# THE MANAGEMENT AND ANALYSIS OF POWER QUALITY IN POWER DISTRIBUTION GRIDS BY USING PQVIEW SOFTWARE SYSTEM

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**Abstract – Nowadays the power quality is considered one of the most important aspect regarding the performance of a power grid operator, concerning equally all the consumers categories, too. Since a low level of the power quality has negative consequences on the technical-economic indices of the power networks'operation, there are perfectly justified the permanent efforts of the power grids operators in finding the best methods and tools able to assist them in managing and analyzing a huge volume of power quality data. The paper presents the capabilities of an intelligent system for the management and analysis of power quality data, PQView. This system is used by power grid operators in their operational activity, as well as within Smart Grid Laboratory of University of Craiova's INCESA for research and testing purposes. This software system was used for an extensive power quality analysis of real operation a PV power plant interconnected to MV power distribution grid.**

**Keywords:** power quality, management, analysis, power distribution network.

## 1. INTRODUCTION

Monitoring of power quality (PQ), as well as the continuous dialogue with the customers are compulsory activities for a fully understanding of the way the power disturbances affect the users of power grids [1].The most of the PQ monitor systems acquire a huge volume of measured values, so that a selection of them is necessary in order to keep the relevant information and unify the data format previously to computing and analysis. By using high performance measuring and monitoring systems, the power grid operators (PGO) can identify the PQ issues and characterize the consumers' performances, as well as those of their supplying network. The monitors' versions and product platforms are dominant for the precision of the historical or present information, as well as for those features allowing the global processing of data based on unitary common formats. This issue becomes the main challenge regarding the present PQ monitoring systems [2].

Presently, the PQ monitoring system of the local PGO covers the surveillance of over 400 sites in LV, MV, and 110 kV networks. This actually supposes quite impressive hardware & software capacities for managing of GBytes order data, supplied by instruments of various fabrication and technologies. Therefore the management of PQ database becomes critical. Most of the monitors have their own software, which can be used as individual platforms for the database management. In these circumstances, the most convenient would be the output data to be supplied in formats characteristic to PQ analysis – e.g. PQDIF (Power Quality Data Interchange Format). The existent database is a valuable reference for the present and future PQ state in the local PGO's network. Nevertheless the maintaining of a widespread infrastructure for PQ data collection during long periods is time consuming and economic-prohibitive (the acquisition costs of a power analyzer are around 10000 Euro) [1, 3]. This situation is likely to impose the necessity of an intelligent system for PQ management and analysis, as the software PQView® is [5].

With clear procedures regarding the data acquisition and storage, as well as methods of these data rebuilding and administration, PQView utilizes PQDIF as an input and output format. PQDIF is a binary file format specified in IEEE® Std 1159.3-2003 (Recommended Practice for the Transfer of Power Quality Data) that is used to exchange voltage, current, power, and energy measurements between software applications, allowing to converge the highly diverse information into a common format adjusted to the PQ issues [4].

## 2. PRESENT AND PERSPECTIVE FOR AVAILABILITY OF PQ DATA

The monitoring of PQ in the local distribution networks is presently achieved by using three systems: (1) the PQ monitoring system (i.e. equipped with fixed PQ monitors MAVOSYS for almost 100 sites) connected to a central server and managed by PQView multi-component system; (2) the system for PQ monitoring at the interface between the distribution network and its users, without a central data management center. In the points of common coupling (PCC) with the distribution grid all the photovoltaic (PV) power plants are obligatorily equipped with PQ analyzers with remote data transmission; (3) the power monitors system (i.e. MEG) connected on the LV side of 20/0.4 kV substations. In order to answer to the customers' requests and/or complaints, the monitoring of PQ is periodically achieved by using portable PQ analyzers.

For an additional assessment of the power supplying service partly of the central control and command system are used, too.

The general features of the PQ monitoring equipment are given in Table 1.

**Table 1. Characteristics of PQ monitors in power distribution grid**

| Product type | Portability | Integrated/integrable in the PQ monitoring system | User |
|---|---|---|---|
| ION 7650 | Static | Directly | Upgraded distribution substation |
| MAVOSIS10 | Static | Directly | Upgraded distribution substation |
| MEG40 | Static | Directly | MV/LV power station |
| CA 8335 | Portable | Directly | Distribution operator |
| Fluke 435 | Portable | Directly | Consultancy expert |
| Janitza | Static | By interface convertor | PCC of PV power plants |
| SCC | Static | By interface convertor | Distribution substation |

Only some of the permanent monitoring equipment provides data regarding PQ and network reliability in PQDIF format, the rest of them exporting data in particular specific formats [6] – see Fig.1.

Basically, each PQ monitor produces its own data file format. This sort of elliptical information, time discontinuous and geographically inequable is in some cases inaccurate or insufficient for assessing the network's observability [3]. These considerations perfectly justify the using of a central PQ monitoring system in compliance with the National Performance Standard for Power Distribution Service (PSPDS) and capable for further upgrade and extending [7].

Since the PQView accepts formats from most PQ monitors, it answers mostly to the need for transferring the output of different vendors' monitors and simulation programs to a common database and analysis program, by using a standard data interchange format (e.g. PQDIF) [8]. For the case of other vendors' equipment, PQView should be assisted by a data handler for these specific formats. The PQDIF conversion capabilities of the PQ monitors installed in the local PDG are given as in Table 2.

**Table 2. The situation of PQDIF conversion capabilities of PQ monitors in substations of PGO**

| Equipment (technology) | Vendor | Direct data export in PQDIF format | Direct data transfer data to PQView |
|---|---|---|---|
| CA | CHAUVIN ARNOUX | No | No |
| Three-phase power energy analyzer | ELSPEC | No | No |
| FLUKE | FLUKE | Yes | No |
| MAVOSYS | GOSSEN METRAWATT | Yes | Yes |
| JANITZA | ALFA ENERG | No | No |
| MEG | MEGA | No | No |
| ION | MERLIN JERIN | Yes | No |

**Table 2. (continuation)**

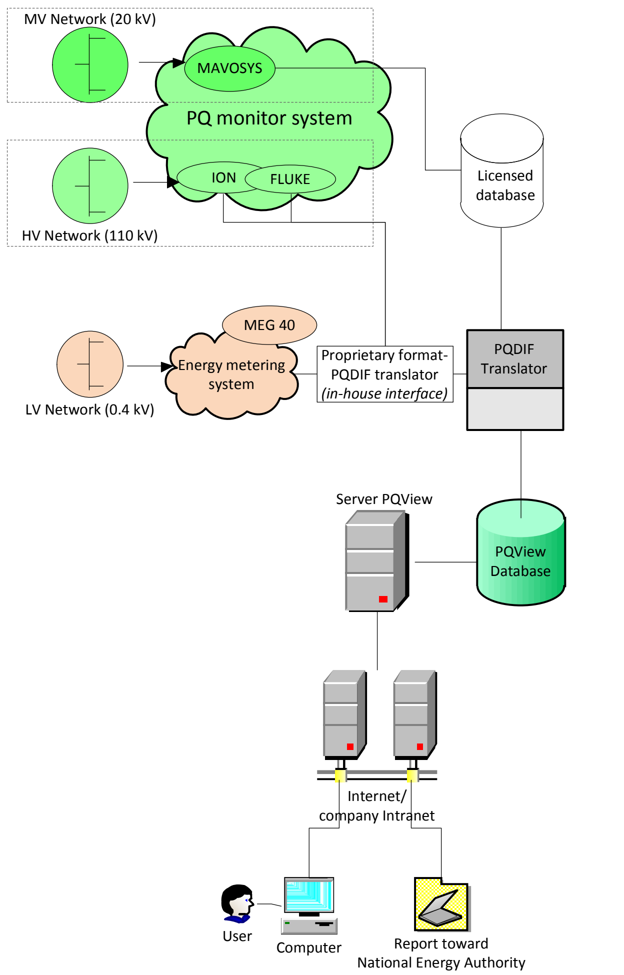


**Fig. 1. Schematic of the solution of PQ monitor interfacing with PQView system**

The present stage of interfacing the PQ monitoring system of the local PGO with the PQView's database is given in Fig. 2.

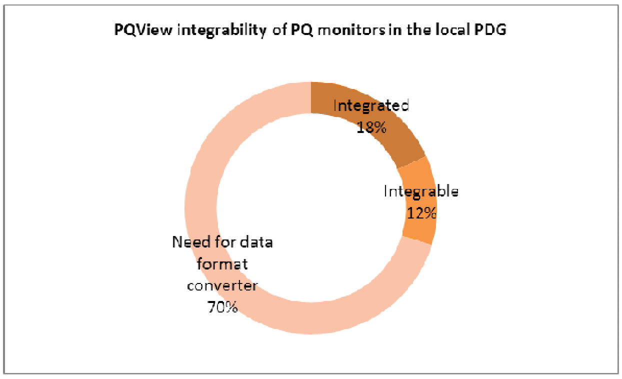


**Fig. 2. PQView integrability stage of the PQ monitors in the local power distribution grid (PDG)**

Usually the measurements performed by the PQ monitors provide the following data, as in Table 3:

**Table 3. Characteristics of PQ monitors in distribution power grid**

| PQ parameters | Station identification | Voltage level |
|---|---|---|
| Number of transitory interruptions<br>Number of short interruptions<br>Number of long interruptions<br>Number of voltage sags<br>Medium frequency (Hz)<br>RMS voltage of the three phases (V or kV)<br>RMS voltage variations (value %, weeks number)<br>Limits violations for rapid voltage variations (no/year)<br>Temporary phase-to-ground overvoltage at 50 Hz (% value / week)<br>Limits violations for long term flicker (no/week)<br>Limit violations for h-th voltage harmonic (% of fundamental / week)<br>Limits violations for THD (% value/week) | | |

The local PGO uses PQView software system in order to manage, analyze and report the PQ data. For this purpose, the PQView's components integrates data from PQ monitors, as well as digital relays, fault recorders, smart meters, and SCADA historians into an open relational database through safety secured connections.

The PGO's are obliged to submit to the Romanian Energy Regulatory Authority the detailed annual PQ assessment report for their operated networks, which includes states of compliance with the PQ limits referred to the PSPDS and in accordance with Std. EN 50160.

The report must include information about: sags & interruptions, long-term voltage variations, harmonics, unbalance, voltage fluctuations (flicker), frequency transients (e.g. statistical values – 95%, 99%, or 100% probability values over minimum a week). The original information is administrated in PQDIF data file format within the PQView database.

## 3. MULTI-COMPONENTS SOFTWARE SYSTEM FOR PQ MANAGEMENT AND ANALYSIS IN THE POWER DISTRIBUTION GRIDS - PQVIEW®

By using a centralized system for the PQ management and analysis in its networks, the PGO has some certain benefits as the following [9, 10, 11]: the evaluation of all of the PQ parameters for individual sites and their zonal global assessment; establishing references for the system's expected performances regarding all the PQ categories; integrated technical-economic evaluation of the PQ problems and their solutions; web-based access to the PQ information; useful tool for training in the PQ field.

PQView is a complex multi-component software system developed by Electrotek Concepts and Power Research Institute Inc. (EPRI) [2, 5, 9], designed for the management and analysis of PQ data files of TBytes order. Its main functions are presented in Fig. 3 and are fulfilled by its three components:

1. Power Quality Data Manager (PQDM);
2. Power Quality Data Analyzer (PQDA);
3. PQWeb.

The first two (PQDM and PQDA) suppose an integrated operation according to the Fig. 4.

The PQDM component loads/imports the measurement data stored in either Microsoft Access or Microsoft SQL Server, builds automatically the databases, manages these databases and further provides the patterned data files toward the PQDA component. By using these data, PQDA creates trends, histograms, and statistical summary tables for more than 125 steady-state characteristics listed within the PQDIF standard. It scores charts, event lists, tables, and indices to analyze voltage sags/dips, swells, and interruptions. PQDA interfaces with Microsoft Word create summary documents and allow the user to filter invalid measurements.

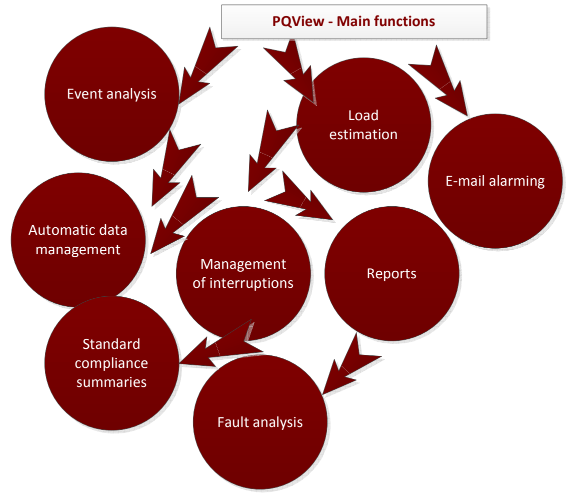


**Fig. 3. The PQView's main functions**

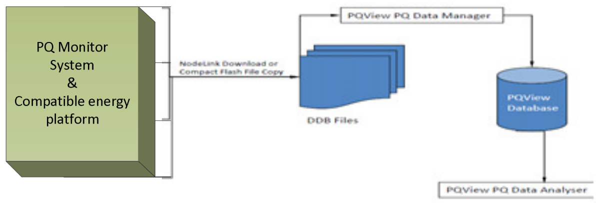


**Fig. 4. Measured data integration in the PQView's components [5]**

So that, PQView can perform extended steady-state data log analysis, event analysis, RMS voltage variation analysis and also can ensure the Internet Accessibility via PQWeb.

## 4. THE PQ ANALYSIS IN THE POWER DISTRIBUTION GRIDS

Presently, the local PGO is intensifying the efforts in assessing the power quality level in its networks with extendable distributed generation. Its PQView system ensures the continuous surveillance, updating and analysis of PQ characteristics such as system average RMS-variation frequency index (SARFI), voltage distortion, voltage imbalance, and flicker (both short-term and long-term) at the PCC of the PV power plants.

The most common voltage variation, which affects electrical equipment of the network users, is the voltage sag. Nevertheless, the flicker level and the harmonic content are easily counted with technical impact related to the PQ level at the grid connection bus of the PV power plants.

By using a similar PQView system in the laboratory of Smart Grid of INCESA (Research Hub for Applied Sciences – University of Craiova), the above characteristics were examined for a 1 MW PV power plant (PVPP) connected to the 20 kV distribution grid. A comprehensive PQ analysis is based on the measurements provided by the local PGO's monitoring system (MAVOSYS type equipment) and performed in accordance with Std. CEI 6000-4-30 specifications. The purpose of this analysis is to assess the influence of the PV power plant integration into the 20 kV grid.

Since the PQ parameters have rather a random behavior, for many of them the registered data are statistically processed. Therefore the information about the CP95% of the PQ parameters is provided at the specific site during a minimum interval of 1 week (in our case 13.05.2017 through 21.05.2017) and its compliance with the PSPDS (respectively EN 50160 Std.) is checked, as in Table 4 is outlined.

**Table 4. The supply voltage characteristics in public LV and MV according to EN 50160**

| Voltage parameter | Permissible deviation ranges |
|---|---|
| Voltage magnitude variations | ±10% for 95% of week, mean 10 minutes rms values |
| Rapid voltage changes Flicker Plt | up to 1 for 95% of week |
| Supply voltage unbalance | up to 2% for 95% of week, mean 10 minutes rms values, up to 3% in some locations |
| Harmonic voltage | VTDF ≤ 8% for 95% of week |

### 4.1. PQDA's outputs

For the considered PV power plant (PVPP), the measurement data were loaded in PQDM database and their validity was checked, the suspicious and discrepant values being filtered. The valid data were further provided toward PQDA, where the general power evolution of the site was analyzed and a statistical analysis of the PQ parameters was performed.

The outputs resulted as following:

- *Voltage, current, and power waveform samples*
- *Trends and histograms of steady-state logs*
- *Aggregated trends for long-term log*
- *Interactive scatter plots*
- *Lists of voltage events*

The PVPP behavior can be described based on the trends and histograms of steady-state logs loaded in the PQView database (voltages, currents, powers, power factors, frequency) – see samples in Fig.5.

Waveform samples are displayed as part of an "event roll" marked on the RMS voltage trend – see Fig. 6.

### 4.2. Assessment of PQ parameters compliance

Actually, the recorded measurements of the electrical values (Fig. 5-6) describe the characteristic of the PVPP operation during the surveillance period in generally, and daily in particularly.

Therefore valuable information can be stated about the dependence of the operation of PVPP on the irradiance/environmental conditions or about particular deficiencies caused by in the power plant's equipment (e.g. inverters) performance.

The PVPP produced a maximum power of 1 MW at apromatively 80 A and a reactive power variation within -50 kVAr and 140 kVAr.

- ***Voltage variations***

By creating timelines to combine the event data with the steady state logs, useful information about the nature of the events can be provided. While the voltage magnitude is maintained in the permissible deviation range (PC95% 21.285 kV), the temporally aggregated lists of voltage sags and swells indicates that 54 events occurred over the span of 7 days, as it is illustrated in Fig. 7. Moreover, a complete SARFI analysis of the event at PCC of the PV power plant can be supplied for instance by PQDA.

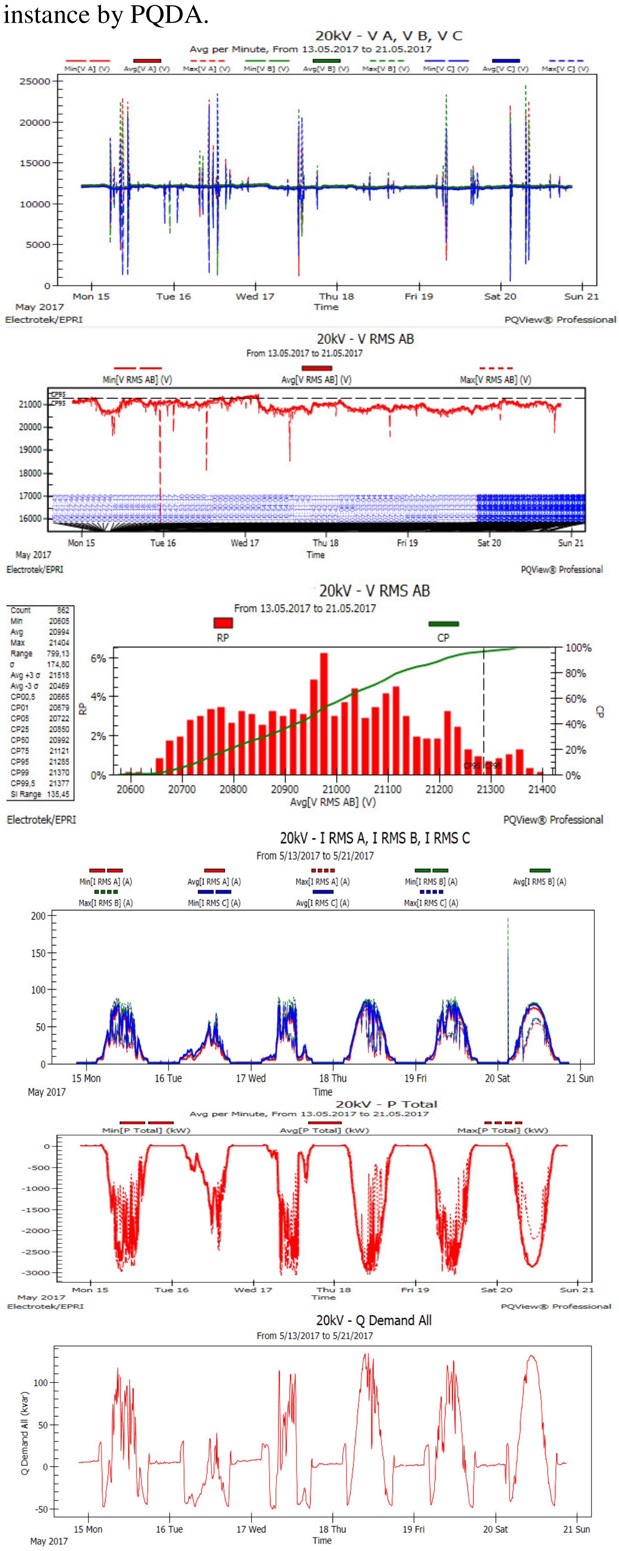


**Fig. 5. Trend of PVPP 20kV's phase/line values per minute, from 13.05.2017 to 21.05.2017**

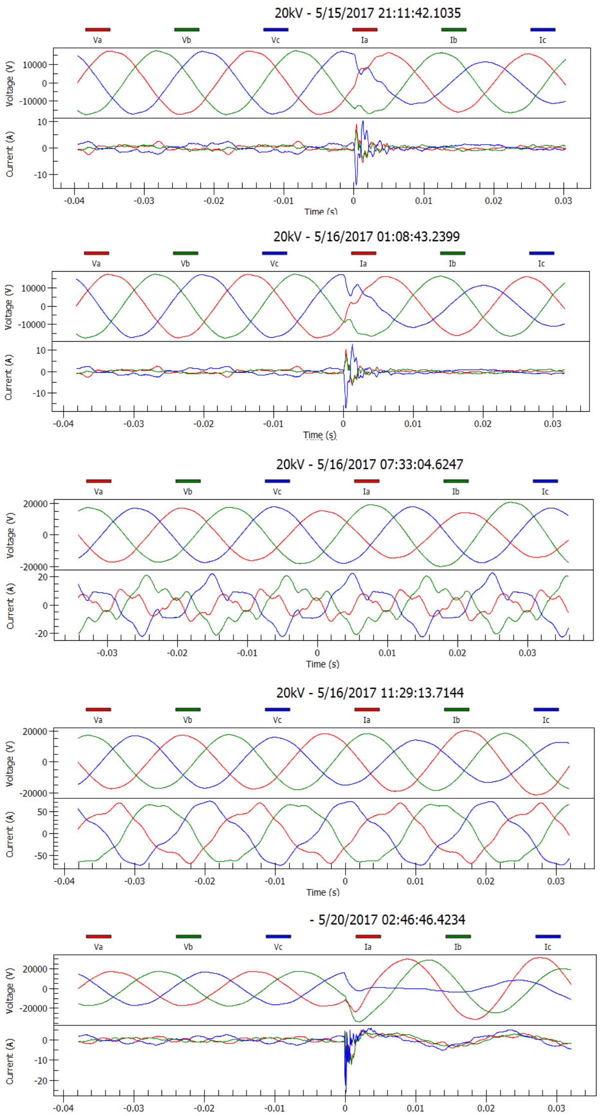


**Fig. 6. Voltage waveforms marked as event roll for relevant PVPP behavior during 1 day interval**

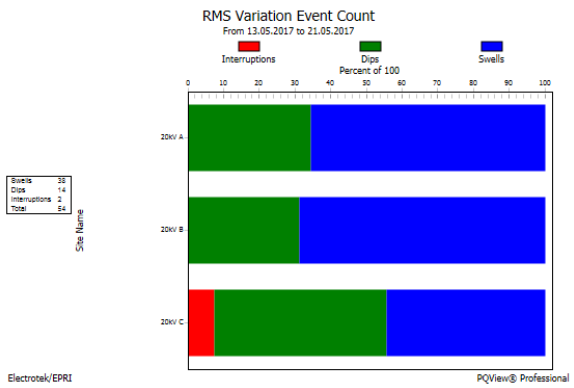


**Fig. 7. Number of events (swells, dips, interruptions) on the monitored period as extracted form PQDA**

- ***Voltage Distortion (THD)***

For the PVPP system a small range of voltage distortion was registered, with a CP 95 of VTHD under 2% (within PSPDS and EN 50160 Std. limit of 8%), and relevant harmonics of 3$^{rd}$, 5$^{th}$ and 7$^{th}$ order within the standard limits, as it can be seen in Fig. 8 – 9.

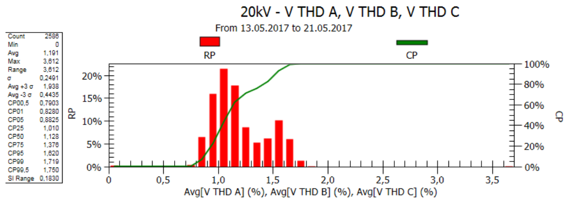


**Fig. 8. Histogram of phase voltage THD**

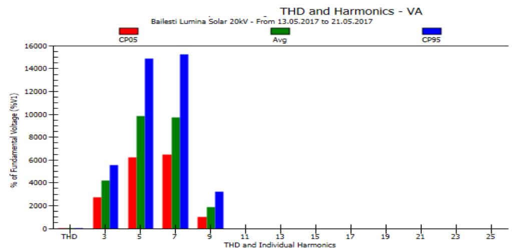


**Fig. 9. Voltage THD and individual harmonics magnitude**

***Voltage Imbalance***

Although the CP 95 of the voltage imbalance in PCC of PVPP is over unit (1.14%), this parameter is within the permissible range (under 2%), according to the information given by the histogram in Fig. 10. However, the PVPP generation has a relative high incidence of voltage imbalance.

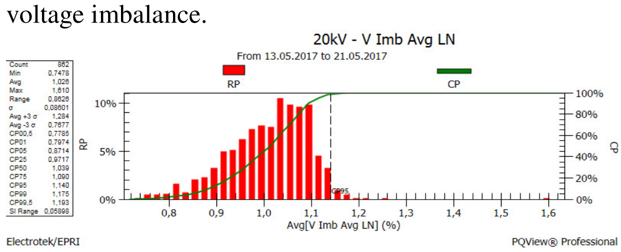


**Fig. 10. Histogram of phase voltage THD**

***Flicker***

The registered long-term (Plt) flicker outlined high daily variations (given as in Fig. 11) that correspond to a CP 95 value of 3.035 far outside of the allowable range within 1 unit, as it can be seen in Fig. 12. The over-unit CP 95 data indicate major problems related to the voltage fluctuations, with disturbing consequences on the level of customer's sides.

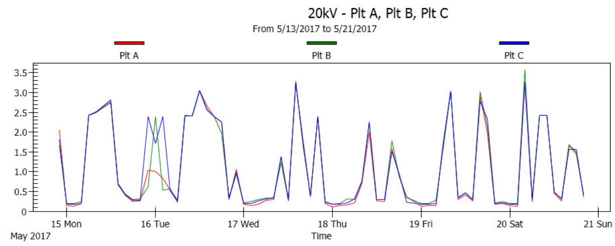


**Fig. 11. Flicker Plt variation during recorded week**

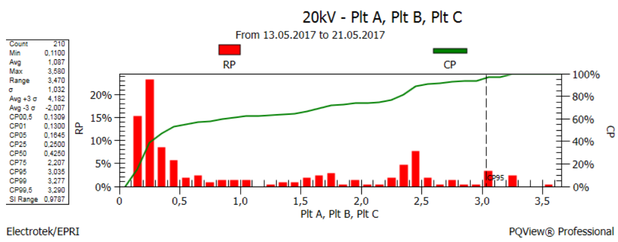


**Fig. 12. Histogram of flicker Plt for recorded week**

- ***Compliance report***

According to the EN 50160 compliance report generated by PQDA as in Table 5, the PVPP installation system appears to be fairly robust on the utility side with no highly significant events occurring within the system, excepting the flicker phenomenon joined by some additional voltage magnitude variations.

**Table 5. EN50160 compliance report for PVPP**

| Standard | Level | Compliant |
|---|---|---|
| Voltage RMS (EN 50160) | 100,00% | Yes |
| Frequency (EN 50160) | 100,00% | Yes |
| Voltage Imbalance (EN 50160) | 100,00% | Yes |
| Voltage Total Harmonic Distortion (EN 50160) | 100,00% | Yes |

## 4. CONCLUSIONS

Since nowadays the penetration of distributed generation is highly anticipated, this evolution is likely to present the power distribution grids operators with high number of technical impacts related to PQ. Consequently, impact studies should be performed based on data provided by monitoring sessions in the strategic sites of the network. In spite of PQ's issue importance there are still two major problems that ask for rapid solutions: the PQ monitoring is performed in a non-satisfactory number of sites; the monitoring systems are composed of a various vendor, family and characteristics equipment that request the interfacing and format compatibility actions/solutions.

A central PQ management and analysis system seems to successfully support the PGO in its PQ assessment activities, by integrating different family equipment data and managing huge and heterogeneous information.

The paper present the processing capabilities of the multi-component software system PQView used by the local PGO to manage and analyze the data supplied by the PQ monitoring system connected to the HV – MV grid.

The detailed power quality analysis performed as study case for a PV power plant connected to the 20 kV grids was assisted by the PQView system endowing the INCESA's Smart Grid Laboratory.

The PQ analysis was performed against the standard specification, establishing the actual performance of the studied network. This information can be further used as reference for reliability studies and operation prediction of this network. Based on the analysis conclusions, the recommendations for mitigation and PQ improvement strategies for both the power system and customer facilities can be developed.

## ACKNOWLEDGMENTS

*This work was supported by a grant of the Romanian National Authority for Scientific Research and Innovation, CNCS/CCCDI – UEFISCDI, project number PN-III-P2-2.1-BG-2016-0269, within PNCDI III.*

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