energies

MDPI

Editorial

Special Issue "Analysis for Power Quality Monitoring"

Juan-José González de-la-Rosa [1,*] and Manuel Pérez-Donsión [2]

1 Research Group PAIDI-TIC-168 in Computational Instrumentation and Industrial Electronics (ICEI), Higher Polytechnic School, University of Cádiz, Ramón Puyol Av., E-11202 Algeciras, Spain

2 Department of Electrical Engineering, ETSII, Campus de Lagoas-Marcosende, University of Vigo, E-36310 Vigo, Spain; donsion@uvigo.es

* Correspondence: juanjose.delarosa@uca.es; Tel.: +34-956028069

Received: 20 January 2020; Accepted: 21 January 2020; Published: 21 January 2020

check for updates

Abstract: We are immersed in the so-called digital energy network, continuously introducing new technological advances for a better way of life. As a consequence, numerous emerging words are relevant to this point: Internet of Things (IoT), big data, smart cities, smart grid, industry 4.0, etc. To achieve this formidable goal, systems should work more efficiently, a fact that inevitably leads to power quality (PQ) assurance. Apart from its economic losses, a bad PQ implies serious risks for machines and, consequently, for people. Many researchers are endeavouring to develop new analysis techniques, instruments, measurement methods, and new indices and norms that match and fulfil the requirements regarding the current operation of the electrical network. This book, and its associated Special Issue, offer a compilation of some of the recent advances in this field. The chapters range from computing to technological implementation, going through event detection strategies and new indices and measurement methods that contribute significantly to the advance of PQ analysis and regulation. Experiments have been developed within the frameworks of research units and projects and deal with real data from industry practice and public buildings. Human beings have an unavoidable commitment to sustainability, which implies adapting PQ monitoring techniques to our dynamic world, defining a digital and smart concept of quality for electricity.

Keywords: power quality (PQ); PQ indices and thresholds; reliability; sensors and instruments for PQ; big data; machine learning; soft computing; statistical signal processing; data scalability; data compression

1. Introduction

Power quality (PQ) consists of a group of electrical limits as defined by several norms and standards thought to allow electrical equipment to operate as designed without a significant loss of performance or life expectancy; this definition implies the constant and stable supply of electricity supply through the electrical network. To achieve this objective, it is necessary to permanently monitor the power conditions within the grid. However, there are a large number of parameters involved in this goal, and many of these still have not been completely defined. This has forced the manufacturers of electronic instruments to develop their own methodologies, which has resulted in incomparable values and rules between instruments such that, despite the fact that they have been conceived for the same purpose, the implemented measurement methods are different. This point is where IEC 6100-4-30 comes in, as it standardizes the measurement methodologies and creates the ability to make a direct comparison of the results of different analyzers. However, there is still a need for new parameters that reflect the current situation in the smart grid (SG), even when a noncomparable measurement is required or when the customer is interested in detecting some specific types of electrical disturbance. Furthermore, current measurement campaigns are demanding new Class S methods and their associated instruments. Despite the fact that their accuracy levels are less demanding, this emerging family of power analysers is conceived to develop a new approach to specific campaigns with "à la carte" measures, with the goal of performing specific energy efficiency analysis.

Indeed, the need goes even further as the increasing complexity of the current electrical network makes it necessary to introduce new methods, parameters, and measurement indices that allow for a characterization that is not only more reliable, but also more energy efficient, and that includes aspects related not only to producers, but also to consumers. Current electrical networks are immersed in a transformation process in order to adapt to new technologies in the framework of a future SG. This conception of the so-called "smart" grid is mainly based on the reliable and permanent capacity of the systems to provide energy behavior information in real time.

Thus, instrumentation solutions tackle big data issues as a consequence of permanent PQ monitoring. For this reason, several fields and disciplines are converging in the analysis for PQ monitoring (e.g., machine learning, data compression, advanced signal processing, communications and network connectivity). Of special interest, Internet of Things (IoT) is a trending topic with serious technical, social, and economic implications. Industrial systems, utility components, and sensors are being combined with Internet connectivity and powerful data analytic capabilities that promise to transform the way we work, live, and play.

Looking again at the norms, the UNE-EN 50160 standard approved by CENELEC in 1994 and entitled "characteristics of the voltage supplied by the general distribution networks" defines the main characteristics that the voltage supplied by a general low and medium voltage distribution network must have, under normal operating conditions, at the point of delivery. However, this standard is far from being updated, in accordance with the reality of the SG. Numerous initiatives are being carried out in this direction, as promoted by organizations such as CIGRE and congresses such as CIRED. The works developed within this organization have provided an overview of PQ monitoring that is supported by the results of the surveys derived from the industry practice. With all of this, CIGRE defines the six major objectives of PQ monitoring, identified (not in order of importance) as compliance verification, performance analysis/benchmarking, site characterization, troubleshooting, advanced applications and studies, and active PQ management. CIGRE also provides a set of recommendations and guidelines for efficient and cost-effective PQ monitoring in existing and future electric power systems.

As Guest Editors of this Special Issue, we were able to open the contributions to several technical areas that address PQ, being well concerned about the need for converging synergies with the goal of developing new instruments that assess the quality of the electrical supply.

Consequently, the goal of this Special Issue is to offer a multidisciplinary approach to PQ, bringing together fields and disciplines that converge in techniques and procedures for enhancing PQ. Energy policy will soon be reflected in PQ more directly, as the need to manage energy systems more efficiently is triggering the development of new standards and norms that will match the current network infrastructure.

All in all, it is of high interest to classify research literature on PQ into the following flourishing topics or branches that are directly and transversely addressed in multidisciplinary work teams:

- Statistical signal processing (SSP) and intelligent methods for PQ analysis
    - Statistical planning and characterization in PQ campaigns;
    - Higher-order statistics (HOS) for PQ characterization;
    - Intelligent methods for PQ analysis;
    - New estimators for PQ monitoring.
- Power quality and reliability characterization
    - PQ indices and thresholds;
    - Customized PQ for utilities, customers and specific geographical areas;

   - Industry research benchmark reports on PQ metrics;
   - New types of electrical perturbations.
- Management of PQ big data in the smart grid
   - Spatial and temporal compression of measurements;
   - Spatial and temporal scalability of measurements;
   - Modelling and forecasting of PQ time-series;
   - Graphical visualization of PQ: plots, diagrams, and trajectories.
- PQ monitoring systems: architectures and communications
   - New tendencies in smart instruments for PQ;
   - Uncertainty in PQ instruments;
   - Sensors networks for PQ monitoring;
   - Nonintrusive load monitoring;
   - PQ for renewable energy systems;
   - Low-cost measurement equipment.
- PQ losses and mitigation assessment
   - Energy efficiency and PQ;
   - Economic impact and losses due to poor PQ;
   - PQ maintenance strategies in networks;
   - PQ mitigation.
- New PQ monitoring norms and standards
   - PQ indices;
   - PQ norms;
   - PQ standardized measurements for phasor measurement units (PMUs);
   - PQ monitoring in the industry 4.0.

In the next section, a brief review of the papers published, which transversally address the above-classified topics, is provided. They constitute the very positive response to this Special Issue and gather a broad range of thematic areas issued by recognized researchers. The works range from emerging signal processing techniques applied to PQ monitoring to low-cost instruments for specific PQ events detection, going through the postulation of prospective indices and statistical indicators within measurement campaigns. They all have a common axis: a new or evolved conception of power quality for a more efficient use of energies.

2. A Short Review of the Contributions in this Issue

Phasor measurement units (PMUs) constitute examples of how manufactures need to converge for a better measurement interpretation. The paper by P. Castelo et al., "PMU's Behaviour with Flicker-Generating Voltage Fluctuations: An Experimental Analysis" [1], presents and discusses the results of experimental tests carried out on commercial PMUs in the presence of voltage fluctuations that give rise to the flicker. The performed characterization of commercial devices remarks on how different possible interpretations could be given to the PMU outputs considering the same signal and depending on the quantity of interest, which is a key issue of instrument development. It reports that the first step in solving the possible misinterpretations of the measurement results is to clearly define the objective of the measurement (e.g., remove all nonfundamental frequency components or tracking the dynamics of the signal being tested), which in turn depends on the requirements of the specific measurement context. Only in this sense, new and more suitable test conditions and performance evaluation criteria could be defined for PMUs targeted to distribution networks. This paper can be allocated within the topic "PQ monitoring systems: architectures and communications: new tendencies in smart instruments for PQ" and in "new PQ monitoring norms and standards: PQ standardized measurements for PMUs", as it addresses the need for homologate measurements in the modern SG.

The second work, "Power Quality in DC Distribution Networks", by J. Barros et al. [2], goes into the emerging topic of PQ in low-voltage DC networks in low-scale network design. The specific types of disturbances dealt with include voltage supply interruptions, voltage ripple, and rapid voltage changes. Different types of sources were tested using measures from different indices over different waveforms. Their conclusions suggest that each type of disturbance has its associated preferable index with which performance is optimum. The paper falls within the topic "power quality and reliability characterization: PQ indices and thresholds" as well as inside the topic "New PQ monitoring norms and standards: PQ indices and PQ monitoring in the industry 4.0."

The work by Sierra-Fernández et al. "Application of Spectral Kurtosis to Characterize Amplitude Variability in Power Systems' Harmonics" [3] shows how higher-order statistics (HOS) in the frequency domain enhance the detection of electrical disturbances, more precisely, low-level harmonics not detected with the traditional power spectrum. An estimator of the spectral kurtosis (SK) was used to assess the amplitude trends of each spectral component. The results confirmed that SK is capable of tracking constant-amplitude harmonics, performing high-resolution frequency analysis for higher-order harmonics, even with low-level amplitudes. Two signals were chosen to validate the method with adequate results: an electric current from an arc furnace and a voltage signal from the power grid of a public building. The paper falls within the topic "statistical signal processing (SSP) and intelligent methods for PQ analysis: HOS for PQ characterization" as well as inside "power quality and reliability characterization: PQ indices and thresholds".

Inside the same set of former topics, the fourth paper, "Reliability Monitoring Based on Higher-Order Statistics: A Scalable Proposal for the Smart Grid" [4] by O. Florencias et al., proposed a new index for both PQ and reliability assessment (depending on the considered analysis window's length) thought to be used in measurement campaigns that require deep statistical characterization. The index consists of a summation of three differential terms: variance, skewness, and kurtosis, each with respect to the ideal value of the statistic. Skewness and kurtosis account for the waveform features, which are really interesting elements to introduce in new standards and norms. Furthermore, 2D graphs were used as complementary tools to track the energy behavior. A long-term monitoring analysis was shown over a power signal in a public building, and the conclusions show that the power supply adopts different patterns in the time domain and in the 2D graphs, depending on the day period. Additionally, the 2D graphs compressed information in the time domain and can also be used for compression issues in the space.

The contribution by Flores-Arias et al., "A Memory-Efficient True-RMS Estimator in a Limited-Resources Hardware" [5], presents an RMS voltage estimator that eludes the inherent uncertainty of complex arithmetic operations related to the discretized RMS algorithm on an ATmega328p microcontroller. Its capability as a sag/swell detector was exhibited on substation signals. The proposal constitutes a step to implement PQ algorithms in low-cost platforms and may be implemented in simple FPGA systems. The results were compared with a TRMS voltmeter (Fluke ScopeMeter™ series 120) in order to check its accuracy. This work is an example of how signal processing functions can be integrated into simple physical platforms in order to produce cheap PQ indicators. Thus, it falls inside the topic "PQ monitoring systems: architectures and communications: low-cost measurement equipment".

M. Ptacek et al. conducted an "Analysis of Dense-Mesh Distribution Network Operation Using Long-Term Monitoring Data" [6] from a municipal distribution network (E.ON) based on long-term data from PQ monitors. The paper showed the lack of usability of data recorded by these instruments that come from transformers and exhibited new results from processing these big data. One of the main results is that it is not necessary to assess the voltage magnitudes while using the measuring over the unified phase data. This constitutes another method for efficiently evaluating large amounts of PQ measurement data within the topic "management of PQ big data in the smart grid", addressing all the subtopics within this issue.

The seventh work, "An Extended Kalman Filter Approach for Accurate Instantaneous Dynamic Phasor Estimation" [7] was conducted by De Apráiz et al. The literature showed that variations of Kalman filters have been proposed in phasor estimation to improve the dynamics of emerging measurement systems conceived to be integrated in the SG. This paper proposed a nonlinear adaptive extended Kalman filter (EKF) to improve the adaptability to the dynamic requirements of power system signals, in the sense that, thanks to the use of the Kalman filters' residuals, it manages to track online the fundamental component, harmonics, and the subsynchronous interharmonic phasors, along with the detection of transient conditions in the waveform under test. The work is to be placed inside the category of "PQ monitoring systems: architectures and communications: new tendencies in smart instruments for PQ and also in "statistical signal processing (SSP) and intelligent methods for PQ analysis: new estimators for PQ monitoring".

The following work [8] by Cifredo-Chacón et al. compares the performance of two different autonomous units that implement the same measurement algorithm: an estimator of the spectral kurtosis (SK). In the "Implementation of Processing Functions for Autonomous Power Quality Measurement Equipment: A Performance Evaluation of CPU and FPGA-Based Embedded System", the authors managed to implement an estimator of the fourth-order spectrum in an FPGA-based system and showed that FPGAs improved the processing capability of the best processor using an operating frequency 33 times lower. One of the main a priori differences, put into practice, between FPGA and processor-based implementations is that the processing time is constant for FPGAs, but not for processor-based implementations. This work showed interesting results related to different performance parameters (e.g., average time per iteration in the main algorithm for the SK). Consequently, the work is considered within the topic "PQ monitoring systems: architectures and communications: new tendencies in smart instruments for PQ and low-cost measurement equipment". Additionally, the paper addresses "statistical signal processing (SSP) and intelligent methods for PQ analysis: higher-order statistics (HOS) for PQ characterization".

The study [9] by Yue Shen et al., "Power Quality Disturbance Monitoring and Classification Based on Improved PCA and Convolution Neural Network for Wind-Grid Distribution Systems", falls within the set "statistical signal processing (SSP) and intelligent methods for PQ analysis". The authors made a deep revision on signal processing and the multivariate techniques applied to feature extraction in PQ contexts. Figures of the intelligent systems architecture are very illustrative and help the reader to understand the operation of the nucleus of the system. The work compares specific PCA-based algorithms to existing ones, assessing the overall performance over a set of different electrical disturbances.

The work [10] "Power Quality Disturbances Assessment during Unintentional Islanding Scenarios" by A. Serrano et al. presents a novel voltage sag topology that occurs during an unintentional islanding operation. This is precisely the value of the paper, because it analyzed and documented a particular and very common case in the industry practice: the effects of large induction motors in islanding cases. The authors proposed an analytical expression for this new type of sag, which was confirmed by simulations and terrain measurements. The work belongs to the topic "power quality and reliability characterization: new types of electrical perturbations".

Finally, the paper [11] by Guerrero-Rodríguez et al., entitled "An Embedded Sensor Node for the Surveillance of Power Quality", investigated a small and compact PQ detector using a low-cost microcontroller and a very simple conditioning circuit and analyzed different methods to implement various surveillance algorithms. The paper belongs to the group "PQ monitoring systems: architectures and communications: low-cost measurement equipment".

Author Contributions: The authors contributed equally to this work. All authors have read and agreed to the published version of the manuscript.

Acknowledgments: The editors Juan José González de la Rosa and Manuel Pérez Donsión would like to express their gratitude to the MDPI Publisher for the invitation to act as Guest Editors of this Special Issue. Our special thanks go to the editorial staff of *Energies* for the fruitful cooperation based on a previous yearly committed engagement. The final acknowledgement should be perhaps the first and goes to the indebted work of the worldwide recognized reviewers, whose positive critiques have enhanced the accepted papers, polishing every detail, and helped researchers to improve their careers, making the reviews profitable.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Castelo, P.; Muscas, C.; Pegoraro, P.A.; Sulis, S. PMU's Behaviour with Flicker-Generating Voltage Fluctuations: A Experimental Analysis. *Energies* **2019**, *12*, 3355. [CrossRef]
2. Barros, J.; De Apráiz, M.; Diego, R.I. Power Quality in DC Distribution Networks. *Energies* **2019**, *12*, 848. [CrossRef]
3. Sierra-Fernández, J.-M.; Rönnberg, S.; González de la Rosa, J.-J.; Bollen, M.H.J.; Palomares-Salas, J.-C. Application of Spectral Kurtosis to Characterize Amplitude Variability in Power Systems' Harmonics. *Energies* **2019**, *12*, 194. [CrossRef]
4. Florencias-Oliveros, O.; González-de-la-Rosa, J.-J.; Agüera-Pérez, A.; Palomares-Salas, J.-C. Reliability Monitoring Based on Higher-Order Statistics: A Scalable Proposal for the Smart Grid. *Energies* **2019**, *12*, 55. [CrossRef]
5. Flores-Arias, J.-M.; Ortiz-López, M.; Quiles Latorre, F.J.; Bellido-Outeiriño, F.J.; Moreno-Muñoz, A. A Memory-Efficient True-RMS Estimator in a Limited-Resources Hardware. *Energies* **2019**, *12*, 1699. [CrossRef]
6. Ptacek, M.; Vycital, V.; Toman, P.; Vaculik, J. Analysis of Dense-Mesh Distribution Network Operation Using Long-Term Monitoring Data. *Energies* **2019**, *12*, 4342. [CrossRef]
7. De Apráiz, M.; Diego, R.I.; Barros, J. An Extended Kalman Filter Approach for Accurate Instantaneous Dynamic Phasor Estimation. *Energies* **2018**, *11*, 2918. [CrossRef]
8. Cifredo-Chacón, M.-Á.; Perez-Peña, F.; Quirós-Olozábal, A.; González-de-la-Rosa, J.-J. Implementation of Processing Functions for Autonomous Power Quality Measurement Equipment: A Performance Evaluation of CPU and FPGA-Based Embedded System. *Energies* **2019**, *12*, 914. [CrossRef]
9. Shen, Y.; Abubakar, M.; Liu, H.; Hussain, F. Power Quality Disturbance Monitoring and Classification Based on Improved PCA and Convolution Neural Network for Wind-Grid Distribution Systems. *Energies* **2019**, *12*, 1280. [CrossRef]
10. Serrano-Fontova, A.; Casals Torrens, P.; Bosch, R. Power Quality Disturbances Assessment during Unintentional Islanding Scenarios. A Contribution to Voltage Sag Studies. *Energies* **2019**, *12*, 3198. [CrossRef]
11. Guerrero-Rodríguez, J.-M.; Cobos-Sánchez, C.; González-de-la-Rosa, J.-J.; Sales-Lérida, D. An Embedded Sensor Node for the Surveillance of Power Quality. *Energies* **2019**, *12*, 1561. [CrossRef]