Standards Roadmap of the IEEE PES Power Quality Subcommittee

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***Abstract*—This paper describes the status of important power quality standards and technical reports recently developed by working groups sponsored by the Power Quality Subcommittee of the IEEE Power & Energy Society. These working groups focus on issues related to harmonics, interharmonics, flicker, voltage imbalance, voltage sag indices, data exchange formats, data analytics, grid modernization, and power quality solutions. The paper provides a preview of future standards being developed by the IEEE PES Power Quality Subcommittee.**

Keywords*—*power quality, standards, roadmap, harmonics, voltage sags, flicker, fault analytics

I. Introduction

Standards related to power quality provide the basis for achieving compatibility between the characteristics of the electric supply system and customer equipment. The standards provide methods for evaluating power system performance, define equipment requirements, and outline relative responsibilities of the power provider and the power consumer. This paper describes the status of important power quality standards and technical reports recently developed or in active development by working groups sponsored by the Power Quality Subcommittee of the IEEE Power & Energy Society.

II. IEEE Standards Association

The IEEE Standards Association (IEEE-SA) is an organization within the Institute of Electrical and Electronics Engineers (IEEE) that develops global standards in a broad range of industries, including: power and energy, biomedical and health care, information technology and robotics, telecommunication and home automation, transportation, nanotechnology, information assurance, and many more.

IEEE has about forty societies, which develop IEEE standards. For example, The IEEE Power & Energy Society (PES) focuses on the scientific and engineering knowledge about electric power and energy. The IEEE Industry Applications Society (IAS) is interested in electrical and electronic engineering in the development, design, manufacture and application of electrical systems, apparatus, devices and controls to the processes and equipment of industry and commerce. The IEEE Electromagnetic Compatibility Society (EMC) is focused on ensuring that the electromagnetic environmental effects of systems are compatible with themselves and their intended operational environment.

Activities of interest to more than one IEEE society can be harmonized by standards coordinating committees. For power quality issues, IEEE-SA Standards Board sponsors the IEEE Standards Coordinating Committee for Power Quality (SCC-22). At present, SCC-22 does not sponsor standards projects or reports, which are the focus of this paper. More information can be found at the SCC-22 website [15].

The Transmission & Distribution (T&D) Committee of IEEE PES focuses on all matters related to the design, theoretical and experimental performance, installation, and service operation of parts of electric power systems that serve to transmit electric energy between the generating sources and substations or customer points of common coupling through AC or DC lines. The IEEE PES T&D Committee has seven subcommittees: Transmission, Distribution, Capacitors, HVDC & FACTS, Overhead Lines, Power Quality, and Engineering in the Safety, Maintenance and Operation of Lines (ESMOL). [17]

IEEE standards are classified into three different types:

- *Standards*: Documents with mandatory requirements
- *Recommended Practices*: Documents in which procedures and positions preferred by the IEEE are presented
- *Guides*: Documents in which alternative approaches to good practice are suggested but no clear-cut recommendations are made

IEEE-SA standards projects are authorized by IEEE-SA New Standards (NesCom) Committee via a Project Authorization Request (PAR). The PAR is approved with an expiration date, which is the final date for the standard to be drafted, completed, and balloted by the working group, and finally approved by IEEE-SA Standards Board.

This paper focuses on the standards activities of the Power Quality Subcommittee of the IEEE PES T&D Committee. The subcommittee has seven active working groups, some of which are subdivided into task forces:

1. Working Group on Harmonics
2. Working Group on Voltage Quality
3. Working Group on Monitoring Electric Power Quality
4. Working Group on Power Quality Solutions
5. Working Group on Voltage Imbalance
6. Working Group of Economic Evaluation of Voltage Sags
7. Working Group on Power Quality Data Analytics

Most standards developed by the IEEE PQ Subcommittee are developed using an "Individual Working Group" method, in which each person has one vote. At the time of writing of this paper, only one standard sponsored by the IEEE PQ Subcommittee was developed using the "Entity Working Group" method, in which each company or corporation has one vote.

III. Working Group on Harmonics

The Working Group on Harmonics is currently developing a revision of IEEE Std 519-2014 [1]. This standard includes power systems harmonic goals useful in the design of electrical systems that include both linear and nonlinear loads. The standard defines the interface between sources and loads as the point of common coupling (PCC). It presents design goals to minimize interference between electrical equipment. The limits in this standard represent a shared responsibility for harmonic control between power providers and power users. The standard provides limits on voltage total harmonic distortion (THD), current total demand distortion (TDD), and individual harmonics for both current and voltage, such as the limits for voltage distortion in Table 1. The PAR expiration date for IEEE P519 is December 31, 2021.

Table 1: Voltage Distortion Limits from IEEE Std 519-2014

Bus Voltage at PCC	**Individual Harmonic (%)**	**THD (%)**
$V \leq 1.0$ kV	5.0	8.0
1 kV < $V \leq 69$ kV 3.0 5.0	3.0	5.0
69 kV < $V \leq 161$ kV	1.5	2.5
161 kV < V	1.0	1.5

A key difference in the IEEE P519 revision project is that the new document will be a standard rather than a recommended practice, meaning its limits will be mandatory rather than preferred. Another difference is that this edition explains the relationship of IEEE 519 to IEEE Std 1547-2018 [8] when evaluating harmonic issues related to interconnection of distributed energy resources (DER) with electric distribution systems. Likewise, the IEEE P519 revision project explains the relationship of IEEE 519 to IEEE P2800 [10] when evaluating harmonic issues related to interconnection of inverter-based resources (IBR) with electric transmission systems.

A. *Supraharmonics*

Research on the topic of supraharmonics was a discussion topic in the IEEE P519 Working Group from 2017 to 2020. This term "supraharmonics" is used to refer to any type of waveform distortion of voltage and current in the frequency range between 2 and 150 kHz. However, as consensus has yet to be reached in IEEE and IEC working groups on how to measure or limit supraharmonics, the IEEE P519 revision will not include supraharmonic limits.

B. *P519.1 Harmonic Limits Guide Task Force*

This task force is developing a guide for applying harmonic limits described in IEEE Std 519. It will provide example applications for applying harmonic limits in power systems. It will be developed upon completion of the IEEE Std 519 revision project. The PAR expiration date for IEEE P519.1 is December 31, 2022.

IV. Working Group on Voltage Quality

The Working Group on Voltage Quality recently completed IEEE Std 1250-2018 [4], which is a Guide for Identifying and Improving Voltage Quality in Power Systems. The guide includes discussions of methods to identify and improve power quality in power systems, as well as references to publications in this area. The guide includes power quality levels from benchmarking studies, such as the distribution of voltage total harmonic distortion (THD) shown in Fig. 1, which was published initially in [24] and includes data from 277 electric distribution system monitoring locations. The guide includes discussions on factors that affect power system performance, information on mitigation measures that improve power system performance, and references to related IEEE standards and other documents. This guide only addresses subjects in depth where no other power quality reference in IEEE does so. It is an introduction for power quality that points the way to other documents in this field.

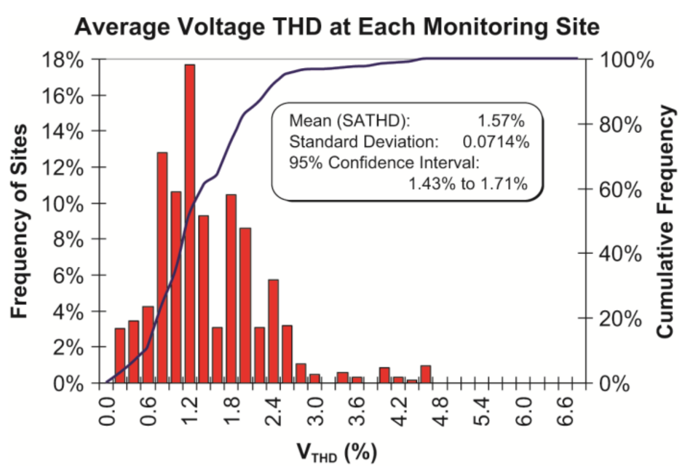

Fig. 1: Distribution of Average Voltage THD Levels for All Monitoring Sites in the EPRI DPQ Project Reprinted in IEEE Std 1250-2018

A. P1453 Task Force on Voltage Flicker

The IEEE P1453 Task Force is completing a revision to IEEE Std 1453-2015 [6], which provides guidance to system operators, owners, and engineers who are responsible for providing electrical service to installations that cause voltage fluctuations The previous edition is a recommended practice with methods for measurement and limits for voltage fluctuations and associated light flicker in power systems. The next edition will be a standard with mandatory requirements. The PAR expiration date for IEEE P1453 is December 31, 2021.

IEEE Std 1453 was adopted initially in 2004, in which IEEE adopted the IEC Flickermeter standard and provided recommended limits. IEEE Std 1453-2011 adopted the 2010 edition of the IEC 61000-4-15 [22], moving the recommended acceptable flicker levels to its annex, facilitating the adoption of the IEC TR 61000-3-7 [23] in IEEE 1453.1-2012 [7]. IEEE 1453 provides definitions for short-term flicker severity (Pst), which is derived over ten minutes, and long-term flicker severity (Plt), which is derived over two hours. IEEE 1453 also provides recommendations for flicker limits and evaluation procedure, such as the planning levels in Table 2 for medium voltage (MV), high voltage (HV), and extra high voltage (EHV).

Table 2: Recommended Planning Levels from IEEE Std. 1453-2015

	MV	**HV-EHV**
Pst	0.9	0.8
Plt	0.7	0.6

B. P1564 Voltage Sag Indices Task Force

The IEEE P1564 Task Force recently submitted a request to IEEE-SA to revise IEEE Std 1564-2014 Guide for Voltage Sag Indices [9]. IEEE Std 1564 identifies voltage sag indices and characteristics of electric power and supply systems as well as the methods for their calculation. IEEE Std 1564 specifies methods to quantify the severity of individual voltage sag events, to quantify the performance at a specific location via single-site indices, and to quantify power system performance via system indices. The methods are appropriate for use in transmission, distribution, and utilization electric power systems. IEEE Std 1564 is summarized in [11]. If approved by IEEE NesCom, the revision work would begin in Summer 2021 and would need to complete before December 2024.

Single-site indices defined in IEEE 1564 include System Average RMS Variation Frequency Index (SARFI), voltage sag magnitude vs duration tables, voltage sag energy, and voltage sag severity. Table 4 presents an example list of voltage sags from IEEE 1564 Annex C.1, including time stamp, retained voltage magnitude, and duration. Table 5 presents the SARFI-X counts and rates that could be derived from Table 4.

Table 3: List of Events Measured at a Single Monitoring Site

Time Stamp	**Retained Voltage**	**Duration**
2000-07-01 09:48:52	73%	9 c
2000-07-01 09:50:16	73%	9 c
2000-07-07 14:20:12	0%	82 c
2000-07-10 15:55:23	13%	100 c
2000-07-21 09:48:52	0%	2.6 s
2000-08-08 07:35:02	49%	34 c
2000-09-02 08:30:28	0%	41 s
2000-09-08 10:30:40	59%	40 c

Table 4: SARFI-X Indices Computed from Table 4

Index	**Count**	**Events per 30 Days**
SARFI-90	8	2.61
SARFI-70	6	1.96
SARFI-50	5	1.63
SARFI-10	3	0.98

V. WORKING GROUP ON POWER QUALITY MONITORING

The Working Group on Power Quality Monitoring recently completed a revision to IEEE Std 1159 Recommended Practice for Monitoring Electric Power Quality [2]. This recommended practice describes nominal conditions and deviations from these nominal conditions that may originate within the source of supply or load equipment or that may originate from interactions between the source and the load. Also, this recommended practice discusses power quality monitoring devices, application techniques, and the interpretation of monitoring results. This standard includes definitions and descriptions of commonly used disturbance categories:

- Impulsive Transients: Nanosecond, Microsecond, Millisecond
- Oscillatory Transients: Low frequency, Medium frequency, High frequency
- Instantaneous RMS Variations: Sag, Swell
- Momentary RMS Variations: Interruption, Sag, Swell, Voltage Imbalance
- Temporary RMS Variations: Interruption, Sag, Swell, Voltage Imbalance
- Long Duration RMS Variations: Sustained Interruption, Undervoltage, Overvoltage, Current Overload

A. IEEE P1159.3 Power Quality Data Interchange Format (PQDIF) Task Force

The IEEE P1159.3 PQDIF Task Force recently completed a revision project that resulted in IEEE Std 1159.3-2019 Recommended Practice for Power Quality Data Interchange Format (PQDIF). IEEE Std 1159.3 specifies the Power Quality Data Interchange Format, which is better known as PQDIF. This binary file format is used for the transfer of power quality data between software and hardware systems. This includes raw, processed, simulated, proposed, specified, and calculated data.

The transfer file format includes the power quality measurements as well as appropriate characterization parameters, such as sampling rate, resolution, calibration status, instrument identification, location, and other related data or characteristics. The recommended practice also provides guidelines for presenting PQDIF files in XML format (see Fig. 2) and for transferring power quality data. IEEE Std 1159.3 was summarized in [12].

Although the current edition of IEEE PQDIF does not expire until 2029, the working group has begun its revision already. A revision project was approved in 2020 and its PAR is valid until December 31, 2024.

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          ▼<tagOneSeriesDefn>
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Fig. 2: Excerpt from an Example PQDIF-XML Record from IEEE Std 1159.3-2019

Additionally, the IEEE P1159.3 Task Force is working with IEEE-SA Open Source Committee (OSCom) to have the IEEE PQDIF Software Libraries that have historically been maintained on a traditional IEEE web server to the new IEEE SA Open Platform. In 2020, IEEE OSCom voted to approve IEEE PQDIF Software Libraries as an Official IEEE Open Source Project using the Apache 2 license. The open source PQDIF will be posted on IEEE's new open source platform to facilitate collaboration among those software engineers interested in IEEE PQDIF [18].

VI. Working Group on PQ Solutions

The IEEE Working Group on Power Quality Solutions recently began work to revise IEEE Std 1409-2012 which is titled a Guide for Application of Power Electronics for Power Quality Improvement on Distribution Systems Rated 1 kV Through 38 kV [5]. This previous edition of the standard focused on medium voltage applications of "custom power" controllers such as dynamic voltage restorers, distribution STATCOM devices, and static transfer switches. The previous edition of the guide is summarized in [13]. In 2020, the working group decided to expand the scope of the project in its revision to beyond custom power controllers and to voltage levels above and below medium voltage.

The name of the project to revise IEEE Std 1409-2012 is IEEE P1409 Draft IEEE Guide for Technology Methods for Power Quality Improvement in Electric Power Systems. This new guide will provide an overview of devices, technology methods, and appropriate circuit configurations used as solutions in electric power systems for the purpose of mitigating power quality problems including voltage sags, harmonic distortion, voltage imbalance, and voltage fluctuations. This guide will include definitions, general need guidelines, performance objectives, electrical environments, input/output criteria, performance measurements, case studies, bibliography, economic assessment, and engineering trade-offs. The range of solutions that will be considered in the IEEE 1409 revision will begin with the technologies summarized in Table 5, which will be expanded and revised. The PAR expiration date for IEEE P1409 is December 31, 2024.

Table 5: Example Solutions for PQ Problems from IEEE Std 1409-2012

Power quality phenomena	**Solutions available to power providers**	**Solutions available to power customers**
Voltage sags and swells	• backup stored energy system • line reactor • modification of protection scheme, line sectionalizing • static or hybrid transfer switch • static series compensation • static voltage regulator • tree trimming	• "hold-in" coil ridethrough device for motor contactors • constant voltage (ferroresonant) transformer • backup stored energy system (UPS systems, battery systems, superconducting magnetic energy storage [SMES] systems, flywheel energy storage systems) • line conditioner • static or hybrid transfer switch • static series compensation • static voltage regulator • reprogramming of controls of sensitive device • voltage regulator
Voltage interruptions	• backup stored energy system • modification of protection scheme, line sectionalizing • static or hybrid transfer switch • tree trimming	• backup stored energy system • coil ridethrough device for motor contactors • line conditioner • static or hybrid transfer switch
Impulsive and oscillatory transients	• high energy surge arrester • preinsertion resistors and inductors • synchronous closing	• line conditioner • surge arrester • line reactor
Harmonic distortion	• passive filters and active filters • static shunt compensation with harmonic cancellation algorithm	• line conditioner • passive filters and active filters • static shunt compensation with harmonic cancellation algorithm
Noise		• grounding and shielding • filter • line conditioner
Flicker	• construction of new/upgraded feeder • construction of new substation • distribution series capacitors • static var compensation • static shunt compensator (distribution STATCOM) • connection to bus with higher short-circuit capacity	• static var compensation • static shunt compensation
Protection of non-linear load from voltage sags, and cancellation of harmonic currents	• combination series and shunt compensation	• combination series and shunt compensation

VII. Working Group on Voltage Imbalance

The Working Group on Voltage Imbalance has begun development of IEEE P2844, which will be a recommended practice for limiting voltage imbalance in electric power systems. This recommended practice will include recommended voltage imbalance limits, methods for determining voltage imbalance levels, and the expected voltage imbalance following the connection of new unbalanced loads. This recommended practice will also include information on the impact of unbalanced supply voltage on common end-user and supplier equipment. The PAR expiration date for IEEE P2844 is December 31, 2023.

VIII. Working Group on Economic Evaluation of Voltage Sags

The IEEE P2938 Working Group has begun work on a Guide for Economic Loss Evaluation of Sensitive Industrial Customers Caused by Voltage Sags. This guide will provide a method to evaluate the economic loss impact of voltage sags on sensitive industrial customers. It will describe how to carry out economic assessment related to cost and loss of voltage sags, what economic indexes and assessment flowcharts can be considered, how to efficiently collect useful data for evaluation. Also, to be addressed will be a recommended experimental method for testing end-user equipment and production lines. The PAR expiration date for IEEE P2938 is December 31, 2024. This standard is the first to be developed within the IEEE PES PQ Subcommittee using the corporate entity working group method.

IX. Working Group on Power Quality Data Analytics

The Working Group on Power Quality Data Analytics promotes and supports PQ data analytics research and applications activities, shares data and experience on PQ data analytics, and develops guidelines for PQ disturbance analytics including algorithms, tools and monitoring networks.

Power quality data analytics is a discipline that in collecting waveform-based power system data, extracting information from it, and applying the findings to solve a wide variety of power system problems in areas such as power quality, power system protection, equipment condition monitoring, and network performance enhancement.

The objective of this working group is to develop use cases, recommendations and guidelines for extracting information and knowledge from the power quality disturbance data for applications including non-traditional power quality concerns, such as condition monitoring and fault diagnosis.

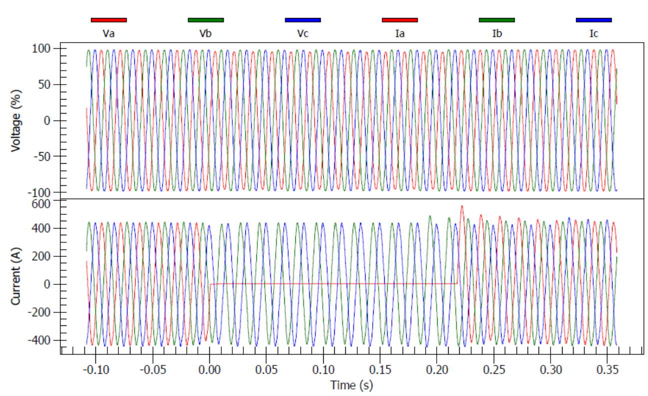

Fig. 3: Voltage and Current Waveforms Recorded during Failure of Substation Transformer Tap Changer

The working group recently published a technical report entitled, “Electric Signatures of Power Equipment Failures” that can be downloaded from the IEEE PES Resource Center [14]. This report was prepared to support the development and application of methods that use power quality data analytics for equipment condition monitoring. The report provides a set of equipment failure signatures collected from various sources and highlights their diverse characteristics, such as the waveform in Fig. 3, which are voltage and current waveforms recorded during a substation transformer tap changer failure.

X. Conclusions

The IEEE PES Power Quality Subcommittee and its working groups meet in person at least twice per year. The first in-person meeting is with the IEEE PES Joint Technical Committee Meeting, which typically meets in early January [19]. The second meeting is with the IEEE PES General Meeting, which typically meets in July or August [20]. Many of the PQ Subcommittee working groups meet in between the in-person meetings via online collaboration tools. In general, all PQ Subcommittee meetings are open but voting on an IEEE standard requires membership in the IEEE Standards Association. For more information, see the IEEE PQ Subcommittee website [16].

IEEE PQ Subcommittee members help organize and participate in the IEEE International Conference on Harmonics and Quality of Power (IEEE ICHQP), which is held once every two years. This conference consists of paper presentations, panel sessions, and tutorials related to power quality topics [21].

XI. Author Biographies

Daniel Sabin is an Edison Technical Expert and Senior Principal Architect with Schneider Electric in Andover, Massachusetts, USA. He is part of the Schneider Electric Digital Power team that accelerates data-based competencies & business by exploring & incubating new analytics applications, new analytics platforms, and new organizational models & processes for analytics. Previously, Dan was a Principal Engineer and Software Architect with Electrotek Concepts, where he led the development of the PQView software team for power quality database management & analysis and automatic fault analysis and fault location. He also developed PQDiffractor, which is a widely used viewer for IEEE Std 1159.3 PQDIF and IEEE Std C37.111 COMTRADE files. He was also a project manager with EPRI Solutions and EPRI focusing on power quality monitoring, grid analytics algorithm development, and distribution fault location automation. Dan has a Master of Engineering Degree in Electric Power from Rensselaer Polytechnic Institute in New York. He is a registered professional engineer in Tennessee, an IEEE Fellow, the Vice Chair for Standards for the IEEE PES Transmission & Distribution Committee and a Past Chair of the IEEE PES Power Quality Subcommittee. He chairs the IEEE P1409 Working Group on Power Quality Solutions and IEEE P1159.3 Power Quality Data Interchange Format (PQDIF) Task Force.

Matthew Norwalk is a Senior Technical Advisor at Southern California Edison in Fullerton, California, USA. As a Journeyman Wireman he worked on a wide range of commercial and industrial projects that include data centers, aerospace manufacturing, petrochemical, and commercial spaces. In 2004 he joined the Power Quality Department at Southern California Edison (SCE) where he has been involved with generation, substation, transmission, distribution, and customer side power quality investigations. Matt serves as a subject matter expert in the areas of grounding and power quality monitoring. He is involved with the grid impact assessment of renewable generation projects and was involved in SCE’s first large scale solar roof top projects that began operation in 2009. He is the Chair of the IEEE PES Power Quality Subcommittee, a voting member of the IEEE PES Transmission & Distribution Committee, and the chair of the IEEE PES Stray & Contact Voltage Working Group of the IEEE PES Distribution Subcommittee.

Kevin M. Kittredge is a Senior Power Systems Engineer with Electrotek Concepts in Salem, Massachusetts, USA. He has been in the power quality field since August of 2000. At Electrotek, he provides support and training for both PQView 3 and PQView 4, including the provisioning of new systems. Prior to working at Electrotek, Kevin was a Senior Engineer at Salt River Project (SRP) in Phoenix, Arizona, USA from 2000 to 2015. While at SRP, his primary responsibility was maintaining, expanding, and collecting data from SRP's power quality monitoring system. This included monthly and annual reporting on the health and performance of the power system. He also developed tools to display data in a geographically visual format and assisted in the implementation of notification systems and administered the procedure SRP developed to track the root cause of all transmission disturbances. Kevin has a Bachelor of Science degree in Electrical Engineering from Arizona State University in Tempe, Arizona, USA. He is the former secretary and president of the Arizona Power Quality Association and is the Vice Chair of the IEEE PES Power Quality Subcommittee.

Steven Johnston is an Advisory Engineer with Eaton Corporation in Houston, Texas, USA. At Eaton he has worked to provide power quality monitoring and mitigation solutions to residential, commercial, industrial and utility customers since 2010. He is also a member of the microgrid and renewables interconnection team at Eaton with the goal of developing products and services to support these customers. He has a Bachelor of Science Degree in Electrical Engineering from Texas A&M in College Station, Texas. He is the Secretary of the IEEE PES Power Quality Subcommittee and is a past chair of the IEEE P1159 Working Group on PQ Monitoring, leading the completion of IEEE Std 1159-2019.

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