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*Review*

# Current Status and Future Trends of Power Quality Analysis

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**Abstract:** In this article, a systematic literature review of 153 articles on power quality analysis in PV systems published in the last 20 years is presented. This provides readers with an overview on PQ trends in several fields related to instrumental techniques that are being used in the smart grid to visualize the quality of the energy, establishing a solid literature base from which to start future research. A preliminary appreciation allows us to intuit that higher-order statistics are not implemented in measurement equipment and that traditional instrumentation is still used for the performance of measurement campaigns, not yielding the expected results since the information processed does not come from an electrical network from 20 years ago. Instead, current networks contain numerous coupled load effects; thus, new disturbances are not simple; they are usually complex events, the sum of several types of disturbances. Likewise, depending on the type of installation, the objective of the PQ analysis changes, either by detecting certain events or simply focusing on seeing the state of the network.

**Keywords:** observational data analysis; power quality; quality indices; big data

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**Citation:** Remigio-Carmona, P.; González-de-la-Rosa, J.-J.; Florencias-Oliveros, O.; Sierra-Fernández, J.-M.; Fernández-Morales, J.; Espinosa-Gavira, M.-J.; Agüera-Pérez, A.; Palomares-Salas, J.-C. Current Status and Future Trends of Power Quality Analysis. *Energies* **2022**, *15*, 2328. https://doi.org/10.3390/en15072328

Academic Editor: Saeed Golestan

Received: 25 February 2022
Accepted: 21 March 2022
Published: 23 March 2022



## 1. Introduction

Power quality (PQ) can be defined as a group of characteristics that electronic systems must follow in their power distribution, supply, and delivery networks, ensuring the adequate supply to end customers (voltage and current), as well as guaranteed optimal performance and as little as possible disturbance to the system in general when used by customers. The concept of PQ requires constant review since a faithful reflection of the behavior of the network has become necessary for each PQ indicator to verify the correct operation of the grid or, on the contrary, the appearance of disturbances. As a reference, some standards have been developed; in fact, the UNE-EN 50,160 standard [1] (entitled "Voltage characteristics of electricity supplied by public electricity networks") describes and specifies the limits or values of voltage characteristics expected at any supply terminal. Among the authors who stand out for their contributions to the elaboration of the regulated bases for the power quality at the end of the 20th century, Math H. J. Bollen [2], Ewald F. Fuchs [3], and Jos Arrillaga [4] are worthy of mention.

Furthermore, with the advent of the new electrical network made up of different distributed energy resources, most of them come from renewable sources, and the PQ becomes more important than ever since the "green power" entails an intermittent energy generation and loads related to renewable energies, affected by the electrical network's stability. Therefore, the reinterpretation of the PQ concept has become necessary. Power quality should no longer consist of complex mathematical calculations which require specific equipment for the monitoring; PQ must be understood from the point of view of consumers–producers, with a simpler, more affordable interpretation.

Several techniques and procedures have been developed to make the PQ concept more understandable and transferable to instrumentation. In addition to traditional methods, researchers have been working with new strategies generated in recent years based on second-order statistics, higher-order statistics, or artificial intelligence. Even so, fully satisfactory results have not been achieved, which allow for implementing these procedures in the instrumentation field by a simple, visual way for the user.

The objective of the paper consists of an exhaustive review of the different techniques which have been recently incorporated during the last decade. For this purpose, the most noticeable ones have been selected, and future lines of research have been defined; thus, the implementation of these processes could be possible, not only in the instrumentation field, but also as a regulated methodology which enables the deployment of appropriate monitoring campaigns.

The paper is organized as follows: Section 2 explains the information search methodology based on the contextualization of the factors or parameters considered of interest. Section 3 provides an overview, and selected papers in the PQ-monitoring field are described. Then, Section 4 includes graphical and statistical results of the analyzed papers. Lastly, conclusions are drawn in Section 5.

## 2. Methodology

This review provides a comprehensive description and structured presentation of the content of recent and emerging international literature on instrumental techniques for power quality monitoring. Therefore, a systematic and replicable analysis of a high number of articles was conducted regarding methods for detection and classification of PQ disturbances, including complex or hybrids events that result from the sum of several types of simple events. The concise literature classification serves as a decision base for fellow researchers to appropriate data models for their projects. Direct and easy access to articles corresponding to a particular set of criteria is provided though structured tables for selected papers in the next section and graphic schemes for an easier understanding of the collected papers. Challenges and future research directions are suggested, and the compiled materials provide a basis for future hypothesis-based quantitative testing.

To provide a time perspective, the search focused on articles published in the last 20 years, but special attention was paid to those published between 2018 and 2022. This method aims for the analysis of the methodology employed in current and future research. The literature base for this review is the result of several queries to IEEE (Institute of Electrical and Electronics Engineers) *Xplore*, among other databases, such as ScienceDirect, World of Science, or Google Scholar, from April 2021 to February 2022. Some of the keywords used for the literature research combined with "power quality" were "monitoring", "indices", "photovoltaic", and some specific terms relative to different methods for PQ disturbance detection and classification, such as "artificial intelligence", "higher-order statistics", or "wavelet transform". Several papers related to reliability of supply were rejected with the objective of focusing the research on continuous monitoring of power quality. Articles are classified according to the properties listed in Table 1. In Table 1, each item represents a property characterizing the techniques applied in the respective articles, and a short description and possible values are given.

**Table 1.** Assessment criteria: An overview of analysis criteria define the collected data. Each item represents a property characterizing the techniques applied in the respective articles, and a short description and possible values are given.

| Analysis Criteria | Description | Possible Values |
|---|---|---|
| Method | Selected method(s) for detection and classification of PQ disturbances | Discrete Fourier Transform (DFT)/Fast Fourier Transform (FFT), Wavelet Transform (WT), S-Transform (ST), Short Time Fourier Transform (STFT), Kalman Filter (KF), Hilbert-Huang Transform (HHT), Singular Spectrum Analysis (SSA), Higher-Order Statistics (HOS), Artificial Intelligence (AI), Total Harmonic Distortion (THD), Root Mean Square (RMS) |
| Complexity of events | Differentiation between events with only one type of disturbance or events with more than one type | Complex events, single events |
| Network environment | Type of network environment to which the study is focused | Generation, industrial environment, urban/domestic environment |
| Renewable energy source | In case of focus on renewable energies, source of energy | Photovoltaic system (PV), wind system |
| PQ disturbances | Type(s) of disturbances detected | Sag, swell, flicker, harmonic, interruption, transient, notch, sag + harmonic, sag + transient, sag + flicker, sag + notch, sag + spike, sag + interruption, swell + harmonic, swell + transient, swell + flicker, swell + notch, swell + spike, swell + interruption, flicker + harmonic, spike + interruption, spike + harmonic, spike + transient, notch + interruption, notch + harmonic, notch + transient, harmonic + interruption, harmonic + transient, more than 2 events |
| Analysis domain | Selected domain for the analysis of PQ disturbances | Time domain, frequency domain |
| HOS cumulant | Cumulants studied for HOS papers | Skewness, kurtosis, 5th order, 6th order |
| Signal source | Type of signal used for the detection of PQ disturbances | Real signal, synthetic signal |
| Instrumentation | Employed instrumentation for real signals | Commercial instrumentation, instrumentation designed by researchers |
| Theorical paper | The paper is a review or a theorical paper. | Yes, no |

## 3. Overview of the Analyzed Papers

Among all the analyzed papers, a few have been selected for further insight and collected to this end in Table 2. The criteria for choosing these has been those with the most relevant contributions to the field of PQ disturbance monitoring and most complete information about the parameters determined in Table 1.

**Table 2.** Selected papers described by the possible values of the analysis criteria defined to characterize the documents in Table 1.

| Year of the Paper | Method(s) | Complexity of Events | Network Environment | Renewable Energy Source | PQ Disturbances | Analysis Domain | HOS Cumulant | Signal Source | Instrumentation | Theorical Paper | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2020 | DFT/FFT, WT, ST, STFT, HHT, KF, HOS, IA | Complex | Urban | PV, wind | Sag, swell, flicker, harmonic, sag + harmonic, swell + harmonic, transient, interruption | Both | Kurtosis | Synthetic, real | Commercial | Yes | [5] |
| 2020 | HOS, IA | Single | Generation | PV | Sag, swell, transient. interruption, notch | Time | Kurtosis, 6th order | Synthetic, real | Commercial | No | [6] |
| 2021 | IA | Single | Urban | PV | Sag, harmonic, interruption | Time | – | Synthetic, real | Commercial | No | [7] |
| 2020 | ST, IA | Complex | Urban | PV | Sag, swell, harmonic, sag + harmonic, swell + harmonic, transient, interruption | Both | – | Synthetic, real | Commercial | No | [8] |
| 2021 | HOS | Complex | Urban | PV, wind | Sag, swell, flicker, harmonic, sag + harmonic, swell + harmonic, transient, sag + transient, harmonic + transient, more than 2 events | Time | Kurtosis | Synthetic, real | Commercial | No | [9] |
| 2020 | HHT, IA | Complex | Urban | – | Sag, swell, harmonic, sag + harmonic, swell + harmonic, transient, sag + transient, interruption, notch, spike + transient, spike, notch + sag, notch + swell, sag + spike, swell + spike, swell + transient, notch + harmonic, spike + harmonic, harmonic + transient, notch + transient, spike + interruption, notch + interruption, harmonic + interruption, sag + interruption, swell + interruption, more than 2 events | Both | – | Synthetic | – | No | [10] |
| 2018 | WT, ST, STFT, THD, HHT | Complex | Urban | – | Sag, swell, flicker, harmonic, sag + harmonic, swell + harmonic, transient, sag + transient, interruption, sag + flicker, swell + flicker, notch, flicker + harmonic, swell + transient, harmonic + transient | Both | – | Synthetic | – | No | [11] |
| 2016 | WT, THD, RMS | Complex | Urban | – | Sag, swell, harmonic, sag + harmonic, swell + harmonic, transient, sag + transient, swell + transient, notch, sag + notch, swell + notch, notch + harmonic, harmonic + transient, more than 2 events | Both | – | Synthetic | – | No | [12] |

## 4. Results

A total number of 153 articles dated between 1998 and 2022 was reviewed, focusing especially on the last lustrum, as Figure 1 shows.

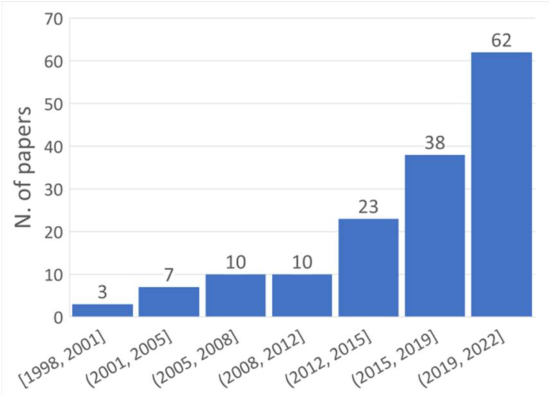


**Figure 1.** Distribution in time of the analyzed papers per year.

In Section 2, the study criteria of each paper were presented and summarized in Table 1. We consider that the use of more visual classifications can help to understand and process the obtained data. For this reason, a series of graphs which facilitate the understanding of the results have been drawn, including an innovative chart known as parallel set, designed by Kosara et al. [13,14]. In parallel set charts, each line set corresponds to a data set, whose categories are represented in each line divide in that line set. The width of each line and the associated flow path that stems from it is determined by the proportional fraction of the category total.

From a first observation, it is worth indicating that the most used methods during the total period studied are artificial intelligence (AI) (44 papers), wavelet transform (WT) (38), and higher-order statistics (HOS) (33). However, the development of each of these methods during the last 20 years is variable in a certain sense. That is, both methods may have been more or less popular during certain time ranges within those 20 years.

To have a reference of the time evolution regarding the AI, WT, and HOS methods, the chart shown in Figure 2 has been created. As can be seen, there is a greater tendency to use the wavelet transform in the papers published between 1998 and 2006 compared to research with AI or HOS. Nevertheless, as of 2007, artificial intelligence techniques begin to gain importance, while studies with higher-order statistics begin to develop. Since 2015 higher-order statistics have been more commonly used in research of PQ disturbances.

With the aim of obtaining additional analysis of the evolution in the last years of the research with these three methods, boxplots have been drawn, corresponding to the last decade (a) and the last five years (b), as shown in Figure 3. For the last ten years, a slight tendency for the wavelet transform research to decrease is observed (18 WT publications versus 25 about HOS and 27 about AI). This trend has clearly increased in the last five years since a greater gap can be appreciated with respect to the annual papers analyzed for AI and HOS (9 about WT versus 13 and 20 about HOS and IA, respectively). This slackening could be occasioned by the inability of WT to appropriately handle both the nonlinear and volatile characteristics of increasingly complex data [15].

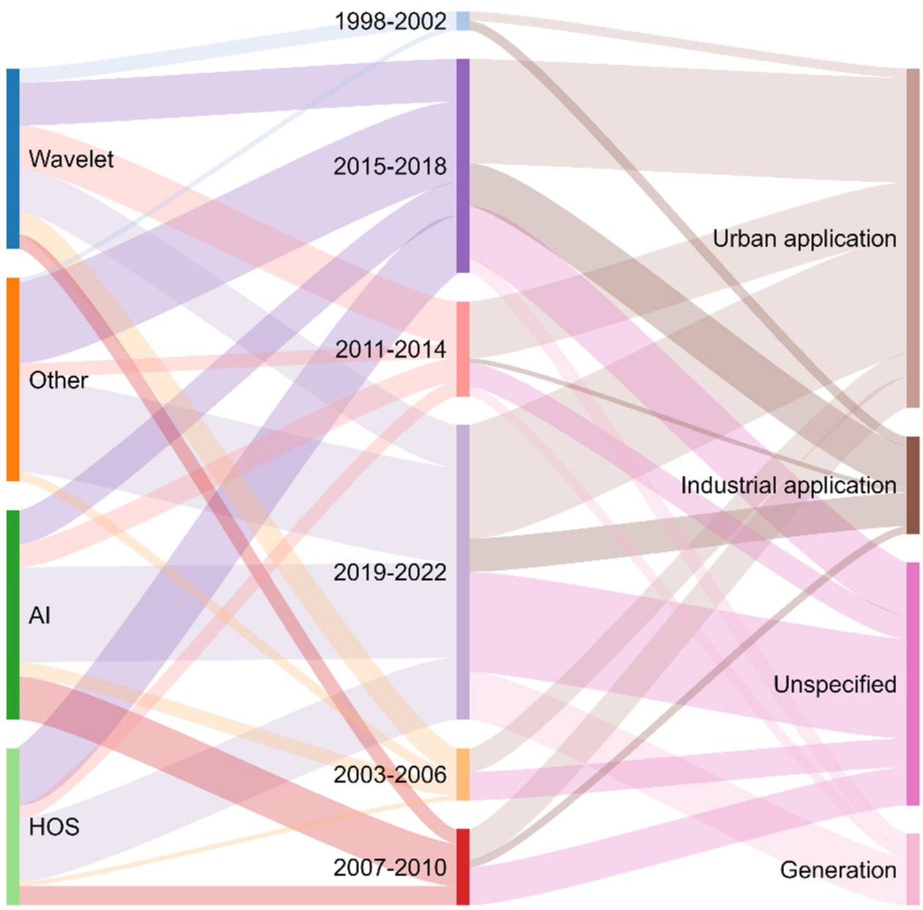


**Figure 2.** Parallel set that relates the method used with the year of publication of the paper and the environment in which it is focused.

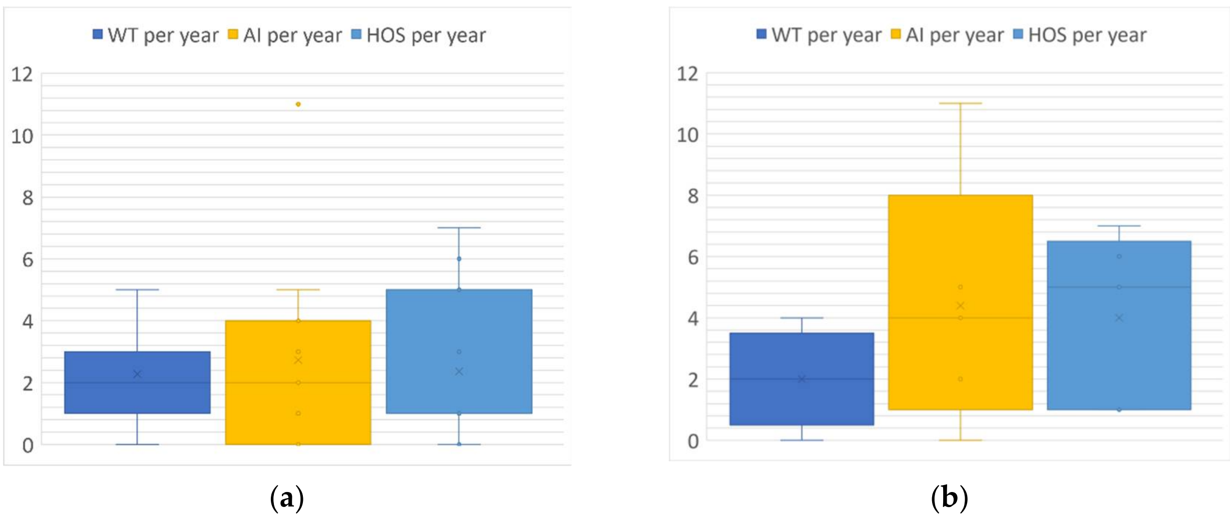


**Figure 3.** Boxplot of papers published per year for wavelet transform, artificial intelligence, and higher-order statistics for: (**a**) last 10 years; (**b**) last 5 years.

On the other hand, both AI and HOS remain at similar levels of publications, although AI stands out particularly due in part that for 2020, 11 AI-oriented papers focused on PQ have been compiled; however, many of them combine several techniques. Papers [5,16] both apply most of the techniques discussed in this review, and [17] exposes a selection of additional techniques, such as KF, HHT, RMS, and HOS. Other authors prefer the combined use of AI with one another technique; this is what happens in the case of [10] with HHT, [18] with RMS, [19] with THD, [6] with HOS, or [8] with ST. Papers [7,20,21] omit the use of other complementary techniques.

Indeed, Figure 2 depicts a timeline relationship among analysis procedures and application fields. Four categories have been established for papers dedicated to the study of power generation, industrial environment, urban or domestic environment, and unspecified for those papers which do not use a specific environment, mostly because they are reviews or theoretical papers.

It is also appreciable that studies about power generation have increased considerably in the last four years. One cause may be the emergence of a new necessity to study the quality of supply that has recently been altered with the incorporation of renewable energy sources. The addition to the current electrical network of photovoltaic and wind systems entails an intermittent energy generation and the appearance of new loads that affect the electrical network's stability [5,22]. In fact, some authors research all the necessary components for renewable sources to specify the origin of the disturbances [9,23–27], although a few researchers go further, providing more unstable but fundamental data, such as the weather [28,29]. Table 3 compares the number of analyzed papers with PV systems, wind systems, or both, which provides a little overview on the application of PQ monitoring in renewable energies.

**Table 3.** Renewable energies related to PQ monitoring papers.

| Renewable Energy | Number of Papers | References |
| --- | --- | --- |
| PV | 20 | [6–8,19,28,30–44] |
| Wind | 3 | [45–47] |
| PV + wind | 13 | [5,9,22–27,29,48–51] |

Another interesting observation that can be extracted from the analyzed papers is the source of the signals used to carry out each study. Even though in some cases both real and synthetic/simulated signals are used to corroborate the programming or calculations made [5–9], in most documents just one of the signal types is chosen. Other clear examples of the use of both types of signals are [52–56], applied to PQ analysis with HOS, [57–59] for WT analysis, and [60,61] for AI. Moreover, in [48], a three-layer Bayesian network is used for the detection and classification of complex events; in [62], an electromagnetic transient model is presented, and, in [63], HHT is applied.

As pointed out previously, the current electrical network suffers the influence of more and more different non-linear loads and, therefore, the exposure to a wider branch of PQ disturbances. Consequently, it is common to find more than one type of disturbance at the same time, that is, complex events, which means that hybrid events must be studied more and more. Then, a dilemma arises for researchers: is it better to study real signals at the risk that these signals do not present hybrid events at that moment, or is it better to use synthetic signals that guarantee the use of complex events but without the instability of an actual network?

To draw the answer to this question in each of the papers contemplated, the chart corresponding to Figure 4 has been made. The chart shows the proportional distinction between real and synthetic signals and their relationship with the development of single and complex events. Likewise, the disturbances are again related to the most used methodologies, and the localized PQ disturbances have been apportioned by typology. A total of 151 papers have shown some specific disturbance in the study of the signal.

Although Figure 4 gives a more global point of view of the PQ disturbances found, those that have appeared more rarely in the research have been included in the category "other disturbances" in Figure 5. This decision allows for a clearer analysis of data.

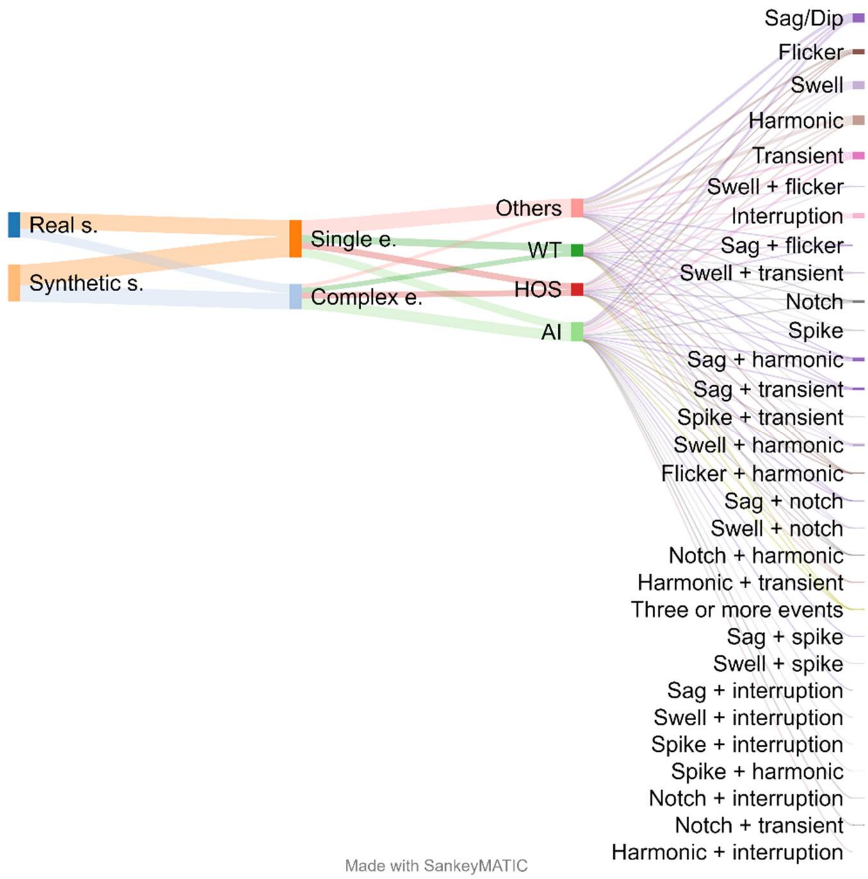


**Figure 4.** Parallel set that relates the signal source with the complexity of events, the method used, and the PQ disturbances.

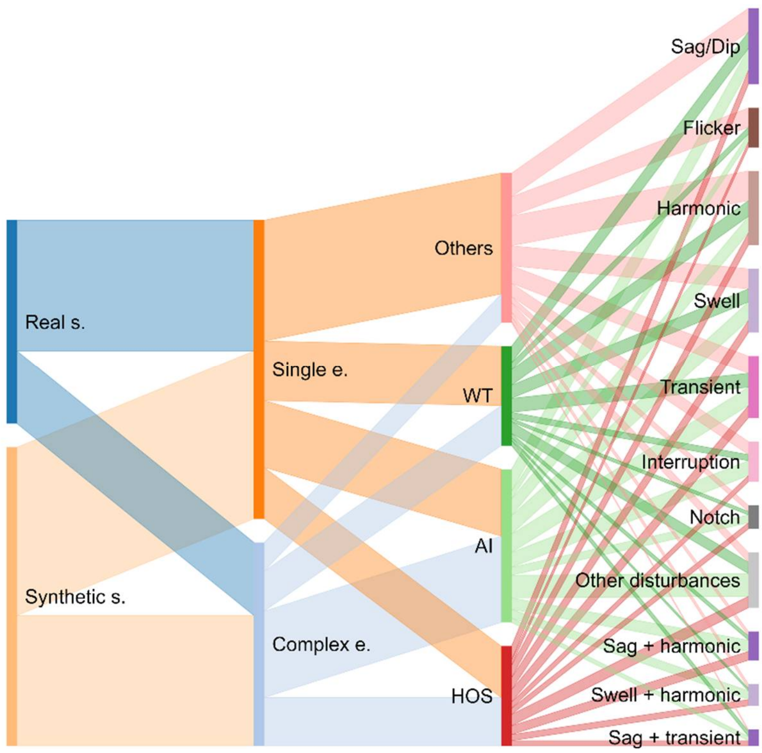


**Figure 5.** Parallel set that relates the signal source with the complexity of events, the method used, and the PQ disturbances, grouping the less common events.

In light of the analyzed papers, even though the tendency to work with single signals continues, synthetic signals with hybrids events are increasingly being used. In other words, the necessity to research more complex events has incrementally grown to reach a better understanding of the operation of the current network and, therefore, the signals obtained synthetically are being adapted to this phenomenon.

In addition, although the most common network faults are still mostly single events, there is a clear trend towards the combination of sag (usually considered the most common disturbance [32,64,65]) with harmonics or transients. Furthermore, by carefully analyzing the data, the number of papers in which harmonics are located as signal disturbances (73) is slightly higher than the number of papers that include sags (71), displacing the last one to second place in most common disturbances.

An additional observation for Figure 5 is that the AI and HOS methods are more used for the detection and classification of complex events. This could mean that both methods facilitate the study of hybrid events compared to more traditional methods, which would justify the great development they have received in recent years.

Focusing on the use of statistics for the monitoring and detection of PQ disturbances, two large groups can be considered. The first group is for the so-called second-order statistics (SOS), which includes most traditional methods such as fast Fourier transform (FFT), wavelet transform, short-time Fourier transform (STFT), or root mean square (RMS). The second group includes the higher-order statistics, that is, cumulants of the 3rd, 4th, 5th, and 6th orders. Cumulants of the 3rd and 4th orders are also known as skewness and kurtosis, respectively. This differentiation is illustrated in Figure 6.

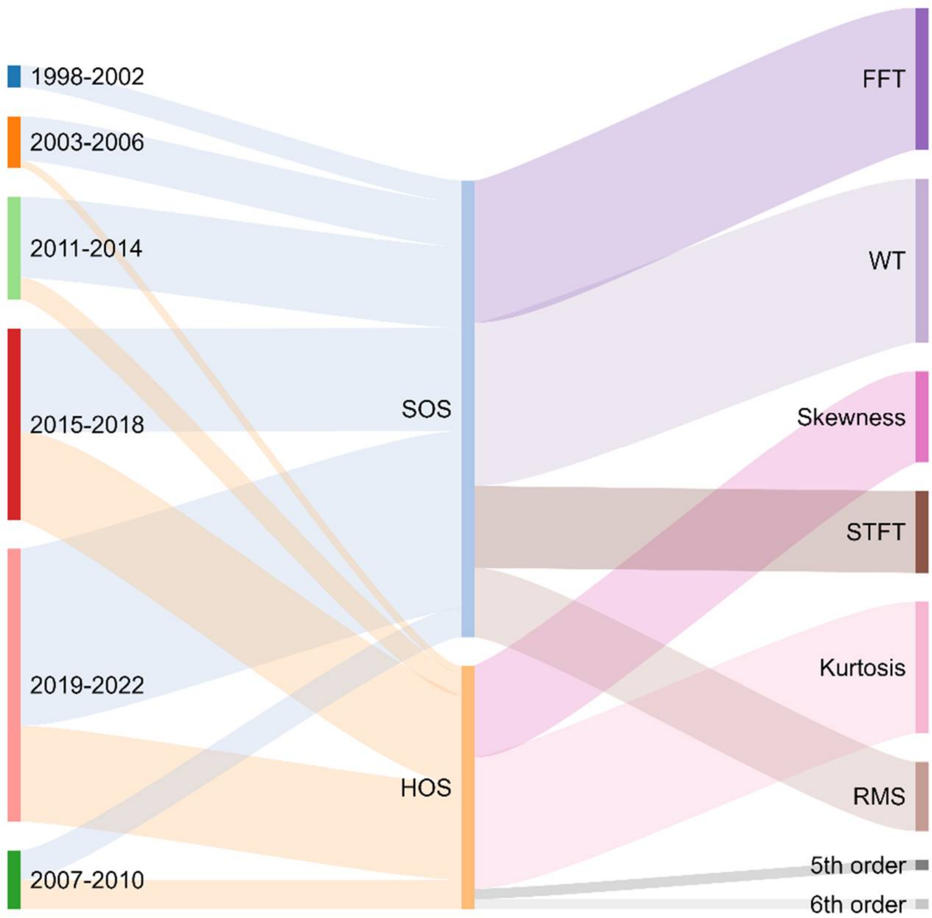


**Figure 6.** Parallel set that relates the year of publication of the paper with the type of statistic employed and apportioned.

Again, the evolution of the HOS over time is portrayed, but, in addition, the type of statistics that is most often used can be seen. While for SOS the wavelet transform stands out as expected, for HOS more cases of kurtosis, or 4th order cumulants, are found (27 papers), followed by 3rd order cumulants (19 papers). Although the use of 5th and 6th order statistics has not yet become very popular, there is a subtle trend towards research with them in recent years: in [6], even order cumulants (2nd, 4th, and 6th) are obtained; in [54], the 3rd, 4th, and 5th order cumulants are used, and, in [47], cumulants of the 3rd, 4th, 5th, and 6th orders are utilized for the detection of complex PQ disturbances.

To serve as a summary of the data analysis carried out, a double pie chart in Figure 7 has been drawn. As can be seen, the analyzed papers can be theoretical, as in the case of reviews or deal with signals obtained in one way or another (real or synthetic). To work with these signals, it is necessary to establish the domain used as a criterion, which can be time-domain, frequency-domain, or both. Then, the total number of papers (153) is divided into three groups: theorical paper, time-domain, and frequency-domain in a first pie. These groups are subdivided in a second pie: theoretical papers could be reviews or non-review papers, and time-domain and frequency-domain could be real or synthetic signals.

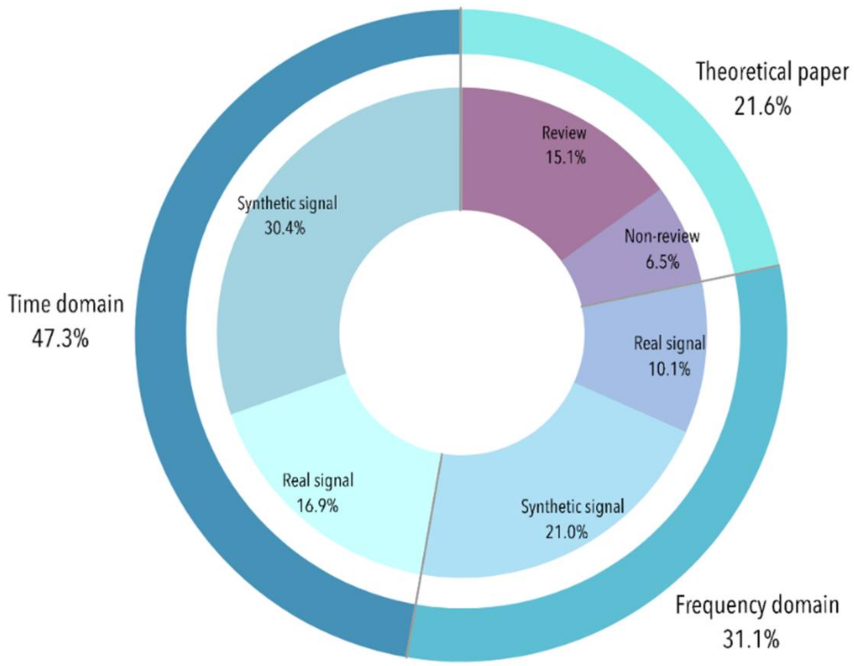


**Figure 7.** Double pie chart of types of papers depending on whether they are theoretical, in-time domain, or in-frequency domain.

In fact, almost all the papers which use frequency analysis use both frequency and time domains (56 papers). This is because many of the detection methods for PQ disturbances require collaborative computing. Those articles that only employ frequency domain tend to use simpler techniques, such as THD [19,26,66,67] or DFT [68–70].

One last point would be the instrumentation used to collect data from the real signals. Although many researchers opt for the use of commercial instrumentation (44 papers), the high cost that this device entails, or the difficulty in programming with complex algorithms with them have forced some studies to use instrumentation designed by the researchers themselves [28,71–79]. Indeed, [71,73–76,79] both focus on explaining in detail how the design for power quality data collection is carried out.

As a final remark, the time range in which each technique has been researched based on the analyzed papers is shown in Figure 8. As can be seen, while some techniques such as DFT or WT have been studied since the end of the last century, others such as HOS or HHT have been developed more recently well into the 2000s.

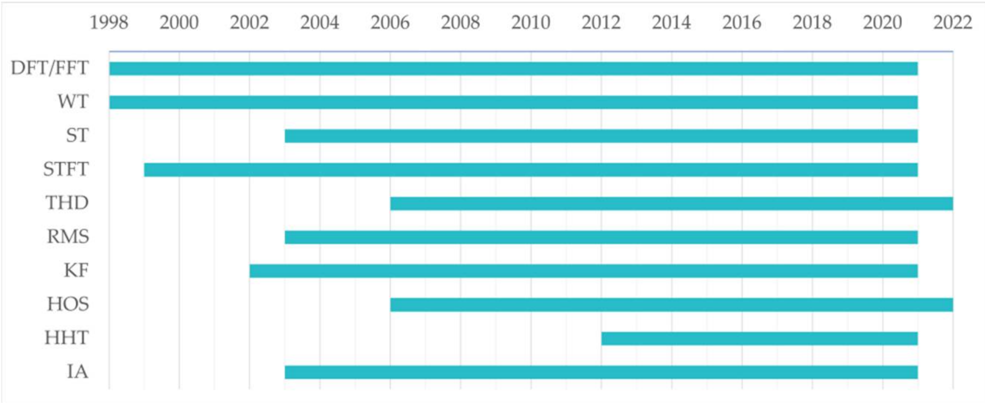


**Figure 8.** Time range in which the different power quality techniques have been developed.

The present analysis of papers shows the increasing trend towards monitoring research and instrumentation for PQ. This growth is currently triggered by energy and quality policies, focused on the European continent within the EU Horizon 2020 program and the 2030 climate and energy framework [80,81], with the support of private investment [82]. This kind of investment is a key factor for the development of renewable energies and the consequent study of power quality. On the one hand, renewable energy is becoming more attractive to companies as carbon dioxide emission rates increase and, therefore, energy from fossil fuels is less profitable [83], as well as the social benefits in terms of the environment that it entails [84]. On the other hand, massive events worldwide that involve large monetary movements increasingly require a fine network supply, which guarantees its excellent quality. Clear examples can be major sports competitions, such as the FIFA World Cup in Qatar or even Expo 2020 in Dubai [85].

In closing, Table 4 collects information related to effects, mitigation measures, and optimization through objective function of different PQ disturbances. The effects and mitigation data are presented from [27,32,86–88] since objective function references are included in the table, considering they require further specification.

**Table 4.** Effects, mitigation measures, and objective function for optimization of simple PQ events.

| Disturbance Type | Effects | Mitigation Measures | Objective Function |
|---|---|---|---|
| Sag | ·AC contactors drop-out<br>·Computers and PLCs resetting<br>·Digital clocks resetting<br>·Incorrect depot in manufacturing<br>·Product manufacturing tolerance<br>·Tripping of loads<br>·Tripping of generators (thermal plants)<br>·Variable Speed Drives (VSDs) interruption | Constant voltage transformers, motor generators, high-speed flywheel, static transfer, standby UPS, on-line UPS, UPS and engine generator, UPQC, DVR | Minimization of the total load disturbed [89]<br>$f(number, location, size) = \omega_e K_e \sum_{k=1}^{N_{SC}} Loss_K + \omega_s K_s \sum_{i=1}^{N_F} L_{DIST_i} + \omega_c K_c \sum_{i=1}^{N_{DG}} P_{DG_i} + K_{th} \sum_{k=1}^{N_{SC}} \delta_{1K} \lvert S_K - S_{K_{max}} \rvert + K_v \sum_{k=1}^{N_b} \delta_{2K} \lvert V_K - V_{K_{min/max}} \rvert$ (1) |
| Swell | ·Overstressing equipment and associated elements: may reduce lifetime or destroy<br>·Tripping of grid-tie inverters<br>·Load tripping (e.g., VSDs) | Constant voltage transformers, motor generators, high-speed flywheel, static transfer, standby UPS, on-line UPS, UPS and engine generator, UPQC, DVR | Reduction of error criteria in performance index [90] |
| Interruption | ·Loss of production<br>·Erasing computer data | STS | Minimization of power losses and damage cost [91] |
| Impulsive and oscillatory transient | ·Increased component and insulation stress due to elevated crest voltage. This will cause degradation of the insulation and components in equipment. Repetition of these events shorten the equipment lifetime<br>·Malfunction due to high *dv/dt*. False switching of solid-state devices causing malfunction or destruction of equipment.<br>·Multiple zero-crossings causing timing issues. Affects time related devices (clocks, magnetic tapes, and disks). | Circuit breakers with preinsertion resistors, circuit breakers with preinsertion inductors, zero-voltage closing control, AC input line or DC-link reactors, IGBT and soft-charge resistor approach | Maximization of transient stability [92]<br>$f = \frac{\left( \frac{\sum_{n=1}^{N_b} \sum_{g=1}^{N_g} FP_n J_g CCKE_{gn}}{\sum_{n=1}^{N_b} \sum_{g=1}^{N_g} FP_n J_g} \right)}{\frac{\sum_{g=1}^{N_g} J_g CKE_g}{\sum_{g=1}^{N_g} J_g}}$ (2) |

**Table 4.** *Cont.*

| Disturbance Type | Effects | Mitigation Measures | Objective Function |
| --- | --- | --- | --- |
| Flicker | ·Results in AM voltage envelope. Human eye-brain senses to different modulation frequencies. Evaluated perceptibility found fluctuations in the range 1 to 35 Hz. Most at 8.8 Hz.<br>·Voltage being outside accepted tolerance<br>·Interference in communication equipment<br>·Mal-operation of control systems depending on phase of voltage waveform<br>·Tripping in electronic equipment | UPQC, SVC | Minimization of estimation error [93] |
| Harmonic | ·Acoustic noise and vibrations<br>·Communications interference<br>·Crawling and cogging of motors<br>·Heating of rotating machines, transformers and cables, resulting in loss of lifetime or destruction<br>·Destruction of noninductor-fitted capacitors<br>·Destruction of smart meters (components) due to increased RMS currents and voltages (e.g., capacitor banks) | Filters, low-voltage line reactors, constant voltage transformers, motor generators, high-speed flywheel, standby UPS, on-line UPS, UPS and engine generator, unified power quality conditioner UPQC, D-STATCOM, spinning reserve, adjustable speed drive | Minimization of THD [94]<br>$f(I_m) = \sum_{k=1}^{K} (THD_k)^2$<br>(3) |
| Notch | ·Equipment malfunctioning due to the voltage-time decrease in commutations<br>·Destruction of semiconductors. Charging current of the capacitance in devices' junctions triggers the device ON at the wrong instant | Band-reject filters | Maximization of SNR [95]<br>$f = \frac{1}{\left((1+\sigma^2)\frac{(1+k_1^2-2\alpha k_1^2)}{1-\alpha^2 k_1^2}+JSR\frac{(1-k_1)^2}{(1-\alpha k_1)^2}-1\right)}$<br>(4) |

## 5. Conclusions

A comprehensive and up-to-date systematic literature review about power quality analysis was presented. A total of 153 articles published between 1998 and 2020 were reviewed.

The analysis carried out confirms that the conception of the evaluation and monitoring of the quality of the electrical supply is a multi-choral fact, which involves signal processing techniques and measurement strategies. This is due to the fact that the connection of distributed energy resources and non-linear loads in the modern electrical network has given rise to the appearance of new and more complex electrical disturbances that make not only the study of the disturbances necessary, but also the characterization of the state of the network, especially in wind and photovoltaic systems.

We, therefore, conclude a fact that has been happening over the years that the complexity of the electrical network leads to new electrical disturbances that are mostly complex or hybrid and that, despite not being too intense, will the quality of energy, which is increasingly demanding in terms of sensitivity.

The increasing need for performing complex event analysis on PQ disturbances has driven the development of methods, such as artificial intelligence and higher-order statistics which improve the study of hybrid events, enhancing non-Gaussian features of the power-line signal. However, and especially in the case of HOS, it is still a developing field, currently working on the development of new cumulants of orders higher than skewness or kurtosis.

Despite the need to incorporate continuous monitoring of PQ, which has especially been seen in the industrial field, this is still an objective to be achieved. The principal cause could be there are still some implementation challenges that sometimes lead to companies refusing to invest resources in network analysis. First of all, PQ instrumentation deployment needs to gain position in the frame of companies' permissions. Not only that, but an increase in the number of measurement points within the company, as well as the number of customized PQ and energy analysis solutions beyond traditional meters, must be considered. Also, the implementations of compression techniques in the time domain, spatial compression, and artificial intelligence should be considered in the prediction of PQ. Finally, another challenge to overcome is the enhancement of business benchmarking in a global context.

**Author Contributions:** P.R.-C. and J.-J.G.-d.-l.-R. designed the whole structure of the paper and wrote the document. O.F.-O. collaborated in the first orientation of the research. J.-M.S.-F. put the focus on the event types. M.-J.E.-G. and J.F.-M. contributed to the criteria used in signal classifications. A.A.-P. and J.-C.P.-S. helped with the review techniques classification. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research is funded by the Spanish Ministry of Science and Education through the project PID2019-108953RB-C21 and has been co-financed by the European Union under the 2014–2020 ERDF Operational Program.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Acknowledgments:** The authors express their gratitude to the Spanish Ministry of Science and Education for funding the research project PID2019-108953RB-C21, entitled "Strategies for Aggregated Generation of Photo-Voltaic Plants-Energy and Meteorological Data" (SAGPV-EMOD).

**Conflicts of Interest:** The authors declare no conflict of interest.

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