Wide-area system of registration and processing of power quality data in power grid with distributed generation

Part I. System description, functional tests and synchronous recordings

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***Abstract*— This paper presents the developed and built comprehensive system of registration, archiving and data processing for the wide-area monitoring of power quality in a separated part of real power grid with distributed renewable generation. Real case studies related to localization of sources of voltage disturbances are presented.**

Keywords-power quality, power distribution faults, power distribution reliability, power system restoration, power system transients, relational databases, distributed generation, location of disturbances, voltage dips

I. INTRODUCTION

Wide-area power quality monitoring is one among the most important and troublesome problems for utilities; so, how to monitor, show and analyze the PQ knowledge in efficient way associated with economic considerations remains an on-going work [1,3]. The keys in realizing the wide-area PQ monitoring is equipment, software, management and communication [11]. Reliable information about Power Quality (PQ) allows the distribution companies to select the proper instruments to improve PQ and acquire the advantages from upgrading the supply circuits [2}. Therefore, several companies perform PQ survey at specific sites to collect the PQ information for a given time period. PQ watching and recording becomes one of the foremost services of the companies for the customers. Besides, the time of energy market deregulation has brought more attention for PQ. E.g. competitive distribution companies may determine their costs on the power quality parameters of energy provided [5,6].

Presented project aims at building a distributed power quality monitoring system. Such a system is located at the nodes of the actual distribution network enables the study of phenomena occurring in the system containing distributed generation units [4]. The monitoring system is equipped with stationary time-synchronized power quality recorders with data transmission network. The software supports data transmission between analyzers and data servers and database where both power quality indices all the other electrical parameters are integrated. It allows to conduct effective research on phenomena occurring in modern distribution systems [7].

Using our previous experience [12, 13, 15] in the implementation of a distributed monitoring using mobile power quality analyzers with GPS synchronization we developed a stationary system to monitor network parameters. Fixed installation allows long-time diagnostic data recorded synchronously in selected locations of the distribution network that may indicate trends related to changes in network configuration, changes in the nature or size of the loads, and the impact of renewable energy sources.

II. DATA TRANSMISSION SYSTEM

The goal for the development of the system was the need to monitor events in networks and power facilities irrespective of their location [4]. Additionally, there was a need for synchronous data capture for quality assessment during PQ multi-measurements . The analysis of the assumptions and limitations in the context of technological and economic possibilities , the decision was made to use commonly available telecommunications systems , in particular in the field of wireless communication allowing the greatest possible coverage of sparsely industrialized and urbanized areas. Basic functional diagram developed and implemented control and measurement system is shown in Figure 1.

The diagram highlights four broad functional areas : monitoring and data acquisition by packet GSM gateway for data transmission in GSM / Internet and ICT infrastructure WAN / LAN . First zone is a set of remote monitoring and control units including wideband GSM modems with protected firewall access and authorization management using VPN (Virtual Private Network) through the Web (web browser) , MAC (Media Access Control) filtering for the physical layer of Ethernet, and also DMZ (Demilitarized Zone) service used to allow direct management without limitation of measuring devices.

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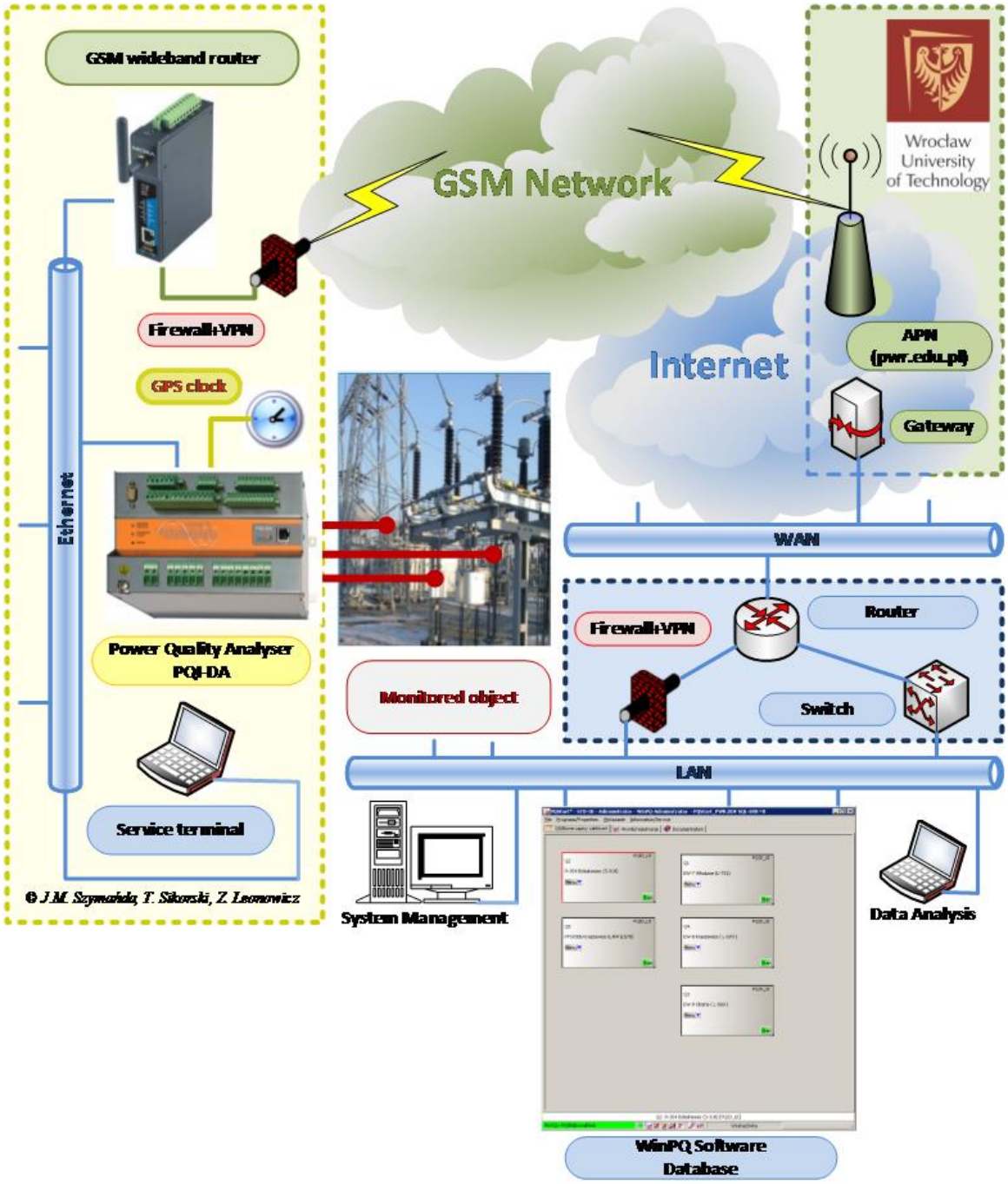

Figure 1. Functional diagram of the system.

According to the GSM subscription tariff plan, the modem can receive calls, depending on their availability and work modes : WCDMA (Wideband Code Division Multiple Access) - the preferred technology is HSPA (High Speed Packet Access), or in the case of very weak network coverage : GPRS (General Packet Radio Service) - but then the packet data transfer is significantly slowed down.

Measuring and recording device is a power quality meter PQI -DA with the possibility of synchronous data logging, the exact time being determined from the satellite transmission of GPS . This feature is particularly desirable in the case mentioned earlier, when multi-measurement are being made for the selected part of the power grid. System configuration also allows optional connection of a portable PC for servicing at the location of measurements. Broadband GSM modem transmits measurements packet data directly after receiving instructions from the terminal operator (or user application) to the nearest AP (GSM Access Point) . The modems is configured in such a way that the data transmission is always routed to the APN (Access Point Name) managed by the Wroclaw University of Technology. The APN-PWR packet data gate (GGSN - Gateway GPRS Support Node) transmits packet data to the

Internet (WAN - Wide Area Network) and LAN (Local Area Network) . Management and monitoring system, including the configuration system of the broadband modems, power quality meter programming and remote reception of the recorded measurement data, is located in the LAN zone - local area network with connected PC terminals . The number and the use of PC depends on the specific tasks in the research program. Communication and control system of measurements uses TCP/IP protocol and is implemented in asynchronous mode. Dedicated programming environment for downloading data from the power quality WinPQ application is responsible for the implementation of cyclic data retrieval, archiving and visualization.

III. Description And Functional Tests of The System

With the participation of the industrial partners involved in the project we considered the choice of placement for the installation of the monitoring system by proposing three areas of interest in the distribution network. Proposed areas are interesting due to the concentration of renewable sources, including hydropower plants operating in the medium voltage networks and wind farms and other specific technical conditions.

The system is based on WinPQ software [16] containing several modules providing functionality of the system in terms of the parameterization facilities, communication, data collection and analysis and reporting :

PQStar : a tool for startup of the various functions of the system ,
PQAdmin : a tool for resource management,
PQRS232 Server: hub for RS232 and TCP/IP data transmission
PQManager: tool to automatically transfer the measurement results to the database,
PQReport : a tool to develop and manage reports and data processing,
PQMail : a tool to automatically send periodic reports to the occasional individual users,
PQPara : a tool for programming the settings of the analyzers,
PQVisu : graphical on-line visualization tool for individual parameters .

Access to individual recorders is possible using the module PQStart . The general appearance of the dialog box shown in Figure 2. The individual measurement points included in the present analysis have internal addresses corresponding MySQL database fields beginning with the letter Q. The following connection points were chosen :

- Q1- 10kV medium voltage,
- Q2- 110kV high voltage,
- Q3- 20kV medium voltage,
- Q4- 20kV MV , medium voltage
- Q5 - low voltage 0.4kV , station 20/0.4kV

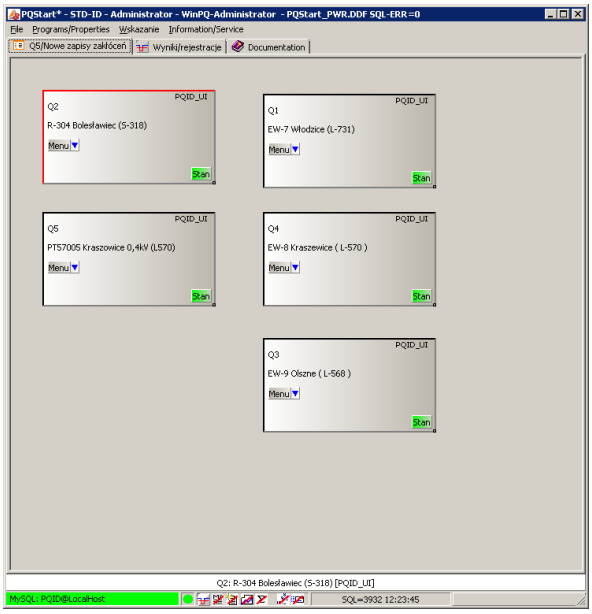

Figure 2. Dialog module PQStart with installed recorders.

Pop-up menu allows to select the desired functions for a given point and opens the relevant modules of the system, like:

PQVisu- overview of the dynamic disturbances' recording, overview of events categorized according to EN 50160, overview of long-term 10-minute, 2-hour values, generation of reports,

PQPara- reading current values measured on-line, reading current recordings and entries to the SQL database

PQID- setting limits and parameterization for triggering of dynamic recordings, etc.

A. Recording of Disturbances

The choice of functionality "Registration of disturbances" leads to launch the PQVisu module and gives the opportunity to review the list of registered events of power quality disturbances. Registrations are categorized in the system as virtual interactive recorders

An exemplary list of dynamic disturbances recorded at the measuring point Q2: are shown in Figure 3. PQVisu module also allows accessing the list of disturbances recorded in the other measuring points Q1 ÷ Q5 visible in the next cards of the module. In addition, visualization of the noise in the recording mode RecA oscilloscope gives the opportunity to perform additional detailed analysis of the disturbance, such as frequency spectrum and phasor distribution and the application's own calculation formulas defined as a new virtual channels and export data to other open formats.

Example of voltage and current waveforms of the selected distortion and frequency spectrum and phasor distribution is shown in Figure 4. Due to limitations in memory allocation the recording of waveforms is limited to 0.5 second of samples obtained with a sampling frequency of 10 kHz.

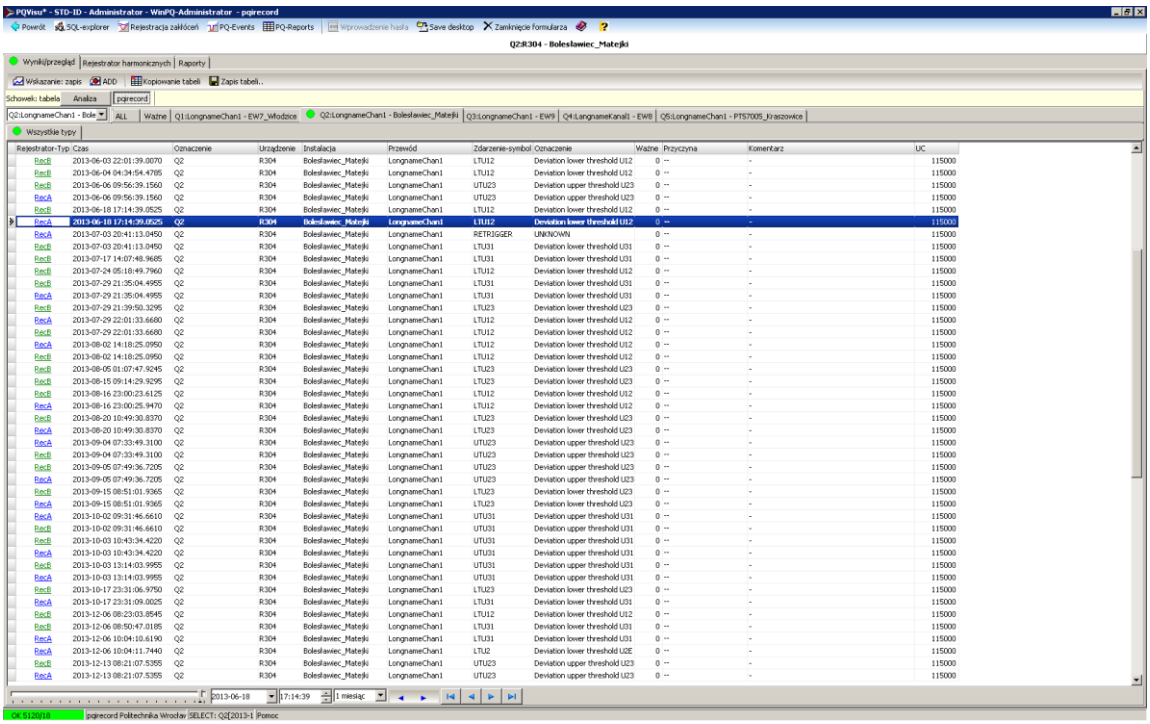

Figure 3. List of power quality disturbances recorded in the test point HV 110kV, Q4 and visible in the module PQVisu.

Writing the RMS values is done on the basis of 10-millisecond is implemented by a virtual recorder RecB. Example of registering the RMS disturbance is given in Figure 5. In both cases, the parameterization of registration includes the definition of the thresholds for triggering and recording time before and after the event (called pre-trigger and post-trigger time).

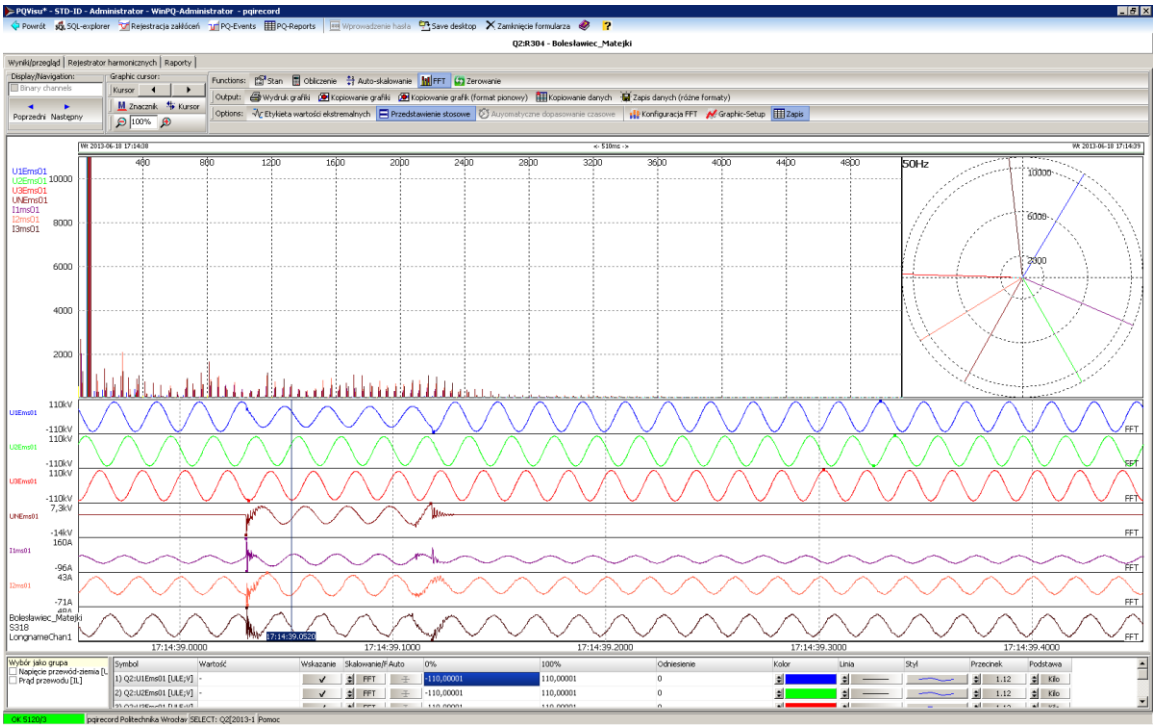

Figure 4. The selected recording of virtual oscilloscope RecA of power quality disturbances recorded in the test point HV 110kV, Q2, FFT frequency analysis and distribution of phasors.

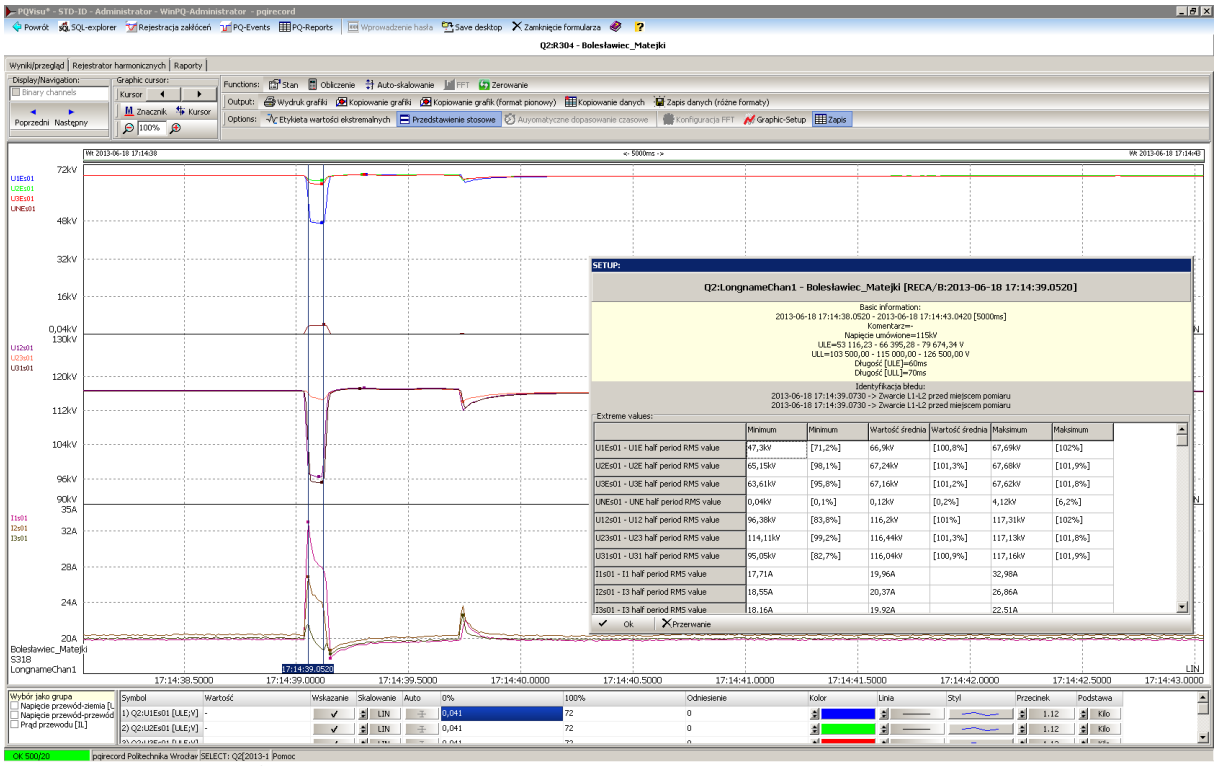

Figure 5. Registration of RecB RMS power quality disturbance recorded in the test point HV 110kV, Q2 and detailed parameters.

B. Synchronous recordings

The main advantage of synchronous monitoring systems is the possibility of so-called "Tracking of disturbance wandering". Figure 6 shows in detail synchronous registrations of disturbances' RMS values of the disturbance observed in different measuring points of the system. Analogous synchronization of disturbances' waveforms is possible , as well. Using the review card of all disturbances in module PQVisu and selecting registrations associated with the disturbance it is possible to present simultaneously of the wandering of disturbance in many measuring points of the system, as shown in Fig. 6.

C. Visualization and analysis of long-term PQ data

The data related to long-term power quality parameters are calculated over averaging periods. Averaged values, which are the basis for the assessment of the PQ indicators, are obtained on the basis of aggregated data in the following intervals:

- Interval of averaging 10s - the average values obtained on the basis of frequency values of 200ms intervals,
- Interval of averaging 10 minutes - the average RMS voltage, current, short-term flicker, obtained on the basis of 10ms average values of harmonics, harmonic ratio, and power asymmetry factor obtained based on 200ms average values,
- Interval of averaging 15 minutes - average values of power and power factor based on 200ms values,
- Interval of averaging 2 hours - the long-term flicker determined on the basis of 10min short-term flicker
- interval averaging of 24 hours- daily values .

At the indicated intervals the algorithm searches are also minimum and maximum values of parameters such as the extreme values determined from time step algorithm (eg, 10 ms , 200 ms) of the averaging interval .

Overview of long-term data is available in the module PQVisu. Organization of the measurement data for each measurement point is realized with the division on the averaging time with a choice of appropriate parameter groups. The following visualization tools and data analysis are available: charts, tables, statistics and reports.

After selecting the appropriate parameter group one can go to the charting tools. The standard observation period is the last calendar month. Any interval of observation can be specified using a timestamp or with a detailed range of dates. Charts of selected parameters update automatically. The advantage of the use of distributed measuring systems is the possibility of analysis of cross- selected power quality parameter , i.e. electrical parameters simultaneously recorded in multiple measuring points [14].

As an example, a comparative analysis chart summarizes the voltage level for the three measurement points connected directly to the MV line, i.e. Q2, Q4, MV 20kV, Q5, LV 0.4kV. Creating charts with multiple simultaneous measurement points is carried out by multiple launching of the tool "Form charts" for data measurement points and selecting of a group of parameters, which results in formation of the corresponding card in the application graphs. The result is a virtual card with the notation of parameter groups with different measuring

points . Results of the comparison of the RMS phase voltage in this example, the analysis of the 3 -point Q2, Q4, Q5 is shown in Figure 7.

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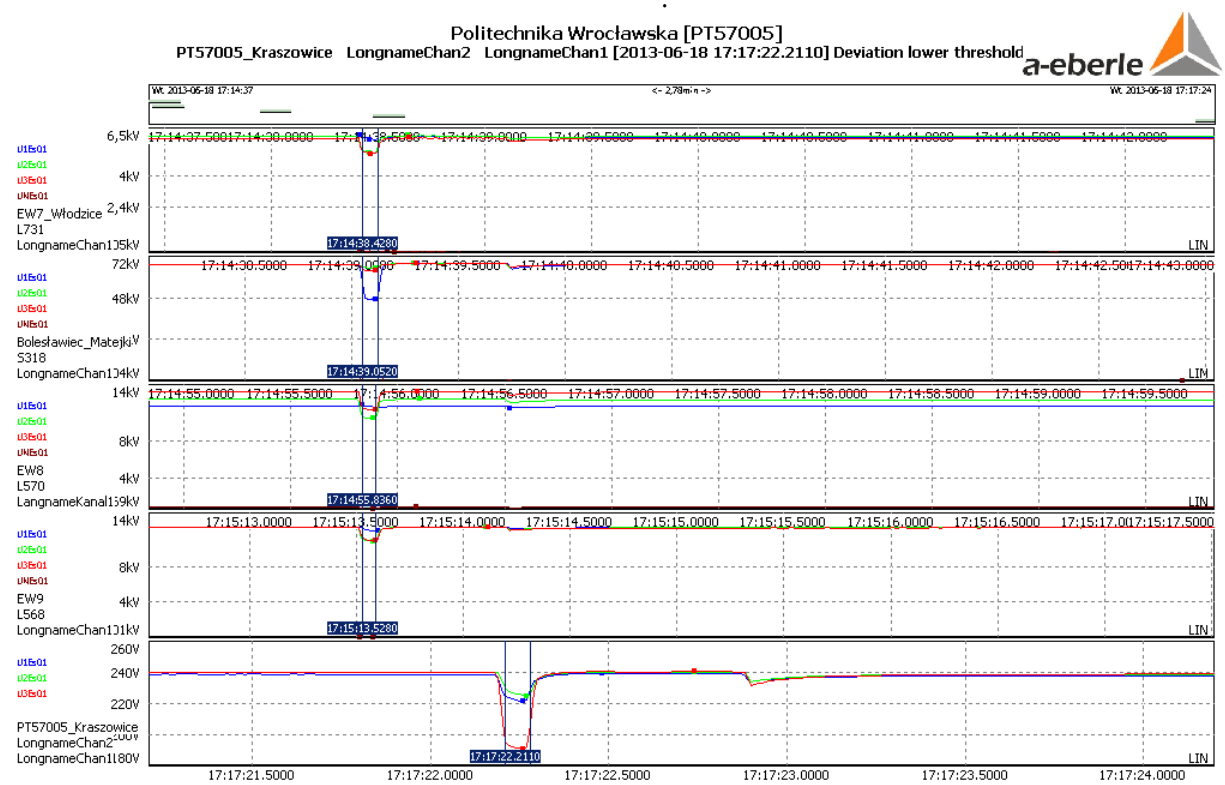

Figure 6. Synchronous registrations of a selected power quality disturbance seen at the measuring points of the system - a summary with time adjustment.

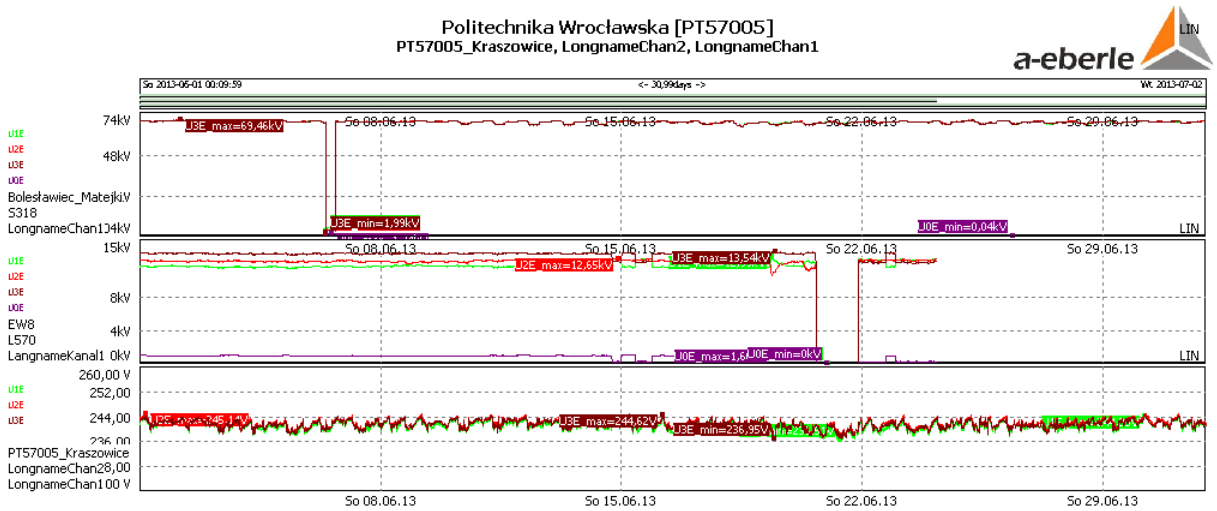

Figure 7. Data analysis tool with simultaneous creation of charts of selected parameters for many points on the example of aggregated 10-minute phase voltage measurement registered in points Q2, Q4 and Q5

IV. SUMMARY

Creation of a monitoring system of power quality installed on a selected part of the power grid containing distributed generation units allows to perform a series of original analyzes of the complex subject of cooperation of distributed generation with the grid .

In contrast to single-point measurements , a collection of synchronous measurement data archived in the database extends the analysis in the direction of simultaneous tracking of dynamic phenomena , area- reporting and statistics covering the monitored areas.

System software includes additional analysis tools to determine flow of harmonics based on the sign on the power of a particular harmonics, harmonic contents of the currents,

interharmonics contents , the classification of the event by UNIPEDE (CBEMA) criteria , evaluation of indicators of continuity of supply.

The structure of recording system is based on the interesting interaction of four types of virtual recorders : digital oscilloscope , recorder of RMS values , harmonics recorder and recorder of fast disturbances. The corresponding memory allocation allows for independent recording in these virtual recorders, depending on the nature of the transient and triggering thresholds. Regardless of these virtual recording, the system performs continuous recording of average values (10 min , N- minute , 2 -hour, daily) . It should be emphasized the possibility of transitions between different types of data loggers while browsing .

Verification work has shown, however, inconsistencies in the parameter recorders and virtual event definitions of power quality disturbances.

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