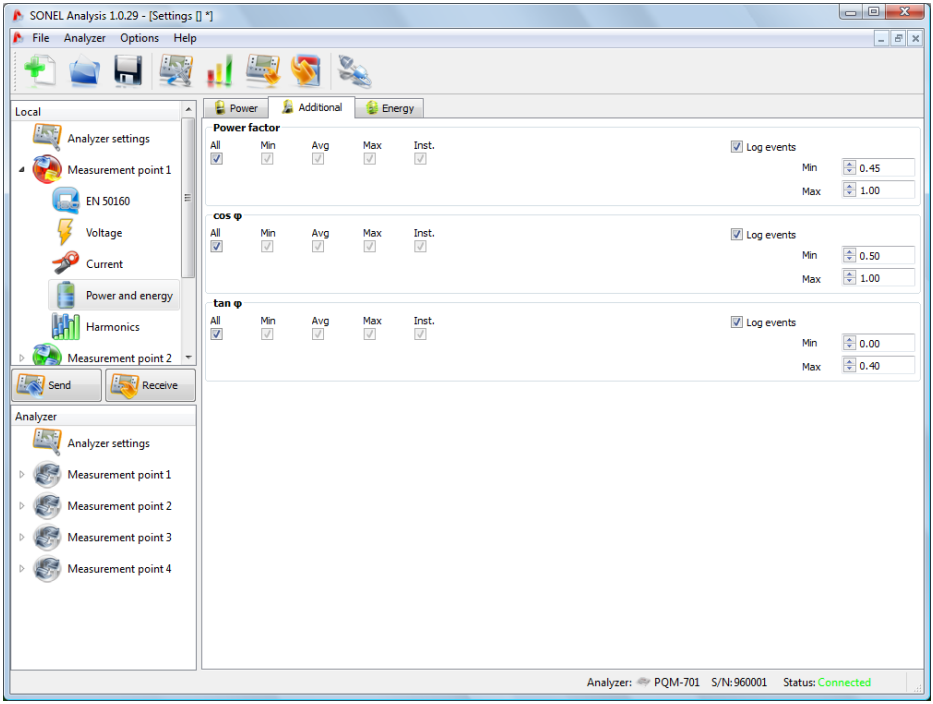


Fig. 22. Power and energy: Additional tab.

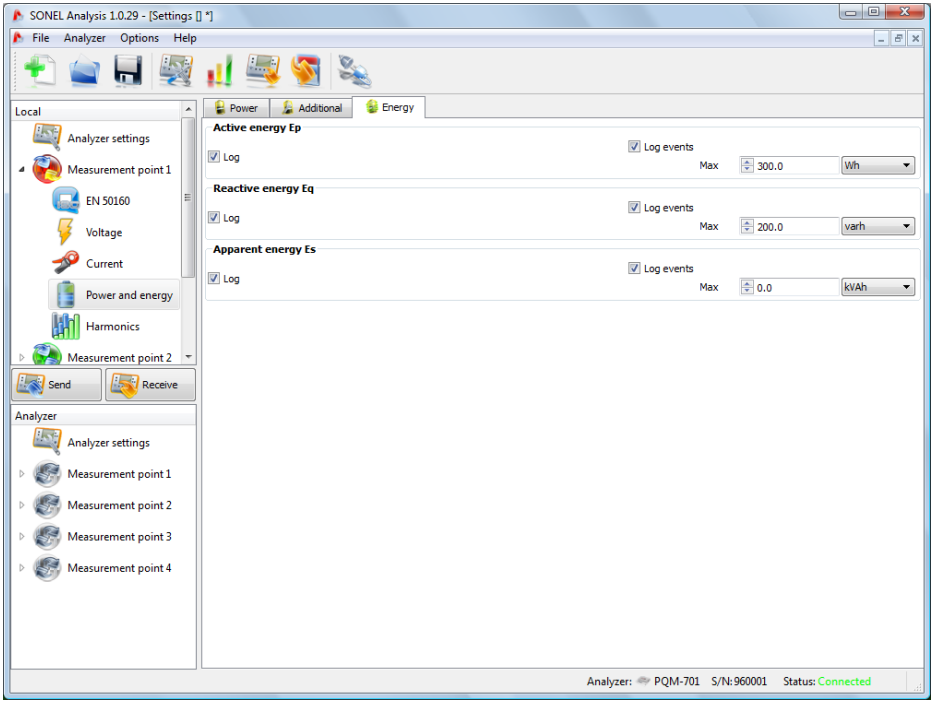


Fig. 23. Power and energy: Energy tab.

5.2.6 Harmonics

The Harmonics branch can be used to configure the recording method and event detection for voltage and current harmonics and other parameters directly related to them. The branch has two tabs: Basic and Additional.

Basic

This tab is shown in Fig. 41.

- In the top part, the user can choose the voltage or current harmonics.
- THD (total harmonic distortion) – similarly to other configuration areas, the fields **Min**, **Max**, **Avg**, **Inst.** are used to set the recording of minimum, maximum, average and instantaneous values according to set averaging period. The event detection can be activated on the right-hand side. The event will be recorded when THD exceeds the user-defined threshold value. The event threshold setting range is 0.0…100.0% with 0.1% increment for voltage, and 0.0…200.0% with 0.1% increment for current.
- Harmonics – here the user decides to activate the recording of harmonic amplitudes and about event detection. The event detection thresholds are settable independently for each harmonic from the 2^{nd} to the 50^{th} order. The setting method is identical as for the harmonics setting according to EN 50160 (see description in section 5.2.2). There is also an additional option of selecting the units of harmonics levels: in absolute units (volts or amperes) or in percent.
  The event threshold adjustment range is as follows:

- For voltage harmonics: in volts 0.0…U_{nom} with 0.1V increment, in percent 0.0…100.0% with 0.1% increment.
- For current harmonics: in amperes 0.0…I_{nom} with 0.1A increment, in percent 0.0…200.0% with 0.1% increment

> ***Note***
> *THD harmonics level (in percent) is referenced to the fundamental component.*

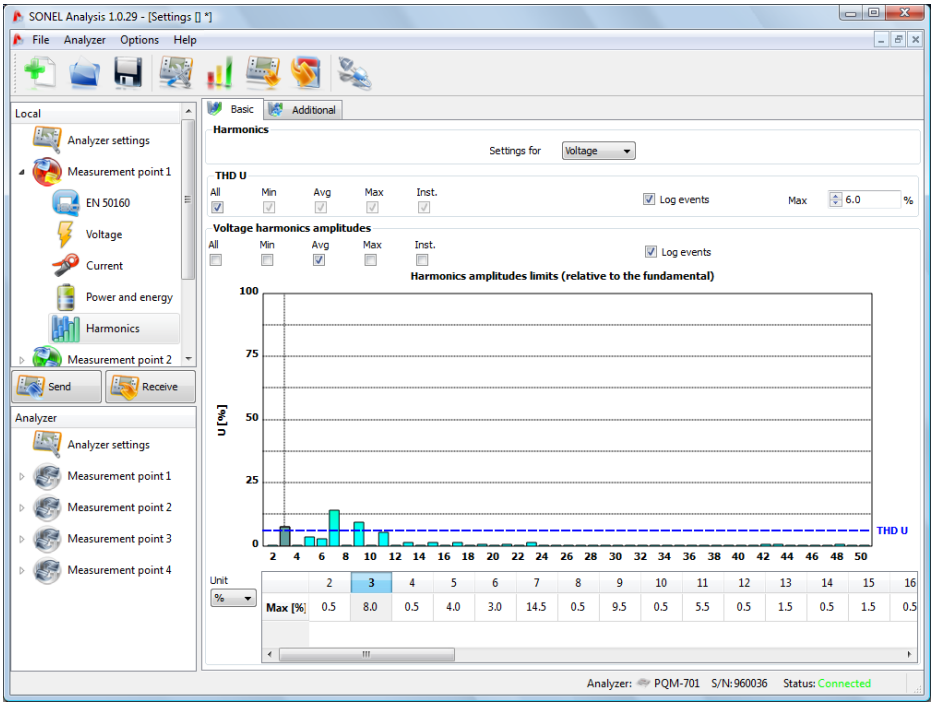


Fig. 24. Basic harmonics settings

Additional

The **Additional** tab includes the following parameters:

- K-factor: the user can activate the recording and event detection when the threshold is exceeded. The threshold is settable in the 0.0…50.0 range with 0.1 increment.
- Angles between voltage and current harmonics: the user can activate the recording – the angles are recorded for the 1..50 harmonics,
- Harmonics active power: cyclical recording of active power for the 1..50 harmonics,
- Harmonics reactive power: cyclical recording of reactive power for the 1..50 harmonics,
- THD calculation method: from first 40 or 50 harmonics.

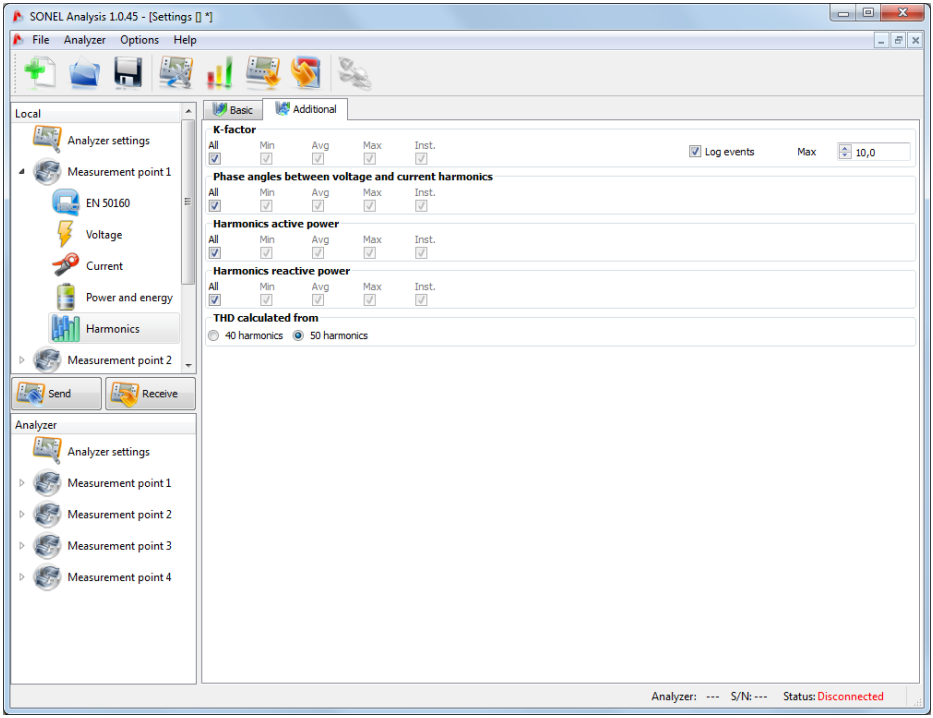


Fig. 25. Additional harmonics settings.

5.2.7 Default configuration profiles

As a standard, after installation the application loads the default analyzer configuration with following measurement points profiles:

- voltage,
- voltage and current,
- power,
- power and harmonics.

The names of these profiles are entered in the measurement points names (PP1 – Voltage, PP2 – Voltage and current, PP3 – Power, PP4 – Power and harmonics). The parameters recorded in given profiles are listed in Table 8.

Table 8. List of recorded parameters for default profiles of measuring points

Voltage	Voltage and current	Power	Power and harmonics
U voltage	U voltage	U voltage	U voltage
U crest factor	U crest factor	U crest factor	U crest factor
Frequency	Frequency	Frequency	Frequency
U symmetrical components and unbalance factor	U symmetrical components and unbalance factors	U symmetrical components and unbalance factor	U symmetrical components and unbalance factor
	I current	I current	I current
	I crest factor	I crest factor	I crest factor
	I symmetrical components and unbalance factor	I symmetrical components and unbalance factor	I symmetrical components and unbalance factor
		P active power	P active power
		Q reactive power	Q reactive power
		S apparent power	S apparent power
		D distortion power	D distortion power
		Cosφ	Cosφ
		Power factor	Power factor
		Tanφ	Tanφ
			K factor
			THD U
			THD I
			U harmonics
			I harmonics
			Flicker P_{st} and P_{lt}

The recording for default profiles does not include waveforms after the averaging period. Only average values of parameters are recorded, and event detection is off. The mains type is set to three-phase wye with neutral conductor, and the averaging time is 10 seconds.

5.3 Time and security

When **Analyzer** → **Time and security** is selected from the main menu (or by a hotkey), the widow appears as shown in Fig. 43. Here the user can set the time and analyzer security parameters. The present analyzer date and time is given on a current basis in the **Analyzer** time field. To set any date and time, in the **User time** drop-down field set required values and press the **Set** button to the right. You can also send the system time to the analyzer – just press the button next to the **System time** field.

If you check the **Keys lock** option, the analyzer will lock the access to keyboard immediately after the start of recording. In such case, to get access to the keyboard the user needs to enter a 3-digit code (using three analyzer buttons in the same manner as during entering of the PIN code). This code is independent of the PIN and can be changed by pressing the **Change** button next to the **Keys lock code** field. The keys lock function protects against an attempt to stop the recoding by unauthorized personnel.

The **Sleep mode during recording** option blanks the analyzer display 10 seconds after the start of recording. The recording is indicated only by flashing dots in the display.

The **Change** button next to the **PIN code** field is used to change the current PIN code. The default setting is 000, but the user can set any code from 000 to 999. When the button is pressed, the window appears as shown in Fig. 44 (the PIN code change procedure is the same as for the keys lock code). An appropriate message is displayed after the successful operation.

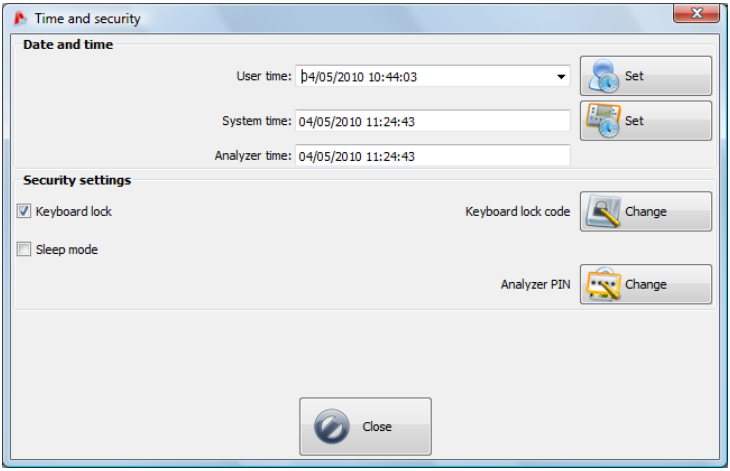


Fig. 26. Setting the time and security options.

Fig. 27. Changing the keys lock code or PIN.

5.4 Reversing the clamp phase

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 the **Analyzer →Clamp phase** option ("Sonel Analysis" 1.0.38 or later, firmware version 1.03 or later). Click a clamp icon in the selected channel to reverse the phase by 180°, which is equivalent to reverse clamp placement on the test lead. The change of direction applies to all measurement points and take effect 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.

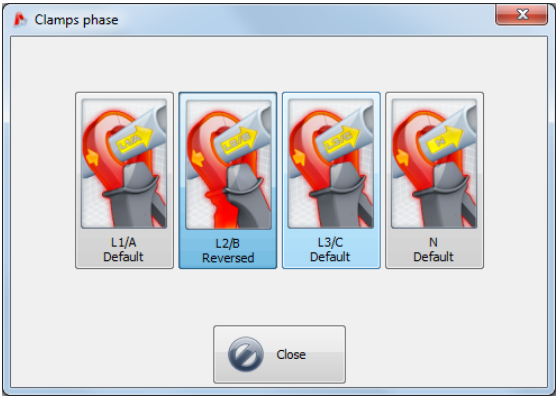


Fig. 28. Reversing the clamp phase.

6 Live mode

To enter the live mode, click the **Live mode** button. If the computer is not connected to the analyzer, the program first goes to the connection screen (see section 4.4 Selecting the analyzer).

In this mode, the screen has a few tabs:

- **Waveforms** – scope waveform of current and voltage,
- **Timeplot** – RMS current and voltage plotted on time scale,
- **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.

The more detailed description of individual tabs is given below.

6.1 Current and voltage waveforms

The voltage and current scope view shows two periods of waveforms. A typical screen is shown in Fig. 46. The diagrams are refreshed instantaneously, allowing the mains viewing in real time.

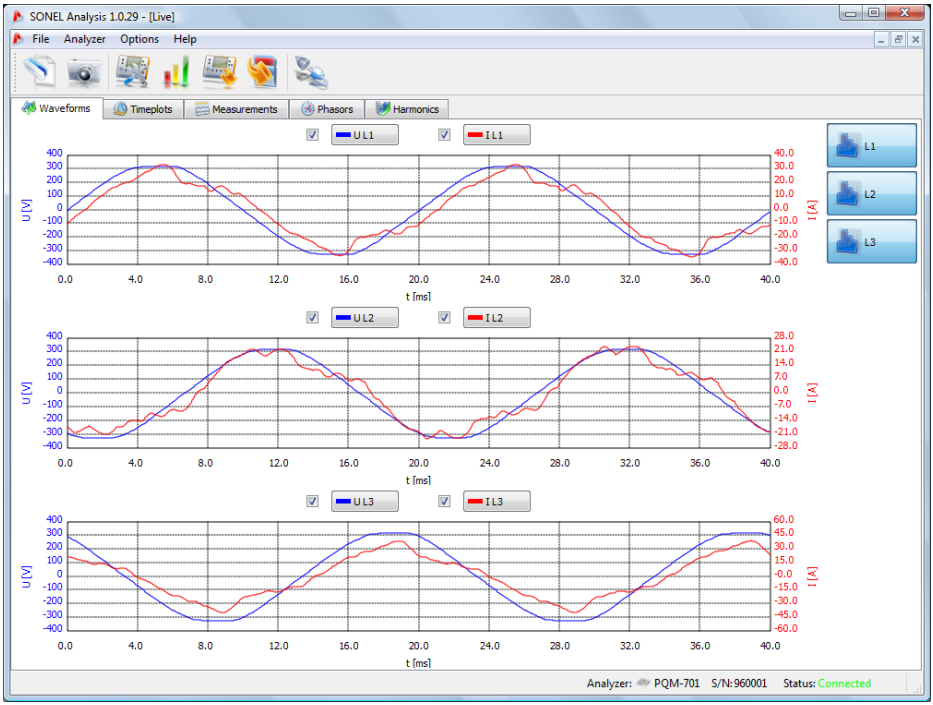


Fig. 29. Live mode – waveforms.

The checkboxes above the diagram are used to activate the display for voltages and currents. Buttons next to the boxes are used to change the colors of presented waveforms.

To the right are the buttons for available phases. Waveforms for each phase are shown when the button is pressed, and each phase is presented on a separate drawing.

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

The left-hand Y axis includes the voltage values, and the right-hand one – current values. The voltage and current units are selected automatically. 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 diagrams are automatically scaled to the highest instantaneous value of the waveform.

The change of scaling mode is available after right-clicking in the diagram area: context menu has the following options: **voltage auto-scaling, current auto-scaling**. When the program is launched, the auto-scaling is set to off.

In case no clamps have been selected in the general measurement point settings, the current waveforms are not active.

6.2 Current and voltage time plot

Fig. 47 shows a screen with current and voltage time plot. The configuration elements are identical as in the waveform screen: current/voltage display on/off and plot color change in the top part, activation of individual phases on the right-hand side.

The time scale on the plot is shown from the moment of activation of the live mode. The time format is hh:mm:ss. The plot is divided into equal 60-second parts. When the end of scale is reached, the whole plot moves by 60 seconds to the left.

The plot is updated irrespective of the fact if the tab is on or off, meaning that it is created in the background, even if the user is, for example, viewing the harmonics.

As in case of waveforms view, the scaling can be static (according to general measurement point settings) or dynamic.

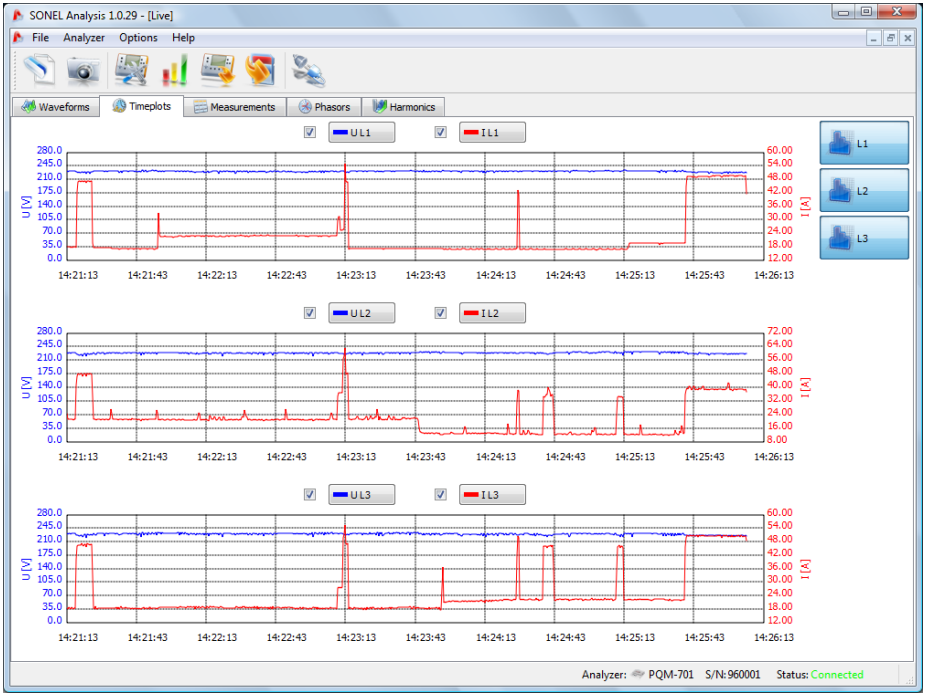


Fig. 30. Current and voltage plot in real time.

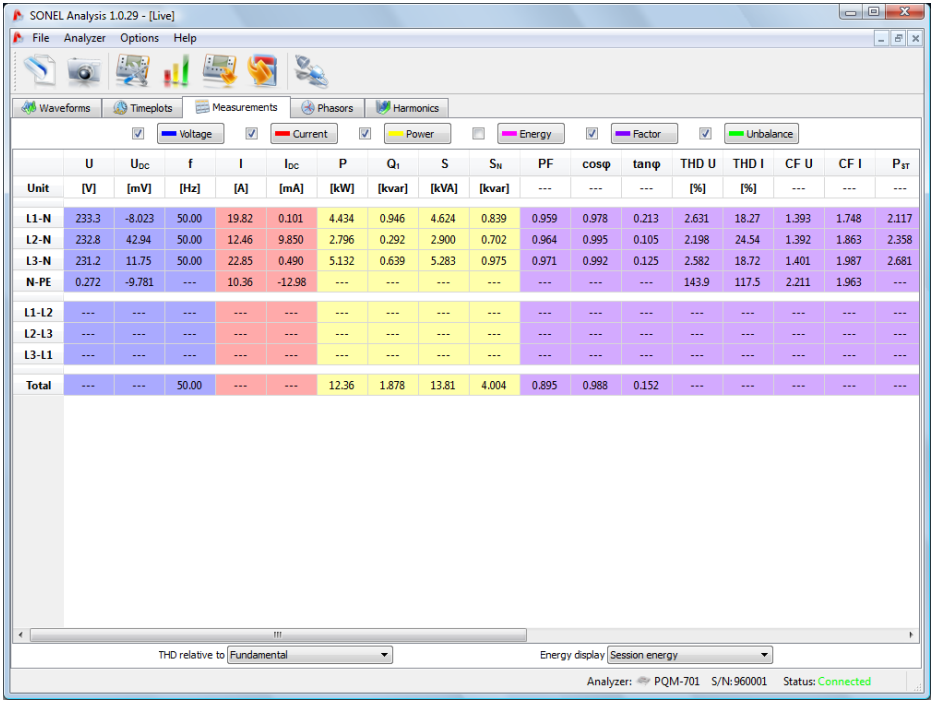
6.3 Phase and total values

The **Measurements** tab allows viewing of a range of parameters of the measured mains.

Fig. 48 shows a typical screen with a table which presents values read from the analyzer and shown in real time.

Individual parameters have been grouped in successive columns in a few categories:

- Voltage – RMS voltage U, DC component U_{DC}, frequency f,
- Voltage – RMS current I, DC component I_{DC},
- Power – active power P, reactive power Q_B (acc. to Budeanu) or fundamental component reactive power (acc. to IEEE 1459), apparent power S, distortion power D (acc. to Budeanu) or nonfundamental apparent power S_N (acc. to 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-} (respectively acc. to Budeanu or IEEE 1459), apparent energy E_S,
- Factors – power factor PF, displacement power factor cosφ, 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 component unbalance u_0; for currents: 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.



	U	U_{DC}	f	I	I_{DC}	P	Q_t	S	S_N	PF	cosφ	tanφ	THD U	THD I	CF U	CF I	P_{ST}
Unit	[V]	[mV]	[Hz]	[A]	[mA]	[kW]	[kvar]	[kVA]	[kvar]	---	---	---	[%]	[%]	---	---	---
L1-N	233.3	-8.023	50.00	19.82	0.101	4.434	0.946	4.624	0.839	0.959	0.978	0.213	2.631	18.27	1.393	1.748	2.117
L2-N	232.8	42.94	50.00	12.46	9.850	2.796	0.292	2.900	0.702	0.964	0.995	0.105	2.198	24.54	1.392	1.863	2.358
L3-N	231.2	11.75	50.00	22.85	0.490	5.132	0.639	5.283	0.975	0.971	0.992	0.125	2.582	18.72	1.401	1.987	2.681
N-PE	0.272	-9.781	---	10.36	-12.98	---	---	---	---	---	---	---	143.9	117.5	2.211	1.963	---
L1-L2	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
L2-L3	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
L3-L1	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Total	---	---	50.00	---	---	12.36	1.878	13.81	4.004	0.895	0.988	0.152	---	---	---	---	---

Fig. 31. Indications of phase and total values

Each group can be switched on and off independently of the other groups and the background color in its column can be changed with the option fields and 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.

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

- **L1-N** – L1 phase in systems with neutral conductor N,
- **L2-N** – L2 phase in systems with neutral conductor N,
- **L3-N** – L3 phase in systems with neutral conductor N,
- **N-PE** – parameter values in the N-PE voltage channel or the I_N current channel,
- **L1-L2** – L1 phase in systems without neutral conductor (with phase-to-phase voltages),
- **L2-L3** – L2 phase in systems without neutral conductor (with phase-to-phase voltages),
- **L3-L1** – L3 phase in systems without neutral conductor (with phase-to-phase voltages),
- **Total value** – total value of the whole system or average of phase values.

For example, for a three-phase system with N conductor, the phase parameters values are displayed in rows **L1-N**, **L2-N**, **L3-N**. If the measurement of N-PE voltage and/or I_N current has been activated in the configuration, the row **N-PE** displays also the values of parameters which are calculated in such case. The **Total** row displays the total values for the whole system.

In case of delta systems, the phase values are displayed in rows **L1-L2**, **L2-L3**, **L3-L1** 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 because 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 given parameter is not calculated, the display shows "---" in its place.

In the bottom part of the tab, you can also determine the calculation method for total harmonic distortion THD: in relation to fundamental component (THD_F) or the RMS value (THD_R).
The displayed energy values depend on the **Displayed energy** selection list. The user can choose if the energy counters should be zeroed when the measuring session starts, or if they should display the total energy measured by the analyzer.

Internal energy counters in the analyzer are zeroed:

- when the measurement point is changed,
- when recording starts,
- when the analyzer is switched on (on start of self-test).

When the energy display mode is selected, the internal energy counters are not modified. The idea behind this mode is that when the application first reads the energy values (i.e. after switching into the **Measurements** tab), these values are remembered and the displayed values are a difference between the presently read energy value and the remembered value.

6.4 Phasor diagram

Phasor diagram (Fig. 49) is used to present the vectors of fundamental voltage and current components. Angles between the vectors correspond to the phase shift angle between individual phases. Table with numerical values is displayed left to the diagram. Individual columns of the table present:

- U – amplitude of voltage fundamental component,
- φ_U – angle of voltage fundamental component in relation to the L1 voltage fundamental component (in degrees),
- I – amplitude of current fundamental component,
- φ_I – angle of current fundamental component in relation to the L1 current fundamental component (in degrees),
- $\varphi_{U,I}$ – angle between voltage and current vectors ($\varphi_U - \varphi_I$) for a given phase (unavailable 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) and angle $\varphi_{U,I}$ and the receiver type. In addition the user can change the default color of the table background for these groups.

Different phasor diagrams and different parameters will be displayed for various mains configurations.

The vector angles are referenced to the L1 vector angle which is always φ **=** 0°.

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

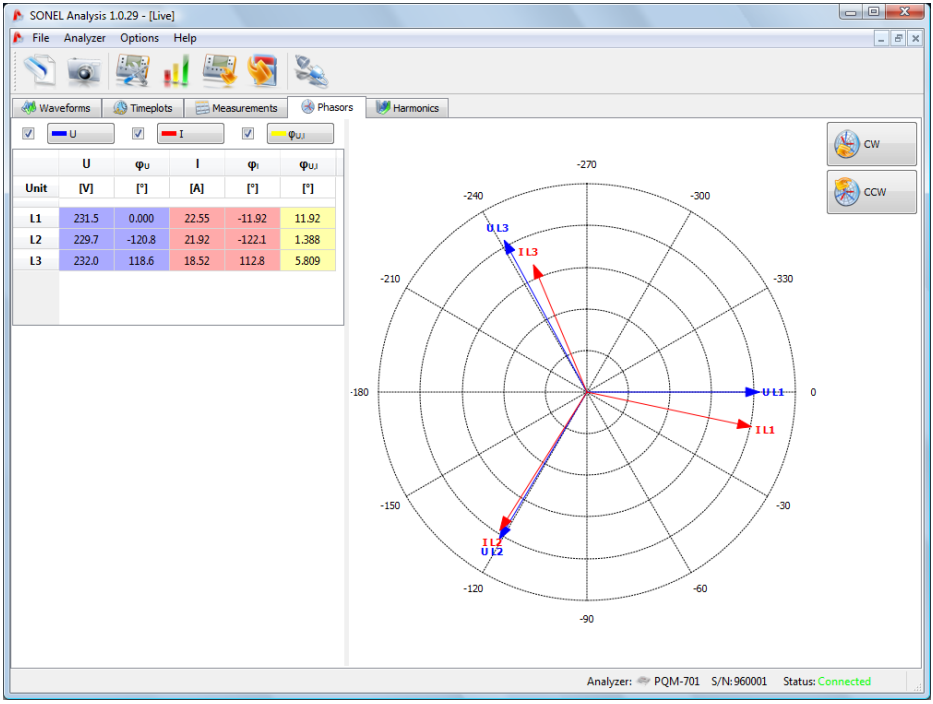


Fig. 32. Phasor diagram for the wye connection.

Next to the diagram are two buttons used to turn the phasor diagram by 90° clockwise or counter clockwise.

6.5 Harmonics

The harmonics tab allows viewing the harmonic values in voltage and current, active and reactive harmonics power, harmonic factors and K-factor. A typical screen is shown in Fig. 50. The displayed parameters are for one phase which is selected with the buttons on the right-hand side.

The bar chart in the central part of the screen presents the harmonics: from the DC component, through the first component up to the 50th.

The **Measure** button in the bottom part of the screen is used to choose one of the two options:

- **Voltage, Current** – voltage and current harmonics are displayed,
- **Power** – active and reactive harmonics power is displayed.

To the left and right of the chart are the axes scaled with units relevant for the selected mode: in the **Voltage, Current** mode, the voltage harmonic axis is on the left and the current harmonics axis is on the right. In the **Power** mode, the active power axis is on the left and the reactive power axis is on the right.

The tables below the bar chart present:

- THD,
- K-factors (only in the **Voltage, Current** mode),
- Table with numerical values of voltage and current harmonics and cosφ displacement power factor (in the **Voltage, Current** mode), or active and reactive harmonics power and cosφ displacement power factor (in the **Power** mode).

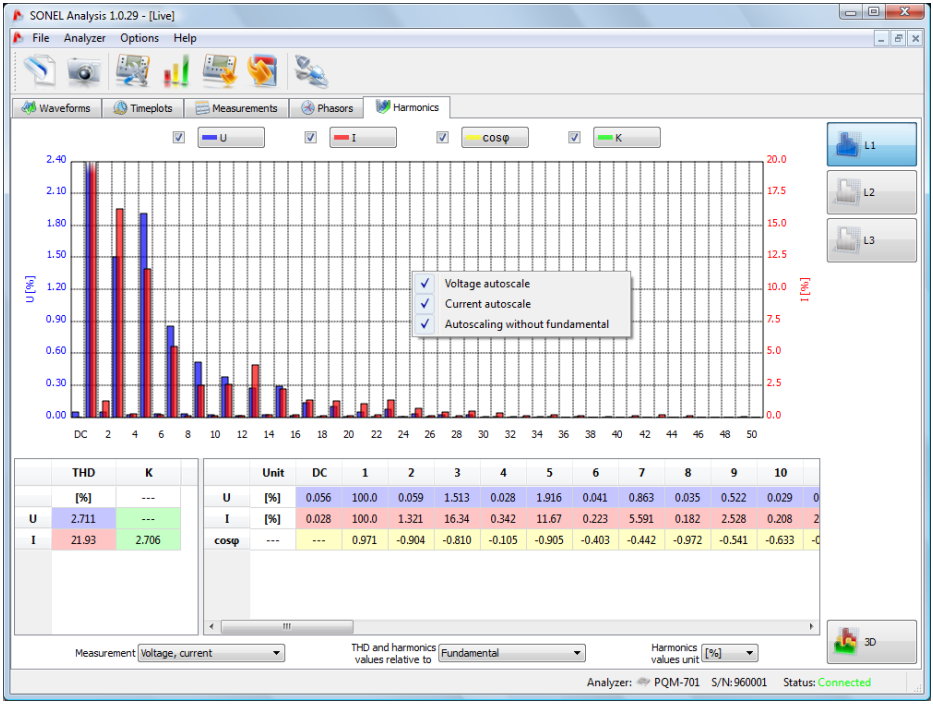


Fig. 33. Harmonics on a 2D diagram.

In the voltage and current harmonics mode, the user has access to two settings:

- **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 percents – see below,
- **Harmonics unit** – also there are two options: in absolute units (V, A) or in percent.

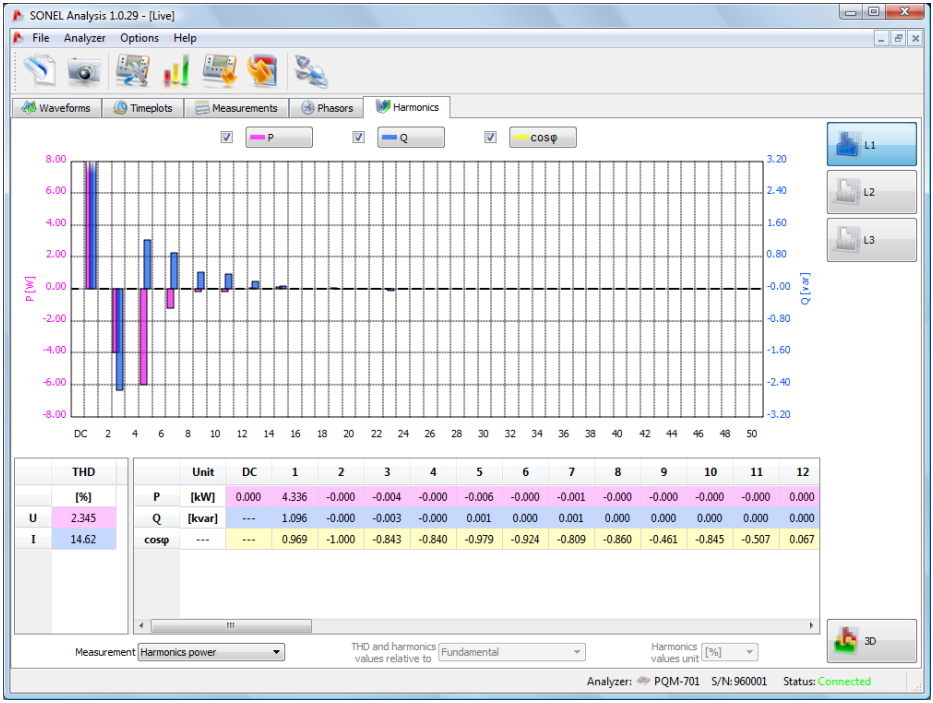


Fig. 34. Harmonics power screen.

Right-click on the chart to display a context menu in which there are the following options:

- **Auto-scaling of voltage, current** or **power P** and **power Q** (depending on the harmonics type). Use this option to scale the harmonics bars and fit them to the chart window height.
- **Do not scale to the first harmonics** – the first harmonics will be skipped during the auto-scaling; consequently, the higher harmonics bars can be quickly made higher – they usually have much lower level than the fundamental component (example shown in Fig. 50).

In the bottom right-hand corner is the 2D/3D button. After clicking, the harmonics are presented in a 3D view. After clicking the **Any view** button, the diagram can be freely set with a mouse. Hold the left mouse button on the diagram and put it in the position you want. Hold the right mouse button to zoom in/out the diagram. You can use also the sliders on the left hand of the window or the mouse scroll wheel.
Press SPACEBAR to start a simple 3D visualization.

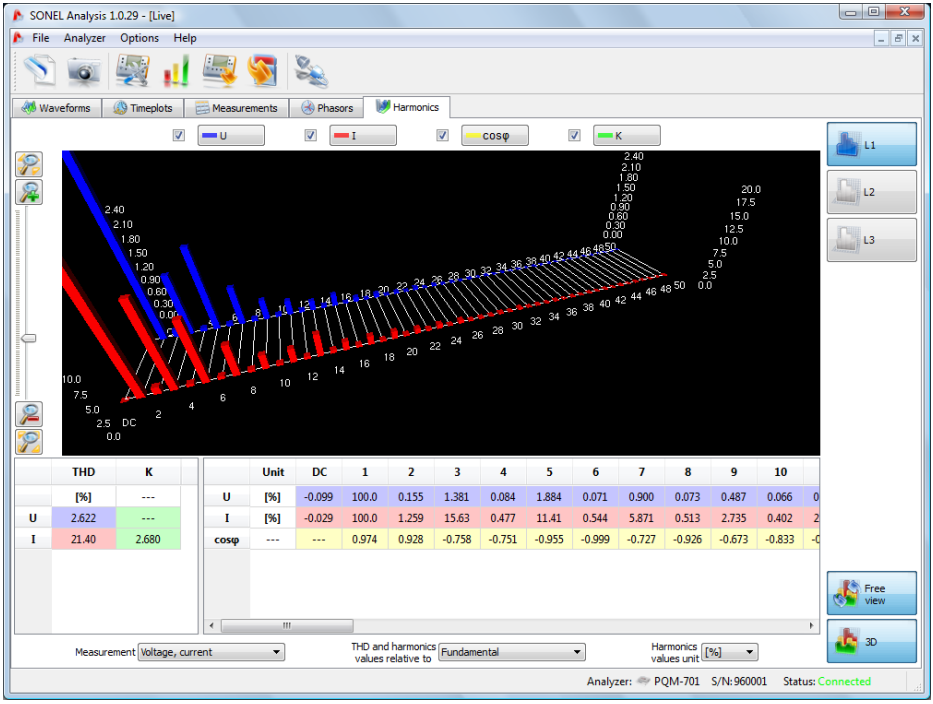


Fig. 35. Harmonics on a 3D view.

7 Data analysis

The data analysis block allows reading the data collected by the analyzer during recording, viewing the numerical data and graphical visualization. It is possible to create reports which characterize the tested system in a concise manner.

There are two methods to read the data saved on memory card:

- by the USB or wireless link from the card located in the analyzer slot,
- by external SD card reader connected to the computer – the card is in the reader.

When the data amount is large, it is recommended to use the reader.
Click an appropriate icon on the toolbar to select one of the two options:

- **Analysis** – reading directly from the analyzer,
- **SD card analysis** – reading the data by means of external reader.

7.1 Reading the data from the analyzer and SD card

After selecting **Analysis** (from top menu or by clicking the icon), if there is no connection between the analyzer and the software, standard connection procedure is carried out (section 4.4).

After clicking **SD card analysis**, the software is searching for available devices with SD cards. If the software finds a correct card in the reader, a widow is displayed with information about the analyzer from which the data originated. Choose an analyzer from the list and click **Select**.

When the computer is correctly connected to the analyzer or the SD card reader, a window is displayed as shown in Fig. 53 and the recorded data can be downloaded. Check the measurement points from which you wish to download the data. To the right of the bar showing the memory use, you can see the percent of memory for a given point and actual data volume.

Selecting the **Delete data after reading** option will cause deletion of data from the point (points) from which the data are read. Accordingly, a suitable warning message will be displayed after pressing the **Read** button and before the start of transmission.

A window with progress bar and the amount of downloaded data is displayed during the reading.

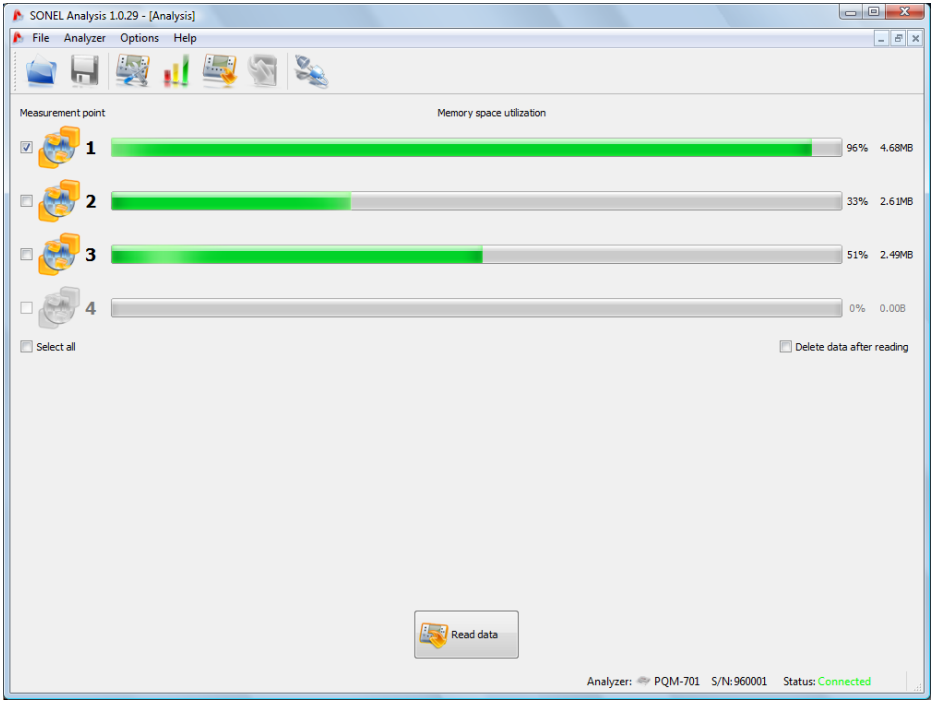


Fig. 36. Selecting the measurement point for reading.

If there is no card in the reader or the card has incorrect data, the **No card with measurements** message will be displayed.

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

7.2 Selecting the analysis time interval

After a correct data reading, a window is displayed to select the analysis time interval. Only data from the indicated interval will be analyzed. The selection window is shown in Fig. 54. Individual window components have the following meaning:

- The list of read measurement points is in the left-hand part. 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.
- Double-click on the Beginning icon to set the **S** slider at the beginning of recording by a given point, and double-click on the End icon to set the **E** slider at the end of recording by a given point.
- The recording periods are represented graphically as bars in the central and right-hand part of the screen. After selecting a measurement point, the bars representing the periods from this point change color to red, showing which data can be analyzed. Simultaneously, the **Data analysis** button becomes active.

- Next to the **Measurement point X** description is an information whether data from this point have been recorded according to the standard (text **EN 50160**) or according to user-defined settings (text **USER**),
- There are three fields that define start, duration and end of the analysis interval which is selected by two sliders: **S** (beginning) and **E** (end). You can use these sliders to select smaller analysis interval. If you select interval longer that a given period, the whole period will be selected for analysis.
- The information about the interval selected for analysis in the week:day:hour:minute:second format appears in central field **Range**. You can select standard time interval from the drop-down list, i.e. 10-min., hour, day, week. If a selected period is longer than recording, the whole recording is checked.
- Click the **Data analysis** button to start the data analysis in selected time interval.

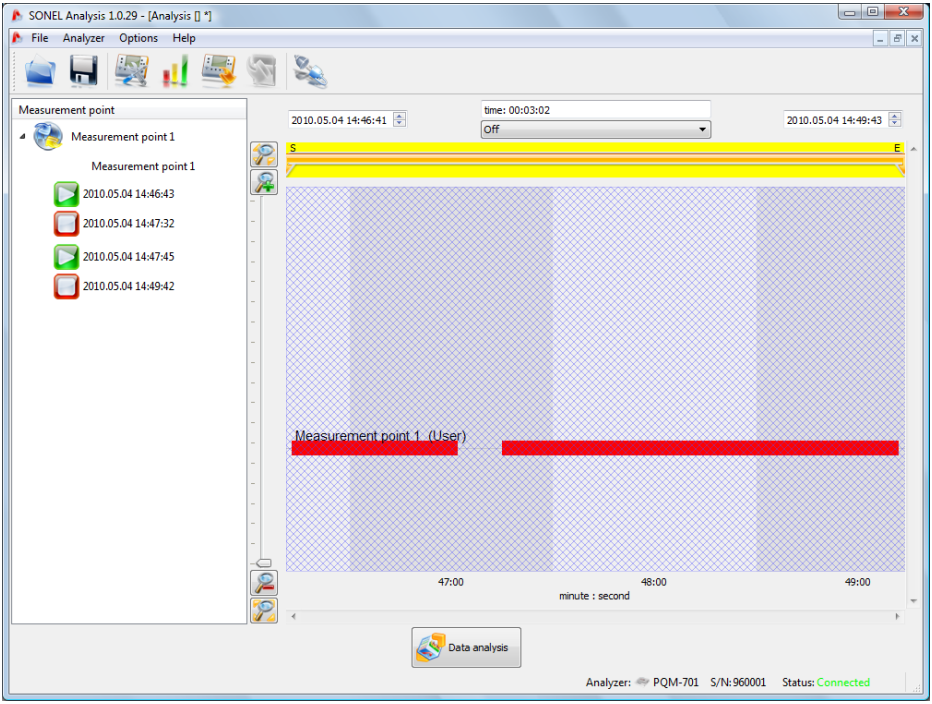


Fig. 37. Selecting the analysis time interval.

If you wish to perform many analyses on the read data, after downloading, save such data on a local disk as a file with the extension *.pqm701. Such file will include a true copy of the read data and can be used at any moment and you can return to the analysis time selection screen (Fig. 54). Please remember that if you send a new measurement points configuration, the SD card is formatted and all recorded data will be irreversibly lost.

Starting the analysis (by pressing the **Data analysis** button) will require a next reading of the data from the card, if you want to perform a next analysis on the basis of the data saved on the card.

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

7.3 Analysis of read data

7.3.1 General

After a correct data reading, the main data analysis module window is displayed. The window is divided into a few parts (Fig. 55):

- The buttons used to display the following data are in the left-hand side:
  - **General** – all data of individual types are displayed as dots (Measurements, Events, and Waveforms),
  - **Measurements** – all types of measurements recorded according to the averaging time are displayed as dots (voltage, frequency, etc.),
  - **Events** – all types of detected events are shown as dots (voltage dips, swells, interruptions).
- If you select a button, also relevant data will be displayed in the table below the diagram.
- The fields with start date, time interval and end date are above the diagram.

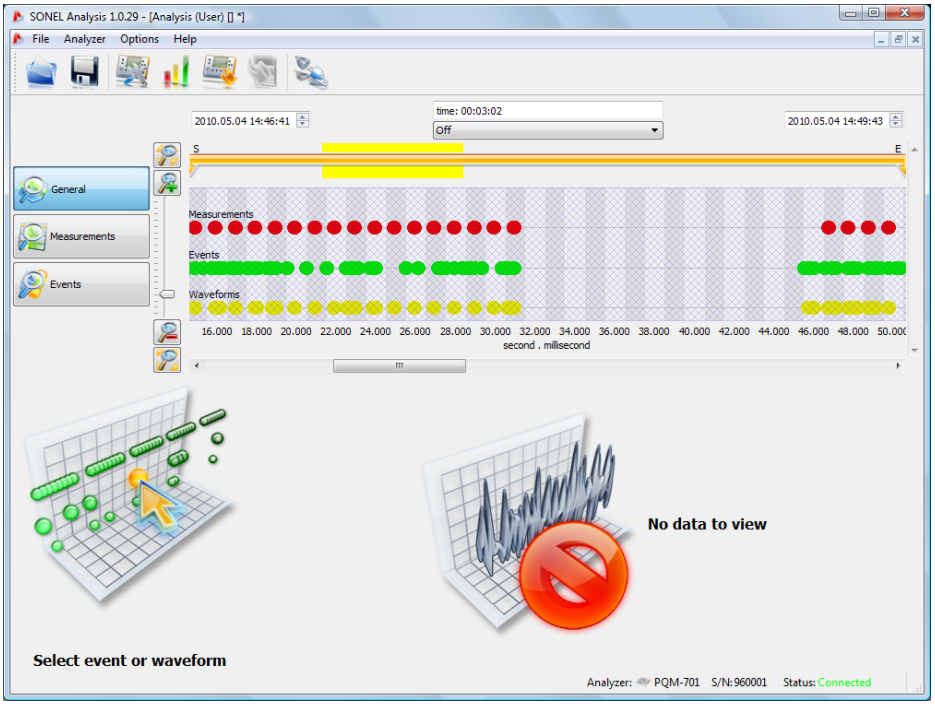


Fig. 38. General data analysis window.

In the **General** view you can have a quick preview of waveform and/or event, but you cannot view the measurements. Put the cursor on an event point and press the left mouse button to display information about this event and the waveform if it was recorded along with the event (Fig. 56).

Sometimes the diagram is very dense and practically in a single place there are a few overlapping points; then, placing the cursor displays the earliest event and waveform, and information is displayed above the selected point about the number of events and waveforms.

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

When an even is selected, the displayed waveform is from the beginning of such event. Use the slider (or the mouse 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. Similarly, if the waveforms were recorded after the averaging period, clicking on the measurement simultaneously highlights the dot of accompanying waveform.

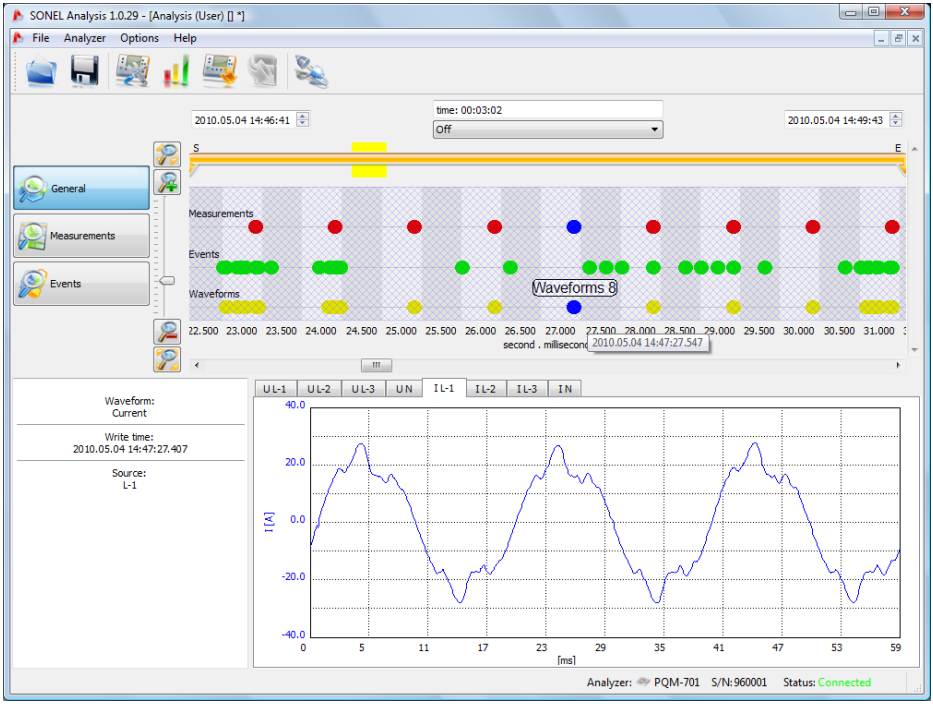


Fig. 39. General window with waveform preview.

7.3.2 Measurements

Clicking the **Measurements** button will change the window to the format shown in Fig. 57. The analyzable parameters appear in the lower part.

The diagram includes the dots which represent the parameters measurement over time. If the data amount is large, the dots can become lines.

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 **P** (start) and **K** (end).

Below the diagram is the summary table with recorded values of the parameters. The table includes the data only from the selected time interval.

The checkboxes on the left-hand 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 appear in the table. To limit the amount of data shown in the table, use the buttons (L1, L2, L3, N) on the right-hand side.

Right-click within the table area to display a context menu with the options: **Average**, **Instantaneous**, **Min**, **Max** (Fig. 57). Check/ uncheck the options to show/ hide relevant values from among the recorded data (as configured by the user). The selected data may also be copied to the clipboard.

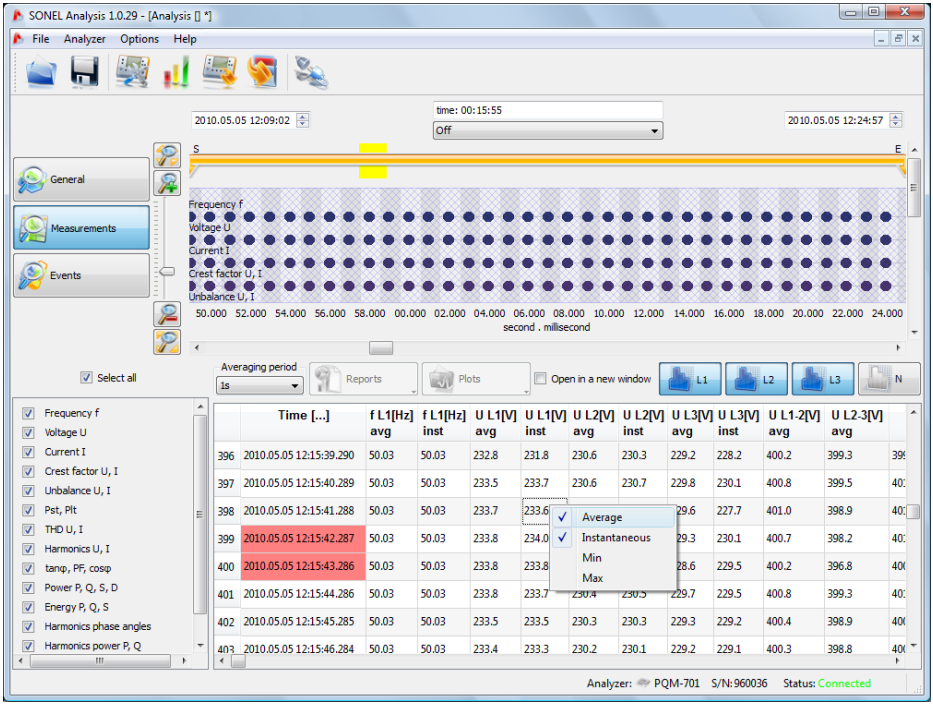


Fig. 40. Measurements window for user's recording.

If you check the **Open in a new window** option, a new diagram or table will always be opened in a new window. If this option is not active, a separate window with diagram or table is refreshed.

Averaging is used to select the time according to which the data in the table will be shown if there are the data with various averaging times (i.e. long-term flicker P_{lt} – 120min and frequency – 10s).

The rows in which the **Time** cell has a red background indicate that a given measuring record is flagged, which means that a voltage swell, dip or interruption event happened during a given averaging period. Such concept of flagging has been introduced by the IEC 61000-4-30 standard. The listed event types can cause incorrect measurements of some mains parameters and the 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 measurements is left to the user.

With the **Plots** button the user can generate a few types of diagrams. The following options are available:

- **Time plot** – when the **Time** column is selected along with any other column (columns) (as in Fig. 57) 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 the **Time** column select the period you are interested in, and then select relevant parameters. You can select any parameter columns, including individual harmonics U, I, f, H03, H05, etc. A typical time plot is shown in Fig. 59,
- **Waveform** – waveforms view for voltage and current (if any), i.e. during the events or at the end of an averaging period (Fig. 63). The waveform can be displayed by highlighting the row with available waveform and selecting the **Plots** option, and then the **Waveform** option, or by double-clicking on a given row,
- **The graph showing semi-periodic rms values (RMS1/2)** for events for which the oscillogram diagram was recorded. This diagram is opened together with the oscillogram (e.g. by double clicking the event line with the event in the table). The time scale for both charts is identical.
- **Harmonics** plot – bar chart presenting the 1..50 order harmonics. This option is active even when only one harmonics 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. 61).

In general, the parameters are recorded according to the averaging time set in the configuration. For example, if you have set a 10-minute averaging time, every 10 minutes a record is written on the memory card with the average values (and possibly also minimum, maximum and instantaneous values) of the parameters. However, in some case there are deviations from this rule, for example:

- Long-term flicker P_{lt} – it is measured every 2 hours, hence at a 10-minute averaging time, a new P_{lt} value appears every 12 averaging periods,
- Frequency – the measurement time for this parameter is 10 seconds,
- 15-minute active and reactive power during 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 of displaying parameters in relation to the indicated averaging period. For example, if you measured with a 10-minute averaging time and wish to quickly display the records in which the P_{lt} values were measured, select 2h from the **Show data every** list. 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.

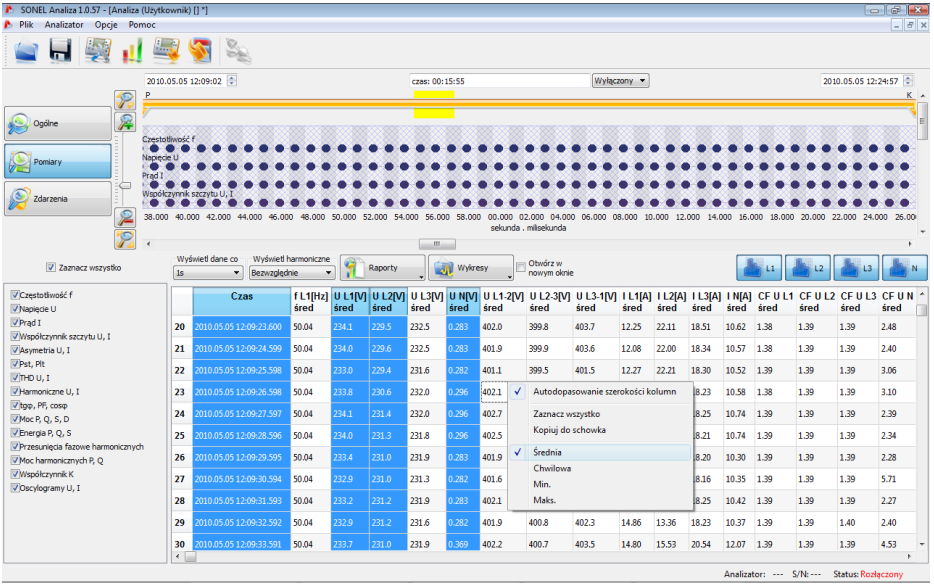


Fig. 41. Selecting data for the plot.

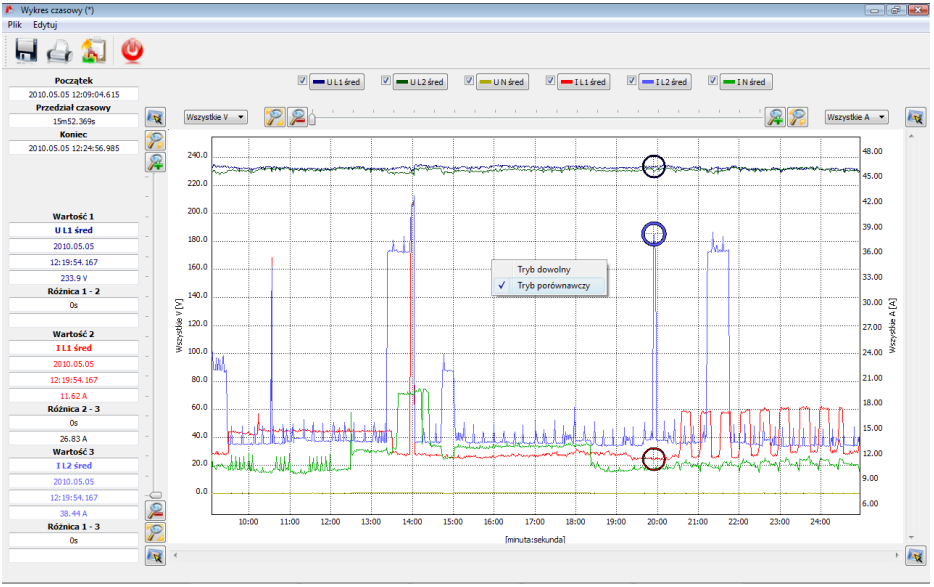
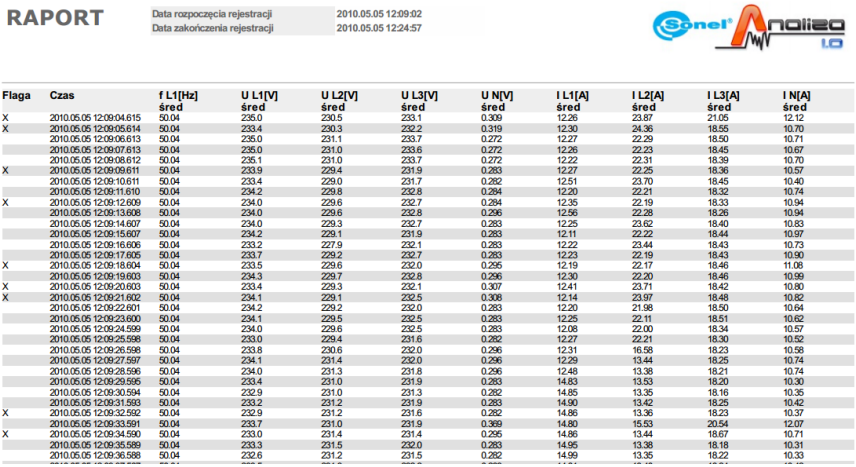


Fig. 42. Timeplot window.

Time plot description:

- information about the start, end and time difference of the plot is included in the top left-hand part,
- information about the values of two independent markers is displayed in the left-hand part below (three circles on the plot),
- the markers can be moved by 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 right-clicking within the plot area, you select the **Free mode enabled** option, the marker can be set without restraint. 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, enabling users easily compare up to the three chosen parameters for a given time.
- use the buttons above the plot to switch on/off individual waveforms and change their colors,
- use the sliders or the mouse wheel to zoom in the plot vertically and horizontally (vertically, if the mouse pointer is placed near the side edges of the plot; horizontally, if the mouse pointer is placed near its top or bottom edge),
- keeping the SHIFT key pressed, use mouse to select a rectangular area to be zoomed in,
- keeping the CTRL key pressed, click with left mouse button in the plot area and without releasing the mouse button move the visible fragment (the cursor arrow turns into a hand),
- the plot has two vertical axes on the left- and right-hand sides; select the scale for the required value to be displayed on the plot from the drop-down lists,
- in addition to the parameters selected by the user (i.e. UL1, K, 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 (for example in V) and all waveforms from this group are rescaled to fit the scale,
- selecting a given group for the left-hand scale Y causes deactivation of this group and its all parameters on the right-hand scale Y, and vice versa,
- click on the icons in the corners of the screen to show 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,
- press one of the buttons in the top of the screen to save the plot on the disk in a user-selectable format (jpg, png or xpm), copy to clipboard, or print,
- maximum number of waveforms on the plot is 12.

Highlight any column (for example f, U L1, THD U, etc.) or any range of cells and click the **Report** button to display a new window enabling users to save the selected data in a required file format (pdf, html, txt, csv) or to copy them to clipboard and print. 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 60. Maximum 12 columns of data may be generated.



RAPORT

Data rozpoczęcia rejestracji	2010.05.05 12:09:02
Data zakończenia rejestracji	2010.05.05 12:24:57

Flaga	Czas	f L1[Hz] średnia	U L1[V] średnia	U L2[V] średnia	U L3[V] średnia	U N[V] średnia	I L1[A] średnia	I L2[A] średnia	I L3[A] średnia	I N[A] średnia
X	2010.05.05 12:09:04.615	50.04	235.0	230.5	233.1	0.309	12.26	23.87	21.05	12.12
X	2010.05.05 12:09:05.614	50.04	233.4	230.3	232.2	0.319	12.30	24.36	18.55	10.70
	2010.05.05 12:09:06.613	50.04	235.0	231.1	233.7	0.272	12.27	22.29	18.50	10.71
	2010.05.05 12:09:07.613	50.04	235.0	231.0	233.6	0.272	12.26	22.23	18.45	10.67
	2010.05.05 12:09:08.612	50.04	235.1	231.0	233.7	0.272	12.22	22.31	18.39	10.70
X	2010.05.05 12:09:09.611	50.04	233.9	229.4	231.9	0.283	12.27	22.25	18.36	10.57
	2010.05.05 12:09:10.611	50.04	233.4	229.0	231.7	0.282	12.51	23.70	18.45	10.40
	2010.05.05 12:09:11.610	50.04	234.2	229.8	232.8	0.284	12.20	22.21	18.32	10.74
X	2010.05.05 12:09:12.609	50.04	234.0	229.6	232.7	0.284	12.35	22.19	18.33	10.94
	2010.05.05 12:09:13.608	50.04	234.0	229.6	232.8	0.296	12.56	22.28	18.26	10.94
	2010.05.05 12:09:14.607	50.04	234.0	229.3	232.7	0.283	12.25	23.62	18.40	10.83
	2010.05.05 12:09:15.607	50.04	234.2	229.1	231.9	0.283	12.11	22.22	18.44	10.97
	2010.05.05 12:09:16.606	50.04	233.2	227.9	232.1	0.283	12.22	23.44	18.43	10.73
	2010.05.05 12:09:17.605	50.04	233.7	229.2	232.7	0.283	12.23	22.19	18.43	10.90
X	2010.05.05 12:09:18.604	50.04	233.5	229.6	232.0	0.295	12.19	22.17	18.46	11.08
	2010.05.05 12:09:19.603	50.04	234.3	229.7	232.8	0.296	12.30	22.20	18.46	10.99
X	2010.05.05 12:09:20.603	50.04	233.4	229.3	232.1	0.307	12.41	23.71	18.42	10.80
X	2010.05.05 12:09:21.602	50.04	234.1	229.1	232.5	0.308	12.14	23.97	18.48	10.82
	2010.05.05 12:09:22.601	50.04	234.2	229.2	232.0	0.283	12.20	21.98	18.50	10.64
	2010.05.05 12:09:23.600	50.04	234.1	229.5	232.5	0.283	12.25	22.11	18.51	10.62
	2010.05.05 12:09:24.599	50.04	234.0	229.6	232.5	0.283	12.08	22.00	18.34	10.57
	2010.05.05 12:09:25.598	50.04	233.0	229.4	231.6	0.282	12.27	22.21	18.30	10.52
	2010.05.05 12:09:26.598	50.04	233.8	230.6	232.0	0.296	12.31	16.58	18.23	10.58
	2010.05.05 12:09:27.597	50.04	234.1	231.4	232.0	0.296	12.29	13.44	18.25	10.74
	2010.05.05 12:09:28.596	50.04	234.0	231.3	231.8	0.296	12.48	13.38	18.21	10.74
	2010.05.05 12:09:29.595	50.04	233.4	231.0	231.9	0.283	14.83	13.53	18.20	10.30
	2010.05.05 12:09:30.594	50.04	232.9	231.0	231.3	0.282	14.85	13.35	18.16	10.35
	2010.05.05 12:09:31.593	50.04	233.2	231.2	231.9	0.283	14.90	13.42	18.25	10.42
X	2010.05.05 12:09:32.592	50.04	232.9	231.2	231.6	0.282	14.86	13.36	18.23	10.37
	2010.05.05 12:09:33.591	50.04	233.7	231.0	231.9	0.369	14.80	15.53	20.54	12.07
X	2010.05.05 12:09:34.590	50.04	233.0	231.4	231.4	0.295	14.86	13.44	18.67	10.71
	2010.05.05 12:09:35.589	50.04	233.3	231.5	232.0	0.283	14.95	13.38	18.18	10.31
	2010.05.05 12:09:36.588	50.04	232.6	231.2	231.5	0.282	14.99	13.35	18.22	10.33

Fig. 43. Example of a report saved as a .pdf file.

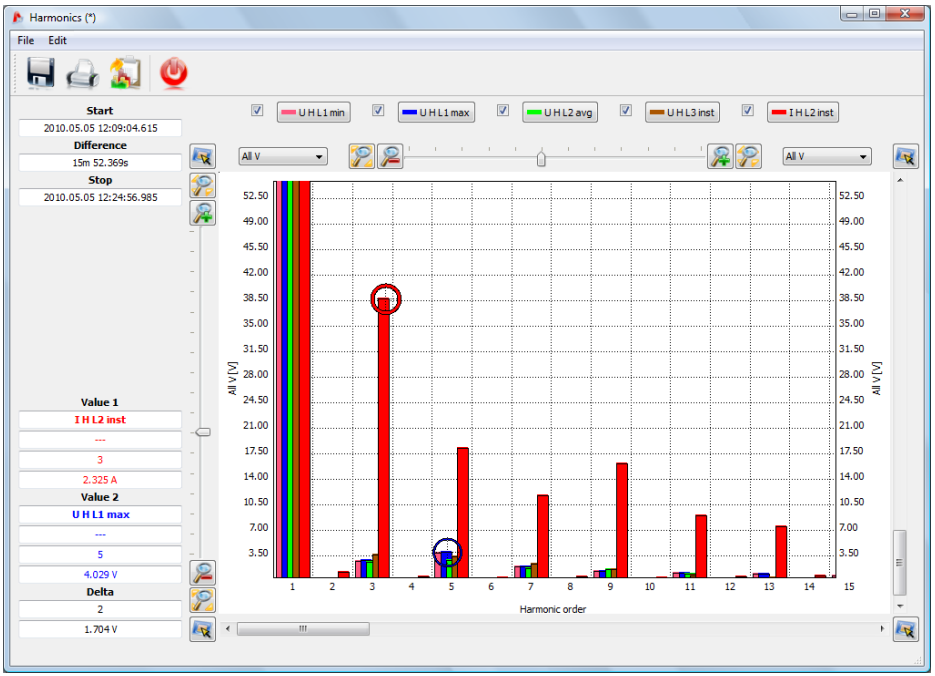


Fig. 44. Harmonics diagram.

7.3.3 Events

Clicking the **Events** button will change the window to the format shown in Fig. 62. This mode can be used to analyze all events recorded by the analyzer.
The recorded events are presented as dots in the diagram.

The parameters listed in the table appear for selection in the top left-hand corner of the screen. Click in relevant checkboxes to include or exclude selected types. Only selected event types will appear in the table.

Description of individual columns:

- **Marker** – select this cell (by double-clicking) to select the event along with the waveform (if any) on the dot chart and add a given event to the list in the **Markers** tab,
- **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** – time of event start and end,
- **Duration** – event duration,
- **Extreme value** – the smallest or largest value during the event,
- **Average value** – the 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** – sign **V** means than an waveform is available for a given event, sign **X** means absence of waveform.

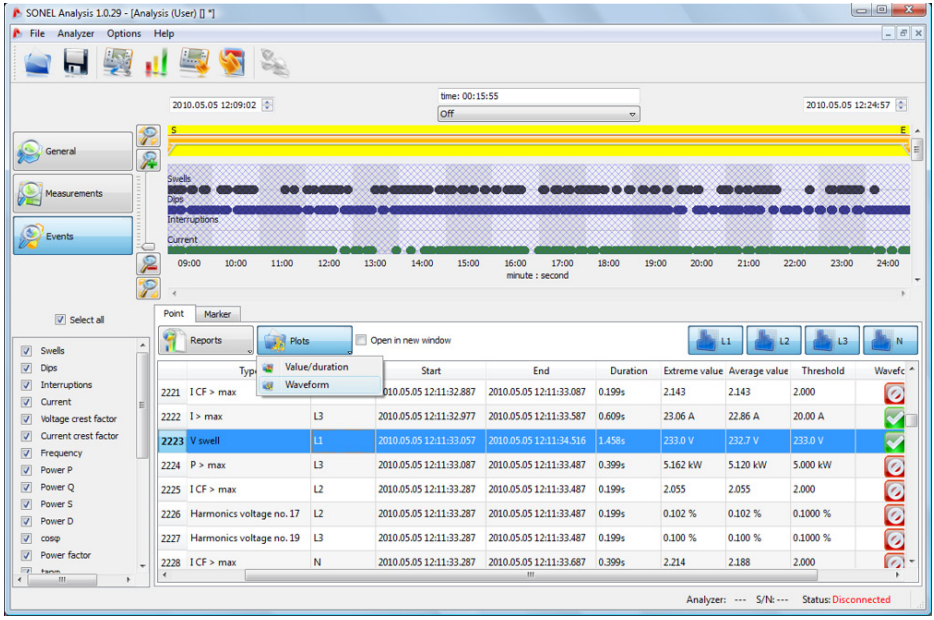


Fig. 45. Event window for User's recording.

Check event with waveform to activate the **Waveform** plot. Select this plot or double-click in the event row to open the event waveform plot window including the graph showing semi-periodic rms values $RMS_{1/2}$ (Fig. 64). The **Open in a new window** option has the same functionality as in the data analysis.

The **Marker** window lists the user-selected events in the table. The rows (that is the events) can be moved in this table so that you can arrange them to your discretion. Use the “drag and drop” method to move the rows – click on any cell in the row, and keeping the left bottom mouse pressed, drag it up or down.

All buttons in the **Marker** tab have the same functionality as in the **Point** tab.

Fig. 63 presents a typical waveform plot. As two waveforms are assigned to this event (start and end of the event), the grayed-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 (2 periods before and 4 after for event beginning, and 2 before and 4 after for event end). The plot can be freely zoomed in as shown in Fig. 64. Operations on the plot are the same as in case of the time plot.

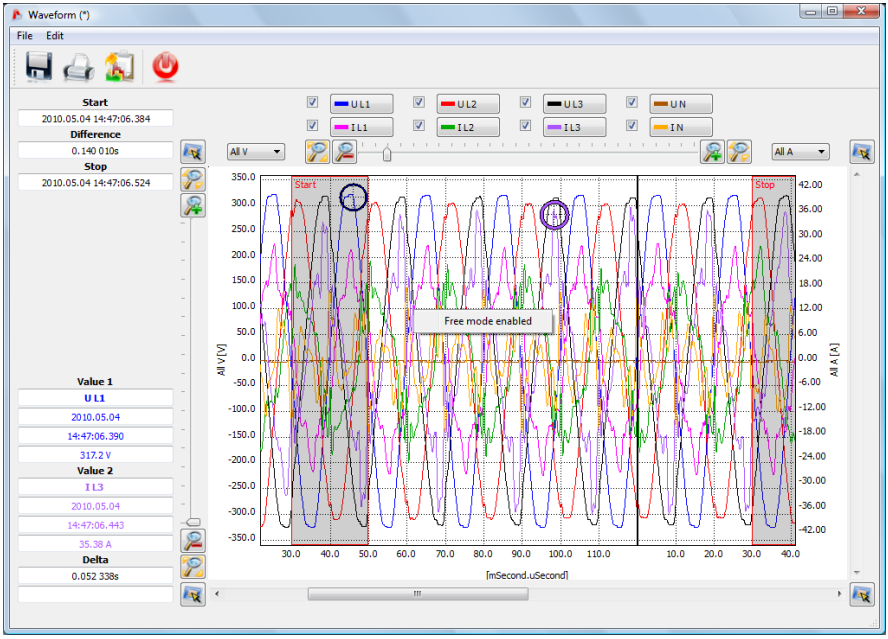


Fig. 46. Plot with start and end waveform.

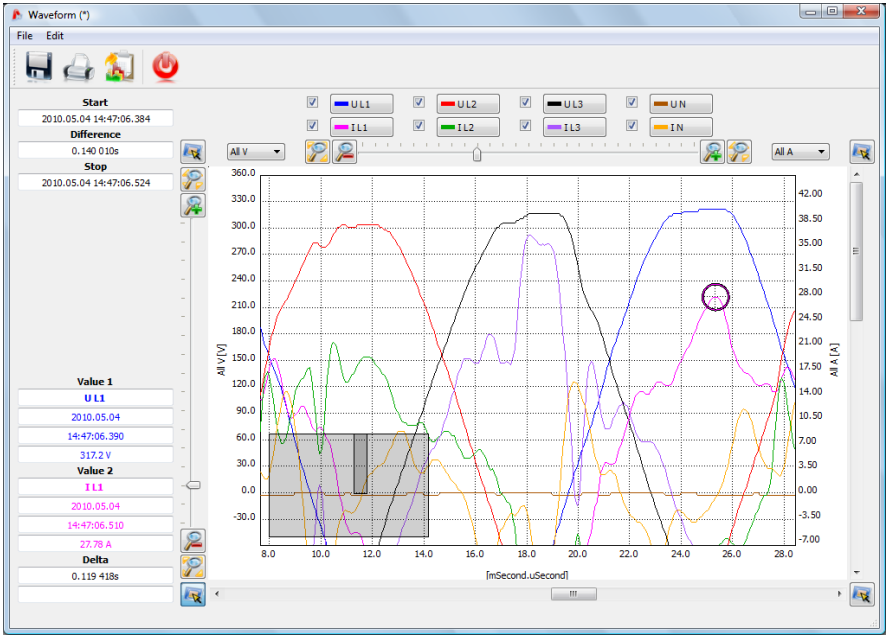


Fig. 47. Zooming in a fragment of waveform.

Use the **Report** → **Event report** option to save the data displayed in the table in a report format. A typical report in pdf format is shown in Fig. 65.

RAPORT

Data rozpoczęcia rejestracji	2010.05.05 12:09:02
Data zakończenia rejestracji	2010.05.05 12:24:57

Typ	Źródło	Początek	Koniec	Czas trwania	Ekstremum	Wartość średnia	Próg
Przepięcie	L3	2010.05.05 12:09:02.616	2010.05.05 12:09:02.856	0.239s	233.8 V	233.7 V	233.0 V
Przepięcie	L1	2010.05.05 12:09:02.616	2010.05.05 12:09:03.216	0.599s	235.0 V	234.8 V	233.0 V
Harmoniczna prądu nr 41	L3	2010.05.05 12:09:02.616	2010.05.05 12:09:03.216	0.599s	0.102 %	0.101 %	0.1000 %
PF > maks.	L1	2010.05.05 12:09:02.616	2010.05.05 12:09:05.015	2.398s	0.952	0.948	0.950
Harmoniczna prądu nr 20	L2	2010.05.05 12:09:02.616	2010.05.05 12:09:06.813	4.197s	0.139 %	0.119 %	0.1000 %
Harmoniczna prądu nr 22	L2	2010.05.05 12:09:02.616	2010.05.05 12:09:06.813	4.197s	0.145 %	0.121 %	0.1000 %
Harmoniczna prądu nr 28	L1	2010.05.05 12:09:02.616	2010.05.05 12:09:07.013	4.396s	0.150 %	0.127 %	0.1000 %
Harmoniczna prądu nr 18	L3	2010.05.05 12:09:02.616	2010.05.05 12:09:07.013	4.396s	0.218 %	0.151 %	0.1000 %
Harmoniczna prądu nr 22	L3	2010.05.05 12:09:02.616	2010.05.05 12:09:07.013	4.396s	0.174 %	0.132 %	0.1000 %
Harmoniczna prądu nr 12	L1	2010.05.05 12:09:02.616	2010.05.05 12:09:07.813	5.196s	0.207 %	0.148 %	0.1000 %
Harmoniczna prądu nr 26	L1	2010.05.05 12:09:02.616	2010.05.05 12:09:07.813	5.196s	0.163 %	0.121 %	0.1000 %
Harmoniczna prądu nr 32	L1	2010.05.05 12:09:02.616	2010.05.05 12:09:08.012	5.396s	0.117 %	0.110 %	0.1000 %
Harmoniczna prądu nr 43	L3	2010.05.05 12:09:02.616	2010.05.05 12:09:09.811	7.194s	0.130 %	0.116 %	0.1000 %
Harmoniczna prądu nr 6	L2	2010.05.05 12:09:02.616	2010.05.05 12:09:20.203	17.586s	0.378 %	0.159 %	0.1000 %
I > maks.	L2	2010.05.05 12:09:02.616	2010.05.05 12:09:25.758	23.142s	30.47 A	22.72 A	20.00 A
P > maks.	L2	2010.05.05 12:09:02.616	2010.05.05 12:09:25.798	23.182s	6.260 kW	5.146 kW	5.000 kW
P < min.	L1	2010.05.05 12:09:02.616	2010.05.05 12:09:28.596	25.979s	2.662 kW	2.726 kW	3.000 kW
I/I$_n$ > maks.	L1	2010.05.05 12:09:02.616	2010.05.05 12:09:32.991	30.375s	25.73 %	20.62 %	3.000 %
Harmoniczna prądu nr 39	L1	2010.05.05 12:09:02.616	2010.05.05 12:09:34.390	31.773s	0.252 %	0.166 %	0.1000 %
Harmoniczna prądu nr 8	L1	2010.05.05 12:09:02.616	2010.05.05 12:09:41.783	39.166s	1.554 %	0.389 %	0.1000 %
Harmoniczna prądu nr 45	L1	2010.05.05 12:09:02.616	2010.05.05 12:09:43.581	40.964s	0.220 %	0.134 %	0.1000 %
Harmoniczna prądu nr 4	L3	2010.05.05 12:09:02.616	2010.05.05 12:09:55.971	53.354s	0.967 %	0.253 %	0.1000 %
Harmoniczna prądu nr 35	L3	2010.05.05 12:09:02.616	2010.05.05 12:09:57.570	54.953s	0.277 %	0.160 %	0.1000 %
Harmoniczna prądu nr 33	L1	2010.05.05 12:09:02.616	2010.05.05 12:10:25.348	1m22.732s	0.425 %	0.192 %	0.1000 %
Harmoniczna prądu nr 12	L3	2010.05.05 12:09:02.616	2010.05.05 12:10:26.347	1m23.731s	0.991 %	0.273 %	0.1000 %
Harmoniczna prądu nr 31	L1	2010.05.05 12:09:02.616	2010.05.05 12:10:26.547	1m23.931s	0.489 %	0.259 %	0.1000 %
Harmoniczna prądu nr 10	L1	2010.05.05 12:09:02.616	2010.05.05 12:10:28.945	1m26.329s	2.257 %	0.461 %	0.1000 %
PF > maks.	L2	2010.05.05 12:09:02.616	2010.05.05 12:10:30.943	1m28.327s	0.991	0.973	0.950
PF > maks.	L3	2010.05.05 12:09:02.616	2010.05.05 12:10:30.943	1m28.327s	0.975	0.957	0.950
cosφ > maks.	L3	2010.05.05 12:09:02.616	2010.05.05 12:10:31.143	1m28.527s	0.995	0.988	0.950
Harmoniczna prądu nr 39	L3	2010.05.05 12:09:02.616	2010.05.05 12:10:31.343	1m28.726s	0.195 %	0.141 %	0.1000 %
Współczynnik K > maks.	L3	2010.05.05 12:09:02.616	2010.05.05 12:10:31.343	1m28.726s	3.371	2.907	2.000
Współczynnik K > maks.	L1	2010.05.05 12:09:02.616	2010.05.05 12:10:31.543	1m28.926s	4.928	3.287	2.000
Harmoniczna napięcia nr 17	L1	2010.05.05 12:09:02.616	2010.05.05 12:10:36.139	1m33.522s	0.194 %	0.149 %	0.1000 %
Harmoniczna prądu nr 6	L3	2010.05.05 12:09:02.616	2010.05.05 12:11:07.110	2m1.493s	1.698 %	0.358 %	0.1000 %
Harmoniczna prądu nr 29	L3	2010.05.05 12:09:02.616	2010.05.05 12:11:07.909	2m5.293s	0.494 %	0.216 %	0.1000 %
Harmoniczna prądu nr 10	L2	2010.05.05 12:09:02.616	2010.05.05 12:13:25.388	4m22.771s	1.016 %	0.278 %	0.1000 %
Harmoniczna prądu nr 20	L3	2010.05.05 12:09:02.616	2010.05.05 12:13:25.588	4m22.971s	1.183 %	0.275 %	0.1000 %
Harmoniczna prądu nr 16	L2	2010.05.05 12:09:02.616	2010.05.05 12:13:25.787	4m23.171s	0.852 %	0.280 %	0.1000 %

Fig. 48. Event report.

Fig. 66 presents the **Value/duration** plot. This plot shows the events as dots and allows presenting many events and the interrelation between event duration (on horizontal axis) and extreme event value (on vertical axis).

If an event is current or voltage-related, select a relevant dot with the mouse and double-click to open a new window with waveform for this event (if any).

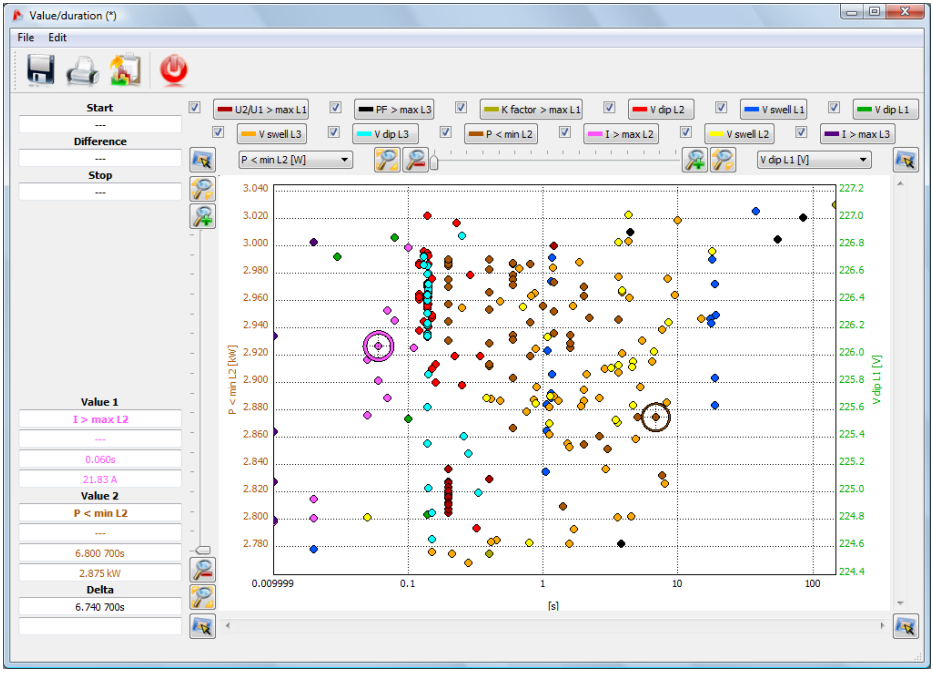


Fig. 49. Data analysis – value/time diagram.

> ***Advice***
> *Zoom in/ zoom out operations, dragging, crosses functions, etc. in Fig. 63, Fig. 64 are analogous to the plots presented in Fig. 59 and Fig. 66.*

7.3.4 Analysis of read data according to EN 50160

Data analysis according to EN 50160 is analogous to the **User's** analysis. The only difference is that only three types of events are taken into consideration (voltage swells, dips and interruptions).

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 tanφ.

There is an additional button - **EN 50160 Report**. Press this button to save the measurement final compliance report with the EN 50160 standard. The report is saved as a PDF file (with graphical diagram), a HTML file, or as a text file. Click the **EN 50160 Report** button to display a window where you can enter additional data to the report (Fig. 67).

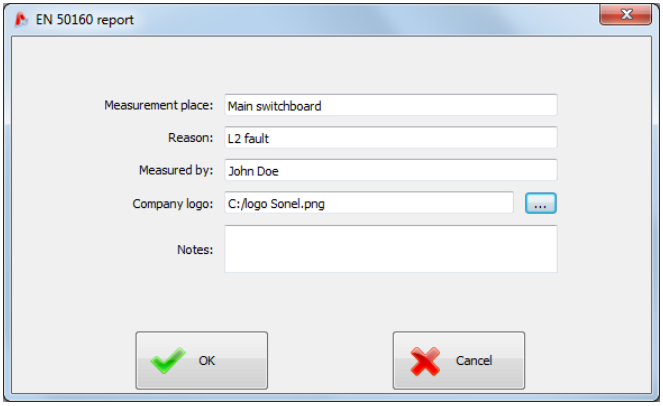


Fig. 50. Entering additional data to the report.

In the **Measurement location** field, appears the information **Measurement point 1, 2, 3 or 4**, or the name entered during configuration. You can fill in the remaining fields. If you leave the fields empty, corresponding fields in the report will be blank as well. If you want a corporate logo or another symbol to appear in the report header, indicate it in the **Company logo** field.

A fragment of a typical report is shown in Fig. 68.

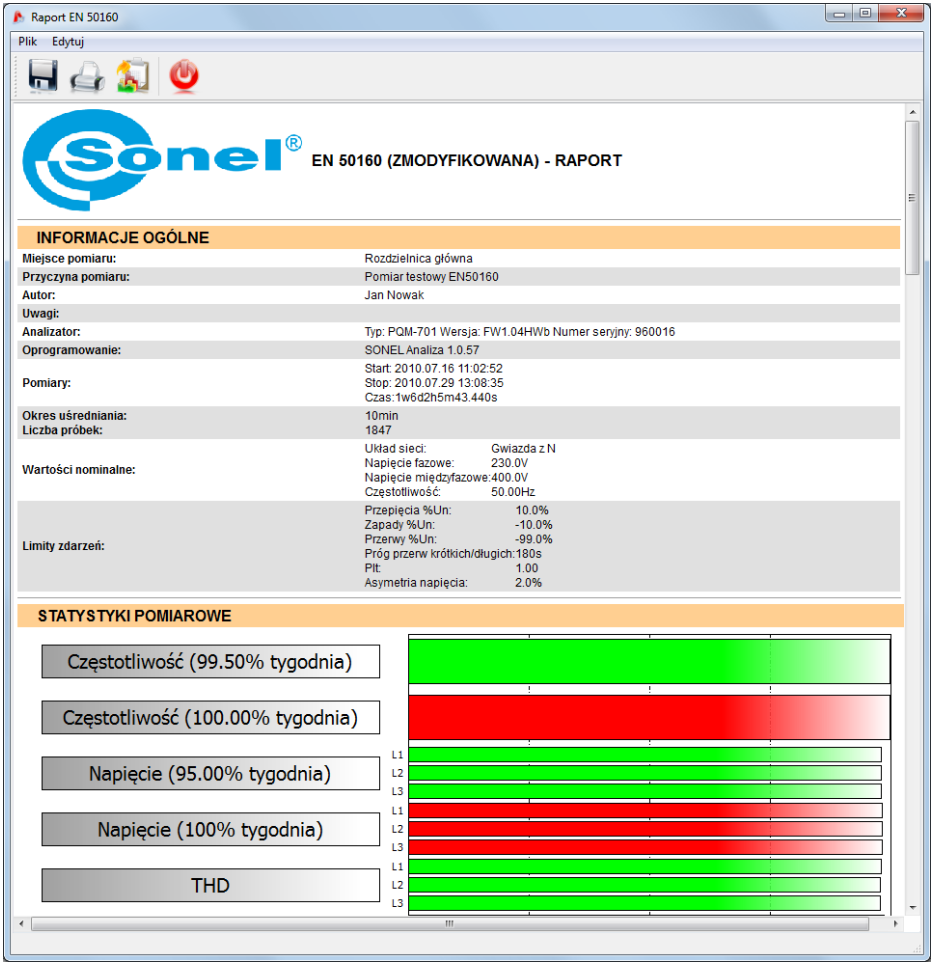


Fig. 51. Measurement report according to EN 50160.

> ***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 a correct time, and before the report generation, the software displays a warning message that the time interval is different than one week.*

7.3.5 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 7.3.2) and for Events (section 7.3.3):

- 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 **P** (start) and **K** (end) in the part with the dotted graph. Then press Reports → User report. A window will pop-up, as shown in Figure 69. To save the data in a desired file format, select **Save**, and then indicate the location, name and format of your file. Available formats:
  1. PDF (export to this format may contain maximum 12 data columns),
  2. HTML (these files may be opened in a web browser)
  3. TXT (standard text files)
  4. CSV, (Comma Separated Values) - files of this type may be easily opened in spreadsheets e.g. in Microsoft Excel. In order to properly load a CSV file into an Excel sheet, select from the top menu "Data ->External Data ->From text". In the opened window indicate a chosen CSV file, and then follow the on-screen instructions of the spreadsheet.
- for 'events', the data range (lines) may be reduced by using two sliders **P** (start) and **K** (end) in the part with the dotted graph. Then press Reports → User report. A window will pop-up, as shown in Figure 69. 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.

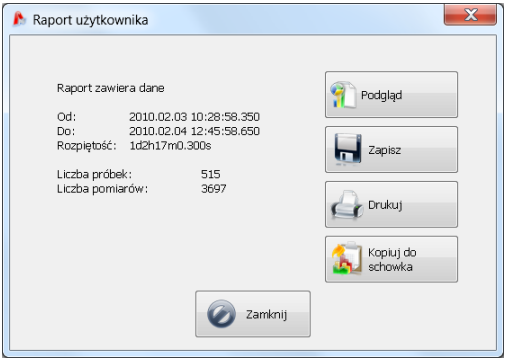


Fig. 69. Export data to a file.

The standard way to export data to CSV files may be configured by selecting **Options → Program Configuration → Report Settings →** and clicking "**Export to CSV**' tab. A window will pop-up, as shown in Figure 70.

- 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 lines 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).

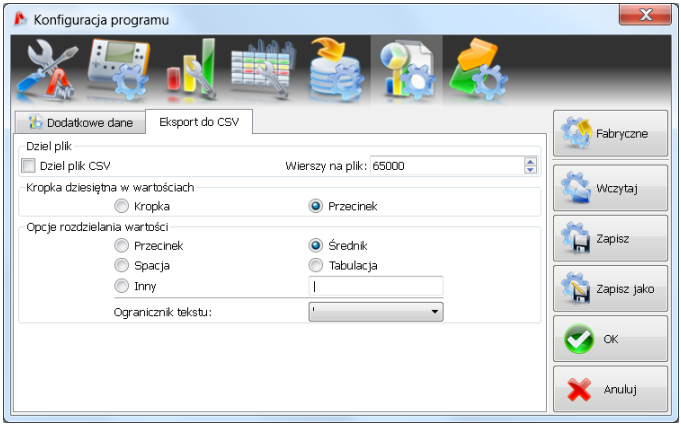


Fig. 70. Export settings for CSV files.

8 Other software options

8.1 Analyzer status

You can check the analyzer status at any time. To display the analyzer status window, in the top menu choose: **Analyzer** → **Status**. A window will appear with analyzer basic parameters (type, status, power source, etc.) as shown in Fig. 71.

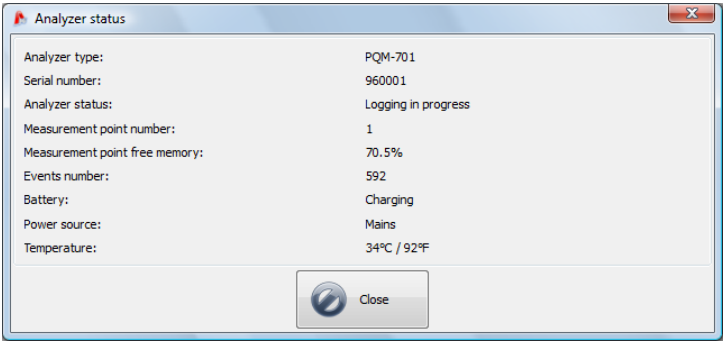


Fig. 71. Analyzer status.

Number of events is equal to the number of events detected at a given measurement point, counting from the beginning of the last triggered recording. If a new configuration is sent or when the analyzer is switched off, the counters will be zeroed.

8.2 Remote starting and stopping the measurements, changing the measurement point

The software offers the option to remotely start and stop the measurements. To use this option, from the top menu choose **Analyzer** → **Start/Stop**. A window will appear (Fig. 72) in which you can choose to start and stop the recording. Below are the **Start/Stop/Close** buttons to choose required action.

> ***Note***
> *When the recording is in progress, you cannot change the measurement point. It can be changed only after the recording is stopped (**STOP** mode).*

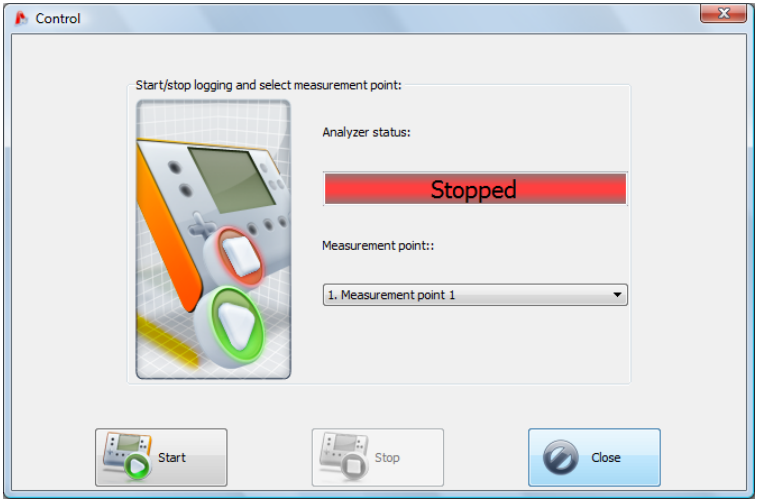


Fig. 72. Remote starting and stopping the measurements and change of measurement point.

8.3 Software configuration

You can change the default application settings after choosing from the software menu **Options** → **Software configuration** (Fig. 73).

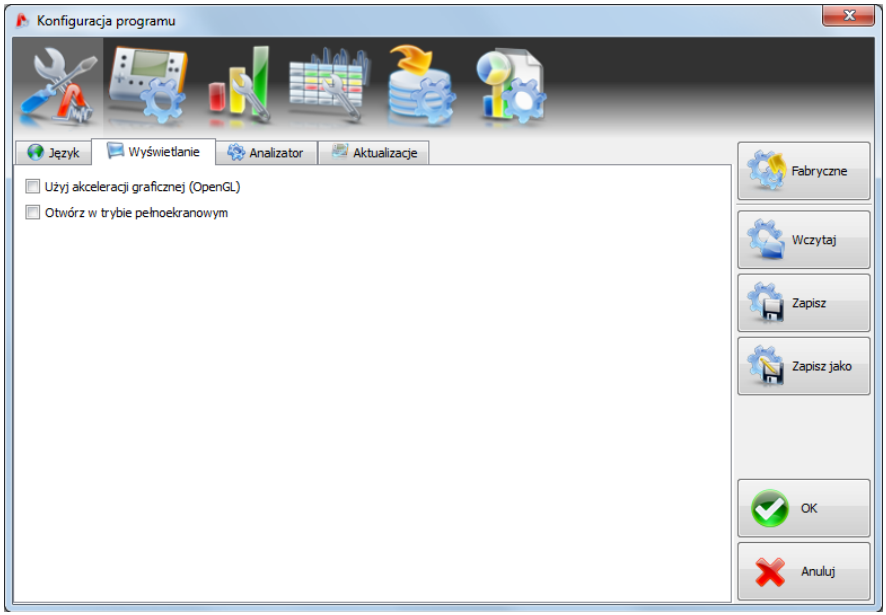


Fig. 73. Preferences main window.

The whole settings have been divided into a few parts, marked by icons in the top left-hand part of the window:

- Main settings,
- Analyzer configuration,
- Live mode,
- Color settings,
- Data analysis,
- Report settings.

When you select each of them, the detailed settings (which additionally can be divided into tabs) are displayed in the central part of the window.

The window navigation buttons are in the right-hand part of the window:

- **Default** – restore the application default settings,
- **Read** – read the software settings from the file,
- **Save/ Save as** – save the software settings to the file,
- **Ok** – remember the changes (only for a present session; the changes are lost when the application is closed),
- **Cancel** – close the window without saving changes.

8.3.1 Main settings

- **Language** tab lets you select default application language.
- **Display** tab (Fig. 73):
  - **Use accelerated graphics (OpenGL)** – select this option to relieve the CPU during the graphics generation (i.e. drawing the diagrams).
  - Last option **Open in full screen mode** - open applications in full screen mode.
- The **Analyzer** tab defines with which analyzer tab the application is to work with – select the PQM-701 analyzer.
- The **Updates** tab allows switching on and off the automatic check for a new "SONEL Analysis" software and the analyzer firmware versions. When this option is checked, at each launch the application will connect to the manufacturer's server and check availability of new versions. You will be informed by means of a suitable message, and then you can decide whether to download and install an update.

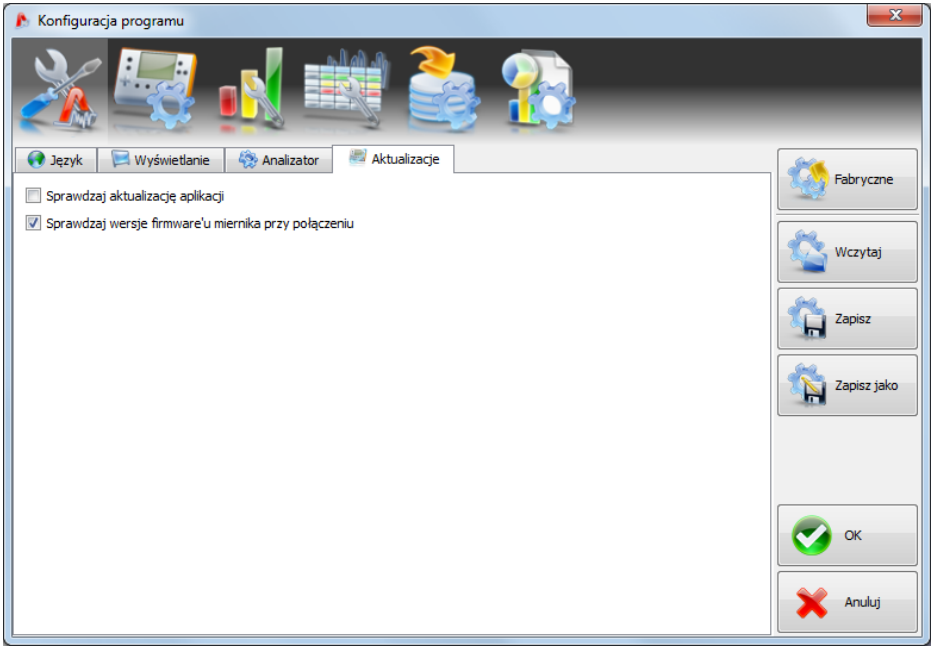


Fig. 52. Software configuration – updates.

8.3.2 Analyzer configuration

This option allows defining a default analyzer configuration after application launch. If you select **From file**, the application will load the default configuration from the saved file with the *.settings extension. If you have not indicated your own configuration file in the **Path** field, the application will use the standard file in the installation catalog.

If the option **From file** is not checked, the software will use the default configuration.

8.3.3 Live mode

This part of the settings (Fig. 75) allows defining the colors of elements and settings in the live mode. The part has the following tabs: **Waveforms**, **Timeplot, Measurements, Phasor, Harmonics**.

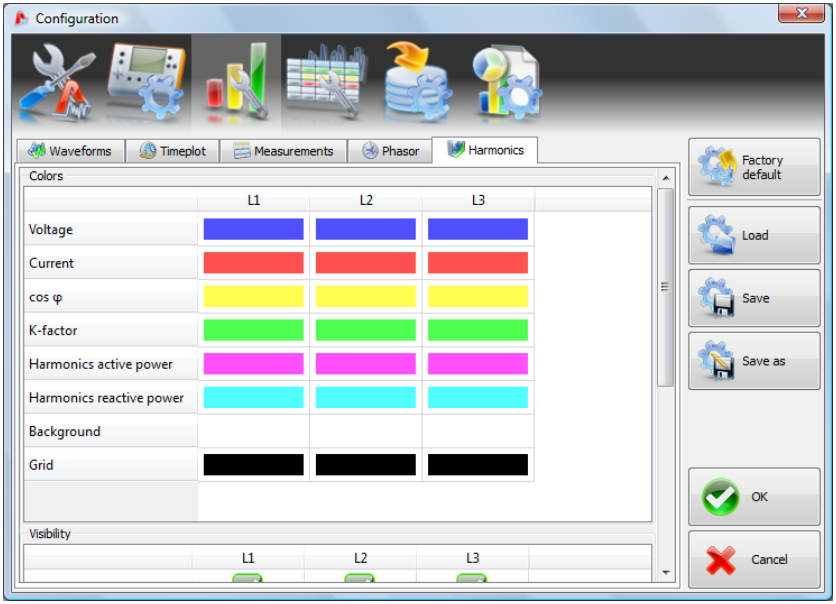


Fig. 53. Live mode settings.

8.3.4 Color settings

This part allows changing the colors of individual application components. It is divided into the following tabs:

- Graph colors,
- General colors,
- Measurements colors,
- Events colors.

8.3.5 Data analysis

The **Scanning** tab is used to indicate the devices (disks) which are to be skipped during the search for connected readers with SD card containing the measurements.

8.3.6 Report settings

In this part you can fill in additional fields used during generation of measurement reports.

8.4 Analyzer database

From the top menu, select **Options** → **Analyzer database** to add or edit the analyzers in the database (Fig. 76).

Only the analyzers entered to the database will be visible in the analyzer selection window during the wireless search. The serial number in the database must conform to the serial number of the analyzer you wish to connect to. The software rejects the analyzers with different serial

numbers which are not shown in the analyzer selection window (does not apply to the USB connection).

The **Auto PIN** informs if the software will request the PIN code before transmission. If the field is not active, you will have to enter the PIN.

In addition, you can activate the option of reminding about the instrument recalibration. The manufacturer gives the time after which the user should calibrate the instrument to maintain declared measurement accuracy. Accuracy is deteriorating as the components are aging.

To activate this functionality, check the option **Notify before the Certificate of Calibration expires**. If this option is checked, the lists **Validity period** and **Remind before** become active. The lists are used for:

- **Validity period** (set to 6 months, 12 months, 12 months, 18 months or 24 months) – frequency of instrument calibration,
- **Remind before** (set to week, two weeks, month) – specify the length of time before expiry of deadline that the software will display the reminding message (during launch).

The **Date of calibration** column gives the date on which the analyzer was calibrated.

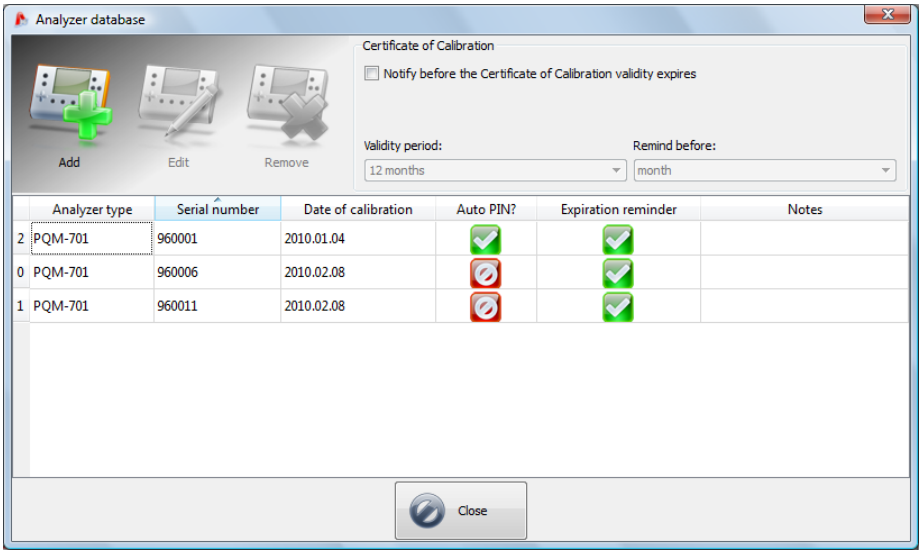


Fig. 54. Analyzer database.

Click the **Add** icon to add a new analyzer, as in the window below:

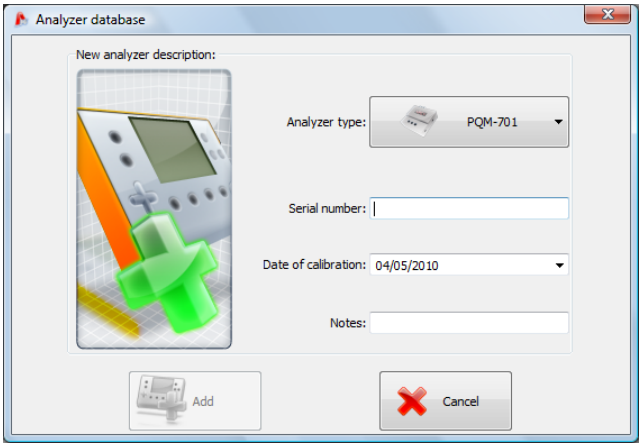


Fig. 55. Adding an analyzer to the database.

Click the **Remove** icon to display the window used to remove the analyzer from the database:

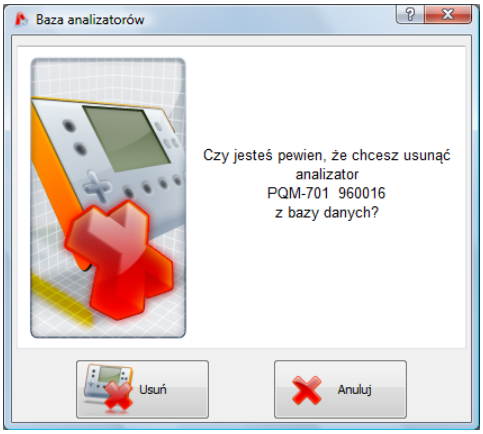


Fig. 56. Confirming the analyzer removal from the database.

8.5 Software and firmware updates

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

8.5.1 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 8.3.1.). 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 Analiza" 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 analyser firmware. Firmware update may be performed only after connecting the analyser 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 analyser automatically disconnects and re-starts.

8.5.2 Manual software update

In order to manually update "Sonel Analiza", download the installation file of the new version from the manufacturer's website: http://www.sonel.pl/. New software can be found in section: Download →Programs → Sonel Analiza. After downloading the software, it has to be started. If an older version of "Sonel Analiza" is detected, the installation wizard will require user to uninstall it. After uninstalling, run the installation program again and install the new version.

To manually update the analyser firmware, download the new version from the manufacturer's website http://www.sonel.pl/ , when it is available. It may be found in the following section: Produce ->Download → Firmware for meters → Firmware for PQM-701. Download the file appropriate for your meter and its serial number. After downloading a ZIP file unpack it and save FIRMWARE.PQF file to the main directory of the SD card removed from the analyser (use a SD card reader). Then, the card must be inserted into the analyser. If the software version is newer and appropriate for your version of the analyser, "**UPDT**" message will appear on the display alternately with detected firmware version. To update, press the START / STOP button on the analyser keypad and the update process will start. The display will show the update progress [in %]. After a successful update the analyser will restart.

> ***Note***
> *Firmware update should be performed with the analyser powered from the mains. Battery supply is permitted only when battery is fully charged. If the battery is discharged during the update, the whole procedure will be interrupted which may damage the internal memory of the program. In such case, the analyser will require authorised servicing.*

9 Support for serial port (only PQM-701Zr)

9.1 Setting the parameters of serial transmission

PQM-701Zr analyser is supplied with the following serial port parameters:

- Baud rate: 115200 bit/s
- Even parity: none
- Flow control: disabled
- Stop bits: 1

After the connection with the analyser is established (via a USB or serial port - this option is unavailable for the connection via a GSM modem) it is possible to change the default serial transmission parameters by selecting in the menu of "Sonel Analiza": **Analyser → Time and Safety** and then pressing "**Change**" button in "**Communication settings**". Then a window pops-up, as shown in Fig. 79.
The change is made immediately after the **Change** button is pressed and the connection is not interrupted (as is the case with the RS-232 connection).

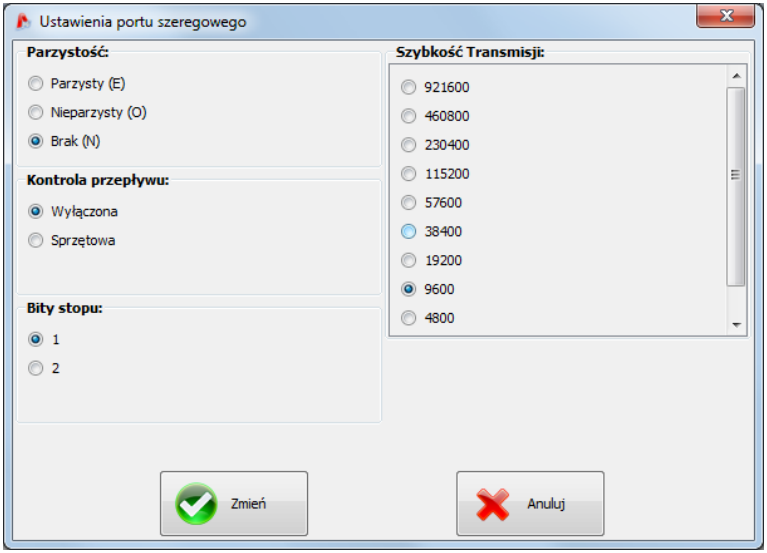


Fig. 79. Changing default settings of RS-232 port.

9.2 Direct RS-232 communication

To activate the analyser search function via RS-232 cable, use the menu of "Sonel Analiza" and select **Options→Program configuration→ General Settings →** and **Active Media** tab, then select Serial **Port option** (see Fig. 80).

Then go to the **Media Settings** card (Fig. 81). In this window select:

- Ports to be scanned - the COM ports detected in the system are listed. If we know the specific port number to which the analyser is connected then just choose this one. If you do not know the specific port number select all of them or a group.
- Parity - indicates the current analyser parity type,
- Flow control - select the flow control method: hardware (CTS/RTS) or off,

- Stop bits - 1 or 2,
- Baud Rate - indicates the transmission speed in bits per second set in the analyser.

To speed up the search for analysers connected through the serial port the option **Do not search for settings other than previously stored has been added**. If it is selected the program stores the transmission parameters when an analyser is found on the COM port to use them exclusively during the next scan. This means that if a different analyser with different parameters is connected it will not be detected. If this is the case the new analyser should be connected to another COM port, or the option **Do not search for settings other than previously stored** has been added should be deselected. In both cases you should ensure that the transmission parameters are specified in the **Media Settings** card.

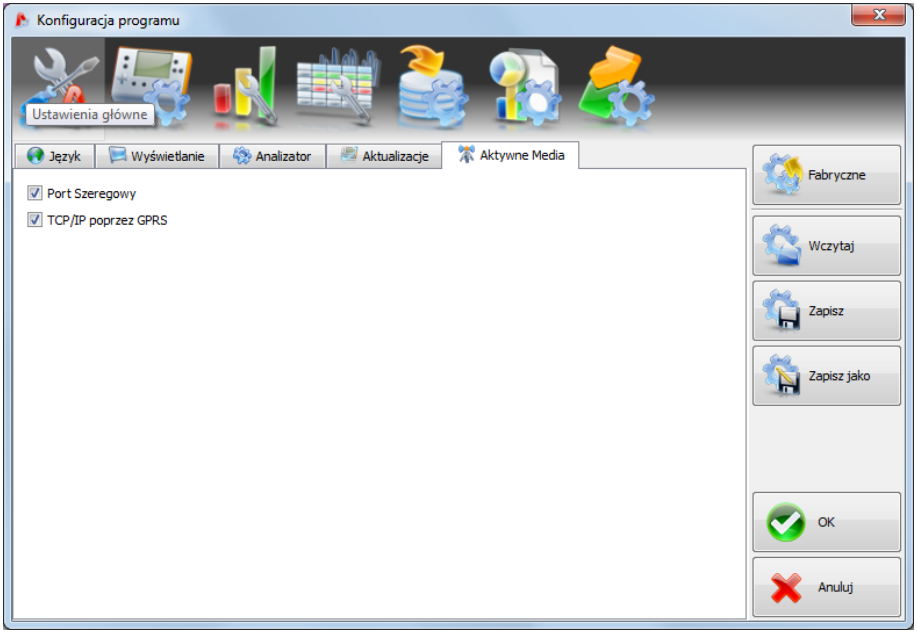


Fig. 80. Selection of additional media for scanning while searching for analysers.

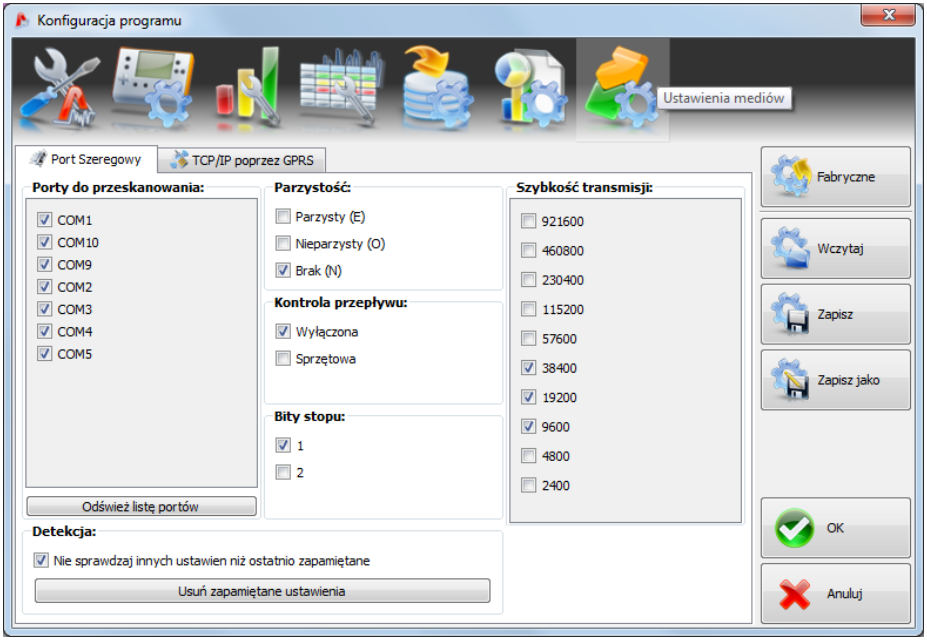


Fig. 81. Selection of scanning parameters for the RS-232 serial port.

The **Delete the saved settings** button causes the removal of the settings for the detected analysers. which means that when a search is initiated all combinations of settings selected in the **Media Settings** card are used.

To speed up the analyser detection process it is advised to narrow down the possible setting combinations.

9.3 Communication with the analyser via the GSM modem

The analyser's serial port may be connected with a GSM modem in the GPRS package data transmission mode, which may be used in transparent mode (through a supplied serial cable). If the modem is configured properly you will be able to connect to the analyser remotely. The configuration process is specific for each modem type and manufacturer and must be performed according to the manufacturer's instructions. It is important however, that the IP number is configured together with the port number, APN access point name and other parameters required by the GSM service provider. In order for the modem to communicate with the analyser properly through the serial port both devices must be configured for identical serial transmission parameters (baud rate, parity, flow control and stop bits).

To activate the function of searching analysers connected to Internet via GSM modem, use the menu of "Sonel Analiza" and select **Options→Program configuration→ General Settings** card→ and **Active Media** tab, then select option "TCP/IP via GPRS" (see Fig. 80). After selecting option "TCP/IP via GPRS" in Active Media tab (Fig. 82), add data required for proper connection in this mode. After pressing the **Add** button enter the IP address of the GPRS and the port number. The field **Name** is for information purposes. You can add more than one analyser to the search base.

When the configuration of the above options is complete, an attempt will be made to establish the connection with the analyser as well as to connect to the analyser connected with the modem via the Internet.

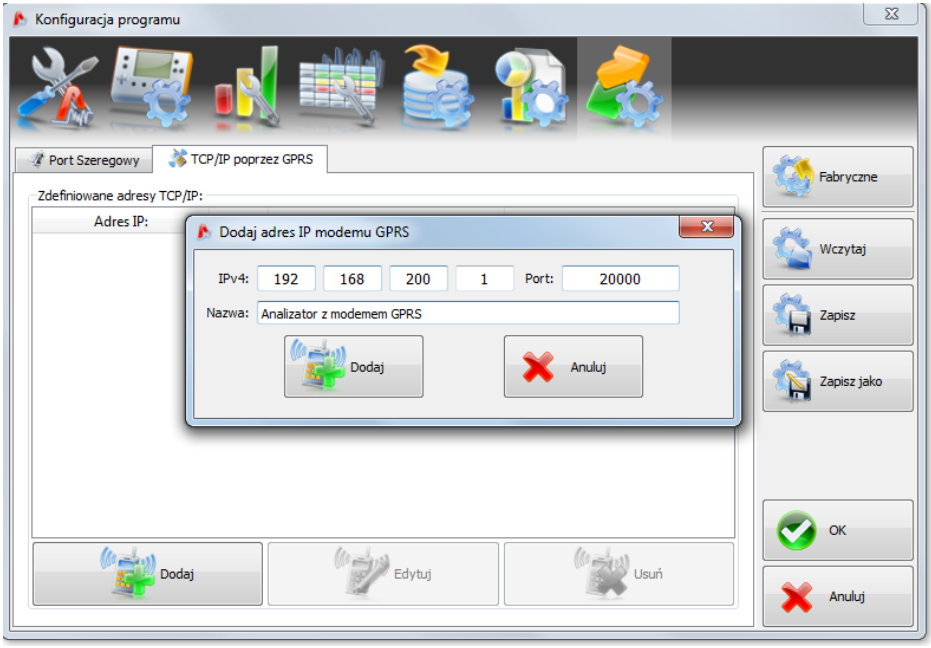


Fig. 82. IP address configuration for the GSM modem.

10 Power quality – a guide

10.1 Basic information

The measurement methodology is mostly imposed by the energy quality standards, mainly IEC 61000-4-30:2009. Rapidly growing interest in these issues and demand for instruments measuring mains parameters has resulted in many various power analyzers available on the market. Unfortunately, these instruments have been based on different algorithms. Consequently, the measurements of the same parameters with various instruments often have given completely different results.

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 these devices have tendency to significantly distort the 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 solution has however a 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. Large 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 electrical energy transport costs. Harmonic components which appear in the current cause additional problems. As a result, the electricity suppliers have started to impose financial penalties upon the customers who have not ensured sufficiently high power factor.

Among entities which can be potentially interested in power quality analyzers are power utility companies on one hand which can use them to control their customers, and on the other hand the power consumers which may use the analyzers to detect and possibly improve the low power factor and solve other problems in connection with widely understood power quality issue.

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

As already mentioned, lack of standardization of measurement methods has caused significant differences in values of individual mains parameters calculated with various devices. As a result of efforts of many engineers, the standard on power quality has been developed - IEC 61000-4-30. For the first time, this standard (and related standards) gives very precise methods, mathematical relationships and required measurement accuracy for power quality analyzers. Conformity to standard (and particularly to 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. 83. Three phase inputs L1/A, L2/B, L3/C 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 inputs can be met in the analyzers with four independent differential channels. In reality, however, a 5-input solution is not inferior to 8-input solutions and can be connected to most operated mains and receiver systems. 5-input solution significantly simplifies connection to the tested facility and reduces the probability of mistake. Fig. 83 shows the solution of the analyzer power supply circuit in the PQM-701. The power supply unit with rated voltage range of 90..760V AC is internally connected between the lines L1/A and N. In

the PQM-701Z the power supply has separate terminals.

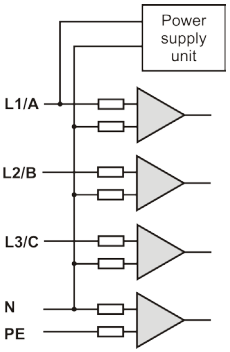


Fig. 83. Voltage inputs with power supply unit (PQM-701 only).

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 inbuilt electronic integrator. However, the PQM-701 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.

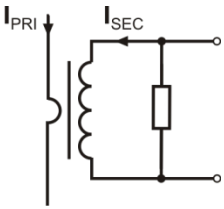


Fig. 84. Current transformer clamp with voltage output.

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-701 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.

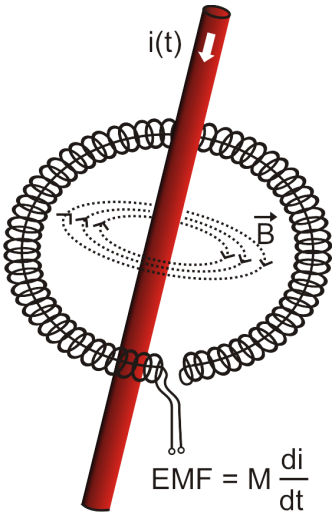


Fig. 85. Rogowski coil.

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-701) 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-701 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-701 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-701 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-701 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.

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

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 is 256 times higher than the mains frequency and equals 12.8kHz for the 50Hz and 15.36kHz for the 60Hz mains systems.
Each period includes then 256 samples. A 16-bit analog-to-digital converter has been used which ensures 64-fold oversampling.

3-decibel channels attenuation has been specified for frequency of about 13kHz, and the amplitude error for the 3kHz maximum usable frequency (i.e. the frequency of 50th harmonics in the 60Hz system) is about 0.3dB. The phase shift for this frequency is below 20°. 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 15°. 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. Assuming 256 samples per period and the 50Hz mains frequency, 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-701 meets the above-mentioned requirements in terms of the PLL system operation also for the lowest supported nominal voltage U_{nom}=110V, i.e. down to about 10 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:

$$P = UI\cos\varphi$$

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

The PQM-701 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 (2560 for the 50Hz and 3072 for the 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:

$$Q = UI\sin\varphi$$

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 non-linear 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 active power to apparent 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-701 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 sinusoidal 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 systems

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

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

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 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 9 presents the phase difference error between the voltage and current harmonics for the PQM-701 analyzer (without clamps and transducers).

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

Table 9. Phase error in the PQM-701 analyzer depending on the frequency

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. 86.

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 $\pm\sqrt{0{,}5^2 + \delta_{ph}^2}$ %.

For the 0..200Hz frequency range, the PQM-701 phase error is 1°. After substituting to the equation:

$$\delta_{ph} = 100\left(1 - \frac{cos(\varphi + \Delta\varphi)}{cos\varphi}\right) = 100\left(1 - \frac{cos(61°)}{cos(60°)}\right) = 3{,}04\%$$

then, the measurement uncertainty is:

$$\delta = \pm\sqrt{0{,}5^2 + 3{,}04^2} = \pm 3{,}08\%$$

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

$$\delta_{ph} = 100\left(1 - \frac{cos(11°)}{cos(10°)}\right) = 0{,}32\%$$

and the measurement uncertainty is:

$$\delta = \pm\sqrt{0{,}5^2 + 0{,}32^2} = \pm 0{,}59\%$$

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

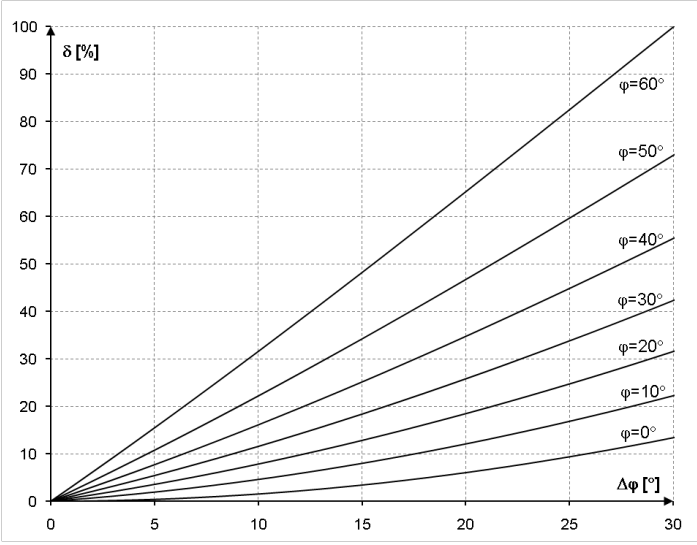


Fig. 86. Additional uncertainty from phase error depending on phase shift angle.

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-701 analyzer collects 256 samples per period, the total number of samples per measuring window is 2560 or 3072 (for 50Hz and 60Hz, respectively). Fast Fourier Transform requires however that the number of samples subjected to transformation equals a power of 2. Consequently, the analyzer changes the sampling frequency (interpolation linked with decimation) as a result of which we receive exactly 2048 samples (2^{11}).

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-701 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).

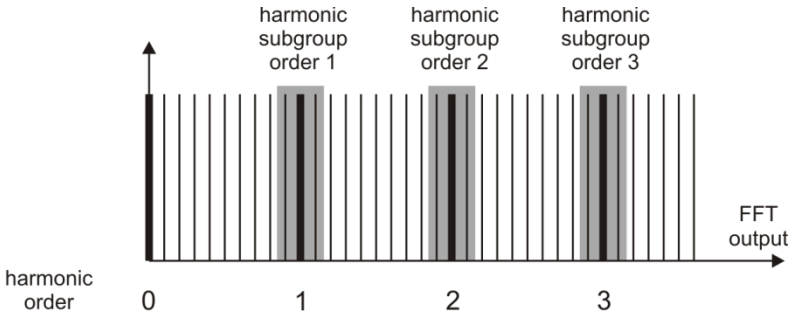


Fig. 87. Determination of harmonic subgroups (50Hz system).

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

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-701 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).

10.8.7 K-Factor

K-Factor, also called the transformer loss factor, is a measure used to determine the requirements for power supply transformers. Higher current harmonics cause increased thermal losses in the windings and metal parts of the transformer. The main reason is the eddy currents generated by high frequency harmonics and the skin effect.

The transformer temperature increase is directly proportional to current components squared, the value called K-Factor takes this into account, and the factor is calculated according to the following formula:

$$KFactor = \sum^{50} I_{hr}^2 h^2$$

I_1 - amplitude of the current fundamental component,
h – harmonic order.

In case of this parameter, the higher harmonics are much more important than the lower – each harmonic component is multiplied by its order squared.

K-Factor is useful when defining the requirements for transformers which must work in conditions of significant current distortion. The transformer which works in conditions with K = x, will generate x times more heat than at purely sinusoidal current (K = 1).

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-701 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.

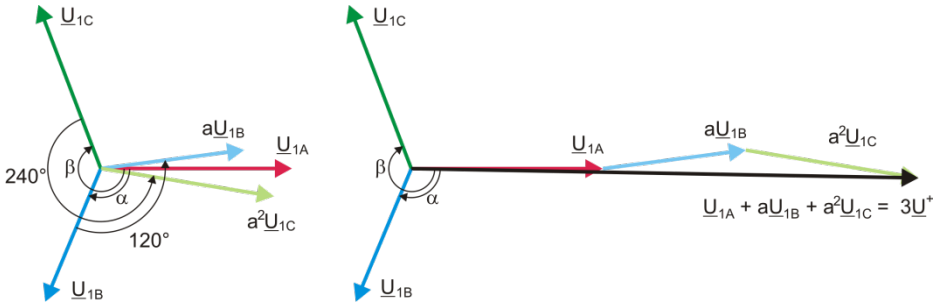


Fig. 88. Example of determination of positive sequence component.

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. 82 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-701 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 10. 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)					•
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 256 samples per period.

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.

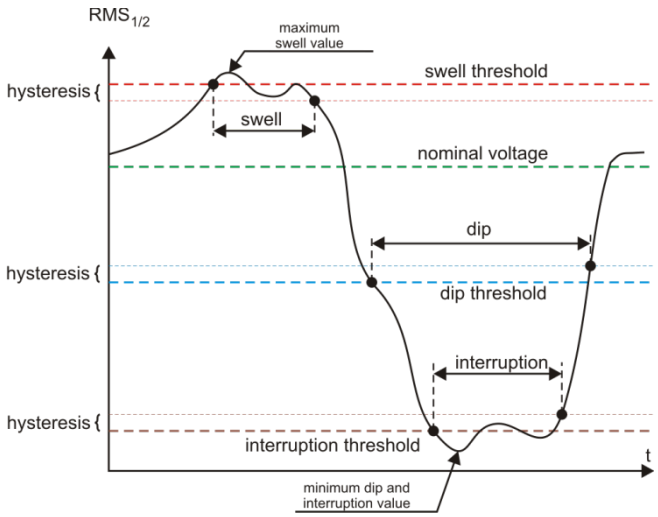


Fig. 89. Voltage swells, dips and interruptions.

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.

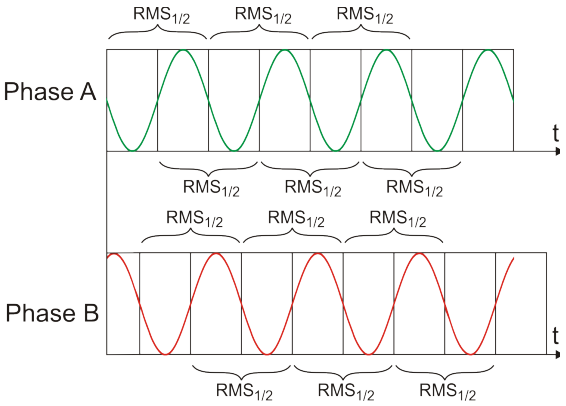


Fig. 90. Determination of the $U_{rms(1/2)}$ value.

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).

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. 84 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 Averaging the measurement results

Mains monitoring over a longer period of time means that a huge amount of data needs to be collected. If analysis of such data is to be possible at all, it is necessary to introduce the mechanisms which will reduce the data size to the values acceptable by both, humans and machines.

Lets 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 of such amount of data would 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 on the basis of about three thousand 200-millisecond values (approximately, because in reality the conventional 200-millisecond value is a 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. 85 presents the method according to which the PQM-701 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 specified in IEC 61000-4-30:2009.

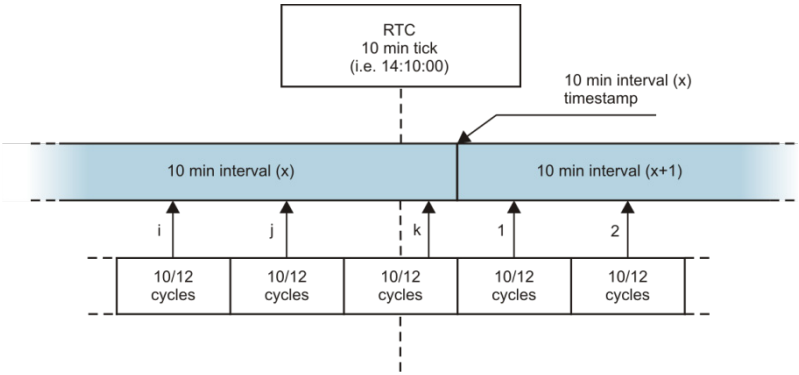


Fig. 91. Determining the averaging intervals equal to or longer than 10 seconds (with the 10-minute averaging).

The average values are synchronized with real time clock in the following manner. When the clock measures a successive full multiple of the averaging period, the instantaneous 10/12-period measurement is added as the last to the average value (*k*th measurement in Fig. 91). Simultaneously, the ending averaging period is given a time stamp which relates to its end. The next 10/12-period measurement is the first in a consecutive averaging period.

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 of a 3-second averaging period means averaging in the time equal to 150/180 mains periods (fifteen 10/12-period measurements).

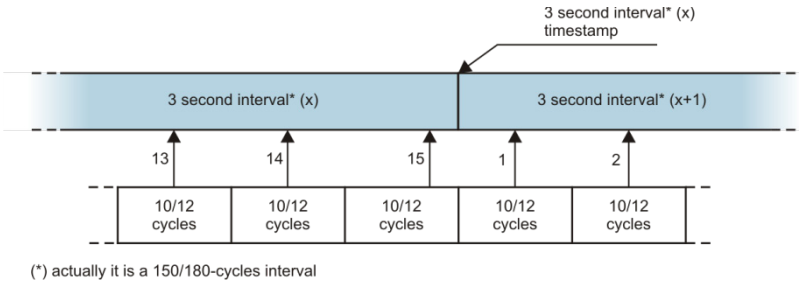


Fig. 92. Determining the averaging intervals shorter than 10 seconds (with the 3-second averaging).

The method of average values determination for such periods is shown in Fig. 92. Here, we do not have synchronization with the real time clock. When a defined number of 10/12-period measurement is collected, the instantaneous averaging period is closed and a new one starts. The time stamp corresponds to the end of the interval.

Averaging of measurement results leads to the loss of extreme values (smoothing of results). In cases when the information about a limit value of the measured parameter is essential, the user can take advantage of 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 the **Min/Max calculation period** parameter. The user can take advantage of 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 – to the $U_{rms(1/2)}$. 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 less 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 period 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 for 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 is 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.

10.13 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 2^{nd} 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 system

One-phase system			
Parameter			**Calculation method**
Name	**Designation**	**Unit**	
RMS voltage (True RMS)	U_A	V	$U_A = \sqrt{\frac{1}{M}\sum_{i=1}^{M} U_i^2}$ where U_i is a successive voltage sample $U_{A\text{-}N}$ M = 2560 for 50Hz systems M = 3072 for 60Hz systems
Voltage DC component	U_{ADC}	V	$U_{ADC} = \frac{1}{M}\sum_{i=1}^{M} U_i$ where U_i is a successive voltage sample $U_{A\text{-}N}$ M = 2560 for 50Hz systems M = 3072 for 60Hz systems
Frequency	f	Hz	number of full voltage periods $U_{A\text{-}N}$ counted during a 10-s clock time interval divided by the total duration of full periods
RMS current (True RMS)	I_A	A	$I_A = \sqrt{\frac{1}{M}\sum_{i=1}^{M} I_i^2}$ where I_i is a successive current sample I_A M = 2560 for 50Hz systems M = 3072 for 60Hz systems
Current DC component	I_{ADC}	A	$I_{ADC} = \frac{1}{M}\sum_{i=1}^{M} I_i$ where I_i is a successive current sample I_A M = 2560 for 50Hz systems M = 3072 for 60Hz systems
Active power	P	W	$P = \frac{1}{M}\sum_{i=1}^{M} U_i I_i$ where U_i is a successive voltage sample $U_{A\text{-}N}$ I_i is a successive current sample I_A M = 2560 for 50Hz systems M = 3072 for 60Hz systems
Budeanu reactive power	Q_B	var	$Q_B = \sum_{h=1}^{50} U_h I_h \sin\varphi_h$ where U_h is the hth voltage harmonics $U_{A\text{-}N}$ I_h is the hth current harmonics I_A φ_h is the hth angle between harmonics U_h and I_h
Fundamental component reactive power	Q_1	var	$Q_1 = U_1 I_1 \sin\varphi_1$ where U_1 is the voltage fundamental component $U_{A\text{-}N}$ I_1 is the current fundamental component I_A φ_1 is the angle between fundamental components U_1 and I_1
Apparent power	S	VA	$S = U_{ARMS} I_{ARMS}$
Nonfundamental apparent power	S_N	VA	$S_N = \sqrt{S^2 - (U_1 I_1)^2}$
Budeanu distortion	D_B	var	$D_B = \sqrt{S^2 - P^2 - Q_B^2}$

power			
Power factor	*PF*	-	$PF = \frac{P}{S}$ If PF < 0 the load has a generator character If PF > 0 the load has a receiver character
Displacement power factor	*cosφ* *DPF*	-	$\cos\varphi = DPF = \cos(\varphi_{U_1} - \varphi_{I_1})$ where φ_{U1} is absolute angle of voltage fundamental component U_{A-N} φ_{I1} is absolute angle of current fundamental component I_A
Tangent φ	*tanφ*	-	$tg\varphi = \frac{Q_1}{P}$
Total harmonic distortion referred to fundamental component	$THDU_F$	-	$THDU_F = \frac{\sqrt{\sum_{h=2}^{50} U_h^2}}{U_1} \times 100\%$ where U_h is the *h*th voltage harmonics U_{A-N} U_1 is the voltage fundamental component U_{A-N}
Total harmonic distortion referred to RMS	$THDU_R$	-	$THDU_R = \frac{\sqrt{\sum_{h=2}^{50} U_h^2}}{U_{ARMS}} \times 100\%$ where U_h is the *h*th voltage harmonics U_{A-N}
Total current harmonic distortion referred to fundamental component	$THDI_F$	-	$THDI_F = \frac{\sqrt{\sum_{h=2}^{50} I_h^2}}{I_1} \times 100\%$ where I_h is the *h*th current harmonics I_A I_1 is the current fundamental component I_A
Total harmonic distortion referred to RMS	$THDI_R$	-	$THDI_R = \frac{\sqrt{\sum_{h=2}^{50} I_h^2}}{I_{ARMS}} \times 100\%$ where I_h is the *h*th current harmonics I_A
Voltage crest factor	*CFU*	-	$CFU = \frac{max\|U_i\|}{U_{ARMS}}$ Where operator $\max\|U_i\|$ expresses the greatest absolute value of voltage U_{A-N} among samples *i* = 2560 for 50Hz systems *i* = 3072 for 60Hz systems
Current crest factor	*CFI*	-	$CFI = \frac{max\|I_i\|}{I_{ARMS}}$ Where operator $\max\|I_i\|$ expresses the greatest absolute value of current I_A among samples *i* = 2560 for 50Hz systems *i* = 3072 for 60Hz systems
K-factor	*K-Factor*	-	$KFactor = \frac{\sum_{h=1}^{50} I_h^2 h^2}{I_1^2}$ Where I_h is the *h*th current harmonics I_A I_1 is the current fundamental component I_A
Harmonics active power	P_h *h=1..50*	W	$P_h = U_h I_h \cos\varphi_h$ Where U_h is the *h*th voltage harmonics U_{A-N} I_h is the *h*th current harmonics I_A φ_h is the angle between harmonics U_h and I_h
Harmonics reactive power	Q_h *h=1..50*	var	$Q_h = U_h I_h \sin\varphi_h$ Where U_h is the *h*th voltage harmonics U_{A-N} I_h is the *h*th current harmonics I_A φ_h is the angle between harmonics U_h and I_h
Short-term flicker	P_{ST}	-	calculated according to IEC 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 the *i*th short-term flicker
Active energy (consumed and supplied)	E_{P+} E_{P-}	Wh	$E_{P+} = \sum_{i=1}^{m} P_+(i)T(i)$ $P_+(i) = \begin{cases} P(i) \ if \ P(i) > 0 \\ 0 \ if \ P(i) \le 0 \end{cases}$ $E_{P-} = \sum_{i=1}^{m} P_-(i)T(i)$ $P_-(i) = \begin{cases} \lvert P(i) \rvert \ if \ P(i) < 0 \\ 0 \ if \ P(i) \ge 0 \end{cases}$ where: *i* is a successive number of 10/12-period measuring window *P(i)* represents active power *P* calculated in the *i*th measuring window *T(i)* represents duration of the *i*th measuring window in hours
Budeanu reactive energy (consumed and supplied)	E_{QB+} E_{QB-}	varh	$E_{QB+} = \sum_{i=1}^{m} Q_{B+}(i)T(i)$ $Q_{B+}(i) = \begin{cases} Q_B(i) \ if Q_B(i) > 0 \\ 0 \ if \ Q_B(i) \le 0 \end{cases}$ $E_{QB-} = \sum_{i=1}^{m} Q_{B-}(i)T(i)$ $Q_{B-}(i) = \begin{cases} \lvert Q_B(i) \rvert \ if \ Q_B(i) < 0 \\ 0 \ if \ Q_B(i) \ge 0 \end{cases}$ where: *i* is a successive number of 10/12-period measuring window $Q_B(i)$ represents Budeanu reactive power Q_B calculated in the *i*th measuring window *T(i)* represents duration of the *i*th measuring window in hours
Fundamental component reactive energy (consumed and supplied)	E_{Q1+} E_{Q1-}	varh	$E_{Q1+} = \sum_{i=1}^{m} Q_{1+}(i)T(i)$ $Q_{1+}(i) = \begin{cases} Q_1(i) \ if \ Q_1(i) > 0 \\ 0 \ if \ Q_1(i) \le 0 \end{cases}$ $E_{Q1-} = \sum_{i=1}^{m} Q_{1-}(i)T(i)$ $Q_{1-}(i) = \begin{cases} \lvert Q_1(i) \rvert \ if \ Q_1(i) < 0 \\ 0 \ if \ Q_1(i) \ge 0 \end{cases}$ where: *i* is a successive number of 10/12-period measuring

			window $Q_1(i)$ represents fundamental component reactive power Q_1 calculated in the *i*th measuring window $T(i)$ represents duration of the *i*th measuring window in hours
Apparent energy	E_S	VAh	$E_S = \sum_{i=1}^{m} S(i)T(i)$ where: *i* is a successive number of 10/12-period measuring window $S(i)$ represents apparent power *S* calculated in the *i*th measuring window $T(i)$ represents duration of the *i*th measuring window in hours

11.2 Split-phase system

Split-phase system (omitted parameters are calculated as in one-phase system)			
Parameter			**Calculation method**
Name	**Designation**	**Name**	
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 fundamental component reactive power	Q_{1tot}	var	$Q_{1tot} = Q_{1A} + Q_{1B}$
Total apparent power	S_{tot}	VA	$S_{tot} = S_A + S_B$
Total nonfundamental apparent 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	$tan\varphi_{tot}$	-	$tg\varphi = \frac{Q_{1tot}}{P_{tot}}$
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 fundamental component reactive energy (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 Three-phase wye with N

Three-phase wye with N (omitted parameters are calculated as in one-phase system)			
Parameter			**Calculation method**
Name	**Designation**	**Name**	
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 fundamental component reactive power	Q_{1tot}	var	$Q_{1tot} = Q_{1A} + Q_{1B} + Q_{1C}$
Total reactive power acc. to IEEE 1459	Q_1^+	var	$Q_1^+ = 3U_1^+ I_1^+ \sin\varphi_1^+$ where: U_1^+ is the voltage positive sequence component (of the fundamental component I_1^+ 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 nonfundamental apparent 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	$tan\varphi_{tot}$	-	$tg\varphi_{tot} = \frac{Q_{1tot}}{P_{tot}}$

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 fundamental component reactive energy (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 a successive number of 10/12-period measuring window $S_e(i)$ represents effective apparent power S_e calculated in the *i*th measuring window $T(i)$ represents duration of the *i*th measuring window in hours
RMS voltage zero sequence component	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-to-neutral voltages U_A, U_B, U_C Operator mag() means vector magnitude
RMS voltage positive sequence component	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-to-neutral voltages U_A, U_B, U_C Operator mag() means vector magnitude $a = 1e^{j120^\circ} = -\frac{1}{2} + \frac{\sqrt{3}}{2}j$ $a^2 = 1e^{j240^\circ} = -\frac{1}{2} - \frac{\sqrt{3}}{2}j$
RMS voltage negative sequence component	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-to-neutral U_A, U_B, U_C Operator mag() means vector magnitude $a = 1e^{j120^\circ} = -\frac{1}{2} + \frac{\sqrt{3}}{2}j$ $a^2 = 1e^{j240^\circ} = -\frac{1}{2} - \frac{\sqrt{3}}{2}j$
Zero sequence unbalance	u_0	%	$u_0 = \frac{U_0}{U_1} \cdot 100\%$
Negative sequence unbalance	u_2	%	$u_2 = \frac{U_2}{U_1} \cdot 100\%$

Current zero component	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 of phase currents I_A, I_B, I_C Operator mag() means vector magnitude
RMS current positive sequence component	I_1	A	$\underline{I}_1 = \frac{1}{3}(\underline{I}_{A1} + a\underline{I}_{B1} + a^2\underline{I}_{C1})$ $I_1 = mag(\underline{I}_1)$ Where $\underline{I}_{A1}$, $\underline{I}_{B1}$, $\underline{I}_{C1}$ are vectors of fundamental components of currents I_A, I_B, I_C Operator mag() means vector magnitude
RMS negative positive sequence component	I_2	A	$\underline{I}_2 = \frac{1}{3}(\underline{I}_{A1} + a^2\underline{I}_{B1} + a\underline{I}_{C1})$ $I_2 = mag(\underline{I}_2)$ Where $\underline{I}_{A1}$, $\underline{I}_{B1}$, $\underline{I}_{C1}$ are vectors of fundamental components of phase currents I_A, I_B, I_C Operator mag() means vector magnitude
Current zero sequence unbalance	i_0	%	$i_0 = \frac{I_0}{I_1} \cdot 100\%$
Current negative sequence unbalance	i_2	%	$i_2 = \frac{I_2}{I_1} \cdot 100\%$

11.4 Three-phase delta and wye without N

Three-phase delta and wye without N (the parameters: RMS voltage and current, voltage and current fundamental components, THD and K, symmetrical components and unbalance factors, flicker are calculated as in one-phase systems; phase-to-phase voltage is used instead of phase-to-neutral voltage)			
Parameter			**Calculation method**
Name	**Designation**	**Name**	
Phase-to-phase voltage U_{CA}	U_{CA}	V	$U_{CA} = -(U_{AB} + U_{BC})$
Current I_2 (Aron's measurement systems)	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 successive voltage sample $U_{A\text{-}C}$ U_{iBC} is a successive voltage sample $U_{B\text{-}C}$ I_{iA} is a successive current sample I_A I_{iB} is a successive current sample I_B M = 2560 for 50Hz systems M = 3072 for 60Hz systems
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 nonfundamental apparent 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	$E_{P+tot} = \sum_{i=1}^{m} P_{+tot}(i)T(i)$ $P_{+tot}(i) = \begin{cases} P_{tot}(i) \ if \ P_{tot}(i) > 0 \\ 0 \ if \ P_{tot}(i) \le 0 \end{cases}$ $E_{P-tot} = \sum_{i=1}^{m} P_{-tot}(i)T(i)$ $P_{-tot}(i) = \begin{cases} \lvert P_{tot}(i) \rvert \ if \ P_{tot}(i) < 0 \\ 0 \ if \ P_{tot}(i) \ge 0 \end{cases}$ where: *i* is a successive number of 10/12-period measuring window $P_{tot}(i)$ represents total active power P_{tot} calculated in the *i*th measuring window $T(i)$ represents duration of the *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 a successive number of 10/12-period measuring window $S_e(i)$ represents total apparent power S_e calculated in the *i*th measuring window $T(i)$ represents duration of the *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
K factor	RMS
The angles between voltage and current harmonics	arithmetic average
Active and reactive power of harmonics	arithmetic average

Note:
RMS average value is calculated according to the formula:

$$RMS = \sqrt{\frac{1}{N}\sum_{i=1}^{N} X_i^2}$$

The arithmetic average (AVG) is calculated according to the formula:

$$AVG = \frac{1}{N}\sum_{i=1}^{N} X_i$$

where:

- X_i is subsequent parameter value to be averaged,
- N is the number of values to be averaged.

12 Technical specification

- Technical specification is subject to change without prior notice. The latest revisions of technical documentation are available at www.sonel.pl.
- Basic uncertainty is uncertainty of a measuring instrument in reference conditions given in Table 11.
- Given uncertainty values refer to the PQM-701 analyzer without additional transducers and clamps.
- Abbreviations:
  - m.v. – measured value,
  - U_{nom} – nominal voltage,
  - I_{nom} – nominal current range (clamp),
  - RMS – root mean square value,
  - n – harmonic order,
  - δ_{ph} – additional uncertainty caused by the error of phase measurement between the voltage and current harmonics.

12.1 Inputs

Voltage inputs	
No. of inputs	5 (L1, L2, L3, N, PE - 4 measuring channels) not galvanically isolated
Maximum input voltage	$690V_{RMS}$
Peak input voltage	1150V
Range of measured direct current voltages	±1150V
Analog pass band (-3dB)	>12kHz
Transducers	user defined
Measuring inputs impedance	14MΩ (without the L1-N internal power supply in the PQM-701)
CMRR	>70dB (50Hz)

Current inputs	
No. of inputs	4 (3 phase + neutral) not galvanically isolated
Nominal input voltage	$1V_{RMS}$
Peak input voltage	3.6V
Analog pass band (-3dB)	>12kHz
Input impedance	CT clamp circuit: 100kΩ Flexible clamp circuit: 12.4kΩ
Measuring range (without transducers)	Flexible clamps F-1/F-2/F-3: 1..3000A (10000A peak) Clamps C-4, C-5: 1..1000A (3600A peak) Clamps C-6: 0.01..10A (36A peak) Clamps C-7: 0..100A (720A peak)
Transducers	user defined
CMRR	60dB (50Hz)

Sampling and real time clock RTC	
analog-to-digital converter	16-bit
Sampling frequency	12.8kHz for 50Hz 15.36kHz for 60Hz Simultaneous sampling in all channels
No. of samples per period	256
PLL synchronization	40..70Hz
Reference channel to PLL	L1
Real time clock	±3.5ppm max (about ±9 seconds/ month) in the -20°C…+55°C temperature range

12.2 Measured parameters – accuracy, resolution and ranges

Table 11. Reference conditions

Reference conditions	
Ambient temperature	23°C ±2°C
Relative humidity	40…60% RH
Voltages unbalance	≤ 0.1% for negative sequence unbalance (only in three-phase systems)
External continuous magnetic field	≤ 40A/m d.c. ≤ 3A/m ac at 50/60Hz frequency
DC voltage and current component	zero
Waveforms	sinusoidal
Frequency	50Hz ±0.2% or 60Hz ±0.2%

Voltage	Range and conditions	Resolution	Basic uncertainty
U_{RMS} (AC+DC)	10% U_{nom} ≤ U_{RMS} ≤ 120% U_{nom} for U_{nom} ≥ 100V	0.01% U_{nom}	±0.1% U_{nom}
Crest factor	1..10 (1..1.65 for 690V) for U_{RMS} ≥ 10% U_{nom}	0.01	±5%

Current	Range and conditions	Resolution	Basic uncertainty
I_{RMS} (AC+DC)	**Input circuit without clamp**		
	0..1V (0..3.6V_{p-p})	0.01% I_{nom}	±0.1% I_{nom} (±0.4% I_{nom} including the error caused by radiated RF disturbance)
	Flexible clamps F-1/F-2/F-3		
	0..3000A (10 000A_{p-p})	0.01% I_{nom}	**Additional uncertainty** ±1% (±2% including additional error caused by location)
	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%
	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%
	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%
	Clamps C-7		
	0..100A (720A_{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} ≥ 1% I_{nom}	0.01	±5%

Frequency	Range and conditions	Resolution	Basic uncertainty
f	40..70Hz 10% U_{nom} ≤ U_{RMS} ≤ 120% U_{nom}	0.01Hz	±0.01Hz

Harmonics	Range and conditions	Resolution	Basic uncertainty
Harmonic order (n)	DC, 1..50, grouping: harmonic subgroups acc. to IEC 61000-4-7		
Amplitude U_{RMS}	0..120% U_{nom}	0.01% U_{nom}	±0.05% U_{nom} if m.v.<1% U_{nom} ±5% of m.v. if m.v.≥ 1% U_{nom} (acc. to IEC 61000-4-7 class I)
Amplitude I_{RMS}	depending on clamp used (see I_{RMS} specification)	0.01% I_{nom}	±0.15% I_{nom} if m.v.<3% I_{nom} ±5% of m.v. if m.v.≥ 3% I_{nom} (acc. to IEC 61000-4-7 class I)
voltage THD-R (n = 2..50)	0.0…100.0% for U_{RMS} ≥ 1% U_{nom}	0.1%	±5%
current THD-R (n = 2..50)	0.0…100.0% for I_{RMS} ≥ 1% I_{nom}	0.1%	±5%
K-Factor	1.0…50.0 for I_{RMS} ≥ 1% I_{nom}	0.1	±10%
Phase angle (voltage)	-180°…+180°	0.1°	±(n × 1°)
Phase angle (current)	-180°…+180°	0.1°	±(n × 1°)

Harmonics power	Conditions	Resolution	Basic uncertainty (1)
Harmonics active and reactive power	80% U_{nom} ≤ U_{RMS} < 120% U_{nom} 5% I_{nom} ≤ I_{RMS} ≤ I_{nom}	depending on U_{nom} and I_{nom}	$\pm\sqrt{\delta_{Uh}^2 + \delta_{Ih}^2 + \delta_{ph}^2}$ % where: δ_{Uh} – Basic uncertainty of voltage harmonic amplitude measurement, δ_{Ih} – Basic uncertainty of current harmonic amplitude measurement, δ_{ph} – Basic uncertainty of phase measurement between voltage and current harmonics

(1) see section 10.8.4.

Power and energy	Conditions **(for power and energy** **80% U_{nom} ≤ U_{RMS} < 120% U_{nom})**	Resolution	Basic uncertainty (1)
Active power Active energy	1% I_{nom} ≤ I_{RMS} < 5% I_{nom} cosφ = 1	depending on U_{nom} and I_{nom}	$\pm\sqrt{1.0^2 + \delta_{ph}^2}$ %
	5% I_{nom} ≤ I_{RMS} ≤ I_{nom} cosφ = 1		$\pm\sqrt{0.5^2 + \delta_{ph}^2}$ %
	2% I_{nom} ≤ I_{RMS} < 10% I_{nom} cosφ = 0.5		$\pm\sqrt{1.0^2 + \delta_{ph}^2}$ %
	10% I_{nom} ≤ I_{RMS} ≤ I_{nom} cosφ = 0.5		$\pm\sqrt{0.6^2 + \delta_{ph}^2}$ %
Reactive power Reactive energy	2% I_{nom} ≤ I_{RMS} < 5% I_{nom} sinφ = 1	depending on U_{nom} and I_{nom}	$\pm\sqrt{1.25^2 + \delta_{ph}^2}$ %
	5% I_{nom} ≤ I_{RMS} < I_{nom} sinφ = 1		$\pm\sqrt{1.0^2 + \delta_{ph}^2}$ %
	5% I_{nom} ≤ I_{RMS} < 10% I_{nom} sinφ = 0.5		$\pm\sqrt{1.25^2 + \delta_{ph}^2}$ %
	10% I_{nom} ≤ I_{RMS} < I_{nom} sinφ = 0.5		$\pm\sqrt{1.0^2 + \delta_{ph}^2}$ %

	10% I_{nom} ≤ I_{RMS} < I_{nom} sinφ = 0.25		$\pm\sqrt{1.25^2+\delta_{ph}^2}$ %
Apparent power Apparent energy	2% I_{nom} ≤ I_{RMS} < 5% I_{nom}	depending on U_{nom} and I_{nom}	±1%
	5% I_{nom} ≤ I_{RMS} ≤ I_{nom}		±0.5%
Power factor (PF)	0…1 50% U_{nom} ≤ U_{RMS} < 120% U_{nom} 10% I_{nom} ≤ I_{RMS} < I_{nom}	0.01	±0.03
Displacement power factor (cosφ/DPF)	0…1 50% U_{nom} ≤ U_{RMS} < 120% U_{nom} 10% I_{nom} ≤ I_{RMS} < I_{nom}	0.01	±0.03

(1) see section 10.8.4.

Flicker	Range and conditions	Resolution	Basic uncertainty
P_{st} (10-min), P_{lt} (2h)	0.2…10 for U_{RMS} ≥ 80% U_{nom}	0.01	±5% within the tabularized values in IEC 61000-4-15

Unbalance (voltage and current)	Range and conditions	Resolution	Basic uncertainty
Positive, zero and negative sequence unbalance	0.0%...20.0% for 80% U_{nom} ≤ U_{RMS} < 120% U_{nom}	0.1%	±0.15% (absolute uncertainty)

12.3 Event detection – RMS voltage and RMS current

Voltage U_{RMS} (dips, interruptions and swells)	Range	Resolution	Basic uncertainty
$U_{RMS(1/2)}$	0.0%...120.0% U_{nom}	0.01% U_{nom}	±0.2% U_{nom}
Detection thresholds	User defined in percent or absolute values. Event detection based on the $U_{RMS(1/2)}$ measurement (1-period RMS voltage, refreshed every half period).		
Duration	hh:mm:ss.ms	half a period	one period
Waveform recording	2 periods before event + 4 periods after event (total of 6 periods) 256 samples per period		

Current I_{RMS} (min, max)	Range	Resolution	Basic uncertainty
$I_{RMS(1/2)}$	0.0%...100.0% I_{nom}	0.01% I_{nom}	±0.2% I_{nom}
Detection thresholds	User defined in percent or absolute values. Event detection based on the $I_{RMS(1/2)}$ (1-period RMS current, refreshed every half period).		
Duration	hh:mm:ss.ms	half a period	one period
Waveform recording	2 periods before event + 4 periods after event (total of 6 periods) 256 samples per period		

12.4 Event detection – remaining parameters

Parameter	Range	Detection method
Frequency (min, max)	40…70Hz (in percent or absolute values)	Based on 10-second values (acc. to IEC 61000-4-30)
Voltage crest factor (min, max)	1.0…10.0	Based on 10/12-period value
Current crest factor (min, max)	1.0…10.0	Based on 10/12-period value
Voltage negative sequence unbalance (max)	0.0…20.0%	Based on 10/12-period value
Current negative sequence unbalance (max)	0.0…20.0%	Based on 10/12-period value

Short-term flicker P_{st} (max)	0..20	Based on 10-minute value
Long-term flicker P_{lt} (max)	0..20	Based on 2-hour value
Active power P (min, max)	Depending on configuration	Based on 10/12-period value (for consumed and supplied power)
Reactive power Q (min, max)	Depending on configuration	Based on 10/12-period value (for consumed and supplied power)
Apparent power S (min, max)	Depending on configuration	Based on 10/12-period value
Distortion power D/ Nonfundamental apparent power S_N (min, max)	Depending on configuration	Based on 10/12-period value
Power factor PF (min, max)	0…1	Based on 10/12-period value
Displacement power factor cosφ/DPF (min, max)	0…1	Based on 10/12-period value
tanφ (min, max)	0…10	Based on 10/12-period value
Active energy E_P (max)	Depending on configuration	Checked every 10/12 periods (for consumed and supplied power)
Reactive energy E_Q (max)	Depending on configuration	Checked every 10/12 periods (for consumed and supplied power)
Apparent energy E_S (max)	Depending on configuration	Checked every 10/12 periods
Voltage total harmonic distortion THD-F (max)	0…100%	Based on 10/12-period value
Current total harmonic distortion THD-F (max)	0…200%	Based on 10/12-period value
Voltage harmonic amplitudes (max)	0…100% or in absolute values	Based on 10/12-period value; Independent thresholds for all harmonics in the 2…50 range
Current harmonic amplitudes (max)	0…200% or in absolute values	Based on 10/12-period value; Independent thresholds for all harmonics in the 2…50 range
(K-Factor) (max)	1.0..50.0	Based on 10/12-period value

Event detection hysteresis	Range	Calculation method
Hysteresis	0..10% with 0.5% increment	For each parameter calculated as a percent of max. threshold

12.5 Recording

Recorder	
Averaging time (1)	200ms, 1s, 3s, 5s, 10s, 15s, 30s, 1min, 3min, 5min, 10min, 15min, 30min, 60min, 120min. Special mode: ½ period (recording only $U_{RMS(1/2)}$ and $I_{RMS(1/2)}$) (2)
min/max averaging for U_{RMS}	½ period, period, 200ms, 1s, 3s, 5s (3)
min/max averaging for I_{RMS}	½ period, period, 200ms, 1s, 3s, 5s (3)
Waveform recording	It is possible to record 3-period waveforms of active channels after each averaging period
Recording activation mode	manual, from the first detected event, according to schedule (four defined time periods)
Measurement points	4 independent user configurations, definable space allocation on memory card, it is possible to allocate the whole space to a given point
Recording time	Configuration dependent
Memory	SD card
Memory model	Linear
Security	Key lock against unauthorized access, PIN code to lock data reading

(1) Averaging times below 10s are actually equal to multiples of mains period: 200ms – 10/12 periods, 1s – 50/60 periods, 3s – 150/180 periods, 5s – 250/300 periods.
(2) $U_{RMS(1/2)}$ and $I_{RMS(1/2)}$ mean 1-period RMS values, refreshed every half a period
(3) min./max. averaging periods 200ms, 1s, 3s, 5s are actually equal to multiples of mains period: 200ms – 10/12 periods, 1s – 50/60 periods, 3s – 150/180 periods, 5s – 250/300 periods

Recorded parameters	Average value	Minimum value	Maximum value	Instantaneous value
Phase-to-phase/ phase-to-neutral RMS voltage U_{RMS} (depending on system type)	•	•	•	•
Phase-to-phase RMS voltage U_{RMS} (only 3-phase wye with N and split-phase systems)	•			
RMS current I_{RMS}	•	•	•	•
Frequency f	•	•	•	•
Voltage crest factor CF U	•	•	•	•
Current crest factor CF I	•	•	•	•
Negative and positive sequence unbalance, symmetrical components: negative sequence, positive sequence and zero sequence (voltage) U_0, U_1, U_2, u_0, u_2	•	•	•	•
Negative and positive sequence unbalance, symmetrical components: negative sequence, positive sequence and zero sequence (current) I_0, I_1, I_2, i_0, i_2	•	•	•	•
Short-term and long-term flicker 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/ Nonfundamental apparent power S_N	•	•	•	•
Power factor PF	•	•	•	•
Displacement power factor cosφ/DPF	•	•	•	•
tanφ	•	•	•	•
Active energy (consumed and supplied) E_{P+}, E_{P-}				•
Reactive energy (consumed and supplied) E_{Q+}, E_{Q-}				•
Apparent energy E_S				•
Voltage total harmonic distortion THD-F	•	•	•	•
Current total harmonic distortion THD-F	•	•	•	•
Voltage harmonic amplitudes U_{h1}…U_{h50}	•	•	•	•
Current harmonic amplitudes I_{h1}…I_{h50}	•	•	•	•
K-Factor	•	•	•	•
Harmonics active power (1…50) P_{h1}…P_{h50}	•	•	•	•
Harmonics reactive power (1…50) Q_{h1}…Q_{h50}	•	•	•	•
Angles between voltage and current harmonics φ_1…φ_{50}	•	•	•	•

12.6 Power supply and heater

Power supply	
Rated voltage range	90…760V AC (connected internally to L1-N terminals in PQM-701; separate terminals in PQM-701Z)
Overvoltage category	CAT IV 600V
Power consumption	max. 30VA
Battery	Li-Ion 6.9Ah
Work on battery power supply	> 5h
Battery charging time (totally discharged)	8h
Battery current consumption in off state (without external power connected)	< 1mA

Heater	
Heater activation temperature threshold	+5°C
Heater power supply	from built-in mains power supply
Heater rated power	max. 10W

12.7 Supported mains systems

Types of supported mains systems	
1-phase with N	One-phase with neutral conductor (terminals L1, N, PE)
split-phase	Split-phase with neutral conductor (terminals L1, L2, N, PE)
3-phase 4-wire wye with N	Three-phase, wye, with neutral conductor (terminals L1, L2, L3, N, PE)
3-phase 3-wire delta	Three-phase, delta (terminals L1, L2, L3, N shorted with L3)
Aron's 3-phase 3-wire delta	Three-phase, delta (terminals L1, L2, L3, N shorted with L3), with two current clamps
3-phase 3-wire wye without N	Three-phase, wye, without neutral conductor (terminals L1, L2, L3, N shorted with L3)
Aron's 3-phase 3-wire wye without N	Three-phase, wye, without neutral conductor (terminals L1, L2, L3, N shorted with L3), with two current clamps

12.8 Supported clamps

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

12.9 Communication

Communication	
USB	optically isolated, Max. transmission speed: 921.6kbit/s, USB 2.0 compatible
Wireless	Built-in 433MHz radio module, Communication by means of OR-1 radio receiver Max. transmission speed: 57.6kbit/s
RS-232 (only PQM-701Zr)	Galvanically isolated, Max. bitrate: 921.6kbit/s, Hardware Flow Control RTS / CTS (optional)

12.10 Environmental conditions and remaining technical specification

Environmental conditions	
Operating temperature range	-20°C…+55°C
Storage temperature range	-30°C…+60°C
Humidity	10…90% with condensation
Ingress protection rating (acc. to IEC 60529)	IP 65 (closed cover) IP 20 (open cover)
Reference conditions	Ambient temperature: 23°C ±2°C Humidity: 40…60% RH
Dimensions	235 x 218 x 122mm (PQM-701) 243 x 218 x 122mm (PQM-701Z and PQM-701Zr) PQM-701Z and PQM-701Zr width with power supply leads inserted: min. 290mm
Weight	about 2.1kg
Display	LED, red, 4 alphanumeric characters
Memory card	SD, SDHC. Cards larger than 4GB are formatted to 4GB available for user data.

12.11 Safety and electromagnetic compatibility

Safety and EMC	
Compliance with	IEC 61010-1
Measurement category	IV 600V (< 2000m above sea level), IV 460V (< 3000m above sea level), pollution class 2, acc. to IEC 61010-1
Insulation	Double acc. to IEC 61010-1 (closed cover), Single ac. to IEC 61010-1 (open cover)
Electromagnetic compatibility	IEC 61326
Immunity to RF disturbances	IEC 61000-4-3 sinusoidal modulation 80% AM, 1kHz 80…1000MHz, 10V/m 1.4…2.0GHz, 3V/m 2.0…2.7GHz, 1V/m
Immunity to electrostatic discharge	IEC 61000-4-2 Air discharge: 8kV Contact discharge: 4kV
Immunity to conducted disturbances induced by RF fields	IEC 61000-4-6 sinusoidal modulation 80% AM, 1kHz 0.15…80MHz, 10V
Immunity to series of fast transients/bursts	IEC 61000-4-4 Amplitude 2kV, 5kHz
Immunity to surges	IEC 61000-4-5 Amplitude 2kV (L-L), 4kV (L-PE)
Emission of radiated RF disturbances	IEC 61000-6-3 30…230MHz, 30dB(μV/m) at 10m 230…1000MHz, 37dB(μV/m) at 10m
Emission of conducted disturbances	IEC 61000-6-3 Levels for quasi-peak detector: 0.15kHz…0.5MHz: 66dBμV…56dBμV 0.5MHz…5MHz: 56dBμV 5MHz…30MHz: 60dBμV

12.12 Standards

Standards	
Measuring methods	IEC 61000-4-30 class S or class A (depending on parameter)
Measuring accuracy	IEC 61000-4-30 class S or class A (depending on parameter)
Energy quality	EN 50160
Flicker	IEC 61000-4-15
Harmonics	IEC 61000-4-7
Quality standard	development, design and manufacture according to ISO 9001

13 Equipment

13.1 Standard equipment

The standard kit delivered by the manufacturer includes:

- F-3 flexible clamp for currents up to 3kA AC (length 45cm) – **WACEGF3OKR**,
- test lead with banana plugs, CAT III 1000V black, length 2.2m (PQM-701 - 3 pcs, PQM-701Z - 4 pcs.) – **WAPRZ2X2BLBB**,
- test lead with banana plugs, CAT III 1000V blue, length 2.2m (PQM-701 - 1 pcs, PQM-701Z - 2 pcs.) – **WAPRZ2X2BUBB**,
- test lead with banana plugs, CAT III 1000V yellow, length 2.2m – **WAPRZ2X2YEBB**,
- "Crocodile" clip K01 black (PQM-701 - 3 pcs, PQM-701Z - 4 pcs.) – **WAKROBL20K01**,
- "Crocodile" clip K02 blue (PQM-701 - 1 pcs, PQM-701Z - 2 pcs.) – **WAKROBU20K02**,
- "Crocodile" clip K02 yellow – **WAKROYE20K02**,
- socket-adapter with banana pins (L1 and N) for charging the batteries – **WAADAAZ1**,

- software for data reading and analysis “SONEL Analysis” – **WAPROANALIZA**,
- USB cable – **WAPRZUSB**,
- OR-1adapter - wireless USB interface transmission receiver – **WAADAUSBOR1**,
- SD card – **WAPOZSD1**,
- hard suitcase for the analyzer and accessories – **WAWALXL1**,
- band for fixing on the pole – **WAPOZOPAKPL**,
- DIN Rail Mounting Clip (ISO) (2 pcs.) – **WAPOZUCH2**,
- built-in battery,
- operating manual,
- certificate of calibration.

The standard equipment supplied by the manufacturer with the PQM-701Zr device includes:

- serial transmission cable, female-male, non-interlaced, RS-232 (DB-9) - **WAPRZRS232**.

13.2 Optional equipment

In addition, the following items not included in the standard kit can be purchased from the manufacturer or the distributors:

- C-4 1000A AC clamp – **WACEGC4OKR**,
- C-5 1000A AC/CD clamp – **WACEGC5OKR**,
- C-6 clamp for small currents 10A AC – **WACEGC6OKR**,
- C-7 clamp 100A AC – **WACEGC7OKR**,
- F-1 flexible clamp for currents up to 3kA AC (length 120cm) – **WACEGF1OKR**,
- F-2 flexible clamp for currents up to 3kA AC (length 80cm) – **WACEGF2OKR**,
- rechargeable battery – **WAAKU09**,
- hand carrying case for clamps – **WAWALL2**.

Note

When ordering the clamps for PQM-701, please state the serial number of the analyser, for which clamps are ordered

13.2.1 C-4 clamp

The C-4 clamp is used to measure the alternating current in medium and high power electrical installations. The output signal is voltage proportional to the measured current. The output signal is supplied by a 1.5-meter lead with a pin adapted for the socket in the meter.

The arrow located on one of the jaws indicates the current flow direction. It is assumed that the current is flowing in the positive direction if it is flowing from the source to the receiver. Such clamp orientation is required for a correct power measurement.

Fig. 93. C-4 clamp.

Note

Currents above 1200A must not be measured. The measurement time for currents above 1000A shall be limited as follows:

Current range	I ≤ 1000A	1000A < I ≤ 1200A
Operation mode	continuous [1]	15-minute measurement, then 30-minute break

[1] For frequency f ≤ 1kHz. Limitation of maximum current for continuous operation for frequencies above 1kHz according to the relationship I_{cont} = 1000A/f[kHz]

Warning

Do not use the device on non-insulated conductors with a potential of more than 600 V in relation to the earth and a measurement category greater than III.

- **Reference conditions**

• Temperature	+20…+26°C
• Humidity	20…75% RH
• Conductor position	conductor centered in jaws
• Sinusoidal current frequency	48…65Hz
• Harmonics content	<1%
• Current DC component	none
• Continuous magnetic field	earth field (<40A/m)
• Alternating magnetic field	none
• Conductors in direct vicinity	no flowing current

- **Technical parameters**

  - Accuracy:

Current range	Basic uncertainty [1]	Phase error
0,1…10A	≤ 3% + 0.1A	not specified
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 measured value

• input signal for max. current	1V AC
• ratio	1mV AC/1A AC
• frequency range	30Hz...10kHz
• insulation type	double, according to IEC 61010-1
• measuring category acc. to IEC 61010-1	III 600V,
• protection rating acc. to IEC 60529	IP40, with open jaws: IP30
• dimensions	216 × 111 × 45mm
• weight	about 640g
• jaws opening	53mm

- open jaws height 139mm
- maximum measured conductor diameter ∅52mm
- clamp lead length 1.5m
- operating temperature –10°C…+55°C
- relative humidity <85%
- height ≤ 2000m
- electromagnetic compatibility IEC 61000-6-3:2008
  IEC 61000-6-2:2008

13.2.2 C-5 clamp

The C-5 clamp is used to measure the alternating and direct current without interrupting the circuit with the flowing current. The measuring range is 1400A for DC and 1000A AC. The output signal is voltage proportional to the measured current. The clamp has one 1000A measuring range, with the 1mV/A sensitivity, DC zero adjustment knob, and LED power supply indicator.
The output signal is supplied by a 1.5-meter lead with a pin adapted for the socket in the meter.

The arrow located on one of the jaws indicates the current flow direction. It is assumed that the current is flowing in the positive direction if it is flowing from the source to the receiver. Such clamp orientation is required for a correct power measurement.

Fig. 94. C-5 clamp.

- **Overload:**
  - Direct current (DC): up to 3000A (continuous mode),
  - Alternating current (AC): up to 1000A in continuous mode up to the 1kHz frequency
  - Limitation of maximum current for continuous operation for frequencies above 1kHz according to the relationship: I_{cont} = 1000A/f [kHz]

- **Switching on**
  To switch on the clamp, put the switch in the 1mV/A position. Green LED indicates the correct operation. If after switching the LED is not lit or goes off, replace the battery.

- **DC zero indication correction**
  Make sure the jaws are closed and there is no conductor inside them. Then, connect the clamp to the analyzer and launch the "SONEL Analysis" software in the instantaneous values viewing mode (check if the measurement point is correctly configured for measurement with the C-5 clamp). Press the knob and turn until the DC current indication is zero.

- **Reference conditions**
  - Temperature: +18…+28°C
  - Humidity: 20…75% RH
  - Battery voltage: 9V ± 0.1V
  - Conductor position: conductor centered in jaws
  - Current: direct (DC) or sinusoidal (AC) f ≤ 65Hz
  - Continuous magnetic field: earth field (<40A/m)

- Alternating magnetic field: none
- Conductors in direct vicinity: no flowing current

- **Technical specification**
  - 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 measured value

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

Current 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:
    - caused by current frequency: 65..440Hz: -2%
440..1000Hz: -5%
1..5kHz: -4dB
    - caused by battery voltage: ≤1A/V
    - caused by temperature: ≤ 300ppm/°C or 0.3%/10°C
    - caused by relative humidity in the10…85% range:
≤0.5%
    - caused by position of ∅20mm conductor:
DC up to 440Hz: <0,5%
DC up to 1kHz: <1%
DC up to 2kHz: <3%
DC up to 5kHz: <10%
    - caused by a parallel conductor with the 50…60Hz AC, at 23mm from the clamp:
<10mA/A
    - caused by the 400A/m (50Hz) external magnetic field on the centered conductor
<1.3A
    - common mode rejection ratio >65dB A/V (50…400Hz)

- **Other data**
  - insulation type: double, according to IEC 61010-1
  - measuring category acc. to IEC 61010-1: III 600V,
  - protection rating acc. to IEC 60529:
IP30
  - power supply: 9V battery (6LR61, 6LF22, NEDA 1604)
  - operating time with alkaline battery: about 120h
  - dimensions: 237 × 97 × 44mm
  - weight: about 520g

- maximum measured conductor diameter: ∅39mm
- clamp lead length: 1.5m
- operating temperature: –10°C…+55°C
- humidity: <85% RH
- height: ≤ 2000m
- electromagnetic compatibility: IEC 61000-6-3:2008, IEC 61000-6-2:2008

13.2.3 C-6 clamp

The C-6 is used to measure the alternating current with frequencies up to 10kHz in the 10mA…10A range.
The output signal is voltage proportional to the measured current with the 100mV/A sensitivity. The output signal is supplied by a 1.5-meter lead with a pin adapted for the socket in the meter.

Fig. 57. C-6 clamp.

The arrow located on one of the jaws indicates the current flow direction. It is assumed that the current is flowing in the positive direction if it is flowing from the source to the receiver. Such clamp orientation is required for a correct power measurement.

Warning
Do not use the device on non-insulated conductors with a potential of more than 600 V in relation to the earth and a measurement category greater than III.

- **Reference conditions**
  - Temperature: +20…+26°C
  - Relative humidity: 20…75%
  - Conductor position: conductor centered in jaws
  - Sinusoidal current frequency: 48…65Hz
  - Harmonics content: <1%
  - Current DC component: none
  - Continuous magnetic field: earth field (<40A/m)
  - Alternating magnetic field: none
  - Conductors in direct vicinity: no flowing current

- **Technical specification**
  - Accuracy

Current range	Basic uncertainty [1)]	Phase error
0.01…0.1A	≤ 3% + 1mA	not specified
0.1…1A	≤ 2.5%	≤ 5°
1…12A	≤ 1%	≤ 3°

[1)] as % of measured value

- ratio: 100mV AC/1A AC
- frequency range: 40Hz...10kHz
- insulation type: double, according to IEC 61010-1
- measuring category acc. to IEC 61010-1: III 600V,
- protection rating acc. to IEC 60529: IP40, with open jaws: IP30
- dimensions: 135 × 50 × 30mm
- weight: about 240g
- jaws opening: 21mm
- open jaws height: 69mm
- maximum measured conductor diameter: ∅20mm
- clamp lead length: 1.5m
- operating temperature: –10°C…+55°C
- humidity: <85% RH
- height: ≤ 2000m
- electromagnetic compatibility: IEC 61000-6-3:2008
  IEC 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. 1. C-7 clamp.

Attention!
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% ±0,1mV	≤ 2°
40Hz…1kHz	±1.0% ±0.2mV	unspecified

- ratio: 5mV AC/1A AC
- output impedance 11Ω
- type of insulation: double, according to PN-EN 61010-1
- measurement category according to PN-EN 61010-1: III 300V,
- dimensions: 100 × 60 × 26mm
- weight: approx. 160g
- maximum diameter of tested cable: ∅24mm
- length of clamp cables: 1,5m
- operating temperature: 0°C…+50°C
- relative humidity: <85% (bez kondensacji)
- electromagnetic compatibility: PN-EN 61326

13.2.5 F-1, F-2, F-3 clamps

F-1, F-2 and F-3 flexible clamps (Rogowski coil) are used to measure the alternating current of frequencies up to 10kHz in the 1A…3000A range.

The only difference between the F-1, F-2 and F-3 flexible clamps is the coil size. The electrical parameters are identical.
The output signal if voltage proportional to the derivative of the measured current, with the sensitivity equal to 38.83mV/1000A for 50Hz and 46.6mV/1000A for 60Hz.

Fig. 97. F-1 clamp.

Fig. 98. F-2 clamp.

Fig. 99. F-3 clamp.

The output signal is supplied by a 2-meter lead with a pin adapted for the socket in the meter.
The arrow located on the closing unit indicates the current flow direction. It is assumed that the current is flowing in the positive direction if it is flowing from the source to the receiver. Such clamp orientation is required for a correct power measurement.

Warning
Do not use the device on non-insulated conductors with a potential of more than 1000 V in relation to the earth and a measurement category greater than III.

- **Reference conditions**
  - Temperature: +18…+22°C
  - Conductor position: centered in relation to the clamp loop

- Continuous magnetic field: earth field (<40A/m)
- Alternating magnetic field: none
- External electric field: none

- **Technical specification**
  - Rated measuring range: 1A…3000A (10000A peak for 50Hz)
  - Input/output ratio: 38.83mV/1000A (50Hz)
46.6mV/1000A (60Hz)
  - Basic uncertainty: ±1% in the 1A…3000A range
  - Linearity: ±0.2%
  - Additional error caused by conductor position: ±2% max.
  - Additional error caused by external magnetic field:
±0.5% max.
  - Additional error caused by temperature: ±0.07%
  - Output impedance: 30Ω/400mm

- **Remaining data:**
  - insulation type: double, according to IEC 61010-1
  - measuring category acc. to IEC 61010-1: III 1000V,
  - protection rating acc. to IEC 60529: IP65
  - coil diameter: 15.5mm
  - closing unit diameter (maximum): 30mm
  - coil circumference: F-1: 120cm
F-2: 80cm
F-3: 45cm
  - internal coil diameter (closed clamp): F-1: 360mm
F-2: 235mm
F-3: 120mm
  - weight: F-1: about 410g
F-2: about 310g
F-3: about 220g
  - clamp lead length: 2m
  - operating temperature: –20°C…+80°C
  - electromagnetic compatibility: IEC 61000-6-3:2008
IEC 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 packagings 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.*

14.5 Laboratory services

SONEL S.A. Calibration Laboratory offers the following range of electrical instrumentation calibration services for the following instruments:

- thermal imagers,
- pyrometers (IR thermometers),
- safety and protective meters: insulation resistance, earth resistance and impedance, short circuit loop, RCD parameters, including multi-function meters with above-mentioned functions,
- safety of electrical equipment meters,
- low resistance meters,
- current and voltage meters (also clamp meters), resistance and multimeters,
- light meters.

A calibration certificate is a document that endorses compliance of the parameters declared by the tested instrument manufacturer with official standards defining the measurement uncertainty.

In compliance **PN-ISO 10012-1** standard**, appendix A** – „Quality assurance requirements for measuring equipment" – SONEL S.A. recommends that their products are subject to periodical metrological checks every 13 months..

Note:
In case the instrument is used in measurements related to fire protection, the person who carries out the tests has to be fully satisfied as to the instrument's performance. Measurements carried out using a device that is not in proper working order, can lead to an incorrect assessment of the health protection safeguards and can contribute to a hazardous or even life threatening situation.

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

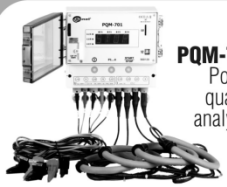
MRU-20
Earth Resistance and Resistivity Meter

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