POWER QUALITY MEASUREMENT AND ANALYSIS USING HIGHER-ORDER STATISTICS

UNDERSTANDING HOS CONTRIBUTION ON THE SMART(ER) GRID

OLIVIA FLORENCIAS-OLIVEROS • JUAN-JOSÉ GONZÁLEZ-DE-LA-ROSA
JOSÉ-MARÍA SIERRA-FERNÁNDEZ • MANUEL-JESÚS ESPINOSA-GAVIRA
AGUSTÍN AGÜERA-PÉREZ • JOSÉ-CARLOS PALOMARES-SALAS

IEEE PRESS

WILEY

Table of Contents

List of Tables

List of Illustrations

Power Quality Measurement and Analysis Using Higher-Order Statistics

Understanding HOS Contribution on the Smart(er) Grid

Olivia Florencias-Oliveros
Juan-José González-de-la-Rosa
José-María Sierra-Fernández
Manuel-Jesús Espinosa-Gavira
Agustín Agüera-Pérez
José-Carlos Palomares-Salas

University of Cádiz
Department of Automation Engineering, Electronics, Architecture and Computer Networks,
Research Group PAIDI-TIC-168. Computational lnstrumentation and Industrial Electronics (ICEI),
Higher Technical School of Engineering of Algeciras (ETSIA), Spain


WILEY


IEEE PRESS

This edition first published 2023

Registered Offices
John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

Editorial Office
The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

For details of our global editorial offices, customer services, and more information about Wiley products visit us at www.wiley.com.

Wiley also publishes its books in a variety of electronic formats and by print-on-demand. Some content that appears in standard print versions of this book may not be available in other formats.

Library of Congress Cataloging-in-Publication Data
Names: Florencias-Oliveros, Olivia, author.
Title: Power quality measurement and analysis using higher-order statistics : understanding HOS contribution on the smart(er) grid / Olivia Florencias-Oliveros [and five others].
Description: Hoboken, NJ : Wiley, 2023. | Includes bibliographical references and index.
Identifiers: LCCN 2022023836 (print) | LCCN 2022023837 (ebook) | ISBN 9781119747710 (cloth) | ISBN 9781119747765 (adobe pdf) | ISBN 9781119747741 (epub)
Subjects: LCSH: Electric power systems–Quality control. | Order statistics.
Classification: LCC TK1010 .F55 2023(print) | LCC TK1010(ebook) | DDC 621.31–dc23/eng/20220722
LC record available at https://lccn.loc.gov/2022023836
LC ebook record available at https://lccn.loc.gov/2022023837

Cover Design: Wiley
Cover Image: © Pand P Studio/Shutterstock

To all the researchers that have inspired this work, those working to bridge the gap between signal analysis and power metering

Preface

The so-called digital energy networks are gathering numerous elements that have emerged from different branches of Engineering and Science. Concepts such as Internet of Things (IoT), Big Data, Smart Cities, Smart Grid and Industry 4.0 all converge together with the goal of working more efficiently, and this fact 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 requirements regarding the current operation of the electrical network. This book offers a compilation of the recent advances in this field. The chapters range from computing issues to technological implementations, going through event detection strategies and new indices and measurement methods that contribute significantly to the advance of PQ analysis. Experiments have been developed within the frames of research units and projects and deal with real data from industry 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.

PQ analysis is evolving continuously, mainly due to the incessant growth and development of the smart grid (SG) and the incipient Industry 4.0, which demands quick and accurate tracking of the electrical power dynamics. Much effort has been put on two main issues. First, numerous distributed energy resources and loads provoke highly fluctuating demands that alter the ideal power delivery conditions, introducing at the same time new types of electrical disturbances. For this reason, permanent monitoring is needed in order to track this a priori unpredictable behaviour. Second and consequently, the huge amount of data (Big Data) generated by the measurement equipment during a measurement campaign is usually difficult to manage due to different causes, such as complex structures and communication protocols that hinder accessibility to storage units, and the limited possibilities of monitoring equipment, based on regulations that do not reflect the current network operation.

The introduction of new indicators in PQ is one of the main subjects of discussion in the CIRED/CIGRÉ working group; however, it is necessary to solve future challenges from new perspectives. Indeed, this book proposes to spread the use of PQ indices based on HOS from event detection up to cycle-to-cycle continuous monitoring, taking advantage of their most simple calculations in order to detect the effect of multiple loads acting/working together on a node for a specific length of time.

Chapter 1 introduces the State of the Art in the power quality field and will help researchers to bridge the gap between traditional methods and those applications that use HOS analysis.

Chapters 2–5 propose different and experimental approaches that have been used to validate HOS applications in monitoring the power system.

Table A summarizes the monitoring objectives that would be accomplished using HOS as part of the results of this book and according to the topics proposed in the Guideline for Selection of Monitoring Parameters. Compared with other simpler methods, such as RMS measurements, HOS are not sensitive to noise. In Chapter 3, the authors demonstrated that HOS can help to detect fundamental frequency changes in the bi-dimensional plane and Chapter 4 introduces techniques in the frequency domain, such as spectral kurtosis.

Table A HOS approach related to different applications.

Monitoring objective	Variables	Sampling rate	Data averaging window	Reference
Compliance verification-connections agreements/premium power contracts	Voltage sags or voltage swells	5 Hz	As specified in the contract	Chapter 3
Performance analysis	Steady-state voltage Voltage sags and swells Highest or lowest RMS voltage per 1 (or 10 min) Fundamental frequency deviations	5 Hz	10 min averaging window 1 min averaging window	Chapter 3
Site characterization		20 kHz		Tables Chapter 4 Chapter 5
Troubleshooting	Disturbance depending on the nature of the problem being investigated			Chapter 3 Chapter 4

Overall, here the authors summarize the last 10 years of power quality research based on HOS techniques that would be incorporated in future PQ measurement campaigns, in order to accomplish the monitoring challenges of the next generation of advanced metering infrastructure in terms of compression, as well as reporting PQ efficiently.

This book gathers new advances in techniques and procedures to describe, measure and visualize the behaviour of the electrical supply, from physical instruments to statistical signal processing (SSP)

techniques and new indexes for PQ that try to go beyond traditional norms and standards. The authors are recognized experts in the field, committed to a main goal: to provide new instrumental and analytical tools to help mitigate the serious consequences of a bad PQ in our digitized society, and thus enhancing energy efficiency for a more sustainable development.

Olivia Florencias-Oliveros
Juan-José González-de-la-Rosa

About the Authors

Dr Olivia Florencias-Oliveros received a PhD degree in Energy and Sustainable Engineering in 2020 (*summa cum laude*) from the University of Cádiz, Spain. She is a lecturer at the University of Cádiz, in the Research Group in Computational Instrumentation and Industrial Electronics (PAIDI-TIC168), and an IEEE Member in the Power and Energy Society and IEEE Measurement and Instrumentation Society. Her research interests include Energy Technologies to manage Energy Efficiency and Renewable Energies: smart grids, energy monitoring techniques in power systems, power quality, smart metering, computational instrumentation technologies, sensor networks, IoT in smart buildings, big data and HOS statistics.

Dr Juan-José González-de-la-Rosa received an MSc degree in Physics–Electronics in 1992 at the University of Granada, Spain and a PhD degree in Industrial Engineering in 1999 at the University of Cádiz, Spain. He has four recognitions in the field of Communication Engineering, Computation and Electronics by the Spanish Government and was also awarded a Knowledge Transfer Recognition by the Spanish Government. Furthermore, he is a Full Professor in Electronics and founder of the Research Group in Computational Instrumentation and Industrial Electronics (PAIDI-TIC-168). His research interests include HOS, power quality and the inclusion of computational intelligence in technologies for measurement systems.

Dr José-María Sierra-Fenández received a PhD degree in Industrial Engineering in 1998 at the University of Cádiz, Cádiz, Spain. He is a Lecturer at the same University in the Research Group in Computational Instrumentation and

Industrial Electronics (PAIDI-TIC-168). His research interests include energy technologies to manage energy efficiency and renewable energies, SG, power quality, instrumentation technologies, smart metering and HOS.

Manuel-Jesús Espinosa-Gavira received an MS degree in 2018 at the University of Cádiz, Cádiz, Spain. He is now a PhD student in Energy and Sustainable Engineering at the University of Cádiz from 2017 and is a Member of the Research Group in Computational Instrumentation and Industrial Electronics (PAIDI-TIC-168). His research interests include power quality, time-series analysis, sensor networks, meteorology applied to renewable energies and energy efficiency.

Dr Agustín Agüera-Pérez received an MS degree in Physics in 2004 at the University of Seville, Seville, Spain and a PhD degree in Industrial Engineering in 2013 at the University of Cádiz, Cádiz, Spain. He is now a Lecturer of Electronics in the Department of Automation Engineering, Electronics, Architecture and Computer Networks at the University of Cádiz and a Researcher in the Research Group in Computational Instrumentation and Industrial Electronics (PAIDI-TIC-168). His research interests include energy meteorology, power quality and virtual instruments.

Dr José-Carlos Palomares-Salas received an MS degree in Industrial Engineering in 2008 and a PhD degree in Industrial Engineering in 2013 (*summa cum laude*), both at the University of Cádiz, Cádiz, Spain. Currently, he is an Associate Professor at the University of Cádiz, in the Department of Automation Engineering, Electronics, Architecture, and Computer Networks and also a Member of the Research Group in Computational Instrumentation and Industrial Electronics (PAIDI-TIC-168). His research interests include power quality, intelligent systems and machine learning.

Acknowledgements

The work has been carried out in the framework of the following competitive Spanish National Research Projects:

TEC2016-77632-C3-3-R-CO – Control and Management of Isolatable NanoGrids: Smart Instruments for Solar Forecasting and Energy Monitoring (COMING-SISEM).

PID2019-108953RB-C21 – Estrategias de producción conjunta para plantas fotovoltaicas: Datos operacionales energéticos y meteorológicos para sistemas fotovoltaicos (SAGPV-EMOD).

In both projects, new techniques for power quality monitoring in the smart grid frame have been developed in the framework of the PAIDI-ICT-168 Research Group on Computational Instrumentation and Industrial Electronics (ICEI), founded by the Junta de Andalucía government.

During this research, a National Patent directly aligned with the method was proposed. ES2711204 Procedimiento y Sistema de Análisis de Calidad de la Energía e Índice de Claidad 2S2PQ, Caracterización de la Señal en un Punto Del Suministro Eléctrico.

In addition, researchers of our unit have been doing different four-month research stays at Dresden University of Technology, at the Institute of Electrical and High Voltage Systems Engineering, under the supervision of Dr Jan Meyer and Dr Ana María Blanco within the Power Quality Research Group.

Acronyms

AMI
Advanced Measurement Infrastructure

CDF
Cumulative Density Function

CENELEC
European Committee for Electrotechnical Standardization

CIGRÉ
International Council of Large Electrical Networks

CIRED
International Congress of Electrical Distribution Networks

dB
Decibel

DER
Distributed Energy Resources

DFT
Discrete Fourier Transform

DSOs
Distribution system operators

EV
Electric Vehicle

FDK
Frequency Domain Kurtosis

FFT
Fast Fourier Transform

HOS
Higher-Order Statistics

IEC
International Electrotechnical Commission

IEC-61000-4-30
Paper of the IEC

IEDs
Intelligent Electronic Devices

IEEE
Institute of Electrical and Electronics Engineers

LV
Low voltage

MV
Medium voltage parameters, such as RMS (root-mean-square)

PDF
Probability Density Function

PMD
Power Monitoring Device (device whose main function is metering and monitoring electrical parameters)

PQ
Power Quality

PQD
Power Quality Events Detection

PQ index
Proposed PQ index based on HOS

PQI
Power Quality Instrument (instrument whose main function is to measure, monitor and/or as certain PQ parameters in power supply systems, and whose measuring methods (class A or class S) are defined in the standards

PQIDif

Standardized PQ data format adopted to make data easily compatible between devices and establish data analysis procedures

Prosumer
A consumer capable to produce energy and consume energy

PMU
Phasor Measurement Units

PV
Photovoltaic Panels

RE
Renewable Energy

RTUs
Remote Terminal Units

RVC
Rapid Voltage Change

SG
Smart Grid

SK
Spectral Kurtosis

SNR
Signal-to-Noise Ratio

STFT
Short Time Fourier Transform

SWM
Sliding Window Method

THD
Total Harmonic Distortion

TSOs
Transmission system operators

U_c
Nominal Supply Voltage

U_{din}
: Supply voltage variations

U_{ref}
: Reference voltage

U_{rms}
: RMS of the nominal voltage

V&I
: Voltage and Current waveforms

WT
: Wavelet Transform