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A Conspectus of PQD Analysis

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Abstract – The sustainability of a stable voltage with consistent amplitude and frequency is paramount for power systems. Various standards, including IEC 61000-4-7, -15, and -30, and IEEE 1159, 1459, address power quality disturbances (PQDs). These standards establish rules and limitations for different voltage parameter values to ensure power system stability. Nevertheless, disturbances in the electrical power systems can cause fluctuations in voltage amplitude and fundamental frequency. These disturbances, such as sag, flicker, interruption, harmonics, swell, and interharmonics, may emerge in different combinations, yielding unpredictable and variable effects on the system components. Hence, conducting a comprehensive analysis and examination of these disturbances is crucial. Studying PQDs faces challenges in obtaining real datasets due to the randomness of power system events. As a result, there is an increasing need for experimental investigations to explore the complexities of these disturbances. The objective of this paper is to assist and enrich research on PQDs by delivering some knowledge of data and experimental arrangements. This paper will make easy further examination and exploration of PQDs. This will empower researchers to acquire profound understandings and devise efficient approaches to tackle these matters, contributing to improved power system performance.

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

I. INTRODUCTION

Stability with an amplitude of $220\ V_{rms}$ and a fundamental frequency of 50 Hz on the system voltage is crucial for power systems in Turkey. Deviations in these parameters can result in inefficiency, improper functioning of electrical devices, and potential damages. Voltage swell, for example, can cause high voltage faults, while voltage sags can lead to malfunctions in sensitive types of equipment. In addition, voltage interruptions can result in energy missing and disruptions to business continuity.

Various standards are available for PQDs and analysis of them. Parameters and measurement methods of power quality are arranged by IEEE 1159, while the interpretation of measurements is focused on by IEEE 1459. Guidelines on testing and evaluation of disturbances in power systems are provided by IEC 61000-4-7, -15, and -30 [1]–[5].

To analyze PQ issues effectively, it is essential to understand the definitions of different PQDs, their causes, and their detractive effects on the systems. Obtaining real-time data acquisition for Power Quality Analysis (PQA) can be challenging owing to the time-varying structure of power systems and associated risks to human safety. Hence, the importance of experimental setups has increased in terms of performing investigations and data acquisition for PQA.

The aim of this paper is to address this requirement by assuring prevalent PQ knowledge and some experimental setups. This study facilitates and supports further research in this field by yielding a piece of knowledge about experimental PQA studies and the setups.

The paper is constructed as follows: The 2nd Section endures a piece of information about quality, including parameters, definitions, impacts, causes, and shown images. Section 3 ensures some

related studies in the literature. The fourth section presents detailed information on experimental setups for power quality analysis as utilized in the existing literature. Finally, the study concludes with a summary and discussion.

II. PARAMETERS AND EVENTS

In power systems, fundamental frequency, and amplitude play a crucial role. The desired signal should be pure sinusoidal, modeled by Eq. (1), with the fundamental frequency (f_0) set at 50 Hz and amplitude (A) at 220 V_{rms} in Turkey. Nevertheless, these parameters can be affected by PQDs such as harmonics, interharmonics, sag, interruption, swell, and others. These disturbances are common and can be described using mathematical models with varying amplitudes, frequencies, and time characteristics. Power quality disturbances can occur individually or in combination, leading to manifestations such as flicker, harmonics, sag, swell, interruption, and more. Some of these disturbances are further defined and visualized through time-series images.

$$v(t) = A\sin(2\pi f_0 t), \quad f_0 = 50\ Hz, A = 220\ V_{rms} \quad (1)$$

A. Deviations of Voltage Amplitude & Fundamental Frequency

Voltage amplitude and fundamental frequency are presented with A, and f_0 in Eq. (1). Fundamental frequency deviation caused by arc furnaces, extreme conditions of loading, or generation loss are not favored and may cause detrimental results like harmonic filters detuning, and motors running slower or trivial most of the time. Voltage fluctuation is also caused by similar cases and led to light flicker impacts on the end users.

B. Harmonics

Harmonics are the most frequent disturbances in power systems and must be minimized. The reasons for the harmonics are generators, industrial furnaces, transformers, rectifier equipment, nonlinear loads, etc. Impacts of these are sensitive equipment maloperation, failures of capacitors & relays, and 3-phase operation interruption, and so.

The 3rd, 5th, and 7th are active in power systems as in Fig. 1 and must be tracked continuously. The time interval is arranged as 0.2 sec in this figure and so on.

C. Interharmonics

Interharmonics, similar to harmonics, are common disturbances in power systems and also need to be mitigated. Interharmonics are often associated with light flicker effects. Fig. 2 illustrates a time-series signal displaying the flickered signal, indicating voltage fluctuation and corresponding fundamental frequency fluctuation in the field.
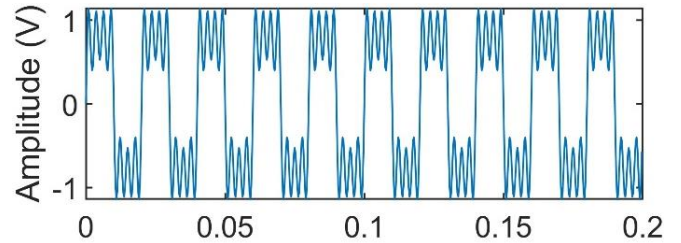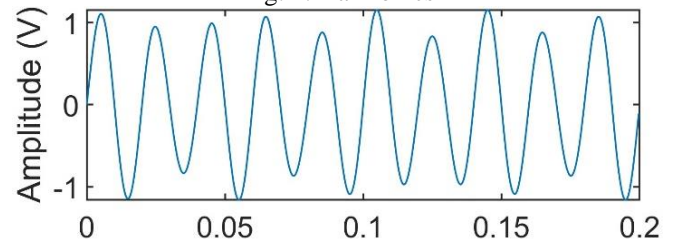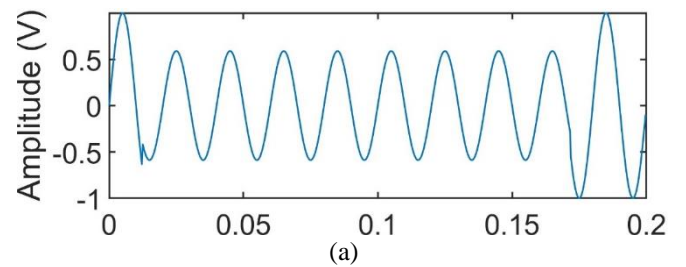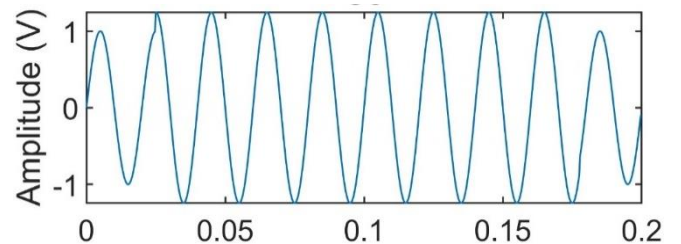

Fig. 1. Harmonics

Fig. 2. Interharmonics leading to Flicker

D. Sag, Swell, and Interruption

Other significant disturbances in power systems include sag, swell, and interruption, which can have severe consequences. These disturbances follow specific intervals defined by the IEEE 1459 standard. Fig. 3 depicts these PQDs.
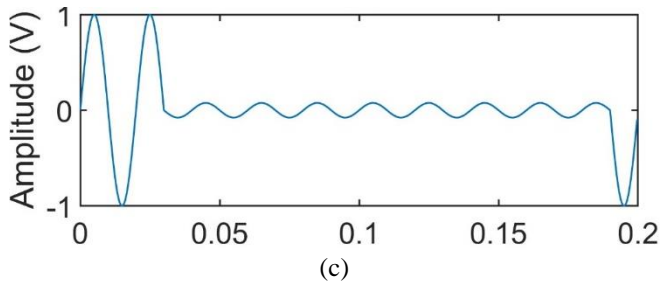

(a)

(b)

Fig. 3. (a) Sag (b) Swell (c) Interruption

The causes of the voltage sag are network overloading, generation loss, inductive loading, poor power factor, remote and local faults, etc. which have some impacts like resetting of a control system, sensitive equipment tripping, and all equipment without backup supply facilities.

Capacitor switching, load switching, and system voltage regulation led to voltage swell which has an impact like unsteady-state voltage.

The other PQD is voltage interruption caused by control malfunctions, circuit breaker tripping, equipment failures, and power system faults. This PQD gives rise to loss of customer supplementation, motor tripping, and computer malfunctioning.

III. LITERATURE OVERVIEW

A study in [6] proposes a model of a two-stage ADALINE (Adaptive Linear Neural Network) for measuring harmonics and interharmonics under variable fundamental frequency. The experimental setup includes a PC (Personel Computer), an Arbitrary Waveform Generator (AWG), and a Multifunction Data Acquisition (DAQ) card. MATLAB is used for data processing and analysis.

Another study in [7] presents a method based on the Extended Real Model of the Kalman Filter to estimate time-varying harmonics. LabVIEW is used for data acquisition, and the method is improved based on the acquired data. Also, the study using variable harmonic and interharmonic sources performs a similar investigation on time-varying harmonics and interharmonics [8]. The setup serves as a virtual instrumentation and educational platform.

For the voltage variations and tracking, a Prony-based solution technique is proposed in [9].

A method for fast estimation of harmonics using FFT and ADALINE is presented in [10]. MATLAB is used for data processing and method development.

In [11], focused on power quality monitoring of an electrical machine using MATLAB and an experimental setup that includes various measurement devices.

The flicker effect of modern lamps caused by interharmonics is investigated using Raspberry Pi, MATLAB, and various instruments [12].

An improved phase-locked loop (PLL) using Raspberry Pi for accurate frequency tracking and reduced phase error is proposed in [13].

For the estimation of harmonic and interharmonic components in power systems, a novel technique using a high-speed digital signal processor (DSP) and Multi-Stage ADALINE is performed [14]. The experimental setup includes current probes, amplifiers, a DSO, and a PC.

To detect the fundamental frequency of three-phase power systems with the help of a digital signal processing algorithm combining a three-phase resonant filter and a PLL, a method is available in [15]. Simulation and experimental setups are used for evaluation.

An experimental setup is discussed for the evaluation of a road lighting system based on nano-grid technology [16].

Another study for power system signals based on a windowing function and a discrete Fourier transform is presented for the detection of harmonic components. It is suitable for real-time applications [17].

A method for power-quality waveform compression is proposed in [18] to reduce storage requirements while preserving important spectral components. The setup includes a power generator, an oscilloscope, an FPGA, a signal conditioner circuit, an ADC board, and a PC.

A method of voltage restoration control is suggested for microgrids using an RWPFNN [19]. An experimental setup involves a host PC, DSPs, SPI, peripheral circuits, and an oscilloscope.

These studies and experimental setups contribute to improving power system monitoring, control, voltage stability, and power quality in various applications.

IV. EXPERIMENTAL SETUP MODEL FOR PQA

As mentioned above, a two-stage ADALINE model was proposed for the harmonics and interharmonics measurement in a fundamental frequency fluctuation [6]. That study used an experimental setup composed of an AWG, a Multifunction DAQ -6036E card, a PC, and the other components illustrated in Fig. 4. MATLAB

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was utilized for Data Acquisition and analysis. Then, a new method was proposed by using this dataset.

This layout can be used in basic analysis. For a comprehensive dataset and more practical experimentations, the setup in Fig. 5 should be used.
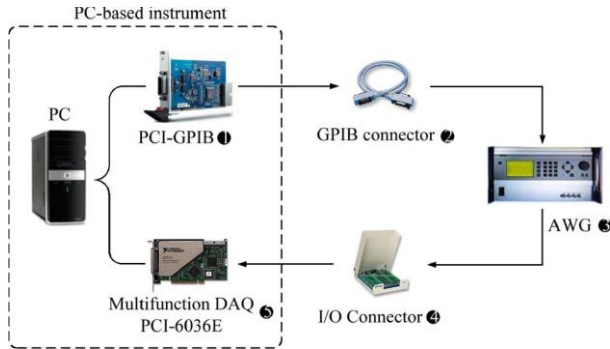

Fig. 4. A Basic Experimental Layout [6]

A method on power systems in [14] is introduced for the estimation of harmonic and interharmonic components. The method utilizes an MS-ADALINE and a DSP to enable real-time implementation. Simulative outputs of this method have been more swift and precise than conventional approaches. This highlights its suitability for monitoring and control of the power system. Nonlinear loads, linear loads, and linear impedances were considered in the experimental setup. MATLAB software was used for analysis. Additionally, a 3-phase hardware platform was utilized, comprising a variable source, a DSO, multimeter, a current amplifier, a fully controlled bridge converter, an isolation transformer, an induction load, a firing angle generation circuit, a resistive load, a 2.2 kW 220 DC motor, and a continuously variable autotransformer as given in Fig. 5. The performance of the method was assessed under different cases, including an input signal with changing amplitude and frequency. Also, the study was implemented in a noisy and disturbed environment. Comparative analysis was conducted between experimental and simulation results, demonstrating the method's superior accuracy, speed, and noise resilience compared to alternative approaches.
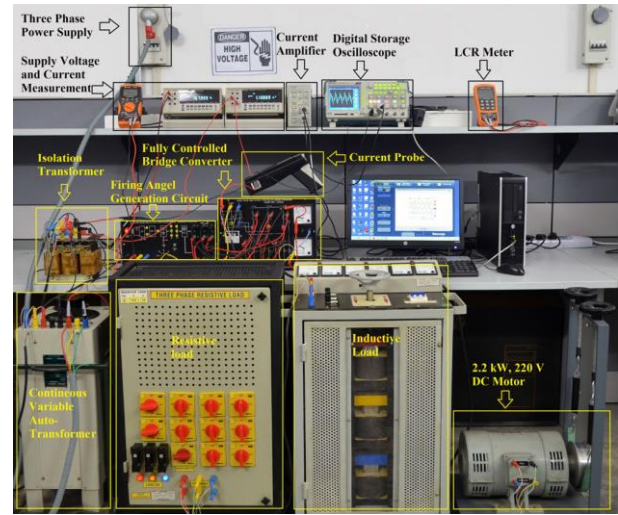

Fig. 5. A Comprehensive Setup for the Investigation of Harmonics & Interharmonics [14]

V. SUMMARY AND DISCUSSION

In summary, this paper ensures a trace of the parameters, assessment, and experimental setups on power quality disturbances. These experimental setups encompass a wide array of instruments, data acquisition systems, and analysis tools necessary for measuring, monitoring, and analyzing various power quality parameters. In addition to hardware devices, software programs are also utilized in the setups. Some methods, and techniques investigated in these experiments conduce to the innovative solutions enhancement aimed at enhancing power systems performance, reliability, and efficiency. This study offers researchers valuable opportunities to gain insights into power quality issues and drive advancements in power system technologies. It's important to note that these setups cater not only to the mentioned power quality parameters but also to other parameters mentioned previously. Moreover, the information provided in this study facilitates the creation of optimized setups by utilizing the presented data. By leveraging these experimental setups, researchers can work towards optimizing power systems and addressing the complexities associated with power quality phenomena.

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