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Empirical Investigations: Power Quality Disturbance Classification

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***Abstract* –** In electrical power systems, one of the most essential parameters is a system signal with stable fundamental amplitude and frequency. Some disturbances have a negative impact on this stability, yet. These disturbances, known as power quality disturbances (PQDs), encompass phenomena such as sag, interruption, swell, harmonics, flicker, interharmonics, spike, notch, and transients. PQDs can arise individually or in some combinations. They pose unpredictable and variable effects on system components giving rise to destructive outcomes. Acquisition of real-world datasets related to these disturbances is challenging due to the randomness and complex nature of power systems. Therefore, the importance of conducting experimental studies to investigate and analyze PQDs has significantly increased. This study aims to serve as a valuable resource for researchers investigating PQDs. It provides a guidance, offering insights into some types of PQDs and their characteristics. This paper supports researchers in understanding and addressing the challenges based on PQDs by presenting knowledge about these disturbances and their impacts. Recognizing the significance of experimental studies, the compilation includes methodologies, experimental setups, and tools employed for studying PQDs. It emphasizes the necessity for experimental datasets to enhance research in this field and highlights the importance of PQD investigation.

Keywords –Power Quality Disturbances, Experimental Setup, Classification, IEEE 1159, IEEE 1459

I. INTRODUCTION

Remaining the stability of main amplitude and frequency parameters is one of the most important item in power systems with the values of 50 Hz and 220 V_{rms} set in Turkey. Any instability in these parameters can result in detrimental consequences, such as losses of efficiency, malfunctioning electrical devices, and even severe damage. For example, voltage swells can lead to faults of high voltage, while voltage sags can cause electronic devices to malfunction. Furtherly, voltage interruptions may cause energy losses and disruption of business operations.

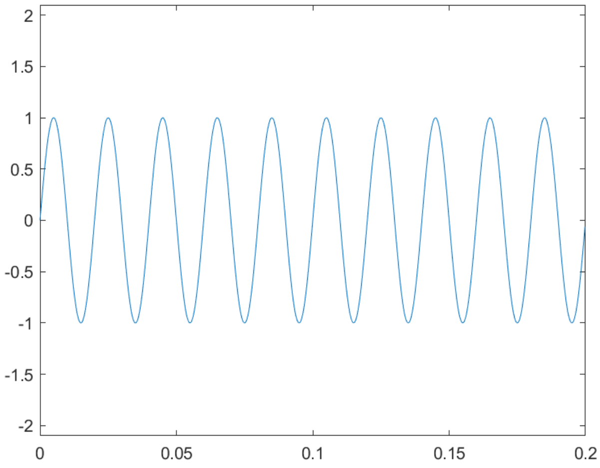
There are several standards that define power quality disturbances and provide guidelines for their analysis. IEEE 1159 standardizes measurement methods and parameters of power quality. IEEE 1459 interprets measurements of power systems meaningfully. Standards like IEC 61000-4-7, -15 and -30 offer guidelines for evaluating and testing power system disturbances [1]–[5]. EN 50160 also establishes similar limits as other standards.

Effectively analyzing power quality issues requires understanding the definitions of various disturbances, their causes, and their impact on power systems. However, obtaining a direct and relevant real-time dataset can be challenging due to the time-varying nature of power systems and safety risks. Therefore, conducting investigations and collecting data for the PQD D&C (detection and classification) necessitates the use of experimental setups. This paper aims to raise awareness for PQD researchers, by providing an overview of some parameters of power quality and related experimental setups. By presenting some information and setups, this paper has a goal to catalyze more research and advance the understanding and management of PQDs.

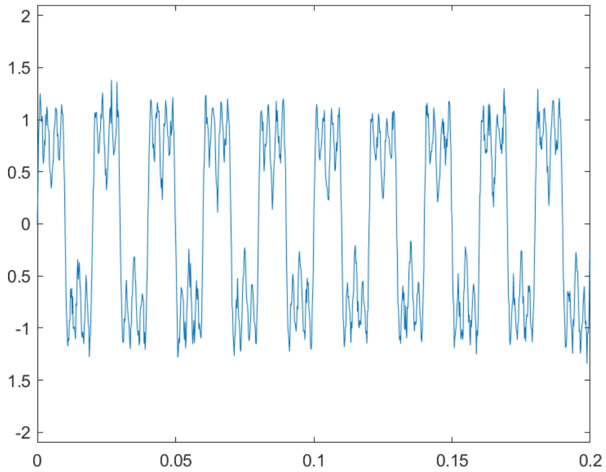
The paper is structured as follows: Section 2 provides information on PQDs in power systems, including single and multiple PQDs with illustrations. The literature on experimental studies related to PQD classification is covered in the 3^{rd}section. The fourth section gives a knowledge of experimental setups for PQD classification. Finally, the last section presents a summary and discussion of the paper.

II. POWER QUALITY DISTURBANCE

In power systems, the primary parameters of interest are the fundamental frequency and amplitude. A pure sinusoidal signal with a frequency of 50 Hz and a 220 V_{rms} amplitude is desired. However, various power quality disturbances such as flicker, harmonics, sag, swell, interruption, notch, spike, and transient can alter these parameters. IEEE 1159 defines that these disturbances have different mathematical models with different time, frequency, and amplitude specifications. They can occur individually or in combination. A pure and a multiple disturbed noisy signal are illustrated in Fig. 1 as the time-series images.



(a)



(b)

Fig. 1. Images of PQD classes a) A pure sinusoidal signal b) A noisy signal with flicker & harmonics

To effectively analyze power quality disturbances, accurate identification and classification are necessary. Obtaining real-time and problem-specific data for analysis is challenging due to the dynamic nature of power systems and associated risks. Therefore, experimental setups are essential for conducting investigations and gathering data for the detection and classification of power quality disturbances. The subsequent sections will provide further details on relevant studies and experimental setups.

III. LITERATURE ON EXPERIMENTAL PQD D&C

Several studies in the literature have focused on the classification of PQDs.

In one study [6], a smart sensor system utilizing the Hilbert Transform is proposed for detecting, classifying, and quantifying PQDs. It provides real-time monitoring, accurate detection, and classification capabilities, offering valuable information for preventive maintenance and grid reliability enhancement. Another study [7] presents a method based on the least mean square (LMS) algorithm and ADALINE for fast and accurate measurement of harmonic / interharmonic / subharmonic parameters. It aims to improve the measurement of amplitudes and phases of these parameters.

A project [8] focuses on diagnosing PQDs in smart grids using hybrid signal processing algorithms based on FFT, DWT, EMD, and machine learning algorithms. Simulation and experimentation are conducted to demonstrate the effectiveness of these techniques in diagnosing PQ issues and enhancing power system efficiency. An innovative signal processing-based method called the Mystery Curve [9] accurately identifies and characterizes PQDs. It separates normal and disturbed PQ conditions by analyzing features and signal characteristics, contributing to improved PQ monitoring and analysis.

For real-time PQD D&C, a cross-correlation analysis-based method compares measured power quality signals with reference waveforms to identify and classify PQDs such as swells, sags, and harmonics [10]. That method offers PQ events identification swiftly and accurately. Another technique for PQD classification considers time-dependent spectral characteristics to enhance precision [11]. It examines the dynamic behaviour of disturbances over time, leading to accurate PQD classification. A method combining FastICA and Random Forest algorithms is introduced to accurately recognize PQDs in the presence of significant background noise to achieve high accuracy [12]. Detrended Fluctuation Analysis method analyses power signal fluctuations and extracts relevant features for D&C. Its ability to detect short-time variations contributes to precise characterization and PQD classification [13]. A novel method based on time-frequency analysis and the S-transform is presented [14]. This method adjusts S-transform parameters according to the specific characteristics of disturbances, allowing accurate feature extraction from complex PQDs like harmonics, interharmonics, and transients. It improves PQD management and monitoring in electrical systems.

An Integrated Deep Learning (I-DL) approach for multi-label PQD classification is performed [15]. It combines convolutional and recurrent neural networks with detection algorithms to detect features and parameter limitations in PQ signals. The I-DL model effectively handles complex and overlapping disturbances. An efficient single-shot-based algorithm is introduced [16] for detecting PQDs. It analyzes voltage and current waveforms using advanced signal processing techniques to identify various types of disturbances. The algorithm captures and analyzes the waveform in a single shot, significantly reducing detection time while maintaining accuracy. A hybrid method using the Multi-objective Grey Wolf Optimizer (MOGWO), 2D-Riesz Transform (RT), and machine learning algorithms [17] is proposed for PQD classification. It extracts features using 2D-RT, first optimizes feature selection with MOGWO, and then, employs SVM and RF for classification. The method identifies and categorizes PQDs accurately, improving PQA and monitoring. In [18], a PQD D & C technique combines DL algorithms with the Stockwell Transform ST for feature extraction. DL models are trained to recognize patterns and classify some PQDs. The technique has high accuracy and robustness, providing an effective solution for PQ analysis and power system management.

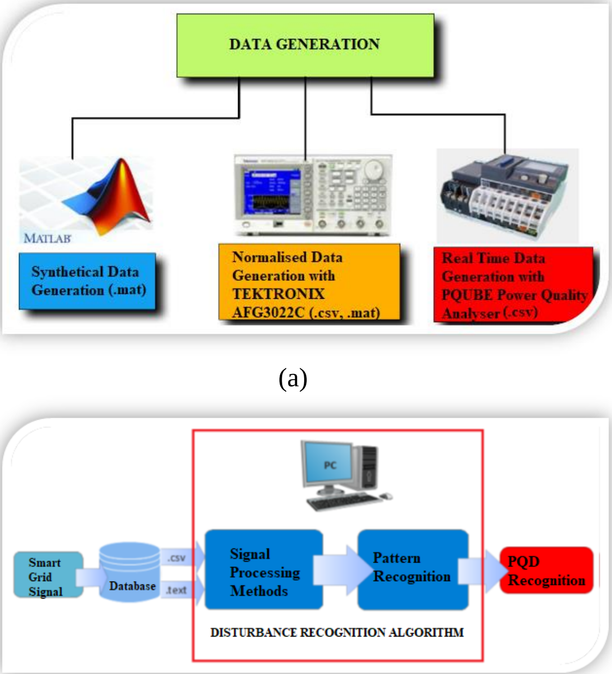
Wasserstein Adversarial (WA) learning technique is a usable way to address incomplete data in PQD identification [19]. This method trains a generator and discriminator network using WA learning. And thus, completion of missing information and accurately identification of PQDs have done. The method shows high effectiveness and potential for power system monitoring.

These studies contribute to the field of PQD classification by introducing various innovative methods and techniques. They offer valuable insights into real-time monitoring, accurate detection, and classification of PQDs, leading to enhanced power system efficiency, reliability, and performance.

IV. EXPERIMENTAL SETUP FOR INVESTIGATION OF PQD CLASSIFICATION

Real-time acquisition is the most realistic but time-consuming and hardest because of the power systems and the randomness of the PQDs. Synthetical data is basic but had better if obtained from the field. For that reason, the most optimised choice is the experimental setup. A basic setup for data acquisition can be made up as synthetically, experimentally or real-time as in Fig 2. a. Then, this acquised dataset will be processed like in Fig 2. b.

The diagram in Figure 2, specifically parts a and b, showcases data acquisition techniques and the basic flowchart of PQD D&C [8]. MATLAB software was utilized for generating synthetic data and refining the method, while the Tektronix AFG 3022C was employed for the experimental dataset. The real-time dataset for PQD detection and classification was acquired using the PQUBE Power Quality Analyser.



(a)

(b)

Fig 2. (a) Data acquisition methods (b) Flowchart of basic PQD D&C Algorithm [8]

If to conduct a comprehensive research, a universal experimental setup like in Fig 3. This setup composes four layers. The first one is a Neutral Point Clamped (NPC) Inverter grid- on/off an experimental platform. The other layer is a Signal Conditioning Block including a CHV-25P/500 card, and a Low-pass filter. The third layer is an NI PCI-6229 Signal Acquisition Block. And the layer is a PC for Signal Processing Block [11].

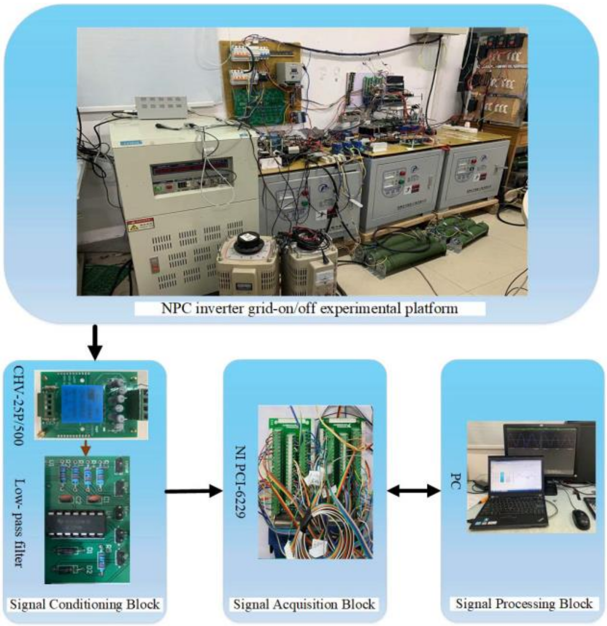


Fig 3. 4-layer experimental setup in [11]

V. SUMMARY AND DISCUSSION

In conclusion, this paper provided an overview of some experimental studies focused on the classification of power quality disturbances (PQDs). It serves as a valuable resource for researchers, highlighting the importance of detecting and classifying PQDs while shedding light on the experimental setups utilized. These setups encompass data generation, lots of instruments, and analysis techniques that enable the measurement, monitoring, and analysis of PQDs. Additionally, software applications compatible with these setups are discussed. The methods, algorithms, and techniques investigated in these setups contribute to the improvement of innovations aimed at enhancing the efficiency, reliability, and performance of power systems. By utilizing these setups, the researchers can raise their knowledge about PQDs and advance their detection and classification. Furthermore, this study can aid in facilitating the creation of optimized experimental setups, enabling researchers to design and implement more effective methodologies for PQDs.

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